PDR 71-9119

TERA

Babcock & Wilcox

Naval Nuclear Fuel Division

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Telephone: (804) 384-5111

License SNM-42
October 2, 1979

Mr. Charles E. MacDonald, Chief
Transportation Branch
Division of Fuel Cycle and Material Safety
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Mr. MacDonald:

Babcock & Wilcox, Naval Nuclear Fuel Division (B&W-NNFD), is in need of the use of a shipping container arrangement as described in Certificate of Compliance No. 9119. This certificate of compliance is issued to the U. S. Department of Energy, Division of Naval Reactors, Washington, D. C. for container model no. BAPL 5910 birdcage. However, the container authorized by this certificate is not approved for use under the general license provisions of 10 CFR 71.

Accordingly, Babcock & Wilcox, Naval Nuclear Fuel Division, requests NRC Certificate of Compliance No. 9119 (USA/9119/B( )F) be revised to include approval for use under the general license provisions of 10 CFR 71.12(b). B&W-NNFD also requests to be registered as an authorized user of shipping assemblies described in this certificate. As required by 10 CFR 71.12(b), B&W-NNFD has obtained a copy of the certificate of compliance and all documents referenced in this certificate. A copy of these referenced documents is attached.

The attached document WAPD-O(AO)-4191 contains the analysis for ten shipping assemblies originally submitted by Bettis Atomic Power Laboratory. The shipping assembly authorized for use under Certificate of Compliance No. 9119 is identified as BE 1270 birdcage in this document.

Enclosed is a check in the amount of $150 to cover the administrative fee required by 10 CFR 170.31.

Sincerely,

BABCOCK & WILCOX

RACordani

R. A. Cordani
Nuclear Safety & Licensing Officer

RAC/bjc
Attachments

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14319

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WAPD-OA(0)-4191

CRITICALITY CONTROL
RECORD COPY

V. OPERATIONS

B. SS Materials Management

L. L. Jones
W. B. Thomas
M. A. Barnisin
T. A. Mangelsdorf
W. A. Stanko

SS Materials Management Containers

17H Drum - 55-Gallon, 30-Gallon or 5-Gallon Type

55-Gallon 17H Drum with Schedule-40 Pipe Insert

55-Gallon 17H Drum with Polyethylene Bottle and Absorbent Material

ICC Specification 15A Wooden Box

B of E Permit No. 2070 Drum

B of E Permit No. 2071 Drum

B of E Permit No. 1270 Birdcage

B of E Permit No. 1885 Birdcage

B of E Permit No. 1926 Drum

B of E Permit No. 1926 Drum (Modified)

1323 088

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Introduction and Scope

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RECORD OF REVISIONS

Original - Issued October, 1965

Revision No.	Type of Revision	Date
1	Complete	March, 1967
2	Partial (Page 2, 3, 4, 5, 45, 55, 56, 63)	February, 1968
3	Partial (Cover Page, Record of Revisions, Page 5a, 6, 6a, 12a, 12b, 16c, 16d)	October, 1968

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U-235 PACKAGING & SHIPPING CONDITIONS AND LIMITS

Introduction and Scope

Many shipments of U-235 material can be made for which specially designed shipping containers are not needed to protect the material against damage during shipment. A number of standard shipping containers, arrangements, and limits have been established for Part I, Fissile Classes I, II and III material (as defined in AECM 0529) which assure adequate nuclear safety and compliance with AECM 0529 and yet provide flexibility for shipments not requiring shielding. These standards and limits for packaging and shipping are delineated in tabular form in Section A. The evaluation to assure adequate nuclear safety and compliance with AECM 0529 and Appendix 0529 Annex 1 through 5, dated August 22, 1966, is discussed in succeeding sections.

SECTION A. U-235 PACKAGING AND SHIPPING CONDITIONS AND LIMITS

MATERIAL DESCRIPTION (Note 10)	FISSILE CLASS I SHIPMENTS				FISSILE CLASS III SHIPMENTS			
	Inner Container		Shipping Container		Inner Container		Shipping Container	
	Description (Note 1)	Limit Grams U-235	Description (Note 2)	Limit Container Per Shipment	Description (Note 1)	Limit Grams U-235	Description (Note 2)	Limit Container Per Shipment
OXIDE (UO_2, UO_3, U_3O_8) a. Powders and mixes (Dry form) or Fuel element sections	Sch 40 pipe	120	55 gal 17H Drum or BE 2071 Drum or BE 1926 Drum	No limit	Sch 40 pipe	10,000	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum	1
					Sch 40 pipe	1,700	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum	2 (Note 4)
					Sch 40 pipe	550	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum	3 (Note 4)
					Sch 40 pipe	400	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum	4 (Note 4)
					Sch 40 pipe	1,900	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum	Note 3
					Thermos jar	350	Wood box	1
b. Powders or mixes (in oil or water)	Sch 40 pipe & Absorbent	60	55 gal 17H Drum	No limit	Sch 40 pipe & Absorbent	800	55 gal 17H Drum	1
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	2
					Sch 40 pipe & Absorbent	275	55 gal 17H Drum	3
					Sch 40 pipe & Absorbent	200	55 gal 17H Drum	4
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	Note 3
c. Chips, fines, & turnings (under oil or water)	Sch 40 pipe & Absorbent	60	55 gal 17H Drum	No limit	Sch 40 pipe & Absorbent	800	55 gal 17H Drum	1
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	2 (Note 4)
					Sch 40 pipe & Absorbent	275	55 gal 17H Drum	3 (Note 4)
					Sch 40 pipe & Absorbent	200	55 gal 17H Drum	4 (Note 4)
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	Note 3
d. Fuel elements (fillers, fuel plates or rods, or sections thereof) or Subassembly and subassembly sections	Sch 40 pipe	120	55 gal 17H Drum or BE 2071 Drum or BE 1926 Drum	No limit	Sch 40 pipe	10,000	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum or BE 1685	1
					Sch 40 pipe	1,700	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum or BE 1685	2 (Note 4)
					Sch 40 pipe	550	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum or BE 1685	3 (Note 4)
					Sch 40 pipe	400	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum or BE 1685	4 (Note 4)
					Sch 40 pipe	1,900	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum or BE 1685	Note 3
					Steel box (Note 2)	1,900	BE 1270	1
Rev. 2, February 1968					Steel box (Note 2)	Note 9	BE 1270	Note 3

All notes are shown on the last page of this section.

MATERIAL DESCRIPTION (Note 10)	FISSILE CLASS I SHIPMENTS				FISSILE CLASS III SHIPMENTS			
	Inner Container		Shipping Container		Inner Container		Shipping Container	
	Description (Note 1)	Limit Grams U-235	Description (Note 2)	Limit Container Per Shipment	Description (Note 1)	Limit Grams U-235	Description (Note 2)	Limit Container Per Shipment
2. <u>METAL ALLOY</u> (U-235 Chemically mixed with other material) a. Powders, and mixes (Dry form) or Fuel element sections or Miscellaneous alloy solids in dry form: e.g. wire, corrosion samples	Sch 40 pipe	120	55 gal 17H Drum or BE 2071 Drum or BE 1926 Drum	No limit	Sch 40 pipe 6-in. end spacing (Note 5)	10,000 5000 if Note 7 applies	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum	1
					Sch 40 pipe	1,700	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum	2 (Note 4)
					Sch 40 pipe	550	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum	3 (Note 4)
					Sch 40 pipe	400	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum	4 (Note 4)
					Sch 40 pipe	1,900	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum	Note 3
					Thermo jar	350	Wood box	1
b. Powders or mixes (in oil or water)	Sch 40 pipe & Absorbent	60	55 gal 17H Drum	No limit	Sch 40 pipe & Absorbent	800	55 gal 17H Drum	1
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	2
					Sch 40 pipe & Absorbent	275	55 gal 17H Drum	3
					Sch 40 pipe & Absorbent	200	55 gal 17H Drum	4
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	Note 3
c. Chips, fines, and turnings (under oil or water)	Sch 40 pipe & Absorbent	60	55 gal 17H Drum	No limit	Sch 40 pipe & Absorbent	800	55 gal 17H Drum	1
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	2 (Note 4)
					Sch 40 pipe & Absorbent	275	55 gal 17H Drum	3 (Note 4)
					Sch 40 pipe & Absorbent	200	55 gal 17H Drum	4 (Note 4)
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	Note 3
d. Fuel elements (fillers, fuel plates or rods, or sections thereof) or Subassembly and subassembly sections	Sch 40 pipe	120	55 gal 17H Drum or BE 2071 Drum or BE 1926 Drum	No limit	Sch 40 pipe 6-in. end spacing (Note 5)	10,000 5000 if Note 7 applies	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum or BE 1885	1
					Sch 40 pipe	1,700	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum or BE 1885	2 (Note 4)
					Sch 40 pipe	550	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum or BE 1885	3 (Note 4)
					Sch 40 pipe	400	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum or BE 1885	4 (Note 4)
					Sch 40 pipe	1,900	55 gal 17H Drum or BE 1926 Drum or BE 2071 Drum or BE 1885	Note 3
					Steel box (Note 2)	1,900	BE 1270	1
					Steel box (Note 2)	Note 9	BE 1270	Note 3

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POOR ORIGINAL

MATERIAL DESCRIPTION (Note 10)	FISSILE CLASS I SHIPMENTS				FISSILE CLASS III SHIPMENTS			
	Inner Container		Shipping Container		Inner Container		Shipping Container	
	Description (Note 1)	Limit Grams U-235	Description (Note 2)	Limit Container Per Shipment	Description (Note 1)	Limit Grams U-235	Description (Note 2)	Limit Container Per Shipment
3. **METAL** (Pure Uranium) a. Metal chopped stock or pellets (Dry form)	Sch 40 pipe	120	55 gal 17H Drum	No limit	Sch 40 pipe 6-in. end spacing (Note 5)	10,000 5000 if Note 7 applies	55 gal 17H Drum	1
					Sch 40 pipe	1,700	55 gal 17H Drum	2 (Note 4)
					Sch 40 pipe	550	55 gal 17H Drum	3 (Note 4)
					Sch 40 pipe	400	55 gal 17H Drum	4 (Note 4)
					Sch 40 pipe	1,900	55 gal 17H Drum	Note 3
					Thermo bar	350	Wood box	1
b. Metal chips, fines, and turnings (under oil or water)	Sch 40 pipe & Absorbent	60	55 gal 17H Drum	No limit	Sch 40 pipe & Absorbent	800	55 gal 17H Drum	1
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	2 (Note 4)
					Sch 40 pipe & Absorbent	275	55 gal 17H Drum	3 (Note 4)
					Sch 40 pipe & Absorbent	200	55 gal 17H Drum	4 (Note 4)
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	Note 3
4. **METALLOGRAPHY MOUNTS IN PLASTIC**	Sch 40 pipe	60	55 gal 17H Drum	No limit	Sch 40 pipe	1,000	55 gal 17H Drum	1
					Sch 40 pipe	550	55 gal 17H Drum	2 (Note 4)
					Sch 40 pipe	275	55 gal 17H Drum	3 (Note 4)
					Sch 40 pipe	200	55 gal 17H Drum	4 (Note 4)
					Sch 40 pipe	350	55 gal 17H Drum	Note 3
5. **IRRADIATION TEST FUEL TRAIN OR OTHER FABRICATED COMPONENTS** Package and ship in accordance with sections 1 or 2 above or by one of the following modes: a. U-235 along length of package is mechanically restricted to 10 grams or less per inch	-	-	-	-	None	500	Wood box	1
b. U-235 along length of package is not mechanically restricted	-	-	-	-	None	175	Wood box	1
6. **NON-COMBUSTIBLE WASTE** a. Grit blast residue (Dry form)	Sch 40 pipe	120	55 gal 17H Drum	No limit	None	-	5 gal 17H Drum or 30 gal 17H Drum or 55 gal [illegible] Drum	Any number or combination of 5, 30, or 55 gal drum permitted with a total limit of 350 grams
or	(Note 6)	10	5 gal 17H Drum	No limit				
Ceramic crucibles	(Note 6)	65	30 gal 17H Drum	No limit				
	(Note 6)	120	55 gal 17H Drum	No limit				
b. Sludge, slurry, wet grit, U-235 suspended in mercury or water, ashes, etc.	Sch 40 pipe & Absorbent	60	55 gal 17H Drum	No limit	Sch 40 pipe & Absorbent	350	55 gal 17H Drum	2
					Sch 40 pipe & Absorbent	275	55 gal 17H Drum	3
					Sch 40 pipe & Absorbent	200	55 gal 17H Drum	4
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	Note 3
c. Filters and small equipment which has been scrapped, but which contains recoverable quantities of U-235	-	-	-	-	None	350	55 gal 17H Drum or [illegible] Drum	1
					None	[illegible]	55 gal 17H Drum or [illegible] Drum	or Note 3

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MATERIAL DESCRIPTION (Note 10)	FISSILE CLASS I SHIPMENTS				FISSILE CLASS III SHIPMENTS			
	Inner Container		Shipping Container		Inner Container		Shipping Container	
	Description (Note 1)	Limit Grams U-235	Description (Note 2)	Limit Container Per Shipment	Description (Note 1)	Limit Grams U-235	Description (Note 2)	Limit Container Per Shipment
7. <u>COMBUSTIBLE WASTE</u> Rags, paper, poly bottles, chem wipes, combustible filters, dust collection bags, etc.	Sch 40 pipe (note 5)	60	55 gal 17H Drum	No limit	Sch 40 pipe (Note 8)	550	55 gal 17H Drum	Note 3
					Sch 40 pipe (Note 8)	850	55 gal 17H Drum	2 (Note 4)
					Sch 40 pipe (Note 8)	275	55 gal 17H Drum	3 (Note 4)
					Sch 40 pipe (Note 8)	200	55 gal 17H Drum	4 (Note 4)
8. <u>SOLUTIONS</u> (Mop water, acid wash solution, neutralized acids, etc. a. Less than 2 grams U-235 per liter	Poly bottle & Absorbent or Sch 40 pipe & Absorbent	22	55 gal 17H Drum	No limit	Poly bottle & Absorbent or Sch 40 pipe & Absorbent	22	55 gal 17H Drum	Note 3
b. More than 2 grams U-235 per liter	Sch 40 pipe & Absorbent	60	55 gal 17H Drum	No limit	Poly bottle & Absorbent	175	55 gal 17H Drum	[illegible]
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	2
					Sch 40 pipe & Absorbent	275	55 gal 17H Drum	3
					Sch 40 pipe & Absorbent	200	55 gal 17H Drum	4
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	Note 3
c. Any amount of U-235 per liter but with cadmium nitrate added on gram for gram basis, i.e. one gram of cadmium for each gram of U-235	Poly bottle & Absorbent or Sch 40 pipe & Absorbent	120	55 gal 17H Drum	No limit	Poly bottle & Absorbent	500	55 gal 17H Drum	1
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	2 (Note 4)
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	3 (Note 4)
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	4 (Note 4)
					Sch 40 pipe & Absorbent	350	55 gal 17H Drum	Note 3)

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Fissile Class II Shipments

MATERIAL DESCRIPTION (Note 10)	Inner Container		Shipping Container		Radiation Units Per Container
	Description (Note 1)	Limit Grams U-235	Description (Note 2)	Limit Container Per Shipment	
Oxide Rods, with inner pellet diameter <0.66 inch	Sch 40 pipe with circular spacing insert (note 11)	8,000 contained in 3 rods	BE 2071 drum or BE 1926 drum (modified)	4	10.0
	Sch 40 pipe with circular spacing insert (note 11)	5,800 contained in 3 rods	55 gal 17H drum	4	10.0

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NOTE 1: Abbreviated descriptions are used in the table and refer to the following:

Sch 40 pipe - Schedule-40 iron or steel pipe with a maximum inner diameter of 5 inches and with threaded endcaps. Six tubular struts welded to each of the endcaps and to circumferential hoops, or eight tubular struts welded to the sides of the pipe 4 inches from its extremities and to circumferential hoops, are used to center the pipe radially in a shipping drum. The endcaps will be tightened to ensure a minimum of 4 threads being engaged. Less than 5-inch diameter polyethylene bottles with screw-on tops, or screw-on top metal cans, or mechanically sealed metal cans, or metal cans with slip-on lids sealed by strong cloth or fiber-glass tape, or other containers of equal or better construction are used inside the Schedule-40 pipe for liquids, powders, or small pieces of material.

Thermo jar - Thermo polystyrene covered glass jar of 1/2-pint, 1-pint, or 1-quart capacity enclosed in a metal can. The metal can is a 28-gauge juice can mechanically sealed, or a 30-gauge can with a slip-on lid sealed with strong cloth or fiber glass tape.

Poly bottle - Polyethylene bottle centered radially with a heavy rod bracket. Bottle is 5-inch diameter and of either 11-liter or 7-liter capacity.

Absorbent - Absorbent material used in the space between the inner container and shipping container, capable of absorbing any leakage from the inner container.

NOTE 2: Abbreviated descriptions are used in the table and refer to the following:

17H Drum - 30 or 55-gallon steel drum with bolted ring closure or 5-gallon steel drum with lug type closure, constructed in accordance with Specification 17H of T. C. George's Interstate Commerce Commission Regulations pertaining to Shipping Container Specifications.

BE 1926 Drum - Steel drum same as the 17H 55-gallon drum except that it is 51 inches high. Bears Bureau of Explosive Permit No. 1926. Also includes BE 1926 Drum (Modified) whenever B of E 1926 is listed.

BE 2071 Drum - Steel drum 53 inches tall constructed from the upper and lower sections of two 17H 55-gallon drums, joined together with a solid circumferential weld and further reinforced with a steel circumferential bar (3/16-in. thick, 2-in. wide) tack welded top and bottom to the drum. Bears Bureau of Explosive Permit No. 2071.

Wood box - Wooden box made in accordance with Specification 15A, 15B, 19A, or 19B of T. C. George's Interstate Commerce Commission Regulations pertaining to Shipping Container Specifications.

BE 1885 - Birdcage type of shipping container with Schedule-40 pipe insert. Bears Bureau of Explosive Permit No. 1885.

BE 2070 Drum - Steel drum 28 inches diameter and 27 inches high; gasketed lid using eight 3/8-inch machine bolts. Sides are reinforced with three tack welded circumferential hoops. Bears Bureau of Explosive Permit No. 2070.

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NOTE 2: BE 1270 - Slotted angle frame birdcage with 14 gauge (or heavier) aluminum or steel box with hinged lid, gasket, and cross sectional area not greater than 20 square inches; box held in frame with steel bands. Box loading up to a net weight of 54 pounds permitted.* When an aluminum box is used, it is centered in the birdcage with sections of slotted steel angle bolted directly against all six sides of the box forming a steel framework around the box. May be used only for material that has a melting temperature of 1700°F or higher. Bears Bureau of Explosive Permit No. 1270. *Per six (6) feet of length.

NOTE 3: Up to a total of 51 55-gallon 17H drums, BE 1926, BE 1926 (modified), BE 2071, BE 2070 or BE 1270 and BE 1885 birdcages containing material covered by this note may be shipped intermingled in a semi-trailer van provided at least 25 percent of the floor space is left vacant and the containers are tied and/or blocked so that they will break loose and slide or tumble or the blocking material will crush more easily than the containers in the event of a severe highway accident. The containers shall be loaded as follows:

55 gallon 17H drums BE 1926 & 1926 mod. BE 2071 drums	On end in a single layer
BE 2070 drums	On end in a single or double layer, or a single layer on top of other drums
BE 1270 birdcages BE 1885 birdcages	On end anywhere in the van trailer; or in one, two, or three layers with the long axis horizontal along the length of the van but not closer than 5 feet to either end of the van

NOTE 4: Limits per container may be exceeded provided the total quantity of U-235 in a group of containers does not exceed 3400 grams for 2 containers, 1650 for 3 containers, and 1600 for 4 containers for unmoderated shipments and one-half these values for moderated shipments (not to exceed 1000 grams of moderated material in any single drum).

NOTE 5: The material must be blocked or supported so that there is 6 inches or more spacing between the material and the ends of the inner container. However, this requirement may be waived by Criticality Control Standards if the linear fuel density is less than 333 grams per inch of inner container length.

NOTE 6: No inner container is required if the shipping container is completely filled.

NOTE 7: If the theoretical density of U-235 is greater than 11,000 grams per liter, then there is a limit of 5000 grams on the amount of U-235 permitted.

NOTE 8: Inner container is not required if quantity of U-235 is determined to be less than 60 grams by use of scintillation counter calibrated for the purpose.

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NOTE 9: When it is desired to ship more than one HE 1270 birdcage, the following limits apply to the material in each steel box:

Cross Sectional Area of Box	Limit Grams U-235	Other Restrictions
Not greater than 20 sq. in.	1,900	50 percent or more of the volume in the box must be filled with metal which is reasonably uniformly distributed along the box length
Not greater than 20 sq. in.	300	None
Not greater than 13 sq. in.	430	None
Not greater than 10 sq. in.	800	None

NOTE 10: The limits in this table do not apply to material compositions in which there are significant amounts of heavy water, beryllium, or graphite.

NOTE 11: Circular Spacing Insert - The steel inserts consist of three 1/8 inch thick steel plates approximately 5 inches in diameter and spaced along the length of Schedule-40 pipe by three 3/8 inch diameter all thread rods which pass through the plates on a triangular pitch rotated 60° from the fuel rods. The 3 fuel rods are located on a 2-1/4 inch diameter bolt circle and are evenly spaced. The six nuts on each of the all thread rods axially position the 3 steel disks. May be used only for steel, zircaloy or other high melting point cladded rods. Additional circular spaced blank inserts shall be used to restrain the axial motion of the rods if the length of the rods represent less than 60% of the length of the Schedule-40 pipe. (Figure 8-1)

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B. DESCRIPTION OF CONTAINERS

55-gallon 17H Drum - This is a standard 55-gallon steel drum with a bolted ring closure, constructed in accordance with specification 17H of T. C. George's Interstate Commerce Commission Regulations pertaining to Shipping Container Specifications. The body is 18 gage steel with 3 rolled hoops. 16 The bottom head is 18 gage steel. The gasketed removable head is ~~14~~ gage steel held onto the drum with a 12 gage bolted ring. The bolted ring uses drop forged lugs which are threaded for a 5/8 inch bolt and nut. The drum has nominal dimensions of 23 inches diameter and 35 inches height. ICC Regulations Section 73.393(f)(4) authorizes use of 17H (single trip) drums for not more than 2700 millicuries of radioactive material. Bureau of Explosives letter 25-3-5, Permissive 25-16-174 dated May 24, 1960, granted authority for re-use of single trip drums.

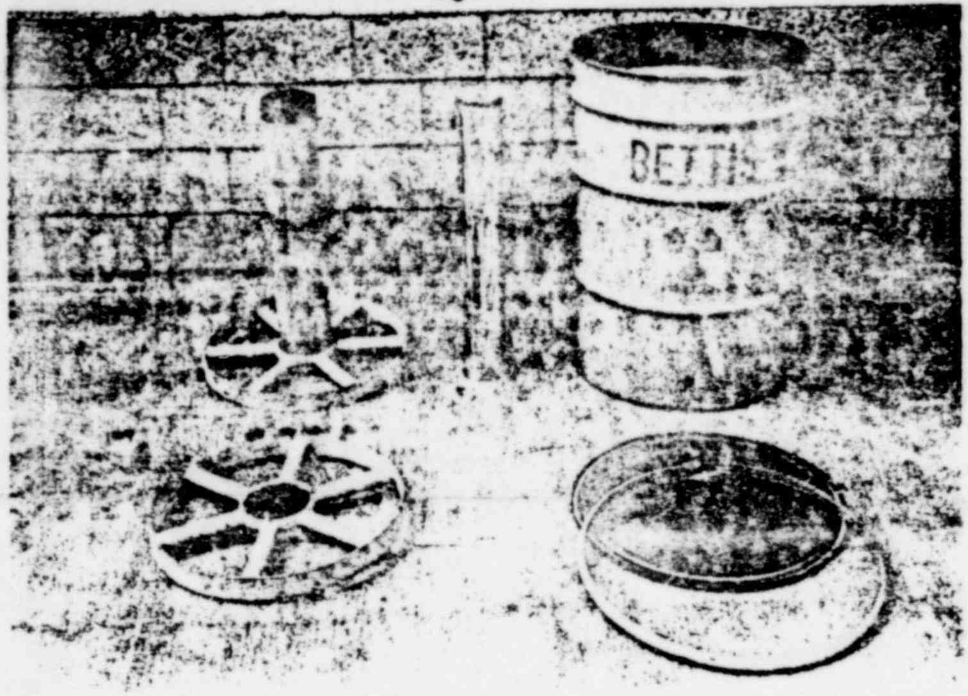
55-gallon 17H Drum with Schedule-40 pipe insert - A Schedule-40 iron or steel pipe with maximum 5-inch inner diameter is centered radially in a 55-gallon 17H drum. The Schedule-40 pipe has threaded endcaps with 9 threads per inch; six 1-1/2 inch diameter solid steel tubular struts welded to the endcaps and to circumferential steel hoops (2 inches wide x 3/16 inch thick) center the pipe radially in the drum. Polyethylene bottles with screw-on tops, or screw-on top metal cans, or mechanically sealed metal cans, or metal cans with slip-on lids sealed by strong cloth or fiber glass tape, or other containers of equal or better construction are used inside the Schedule-40 pipe for liquids, powders, or small pieces of material. (Figure 1)

Thermo Jar - This container is a polystyrene covered glass jar of 1/2-pint, 1-pint, or 1-quart capacity which is sold commercially as a "Thermo Jar." For this application the jar is enclosed in a metal can which is either a 28-gauge juice can mechanically sealed, or a 30-gauge can with a slip-on lid sealed with strong cloth or fiber glass tape. (Figure 2)

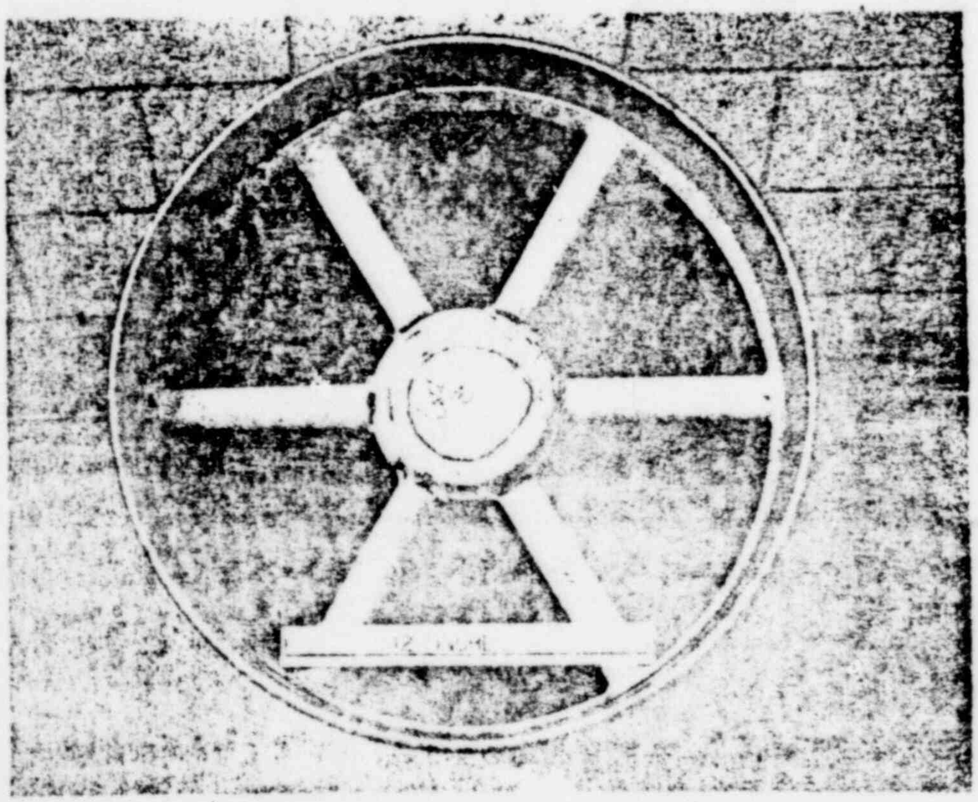
Polyethylene Bottle - This bottle is either a standard 11 liter polyethylene bottle 5 inches in diameter and 33 inches tall with a screw-on cap or a 7-liter polyethylene bottle 5 inches in diameter and 22 inches tall with a screw-on cap. It is centered radially in a 55-gallon 17H drum with two brackets made from 1/4-inch rod. The space between the bottle and the drum is filled with absorbent material. (Figure 3)

Wooden Box - Wooden boxes used for shipping containers are made in accordance with Specification 15A, 15B, 19A, or 19B of T. C. George's Interstate Commerce Commission Regulations pertaining to Shipping Container Specifications. ICC Regulations Section 73.393(f)(1) authorizes shipment of radioactive material in Specification 15A, 15B, 19A, and 19B wooden boxes for not more than 2700 millicuries per container.

Drum B.E. 1926 - This is a steel drum with a bolted ring closure similar to the standard 55-gallon 17H drum except that it has nominal dimensions of 23 inches diameter and 51 inches height. A 45-inch long, maximum 5-inch inner diameter, Schedule-40 iron or steel pipe with threaded endcaps (9 threads per inch) is centered radially in the drum by two-wagon wheel supports which



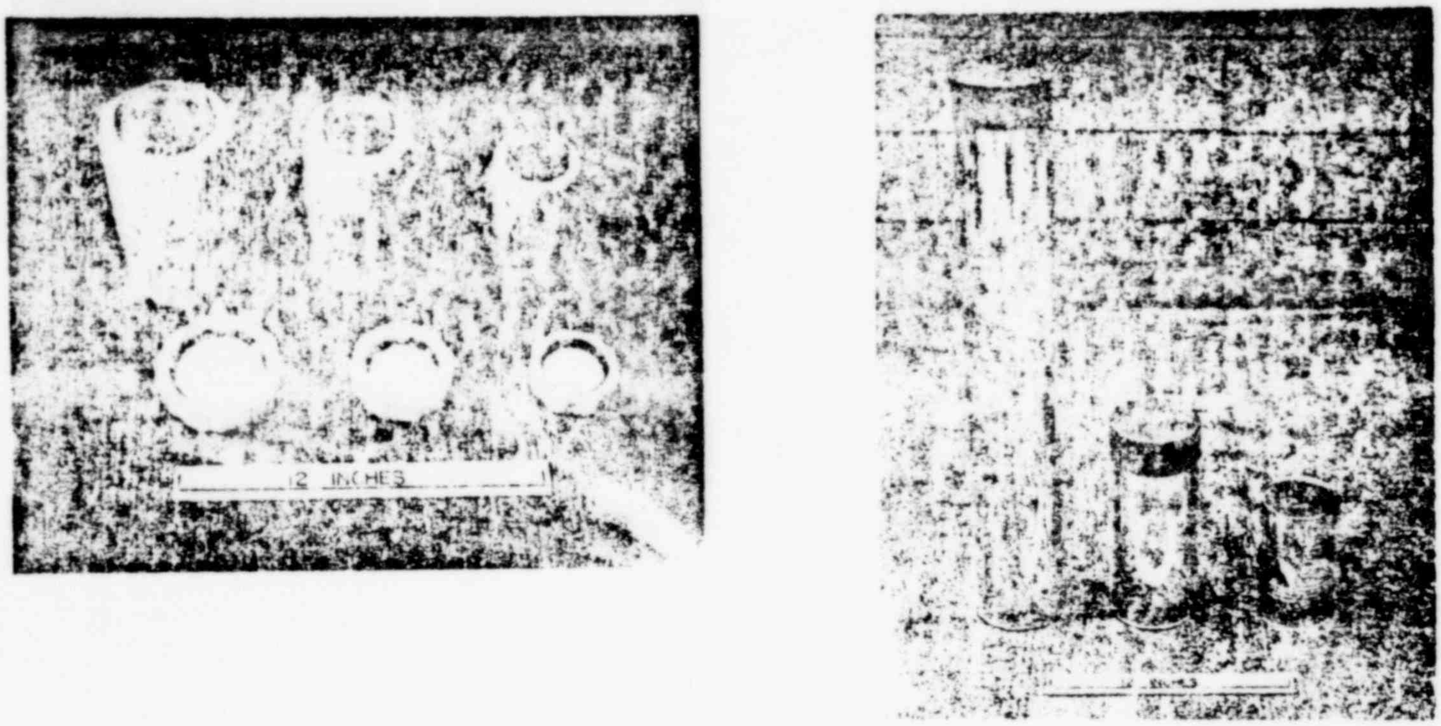
a. Drum and pipe insert before assembly



b. Drum with pipe in shipping position

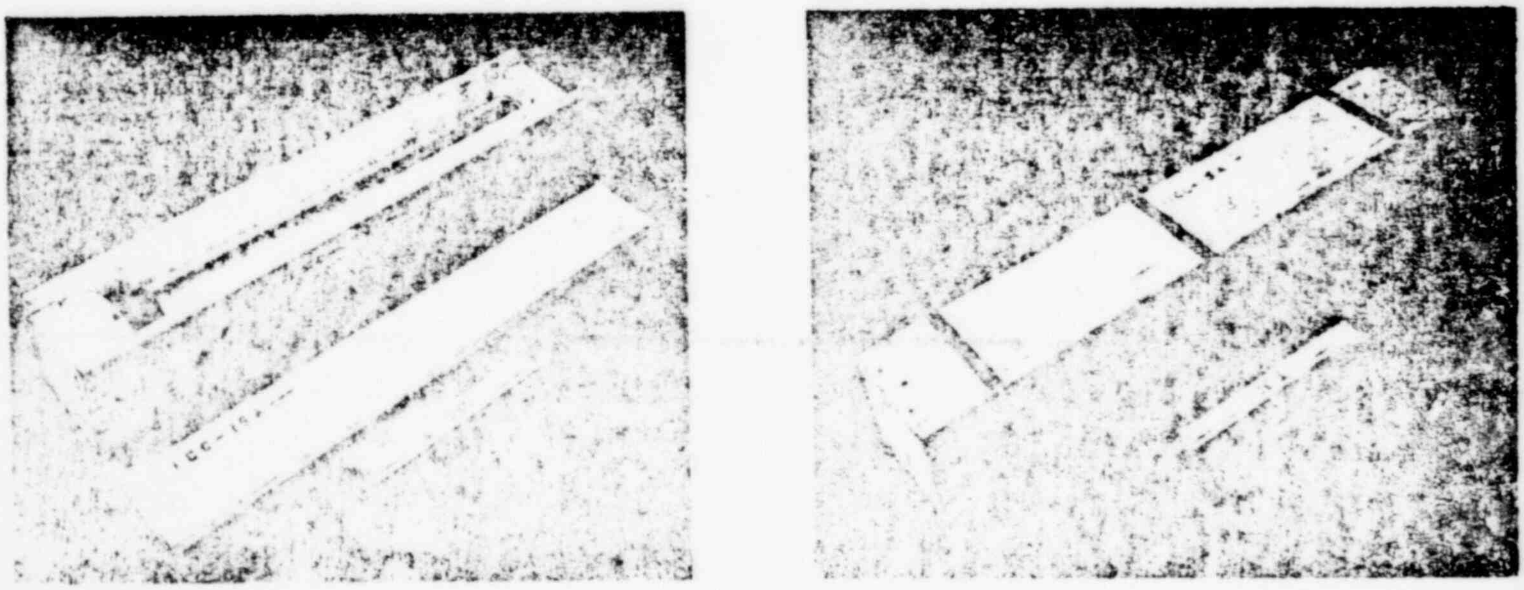
Figure 1

55-gallon 17H Drum with Schedule-40 Pipe Insert



a. 1-quart, 1-pint, and 1/2-pint Thermo Jars

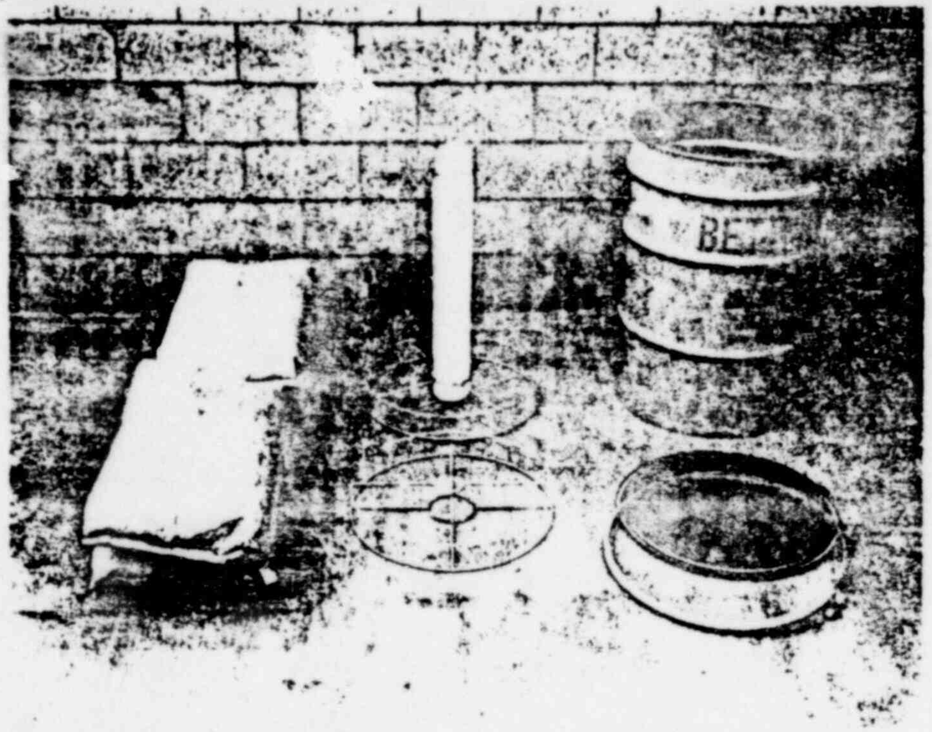
b. Metal cans used to enclose Thermo Jars



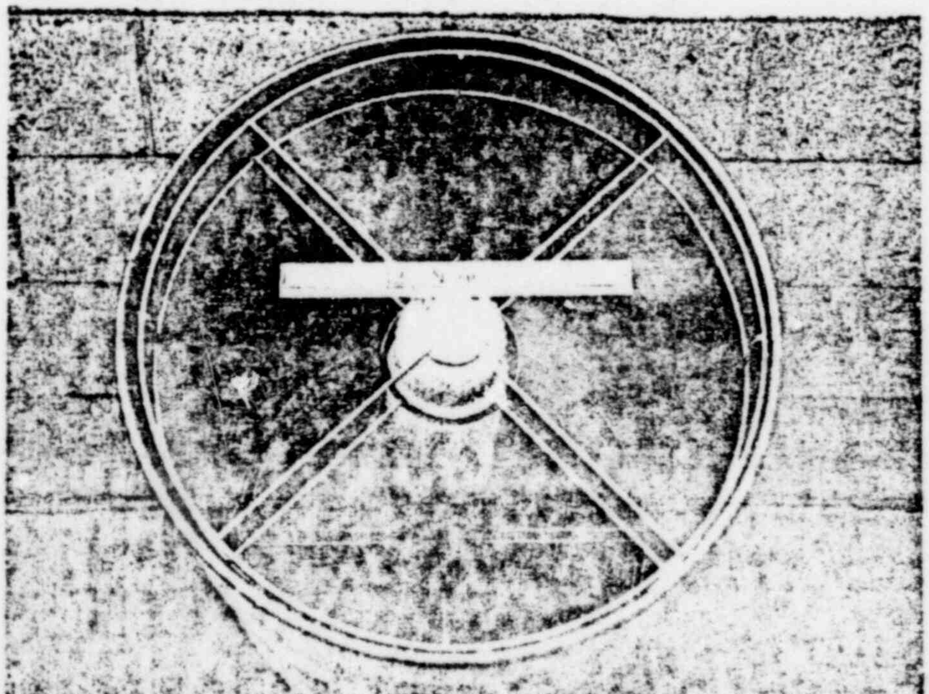
c. Thermo Jar, metal can, and wooden box before final assembly

d. Typical final package using Thermo Jar inner container

Figure 2
Thermo Jar Shipping Container



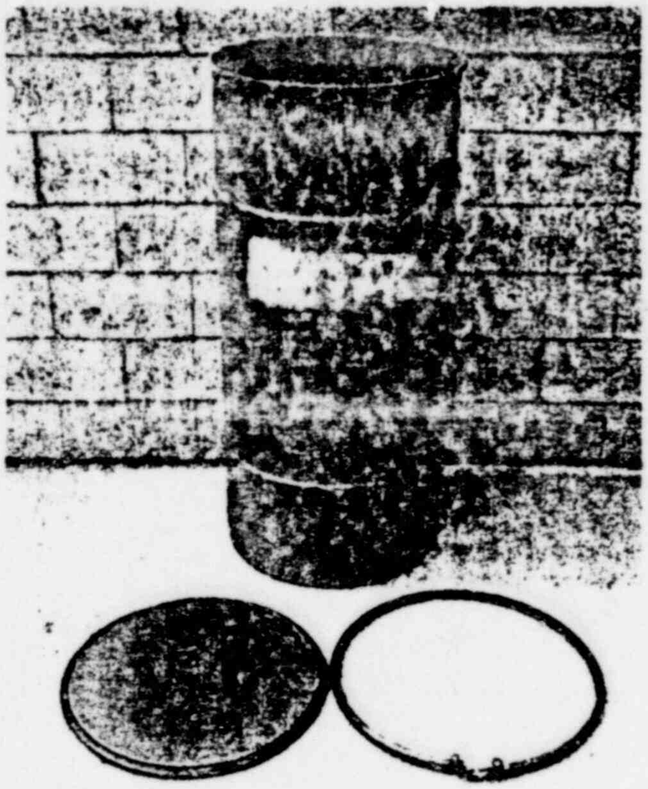
a. Drum, polyethylene bottle and spacer bracket before assembly



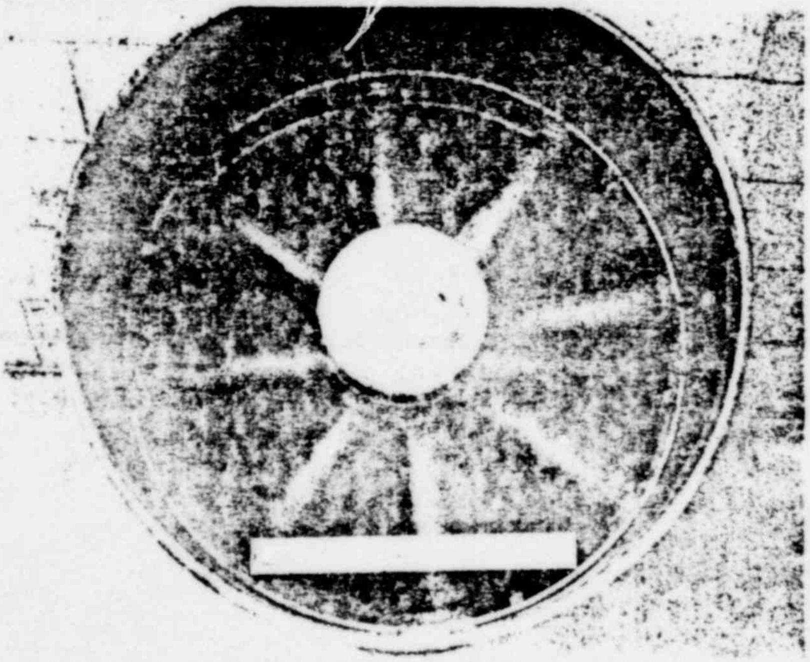
b. Drum with polyethylene bottle in shipping position before absorbent material is added

Figure 3

55-gallon 17H Drum with Polyethylene Bottle



a. Drum and pipe insert before assembly



b. Drum with pipe in shipping position

Figure 4

B of E Permit No. 1926 Drum with Schedule-40 Insert are located 4 inches from the extremities of the pipe. Each support consists of 8 tubular struts (2 inches in diameter of solid steel) welded to the pipe and to a circumferential hoop, 3/16-inch thick and 2 inches wide. The upper circumferential hoop is bolted to the side of the drum with 3/8 inch diameter x 1 inch long steel machine bolts. Bureau of Explosives Permit No. 1926 authorizes use of this type drum for shipments of radioactive material up to 2700 millicuries. (Figure 4)

Drum BE 2071 - This is a steel drum constructed from the upper (including the bolted ring closure) and lower sections of two 17H 55-gallon drums, joined together with a solid circumferential weld and further reinforced with a steel circumferential bar (3/16-in. thick, 2-in. wide) tack welded top and bottom to the drum. This drum has nominal dimensions of 23 inches diameter and 53 inches height. The body is 18 gage steel with 5 rolled hoops. The bottom head is 18 gage steel. The gasketed removable head is 14 gage steel held onto the drum with 12 gage bolted ring. The bolted ring uses drop forged lugs which are threaded for a 5/8 inch bolt and nut. A 48 inch long, schedule-40 iron or steel pipe with maximum 5 inch inner diameter is centered radially in the drum. The schedule-40 pipe has threaded endcaps with 9 threads per inch; six tubular struts, 1-1/2 inch in diameter of solid steel, welded to the endcaps and to the circumferential steel hoops (2 inches wide x 3/16 inch thick) center the pipe radially in the drum. Bureau of Explosives Permit No. 2071 authorizes use of this type drum for shipments of radioactive material up to 2700 millicuries. (Figure 5)

Drum BE 2070 - This is a steel drum 28 inches in diameter and 27 inches high with a gasketed cover held in place with eight 3/8-inch machine bolts. The drum body, bottom, and top are made from steel as heavy or heavier than specified [illegible] 55-gallon drums. The sides are reinforced with three tack welded c[illegible] hoops. Bureau of Explosives Permit No. 2070 authorizes use of [illegible] drum [illegible] shipments of radioactive material up to 350 grams of U-2[illegible] single [illegible] shipments and 120 grams of U-235 for shipments of three or more drums. (Figure 6)

Bi[illegible] - This container is a Schedule-40, 5-inch inner diameter pipe [illegible] threaded endcaps, and which is centered in a wel[illegible] 4 inches square. Steel angles 1-1/2" x 1-1/2" (angle s[illegible]ed to the schedule-40 pipe and the 24" square steel f[illegible] schedule-40 pipe in a series of "X" patterns spaced e[illegible] 3" [illegible] the 12 foot length of pipe. The steel frame is covered with 0.06[illegible]-inch steel sheet. Bureau of Explosives Permit No. 1885 authorizes use of this container for shipments of radioactive material up to 2700 millicuries. (Figure 7)

Bir[illegible]70 - These birdcages consist of a steel or aluminum box fastened in a [illegible] made of slotted steel angle 3 x 1-1/2 x 0.104-inch, fastened together with 3/8-inch bolts. The frame is 2-feet square and from 5 to 10 feet long. The box is made of 14-gauge steel with a piano hinged lid and a [illegible] gasket. The box may be of a variety of cross sections, but none exceed [illegible] square inches. The box is centered in the birdcage frame with [illegible] sections of slotted angle and in addition is banded to the deck of the frame with 3/4-inch steel band. When an aluminum box is used, it is centered in the birdcage with sections of slotted steel angle bolted directly against all six sides of the box forming a steel framework around the aluminum box to provide geometric restraint which will withstand a "standard fire". (Figure 8, 8a, 8b)

I, Description of Container

A, Drum BE 1926 (Modified) - This drum incorporates the BE 2071 outer specifications with the BE 1926 inner specifications. This is a steel drum constructed from the upper (including the bolted ring structure) and lower sections of two 17-H 55-gallon drums, joined together with tack welds and further reinforced with a steel circumferential bar (3/16 inch thick, 2 inches wide) that is welded to the drum solidly at the top and bottom of the bar. This drum has nominal dimensions of 23 inches diameter and 53 inches height. The body is 18 gage steel with 4 or 5 rolled hoops. The bottom head is 18 gage steel. The gasketed removable head is 14 gage steel held onto the drum with a 12 gage bolted ring. The bolted ring uses drop forged lugs which are threaded for a 5/8 inch bolt and nut. A 48 inch long, maximum 5 inch inner diameter, schedule 40 iron or steel pipe with threaded endcaps (9 threads per inch) is centered radially in the drum by two wagon wheel supports which are located 2 inches from the extremities of the pipe. Each support consists of 8 tubular struts (2 inches in diameter of solid steel) welded to the pipe and to a circumferential hoop, 3/16 inch thick and 2 inches wide. The upper circumferential hoop is bolted to the side of the drum by 3/8 inch diameter by 1 inch long steel machine bolts. (Figure 4A)

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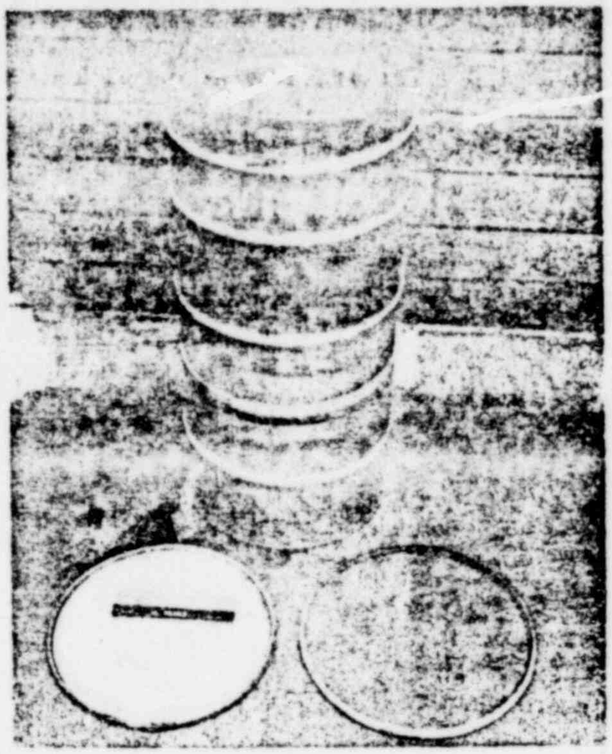
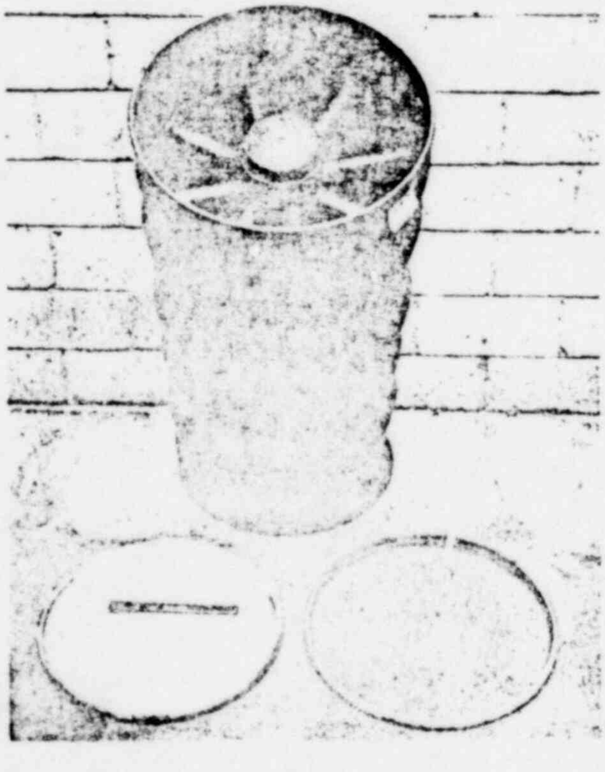


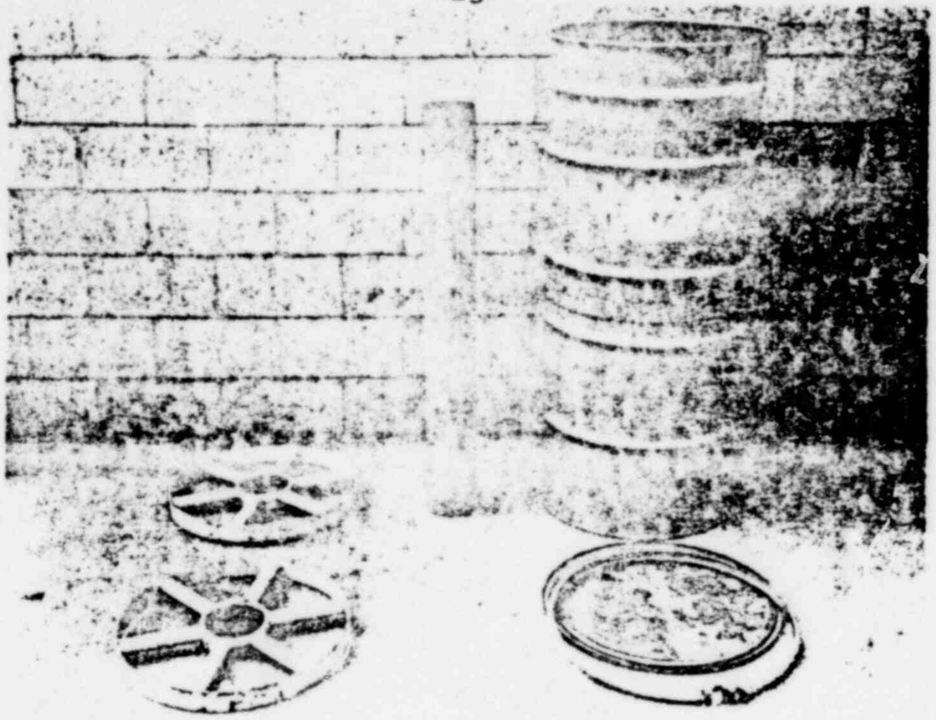
a. Drum with pipe in shipping position



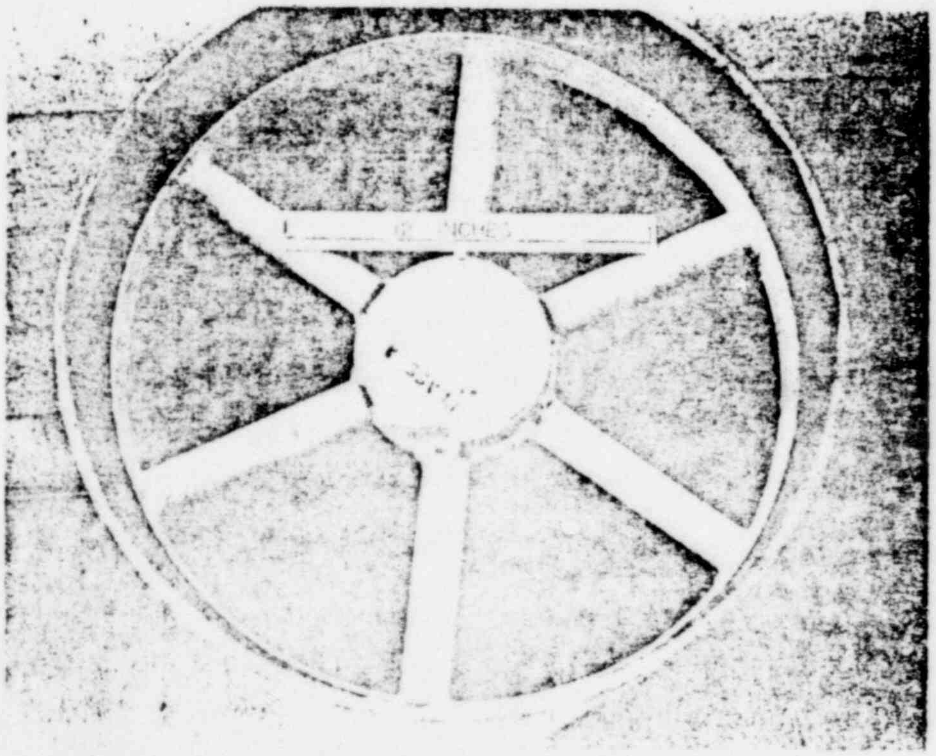
b. Overhead view showing bolted wagon wheel support with tubular struts and screw-on end-cap

Figure 4A

B of E Permit No. 1926 Drum (Modified) with Schedule-40 Insert



a. Drum before assembly

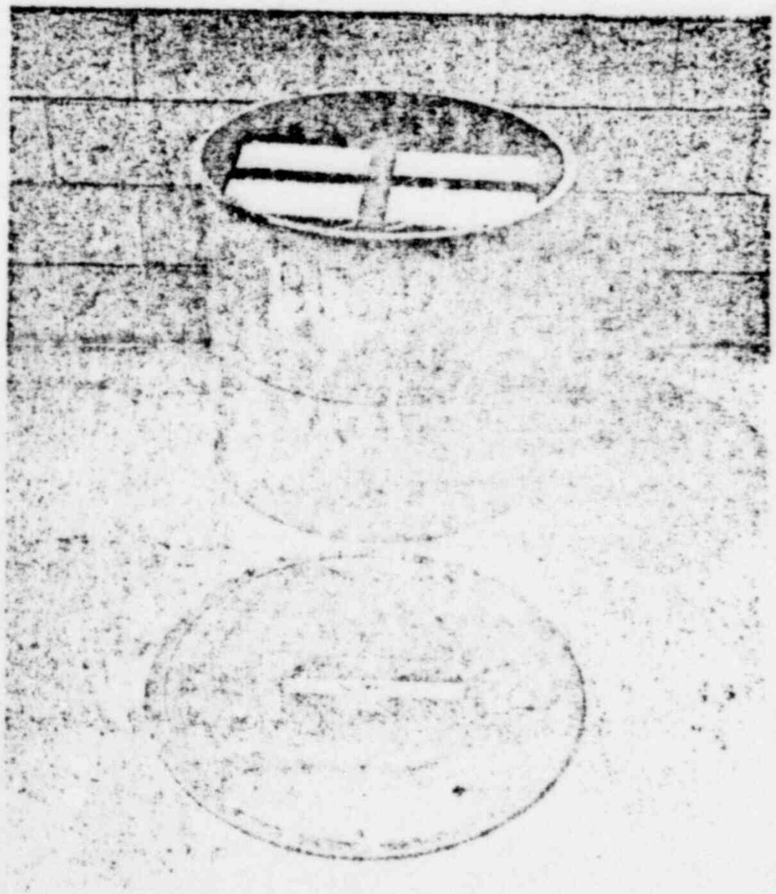


b. Drum with pipe in shipping position

Figure 5

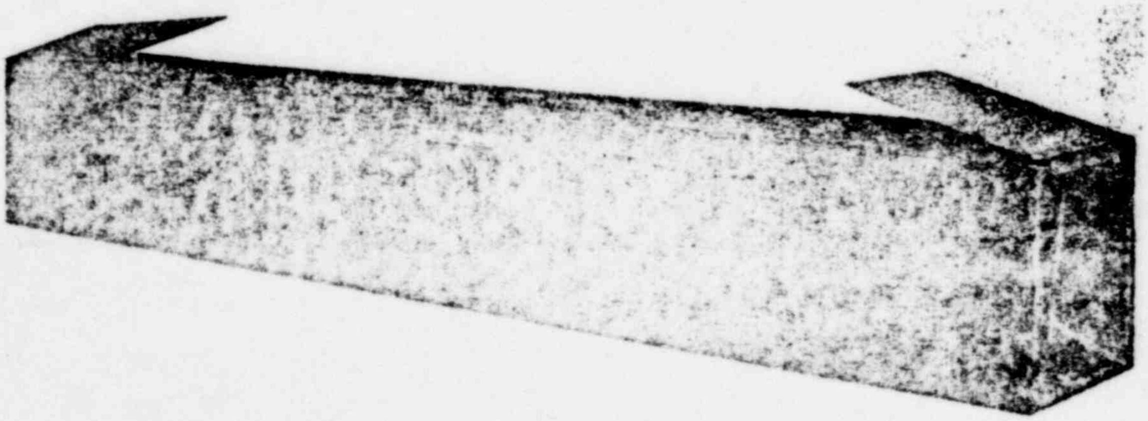
B of E Permit No. 2071 Drum with Schedule-40 Insert

a. Empty drum



b. Drum loaded with scrap filter
Figure 6 - B of E Permit No. 2070 Drum

a. End view of birdcage



b. Side view of birdcage

Figure 7

B of E Permit No. 1885 Birdcage

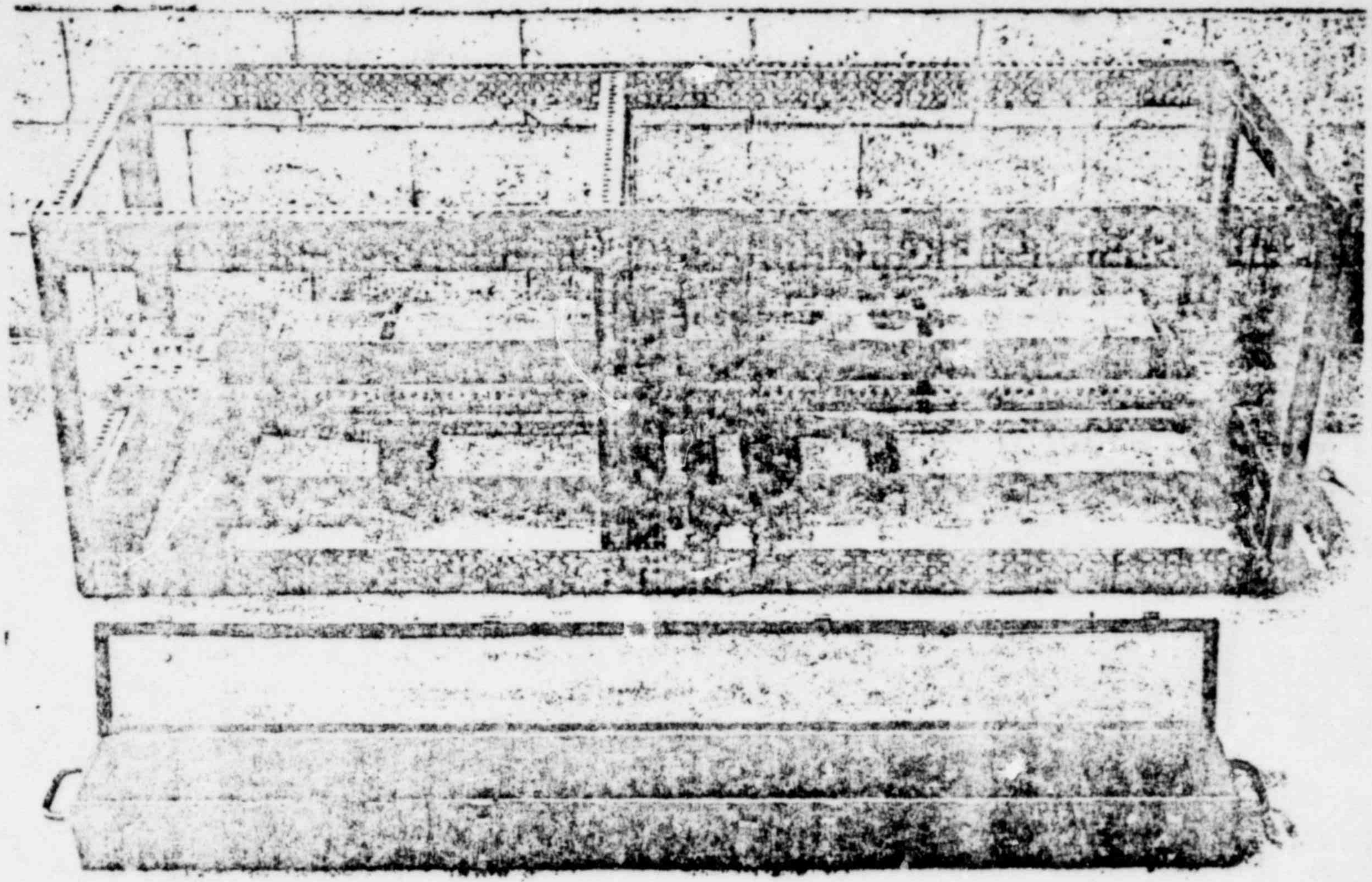


Figure 8

B of E Permit No. 1270 Birdcage (6')
(Typical Arrangement)
(Not modified with additional angular braces and angle iron cover above primary container)

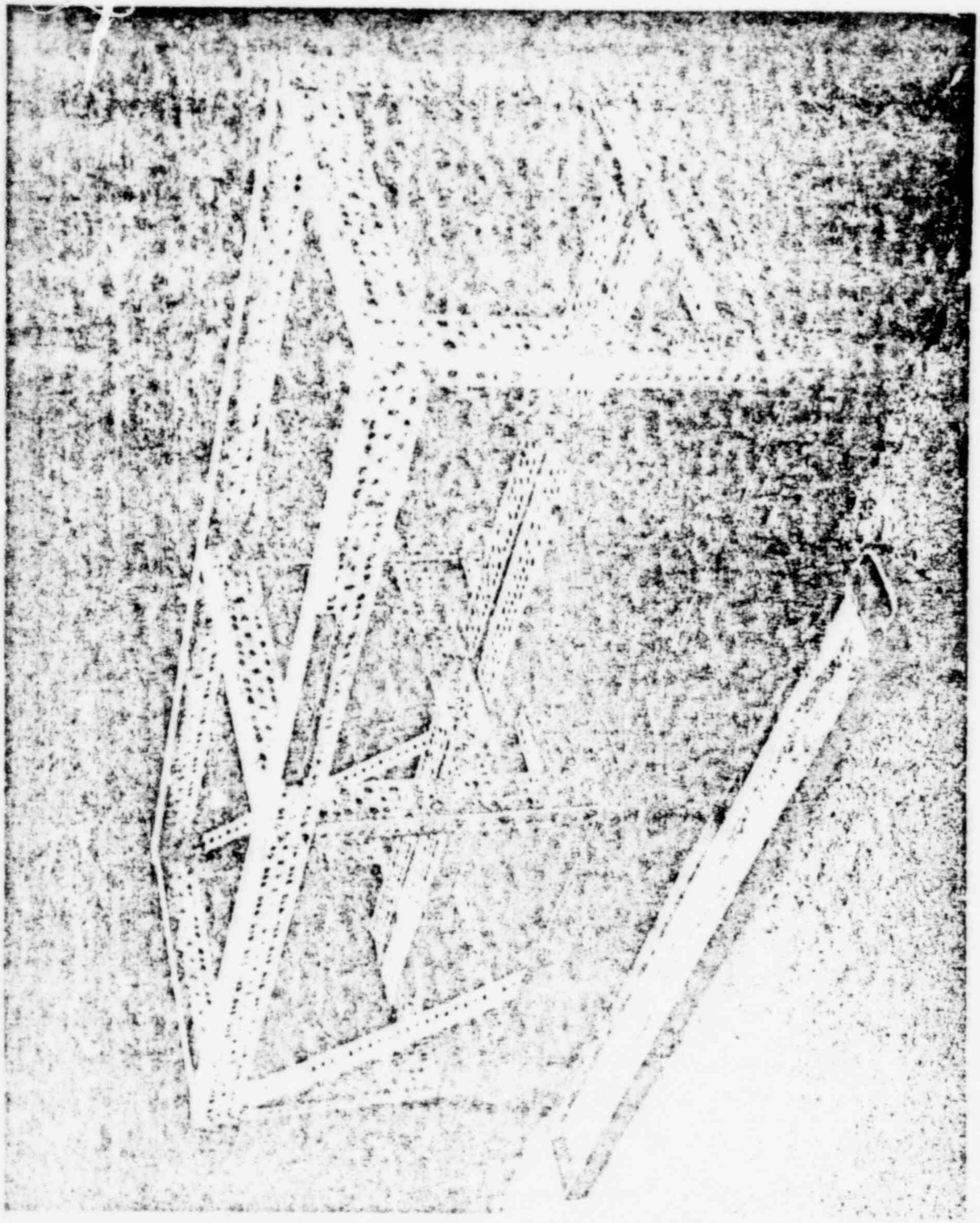


Figure 8a
B of E Permit No. 1270 Birdcage (6-1/2')

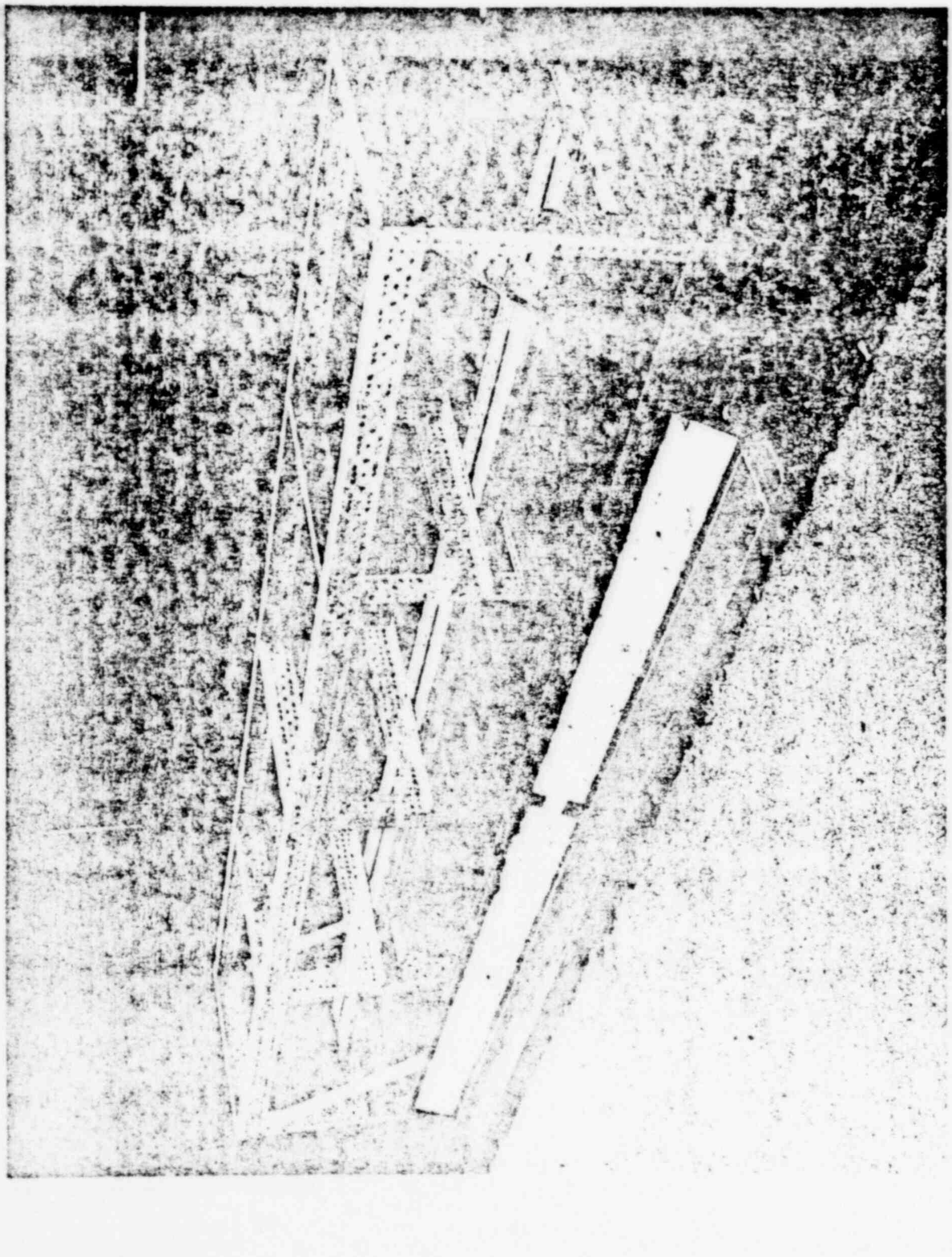
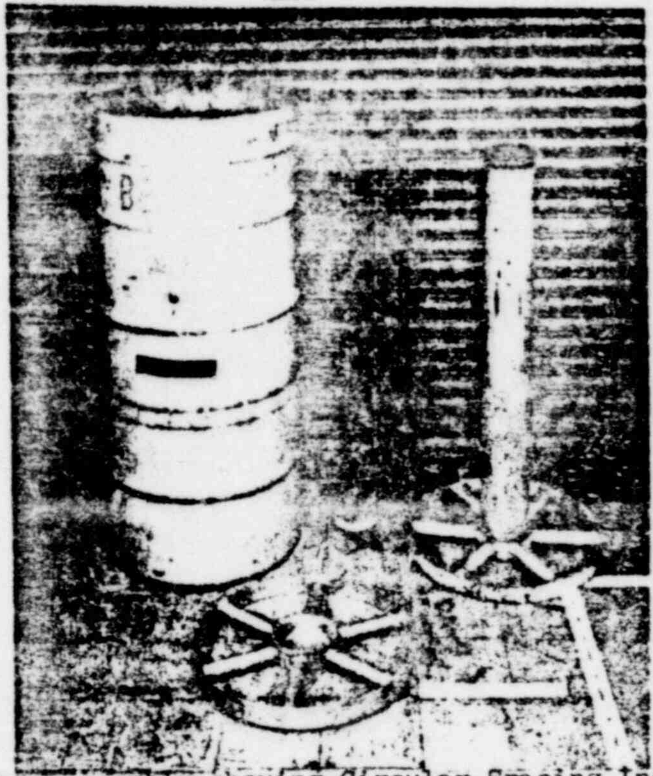
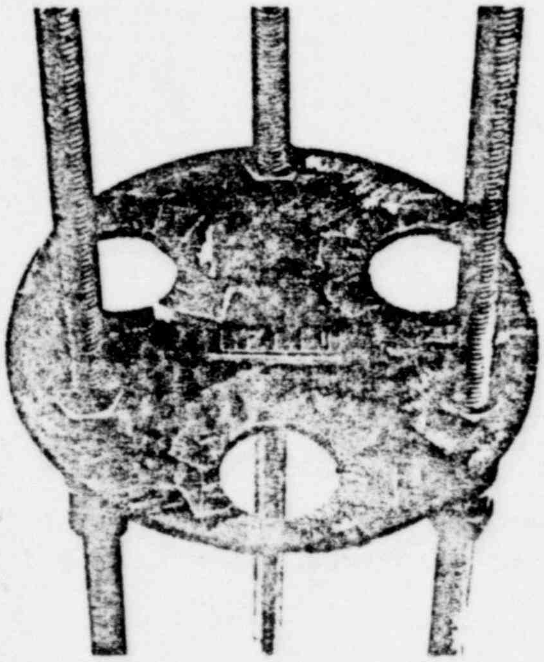


Figure 8b
B of E Permit No. 1270 Birdcage (12')



Drum before assembly showing Circular Spacing Insert



Detail View of Circular Spacing Insert

BE 2071, 1926, or 1926 (Modified Drum with Inner Circular Spacing Insert

Figure 8-1

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C. REQUIREMENTS FOR PACKAGING

1. ICC Approval Requirements

Packaging described herein for fissile materials may continue to be used until July 1, 1968, if there is no change in the use for which it has been approved. After that date, all such packaging must have ICC approval. As noted elsewhere, packaging described herein has BE permits. After ICC permits are obtained, appropriate changes in this report will be made.

2. Exemptions

The following types of material are exempt from the packaging requirements of Section A.

a. Not more than 15 grams of fissile material; or

b. Thorium.

D. PACKAGE STANDARDS

1. General Standards for All Packaging

a. Packaging shall be of such materials and construction that there will be no significant chemical, galvanic, or other reaction among the packaging components, or between the packaging components and the package contents.

Except for rusting of the steel and the possible leakage of acid solution from the primary polyethylene container, no serious reactions are expected. In the latter case, the absorbent material surrounding the polyethylene containers will contain any such spillage.

b. Packaging shall be equipped with a positive closure which will prevent inadvertent opening.

The lids of the 17H, BE 1926 and BE 2071 Drums are secured by bolted rings. The lid of BE 2070 is held in place by 8 machine bolts. Both ends of BE 1885 are held in place by machine bolts. The inner steel or aluminum box of BE 1270 is secured by 2 steel bands. The lids of the Wooden Boxes are nailed, and all boxes are banded.

c. Lifting devices

(1) If there is a system of lifting devices which 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.

There are no lifting devices specifically incorporated.

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D. 1. c. (2) If there is a system of lifting devices which is a structural part only of the lid, 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.

There are no lifting devices specifically incorporated.

(3) If there is a structural part of the package which could be employed to lift the package and which does not comply with subparagraph (1) of this paragraph, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.

The framework of BE 1270 Birdcage is employed for lifts. No birdcages are used for Fissile Class I or II shipments. The birdcages used for Class III shipments are transported by sealed van or are escorted and are not accessible; therefore, complete enclosure is not necessary. Loading and unloading of the truck is not considered transport.

(4) Each lifting 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 containment or shielding properties of the package.

Not applicable.

d. <u>Tie-down devices</u>

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

There are no tie-down devices specifically incorporated.

(2) If there is a structural part of the package which could be employed to tie the package down and which does not comply with subparagraph (1) of this paragraph, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.

D. 1. d. (2) The framework of BE 1270 birdcage may be employed for tie down. This component has not been evaluated with respect to d.(1) above; however, failure of packaging is assumed to be a possible accident and such failure is shown to be acceptable. See Table A, Note (3) All such tie downs are prepared by Bettis personnel. Tie downs used are restricted to the use of 2 by 4 boards and nails.

(3) Each tie-down device which is a structural part of the package shall be so designed that failure of the device under excessive would not impair the ability of the package to meet other requirements of this subpart.

Not applicable.

2. Structural Standards for Large Quantity Packaging

Packaging used to ship a large quantity of radioactive material, as defined in I.A.6 (of AECM 0529), shall be designed and constructed in compliance with the structural standards of this section. Standards different from those specified in this section may be approved by the manager or other designated official if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

Not applicable.

3. Criticality Standards for Fissile Material Packages

a. A package used for the transport of fissile material shall be so designed and constructed and its contents so limited that it would be subcritical if it is assumed that water leaks into the containment vessel, and:

(1) Water moderation of the contents occurs to the most reactive credible extent consistent with the chemical and physical form of the contents; and

(2) The containment vessel is fully reflected on all sides by water.

Calculated data has confirmed that each unit being shipped is subcritical. (See Criticality Analyses, Sections H, I and J).

b. A package used for the transport of fissile material shall be so designed and constructed and its contents so limited that it would be subcritical if it is assumed that any contents of the package which are liquid during normal transport leak out of the containment vessel, and that the fissile material is then:

(1) In the most reactive credible configuration consistent with the chemical and physical form of the material;

(2) Moderated by water outside of the containment vessel to the most reactive credible extent; and

D. 3. b. (3) Fully reflected on all sides by water.

(See Criticality Analyses, Sections H, I and J).

c. The manager or other designated official may approve exceptions to the requirements of this section where the containment vessel incorporates special design features which would preclude leakage of liquids in spite of any single packaging error and appropriate measures are taken before each shipment to verify the leak tightness of each containment vessel.

No exception requested.

4. Evaluation of a Single Package

a. The effect of the transport environment on the safety of any single package of radioactive material shall be evaluated as follows:

(1) The ability of a package to withstand conditions likely to occur in normal transport shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the normal conditions of transport as specified in II.E. of AECM 0529.

The various aspects of normal conditions of transport as specified in II.E. of AECM 0529 are described in Section D.5. below. Normal Transport Condition Tests as specified in Annex 1 of AECM 0529 are described and qualified in Appendix I of this report.

(2) The effect on a package of conditions likely to occur in an accident shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the hypothetical accident conditions as specified in II.F. of AECM 0529.

The various aspects of accident conditions as specified in II.F. of AECM 0529 are described in Section D.6. below. Accident Condition Tests as specified in Annex 2 of AECM 0529 are described and qualified in Appendix II of this report.

b. Taking into account controls to be exercised by the shipper, the manager or other designated official may permit the shipment to be evaluated together with or without the transporting vehicle, for the purpose of one or more tests.

Not applicable.

c. Normal conditions of transport and hypothetical accident conditions different from those specified in II.E. and II.F. of AECM 0529 may be approved by the manager or other designated official if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

D. 4. c. The following exceptions to normal or hypothetical accident conditions (as described in Appendices I and II) qualify for special approval as stated above:

(1) Reference II.E.2.(3). of AECM 0529 - Occurrence of any aperture in the outer surface of the packaging large enough to permit the entry of a four-inch cube.

BE 1270 Birdcages, shipped as Fissile Class III in a sealed van or under escort, will have no fissile packages smaller than other birdcages.

(2) Annex 1 of AECM 0529 (Normal Conditions of Transport, Item 6) - Within 2-1/2 hours after conclusion of the water spray, a free drop through the distance specified below (4 ft.) onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.

The water spray test was not conducted within 2-1/2 hours of the free drop but subsequent to it. It is not expected that any dampness would affect the results of the free drop test.

(3) Annex 1 of AECM 0529 (Normal Conditions of Transport, Item 1 - Heat and Item 2 - Cold)- The effect of an ambient temperature of 130°F or -40°F on solutions packaged in 55-gallon 17H drums with a polyethylene bottle and absorbent material (see Appendix I.B) was not tested. The manufacture indicates that structural integrity of the poly bottles containing solutions which freeze will be maintained at temperatures at least 20°F above and below the AECM 0529 temperature limits.

(4) Annex 1 of AECM 0529 (Normal Conditions of Transport, Item 7 - Corner Drop) - The Corner Drop Test onto each corner of the package from a height of one foot was not conducted and documented for the wooden box since this was not an original AECM 0529 requirement. The free drop from four feet, which is a more severe test, showed no external or internal damage to the box whatsoever (see Appendix I.C.); it is assumed that the one foot corner drops would also produce no damage considering that wooden box shipments generally weigh less than 100 lbs. This assumption is also substantiated by the fact that, except for splintering, there was no damage to the wooden box after a 30 foot drop test.

(5) Annex 2 of AECM 0529 (Hypothetical Accident Conditions, Item 3 - Thermal) - The Thermal Test was not conducted. See Section J.5. and Appendix II, General for explanatory considerations.

(6) Annex 2 of AECM 0529 (Hypothetical Accident Conditions, Item 4 - Water Immersion) - Water Immersion Tests were not conducted since packaging limits are established that are safe even if the container is optimally moderated.

D. 5. Standards for Normal Conditions of Transport for a Single Package

a. A package used for the shipment of fissile material or a large quantity of radioactive material, as defined in I.A.6. of AECM 0529, shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in Annex 1;

(1) There will be no release of radioactive material from the containment vessel.

Tests have shown that, under most normal conditions of transport, there is no release of material from the containment vessel. See Section c.(4). above for waiver condition and Appendix I for test descriptions and qualifications

(2) The effectiveness of the packaging will not be substantially reduced.

Tests have shown that normal conditions of transport will not reduce the effectiveness of the packaging. (See Appendix I)

(3) There will be no mixture of gases or vapors in the package which could, through any credible increase of pressure or an explosion, significantly reduce the effectiveness of the package.

Not applicable.

(4) Radioactive contamination of the liquid or gaseous primary coolant will not exceed 10^{-7} curies of activity of Group I radionuclides per milliliter, 5×10^{-6} curies of activity of Group II radionuclides per milliliter, 3×10^{-4} curies of activity of Group III and Group IV radionuclides per milliliter.

Not applicable.

(5) There will be no loss of coolant or loss of operation of any mechanical cooling device.

Not applicable.

b. A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in Annex 1 of AECM 0529, considered individually;

(1) The package will be subcritical.

Calculated data has confirmed that each package is subcritical even when completely flooded. (See Sections H, I and J).

(2) The geometric form of the package contents would not be substantially altered.

D. 5. b. (2) Tests have shown that normal conditions of transport, as described in Appendix I, will not alter the geometric form of the package contents.

(3) There will be no leakage of water into the containment vessel. This requirement need not be met if, in the evaluation of undamaged packages under II.H.1., II.I.1.a., or II.4.1. of AECM 0529 it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material.

No leakage of water into containment vessel was observed in the normal conditions of transport test on any packages.

(4) There will be no substantial reduction in the effectiveness of the packaging, including:

(a) Reduction by more than five percent in the total effective volume of the packaging on which nuclear safety is assessed.

The normal conditions of transport tests conducted on each type of package indicated no significant change in dimensions. (See Appendix I).

(b) Reduction by more than five percent in the effective spacing on which nuclear safety is assessed, between the center of the containment vessel and the outer surface of the packaging.

The normal conditions of transport tests conducted on each type of package indicated no significant change in dimensions.

(c) Occurrence of any aperture in the outer surface of the packaging large enough to permit the entry of a four-inch cube.

BE 1270 Birdcage is an open structure; however, since it is used only in Fissile Class III shipments using escort or a sealed van, no fissile packages smaller than a birdcage will be present. (See D.4.c.(1). for waiver request).

c. A package used for the shipment of a large quantity of radioactive material as defined in I.A.6. of AECM 0529, shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in Annex 1, considered individually, the containment vessel would not be vented directly to the atmosphere.

Not applicable.

6. Standards for Hypothetical Accident Conditions for a Single Package

a. Packages used for the shipment of a large quantity of radioactive material.

Not applicable.

D. 6. b. A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in Annex 2 of AECM 0529 as the Free Drop, Puncture, Thermal, and Water Immersion conditions, in the sequence listed in Annex 2, the package would be subcritical. In determining whether this standard is satisfied, it shall be assumed that:

(1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents;

(2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents; and

(3) There is reflection by water on all sides and as close as is consistent with the damaged condition of the package.

Calculations have established that each package is subcritical under these conditions (See Sections H, I and J).

7. Evaluation of An Array of Packages of Fissile Material

a. The effect of the transport environment on the nuclear criticality safety of an array of packages of fissile material shall be evaluated by subjecting a sample package or a scale model, by test or other assessment, to the hypothetical accident conditions specified in II.H., II.I., or II.J of AECM 0529 for the proposed fissile class, and by assuming that each package in the array is damaged to the same extent as the sample package or scale model. In the case of a Fissile Class III shipment, the manager or other designated official may, taking into account controls to be exercised by the shipper, permit the shipment to be evaluated as a whole rather than as individual packages, and either with or without the transporting vehicle, for the purpose of one or more tests.

b. In determining whether the standards of II.H.2., II.I.1.b., and II.J.2. of AECM 0529 are satisfied, it shall be assumed that:

(1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package, the chemical and physical form of the contents, and controls exercised over the number of packages to be transported together; and

(2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.

For each type of package the evaluation was made assuming that the array of packages was subjected to the most reactive condition of partial flooding. In each case, entry of water into the containment vessel was assumed to be possible under the hypothetical accident conditions (See Sections H, I, and J).

D. 8. Specific Standards for a Fissile Class I Package

A Fissile Class I package shall be so designed and constructed and its contents so limited that:

a. Any number of such undamaged packages would be subcritical in any arrangement, and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered; and

b. Two hundred fifty such packages would be subcritical in any arrangement, if each package were subjected to the hypothetical accident conditions specified in Annex 2 of AECM 0529 Appendix as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in Annex 2, with close reflection by water on all sides of the array and with optimum interspersed moderation in the packaging, in which case that greater amount may be considered. The condition of the package shall be assumed to be as described in II.G. of AECM 0529.

The criticality analysis for Fissile Class I packages under hypothetical accident conditions is contained in Section H.2.

9. Specific Standards for a Fissile Class II Package

a. A Fissile Class II package shall be so designed and constructed and its contents so limited, and the number of such packages which may be transported together so limited, that:

(1) Five times that number of such undamaged packages would be subcritical in any arrangement if closely reflected by water; and

(2) Twice that number of such packages would be subcritical in any arrangement if each package were subjected to the hypothetical accident conditions specified in Annex 2 of AECM 0529 Appendix as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in Annex 2, with close reflection by water on all sides of the array and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered. The condition of the package shall be assumed to be as defined in II.G. of AECM 0529.

b. The minimum number of radiation units for each Fissile Class II package is calculated by dividing the number 40 by the number of such Fissile Class II packages which may be transported together as determined under the limitations of paragraph a. of this section. The calculated number shall be rounded up to the first decimal place.

The criticality analisis for Fissile Class II packages is contained in Section I.2.

10. Specific Standards for a Fissile Class III Shipment

A package for Fissile Class III shipment shall be so designed and constructed and its contents so limited, and the number of packages in a Fissile Class III shipment shall be so limited that:

1. The undamaged shipment would be subcritical with an identical shipment in contact with it and with the two shipments closely reflected on all sides by water; and

2. The shipment would be subcritical if each package were subjected to the hypothetical accident conditions specified in Annex 2 of Appendix AECM 0529 as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in Annex 2, with close reflection by water on all sides of the array and with the packages in the most reactive arrangement and with the most reactive degree of interspersed hydrogenous moderation which would be credible considering the controls to be exercised over the shipment. The condition of the package shall be assumed to be as described in II.G. of AECM 0529. Hypothetical accident conditions different from those specified in this subparagraph may be approved by the manager or other designated official if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

   The number of packages permitted in Fissile Class III shipments is shown in the Table in Section A. The criticality analyses for each type of shipment is contained in Section J. This data demonstrates that each shipment will be subcritical under the hypothetical accident conditions. In addition, the analyses considers the effect of severe one dimensional crushing of the containers.

E. OPERATING PROCEDURES

1. Establishment and Maintenance of Procedures

a. The shipper shall establish and maintain:

   (1) Operating procedures adequate to assure that the determinations and controls required by AECM 0529 are accomplished; and

   (2) Regular and periodic inspection procedures adequate to assure that the shipper follows the procedures required by subparagraph (1). of this paragraph.

   Bettis will comply with all these requirements. Bettis Criticality Control Standards will independently review operating procedures as part of its monthly inspections; the Bettis Fuel Handling Safeguards Committee will also review these procedures as part of its annual criticality inspection.

E. 2. Assumptions as to Unknown Properties

When the isotopic abundance, mass, concentration, degree of irradiation, degree of moderation, or other pertinent property of fissile material in any package is not known, the shipper shall package the fissile material as if the unknown properties have such credible values as will cause the maximum nuclear reactivity.

Bettis will comply with these requirements.

3. Preliminary Determinations

a. Prior to the first use of any packaging for the shipment of a large quantity of radioactive material or fissile materials, such packaging shall be inspected to ascertain that there are no cracks, pinholes, uncontrolled voids or other defects which could significantly reduce its effectiveness.

Bettis will comply with these requirements by performing a visual inspection.

b. Prior to the first use of any packaging for the shipment of a large quantity of radioactive material or fissile materials, where the maximum normal operating pressure will exceed 5 pounds per square inch gauge, the containment vessel shall be tested to assure it will not leak at an internal pressure fifty percent higher than the maximum normal operating pressure.

Not applicable.

c. Packaging shall be conspicuously and durably marked with its model number. Prior to applying the model number, an inspection shall be made to determine that the packaging has been fabricated in accordance with the approved design.

Bettis will comply with these requirements.

4. Routine Determinations

Prior to each use of a package for shipment of radioactive or fissile material the shipper shall ascertain that the package with its contents satisfies the applicable requirements of section II of AECM 0529 appendix including determinations that:

a. The packaging has not been significantly damaged;

b. Any moderators and non-fissile neutron absorbers, if required, are present and are as authorized;

c. The closure of the package and any sealing gaskets are present and are free from defects;

d. Any valve through which primary coolant can flow is protected against tampering;

E. 4. e. The internal gauge pressure of the package will not exceed, during the anticipated period of transport, the maximum normal operating pressure;

f. Contamination of the primary coolant will not exceed, during the anticipated period of transport, the limits specified in II.E.1.d.

Bettis will comply with item a. Items b, d, e and f are not applicable. The closure of the package, as indicated in the first part of Item c. will be checked to insure structural integrity; since Bettis criticality evaluations are made assuming the most reactive flooded conditions, reliance upon the integrity of sealing gaskets is not a determining factor (second part of item c.).

5. Reports

The shipper shall maintain for a period of at least two years after its generation a record of each shipment of fissile material and of a large quantity of radioactive material, as defined in I.A.6. of AECM 0529, in a single package, showing, where applicable:

a. Identification of the packaging by model number;

b. Details of any significant defects in the packaging, with the means employed to repair the defects and prevent their recurrence;

c. Volume and identification of coolant;

d. Type and quantity of material in each package, and the total quantity in each shipment;

e. For each item of irradiated fissile material:

(1) Identification by model number;

(2) Irradiation and decay history to the extent appropriate to demonstrate that its nuclear and thermal characteristics comply with approved conditions;

(3) Any abnormal or unusual condition relevant to radiation safety.

f. Date of the shipment;

g. For Fissile Class III, any special controls exercised;

h. Name and address of the transferee;

i. Address to which the shipment was made; and

j. Results of the determinations required by III.C. and III.D. of AECM 0529.

E. 5. Items c and e are not applicable. Bettis will comply with all other requirements. Required information is recorded on either the AEC 101 Shipping Form or on Bettis Form 73228 (SS Shipping Request Form).

F. LABELING

AECM 0529 requires that "each shipment of fissile material and other radioactive material shall be in compliance with the safety regulations of the Interstate Commerce Commission (ICC), Federal Aviation Agency (FAA), Post Office Department, or Coast Guard depending on the mode of transportation, when offered to the carrier." Bettis complies with this requirement.

G. ADMINISTRATIVE CONTROL

AECM 0529 requires that Fissile Class III packages must be transported under the administrative control of the shipper to prevent comingling with other shipments of fissile material. Bettis complies with this requirement by making Fissile Class III shipments with exclusive use of vehicles, or escort. In some cases a specific type of vehicle is required. (See Note 3 of Table, Section A). Fissile Class I and II require no administrative control.

H. FISSILE CLASS I SHIPMENTS

1. General

The specific standards as required by AECM 0529 for Fissile Class I packages are described in Section D.8. of this report. Normal conditions of transport tests for Bettis containers which qualify for Fissile Class I shipments are described in Appendix I. Hypothetical accident test conditions are described in Appendix II.

2. Criticality Analysis

a. Moderated Criticality

The data in figure 4 of LAMS 2415, "Critical Data For Nuclear Safety Guidance," dated May 16, 1960, for semi-infinite slabs of water moderated U-235 indicates that the minimum critical mass of U-235 per unit slab area is 365 grams U-235/ft^2. This indicates that a safe mass density is 165 grams U-235/ft^2, using the 2.3 mass safety factor. In semi-infinite slab geometry the neutron multiplication is independent of the density of the materials provided all materials, including the reflector materials, be reduced in density in inverse proportion to the height of the slab.

Therefore the 4-inch semi-infinite slab data in LAMS 2415 is applicable to a slab 10.5 feet high (4, 55-gallon drums high) if the densities of the materials are reduced by a factor of 32. Calculations have established that replacing the 1/32 normal density water reflector at the top and bottom of the slab by water at normal density only reduces the multiplication of the slab.

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H. 2. a.

In a hexagonal close packed array of 55-gallon drums or BE 2071 drums standing on their bottoms, the slab area per drum is 2.9 sq. ft; hence, the volume above this area may safely contain 480 grams, or four drums high and 120 grams per drum. If the drums are stacked laying down, their horizontal projected area is 5.6 sq. ft. for the 55-gallon drums. The volume above this area may safely contain 870 grams or seven drums high (13 ft.).

The uniform distribution of fuel within the drum with water present uniformily at approximately 3% by volume is the most reactive arrangement. Re-arranging the fuel to confine it within an inner 5-inch cylinder, or any other arrangement, will reduce the multiplication. Changes in the amount or distribution of water within the drum, or the addition of any other non-fissile materials (exclusive or significant amounts of heavy water, beryllium and graphite), will also reduce the multiplication.

b. Unmoderated Criticality

When 55-gallon drums, each containing 120 grams U-235, are hexagonal close packed in a cubic array, the lattice density is 0.0155 kg U-235/ft^3. Figure 22 of TID-7016, Rev. 1, "Nuclear Safety Guide," 1961, may be used to show that at this low lattice density, fast criticality cannot occur even in a closely reflected cubic array of 31,000 drums. The range of Figure 22 is such that a maximum size unit occupies 30 cu. ft. and contains not more than 18.5 kg U-235. Since it is conservative to reduce the volume of the drums, their volume may be reduced by a factor of 40 without exceeding the 18.5 kg limit for the maximum size unit of 30 cu. ft. (A review of the basic principles used to construct Figure 22 has shown that under conditions where there is no moderator present, there is no need for the 8-inch minimum surface-to-surface spacing specified in Figure 22.) At this reduced volume of a drum, the 30 cubic feet of lattice volume will contain 155 drums. Figure 22 of TID-7016 allows a cubic array with 200 maximum size units, or 31,000 of the reduced volume drums, under conditions where there is no moderator present. It is thus concluded that the moderated array limits associated with a semi-infinite plane are more restrictive in any realistic shipping or storage condition.

c. Appendix 0529 Requirements for Single Package and Arrays

The limit of 120 grams U-235 per drum insures under any conceivable accident condition that the mass of U-235, which is the controlling factor, does not exceed 80% of the critical mass.

An infinite number of undamaged drums is subcritical in any array subject only to the condition that if the drums are stacked standing up in horizontal layers that the number of tiers does not exceed 8 (23 feet for the 55-gallon drums and 35 feet for the BE 2071 drums), or stacked laying down that this semi-infinite array is not higher than 16 layers of drums (30 feet for either drum). Since the vertical dimensions of these two stacking arrangements are greater than can reasonably be expected to occur, such a condition is considered to meet the intent of the AEC requirement of subcritical in "any array."

The results of the drop tests on the 55-gallon drums and BE 2071 drums indicate that the array accident test conditions referred to in AEC Appendix 0529 do not alter the condition of the drums in any manner which affects the criticality of arrays of drums. Therefore, the subcriticality of an array of 250 drums, each damaged to this extent, is assured in the same manner as the subcriticality of an infinite number of undamaged drums.

3. Hazards Evaluation

Each of the shipping conditions has been evaluated as regards satisfying the "double accident" criterion. Moderation within the drums (except for material which is moderated when packed) or double fuel loading of the material is considered as the first accident. Unlikely though it may be, the only other second accident to an array of drums which conceivably could result in accidental criticality is one-dimensional crushing; therefore, one-dimensional crushing has been considered in the evaluations below.

Stacking of the drums in a four high semi-infinite array must be considered a normal (non-accident) condition. If this array is stacked out of doors, accumulation of snow and ice can result in optimum moderation between the undamaged drums. Under such a condition the semi-infinite array would not meet a postulated double accident condition of both double fuel batching and double fuel loading (that is, four times the permitted fuel loading in each drum). However, quadruple loading is very unlikely to occur throughout a four high array of drums large enough to permit criticality to occur with 480 grams U-235 per drum. It is estimated that the critical size for a fully reflected, four high array of drums each containing 480 grams uniformly distributed in the drum with optimum moderation is approximately 250 drums. Under these conditions quadruple loading requires that approximately 100 kg U-235 be unknowingly present. Also, the array is safe with either a double batching or a double loading accident. Therefore, this condition is considered to be acceptable.

Various types of shipments are evaluated below.

a. Solutions - For solutions in which the U-235/liter is less than two grams, an infinite number of drums will satisfy the double accident criterion of double loading plus one-dimensional crushing. If more than 2 grams U-235/liter are present, cadmium nitrate is added on a gram for gram basis. If it is necessary to ship more than 2 grams U-235/liter without addition of cadmium nitrate (limited to 60 grams U-235 per drum), then a Schedule-40 pipe inner liner is required to give higher integrity. In this case at least 15 inner cylinders must be damaged and leak and the solution collect in a single pool before a critical condition is achieved. Considering the integrity of the inner container (Schedule-40 pipe) and the presence of enough absorbent to absorb all of the liquid, such a series of events is considered implausible even under accident conditions involving severe one-dimensional crushing.

b. Low Concentration U-235 (Less than 20 grams/cubic foot) in Waste Material -

These materials normally may be packaged under optimum moderation conditions. Hence the double accident criteria must be double loading plus one-dimensional crushing. These materials will normally be packaged within the entire drum. If the materials are compressible and hence remain within the drum when the drum is one-dimensionally crushed, they form an iron/U-235 mixture with an iron/U-235 atom ratio of approximately 300 if the drums are double loaded or iron/U-235 atom ratio of approximately 600 if they are not. These systems are safe for an infinite number of crushed drums because of the high iron/U-235 ratio.

If the materials are not compressible, the lids may pop off when the drums are crushed one-dimensionally and the iron will be ineffectual as a poison since the material will not be within the crushed drums. However, in this case, since the density of material in the system will not be significantly altered, safety is still assured since it is unlikely that the height of the disturbed semi-infinite array will at any point exceed the height which is safe; in this case, if the material is incompressible and the drums were completely filled, the safe semi-infinite slab height is approximately 9 ft (if the drums were double loaded).

c. Powder and Fuel Elements - These shipments are considered as unmoderated and hence the accidents of interest are one-dimensional crushing plus moderation inside the container. These shipments are packaged with the fuel contained within a 5-inch diameter inner cylinder of Schedule-40 pipe. A single row, infinitely long, of these drums may be crushed (in the direction along the row length) to a drum thickness of 3 inches before the 40 gram/inch critical loading is approached. It is considered unlikely that the 5-inch diameter Schedule-40 pipe will be crushed (as is required to approach 3-inch width per unit) when significant numbers of drums which crush more easily are present. It should be noted that if less than eight drums are present the crushing of the inner cylinder is of little importance, since the system is safe by virtue of the mass of fuel present.

Two-dimensional crushing in the horizontal plane of an array of these drums one tier high is safe with optimum moderation down to a packing density of one crushed drum plus 5-inch inner diameter cylinder per 1/3 sq. ft (7 inch sq) of crushed array area since this constitutes the minimum critical loading per sq. ft.

d. Chips Under Oil or Water - The comments above apply to moderated chips provided the amount of fuel is restricted to 60 grams U-235 per drum. Since these systems are deliberately moderated the accidents of interest are double loading plus crushing. The above considerations show that for materials packaged according to the restrictions indicated above and summarized in the table in Section A, there is little likelihood of the one-dimensional crushing accident resulting in a critical array regardless of the number of drums in the array.

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I. FISSILE CLASS II SHIPMENTS

1. General

The specific standards as required by AECM 0529 for Fissile Class II packages are described in Section D.9. of this report. At present, Bettis qualifies only one type shipment under Fissile Class II requirements. BE 2071 drum or 55-gallon 17H drum with a schedule-40 pipe insert is used for shipments of fissile material in rod form. Integrity of the BE 2071 drum or 55-gallon 17H drum with schedule-40 pipe insert under normal conditions of transport and under hypothetical test conditions is described in Appendices I and II respectively.

For Class II shipments of fissile material in rod form, a 1/8 inch steel insert will be used within each of the schedule-40 pipes to maintain 3 rods on a triangular pitch with their axis located on a 2-1/4 inch diameter bolt circle which will restrain the rods to a minimum 1.8 inch surface to surface spacing. The steel inserts consist of three 1/8-inch thick steel plates approximately 5 inches in diameter and spaced along the length of the schedule-40 pipe by three 3/8-inch diameter all thread rods which pass through the plates on a triangular pitch rotated 60° from the fuel rod holes. The six nuts on each of the threaded rods axially position the three centering disks. The fuel rods may contain U-235 in any uranium oxide enrichment and concentration with the pellet diameter less 0.66 inch. Maximum fuel loading per drum is 8 kgs. U-235 limited to 4 drums per shipment.

2. Criticality Analysis

a. Single Package

The restrictions imposed of:

(1) only 3 rods per package, and

(2) rod lengths limited by the maximum drum height of 53 inches.

(3) Fully enriched UO_2 pellets (all internal to the rod) must be less than 0.66 inch diameter.

ensure that no more than 8 kgs. U-235 will be transported in any single package. Therefore, the analysis in Section J.1. which justified a single package limit of 10 kgs. U-235 for a similar container, is applicable to this case.

An actual calculation of the k_{eff} for a single, flooded package containing 3 rods of the maximum size and fuel loading yielded a k_{eff}=0.53. In this calculation, the thermal neutron group utilization factor was calculated for an infinite medium of rods in a square pitch with a 1.8 inch surface-to-surface spacing. This is conservative since for a system with only 3 rods, the thermal utilization factor must be considerably less than that for an infinite medium of rods at the same spacing.

I. 2. b. Array of Packages

Five (5) times the number of approved packages (i.e. a total of 20 packages) in an undamaged condition must be subcritical when there is no internal moderation, other than the packaging materials, and the array is closely reflected by water.

To show that the packages meet this criteria, reference may be made to the fast criticality curves in reference 1*. The maximum fuel loading is 8 kgs. U-235 per 53-inch high drum, or 0.7 kgs. U-235 per cubic foot of packaging. The data in Figure 1 indicate that a total loading in excess of 1000 kgs. U-235 (or 125 packages) is safe from fast criticality at this density provided the H/U radio within the 5" diameter pipe is not more than 2.0.

A second method of evaluating this condition, a method which does not restrict the H/U ratio resulting from the packaging materials, is to use the interaction calculations described in reference 2*. Since the reference 2* method is applicable only to unreflected arrays, the data in reference 3* has been used to find the unreflected array size equivalent to a fully reflected array. Since the data in reference 3* indicate that the critical number of interacting units is reduced by a factor of 6 by adding optimum reflection to an unreflected array, the interaction calculation was done for 6 x 20 or 120 containers in an unreflected array. Using the notation of reference 2*, and making the following very conservative assumptions:

(1) No fuel is shielded from the central subcrit and

(2) $q_i = 1.0$ for all positions in the array.

(3) Packaging material is highly moderating and is approximated by filling the entire 5" diameter inner cylinder with water.

(4) $f = 0.515$ (thermal utilization factor for an infinite medium of rods at the 1.8 inch surface-to-surface spacing,

the following results were obtained:

$$\sum q_i \; \Omega_i < 1.0$$

$$U_f = 0.32$$

$$K_{subcrit} = 0.165$$

$$V = (1 - U_f)\sum q_i \Omega_i < 0.68$$

$$K_{array} = \frac{K_{subcrit}}{1-V} < 0.515$$

Hence, it is concluded that 20 packages, in an optimum, reflected, array are subcritical.

Reference 1* WAPD-O(IHH)-133, 4th Edition
2* K-1478, "Extension of Neutron Interaction Criteria"
3* ORNL-TM-719

I. 2. b. Twice the number of approved packages (i.e., a total of 8 packages) each damaged to the extent produced by the array accident test conditions must be subcritical in an optimum arrangement and with full water reflection. While the specified array accident test conditions do not cause severe distortion of the outer container, it is necessary to consider the containers one-dimensionally crushed in order to ensure that they meet the Bettis double accident criteria. The analysis of this condition assumed that all the schedule-40 pipes and endcaps in the 20 containers were in metal-to-metal contact. In this condition, the internal rod spacers have been designed to provide a 1.8 inch minimum surface-to-surface spacing between any two adjacent fuel rods. The thermal neutron group utilization factor, f, for an infinite array of the maximum size and loaded rods has been calculated to be 0.515 for this condition when the rods are arranged in a square pitch with this spacing and all the volume between the rods is occupied by water. This is a conservative calculation for the actual flooded case since the iron in the schedule-40 pipes would reduce the f factor. The fuel in the rods was completely smeared in the three fast groups with the maximum amount of water which can be present assuming it is displaced only by the uranium present. This is a conservative assumption since the pipe walls and actual rod volume will displace about 15% of this water volume. The crushed system size was chosen as the size resulting from 24 fuel rods on a square 1.8 inch surface-to-surface pitch. With these assumptions, the calculated k_{eff}=0.95. Since in this analysis the array has been actually subjected to a 2-dimensional crushing, it is concluded that when the approved number of containers is set at four, all the requirements of the AEC Manual Chapter 0529 and the Bettis double accident criteria are met with a considerable margin to criticality.

J. FISSILE CLASS III SHIPMENTS

The specific standards as required by AECM 0529 for Fissile Class III packages are described in Section D.10. of this report. Hypothetical accident test conditions for the Bettis containers which qualify for Fissile Class III shipments are described in Appendix II.

For purposes of making a criticality analysis and hazards evaluation, the following shipping arrangements must be considered:

1. Single metal container shipments with up to 10 kg. U-235.
2. Two, three, or four metal container shipments with lesser amounts of U-235.
3. **Wooden box containers.**
4. Multi metal containers shipped in a semi-trailer truck van.

1. Single Containers - up to 10 kg U-235

   a. Effectiveness of 5-inch diameter geometric restraint

      (1) Hydrogen/Uranium-235 ratio greater than 20

The volume of the 5-inch diameter inner container is approximately 11 liters (in a 55-gallon drum outer container). TID-7016 ~~Figure~~ 3 shows that confining solutions (or metal-water mixtures) to a 5-inch diameter cylinder, and with optimum reflection, even infinite length is criticality safe up to a solution limit of 1 kg/liter with a H/U ratio of 20. Above this density the analysis of paragraph (2) below is applicable.

TABLE

for $\frac{H}{U} \geq 20$

which → $\rho \leq 1.0$ kg/l

The low U-235 density of waste materials and uranium alloy chips and turnings physically limit the shipping of these materials to less than 5 kgs per 11 liter cylinder. Since solutions, alloy chips and turnings, waste materials, and metallography samples are the only shipments which are deliberately moderated, shipments of this type in this container satisfy the double accident criteria for moderated materials, i.e. subcritical after double loading followed by double batching. While a 5 kgs limit is adequately safe, 1 kg. limit has been arbitrarily established since it is consistent with operational requirements.

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(2) H/U-235 ratio less than 20 and fuel density greater than 1 kg/liter

Examination of TID-7016 ~~figure~~ Table 3 shows that the 5-inch cylinder geometry control is not nuclearly safe for H/U ratios less than 20. For this range the addition of a mass control limit is required. Examination of TID-7016 figures 1 and 2 show that in the range H/U ≦20 to 0 and U-235 density in excess of 1 kg/liter, the safe critical mass of the optimum geometry (a sphere) varies from 3 kgs to 10 kgs. However, when materials of this composition are limited in shape by a 5-inch cylinder the safe critical mass increases to 10 kgs or greater. One shape transformation of an optimum sphere geometry to a 5-inch diameter, finite length cylinder while holding the material composition constant, will illustrate this point.

Consider the 4 kg/liter point on figure 1 of TID-7016. Assume that the inner container is double loaded by accident with 20 kg. The 20 kgs occupy 5 liters at the assumed density. This 5 liter volume when placed inside the 5-inch diameter inner cylinder has a height to diameter ratio of 3 and hence by figure ~~[illegible]~~ of TID-7016 a 3 shape allowance factor on critical mass of 1.5. For this geometry then the critical mass is 1.5 times the minimum critical mass for material of this composition. Figure 1 of TID-7016 specifies this minimum critical mass as 2.3 x 7.8 kg. Thus it is concluded that for U-235 concentrations of 4 kg/liter, 20 kg is not critical when confined to a 5-inch diameter cylinder since for this geometry the minimum critical mass is 1.5 x 2.3 x 7.8 = 27 kg. Similar reasoning applies to all materials with compositions of greater than 1 kg/liter but less than 7 kg/liter.

It is thus concluded that since any single container with U-235 loadings of greater than 1 kg will be shipped in a non-moderated condition, that these materials meet the double accident criteria of being subcritical after double loading and flooding.

The 10 kg U-235 limit by itself is insufficient to protect against dry criticality. In this case the double accident condition to be applied is double loading and double batching; this results in a dry accident condition mass of 40 kg. Dry subcriticality of 40 kg U-235 in a 5-inch diameter cylinder is only assured if the theoretical density of the U-235 is less than 11 kg/liter. This may be shown as follows: Figure 19 of TID-7016 indicates that the effect on dry criticality of the density reduction from 17.6 to 11 gram/cc is a mass allowance factor (in optimum shape) of 1.5. The reduced density increases the minimum volume of the 40 kg U-235 to 3,640 cc, which when confined to a 5-inch diameter cylinder produces a Height to Diameter ratio of 2.3 and hence a shape allowance factor of 1.25. Therefore, for the postulated conditions the minimum dry critical mass of 22.8 kg is increased to 22.8 x 1.5 x 1.25 or 43 kg of U-235. Thus for theoretical U-235 density greater than 11 kg/liter, the mass limit of 10 kg must be reduced to 5 kg to ensure meeting the double accident criterion.

b. Interaction between two identical shipments

The shipping guide TID-7019, Table IX specifies that two 5-inch diameter cylinders of uranium solution of infinite length are safe for shipment with a spacing of 12 inches or greater between cylinders. The 55-gallon 17H drums, the BE 1926 and BE 2071 drums, and the BE 1885 and BE 1270 birdcages all provide 12-inch or greater spacing from adjacent units.

Since two identical shipments with U-235 loadings of greater than 333 gram/inch of inner container height are not necessarily safe if placed end to end (since they are mass limited) such shipments require 6 inches of spacing at either end of the inner container to assure a minimum of 12-inch spacing between two identical shipments each contained within a 5-inch diameter sphere. Table IX of TID-7019 indicates that this is a safe spacing for a more restrictive case, that of a 4.8 liter sphere.

c. Protection from criticality resulting from one-dimensional crushing

The analysis discussed in paragraph a. above is valid only as long as the shipment is contained within the 5-inch diameter inner cylinder (or equivalent cross sectional area steel box). The double accident criterion requires that one-dimensional crushing be considered as one of the accidents unless such an accident is not credible. For this reason when fuel is in a form and present in sufficient amounts that rearrangement of the fuel can result in criticality, only the highest integrity inner container (Schedule-40 pipe with threaded endcap) is used.

2. Two, Three, or Four Containers

The previous section dealt only with the limits for shipments involving a single container. Shipments sometimes must be made in more than a single container, however, because of physical capacities even though the U-235 limit is not controlling. Therefore, shipping arrangements and limits have been established for two, three, and four container shipments in which the inner container is Schedule-40 pipe.

The analysis was initiated with the following assumptions:

(a) Fuel will be in a 5-inch I.D. Schedule-40 pipe centered radially in a 55-gallon 17H drum, a BE 1926 drum, or a BE 2071 drum.

(b) The location of containers in a carrier is unrestricted when the carrier gives a non-comingling certificate.

The most limiting double accident condition is one-dimensional crushing of the outer containers until the Schedule-40 pipes are in contact and then there is complete flooding of all void spaces; it is assumed the

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pipes are fully reflected by water. For moderated materials the second accident is double loading. To simplify the analysis, and to ensure that the results were conservative, the following additional assumptions were made:

(a) Fuel is uniformly distributed in equal amounts within each of the 5-inch diameter cylinders over a height which maximizes the k_{eff} for the crushed array.

(b) The fuel within the 5-inch diameter cylinder is assumed to occupy zero volume so that a maximum volume is available for H_2O.

(c) The one-dimensional crushing (the most severe accident that could occur) results in the most closely packed array of cylinders possible with no intervening material other than the pipe walls. (Actually this is equivalent to two-dimensional crushing.)

a. Method of Analysis

The k_{eff} for the crushed array of an isolated set of 2, 3, and 4 cylinders in contact was calculated using 4 group PDQ-05(1) xy geometry problems. The circular geometry was represented by a rectangular mesh using a minimum of a 0.25-inch step. The steps were arranged so that the total area of the metal wall of the Schedule-40 pipe was represented as 90% of its actual area, and the area inside the pipe at 100% of its actual area. The thermal neutron absorptions in the iron (the steel pipe was considered as pure iron) were included in the calculations, but no epi-thermal absorptions in the iron were considered.

Table I shows the results of the calculations and a comparison of the calculational model (minus the iron wall) with the experimental data in TID-7028(2), Figure 56 for two 5-inch diameter cylinders separated by 0.5 inches. This is the only experimental data applicable to this problem. Based on this result, a calculated $k_{eff} = 0.95$ was chosen to set the maximum permissible loading per cylinder. Figure 9 shows the method of interpolating the results in Table I to other cases. Figures 10, 11, and 12 show the calculated k_{eff} for various arrays as a function of kg U-235 per cylinder.

cont. on p 45

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(1) W. R. Cadwell, et al, "PDQ-5, A Fortran Program for the Solution of the Two Dimensional Neutron-Diffusion Problem, Part I: Steady-State Version," WAPD-TM-363, February, 1963.

(2) TID-7028, "Critical Dimensions of Systems Containing U-235, Pu-239, and U-233," June, 1964.

KEFF VS HEIGHT FOR FLOODED ARRAYS OF 5 INCH DIAMETER CYLINDERS
(SCHEDULE-40 PIPES IN CONTACT)

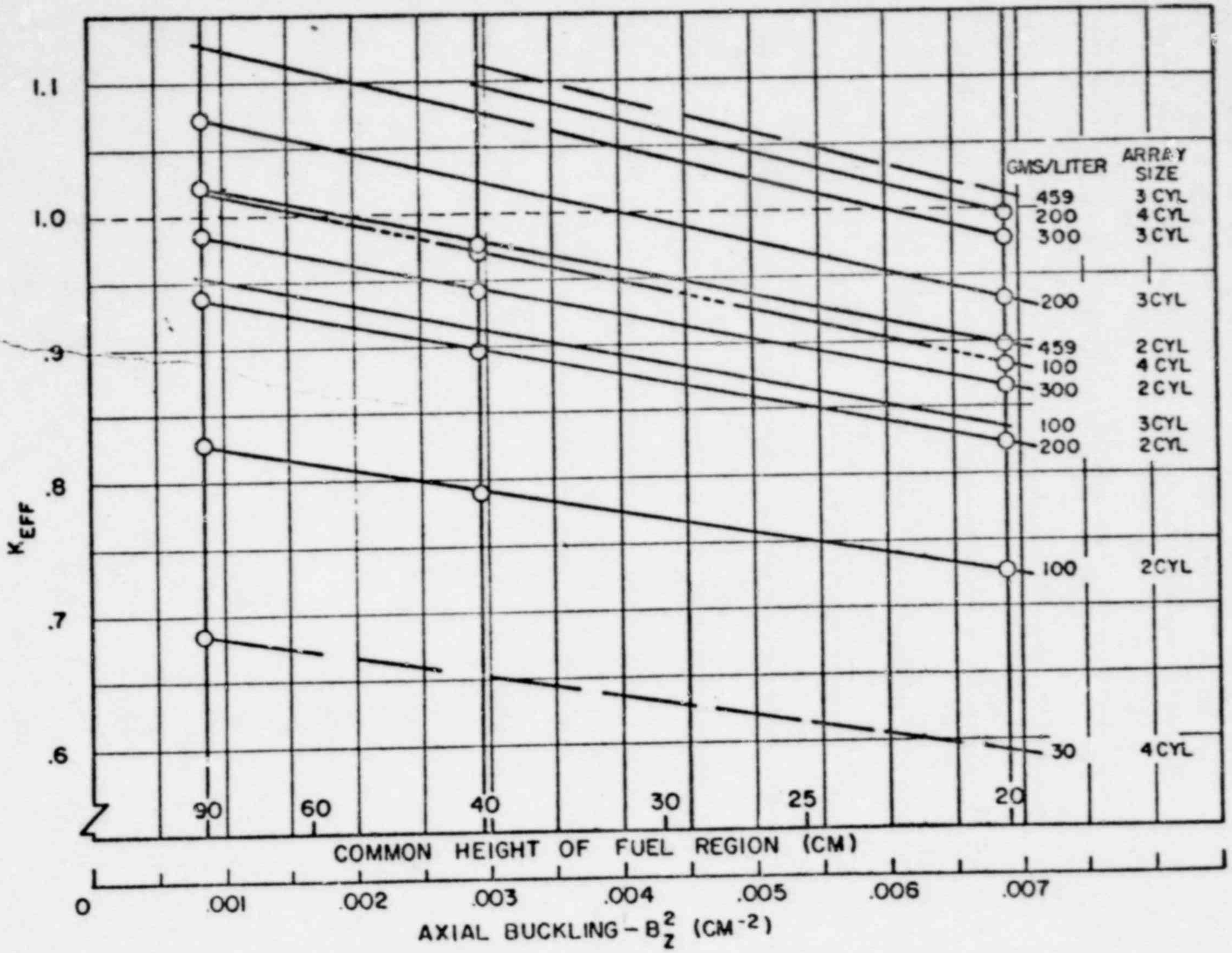


Figure 9

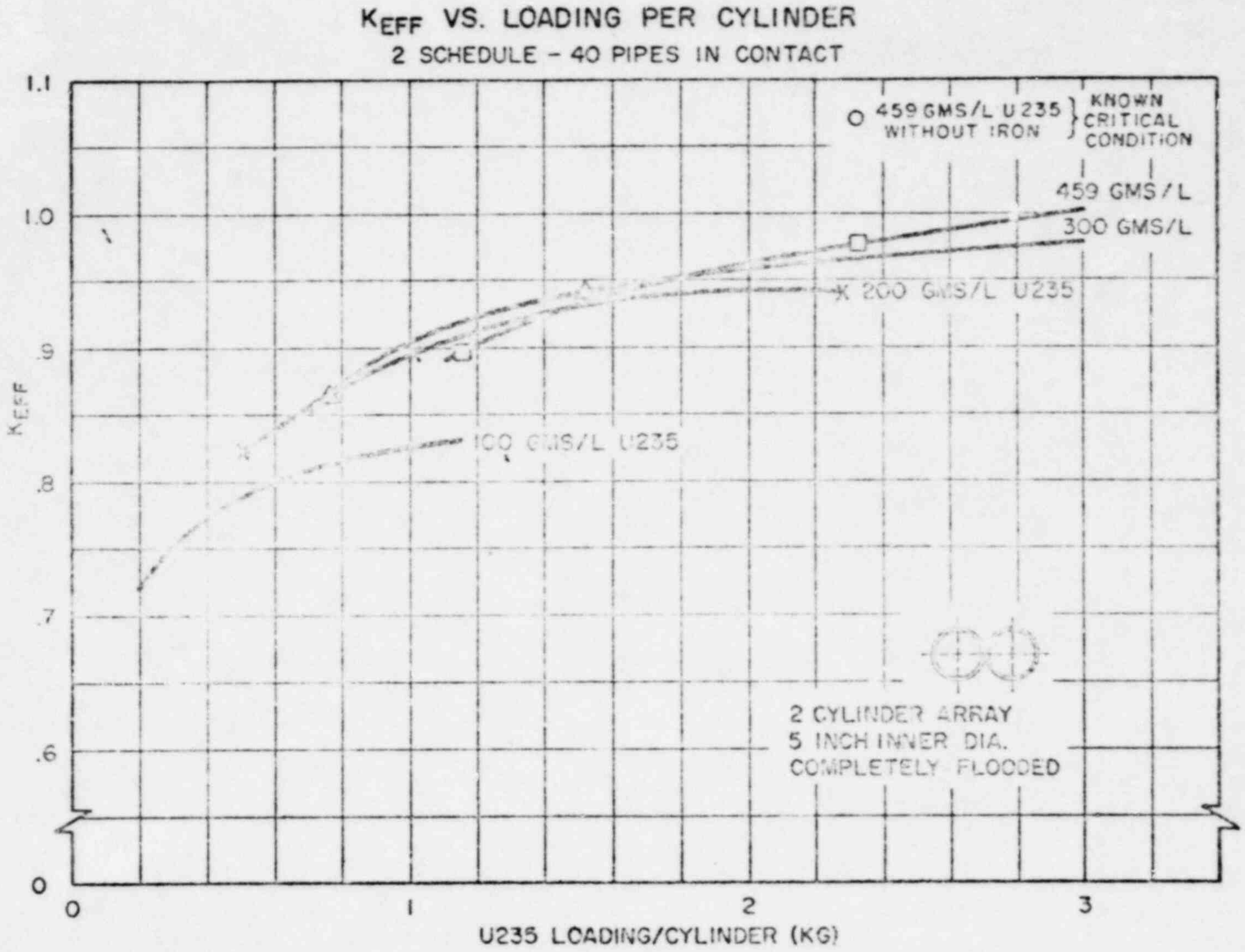

K_EFF VS. LOADING PER CYLINDER
2 SCHEDULE - 40 PIPES IN CONTACT
K_EFF
U235 LOADING/CYLINDER (KG)
1.1
1.0
.9
.8
.7
.6
0
0
1
2
3
O 459 GMS/L U235 WITHOUT IRON } KNOWN CRITICAL CONDITION
459 GMS/L
300 GMS/L
X 200 GMS/L U235
100 GMS/L U235
2 CYLINDER ARRAY
5 INCH INNER DIA.
COMPLETELY FLOODED

Figure 10

K$_{EFF}$ VS. LOADING PER CYLINDER
3 SCHEDULE - 40 PIPES IN CONTACT

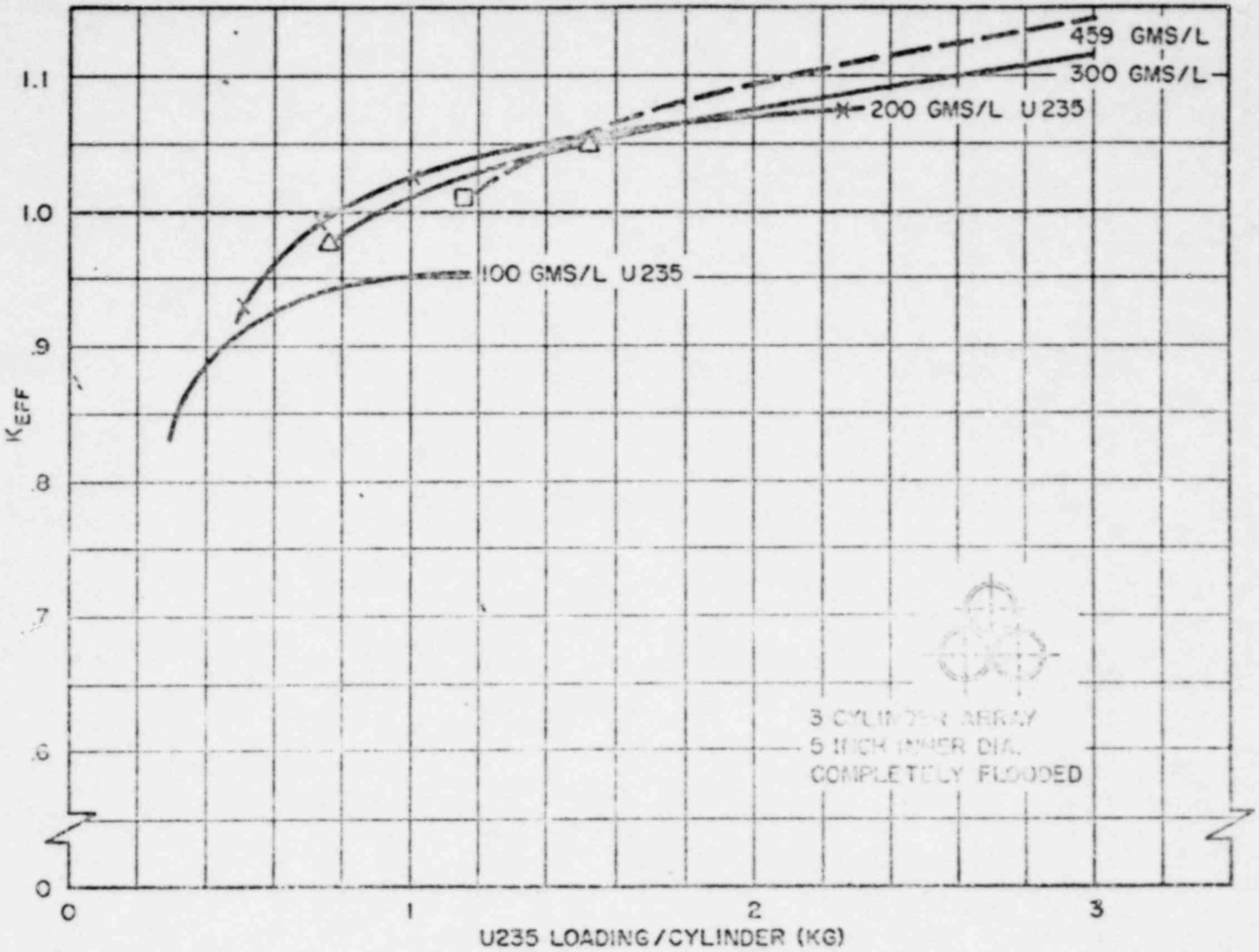
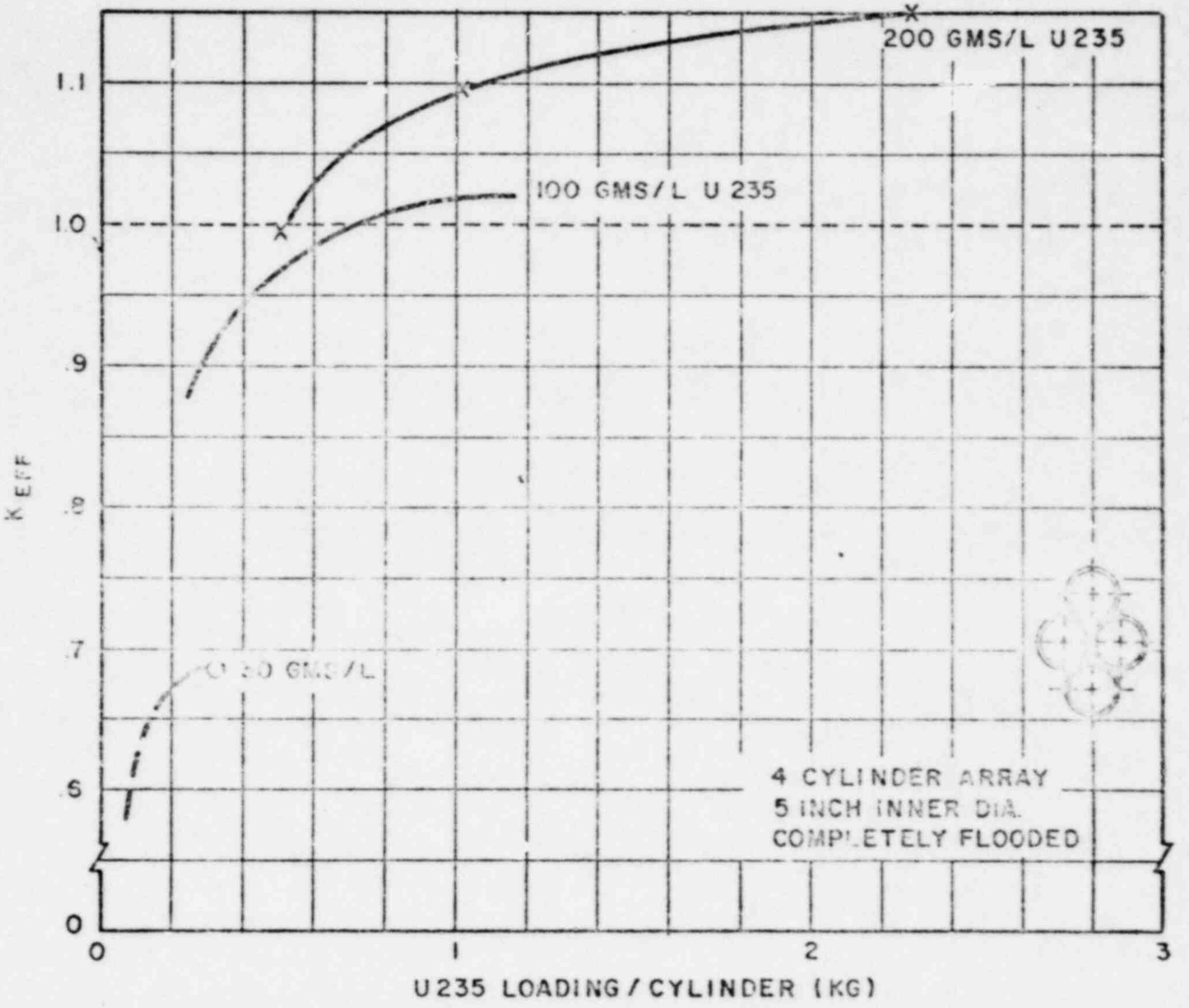


Figure 11



K_{EFF} VS LOADING PER CYLINDER
4 SCHEDULE-40 PIPES IN CONTACT

Figure 12

TABLE I

Summary of PTQ Results for 2, 3, and 4 Cylinders in Contact

		Fraction of Neutron Captures by Region			λPTQ for a Fuel Region Height of:			
U^{235} Loading Grams/Liter	K_∞	Fuel	Iron Wall	H_2O Refl.	20cm	40cm	90cm	Remarks
			2 Cylinders in Contact- ∞					
100	1.823	.49	.109	.40	.726	.791	.830	Fuel Region is H_2O+U^{235}
200	1.915	.52	.082	.40	.824	.897	.940	" " " " "
300	1.937	.54	.069	.39	.865	.942	.986	" " " " "
459	1.940	.56	.057	.38	.898	.977	1.023	" " " " "
459	1.939	.55	.058	.39	-	.964	-	UO_2F_2 Solution
459	1.939	.60	0	.40	-	1.073	-	UO_2F_2 Solution--Iron Wall Replaced by H_2O, known Critical Condition
			3 Cylinders in Contact - ∞					
200	1.915	.59	.086	.33	.933	-	1.074	Fuel Region is H_2O+U^{235}
300	1.937	.62	.072	.31	.978	-	-	" " " " "
			4 Cylinders in Contact - ∞					
30	1.452	.49	.19	.32	-	-	0.686	" " " " "
100	1.823	.60	.12	.28	.883	.971	-	" " " " "
200	1.915	.64	.09	.27	.996	-	-	" " " " "

b. Conclusions

The results in Figures 10, 11, and 12 indicate that when the average unmoderated U-235 loading per container is limited to the values given in Table II, criticality cannot occur as a result of any credible accident. It is also concluded that the analysis is conservative for any combination of loading within the individual cylinders, provided that the total loading is consistent with the value stated in Table II for the total number of containers containing U-235. No additional limit is required on the form of U-235 or end spacing in the pipe.*

TABLE II

Several Container Shipments

	Number of Containers		
	2	3	4
Unmoderated Material			
Average loading per container (grams U-235)	1700	550	400
Maximum total loading per shipment (grams U-235)	3400	1650	1600
Moderated Material			
Average loading per container (grams U-235)	850	275	200
Maximum total loading per shipment (gms U-235)	1700	825	800

*(However, the possibility that finely divided forms of U-235 may be expelled from the pipe in a fire due to the buildup of pressure within the container, has required lower mass limits for some forms of material.)

3. Wooden Box Containers

The maximum amount of U-235 allowed in a single shipment of one outer container when a wooden box (built to meet ICC specifications) is used for the outer container is 350 grams for any form of unmoderated material and 500 grams of unmoderated material if it is mechanically restricted along the length of the package to 10 grams or less per inch. Since with these limits, twice this amount of U-235 is subcritical under optimum conditions of moderation and reflection, it is considered that all of the requirements for Fissile Class III are satisfied including that of meeting another identical shipment.

4. Multi-Container Shipments

All of the shipping arrangements described above have been established so that the shipment is nuclearly safe even in the event of such a severe accident that one-dimensional crushing of all the shipping containers occur, unlikely as such an accident may be. Some shipments must be made, however, involving many containers (e.g. shipments of scrap material for reclamation) and a substantial amount of U-235 material. Separating the total quantity of material into a few separate single drum shipments of the order of 8 - 10 kg frequently is not physically possible. On the other hand packaging the material to the low limits of Fissile Class I, or even the 2, 3, or 4 container limits, results in such a number of containers and vehicles that shipping costs are excessive. Therefore, there are operational and economic requirements for a shipping arrangement that permits shipping many containers, each with a material limit that permits effective utilization of the space available in the container. A limit of 1900 grams of U-235 per container is high enough to permit reasonably effective utilization of container capacity. While a truckload of such containers is shown below to be nuclearly safe for the usual accident conditions of optimum moderation, double loading, and double batching, such a shipment cannot be shown to be nuclearly safe if large numbers of the containers are one-dimensionally crushed and moderated. Therefore, it is necessary to limit the shipment in a manner that the effects of severe one-dimensional crushing of the containers are tolerable in a highway accident. This is discussed in section b. below.

a. Criticality Analysis

The principal criticality accidents of interest are:

- rearrangement of the array into a fully reflected cubic array,
- partial moderation of the array,
- leakage of the contents of the 5-inch diameter inner cylinders (where solutions are involved),
- lack of poison material in cases where cadmium nitrate is specified to be added to solutions,
- double loading and/or double batching of the contents of the inner 5-inch diameter cylinders.

(1) Method of Analysis

Figures 13 through 15 show the nine different geometries which were utilized in calculating the neutron multiplication for

PDQRZ GEOMETRY FOR 55 GALLON DRUMS WITH 5 INCH INNER DIAMETER CYLINDERS

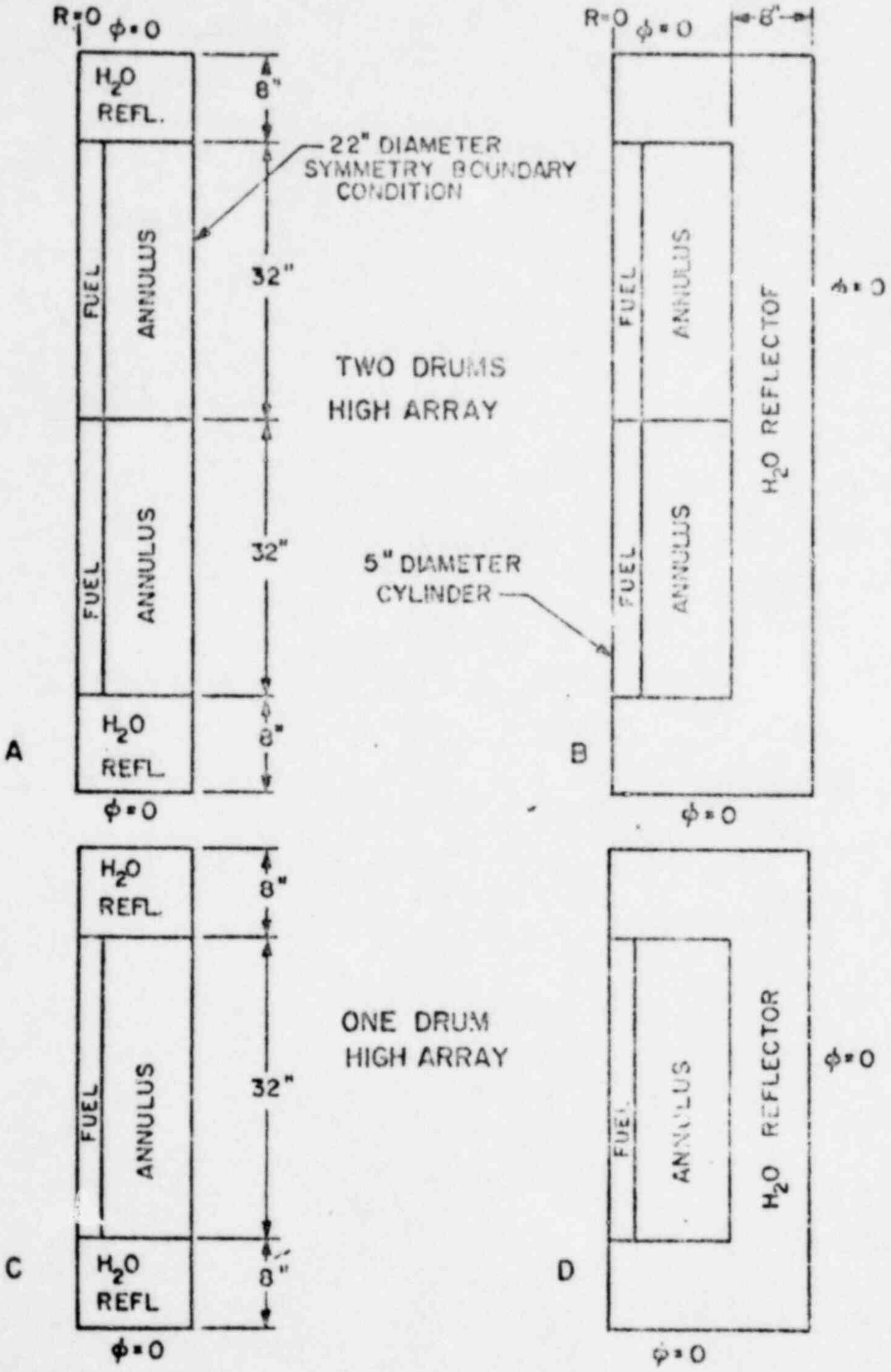
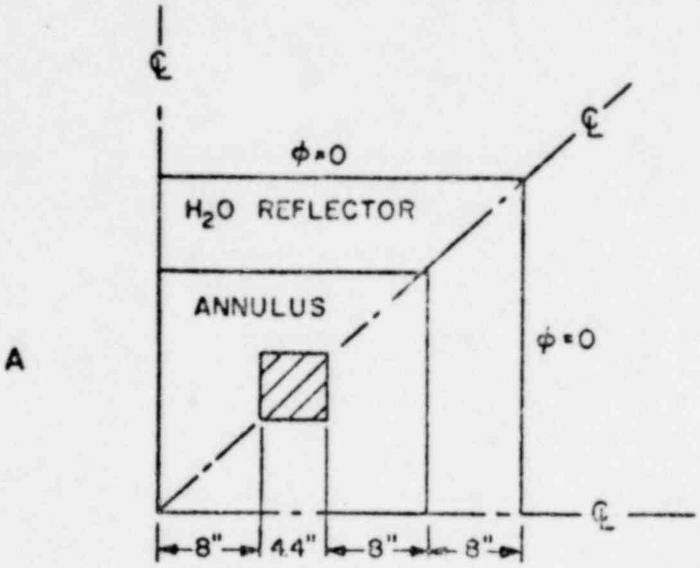
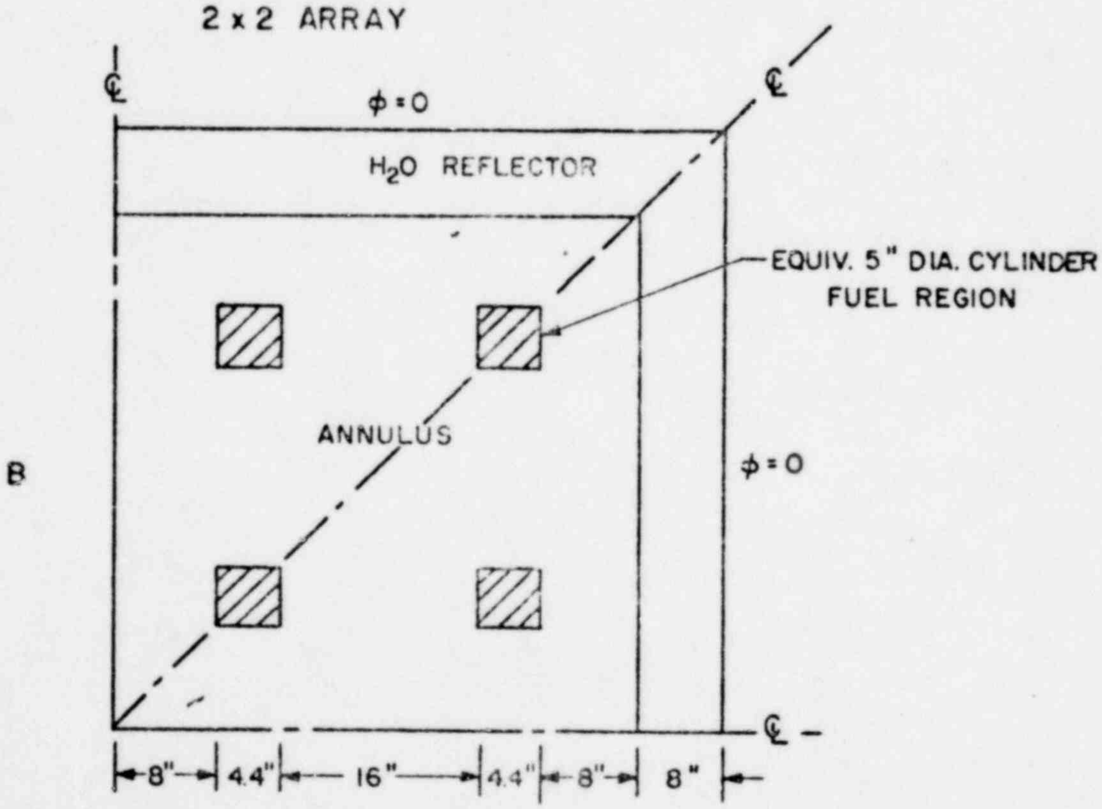


Figure 13

PDQXY GEOMETRY FOR 55 GALLON DRUMS WITH 5 INCH DIAMETER CYLINDERS



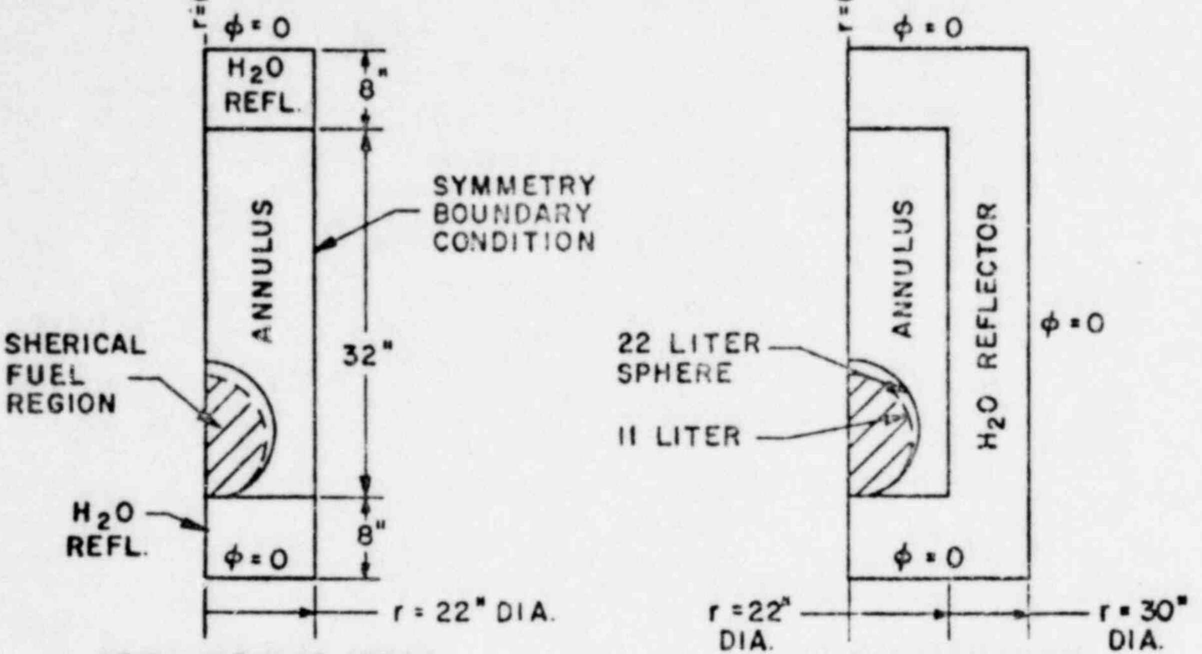
2 x 2 ARRAY



4 x 4 ARRAY

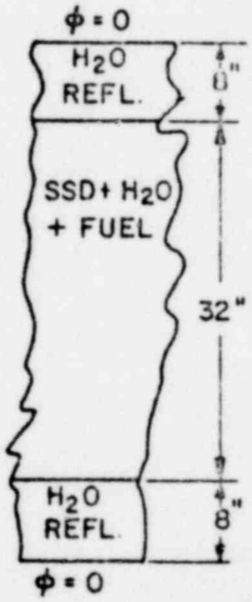
Figure 14

PDQRZ GEOMETRY FOR DISPERSION OF FUEL IN SOLUTION LEAKING FROM AN INNER CONTAINER



SEMI - INFINITE ARRAY
A

1 ISOLATED DRUM
B



UNIFORM DISPERSION OF FUEL IN DRUM - SEMI-INFINITE ARRAY
C

Figure 15

various physical situations. The calculations were all performed with 4-group diffusion theory model. "Three" dimensional calculations were possible only in the case of a single isolated drum, since in this case the real 3-dimensional problem reduces to a true 2-dimensional problem (see figures 13B, 13D, and 15B). In the case of arrays of drums, it was only practical to solve cases where the array was semi-infinite in one plane or direction (see figures 13A, 13C, 14A, 14B, 15A, and 15C).

Solutions were then obtained for 32 cases utilizing the nine basic geometries which were considered to be meaningful. The results (see Table III) were then cross plotted in a number of ways to assist in evaluating particular sets of double accidents.

(2) Results

Consider first the case of unmoderated materials. The basic limit for these cases is 1900 grams of U-235/container. The double accident of partial moderation plus double loading is evaluated directly for 55-gallon drums by referring to Figure 17. The results for a semi-infinite array one drum high indicate that k_{eff} is less than 1.02 after this double accident. Since the actual shipping array is only three containers wide, the actual k_{eff} is less than 1.0. The double accident of rearrangement of the planar array into a cubic array plus partial moderation is evaluated by referring to Figure 16. Figure 16 has been obtained from the data in Table III by plotting the k_{eff} vs the array surface-to-volume ratio. The surface area is defined as the area of those surfaces which define the boundary between the H_2O reflector and the array of containers. The accuracy achieved by this method of correlating the calculational results has been demonstrated in Appendix III. The number of loaded containers per shipment is limited to 51; i.e. a 3 x 17 array. The results in Figure 16 for 51 containers in a cubic array, with 1900 grams/container and an annulus water fraction of 0.08 H_2O, indicate a k_{eff} [illegible] 0.86. Figure 17 indicates that if the annulus water fraction is reduced from 0.08 to zero when Sol Speedi-Dry is present, the k_{eff} increases by approximately 0.04 Δk. It is not possible with diffusion theory to rely on the calculated k_{eff} with zero water fraction in the annulus, however, the S/V estimates of k_{eff} in this range have been shown to be correct by Monte Carlo calculations reported in Appendix IV. The calculations in Appendix IV also show that reductions in center-to-center spacing of the Schedule 40 pipes as occurs under the accident test conditions, can be tolerated.

For other containers, such as BE 2071 drum or the BE 1270 birdcage, the mass limits per container are the same; however, the U-235 may be distributed over a greater length, effectively increasing the height of the nominal 3 x 17 x 1 array. For a nominally tall array, the double accident of double loading plus optimum moderation and reflection may be more limiting than the double accident of rearrangement into a cubic array plus optimum moderation and reflection. The k_{eff} for these two combinations of accidents may be compared for containers of various heights by computing the surface/volume ratio for each

TABLE III

	55-gallon Container Geometry				Fuel Region Description			
Case No.	Figure	XY Plane	Height	Annulus *	Geometry	Loading Density gU^{235}/liter(1)	Loading/ Container grams U^{235}	Calculated k_{eff}
1	15-A	Infinite	1 high	SSD + .10 H_2O	22 liter sphere	100	2200	1.024
2	15-B	Isolated Drum	1 high	"	"	100	2200	0.74
3	15-A	Infinite	1 high	"	11 liter sphere	200	2200	1.11
4	15-A	Infinite	1 high	"	"	100	1100	1.02
5	15-B	1 isolated drum	1 high	"	"	200	2200	0.966
6	15-B	1 isolated drum	1 high	"	"	100	1100	0.893
7	14-A	2 x 2 array	Infinite	SSD + .08 H_2O	5" dia cylinder	459	5000	0.83
8	14-B	4 x 4 array	Infinite	"	"	459	5000	1.12
9	13-D	1 isolated drum	1 high	"	"	459	5000	0.57
10	13-A	Infinite	2 high	"	"	100	1100	1.02
11	13-A	Infinite	2 high	"	"	200	2200	1.16
12	13-A	Infinite	2 high	"	"	459	5000	1.27
13	13-A	Infinite	2 high	SSD + .30 H_2O	"	459	5000	0.89
14	13-C	Infinite	1 high	SSD + no H_2O	"	200	2200	0.967
15	13-C	Infinite	1 high	SSD + .05 H_2O	"	200	2200	0.96
16	13-C	Infinite	1 high	SSD + .10 H_2O	"	200	2200	0.91
17	13-C	Infinite	1 high	SSD + no H_2O	"	459	5000	1.06
18	13-C	Infinite	1 high	SSD + .10 H_2O	"	459	5000	1.00
19	13-C	Infinite	1 high	0.08 H_2O	"	100	1100	0.80
20	13-C	Infinite	1 high	0.08 H_2O	"	200	2200	0.92
21	13-C	Infinite	1 high	0.08 H_2O	"	459	5000	1.01
22	13-C	Infinite	1 high	0.30 H_2O	"	459	5000	0.84
23	13-D	1 isolated	1 high	1.00 H_2O	"	459	5000	0.94
24	15-C	Infinite	1 high	SSD + 0.50 H_2O	55-gallon Drum	5	1100	0.77
25	15-C	Infinite	1 high	SSD + 0.30 H_2O	"	5	1100	0.89
26	15-C	Infinite	1 high	SSD + 0.10 H_2O	"	5	1100	0.88
27	15-C	Infinite	1 high	SSD + 0.05 H_2O	"	5	1100	0.74
28	15-C	Infinite	1 high	SSD + .50 H_2O	"	10	2200	1.09
29	15-C	Infinite	1 high	SSD + .30 H_2O	"	10	2200	1.19
30	15-C	Infinite	1 high	SSD + .10 H_2O	"	10	2200	1.07
31	15-C	Infinite	1 high	SSD + .05 H_2O	"	10	2200	0.88

* SSD is Sol Speedi-Dry absorbent material

(1) H_2O in fuel region is water at 1/2 normal density for Cases 1 and 2. For cases 3 through 23 the H_2O in fuel region is water at normal density. For cases 24 through 31 the fuel region is the annulus.

K_{EFF} FOR FULLY REFLECTED, PARTIALLY MODERATED ARRAYS OF 55 GALLON DRUM SHIPPING CONTAINER-5 IN. INNER DIA. CYLINDER

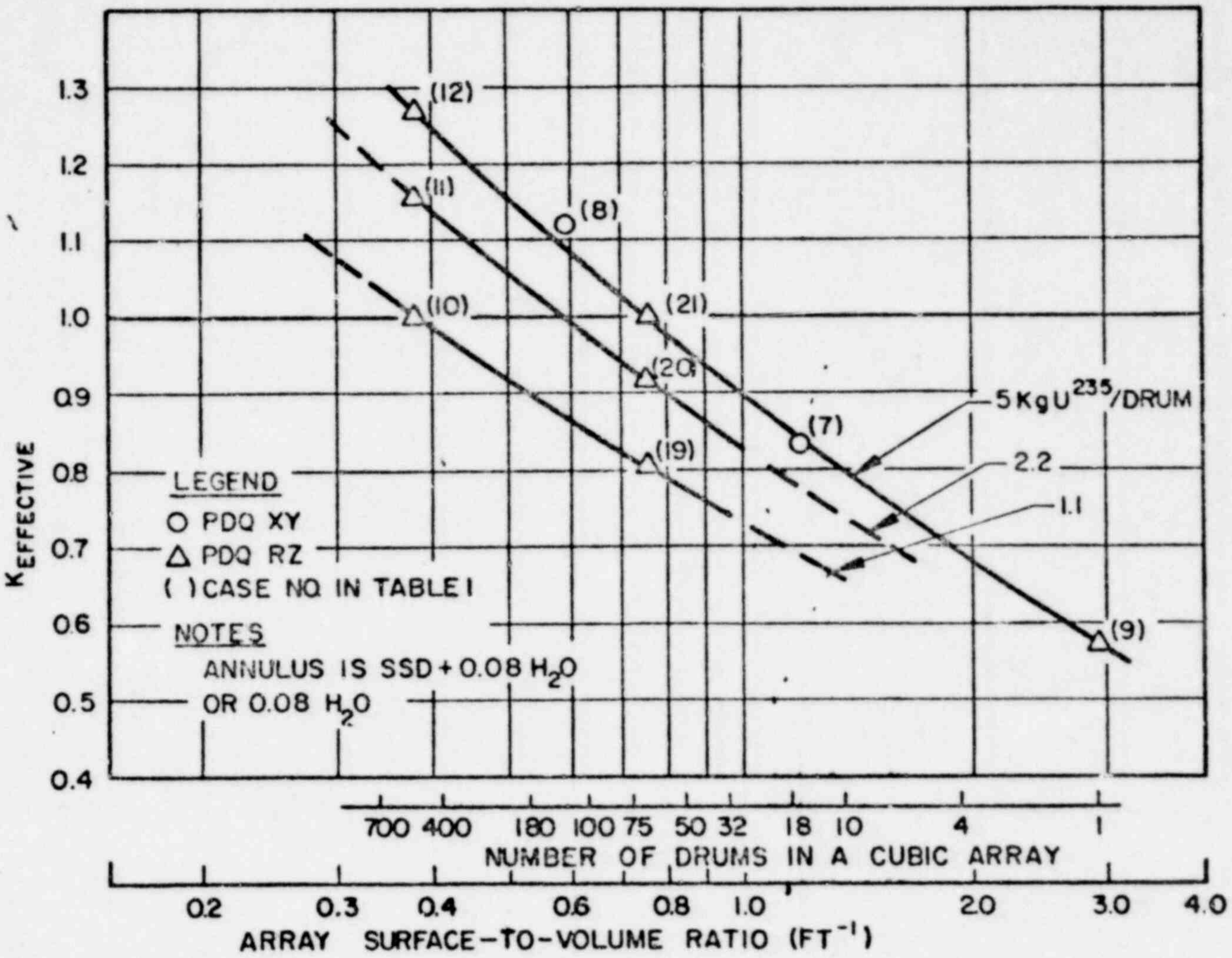


Figure 16

K_{EFF} VS ANNULUS WATER DENSITY – FULLY REFLECTED ARRAYS

55 GALLON DRUM SHIPPING CONTAINERS – 5INCH DIA. INNER CYLINDER

(DATA FOR SEMI-INFINITE, ONE HIGH ARRAY)

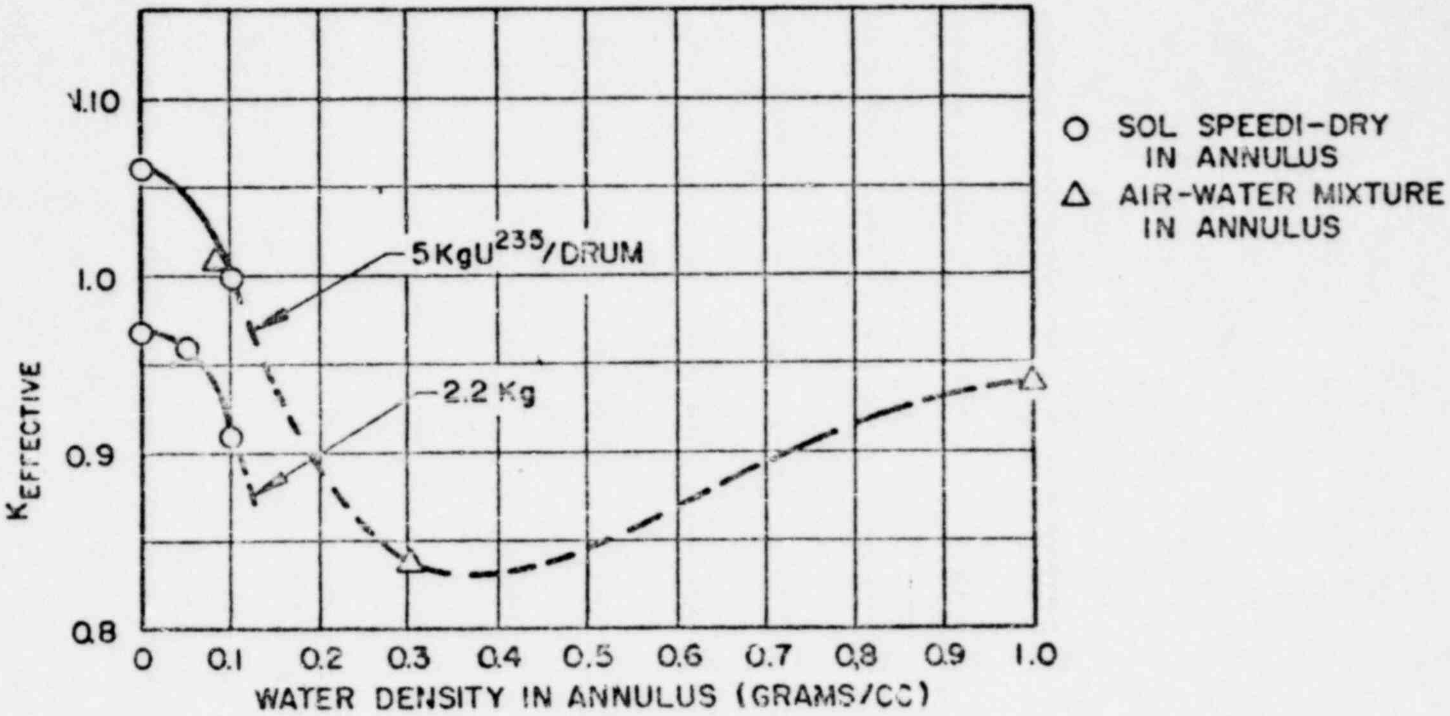


Figure 17

array of 51 containers and obtaining the k_{eff} from Figure 16. Table IV shows the results of such a calculation for containers whose heights are multiples of a standard 55-gallon drum.

TABLE IV

k_{eff} for partial moderated, fully reflected array

Height of Container	Nominal Array (3 x 17 x 1) Nominal U-235 Loading per Container	Nominal Array (3 x 17 x 1) Double U-235 Loading per Container	Cubic Array Nominal U-235 Loading per Container
32"	.75	0.83	0.87
64"	.77	0.88	0.82
90"	(.70)*	0.85	(0.81)*

*Estimate based on Figure 16 results for double loaded containers corrected for change in ηf when reducing fuel concentration from 116 grams/liter to 58 grams/liter.

Table IV indicates that for the 55-gallon drum the most restrictive of the two double accidents in rearrangement into a cubic array plus moderation, whereas for the BE 2071 drum the most restrictive is double loading plus moderation. This follows from the fact that for short arrays, rearrangement into a cubic array has a more significant effect on the neutron leakage than for tall arrays. Table IV also indicates that in a cubic array, with a given number of containers and fixed loadings per inner 5-inch diameter container, the k_{eff} increases as the height of the container is reduced. For this reason, no Fissile Class III containers requiring 5-inch inner diameter cylinders (or equivalent 20 square inch boxes) are permitted to be shorter than a 55-gallon 17H drum.

Since all of the above results were obtained from Figure 16, it is significant to note that Figure 17 indicates that if the annulus water fraction is reduced from 0.08 to zero when Sol Speedi-Dry is present, the k_{eff} increases by approximately 0.04 Δk. Thus for the worst case double accident involving the 3 x 17 x 1 array, it is concluded that k_{eff} is 0.92. While the case where only air is present in the annulus cannot be solved by diffusion theory, experimental data(1) indicates that the case with partial moderation in the annulus region is more reactive than air spaced, fully reflected arrays that are otherwise identical.

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(1) Reference - ORNL-TM-719, "Critical Three-Dimensional Arrays of Neutron-Interacting Units," dated October 1, 1963, page 8.

For moderated solid materials, a part of the double accident evaluation is obtained by analogy with unmoderated materials by substituting double spacing, or double batching, for the partial moderation condition which is no longer an accident condition but rather the normal condition. (In this connection, it should be noted that in most cases of moderated materials since a liquid is present, an absorbent material, such as Sol Speedi-Dry, is present in the annulus of the container. It is not unlikely for these absorbent materials to have 0.05 to 0.10 of normal water density present.) The basic limit for moderated solid materials is 950 grams of U-235 per container. Thus an accident involving the doubling of this loading brings the loading to 1900 grams, the case which has been considered above. All moderated shipments are made using a 55-gallon drum as the outer container.

In cases where U-235 is present in solution form (or slurry), there is an additional accident which must be considered, and that is the leakage of uranium solution from the polyethylene bottle in which it is contained. The threaded endcaps on the Schedule-40 pipe which contains the bottle are not leak tight. The absorption characteristics of Sol Speedi-Dry are such that if the solution leaks out of a 5-inch diameter inner cylinder, it will diffuse out into the Sol Speedi-Dry maintaining a liquid density which is substantially less than normal water density. The shape of the region containing the expanding uranium solution may approach a spherical region. Case 2 in Table III shows results for an isolated, full reflected drum containing 2200 grams of U-235 in a 22-liter sphere formed from 11 liters of solution which has diffused out to twice the solution volume, with consequent 50% reduction in water and fuel density. Comparison of Case 2 with Case 5 shows that this reduction in density provides a significant reduction in the maximum k_{eff} which can be achieved by a rearrangement of the solution into an 11-liter sphere. However, since the maximum solution or slurry density which can be achieved in the absorbent material (which is not restricted to Sol Speedi-Dry) has not been verified experimentally, and the controls are such that there is no absolute assurance that the absorbent material fills are interior spaces of the drum, the U-235 mass limit per container for solutions has been set at 350 grams U-235 per container. With this limit, a single container will meet the double accidents of double loading plus leakage from the inner container, or the double accident of leakage from the inner container plus addition of water from a source external to the outer container.

In order to evaluate the effect of more than one inner cylinder leaking, calculations have been performed which assume that all inner cylinders in the shipment leak simultaneously. The results are shown in Figure 18. Even for a loading of 1100 grams U-235 per container, Figure 18 shows that criticality is not expected to occur since the transformation from an 11-liter cylinder to a spherical volume will not occur at constant volume (vertical path in Figure 18) but rather along a line of increasing volume of dispersed solution. The accident condition where the contents of three inner containers are in close contact, a condition which might occur if the solution leaking from the inner containers in three adjoining drums passes through the absorbent material to adjoining interior regions of the 3 drums, has not been examined in detail. However, the data in Figure 9 of TID-7028 indicates that for a nominal loading of 350 grams U-235 per container, this condition is not expected to be critical if there is the usual space at the intersection of the three drums. Near optimum geometry is required for criticality with 1050 grams U-235.

b. Hazards Evaluation

If drums and birdcages are loaded in a van-type semi-trailer, it is conceivable (albeit unlikely) that the truck could be involved in an accident of such severity that several of the outer containers are crushed sufficiently that the array would not be nuclearly safe under the condition of optimum moderation. If the truck-trailer jack-knifed across the road, it is possible that the trailer could be hit broadside by another heavy truck, or the trailer could be hit end-on while on the highway or parked at roadside. If the van broke open and the containers scattered, or if the trailer overturned and most of the collision force was taken by damage to the undercarriage and sliding of the trailer on the ground, then severe crushing of the containers probably is not plausible. However, if one side of the trailer is against (or very near) an immovable object (e.g. a concrete abutment or a rock wall at the side of the road) and the other side is struck, then it is necessary to consider the possibility of some of the containers being crushed.

In such a very severe accident it is not possible to state exactly what will happen or how severely the van trailer is crushed. If the van trailer has any room at all to slide or partially tip, this will ameliorate the crushing damage. Also there could be a tendency for the oncoming truck cab to ride under the van trailer and lift it. It also would be expected that the oncoming vehicle would suffer substantial damage. All of these effects will absorb some of the energy of the oncoming vehicle; how much cannot be calculated with supportable assumptions. However, it is reasonable to conclude that while the van trailer certainly will be damaged, all of the energy of the oncoming vehicle will not be dissipated in crushing the van trailer and its load. The van trailer offers substantial resistance to colliding forces with its heavy steel underframe. (Fruehauf trailers, for example, have 4-inch I-beam cross members spaced on 12-inch centers the length of the trailer.)

If the containers are loaded in the van trailer so that they are tightly packed against the sidewalls, either directly or with rigid

K_{EFF} VS. VOLUME OF DISPERSED SOLUTION - ONE HIGH FULLY REFLECTED SEMI-INFINITE ARRAY OF 55 GALLON SHIPPING CONTAINERS

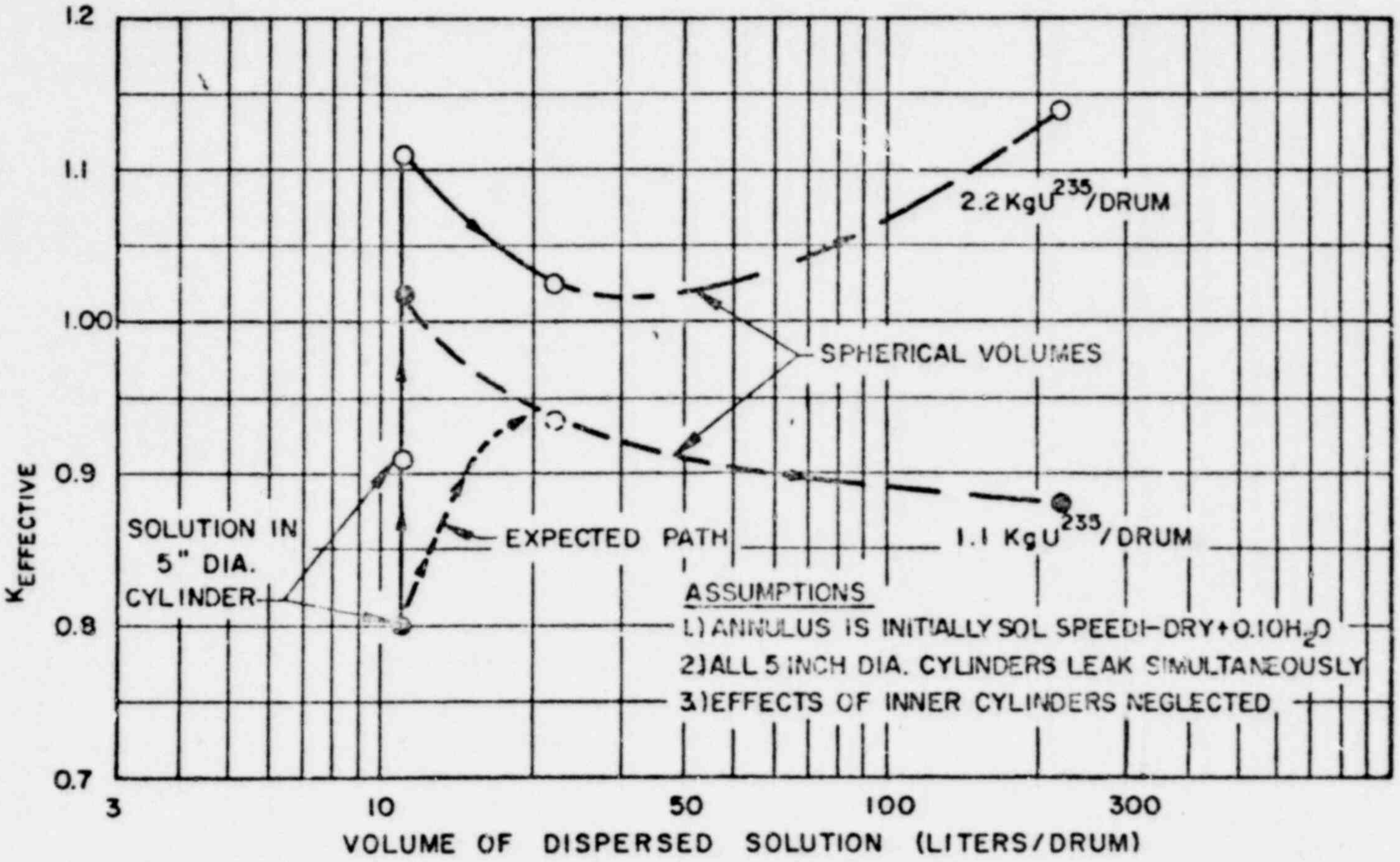

Figure 18

blocking, then any crushing forces on the sides of the trailer will be transmitted directly to the containers. If, however, void floor-space is left so that the containers are free to slide and tumble in an accident, then the van trailer frame can be partially deflected or buckled without large forces being impinged upon the containers. The containers can, of course, withstand a fairly large force themselves with only minor damage as has been demonstrated in drop tests from a height of 30 feet onto a concrete surface. In these tests the velocity at the instant of impact (44 feet/second) is that equivalent to 30 mph.

Taking into account all of the above factors and effects, it is judged that if some reasonable amount of floor space is left vacant and the containers are tied or blocked so that they can slide and tumble in the event of a severe collision, it is reasonable to conclude severe one-dimensional crushing of the containers will be limited to a 3 x 3 array of containers nearest the point of impact. The question is what is a reasonable amount of space to leave. The standard trailer of an oncoming vehicle is eight feet wide; the tractor front end is less. A path eight feet wide would represent 20% of the length of a standard 40-foot van trailer or 23% of the length of a standard 35-foot trailer. It is thus concluded that vacant floor space of 25% is acceptable in addition to the void space normally existing above the containers.

The addition of the requirement that 25% of the floor space in the van be left vacant ensures that the one-dimensional crushing accident is indeed an "unlikely accident." An unlikely accident is one which is other than the expected result of an event which is reasonably likely to occur. Under the Bettis double accident criteria, the single unlikely accident of one-dimensional crushing must not result in a situation in which criticality is possible even under conditions of optimum reflection. After the double accidents of one-dimensional crushing plus double loading (of moderated materials) or one-dimensional crushing plus moderation (of unmoderated materials), there must be a small margin to criticality. The two unlikely accidents must be unrelated. The maximum credible number of containers that could be crushed one-dimensionally until the inner containers are in contact is a 3 x 3 x 1 array of containers.

An evaluation of these accidents may be made using the data in Table V and Figure 10. From Figure 10 it is seen that for two Schedule-40 pipes in contact, k_{eff} is calculated to be 0.89 for the 950 gram U-235 mass limit. In order to evaluate the 3 x 3 x 1 one-dimensional crushed array, it is convenient to represent the circular pipe as a square pipe of equivalent area (Figure 19). From the data in Table V it is seen (by comparing problem 912 adjusted to $B_z^2=0$ with problem 312) that for pipes in contact the square geometry is approximately 0.036 Δk more reactive than the circular geometry.

By comparing problem 312 and 311, it is concluded that for the completely flooded case, three pipes in contact (in a linear array) is 0.075 Δk more reactive than two pipes in contact. Comparison of

TABLE V

PDQXY Results Required for Evaluation of One-Dimensional Crushing of 3x3x1 Array of 55-Gallon Drums With 5-inch Inner Diameter Cylinder

Problem #	Array Geometry			Axial Buckling CM-2	Fuel Region grams U^{235}/liter	k_{eff}
	Figure	Description	Annulus Material			
912	10	2 Sch 40 pipes in contact, completely flooded	None	0.00085	200	0.940
-	10	" " "	"	0	"	0.955 (Fig. 9)
312	10	Same as above except Rectangular Geometry used as shown in Fig. 19	"	0	"	0.991
311	19	3x3x1 array subjected to 1-dim. crushing	1.0 H_2O	0	"	1.066
308	19	" " " "	SSD + .10 H_2O	0	"	1.0735
309	19	" " " "	SSD + .05 H_2O	0	"	1.074
310	19	" " " "	SSD + zero H_2O	0	"	1.0790
313	10	2 Sch 40 pipes, 1" separation, completely flooded	None	0.00085	"	0.900
314	10	Same as above with 2" separation	None	0.00085	"	0.860
325	19	Same as 309 except 1" spacing between pipes	SSD + .05 H_2O	0	"	1.037
326	19	Same as 309 except 2" spacing between pipes	SSD + .05 H_2O	0	"	1.018

PDQXY GEOMETRY FOR NINE 55 GALLON DRUMS
1-DIMENSIONALY CRUSHED TO INNER CYLINDERS CONTACT

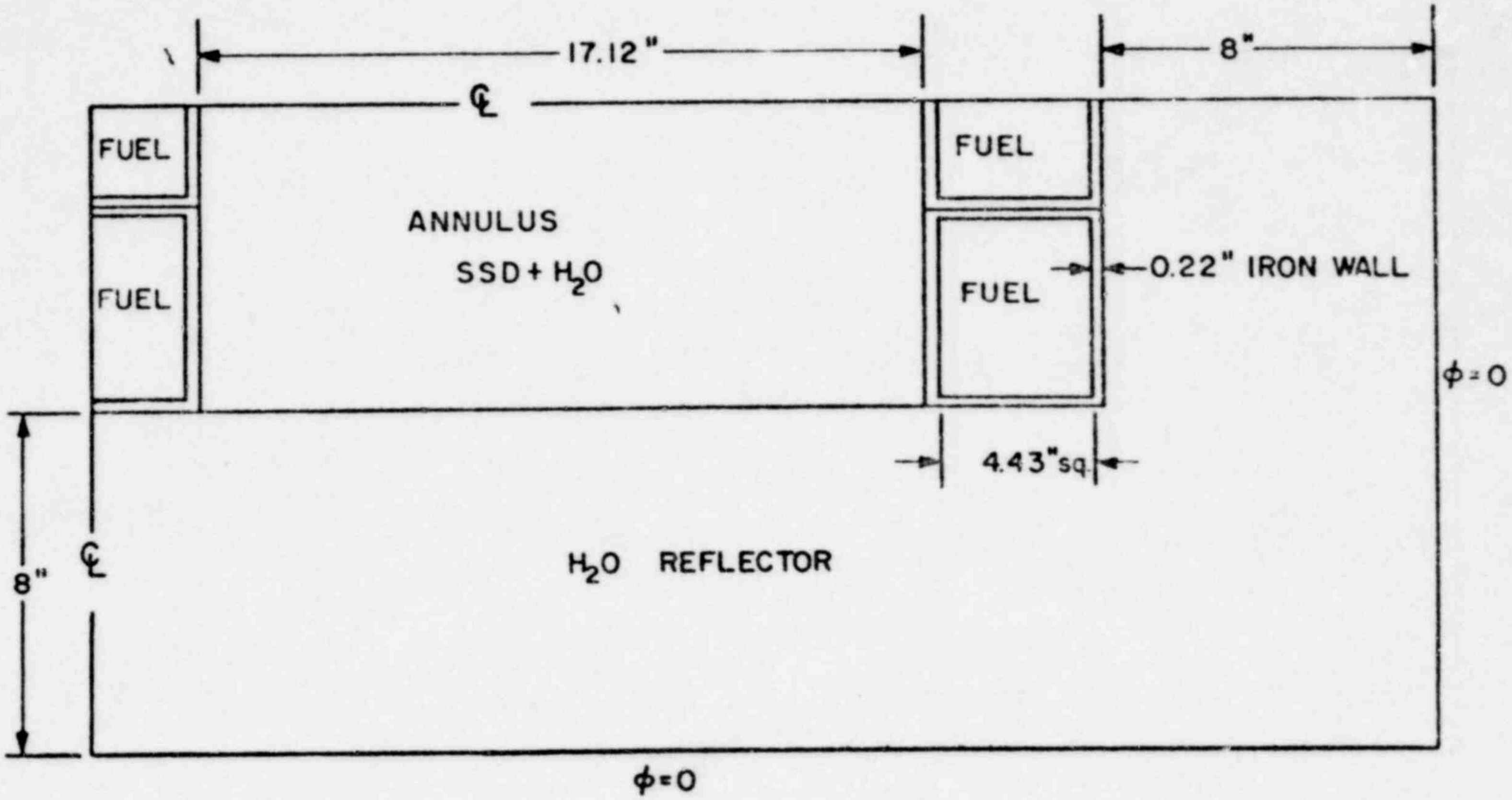

Figure 19

problem 312 and 310 indicates that the partially moderated 3 x 3 x 1 one-dimensionally crushed array is $\leq 0.09\ \Delta k$ more reactive than two pipes in contact and flooded. Table VI k_{eff} values are obtained by referencing these changes in k_{eff} to the basic results in Figure 10.

TABLE VI

U^{235} Loading per Inner Container	k_{eff} for 3x3x1 Array one-dimensionally crushed and completely reflected by H_2O		
	Pipes in Contact	1"spacing between pipe walls	2"spacing
(Solutions) 500 grams	0.915	0.875	-
(Moderated Solids) 950 grams	0.98	0.94	-
Unmoderated Solids 1900 grams	1.045	1.008	0.988

The effect of a small separation between pipe walls has been estimated for flooded cases from a comparison of problems 313 and 912 in Table V ; for partially moderated systems the estimates are based on a comparison of problems 309, 325, and 326.

These results assume that there is only H_2O and U-235 in the Schedule-40 pipe and that these materials are uniformily distributed within the maximum volume possible. They are calculations of the worst case conditions which can only be approached in the case of solution or powder shipments. In evaluation of Table VI it is important to note that the endcaps on the Schedule-40 pipe inner containers provide a minimum of a ½-inch separation between pipes. In the case of powder shipments the intent of the Bettis double accident criteria is considered to be met (even though there is no margin to criticality) after the following series of events, on the basis of their cumulative unlikeliness:

a. Three drums, each containing a maximum of 1900 grams U-235 are one-dimensionally crushed until their Schedule-40 pipes are within 1 inch of each other and their axes are parallel.

b. The metal cans inside the Schedule-40 pipe, containing the enriched UO_2 powder, are broken open.

c. The pipes are completely flooded and the enriched power is distributed uniformily inside the pipe.

For materials other than powder, the actual k_{eff} is expected to be lower than 1.0 because of either heterogeneity effects in the thermal neutron group, metal/water ratio effects on the non-leakage probability for the fast neutron groups, or the reduced loading of 500 grams/container in the case of solution shipments.

For birdcages containing fuel plates or subassemblies the worst case occurs when three rectangular parallelepipeds each with a 20 sq. inch cross section and filled only with U-235 uniformly distributed in space are brought into contact by a one-dimensional crushing accident and completely flooded. Calculations for this case indicate that k_{eff} is approximately 1.24 when a mass limit of 1900 grams U-235 is applied to each container. While in actual practice this value will be reduced by metal/water ratio and heterogenity effects, it is not possible to show that these effects will always reduce this k_{eff} to less than 1.0. In order to ensure that material shipped in birdcages will meet this double accident, it is necessary to impose one additional control on the contents of the inner container. The control exercised is to require by procedure that at least 50% of the volume within the box be metal (i.e. to ensure that metal/water ratio $\geq$ 1.0) and that this metal be distributed reasonably uniformly along the length of the box.

The justification for the choice of a metal/water ratio $\geq$1.0 is the result of calculations made for PWR Core 2 Seed 2 clusters. With a nominal loading of 1 kg. U-235 per five-inch length and zero poison, this 60 sq. inch cluster has a k_{eff} of 0.92 and a metal/water ratio equal to 1.0.

In order to provide some flexibility in the event that the 50% metal condition cannot be met, reduced mass limits are provided which give an acceptable k_{eff} for the worst case condition where the double accident of one-dimensional crushing plus moderation is applied to a system in which the inner container contains only U-235 uniformly distributed in an optimum length space. Table VII shows the reduced mass limits which will meet this worst case condition analysis:

TABLE VII

Total Cross Sectional Area obtained when 3 inner containers are in edge-to-edge contact	U^{235} Mass Limit per Inner Container which ensures that Worst Case	
	k_{eff} = 0.95	k_{eff} = 1.0
60 sq. inch	250 grams	300 grams
40	270	430
30	430	800

The mass limits associated with a worst case calculated k_{eff} = 1.0 are considered to provide a condition equivalent to that achieved with the 1900 gram U-235 limit for 5-inch diameter Schedule-40 pipes and hence these limits are listed in the guide as an alternative to meeting the 50% metal rule. It is apparent that both the 50% metal rule and the Table VII values encourage the use of the minimum size inner container.

In the Table (Section A) the shipping conditions have been specified as:

> "Up to a total of 51 55-gallon 17H drums, BE 1926 drums, BE 2071 drums, BE 2070 drums, BE 1270 or BE 1885 birdcages containing material covered by this note may be shipped intermingled in a semi-trailer van provided at least 25% of the floor space is left vacant and the containers are tied and/or blocked so that they will break loose and slide or tumble or the blocking material will crush more easily than the containers in the event of a severe highway accident. The containers shall be loaded as follows:

55-gallon 17H drums	On end in a single layer
BE 1926 drums	
BE 2071 drums	
BE 2070 drums	On end in a single or double layer, or a single layer on top of other drums
BE 1270 birdcages	On end in a single layer; or in one, two, or three layers with the long axis horizontal along the length of the van but not closer than 5 feet to either end of the van
BE 1885 birdcages	

5. General Considerations on the Effect of Fire on Packages

In the case of the thermo jar in the wooden box, it has already been noted that the integrity under accident test conditions is not required. In the case of the 55 gallon drums and similar but taller containers, there are several areas of concern which are discussed below.

There is no evidence of excessive pressure buildup between the inner and outer container in the test reported in LAMS-2983 even though this space is not vented to the atmosphere. It is also noted that the ICC 6L Specification Container, which is similar to the Bettis designs, does not incorporate any vent for this volume. It is therefore concluded that any adverse effects of fire will be limited to a possible loss of contents from the inner container (non-leakage into the inner container, a factor usually requiring a fire test to verify, has not been assumed in the Bettis analysis).

In the case of fuel in solution form being heated in a fire, the liquid will either be expelled from the inner container by a buildup of pressure in the inner container, or the solution will be converted within the inner container to the dry salt form. If the temperature is high enough, the salt may be converted to the oxide form; however, no ignition of the material will occur. If the liquid is expelled from the inner container, the situation is similar to a contingency already examined in detail in the analysis, that of leakage from the inner container.

The maximum amounts of U-235 in finely divided form in either a solution or slurry which are permitted have been restricted to amounts consistent with the credibility of leakage or expulsion of the slurry of solution from the inner container due to pressure buildup under accident conditions.

In the case of the shipment of fuel in a solid form, the only fuel materials being shipped which have a melting point below 1475° are U-Al alloys and uranium salts. The effects of heating uranium salts were discussed above. It should be noted that low melting point alloys are specifically excluded from shipment in BE 1270 type birdcages. In the case of a Schedule-40 pipe inner container, a judgment has been made that it is unlikely that any significant quantity of U-Al alloy in molten form would leak out of the Schedule-40 pipe threads during a fire.

K. CONCLUSION

It is concluded that the U-235 packaging and shipping conditions and limits delineated in Section A are in accordance with the requirements of AECM 0529 and Appendix 0529, Annex 1 through 5, dated August 22, 1966, and that adequate nuclear safety is assured in the shipments.

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APPENDIX I

NORMAL TRANSPORT CONDITION TESTS

GENERAL

Tests were not conducted to evaluate the following normal conditions of transport criteria: heat, cold, pressure, vibration and corner drop. The free drop tests were not conducted within 2-1/2 hours after conclusion of the water spray tests for each container. The following explanations represent Bettis justification for these actions.

1. Heat and Cold - These conditions would only affect solution shipments. The manufacturer indicates that the structural integrity of the polyethylene bottles containing solutions which freeze will be maintained at temperatures at least 20°F higher or lower than the AECM 0529 temperature limits. Reference D.4.c.(3). for waiver request.

2. Pressure and Vibration - These conditions have little or no effect on the shipping containers covered by this report.

3. Corner Drop - Affects wooden boxes weighing less than 10,000 pounds. Since a 30 foot drop test on a wooden box resulted in only superficial splintering, it is assumed that the corner drop test will produce no discernible effects on the box or its contents. Reference D.4.c.(4). for waiver request.

4. Within 2-1/2 hours after the conclusion of the water spray tests, the related free drop tests were not conducted. It is not expected that any dampness resulting from the spray test would affect the results of the drop test. Reference D.4.c.(2) for waiver request.

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A. CONTAINER TESTED - 55-gallon 17H drum with 5-inch inner diameter Schedule-40 pipe insert

1. Identification - See Figure 1 for pictures showing external drum and inner components.

2. Weight

   a. 55-gallon 17H drum weight - 53 lbs.

   b. Schedule-40 pipe insert and hoops - 106 lbs.

   c. Simulated shipment - 44 lbs. of steel plates, comparable to the weight of a subassembly or a group of plates, the heaviest shipping load expected, were loaded inside the Schedule-40 pipe.

   d. Total gross weight - 203 lbs.

3. Free Drop Test

   a. Surface used for test - 4-inch reinforced concrete floor at ground level used for loading dock.

   b. Surface of container tested - drum dropped with its long axis horizontal so that the thinnest portion of the drum, its 18-gauge steel body, was the surface tested.

   c. Height of fall - 4 feet, as measured from the ground to the bottom of the forks of a hi-lift supporting the drum.

   d. Description of test effects - Figure 20a shows that this 4-foot drop test had no significant effect on the external surface of the drum. No damage occurred to the structure or material inside of the drum.

   e. Date test performed - September 16, 1965.

   f. Performed by - F. Coyne.

   g. Witnessed by - W. Stanko, W. B. Thomas.

4. Penetration Test

   a. Weight and measurement of steel cylinder used - 12 lbs., 36-1/8 inches in length and 1-1/4 inches in diameter.

   b. Surface of container tested - the flat end of the cylinder struck the side of the drum, its thinnest section.

   c. Height of cylinder drop - 4 feet, as measured from the top of drum laying on its side to the bottom of the forks of a hi-lift supporting the cylinder.

   d. Description of test effects - Figure 20b shows that while a small dent occurred, there was no penetration of the side of the drum.

   e. Date test performed - September 16, 1965.

   f. Performed by - F. Coyne.

   g. Witnessed by - W. B. Thomas, W. Stanko.

5. Water Spray Test

   a. Rate of water spray - 1.1 gallons per minute.

   b. Time container exposed to spray - 30 minutes.

   c. Position of container - positioned atop a metal skid so as to ensure that container would not become immersed in water during test. (Figure 20c)

   d. Weight of container - before test - 55 lbs.
      - after test - 55 lbs.
      Net weight change - None

   e. Description of test effects - There was no water leakage into the drum as evidenced by the fact there was no net weight change. Also, upon opening of the container, no water was found inside.

   f. Date test performed - September 15, 1965.

   g. Performed by - A. Ulyas.

   h. Witnessed by - A. Ulyas, W. Stanko.

6. Compression Test

   a. Gross weight of container - 203 lbs.

   b. Test specifications (5 times container weight or 2 lbs/sq. inch times vertically-projected area in sq. inches of the upright container, whichever is greater).

      (1) Five times container weight - 5 x 203 lbs = 1015 lbs.

      (2) Vertically-projected area - 415 sq. inches; area x 2 lbs = 830 lbs.

   c. Actual test load used - 1090 lbs.

   d. Description of test load - two 55-gallon drums containing silicon carbide grit and a wooden pallet placed atop the test container. (Figure 20d)

   e. Duration of test - <u>24 hours</u>; Started - 6:00 p.m. on 9/16/65
      Ended - 6:00 p.m. on 9/17/65

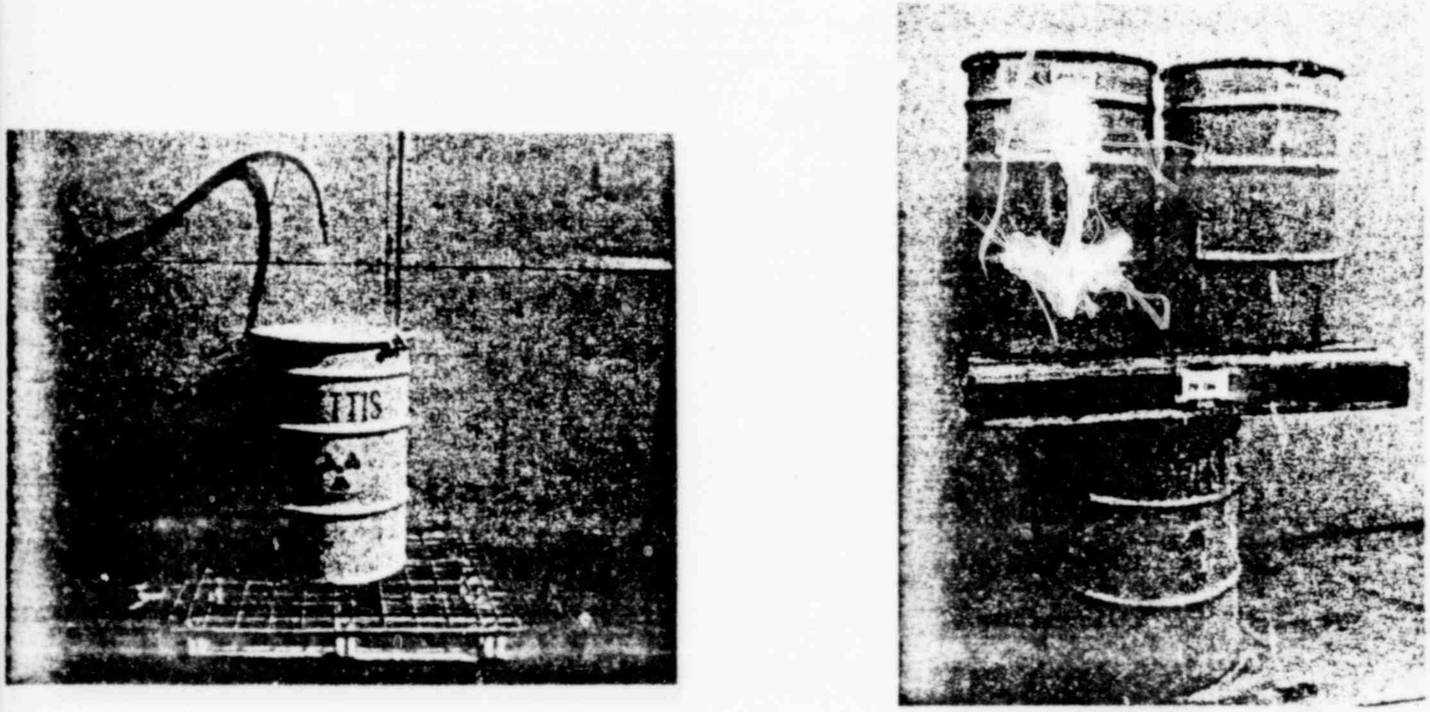
   f. Description of test effects - At the end of the test there was no discernible effect on the drum.

   g. Performed by - F. Coyne.

   h. Witnessed by - A. Ulyas, W. Stanko.

a. After 4-ft. Impact Test

b. After Penetration Test



c. During Water Spray Test

d. During Compression Test

Figure 20

Normal Transport Condition Tests
Upon 55-gallon 17H Drum with Schedule-40 Pipe Insert

B. CONTAINER TESTED - 55-gallon 17H drum with polyethylene bottle and absorbent material

1. Identification - See Figure 3 for pictures showing external drum and inner components.

2. Weight

   a. 55-gallon 17H drum weight - 55 lbs.

   b. Polyethylene bottle - 3 lbs.

   c. Brackets - 5 lbs.

   d. Simulated shipment - 11 liters of water in the poly bottle - 15 lbs.

   e. Absorbent material - 200 lbs.

   f. Total gross weight - 278 lbs.

3. Free Drop Test

   a. Surface used for test - 4-inch reinforced concrete floor at ground level used for loading dock.

   b. Surface of container tested - drum dropped with its long axis horizontal so that the thinnest portion of the drum, its 18-gauge steel body, was the surface tested.

   c. Height of fall - 4 feet, as measured from the ground to the bottom of the forks of a hi-lift supporting the drum.

   d. Description of test effects - Figure 21a shows that this 4-foot drop test had no significant effect on the external surface of the drum. No damage occurred to the structure inside of the drum; no liquid was lost from the polyethylene bottle.

   e. Date test performed - September 17, 1965.

   f. Performed by - A. Ulyas.

   g. Witnessed by - W. Stanko, A. Ulyas.

4. Penetration Test

   a. Weight and measurement of cylinder used - 12 lbs, 36-1/8 inches in length and 1-1/4 inches in diameter.

   b. Surface of container tested - the flat end of the cylinder struck the side of the drum, its thinnest section.

   c. Height of cylinder drop - 4 feet, as measured from the side of the tested drum to the bottom of the forks of a hi-lift supporting the cylinder.

   d. Description of test effect - Figure 21b shows that while a small dent occurred, there was no penetration of the side of the drum.

   e. Date test performed - September 17, 1965.

   f. Test performed by - A. Ulyas.

   g. Witnessed by - W. Stanko, A. Ulyas.

5. Water Spray Test - A separate water spray test was not conducted. The results would be the same as for the 55-gallon 17H drum with 5-inch diameter Schedule-40 pipe insert.

6. Compression Test

   a. Gross weight of container - 278 lbs.

   b. Test specifications (5 times container weight or 2 lbs/sq. inch times vertically-projected area in square inches of the upright container, whichever is greater).

      (1) Five times container weight - 5 x 278 lbs = 1390 lbs.

      (2) Vertically-projected area - 415 sq. inches; area x 2 lbs = 830 lbs.

   c. Actual test load used - 1541 lbs.

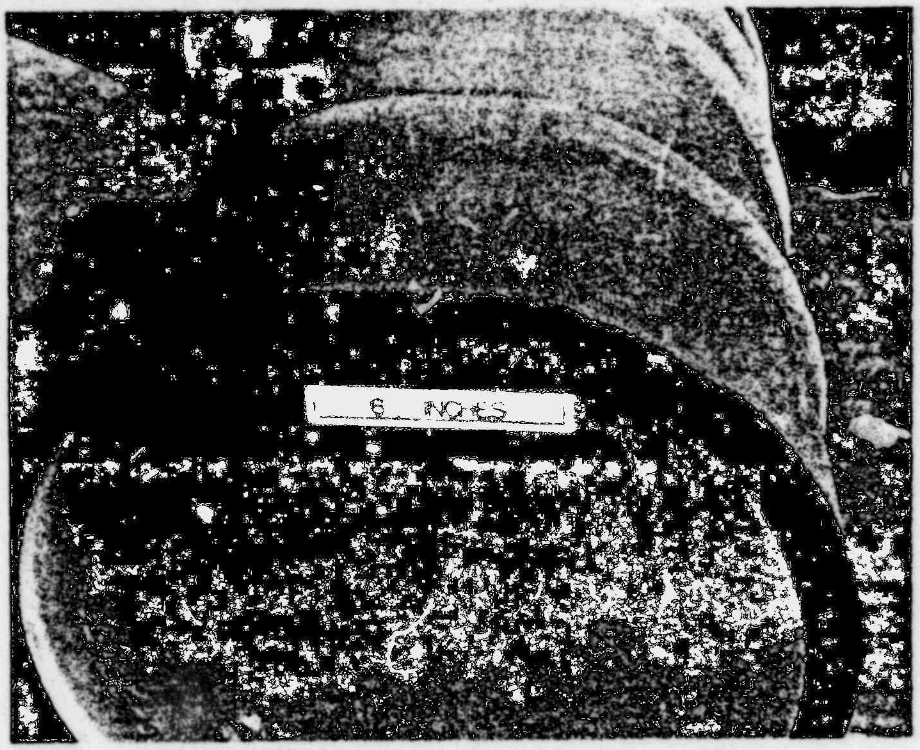
   d. Description of test load - three 55-gallon drums containing silicon carbide grit and a wooden pallet placed atop the test container.

   e. Duration of test - 24 hours; Started 9:10 a.m. on 9/28/65
      Ended 9:10 a.m. on 9/29/65

   f. Description of test effects - At the end of the test there was no discernible effect on the drum.

   g. Performed by - A. Ulyas.

   h. Witnessed by - A. Ulyas, W. Stanko.



a. After 4-ft. impact test

b. After penetration test

Figure 21

Normal Transport Condition Tests upon

55-gallon 17H Drum with Polyethylene Bottle and Absorbal

C. CONTAINER TESTED - Outer container - ICC Specification 15A wooden box; Inner container - Thermo polystyrene-covered glass jars of one-half pint, one pint and 1 quart capacity in a 30-gauge metal can with slip-on lid sealed by cloth tape.

1. Identification - See Figure 2 for pictures showing wooden box and its inner components and the box final assembled.

2. Weight

   a. 15A wooden box and bands - 13 lbs.

   b. Primary containers - 3 lbs.

   c. Intermediate can and tape - 5 lbs.

   d. Simulated shipment (chunks of steel) - 3 lbs.

   e. Total gross weight - 24 lbs.

3. Free Drop Test

   a. Surface used for test - 4-inch reinforced concrete floor at ground level used for loading dock.

   b. Surface of container tested - Three surfaces were tested. The box was dropped on its short flat side, on its long flat side, and on a short edge.

   c. Height of fall - 4 feet, as measured from the ground to the bottom of the forks of a hi-lift supporting the box.

   d. Description of test effects - Figure 22a shows the points of impact on all three tests (point 1 - the short side; point 2 - the edge; and point 3 - the long side). No significant damage occurred to the box . Also, no damage occurred to the inner containers.

   e. Date test performed - September 17, 1965.

   f. Performed by - A. Ulyas.

   g. Witnessed by - W. Stanko, W. B. Thomas.

4. Penetration Test

   a. Weight and measurement of steel cylinder used - 12 lbs, 36-1/8 inches in length and 1-1/4 inches in diameter.

   b. Surface of container tested - the flat end of the cylinder struck one long side of the box.

   c. Height of cylinder drop - 4 feet, as measured from the top of the tested box to the bottom of the forks of a hi-lift supporting the cylinder.

   d. Description of test effects - Figure 22b shows the results of the test on the closed box. A small mark was made on the surface of the wood; however, no penetration occurred.

   e. Date test performed - September 17, 1965.

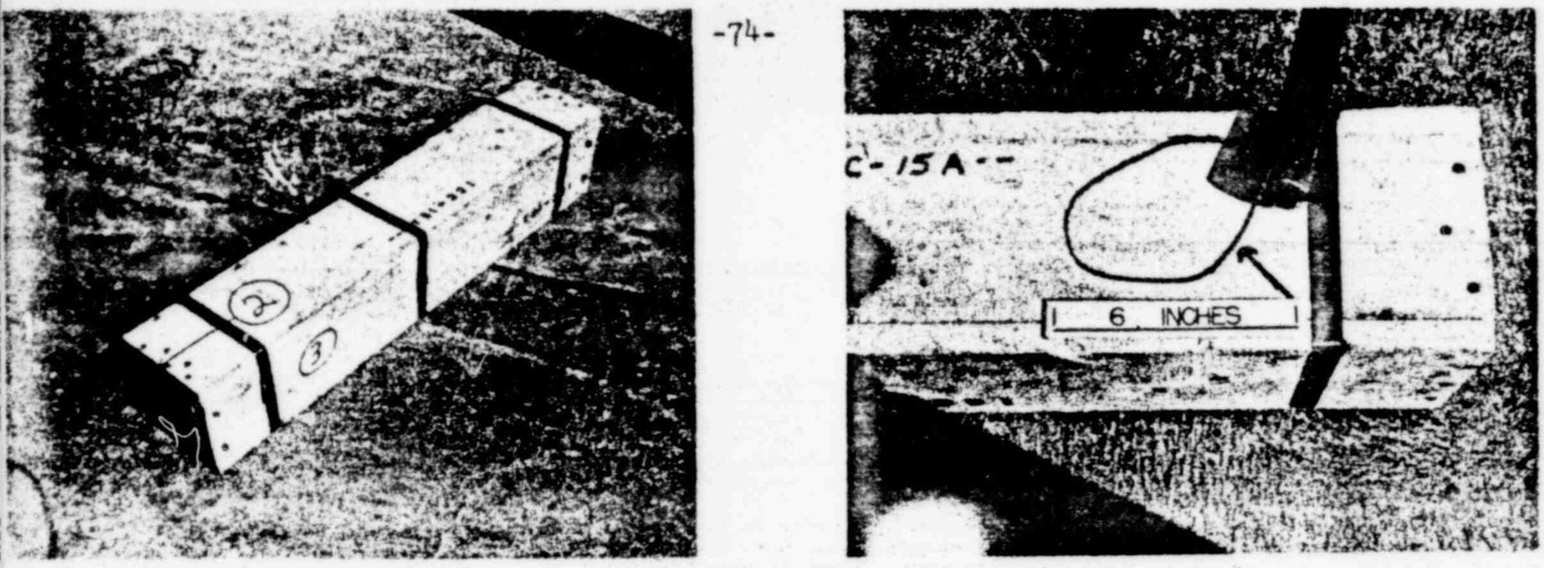
   f. Performed by - A. Ulyas.

   g. Witnessed by - W. Stanko, A. Ulyas.

5. Water Spray Test
   a. Rate of water spray - 1.1 gallons/minute.
   b. Time container exposed to spray - 30 minutes.
   c. Position of container - positioned atop a metal skid so as to ensure that container would not become immersed in water after test. (Figure 22c)
   d. Weight of container - before test - 13 lbs.
      - after test - 13 lbs.

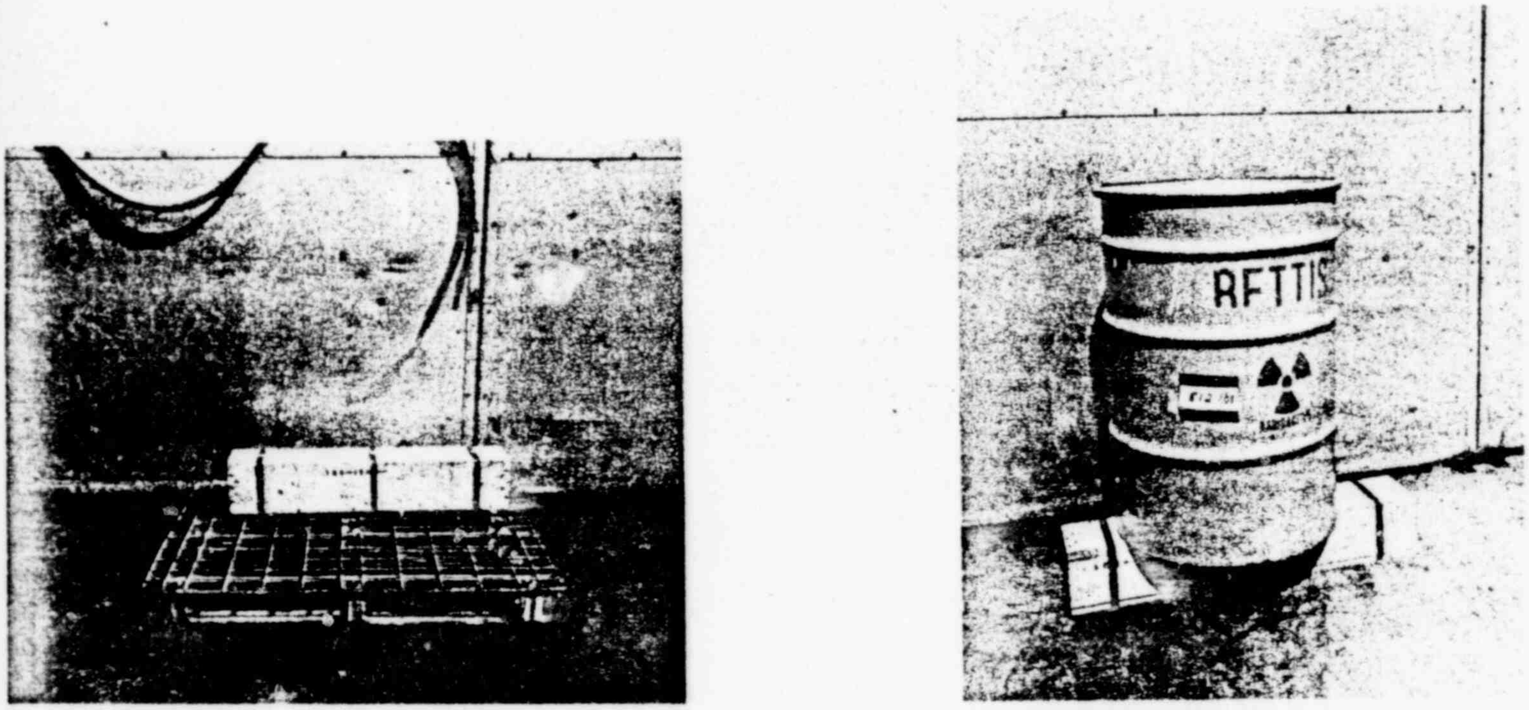
      Net weight change - None
   e. Description of test effects - Upon opening of the box, slight dampness was noticed on one inner side of the box. However, there was no significant water leakage into the box as evidenced by the fact there was no net weight change.
   f. Date test performed - September 15, 1965.
   g. Performed by - A. Ulyas.
   h. Witnessed by - W. Stanko, A. Ulyas.

6. Compression Test
   a. Gross weight of container - 24 lbs.
   b. Test specifications (5 times container weight or 2 lbs/sq. inch times vertically-projected area in square inches of the upright container, whichever is greater).
      (1) Five times container weight - 5 x 24 lbs = 120 lbs.
      (2) Vertically-projected area - 241 sq. inches; area x 2 lbs = 482 lbs.
   c. Actual test load used - 512 lbs.
   d. Description of test load - one 55-gallon drum containing silicon carbide grit material. (Figure 22d)
   e. Duration of test - 24 hours; Started - 8:30 a.m. on 9/14/65
      Ended - 8:30 a.m. on 9/15/65
   f. Description of test effect - At the end of the test there was no discernible effect on the box or its contents.
   g. Performed by - A. Ulyas.
   h. Witnessed by - W. Stanko, A. Ulyas.



a. After Three Impact Tests

b. After Penetration Test



c. During Water Spray Test

d. During Compression Test

Figure 22

Normal Transport Condition Tests
Upon ICC Specification 15a Wooden Box

D. CONTAINER TESTED - B of E Permit No. 2070 Drum

1. Identification - See Figure 6 for pictures of the empty drum and drum with a typical filter addition.

2. Weight

   a. Container weight - 103 lbs.

   b. Simulated shipment - A clean filter - 68 lbs.

   c. Total gross weight - 171 lbs.

3. Free Drop Test

   a. Surface used for test - 4-inch reinforced concrete floor at ground level used for loading dock.

   b. Surface of container tested - drum dropped so that the point of impact was the edge where the side (15-gauge) and bottom (20-gauge) of the drum are joined.

   c. Height of fall - 4 feet, as measured from the ground to the bottom of the forks of a hi-lift supporting the drum.

   d. Description of test effects - Figure 23a shows the small dent that resulted. There was no significant effect on the external shape of the container.

   e. Date test performed - September 17, 1965.

   f. Performed by - A. Ulyas.

   g. Witnessed by - W. Stanko, W. B. Thomas.

4. Penetration Test

   a. Weight and measurement of steel cylinder used - 12 lbs, 36-1/8 inches in length and 1-1/4 inches in diameter.

   b. Surface of container tested - Two surfaces were tested. The cylinder struck the side of the drum and the bottom of the drum.

   c. Height of cylinder drop - 4 feet, as measured from the top of the drum during test conditions to the bottom of the forks of a hi-lift supporting the cylinder.

   d. Description of test effects - Figures 23b and 23c show the results of the two tests. There was only a minor dent on each surface of the drum tested; no penetration of the container walls occurred.

   e. Date test performed - September 17, 1965.

   f. Performed by - A. Ulyas.

   g. Witnessed by - W. Stanko, W. B. Thomas.

5. Water Spray Test

   a. Rate of water spray - 1.1 gallons/minute.

   b. Time container exposed to spray - 30 minutes.

   c. Position of container - positioned atop a metal skid so as to ensure that container would not become immersed in water during test.

Water Spray Test - continued

d. Weight of container - before test - 103 lbs.
- after test - 103 lbs.

Net weight change - None

e. Description of test effects - There was no water leakage into the drum as evidenced by the fact there was no net weight change. Also, upon opening the drum, no water was found inside.

f. Date test performed - September 16, 1965.

g. Performed by - W. Stanko.

h. Witnessed by - D. Zontek, E. Jackson.

6. Compression Test

a. Gross weight of container - 171 lbs.

b. Test specifications (5 times container weight or 2 lbs/sq. inch times vertically-projected area in square inches of the upright container, whichever is greater).

  (1) Five times container weight - 5 x 171 lbs = 855 lbs.

  (2) Vertically-projected area - 616 sq. inches; area x 2 lbs = 1232 lbs.

c. Actual test load used - 1332 lbs.

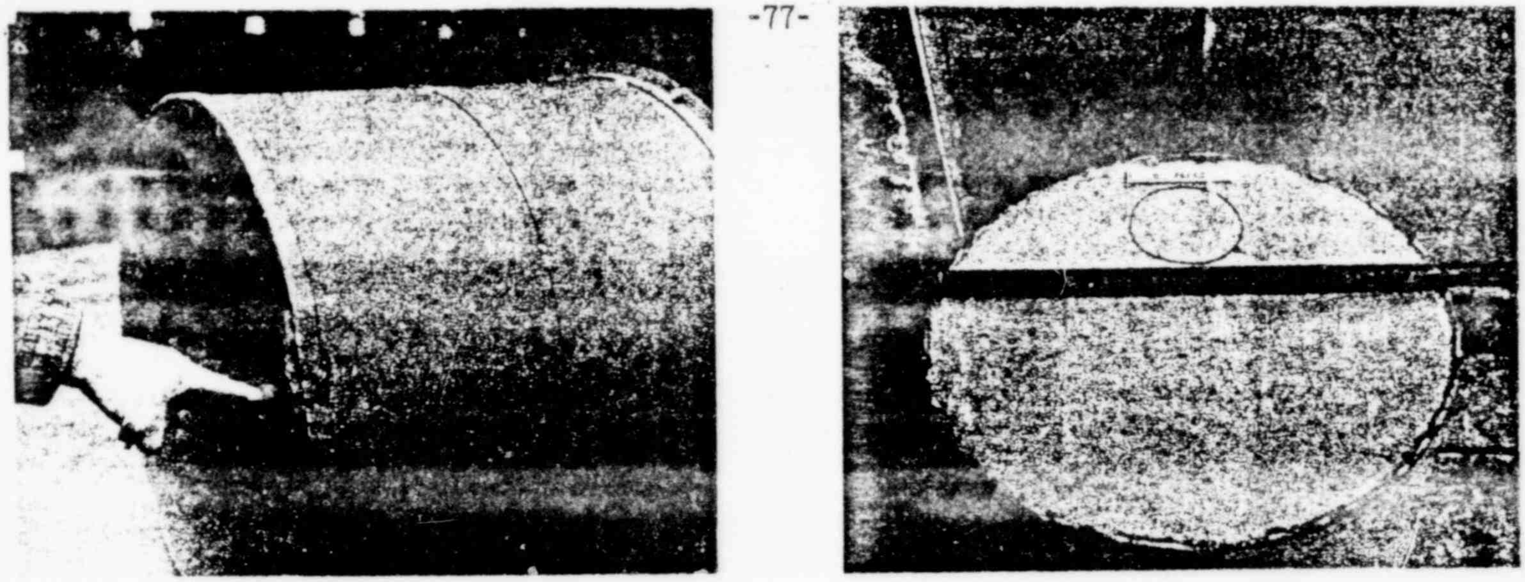
d. Description of test load - Two 55-gallon drums containing silicon carbide grit and a wooden pallet placed atop the test container. (Figure 23d)

e. Duration of test - 24 hours; Started - 8:30 a.m. on 9/13/65
Ended - 8:30 a.m. on 9/14/65

f. Description of test effects - There was no discernible effect on the drum.

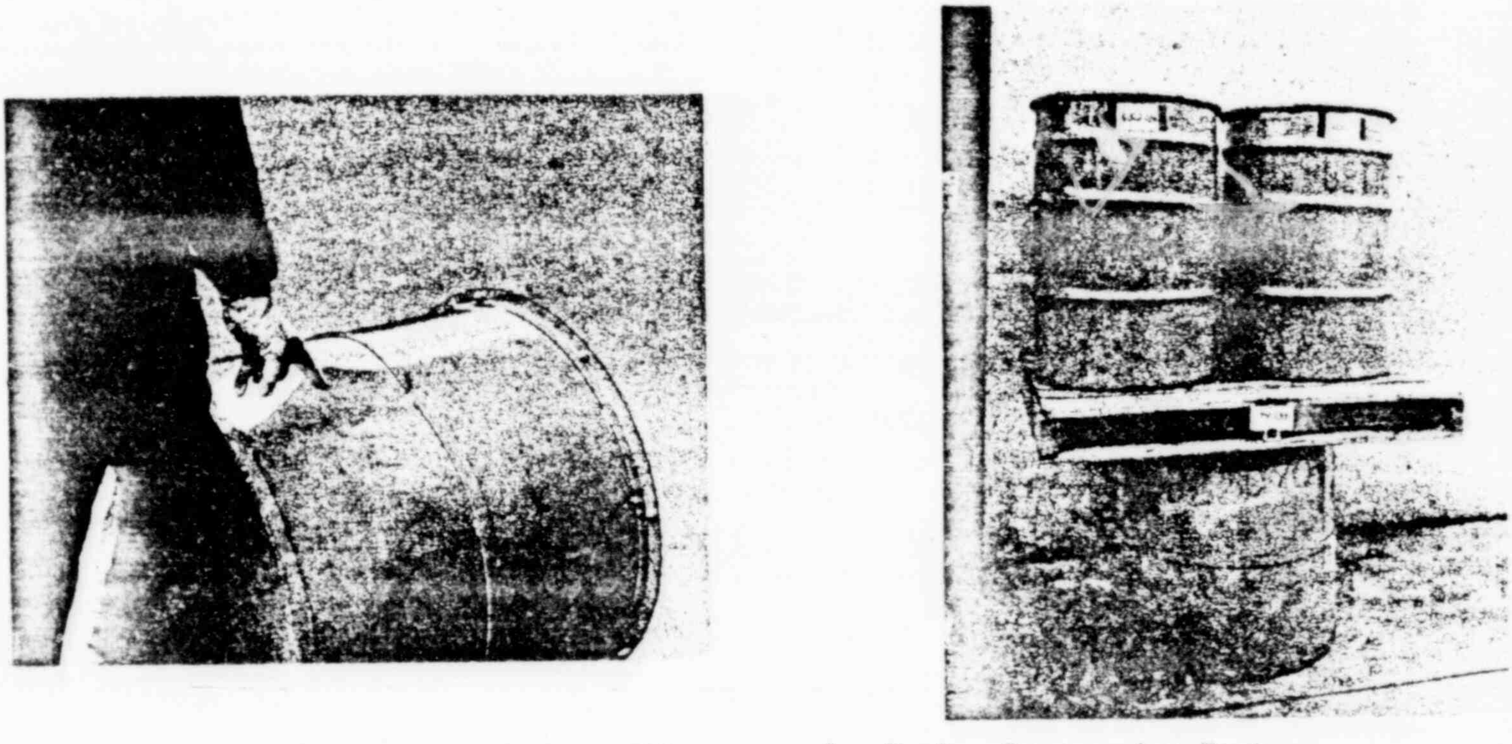
g. Performed by - A. Ulyas.

h. Witnessed by - W. Stanko, W. B. Thomas.



a. After 4-ft. Impact Test

b. After Penetration Test on Bottom



c. After Penetration Test on Side

d. During Compression Test

Figure 23

Normal Transport Condition Tests
Upon B of E Permit No. 2070 Drum

E. CONTAINER TESTED - B of E Permit No. 2071 Drum

1. Identification - See Figure 5 for pictures showing external drum and inner components.

2. Weight

   a. Outer container weight - 70 lbs.

   b. Schedule-40 pipe insert and hoop - 135 lbs.

   c. Simulated shipment - Scrap subassembly - 45 lbs. - was loaded inside the Schedule-40 pipe.

   d. Total gross weight - 250 lbs.

3. Free Drop Test

   a. Surface used for test - 4-inch reinforced concrete floor at ground level used for loading dock area.

   b. Surface of container tested - drum dropped with long axis horizontal so that the thinnest portion of the drum, its 18-gauge steel body, was the surface tested.

   c. Height of fall - 4 feet, as measured from the ground to the bottom of the forks of a hi-lift supporting the drum.

   d. Description of test effects - Figure 24a shows that this 4-foot drop test had no significant effect on the external surface of the drum. No damage occurred to the structure or material inside of the drum.

   e. Date test performed - September 17, 1965.

   f. Performed by - A. Ulyas.

   g. Witnessed by - W. Stanko, W. B. Thomas.

4. Penetration Test

   a. Weight and measurement of steel cylinder used - 12 lbs, 36-1/8 inches in length and 1-1/4 inches in diameter.

   b. Surface of container tested - the flat end of the cylinder struck the side of the drum, its thinnest section.

   c. Height of cylinder drop - 4 feet, as measured from top of the drum laying on its side to the bottom of the forks of a hi-lift supporting the cylinder.

   d. Description of test effect - Figure 24b shows the result of this test. There was slight denting of the drum; however, penetration did not occur.

   e. Date test performed - September 17, 1965.

   f. Performed by - A. Ulyas.

   g. Witnessed by - W. Stanko, W. B. Thomas.

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5. Water Spray Test

   a. Rate of water spray - 1.1 gallons/minute.

   b. Time container exposed to spray - 30 minutes.

   c. Position of container - positioned atop a metal skid so as to ensure that container would not become immersed in water during test. (Figure 24c)

   d. Weight of container - before test - 250 lbs.
      - after test - 250 lbs.
      Net weight change - None

   e. Description of test effects - There was no water leakage into the drum as evidenced by the fact there was no net weight change. Also, upon opening of the drum, no water was found inside.

   f. Date test performed - September 15, 1965.

   g. Performed by - A. Ulyas.

   h. Witnessed by - W. Stanko, C. W. Hughes.

6. Compression Test

   a. Gross weight of container - 250 lbs.

   b. Test specifications (5 times container weight or 2 lbs/sq. inch times vertically-projected area in square inches of the upright container, whichever is greater).

      (1) Five times container weight - 5 x 250 lbs =1250 lbs.

      (2) Vertically-projected area - 415 sq. inches; area x 2 lbs = 830 lbs.

   c. Actual test load used - 1319 lbs.

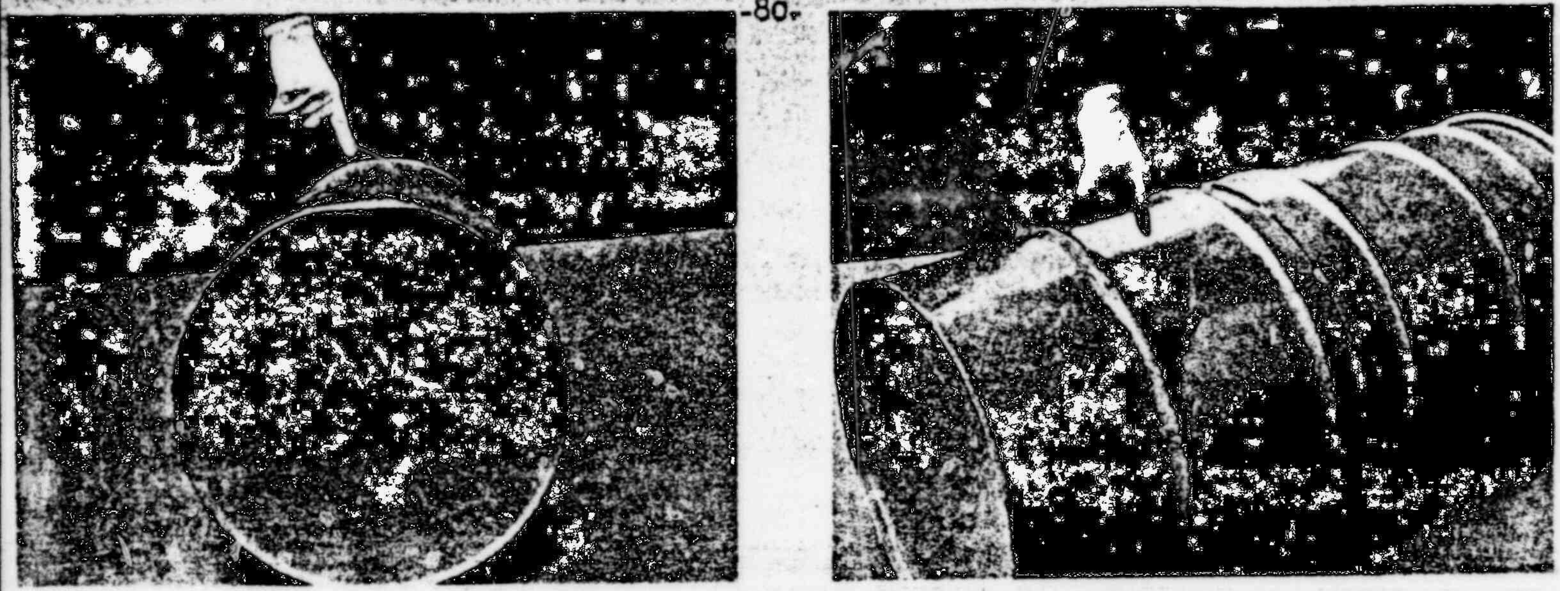
   d. Description of test load - Three 55-gallon drums containing silicon carbide grit and a wooden pallet placed atop the test container. (Figure 24d)

   e. Duration of test - 24 hours; Started - 8:30 a.m. on 9/14/65
      Ended - 8:30 a.m. on 9/15/65

   f. Description of test effects - At the end of the test there was no discernible effect on the drum.

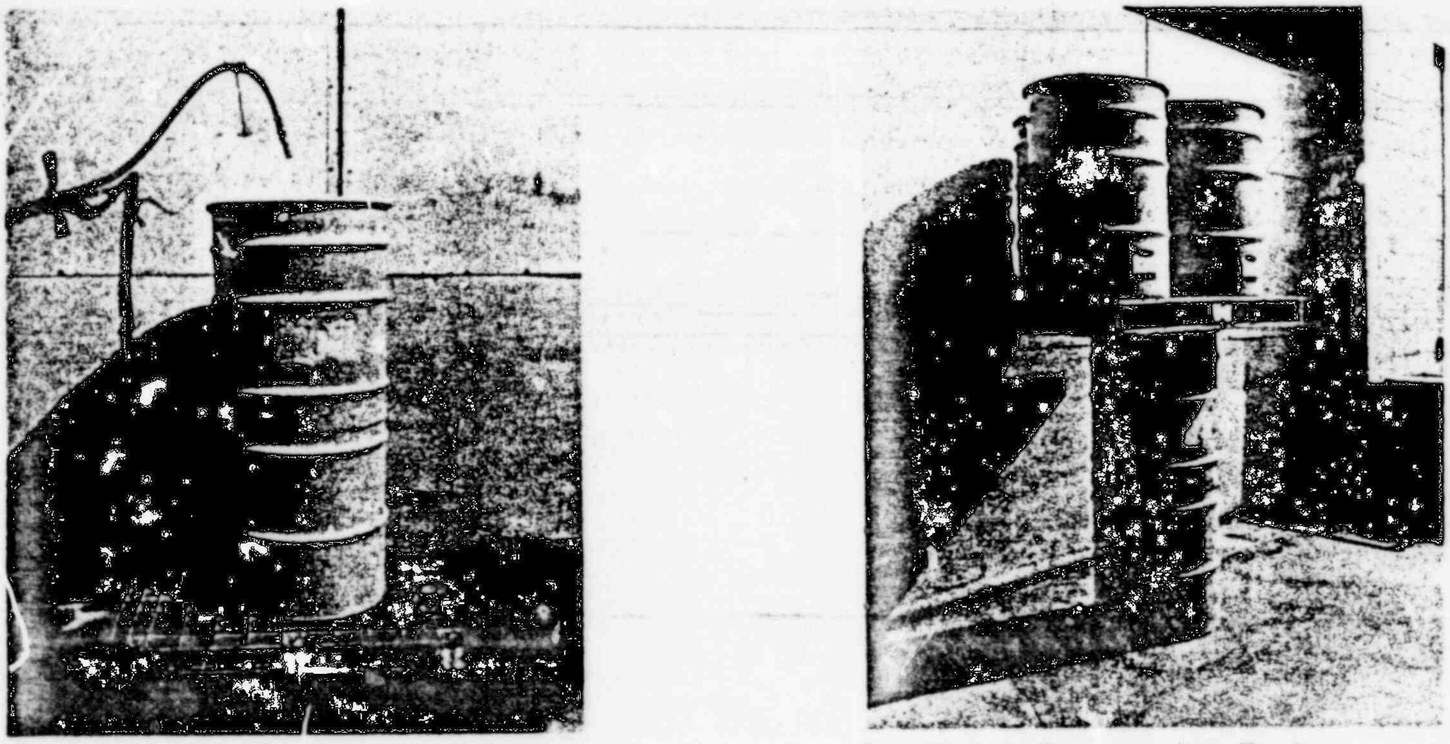
   g. Performed by - A. Ulyas.

   h. Witnessed by - A. Ulyas, W. Stanko



a. After 4-ft. Impact Test

b. After Penetration Test



c. During Water Spray Test

d. During Compression Test

Figure 24

Normal Transport Condition Tests
Upon B of E Permit No. 2071 Drum

F CONTAINER TESTED - B of E Permit No. 1270 Birdcage

1. Identification - See Figure 8 for picture showing birdcage ready for shipment and an empty rectangular box.

   Dimensions of birdcage frame tested - 2 feet square by 6 feet long.

2. Weight

   a. Weight of outer container (with rectangular cross section box) - 118 lbs.

   b. Simulated shipment - Steel plates - 45 lbs.

   c. Total gross weight - 163 lbs.

3. Free Drop Test

   a. Surface used for test - 4-inch reinforced concrete floor at ground level used for loading dock.

   b. Surface of container tested - birdcage dropped with its long axis horizontal; point of impact was the long edge of the frame.

   c. Height of fall - 4 feet, as measured from the ground to the bottom of the forks of a hi-lift supporting the birdcage.

   d. Description of test effects - Figure 25a shows that there was negligible effect on the structure of the birdcage.

   e. Date test performed - September 17, 1965.

   f. Performed by - A. Ulyas.

   g. Witnessed by - W. Stanko, A. Ulyas.

4. Penetration Test

   a. Weight and measurement of cylinder used - 12 lbs, 36-1/8 inches in length and 1-1/4 inches in diameter.

   b. Surface of container tested - the flat end of the cylinder struck the top of the rectangular box.

   c. Height of cylinder drop - 4 feet, as measured from the top of the rectangular box to the bottom of the forks of a hi-lift supporting the cylinder.

   d. Description of test effects - Figure 25b shows the circular dent made on the rectangular box; however, no penetration occurred.

   e. Date test performed - September 17, 1965.

   f. Performed by - A. Ulyas.

   g. Witnessed by - W. Stanko, A. Ulyas.

5. Water Spray Test

   a. Rate of water spray - 1.1 gallons/minute.

   b. Time container exposed to spray - 30 minutes.

Water Spray Test - continued

c. Position of container - Positioned atop a metal skid so as to ensure that container would not be immersed in water during test. (Figure 25c)

d. Weight of container - before test - 118 lbs.
- after test - 118 lbs.
Net weight change - None

e. Description of test effects - There was no water leakage into the rectangular cross section box as evidenced by the fact there was no net weight change. Also, upon opening the container, no water was found inside.

f. Date test performed - September 16, 1965.

g. Performed by - E. Jackson.

h. Witnessed by - C. W. Hughes, W. Stanko.

6. Compression Test

a. Gross weight of container - 163 lbs.

b. Test specifications (5 times container weight of 2 lbs/sq. inch times vertically-projected area in square inches of the upright container, whichever is greater).

   (1) Five times container weight - 5 x 163 lbs = 815 lbs.

   (2) Vertically-projected area - 1728 sq. inches; area x 2 lbs = 3456 lbs.

c. Actual test load used - 3633 lbs.

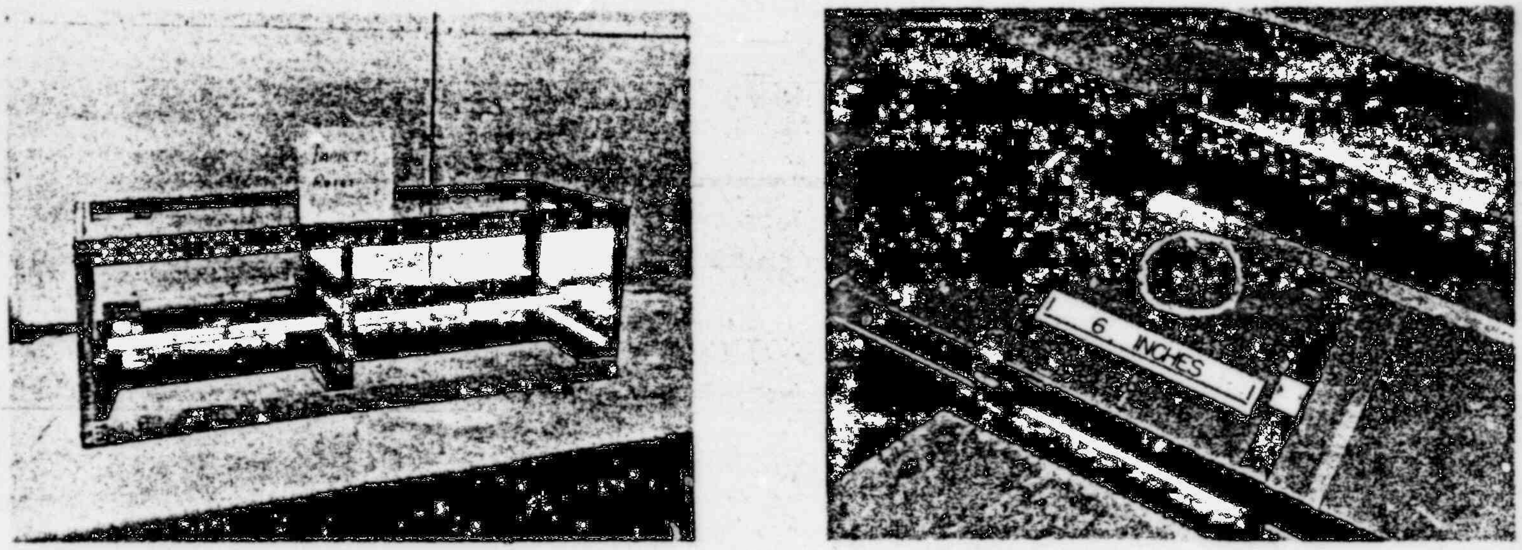
d. Description of test load - Eight 55-gallon drums containing silicon carbide grit, and one wooden pallet and one metal skid placed atop the tested birdcage. (Figure 25d)

e. Duration of test - 24 hours; Started - 9:00 a.m. on 9/15/65
Ended - 9:00 a.m. on 9/16/65

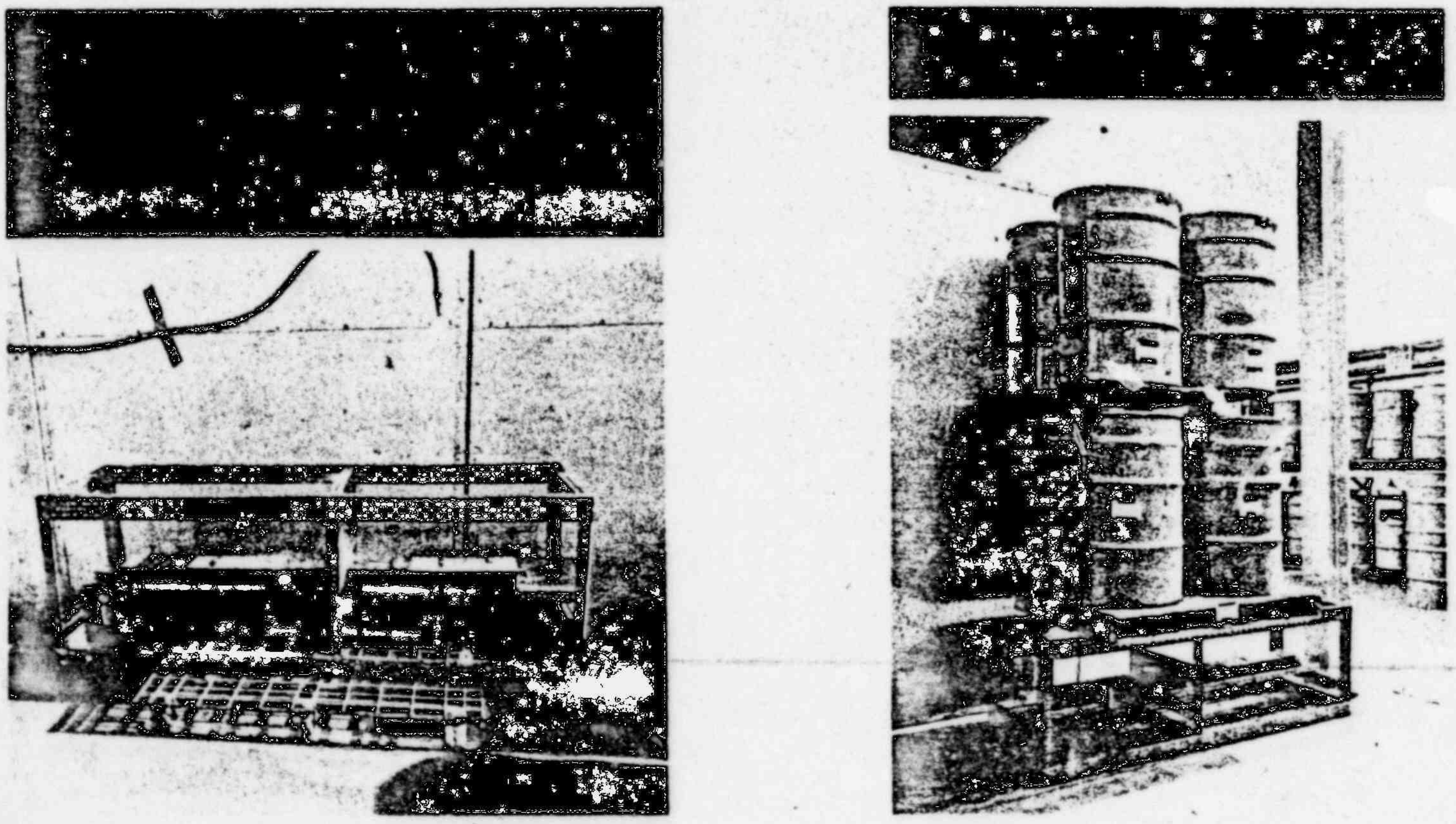
f. Description of test effects - At the end of the test there was no discernible effect on the birdcage.

g. Performed by - A. Ulyas.

h. Witnessed by - W. Stanko, A. Ulyas.



a. After 4-ft. Impact Test **b. After Penetration Test**



c. During Water Spray Test d. During Compression Test

Figure 25

Normal Transport Condition Tests
Upon B of E Permit No. 1270 Birdcage
Unmodified

GENERAL

The integrity of the packages (55-gallon 17H drum, BE 2070 and 2071 drums and BE 1270 birdcage) under hypothetical accident test conditions specified in AECM 0529, Annex 2 has been demonstrated to be adequate as follows:

1. Accident Test Conditions

   a. Single Package Conditions

      Requirement (1): Free Drop - A free drop, from a height of 30 feet, onto an unyielding, flat, horizontal surface, with the package striking the surface in such a position as to suffer the maximum damages; followed by the puncture test.

      This requirement has been demonstrated by test to be satisfied. The test results are summarized in Appendix II.

      Requirement (2): Puncture - A fall onto a cylindrical target through a distance of 40 inches measured from the lowest point of the package to the surface of the target, striking the target in such a position as to suffer the maximum damage. The cylindrical target shall be the flat, horizontal end surface of a vertical, solid, structural carbon steel cylinder, 8 inches long and 6 inches (±0.2 inch) in diameter. The edges of the surface may be rounded to a radius of not more than 0.25 inch. The bar shall be rigidly mounted on a flat horizontal unyielding surface; followed by the fire test.

      This requirement has been demonstrated by test to be satisfied. The test results are summarized in Appendix II.

      Requirement (3): Thermal - Since the criticality analysis for Fissile Class I shipments makes no assumptions concerning the location or properties of the material within the 55 gallon drums, other than the U-235 mass per unit area, it is concluded that the integrity of the outer container is the only factor which must be demonstrated in a fire test. LAMS-2983, "Impact and Thermal Tests on Transport Containers ICC 2R and 6J" dated December 16, 1963, reported the results of a fire test on 55 gallon, 18 gauge steel drums with the only effect being burned-off-paint. It is therefore concluded that this requirement has been satisfied.

      Requirement (4): Water Immersion - Immersion in water so that the package is at least three feet below the surface for 24 hours.

      This test was not performed since packaging limits are established that are safe even if the container is optimally moderated.

APPENDIX II

ACCIDENT CONDITION TESTS

1323 186

A. CONTAINER TESTED - 55-gallon 17H drum with 5-inch inner diameter Schedule-40 pipe insert.

1. Identification - See Figure 1.

2. Weight

   a. 55-gallon 17H drum and Schedule-40 pipe insert and hoops - 152 lbs.

   b. Simulated shipment - Steel plates - 48 lbs.

   c. Total gross weight - 200 lbs.

3. Free Drop Test

   a. Surface used for test - 4-inch reinforced concrete pad located behind Hangar #3 at Bettis.

   b. Surface of container tested - With the free fall from 30 feet, the drum landed on its bottom rim.

   c. Height of fall - 30 feet, as measured from the ground to the bottom of the drum, which was suspended on a truck crane.

   d. Description of test effects - Figure 26a shows the drum at impact. Although some external distortion of the drum occurred, no damage occurred to the Schedule-40 pipe insert and there was no loss of material.

   e. Date test performed - August 26, 1964.

   f. Performed by - A. Ulyas.

   g. Witnessed by - W. B. Thomas, C. W. Hughes.

4. Followed by Puncture Test

   a. Surface used for test - 4-inch reinforced concrete floor, at ground level used for a loading dock.

   b. Weight and measurement of cylinder - 78 lbs, 8 inches in length and 6 inches in diameter.

   c. Surface of container tested - the drum body.

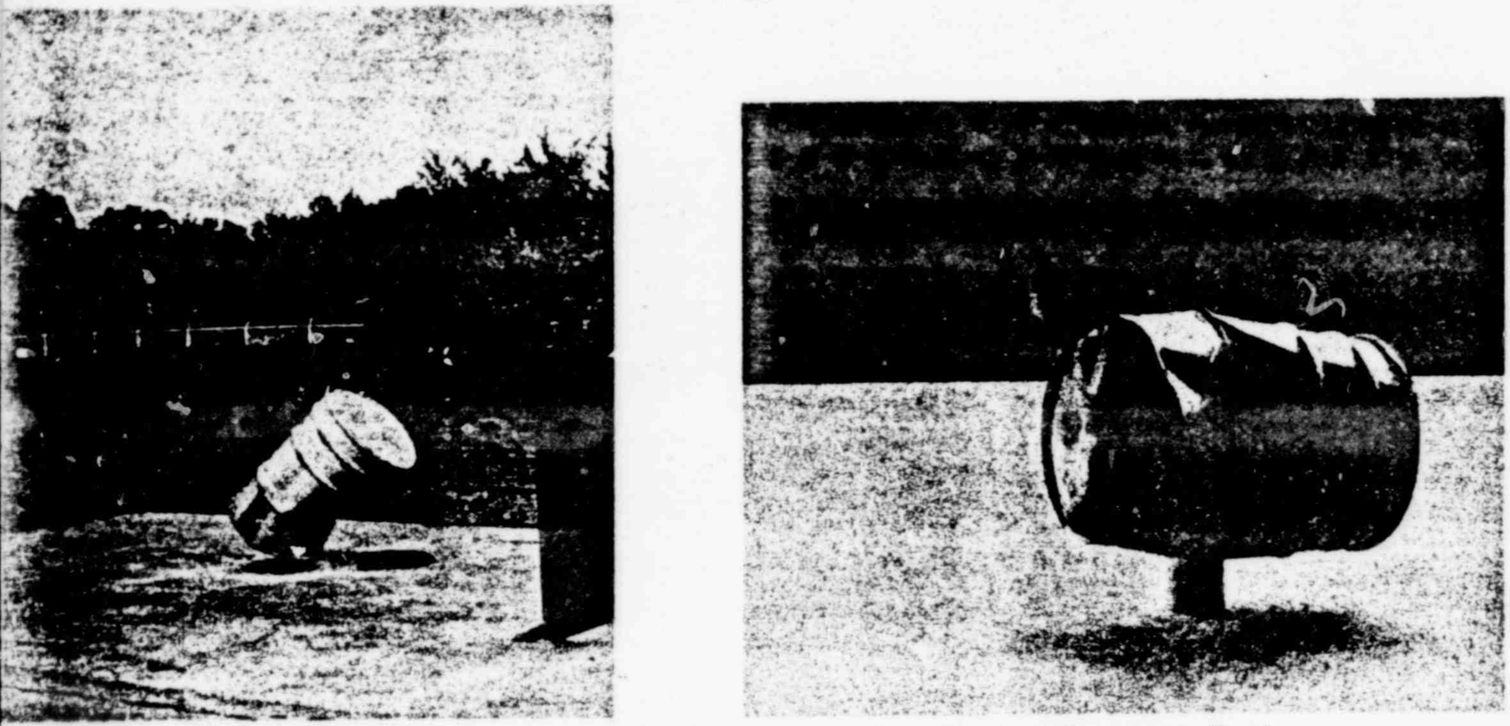
   d. Height of drop - 40 inches, as measured from the top of the cylinder to the bottom of the drum which was positioned atop the forks of a hi-lift.

   e. Description of test effects - Figures 26b and 26c show the moment of the impact and the dent resulting from the test; however, no penetration occurred.

   f. Date test performed - August 26, 1964.

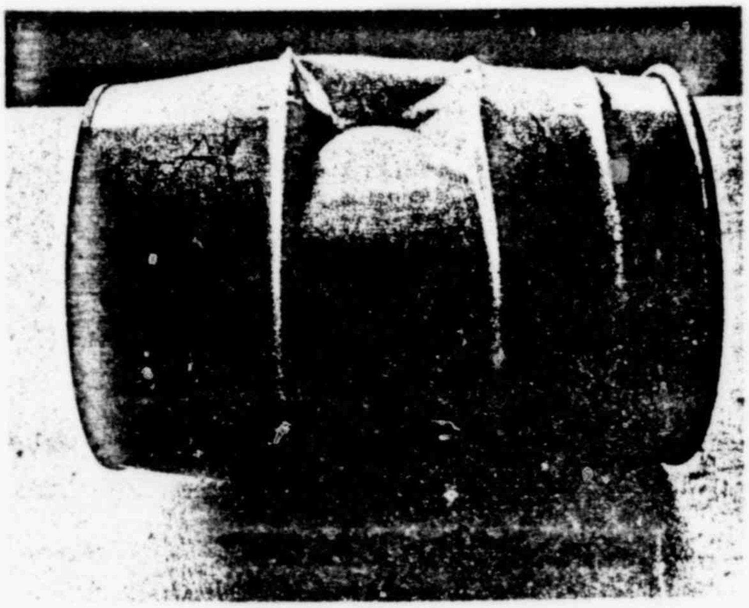
   g. Performed by - A. Ulyas.

   h. Witnessed by - W. B. Thomas, C. W. Hughes.



a. 30-ft. Drop Test

b. During Puncture Test



c. After Drop Test and Puncture Test

Figure 26

Accident Condition Tests Upon
55-gallon 17H Drum with Schedule-40 Pipe Insert

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B. CONTAINER TESTED - B of E Permit No. 2071 Drum

1. Identification - See Figure 5.

2. Weight

   a. Outer container weight and Schedule-40 pipe insert and hoop weight - 210 lbs.

   b. Simulated shipment - Steel plates - 55 lbs.

   c. Total gross weight - 265 lbs.

3. Free Drop Test

   a. Surface used for test - 4-inch reinforced concrete pad located behind Hangar #3 at Bettis.

   b. Surface of container tested - with the free fall from 30 feet, the drum landed on the edge of the top closure.

   c. Height of fall - 30 feet, as measured from the ground to the bottom of the drum, which was suspended on a truck crane.

   d. Description of test effects - Figure 27a shows the result of the 30-foot drop test. The photograph shows the bolt removed from the top. This was not the result of the drop test, but was removed to open the container after the test in order to observe the condition of the inner container. The test resulted in denting of the top closure; however, there was no significant displacement of the inner container and no material escaped from the drum.

   e. Date test performed - June 24, 1965.

   f. Performed by - A. Ulyas.

   g. Witnessed by - C. W. Hughes, W. B. Thomas.

4. Followed by Puncture Test

   a. Surface used for test - 4-inch reinforced concrete floor at ground level used for loading dock.

   b. Weight and measurement of cylinder - 78 lbs, 8 inches in length and 6 inches in diameter.

   c. Surface of container tested - the drum body.

   d. Height of drop - 40 inches, as measured from the top of the cylinder to the bottom of the drum which was positioned atop the forks of a hi-lift.

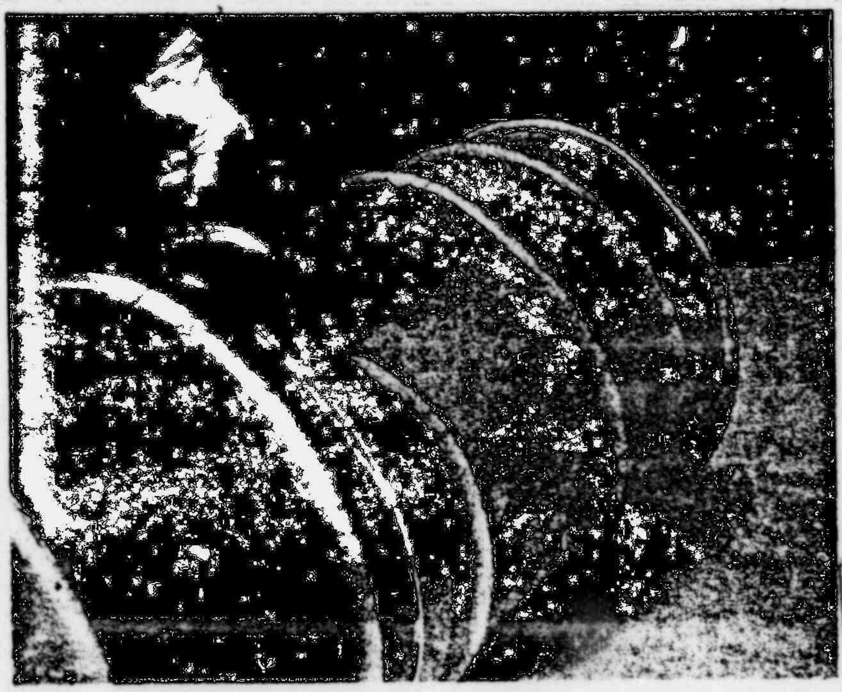
   e. Description of test effects - Figure 27b shows the result of this test. Although there was a dent in the side of the drum, penetration did not occur.

   f. Date test performed - June 24, 1965.

   g. Performed by - A. Ulyas.

   h. Witnessed by - C. W. Hughes, W. B. Thomas.

a. After 30-ft. Drop Test



b. After Drop Test and Puncture Test
Figure 27
Accident Condition Tests Upon B of E Permit No. 2071 Drum

C. CONTAINER TESTED - B of E Permit #2070 Drum

1. Identification - See Figure 6

2. Weight

   a. Container Weight - 105 lbs.

   b. Simulated Shipment - 63 lbs. filter

   c. Total Gross Weight - 168 lbs.

3. Free Drop Test

   a. Surface used for test - 4-inch reinforced concrete pad located behind Hanger #3 at Bettis.

   b. Surface of container tested - With the free fall from 30-feet the drum landed on the edge of the top closure.

   c. Height of fall - 30-feet, as measured from the ground to the bottom of the drum, which was suspended from a truck crane.

   d. Description of test effects - There was no rupture of the top at the bolt holes although the drop did produce a slight distortion of the drum. See Figure 28a.

   e. Date test performed - June 24, 1965

   f. Performed by A. Ulyas

   g. Witnessed by - C. W. Hughes, W. B. Thomas.

4. Followed by Puncture Test

   a. Surface used for test - 4-inch reinforced concrete floor.

   b. Weight and measurement of cylinder - 78 lbs., 8 inches in length and 6 inches in diameter.

   c. Surface of container tested - the drum body.

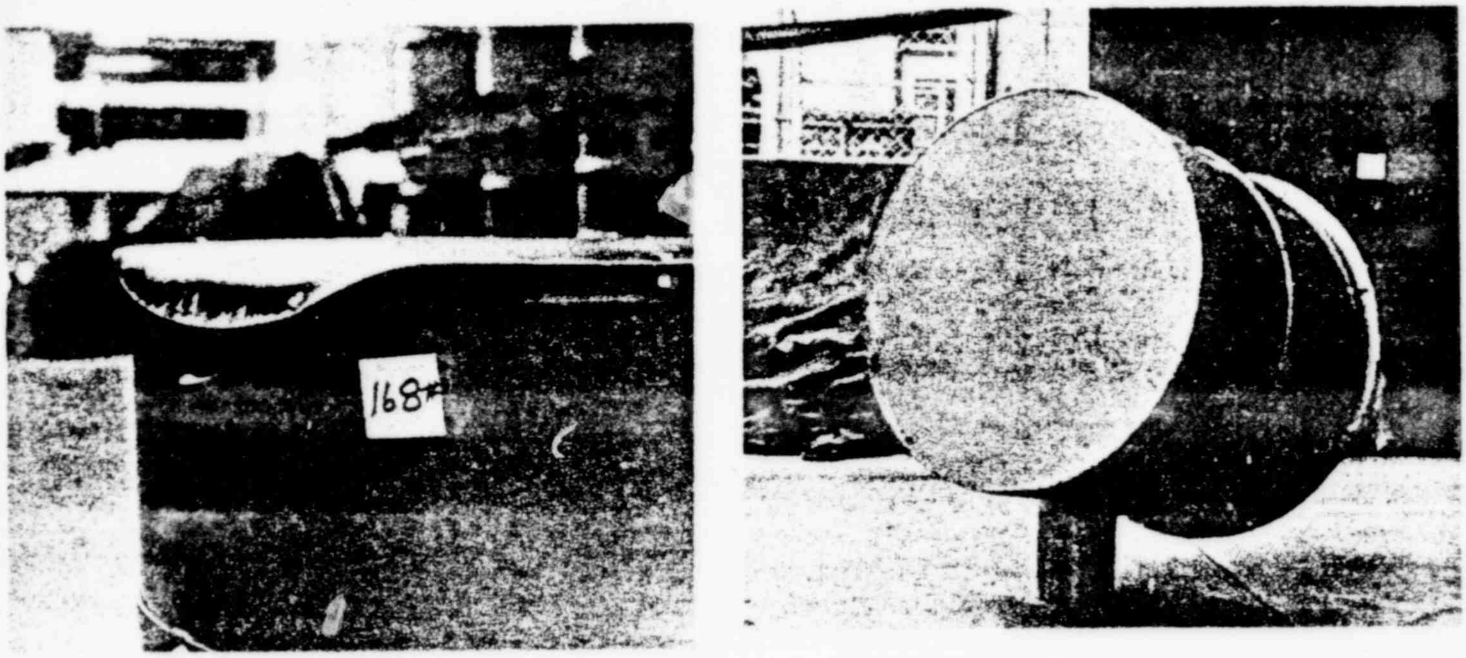
   d. Height of drop - 40 inches, as measured from the top of the cylinder to the bottom of the drum which was positioned atop the forks of a hi-lift.

   e. Description of test effects - There was little or no denting of the drum and neither penetration nor rupture occurred. See Figures 28b and 28c.

   f. Date test performed - June 24, 1965

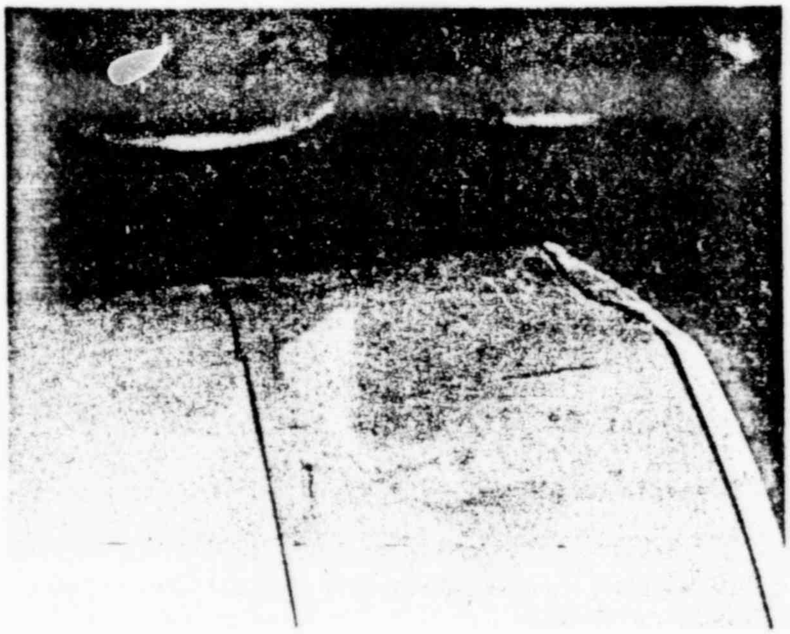
   g. Performed by A. Ulyas

   h. Witnessed by C. W. Hughes, W. B. Thomas.



a. After 30-ft. Free Drop Test

b. During Puncture Test



c. After Free Drop Test and Puncture Test

Figure 28

Accident Condition Tests Upon B of E
Permit No. 2070 Drum

D. CONTAINER TESTED - B of E Permit #1270 Birdcage

1. The 2-feet square by 6-1/2 feet long birdcage

   a. Identification - See Figure 8a (This represents a modification (additional angular braces and angle iron cover above the primary container) to the birdcage shown in Figure 8.)

   b. Weight

      (1) Weight of outer container (with rectangular cross section (box) primary container) - 129 lbs.

      (2) Simulated Shipment - 54 lbs.

      (3) Total Gross weight - 183 lbs.

   c. Date tests performed - April 12, 1967.

   d. Performed by A. Ulyas.

   e. Witnessed by W. B. Thomas, W. A. Stanko.

   f. Free Drop Tests

      (1) Surface used for test - 4-inch reinforced concrete pad located behind Hangar #3 at Bettis.

      (2) Height of fall - 30-feet as measured from the ground to the bottom of the birdcage which was suspended from a truck crane.

      (3) First test

         (a) Surface of container tested - with a free fall from 30-feet a 6-1/2 foot birdcage was dropped with its long axis at 45°, the point of impact being the bottom end cross member.

         (b) Description of test effects - Figure 29a shows the birdcage at impact and figure 29b shows the results of the test. No damage occurred to the primary container. There was no loss of material from the primary container nor was there any displacement of the primary container from the center of the birdcage. The bottom cross member was deformed approximately 1" and the side member slightly damaged; there was no loss of spacing.

      (4) Second test

         (a) Surface of container tested - with a free fall from 30-feet, another 6-1/2 feet birdcage was dropped with its long axis horizontal. The birdcage was upside down; the point of impact was the top of the birdcage. The birdcage tested was similar to that shown in Figure 8 - no angle iron cover above the primary container but with angular braces.

POOR ORIGINAL

D. 1. f. (4) (b) Description of test effects - Figure 30a shows the birdcage immediately after impact and Figure 30b shows a close-up of the birdcage on its side showing the bottom of the birdcage. There was no damage to the birdcage frame; however, the bottom angle iron enclosure around the primary container spread allowing the primary container to leave its restraint. (All birdcages will hereafter be constructed with three angle iron cross members perpendicular and adjacent to the top and bottom angle iron enclosures around the primary container similar to that used for the 12' birdcage shown in Figure 8b. This configuration was demonstrated to effectively prevent a similar occurrence - See results of second test for the 12' birdcage).

g. Followed by Puncture Test

(1) Surface used for test - 4-inch reinforced concrete floor at ground level used for a loading dock.

(2) Weight and measurement of cylinder - 78 lbs.; 8-inches in length and 6-inches in diameter.

(3) Surface of container tested - the long axis of the birdcage frame and the primary container (two tests).

(4) Height of drop - 40-inches, as measured from the top of the cylinder to the bottom of the birdcage for the first test and 40-inches, as measured from the top of the cylinder to the bottom of the primary container for the second test.

(5) Description of test effects - there was a slight distortion of the angle iron frame as a result of the first test; there was only a slight mark on the primary container as a result of the second test. This puncture test was considered to have no harmful effect on either the angle iron frame or the primary container

(6) Date test performed - April 21, 1967.

(7) Performed by A. Ulyas.

(8) Witnessed by W. B. Thomas, W. A. Stanko.

2. The 2-feet square by 12 feet long birdcage

a. Identification - See Figure 8b (This represents a modification (additional angular and horizontal braces and angle iron cover above the primary container) to the birdcage shown in Figure 8.)

b. Weight

(1) Weight of outer container (with rectangular cross section (box) primary container) - 230 lbs.

D. 2. b. (2) Simulated Shipment - 100 lbs.

(3) Total Gross Weight - 330 lbs.

c. Date tests performed - April 12, 1967.

d. Performed by A. Ulyas.

e. Withessed by W. B. Thomas, W. A. Stanko.

f. Free Drop Tests

(1) Surface used for test - 4-inch reinforced concrete pad located behind Hangar #3 at Bettis.

(2) Height of fall - 30-feet as measured from the ground to the bottom of the birdcage which was suspended from a truck crane.

(3) First Test

(a) Surface of container tested - with a free fall from 30-feet, a 12' birdcage was dropped with its long axis at 45°, the point of impact being the bottom cross member. This test was performed on each end of the same birdcage.

(b) Description of test effects - Figure 31a shows the birdcage at impact during the first drop; figure 31b shows the same birdcage at impact during the second drop (point of impact was the opposite end); figure 31c shows the birdcage at the end of the test. The bottom ends of the birdcage were deformed two inches; there was no loss of spacing and no displacement of the primary container from the center of the birdcage. As a result of the first drop, however, the primary container shifted within the angle iron enclosure to the edge of the birdcage frame.

(4) Second Test

(a) Surface of container tested - With a free fall from 30-feet, another 12' birdcage was dropped with its long axis horizontal. The birdcage was upside down. The point of impact was the top of the birdcage.

(b) Description of test effects - Figure 32 shows the results of the test. The birdcage is shown upside down as it landed. The three top supports of the birdcage frame were deformed reducing the spacing 3-inches, i.e. from 15-inches to 12-inches between the primary container and outer edge of the birdcage.

D. 2. g. Followed by the Puncture Test

(1) Surface used for test - 4-inch reinforced concrete floor at ground level used for a loading dock.

(2) Weight and measurement of cylinder - 78 lbs.; 8-inches in length and 6-inches in diameter.

(3) Surface of container tested - the long axis of the birdcage frame and the primary container (two tests).

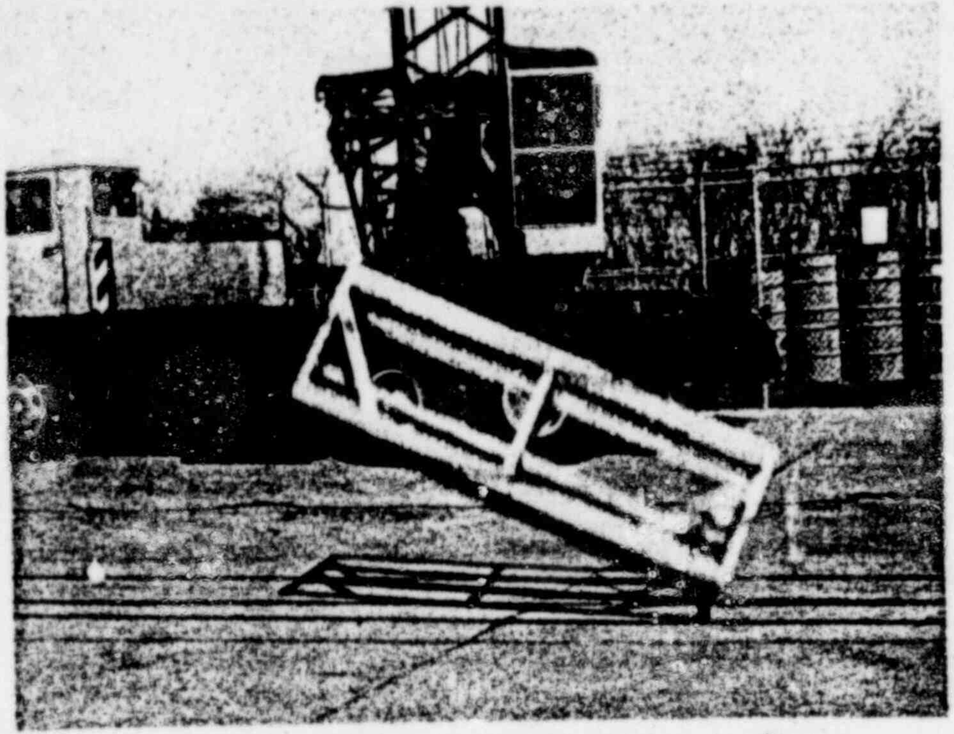
(4) Height of drop - 40-inches, as measured from the top of the cylinder to the bottom of the birdcage for the first test and 40-inches, as measured from the top of the cylinder to the bottom of the primary container for the second test.

(5) Description of test effects - there was a slight distortion of the angle iron frame as a result of the first test; there was only a slight mark on the primary container as a result of the second test. This puncture test was considered to have no harmful effect on either the angle iron frame or the primary container.

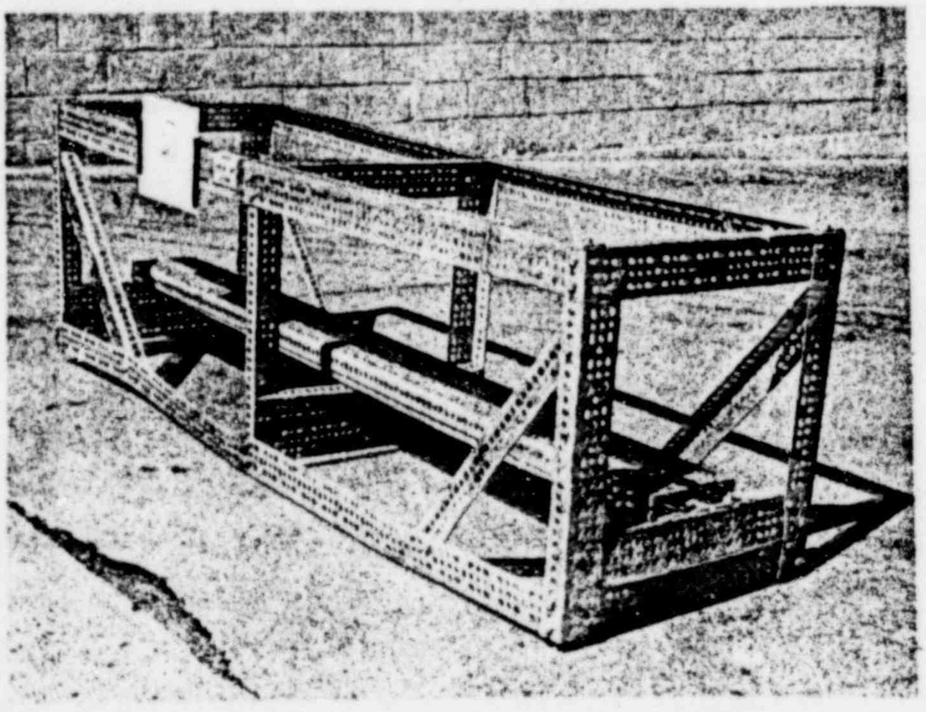
(6) Date test performed - April 21, 1967.

(7) Performed by A. Ulyas.

(8) Witnessed by W. B. Thomas, W. A. Stanko.



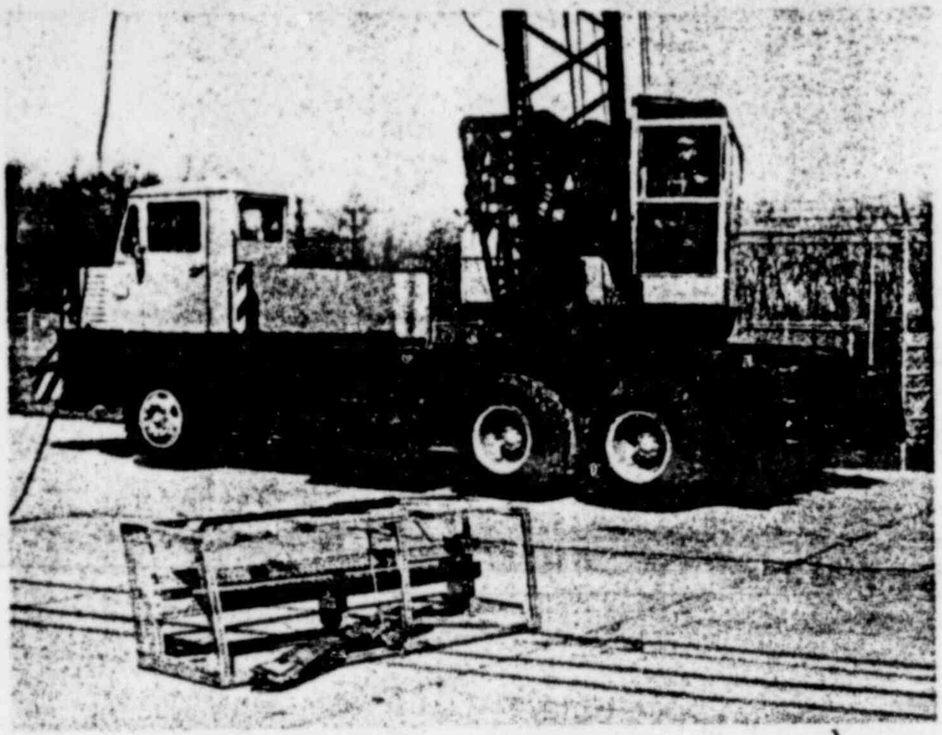
a. During Free Drop Test (Jan.t)



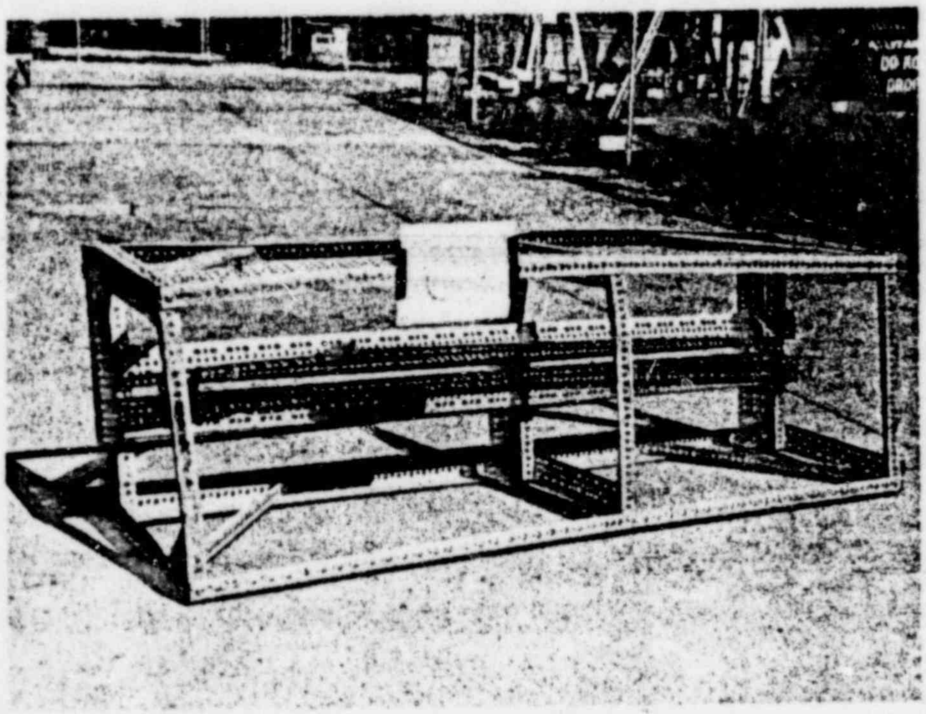
b. After Free Drop Test (Jan.t)

Figure 29
Accident Condition Test Upon B of E
Permit No. 1270 Birdcage - 6-1/2'

POOR ORIGINAL



a. After Free Drop Test (Second)

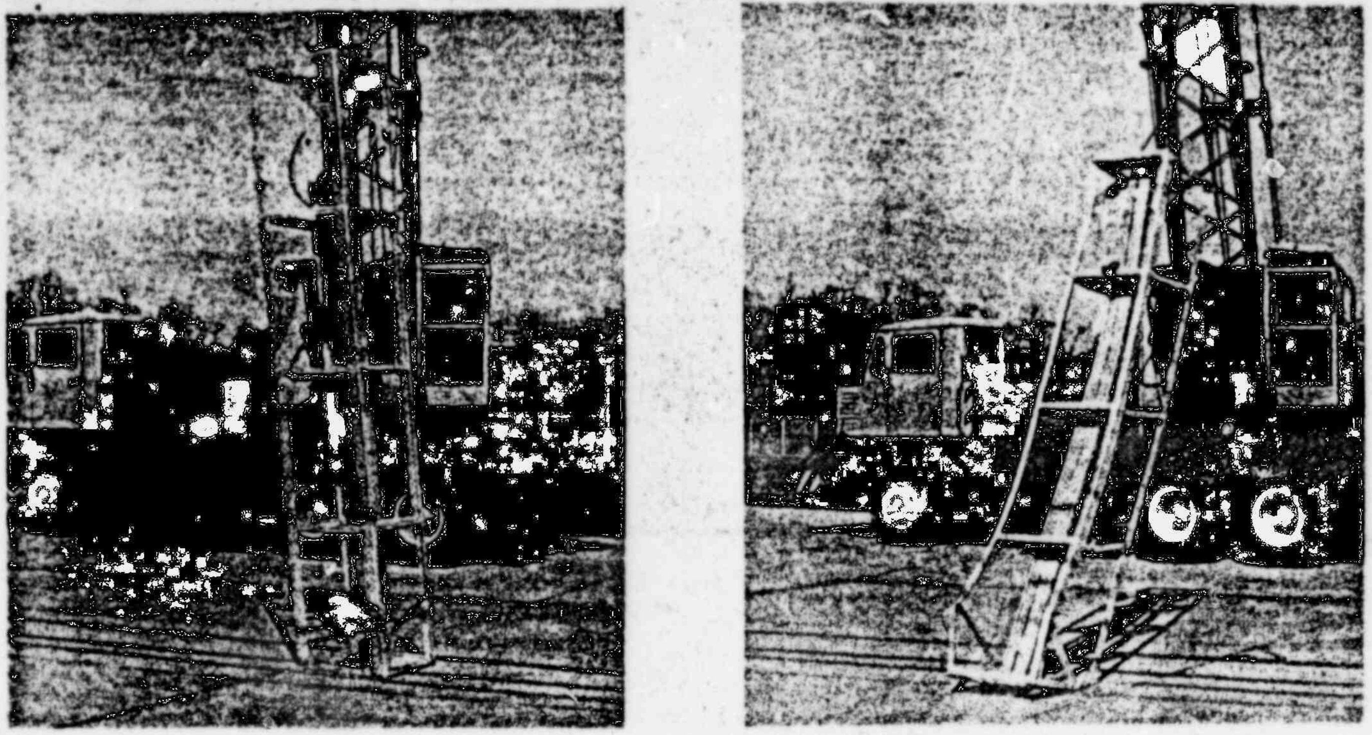


b. After Free Drop Test ([illegible])

Figure 30

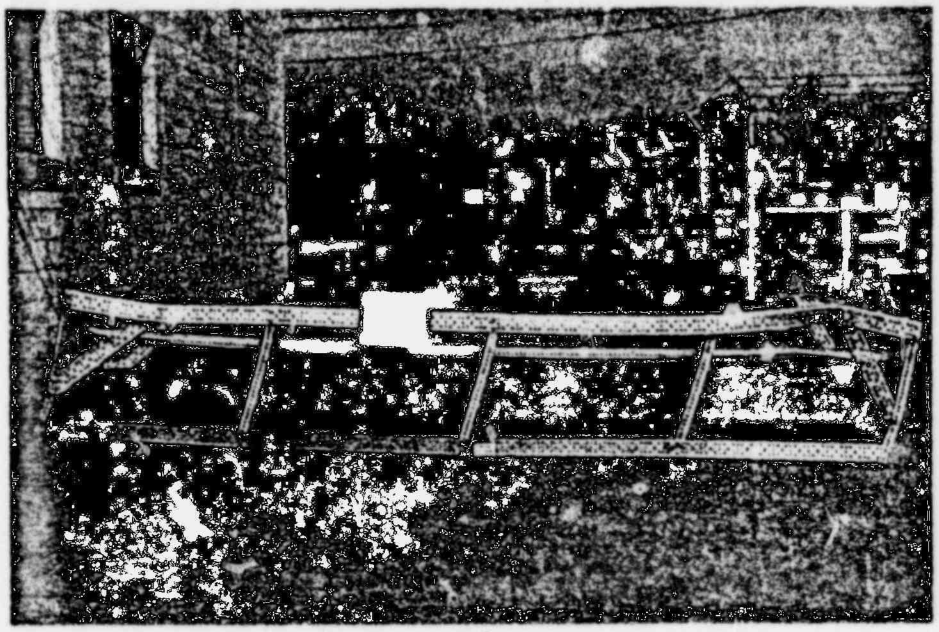
Accident Condition Tests Upon B of E
Permit No. 1270 Birdcage - 6-1/2'

1323 198



a. During Free Drop Test ([illegible])

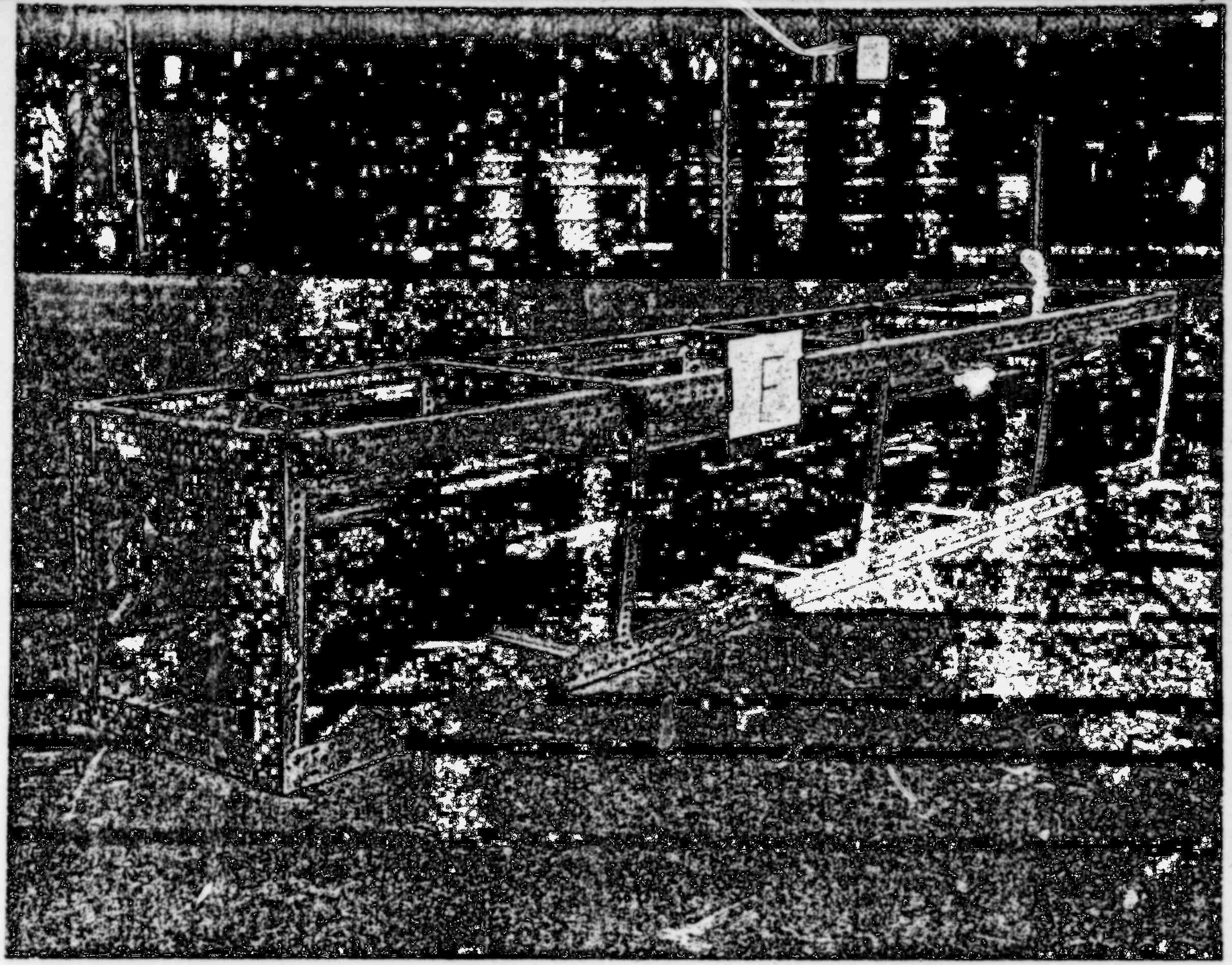
b. During Free Drop Test ([illegible])



c. After Free Drop Test ([illegible])

Figure 31

Accident Condition Tests Upon B of E
Permit No. 1270 Birdcage - 12'



After Free Drop Test (Second)

Figure 32

Accident Condition Tests Upon B of E
Permit No. 1270 Birdcage - 12'

APPENDIX III

SURFACE-VOLUME ANALYSIS

L. L. Jones
M. A. Barnisin

INTRODUCTION

The rapidity with which 2-dimensional diffusion theory calculations may be performed provides a strong incentive for determining the validity of estimating the k_{eff} for an actual 3-dimensional array of interacting fissile units from geometrically similar 2-dimensional arrays. Intuition suggests that a useful parameter for making this estimate in cases where the array is fully reflected is the surface-to-volume ratio computed for the region bounded by the reflector surfaces. Experience has shown that there is a correlation between the calculated k_{eff} and the S/V ratio for all 2-dimensional fully reflected arrays which can be formed using the same basic spacing and geometry for identical interacting fissile units.

The experimental data for critical fully reflected arrays presented in ORNL-TM-719(1) provides an excellent test of the accuracy of this method of analysis. In the following sections this method of analysis is applied to three of the critical arrays described in ORNL-TM-719.

METHOD OF ANALYSIS

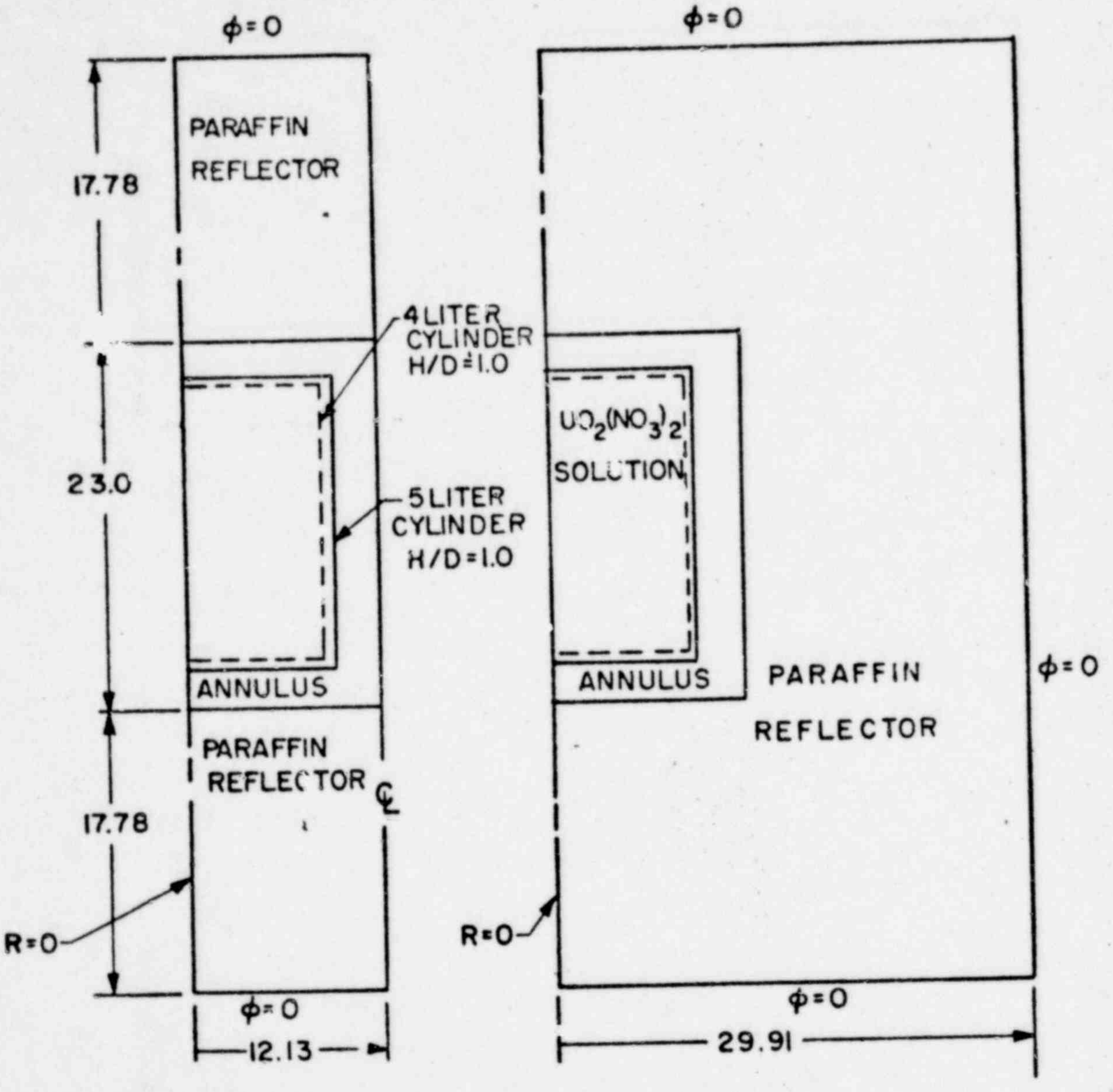
In the experiments each subcritical fissile unit was a 5-liter right circular cylinder of aqueous uranyl nitrate solution contained in a 0.64 cm thick plexiglass container with a Height/Diameter ratio of approximately 1.0. The solution contained 415 grams total U/liter. The uranium was 92.6 wt% U-235. The reflector was composed of paraffin, 15.24 cm thick, and enclosed the air spaced arrays on all six sides. The reflector was spaced away from the outside rows of containers at a distance equal to 1/2 the surface-to-surface spacing between containers.

Since air spaced arrays cannot be calculated by diffusion theory, it was necessary to smear out the plexiglass container into the region between the cylinders of solution. Since the process of smearing out the plexiglass container reduces the multiplication of the array slightly, it is known that the actual k_{eff} for the array being calculated is slightly less than 1.0. Since it is known that replacing a thin layer of uranium solution at the surfaces of a cylinder by pure water reduces the multiplication only slightly, a second subcritical array, capable of being described by diffusion theory, may be formed by removing one liter of solution from the container and smearing it out as pure H_2O into the space between the cylinders.

Four group diffusion theory calculations were performed for the 2-dimensional geometries shown in Figures 33 thru 35. The two geometries shown in each figure maintain the spacings characteristic of the critical array except as they were modified by the smearing process. Since in the calculation the flux in each group is forced to zero at the outer edge of the paraffin, the

(1) ORNL-TM-719, "Critical Three-Dimensional Arrays of Neutron-Interacting Units," dated October 1, 1963.

PDQ-RZ GEOMETRY FOR ORNL-TM-719 CRITICAL
1x2x2 ARRAY OF 4 UNITS FULLY REFLECTED



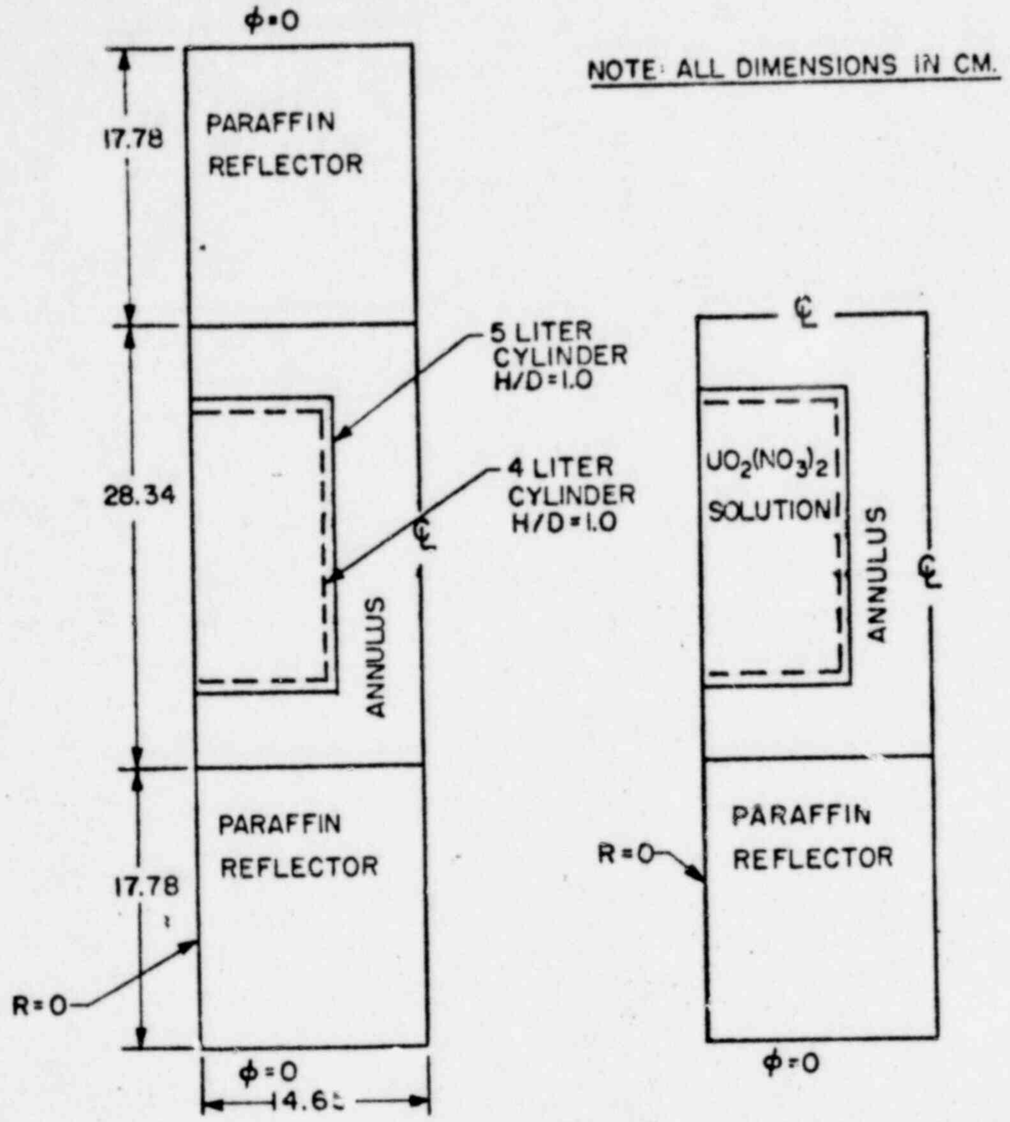
NOTE: ALL DIMENSIONS ARE IN CM.

A- SEMI-INFINITE
ONE TIER HIGH ARRAY

B- ONE ISOLATED, FULLY
REFLECTED UNIT

Figure 33

PDQ-RZ GEOMETRY FOR ORNL-TM-719 CRITICAL, CUBIC ARRAY OF 8 UNITS - FULLY REFLECTED



A- SEMI-INFINITE
ONE TIER HIGH ARRAY

B- SEMI-INFINITE
TWO TIER HIGH ARRAY

C- SAME AS ABOVE-RIGHT HAND
℄ REPLACED BY 17.78 CM.
PARAFFIN REFLECTOR

Figure 34

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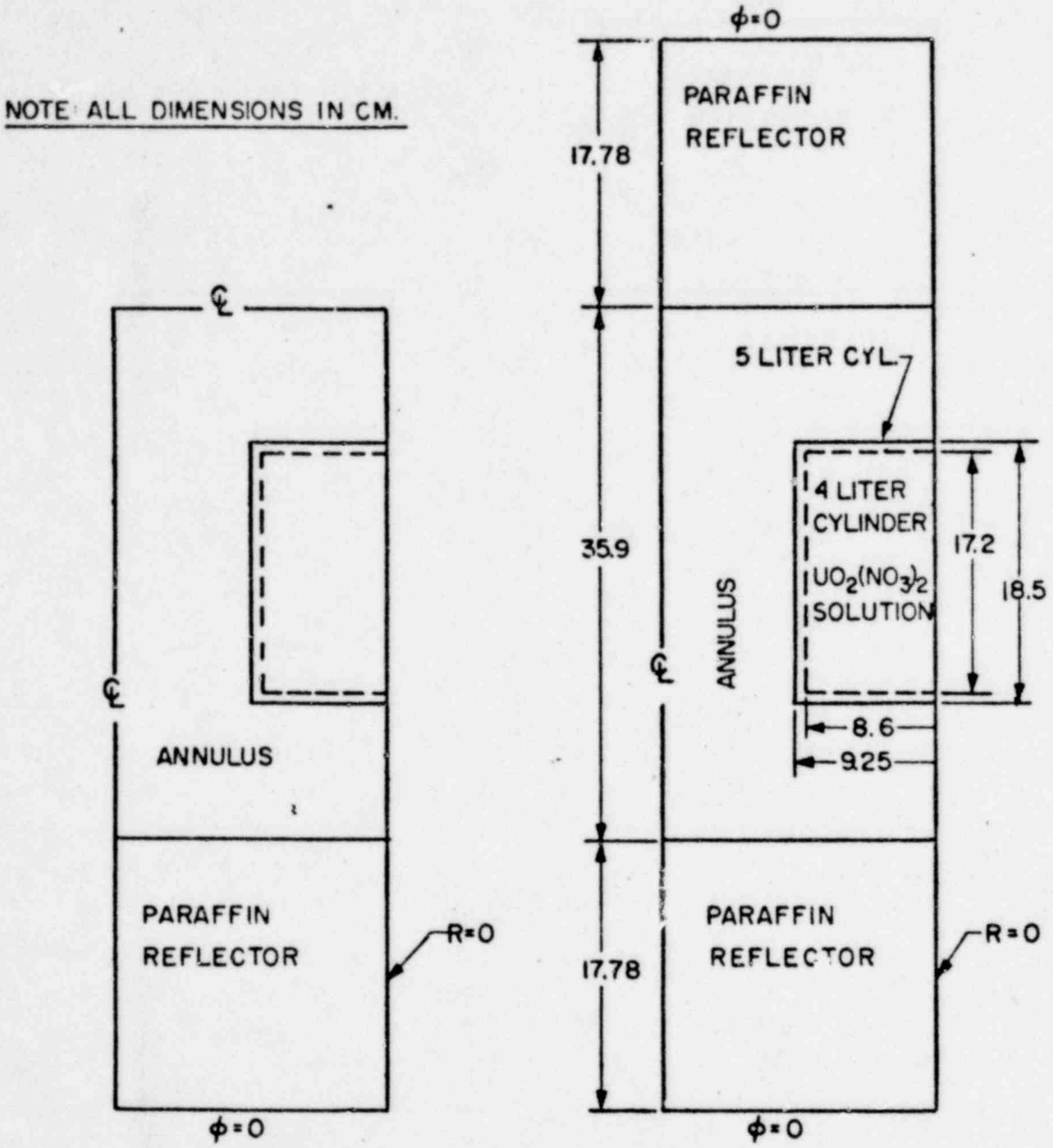
PDQRZ GEOMETRY FOR ORNL-TM-719 CRITICAL, CUBIC ARRAY OF 27 UNITS FULLY REFLECTED



A- SEMI-INFINITE TWO TIER ARRAY

B- SEMI-INFINITE ONE-TIER ARRAY

Figure 35

1323 204

thickness of the paraffin was increased to account for the bare extrapolation length which was estimated to be 2.54 cm. All of the chemical elements in the fuel solution, plexiglass and paraffin were represented explicitly in the Muft V(1) and Kate(2) problems used to generate the 4-group mixed number density constants. The number densities of these various elements in each material are listed in Table X.

The results of these calculations are shown in Table VIII along with the S/V ratio which characterizes each geometry. Table IX shows S/V ratio which characterized the 3-dimensional arrays which were determined experimentally to be critical.

TABLE IX

Array Size	Surface-to-Surface spacing between containers	Surface-to-Volume Ratio (ft^{-1})
2 x 2 x 1	3.94 cm	4.73
2 x 2 x 2	8.99	3.20
3 x 3 x 3	16.53	1.58

Figure 31 shows a plot of the calculated k_{eff} vs S/V ratio for each characteristic spacing. The k_{eff} values inferred from these curves at the S/V ratio corresponding to the critical experiments are shown in Table X..

TABLE X

	Calculated k_{eff}	
Array Size	with only the plexiglass smeared	with one liter of solution and the plexiglass smeared
2 x 2 x 1	1.00	-
2 x 2 x 2	0.96	0.84
3 x 3 x 3	1.00	0.93

---

(1) H. Bohl, Jr. and A. P. Hemphill, "Muft-5, A Fast Neutron Spectrum Program for the Philco 2000," WAPD-TM-218, February, 1961.

(2) H. J. Amster and J. B. Callaghan "Kate-1, A Program for Calculating Wigner-Wilkins and Maxwellian Averaged Thermal Constants on the Philco-2000," WAPD-TM-232, October, 1960.

TABLE VIII - 4-Group Diffusion Theory Results for 2-Dimensional Calculations

Problem No.	Figure No.	Geometry		Annulus Mtrl. Description	Surface-to-Volume Ratio	Calculated k_{eff}
		$UO_2(NO_3)_2$ Cylinder Size	Array Size			
297	28-B	5 liters	1 unit isolated	.0633(1) Plexiglass	7.65 ft^{-1}	.784
298	28-A	5 liters	One high, semi-infinite	.0633 "	2.65	1.251
299	29-A	4	" " " "	.0463 Plexiglass +.0497 H_2O	2.15	1.058
300	29-A	5	" " " "	.0485 Plexiglass	2.15	1.129
303	29-B	4	Two high, semi-infinite	.0463 Plexiglass +.0497 H_2O	1.075	1.438
304	29-B	5	" " " "	.0485 Plexiglass	1.075	1.473
301	30-B	4	One high, semi-infinite	.0210 Plexiglass +.0226 H_2O	1.70	.899
302	30-B	5	" " " "	.0215 Plexiglass	1.70	.973
305	30-A	4	Two high, semi-infinite	.0210 Plexiglass +.0226 H_2O	0.85	1.151
306	30-A	5	" " " "	.0215 Plexiglass	0.85	1.210
307	29-C	5	1 unit isolated	.0485 Plexiglass	6.30	0.696

Note (1) - This number denotes the fraction of normal density material which was used to generate the region constants.

PDQRZ RESULTS FOR K_{EFF} VS S/V FOR ARRAYS OF ORNL-TM-719 UNITS WITH CRITICAL SPACINGS

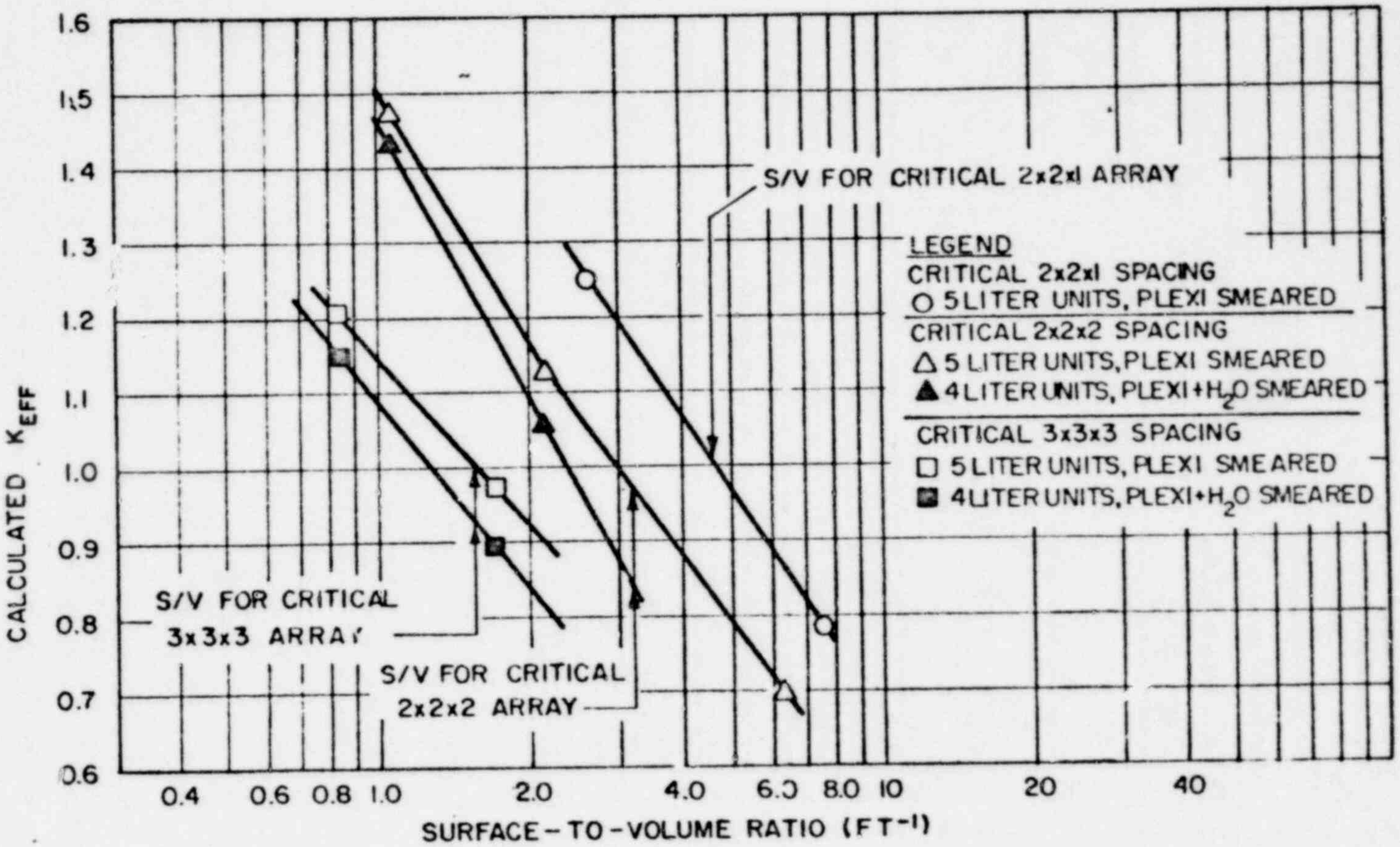


Figure 36

TABLE XI

Compound	Number densities of Constituents
Plexiglass $(C_5H_8O_2)_n$ density = 1.18 g/cc	H = .5679 - 1 O = .1420 - 1 C = .3549 - 1
Paraffin $(C_{25}H_{52})$ density = 0.93 g/cc	C = .3971 - 1 H = .8259 - 1
Aqueous Uranyl Nitrate $UO_2(NO_3)_2$ Sp.Gr. = 1.555 415 gram total U/cc 92.6% U^{235} enrichment	H = .5811 - 1 O = .3712 - 1 N = .1976 - 2 U^{235} = .9849 - 3 U^{238} = .7871 - 4
Water (H_2O) density = 1.000 g/cc	H = .6686 - 1 O = .3343 - 1

The results for 3 different spacings are plotted in Figure 36 as a function of the S/V ratio. In cases where k_{eff} results for only one spacing are presented in each figure, each point on the S/V scale may be replaced by a measure of the array size which has the specified S/V ratio. The scale in Figure 16 was generated in this manner.

APPENDIX IV

RECAP 4C ANALYSIS OF 56 DRUM, PARTIALLY MODERATED, H_2O REFLECTED ARRAY

H. C. Romesburg
J. W. Lankford

RECAP-4C Program

The fueled arrays analyzed are characterized by large regions with low scattering materials so that the neutron balance equations cannot be represented in terms derived from particle diffusion analogy. Exact neutron balance in this case requires accounting for transport effects through low scattering media. For this reason the full energy range (10 Mev-0 ev) RECAP-4C Monte Carlo program was used in this analysis to estimate neutron capture fractions. (See reference 1)

RECAP-4C performs a probalilistic analysis by tracking simulated neutrons from birth to capture and recording all information necessary to form capture fractions and associated statistical uncertainties. The collection of many of these trackings, termed histories, constitutes a random sample of the total neutron population. 1000 histories are generally sufficient so that the probable error for the neutron multiplication associated with a given fission source spatial distribution is ±2%. Beside statistical error and uncertainty in the spatial distribution of the fission source, both of which can be made arbitrarily small by increasing the number of neutron histories, the only other errors which occur are in the modeling of neutron collisions and the cross section data used with the models.

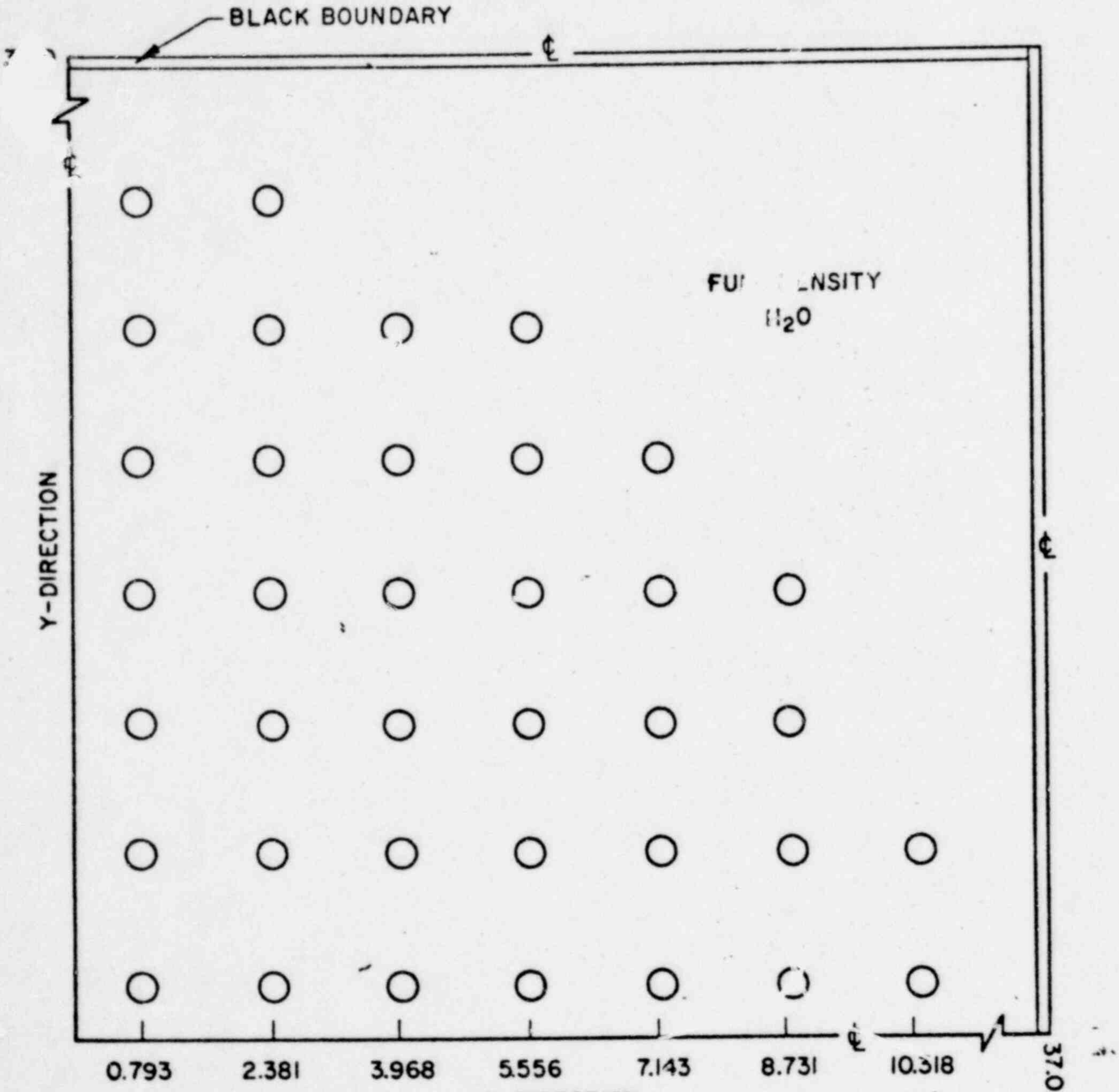
Confidence in the formulation of RECAP-4C has been obtained by comparison of RECAP-4C and experimental results. The critical experiment (taken from Reference 2) chosen for analysis consisted of 1/8 by 12 in. oralloy (94.3% enrichment) rods immersed in an infinite water reflector. The center-to-center rod spacing was 0.625 in. which nearly corresponds to that associated with the minimum critical mass. The quarter configuration used in RECAP-4C is shown in Figure 37. It differs from the experiment arrangement only in that symmetry requires dictated that one additional rod be added.

For 3000 neutron histories the neutron multiplication observed was $K_{eff} = 1.013 \pm 0.016$ with respect to the experimentally measured $K_{eff} = 1.00$. In the next section "RECAP-4C Method of Analysis" the method used to approximate the fission source spatial distribution and to reduce the capture fractions to K_{eff} is described.

A similar critical experiment with a large amount of Th-232 present in the fuel with U-235 was analyzed also (Core 15D, taken from Reference 3). RECAP-4C gave K_{eff} to within 1% of that experimentally measured.

RECAP-4C CRITICAL EXPERIMENT GEOMETRY
(XY PLANE)

1/8 IN. BY 12 IN. URANIUM METAL RODS
94.3 w/o U-235
0.625 IN. CTC ROD SPACING
K_{eff} = 1.00 EXPERIMENTALLY MEASURED
WATER MODERATED
RADIAL, AXIAL WATER REFLECTED



ALL DIMENSIONS IN CENTIMETERS

FIGURE I

Figure 37

RECAP-4C Method of Analysis

Arrays of identical and regularly spaced fueled assemblies with low hydrogen content or a small diameter with high hydrogen content can be analyzed for criticality hazard potential satisfactorily when a two region, region wise flat fission source shape is assumed. For such systems the fraction of the fission neutrons which lead to fission again is not extremely sensitive to the spatial points where the fissions occur. This assumption of a flat fission source shape can be checked for validity in any system of this type by separating the assembly, for edit purpose, into the two roughly equal volume regions which are expected to differ the most in fission neutron importance. Two RECAP-4C problems are then run with a flat source in each of the arbitrary volumes only. The two problems can then be superpositioned giving one problem for the case of a flat input fission source shape throughout the fueled assembly. An estimate of the sensitivity of neutron multiplication to fission source shape assumption can be obtained by comparing the one generation K_{eff}, as determined from each of the partial source problems with the K_{eff} determined from the flat source results obtained from the superpositioned problem. It may be expected that this technique will result in a spread of ±10% in K_{eff}. Knowledge of this spread does not come from quantitative analyses, but rather is empirical in nature arising from the experience of the authors in examining many different systems.

Systems which are not homogeneous in the sense of fuel loading and hydrogen content and simple in geometry have a spatial variation of the converged fission source which cannot be readily obtained prior to commencing a RECAP-4C analysis. This detail can be obtained by the iteration technique of neutron diffusion or transport equations by modifying the input fission source shape of the N'th generation by the output fission source shape of the N-1'th generation. However, RECAP-4C is not equipped to iterate so that the execution of this method requires considerable hand preparation between iterations. The process is unwieldly, time consuming, and requires a large number of neutron histories. When a large number of cases are to be examined this process must be greatly simplified.

The approach taken in this analysis method gives results which fall in a range of accuracy between that obtained with a flat input fission source shape and an iterated source. While not proven for all classes, the results have been found in several cases to be close to those obtained with the iterative method. It may be stated unequivocally that this approach provides a better estimate of K_{eff} than obtained with a flat fission source shape.

The two partial source problems used in constructing the flat input source problem are used as a starting point. Each problem gives first generation fission neutron source rates in the region containing the input source and in the region where the input source is absent. The two problems, therefore, contain sufficient information to fix the average fission source magnitude in each region relative to the other in a manner which ensures that the input source equals the output source on a regionwise averaged basis.

The equations which relate these quantities are:

$$af_1^1 + (1-a)\, f_1^2 = 2\lambda$$

$$af_2^1 + (1-a)\, f_2^2 = (1-a)\, \lambda$$

where,

a = weight given to region 1

$(1-a)$ = weight given to region 2

f_1^1 = fission neutron source rate in region 1 when input source* is in region 1

f_1^2 = fission neutron source rate in region 1 when input source is in region 2

f_2^1 = fission neutron source rate in region 2 when input source is in region 1

f_2^2 = fission neutron source rate in region 2 when input source is in region 2

λ = system eigenvalue

The solution of these equations for a and λ when the fission source rates are known from RECAP-4C specify the relative source magnitude and eigenvalue. Only the fundamental mode roots denoted by a positive value of a and λ are of interest.

*Note - The RECAP-4C is one neutron per second in the entire source region.

Results for 56 Drums, 1.9 Kg. U-235/Pipe, When All Pipes Leak

Diffusion theory calculations performed by Bettis (Reported on page 50) to examine the general characteristics of 55 gallon drum centered, water reflected arrays of Schedule 40, 5" diameter pipes, which contain a homogenous H_2O U-235 mixture indicate that 200 drums each containing 1.9 kg. U-235 are substantially supercritical ($K_{eff} \sim 1.1$) under the partially moderated condition. Bettis has limited its shipments to 51 drums, each with a maximum of 1.9 kg. U-235 to ensure that this condition is subcritical. It is of interest to confirm that this restriction is required and is adequate to prevent criticality even if the C.T.C. spacing of the internally flooded pipes in the array is significantly reduced.

The array geometry which was examined is shown in Figure 33. Since the pipes contained hydrogen in the atom ratio H/U-235 $\sim$ 150, the effect of small amounts of water in the vermiculite was unknown but not expected to increase K_{eff} significantly. To resolve this, two RECAP-4C problems were run with the source in the inner volume only for 0% and 5% water. As shown in Table XII the reactivity change is obscured by the probable errors. Hence the water density was taken as 0%. Inner and outer source volume problems were combined giving a $K_{eff} = 0.908 \pm .0234$. The system is subcritical. These RECAP-4C results are in fair agreement with the diffusion theory results presented in Section 2 , page 50 .

TABLE XII

RECAP-4C RESULTS FOR 56 DRUM ARRAY

Problem Type	Prob. No.	Source Position	Vermiculite H_2O%	C.T.C. Spacing of Schedule 40 Pipes	K_{eff}	Number Histories	CP*(sec.)
PARTIAL SOURCE PROBLEMS							
56 Drums	1	Inner	0	Nominal	.959 ± .032	1000	924
	2	Inner	5	"	.983 ± .034	1000	960
	3	Outer	0	"	.863 ± .033	1000	969
	4	Outer	0	9" Closer	1.027 ± .033	1000	87[illegible]
COMBINED SOURCE PROBLEMS							
56 Drums	Comb. Prob. No. 1 & 3		0	Nominal	.908 ± .023	2000	

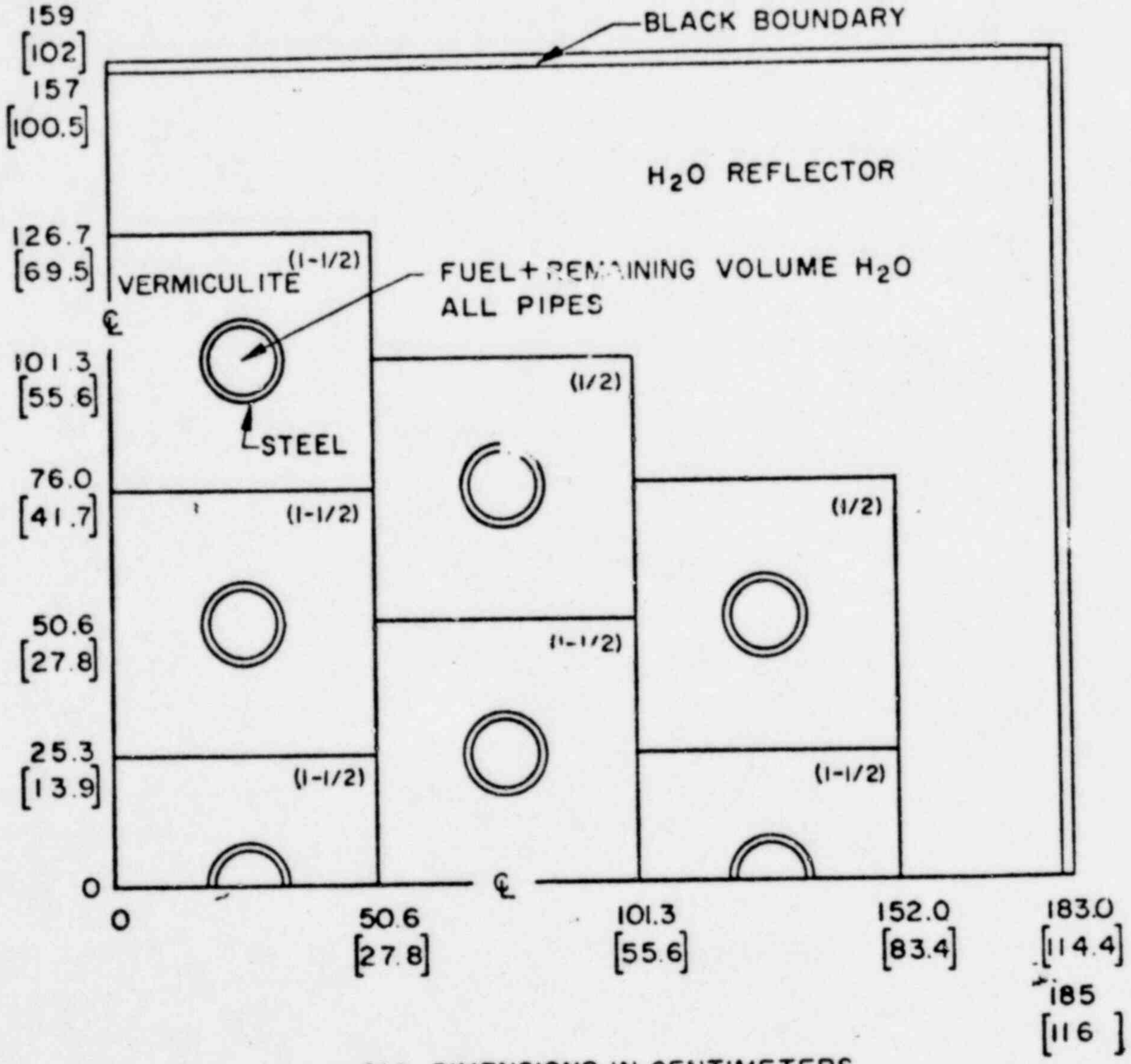
*Note - CP time is CDC-6600 central processing time required for the indicated number of histories.

The effect on reactivity of crushing the drums together was investigated by running an outer source problem with the pipes 9 inches closer. This, with the corresponding problem for nominal spacing, was used to construct a curve of K_{eff} vs spacing as shown in Figure 34. The probable errors are used in drawing the curve so as to maximize the effect. The slope of the curve is approximately .02 units K_{eff}/inch. Therefore, a crushing of 3 to 4 inches in diameter of all drums is needed before the array is critical. Crushing resulting in a reduction of 2 inches in diameter from a 30 foot drop test is of the magnitude that has been observed. Hence it is concluded the restrictions applied on container loading and number of containers per shipment are both necessary and sufficient.

1323 214

56 DRUM ARRAY
(BETTIS TYPE SHIPPING CONTAINERS)

1. TOP DRUMS IN ARRAY DIVIDED SO AS TO ALLOW INNER AND OUTER SOURCE TO BE 50% OF THE FUEL VOLUME.
2. [ ] - REDUCED SIZE DIMENSIONS
3. NUMBER IN ( ) SPECIFY HOW MANY DRUMS HIGH IN OCTANT
4. OUTER RADIUS = 7.30 CM } FOR ALL PIPES
   INNER RADIUS = 6.66 CM }



ALL DIMENSIONS IN CENTIMETERS

FIGURE 6

Figure 38

56 DRUM ARRAY
K_{eff} VS. CTC SPACING

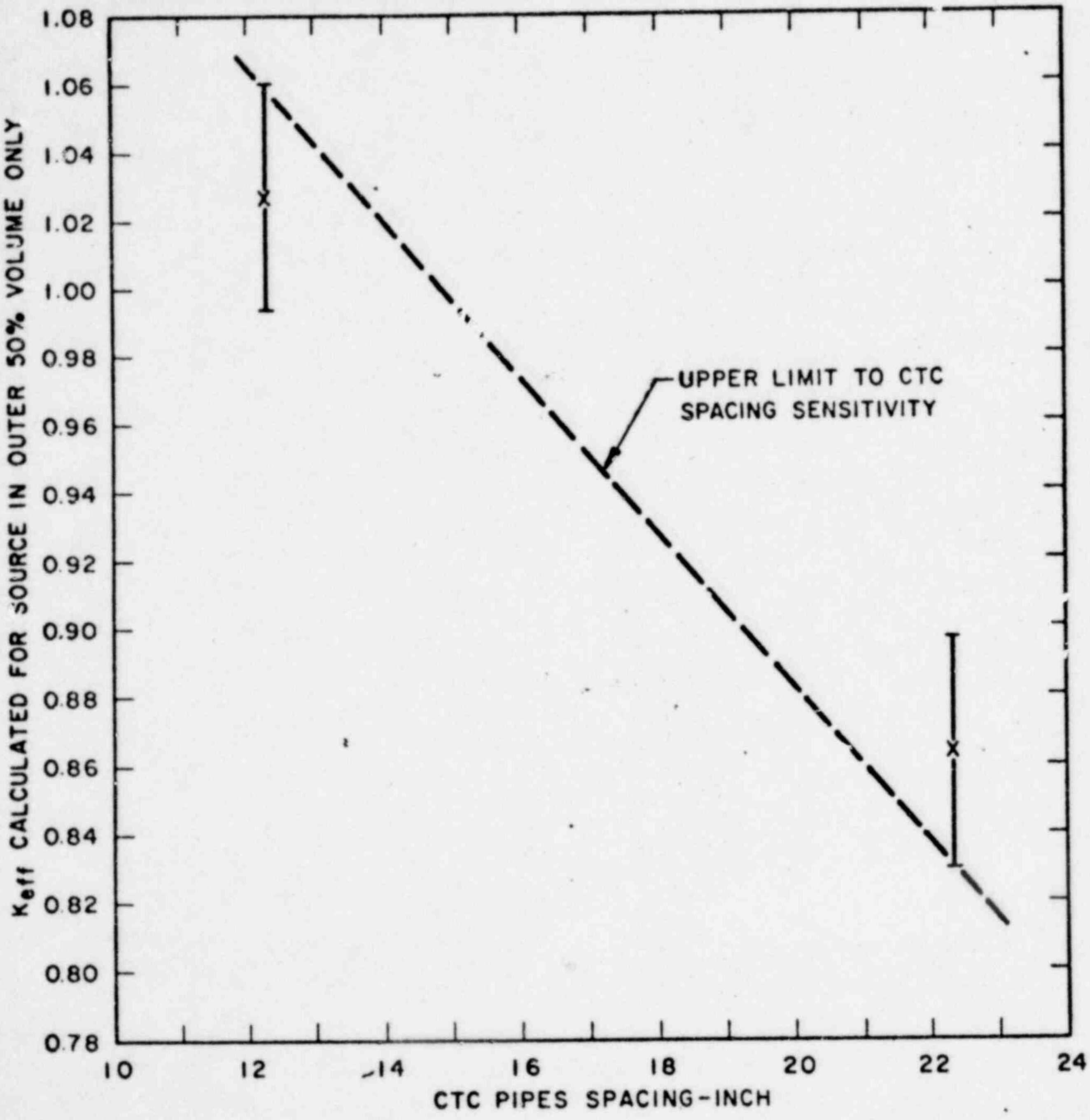


FIGURE 7

Figure 39

References

1. Candelore, N. R. and Gast, R. C.
   Revised Preliminary Report of RECAP-4C: A Monte Carlo Program for Estimating Neutron Capture Fractions in the 10 Mev to 0 ev Energy Range for Two dimensional Geometries, WAPD-D(PK)-83.

2. Hoogterp, J. G., "Critical Masses of Oralloy Lattices Immersed in Water", USAEC Report LA-2026, Los Alamos Scientific Laboratory, March 6, 1957

3. Snidlow, N. L. et al, "Thorium Uranium Physics Experiments Final Report", BAW-1191, May 1960

WAPD-RS(CC)-1269

Revision to the
BAPL 5910 Birdcage
Safety Analysis Report

April 1975

A. Introduction

This report is a revision to the Safety Analysis Report for the BAPL 5910 Birdcage as presented in References (a) and (b).

The birdcage design has been modified to improve the containment of the fuel after the 30 foot drop test specified as part of the Hypothetical Accident Conditions of AECM Appendix 0529. The modifications consist of strengthening the lateral supports and providing improved endclosures. The revised design is described in Section B. The inspection procedures were also revised to correspond to the new design and are included as Section C.

The modified birdcage was subjected to thirty foot drop tests to ensure that the new design would not result in loss of containment and to verify the damage assumptions used in the nuclear safety analysis. The drop tests and the results are described in Section D.

The original nuclear safety analysis was based on a comparison to diffusion theory calculations for arrays of 55 gallon specification 6L drums. The analysis was repeated for the birdcage geometry using the Bettis RCP01 Monte Carlo Neutron Transport Program. It was shown that the limits established on the basis of the original analysis met all applicable requirements of AECM Appendix 0529. It was also shown that by reducing the shipment limit from 51 to 36 birdcages, the permitted contents could be increased and the corresponding restrictions simplified. Since the reduced shipment limit is not expected to be a limiting item, the new package limit (1900 grams ^{235}U per package) was incorporated into the Certificate of Compliance for the birdcage. The revised nuclear safety analysis has been included as Section E.

Reference:

(a) **WAPD-(AO)-4191, dated 2/27/68**
Section V.B., Revision 3, "Westinghouse Bettis Atomic Power Laboratory Radioactive and Fissionable Material Shipping Containers"

(b) WAPD-RS(SA)-165, dated 4/28/72
"Technical Summary Documents for Bettis Nuclear Materials Management Off-Site Shipping Containers"

Section B - PACKAGING DESCRIPTION

General

The BAPL 5910 birdcage shipping containers are fabricated at Bettis as needed. The birdcages are assigned container identities as follows: AB001, AB002, AB003, etc.

Figure B-1 shows an 8 foot birdcage ready for loading; Figure B-2 shows a loaded 12 foot birdcage ready for shipment.

Description

The external frame of the birdcage is 2 feet square and from 5 to 12 feet long. The frame consists of 4 pieces of slotted steel angle along the length of the birdcage and supported by vertical "squares", also constructed of slotted steel angle. The number of squares, including end supports, used is dependent on the overall length of the cage. That is, 5 to 8 foot cages require 3 squares, cages over 8 feet but less than 10 feet require 4 squares, and cages 10 to 12 feet long require 5 squares; the inner squares equally spaced along the length of the cage. A total of four two foot long angular braces are used to provide added rigidity to the external frame and are positioned at the ends. Suspended within the external frame of the birdcage is an inner cage. The inner cage is supported, above and below, with sections of steel angle fastened to the 2 foot square supports. The inner cage is centered and provides the needed support for the steel or aluminum inner container. The external and internal frames of the birdcage are made from 3 1/8" x 1 5/8" x 0.104" slotted steel angle held together with 3/8" bolts tightened to approximately 25 foot pounds. The inner frames must have two angles back to back above and below the angles enclosing the inner container (see Figure B-3). The outer frames require only two angles as shown in Figure B-5. All joints, except those for the four braces, must be made with two bolts. The joints for the braces may be made with one or two bolts depending on the alignment of holes in the steel angles. The inner container is supported and enclosed by additional steel angle bolted to the frames. Both the box and the angles enclosing it are banded with 3/4" steel banding (see Figure B-2). The configuration shown is for steel boxes. Aluminum boxes must be completely enclosed with steel or steel angle, including the spaces between angles. Small pieces of angle iron placed against each end of the box are backed up with two additional pieces of angle iron (at each end) positioned at right angles to them for additional strength (see Figure B-4). After the cage is loaded and bolted together four additional 3/8" bolts are put through the long pieces, forming the inner enclosure for the transport box to give it additional strength (see Figure B-5).

Fabrication Instructions

Methods of Fabrication

(a) Use unrusted slotted steel angle.

(b) Cut slotted angle to required lengths.

(c) Construct the required number of square (two vertical and two horizontal 24" pieces form a square).

1. For birdcages up to 8 feet in length, a minimum of three squares is needed.

2. For birdcages measuring 8 feet to 10 feet in length, a minimum of four squares is needed.

3. For birdcages measuring 10 feet to 12 feet in length, a minimum of five squares is needed.

(d) At each joint, use two bolts to secure square.

(e) Provide four pieces of angle for the longitudinal structural members of the cages. These pieces are bolted to the squares at each corner. The length of the longitudinal braces is dependent on the length of the birdcage being built.

(f) Angular braces, which are two foot long pieces of angle steel, are positioned at approximately 45° angles at the end and may be bolted with one or two bolts at each joint depending on the alisnment of the bolt holes.

(g) Bolt horizontal slotted angle cross members to each square. Position these cross members so they will support the primary container in the center ($\pm \frac{1}{2}$") of the square. The frame which encloses the primary container will be bolted to these cross members.

(h) Provide two slotted angle sections centered along the length of the cage and bolted to the cross members described in (g) above. Sections should provide a snug fit for the primary container being used.

(i) Bolt two pieces of slotted angle, each the width of the primary container at each end of the two centered longitudinal pieces described in (h) above butted against the end of the primary container.

(j) The small pieces of angle iron which are against each end of the box are backed up with two additional pieces of angle iron positioned at right angles to them for additional strength (see Figure B-4).

(k) Two more similar sections (as in item (g) above) are to be bolted over the top of the primary container.

(l) Bolt two horizontal slotted angle cross members to the frame above and below the primary container at each vertical support structure unit location.

(m) Tighten all bolts to approximately 25 foot pounds.

(n) Secure steel strapping around the slotted angles enclosing the inner container. Straps are equally spaced between vertical supports.

(o) Four additional 3/8" bolts are put through the long pieces of angle iron forming the enclosure for the primary box to give it additional strength. The bolts are to be secured as close as possible to the ends of the box (see Figure B-5).

Material Required

The following material will be used:

(a) Angle, Steel, Slotted. Steel City No. RA 300 - 12 or equivalent. Storeroom number D0198003BD - 3 1/8 x 1 5/8 x 0.104 inch.

(b) Electro-galvanized Hex Head bolts with serrated nuts (3/8 - 16 NC x 3/4" long) for RA - 300 Slotted angle or equivalent.

(c) Steel strapping, flat, zinc-coated 3/4 inch width x 0.023 inch thick 17.1 feet/pound or equivalent. Storeroom number P7702003CL.

(d) 14 gage steel or aluminum box with a hinged and gasketed lid. Cross section of the box must be 20 square inches or less.

(e) A metallic tag must be bolted to the birdcage frame. This tag, in half inch lettering, will read as follows: USA/5910/BF (ERDA-NR); Fissile Radioactive Material; Westinghouse - Bettis Lab - West Mifflin, Pa., and the birdcage identification number.

Figure B-1

8' Birdcage Prepared for Loading

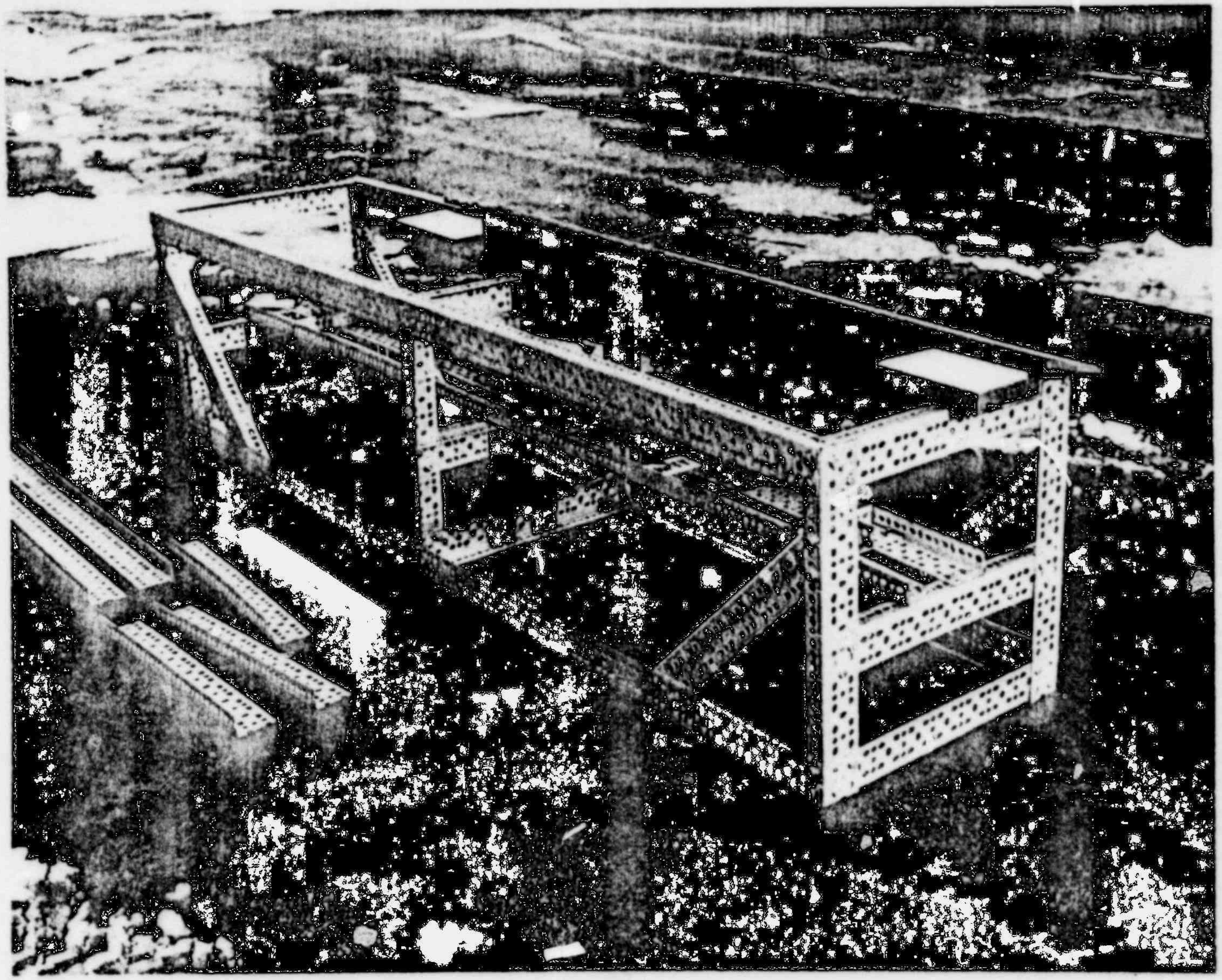
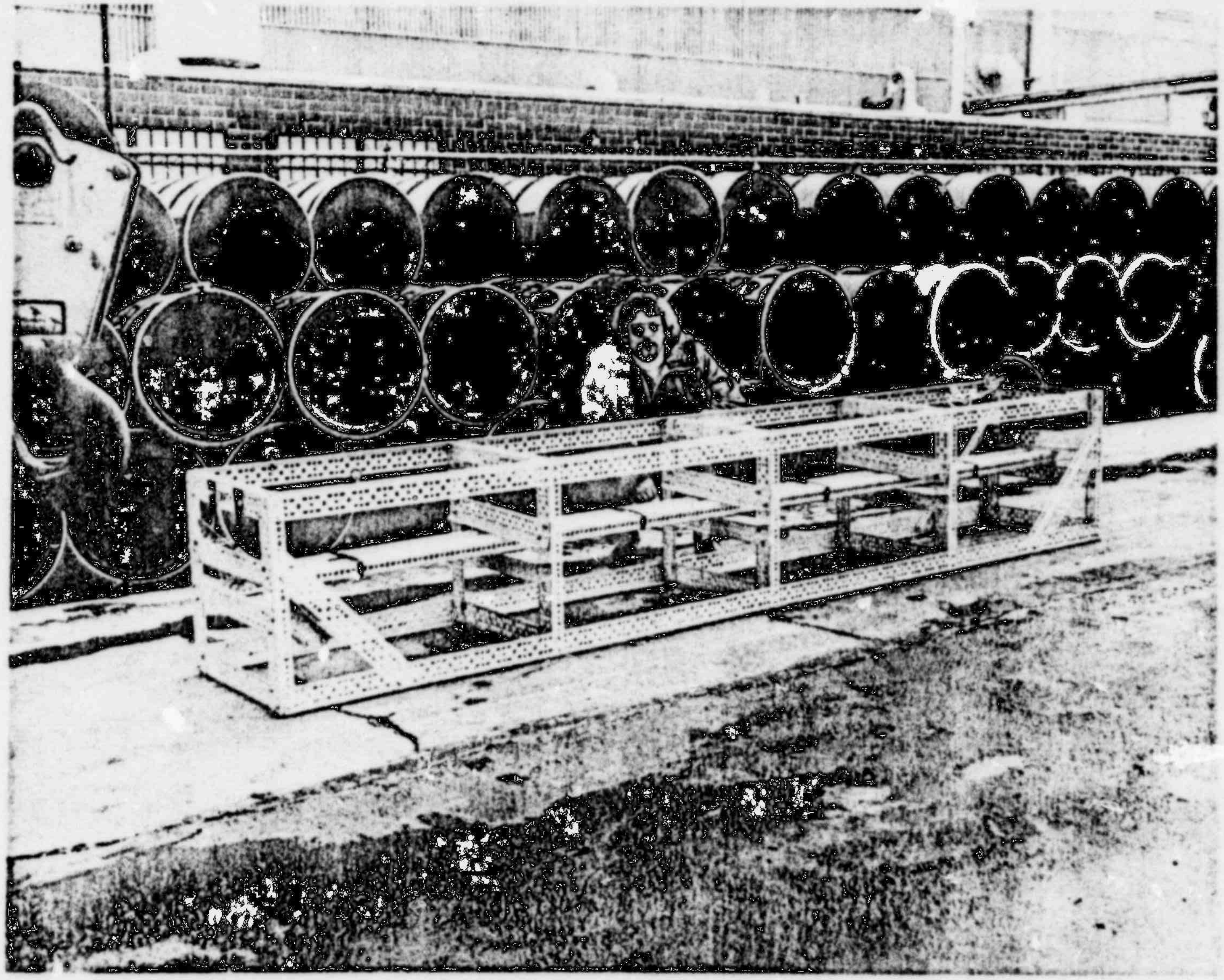
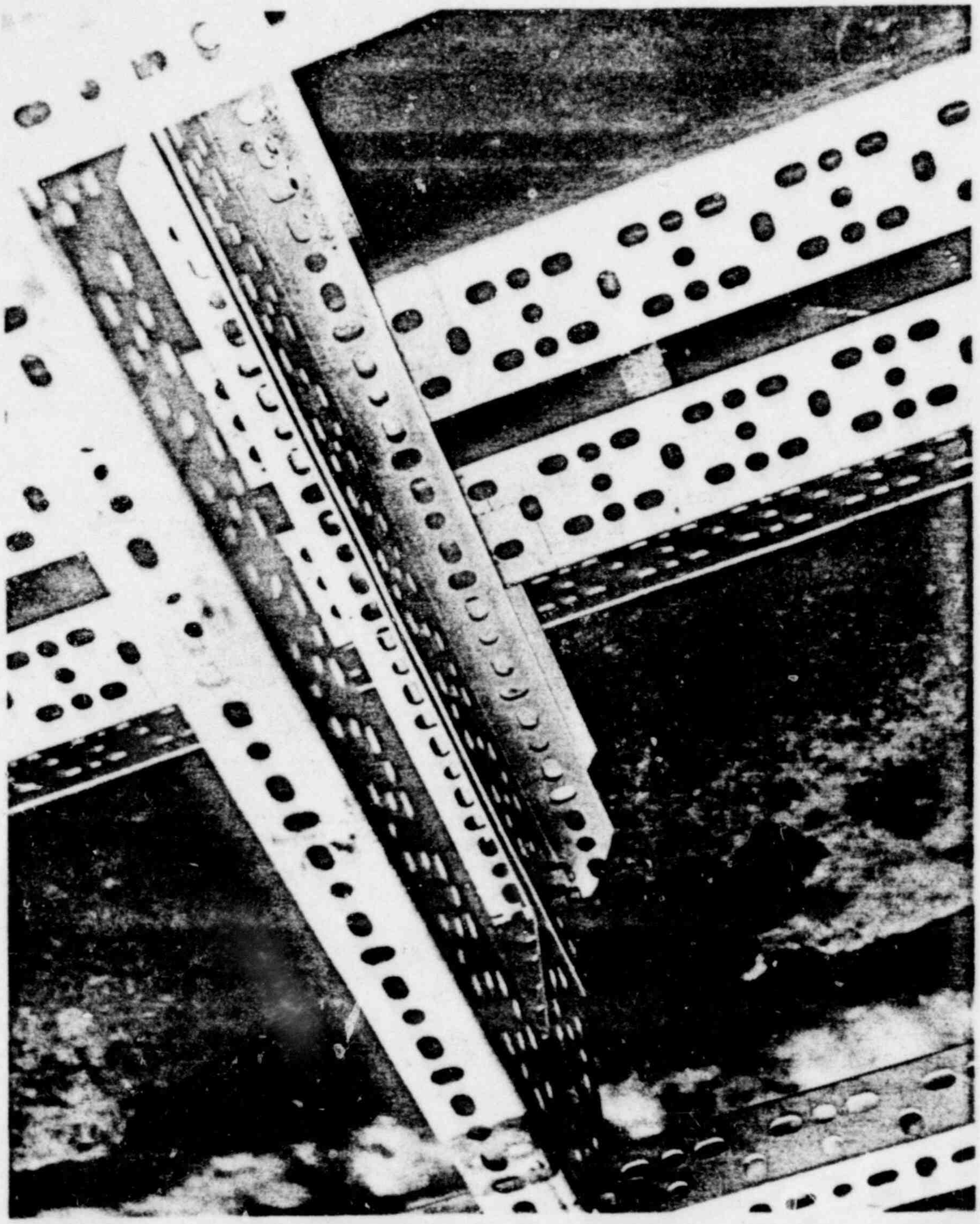


Figure B-2

12' Birdcage Assembled



POOR ORIGINAL



Detail of Inner Container Supports

Figure B-3

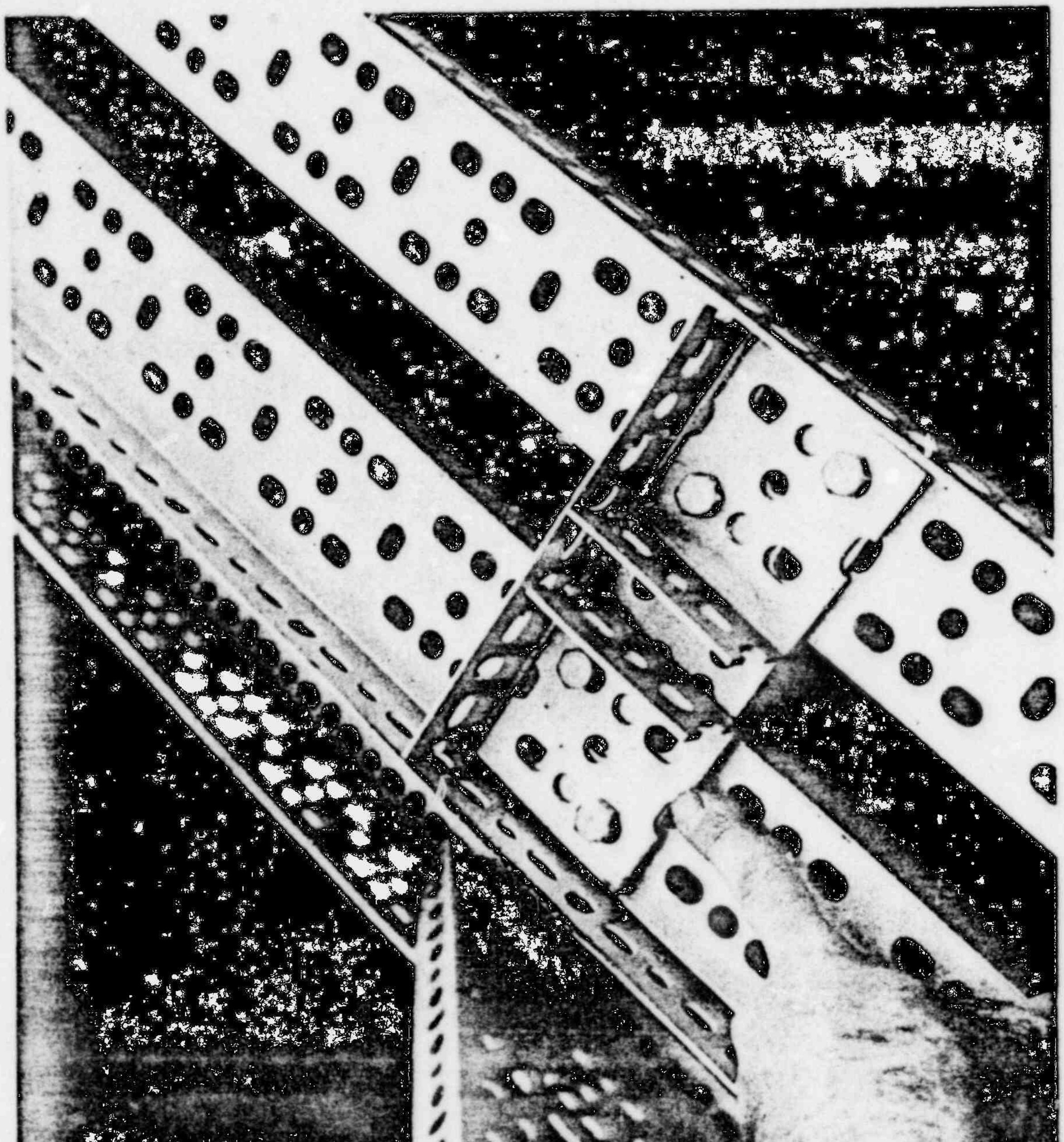
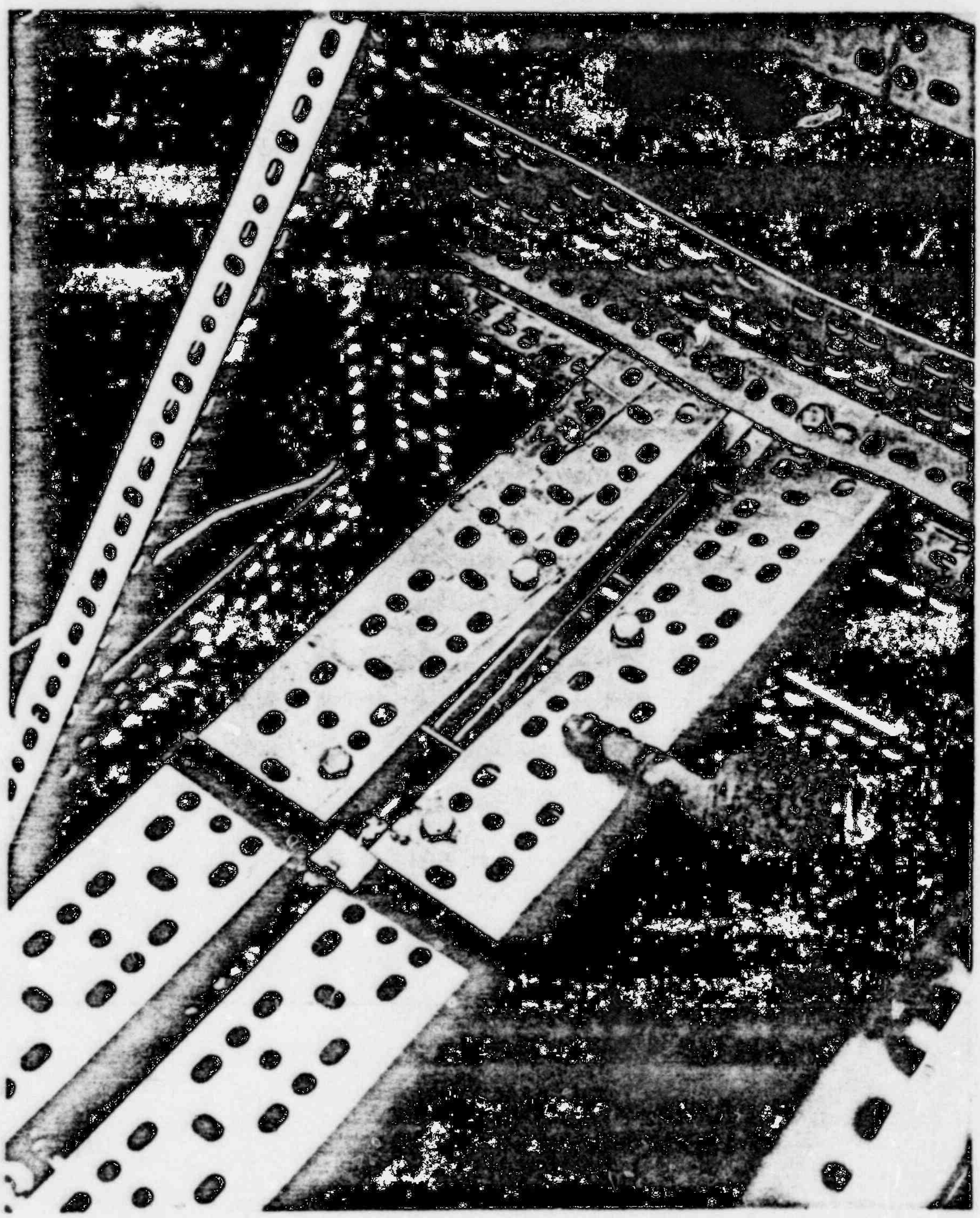


Figure B-4

Detail of Inner Container End Restraints

Figure B-5

Bolts Required Following Assembly



Section C - INSPECTION PROCEDURES

1. General

Since the birdcages are fabricated by the shipper as required for use, the new container and pre-shipment inspections required by AECM 0529 are the same. The purpose of the inspection is to ensure that the loaded container meets all applicable requirements.

2. Inspection Procedure

a. Contents

(1) The contents must be ^{235}U oxide or alloy fuel elements and/or assemblies.

(2) ^{235}U content shall not exceed 1,900 grams.

(3) Melting points of contents shall not be less than 1700°F. (Steel or zircalloy elements meet this requirement without further certification.)

(4) Significant quantities of heavy water, carbon or beryllium are not permitted.

(5) The weight of the contents shall not exceed 9 pounds per foot of the inner container.

b. Inner Container

(1) Container is 14 gauge steel or aluminum.

Nominal thickness - 0.0747 inches
Minimum thickness - 0.0677 inches

(2) Gasket is present and in good condition.

(3) Hinges are in good condition.

(4) No other apparent defects in container (give details if defects are present).

(5) Box is banded shut with 3/4" steel banding.

c. Birdcage Construction (Prior to Loading)

(1) Birdcage is constructed of 3 1/8" x 1 5/8" x .104" steel angle in good condition--no significant rust and no bent or damaged pieces.

(2) Width and height are 24" ± 1/2".

(3) Length is not less than 5' and not more than 12'.

(4) The square must be straight (not deviating more than 1" along its length using a straight edge as a guide).

(5) Correct number of squares:

3 for 5 to 8'
4 for > 8'
5 for > 10'

(6) Four braces present

(7) Bolts - 2 at each joint except braces, which may have 1 or 2.

(8) Support for inner container centered (with 1/2" of vertical and horizontal centerline).

(9) End restraints present and not closer than 6" to end of box.

d. Loaded Birdcage

(1) Inner container centered - with ± 1/2" of centerline and not closer than 6" to end of birdcage.

(2) Inner container fits snugly into steel angle enclosure.

(3) Steel angle cover and additional lateral supports added and bolted in place.

(4) If inner container is aluminum, it must be completely surrounded by steel and/or steel angle.

(5) Steel banding placed around steel angle.

(6) Four bolts in place at each end of inner container.

(7) All bolts tightened to approximately 25 foot-pounds.

(8) Identification Tag

- (a) fastened to square with bolts
- (b) legible with correct wording
- (c) includes container identification number

3. Record of Inspections

Inspection Records for each birdcage in use must be maintained on file during the useful life of the container.

BAPL 5910 Birdcage Inspection Record
Certificate of Compliance USA/5910/BF (ERDA-NR)

I. Shipment Number ____________

Birdcage Identification Number ____________

Seal Number ____________

Date of Inspection ____________

	Acceptable	Acceptable After Repair	Not Acceptable
II. Before Loading			
A. Birdcage integrity			
1. No excessive rust	☐	☐	☐
2. No structural member bent greater than 1"	☐	☐	☐
3. Correct number of squares (3 for 6' to 8', 4 for > 8', 5 for > 10' birdcage)	☐	☐	☐
4. Corner braces intact	☐	☐	☐
5. Cage 24" h ± $\frac{1}{2}$" x 24" w ± $\frac{1}{2}$"	☐	☐	☐
6. ID tag in place	☐	☐	☐
B. Inner Container Integrity			
1. Box cross section 20 square inches or less	☐	☐	☐
2. Box gasket intact	☐	☐	☐
3. Box lid hinged	☐	☐	☐
III. After Loading			
A. Inner Container			
1. Box banded closed	☐	☐	☐
2. Centered ± $\frac{1}{2}$"	☐	☐	☐
3. 6" or more from end of cage	☐	☐	☐
4. Closure around box snug	☐	☐	☐
5. Aluminum box completely encased in steel (N/A for steel box)	☐	☐	☐
B. Outer Container			
1. All bolts intact	☐	☐	☐
2. All bolts tightened to 25 ft-lbs or greater	☐	☐	☐
3. Closure around outer container bended between each square	☐	☐	☐
4. 4 bolts in place at each end of inner container	☐	☐	☐
5. Security seal(s) intact	☐	☐	☐
IV. Birdcage acceptable for shipment	☐	☐	☐

V. Signature of person completing the inspection

______________________ NAME

______________ DATE

Section D - DESCRIPTION OF THE THIRTY FOOT DROP TESTS

The drop tests were conducted on a four inch thick concrete pad located at the Bettis Hot Waste Area. A total of seven drops were made, using representative 8' and 12' birdcages. The first three were bottom drops and showed that there was no loss of containment and less than a 2" reduction in spacing provided that the required steel banding around the inner container was used. The remaining drops were end drops and showed that the end restraints previously used were not sufficient to prevent loss of containment. However, the tests were repeated with the modified end restraints described in Section B and were successful.

Drop #1

This was a bottom drop of a 12' birdcage with a 90 pound load in a 10 foot long box. The birdcage is shown in Figure D-1 prior to the drop. Figure D-2 shows the method of suspending the birdcage for the drop. A quick-release mechanism was used to release the cage and is shown attached to the crane hook. A 30 foot long rope attached to the bottom of the cage was used to insure that the 30 foot height requirement was met. This and the next 2 drops were performed on December 11, 1974.

The cage dropped was horizontal during the drop as shown in Figure D-3 and landed flat on the concrete. The damaged birdcage is shown in Figure D-4. The frame remained essentially intact. The inner container was displaced downward by approximately 1 1/4" at each of the three center supports as shown in Figure D-5. There was also some separation of the angles enclosing the inner container (Figure D-6). To reduce this, steel banding will be required between every pair of adjacent supports; for this test banding had been used between the center 3 supports only.

Drop #2

The second drop used an 8' birdcage with 54 pounds in a 6' box. This should be the most severe test for the horizontal drop since 1) all the weight is supported on one center support and 2) the 8' birdcage has the longest span between supports, allowing the most bending to occur. Figure D-7 shows the damage resulting from the 30' drop. The maximum deflection occurred at the center and was less than 2".

Drop #3

To determine the effect of omitting the steel banding, a second 8' birdcage, identical to that used in Drop #2 but without the two steel bands, was dropped. Less damage occurred at the center, but there was significant distortion of the angles enclosing the inner container. The results are shown in Figure D-8. This confirms the need for the steel banding.

It was concluded from the 3 horizontal drops that with steel banding the package will survive the side drop test with less than a 2" decrease in spacing and with no loss of containment. The horizontal drops were followed on the same day by two end drops designed to test containment.

Drop #4

This was an end drop of the 12' birdcage used in Drop #1. Figure D-9 shows the birdcage at the moment of impact. The box flattened the end closure (a short piece of angle at a right angle to the length of the box) and continued to the end of the birdcage, hitting the concrete. The distortion of the box enclosure is shown in Figure D-10. This was considered a failure of the package containment.

Drop #5

To be sure that the failure noted after Drop #4 was not a result of the damaged sustained during Drop #1, the drop was repeated with an undamaged 12' birdcage. The results were approximately the same as in Drop #4, with the box impacting directly on the concrete. A closeup of the damaged end of the birdcage is shown in Figure D-11. The fractured end of the aluminum box may be seen between the two center angles. Following this drop with the hypothetical fire would melt the aluminum, probably releasing the contents. However, even if a steel box were used, it is possible that, with a slightly different orientation, the box could be damaged to an extent to permit the contents to slide out of the birdcage.

Following these tests, the end closure was redesigned to better contain the inner box. The modified design was tested on December 20, 1974. Since the changes would not affect the results of the bottom drops, these were not repeated. The modification consisted basically of adding additional sections of steel angle at the ends of the box to restrict box movement.

Drop #6

This drop test was conducted with a 12' birdcage similar to those in the first series of tests with the exception of the end closures, which are shown in Figure B-4. The end drop of this birdcage again failed due to separation of the angles surrounding the inner container (Figure D-12).

Drop #7

Following the failure of Drop #6, the end closure was further reinforced by the addition of four 3/8" bolts passing through both the upper and lower angles as shown in Figure D-13. Two were at the end of the box and two through the reinforcing angles. These bolts served two purposes—to resist in shear the motion of the box and to resist in tension the tendency of the upper and lower angles to spread apart, allowing the box to pass over the reinforcing angles. As shown in Figure D-14, the drop test resulted in the failure of the bolts nearest the box, but the other two held and the box containment remained intact.

On the basis of Drop #7, it was concluded that with the noted modification to the end closure (which has been included in the package description in Section B) the birdcage will survive the end drops with no loss of contents.

Figure D-1

Drop #1: 12' Birdcage Prior to Drop

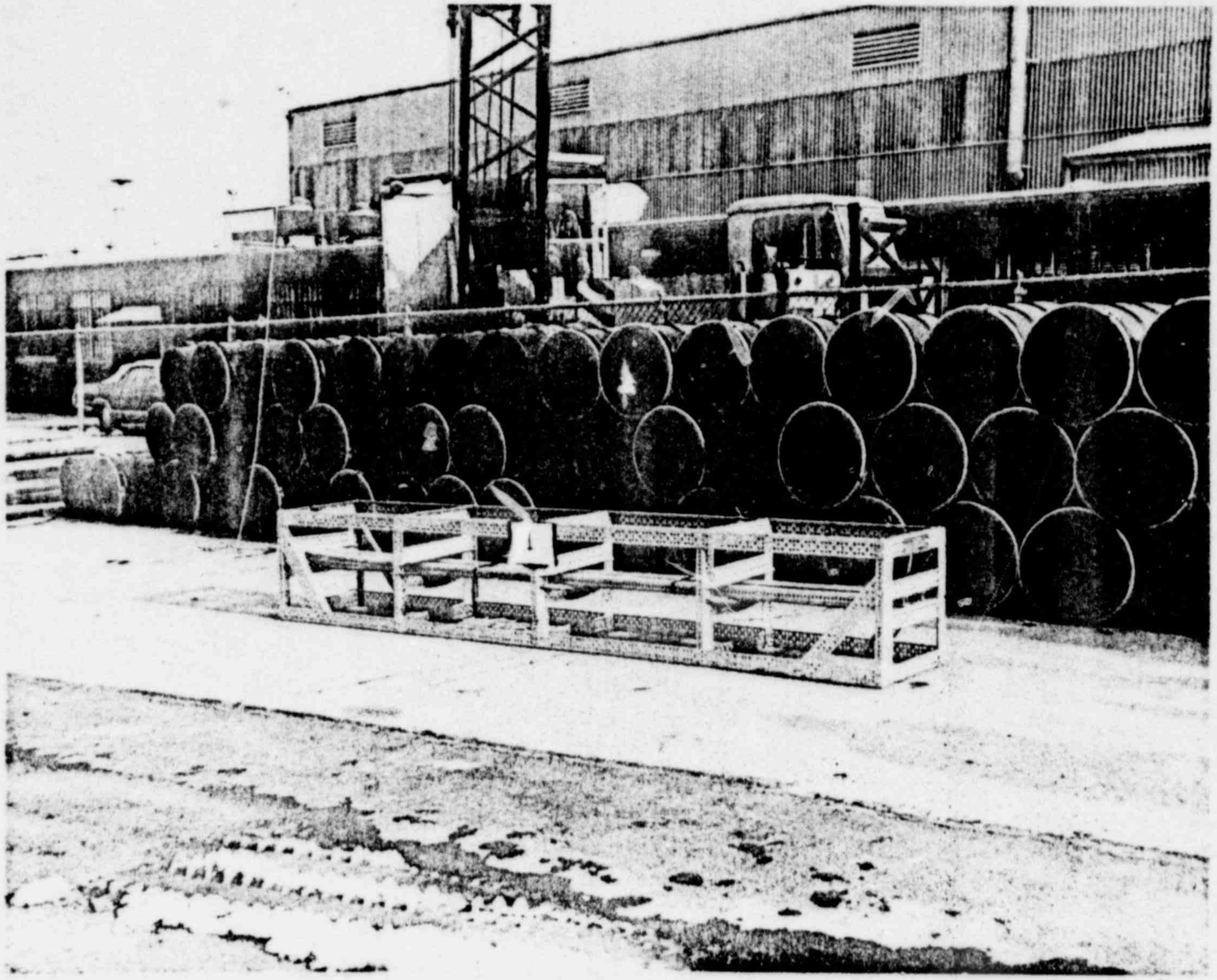


Figure D-2

Drop #1: Suspension of Birdcage from Crane

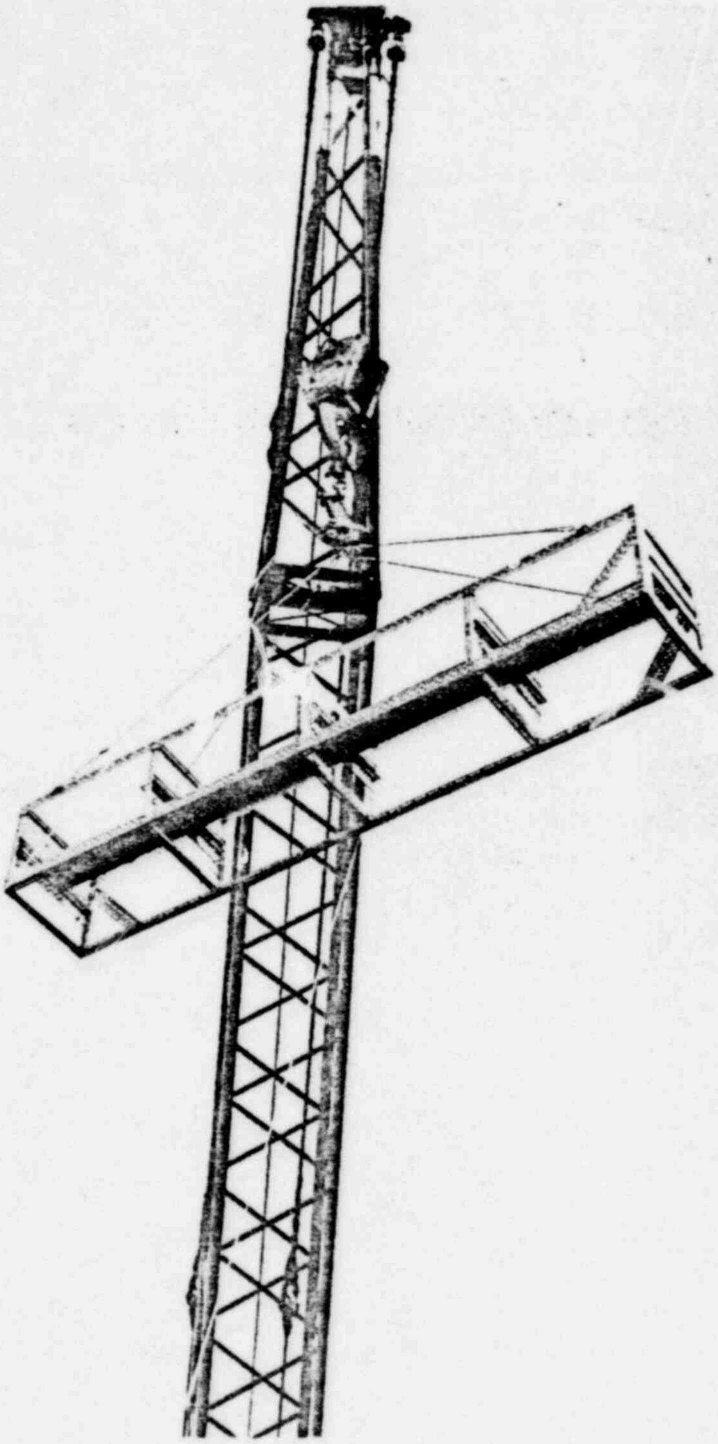


Figure D-3

Drop #1: Drop of Birdcage Showing Impact

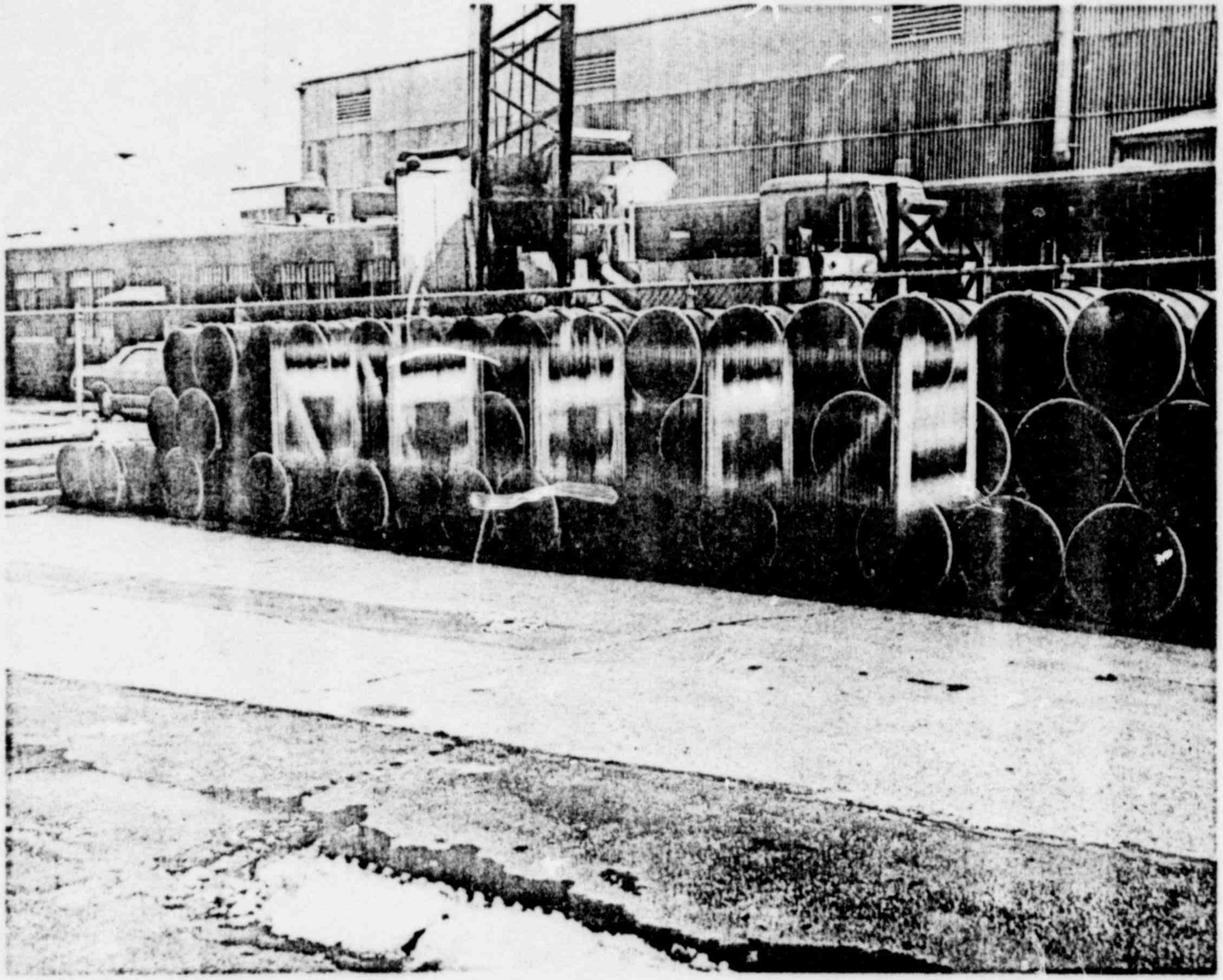


Figure D-5

Drop #1: Displacement of Inner Container

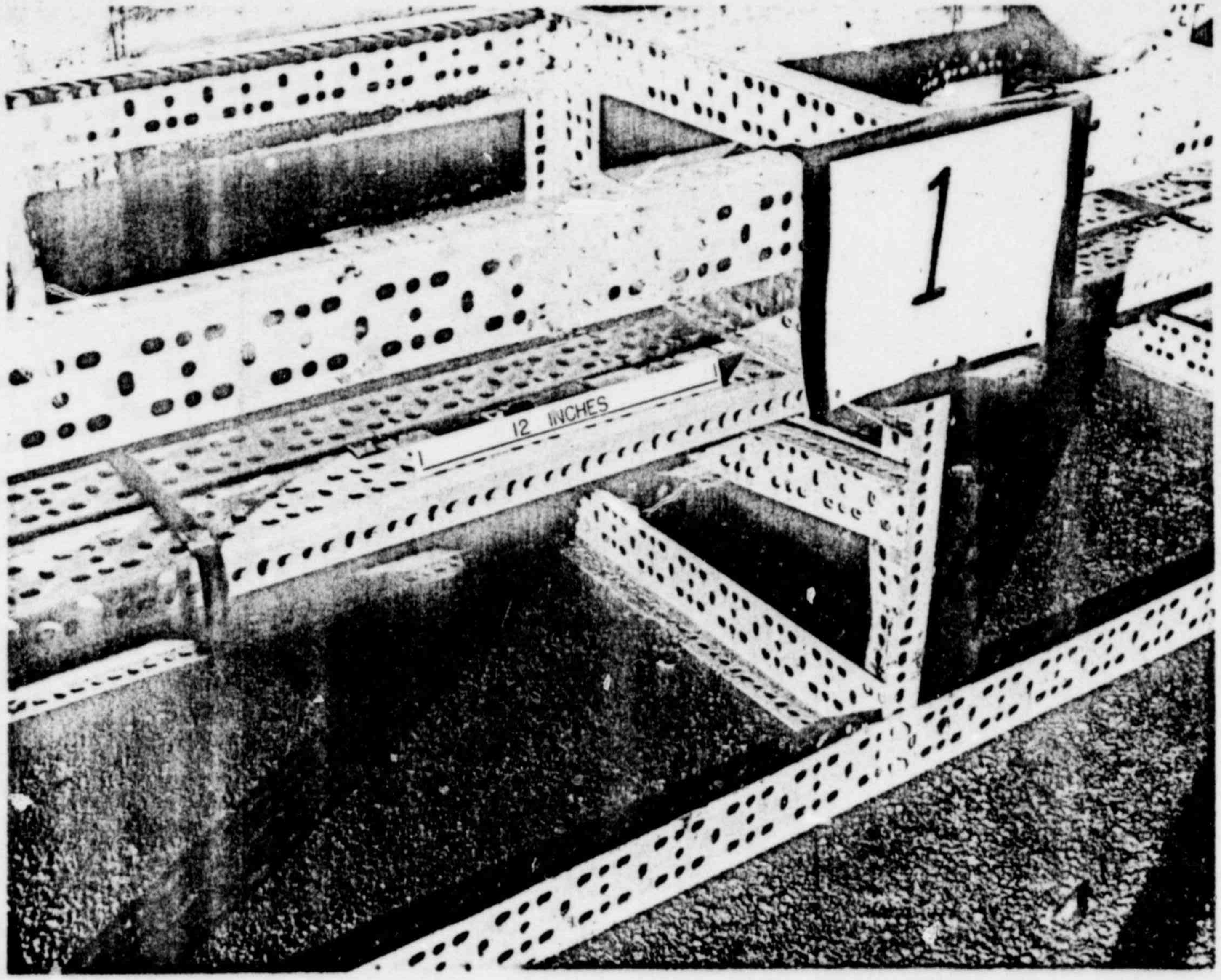


Figure D-6

Drop #1: Separation of Angles Around Inner Container

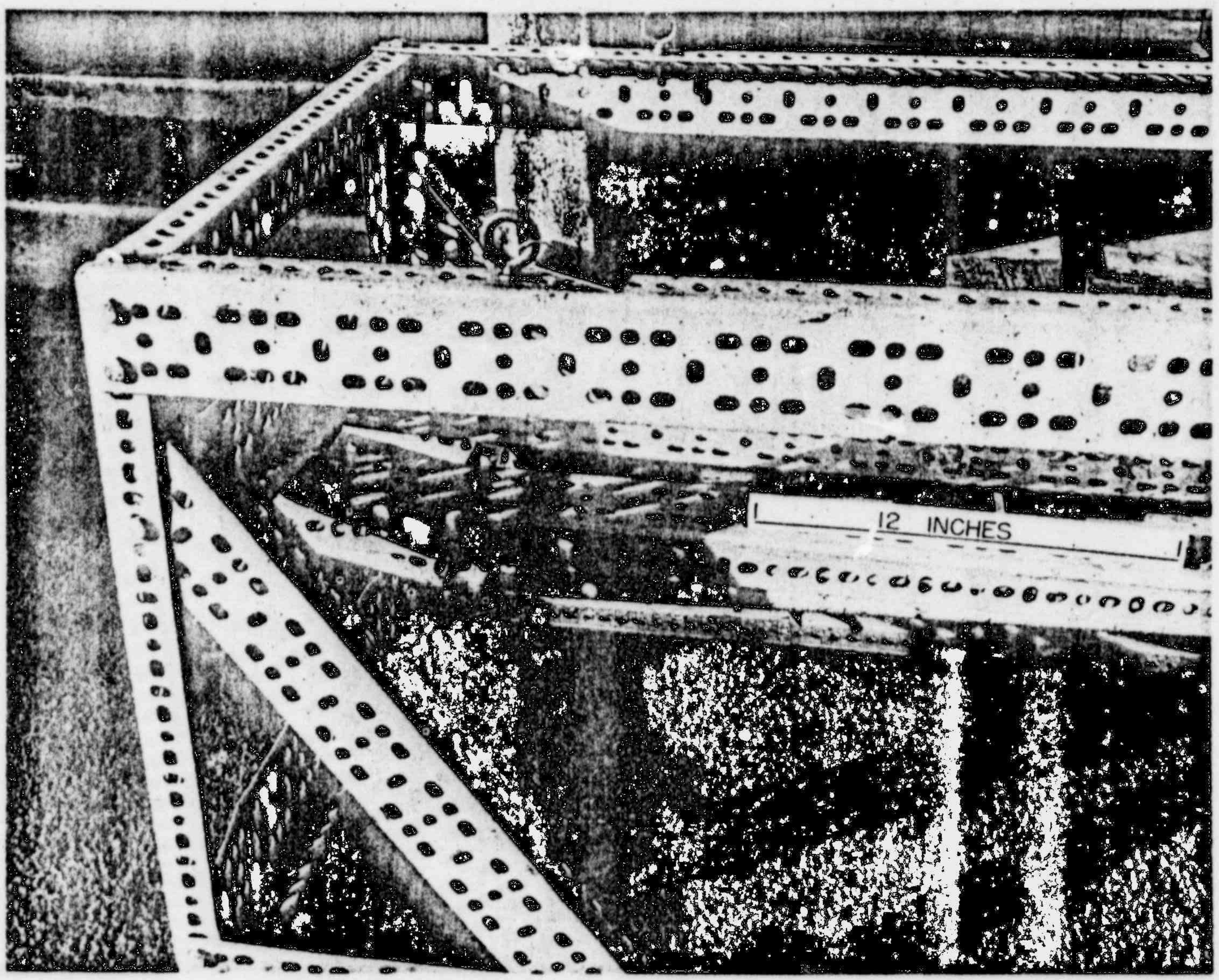


Figure D-7

Drop #2: Damage to 8' Birdcage After 30' Bottom Drop

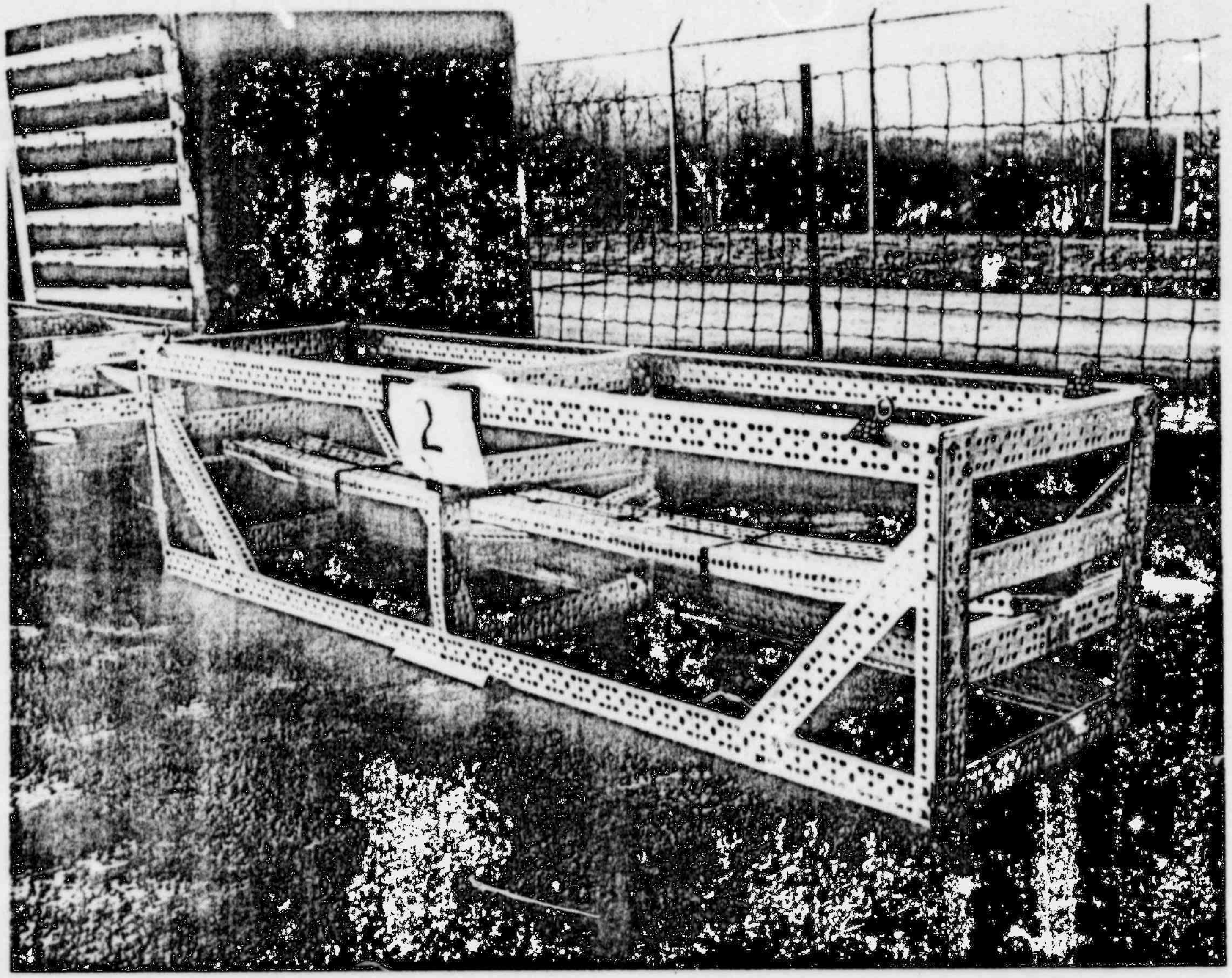


Figure D-8

Drop #3: Effect of Omitting Steel Banding

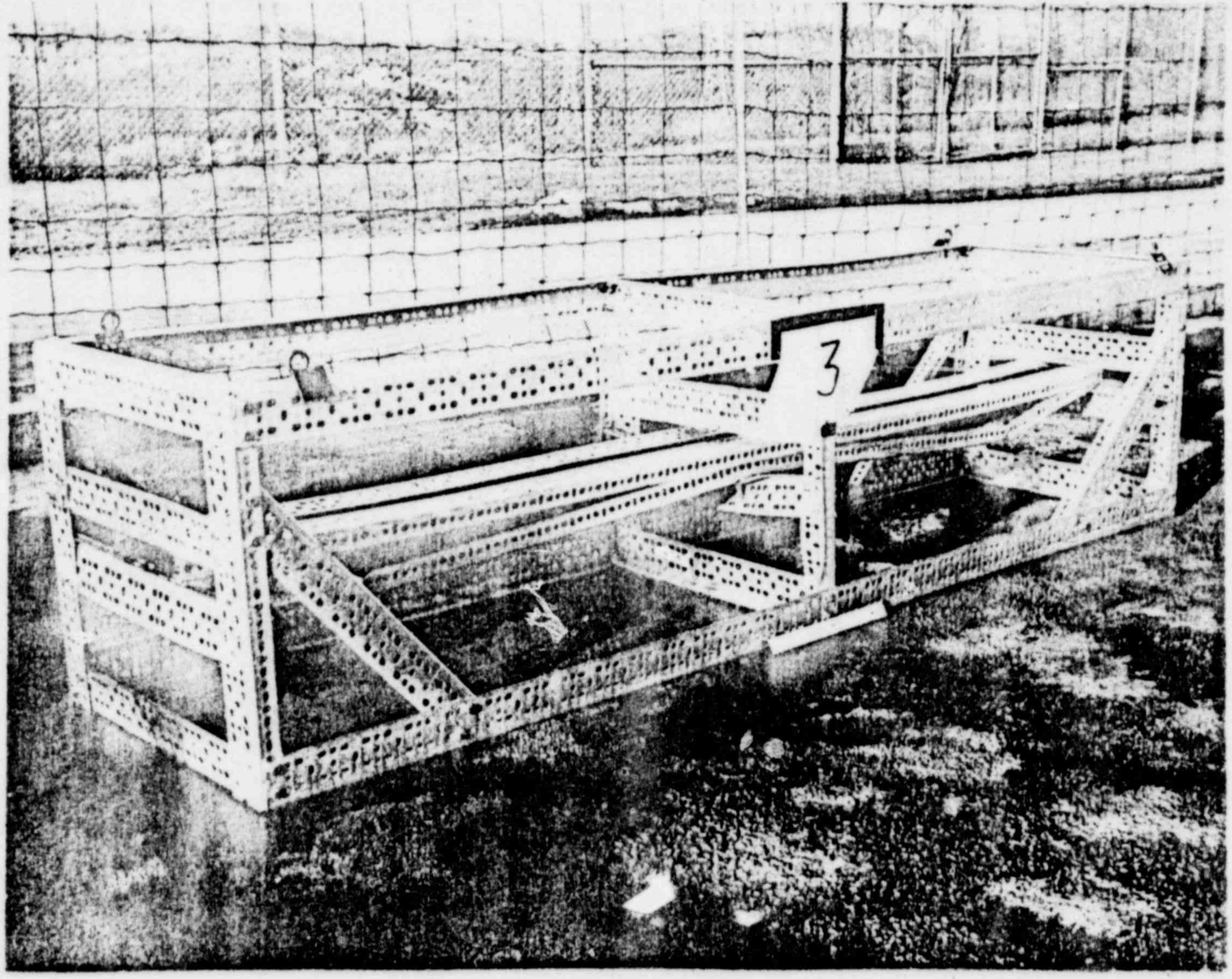


Figure D-9

Drop #4: Angle of Impact for End Drop

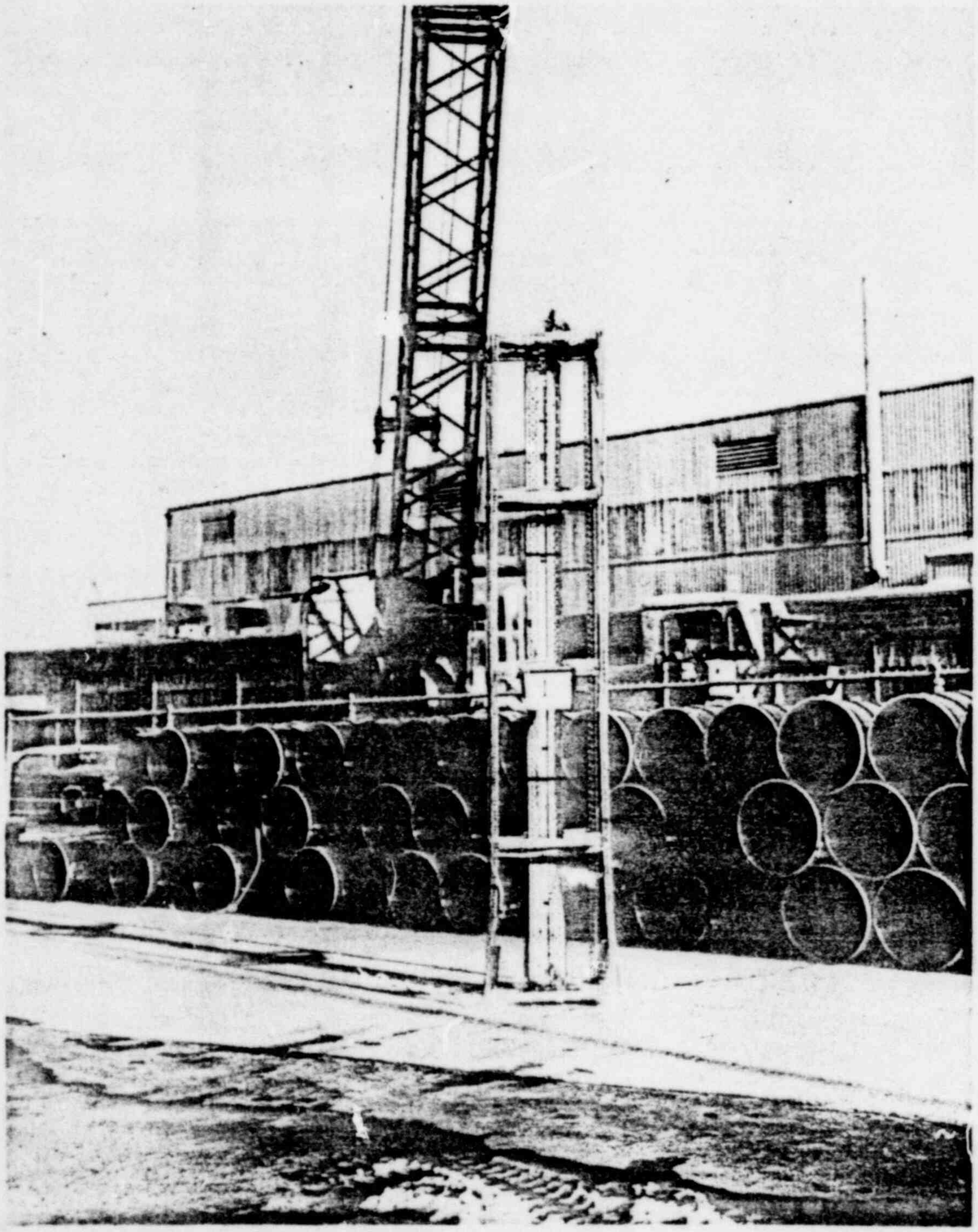


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Figure D-10

Drop #4: Resulting Damage to End Closure

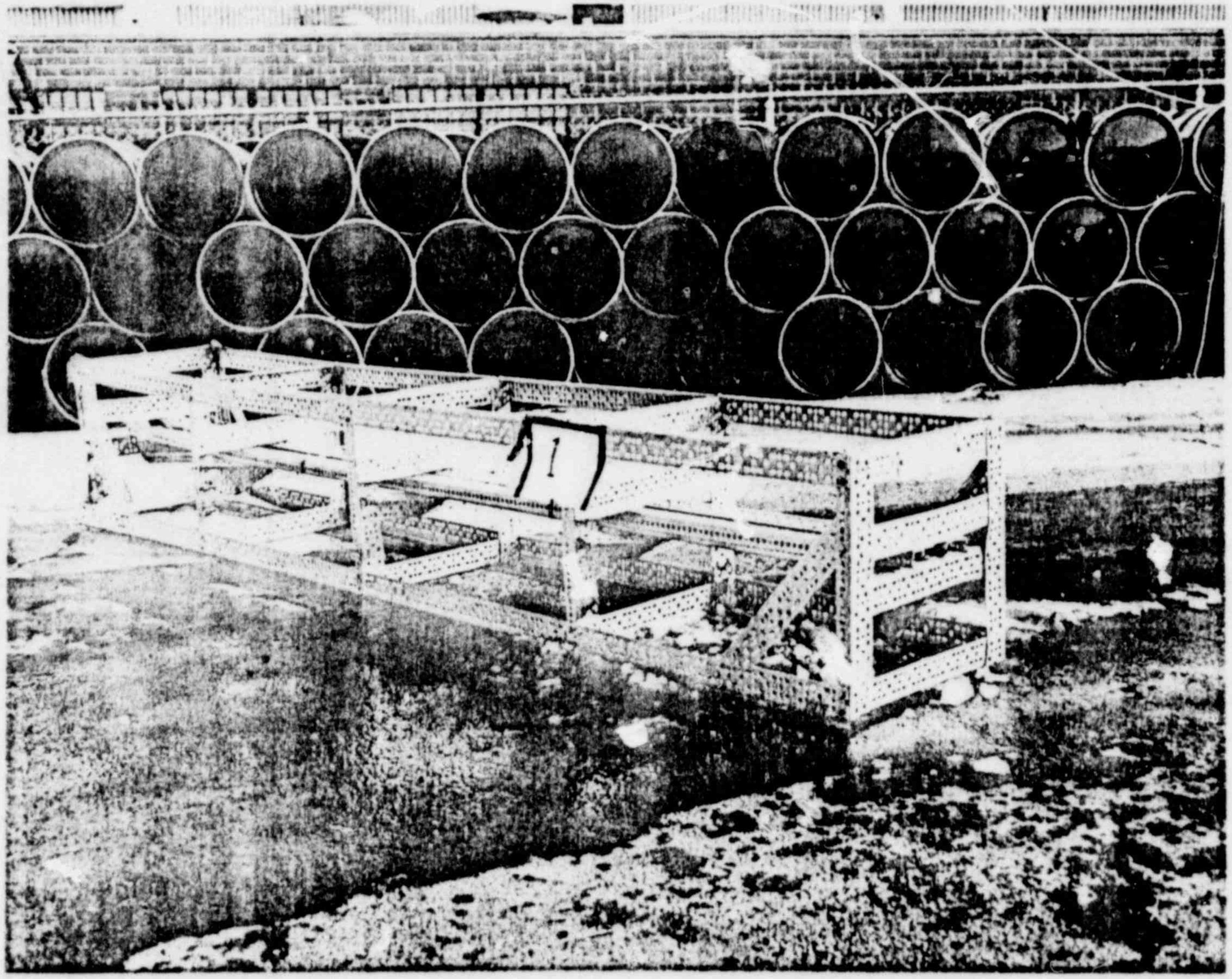

Figure D-11

Drop #5: Damage to End of Inner Container

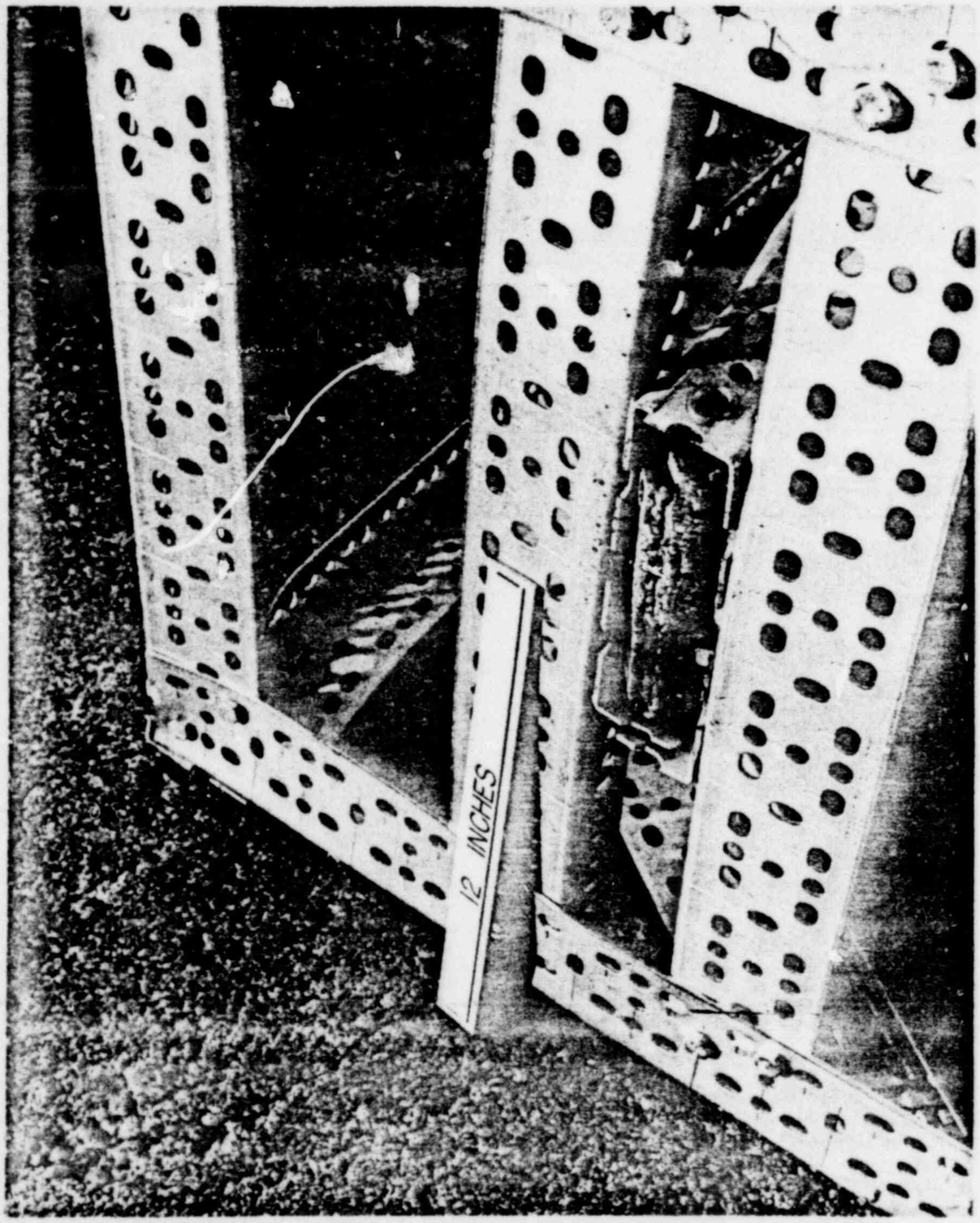

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Figure D-12

Drop #6: Damage to End Containment Following Thirty Foot End Drop

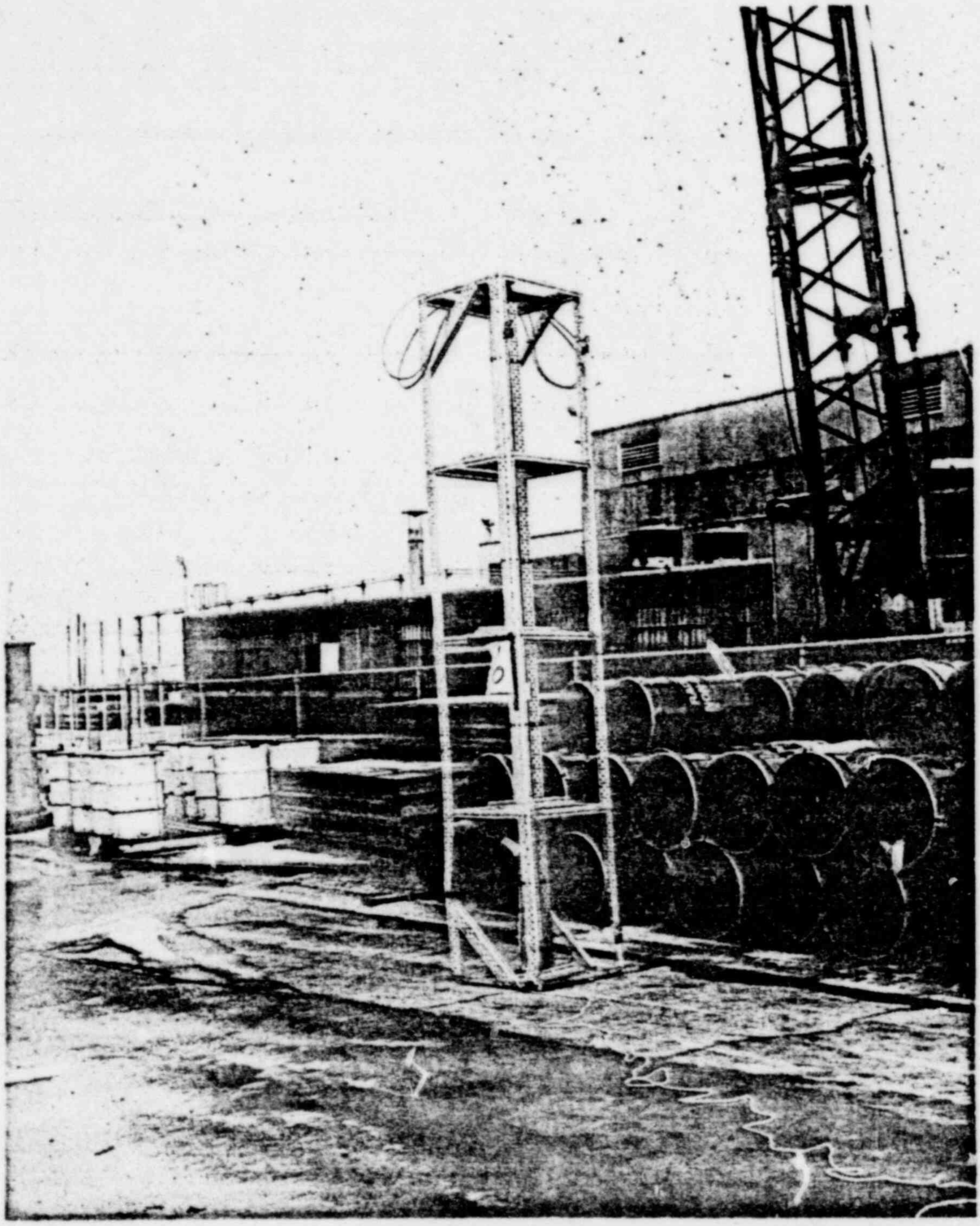


Figure D-13

Drop #7: Bolts Added to Provide Additional Restraint

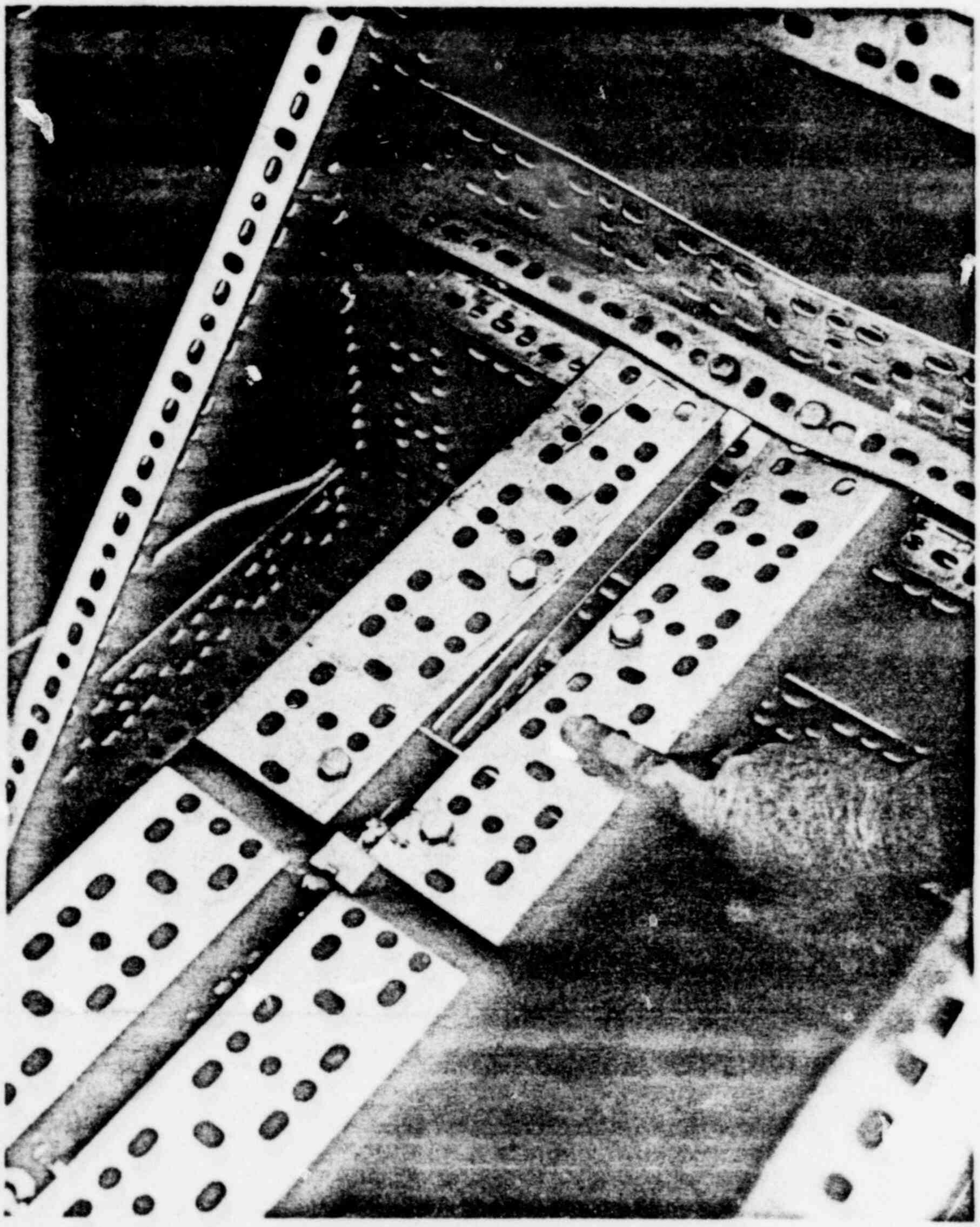
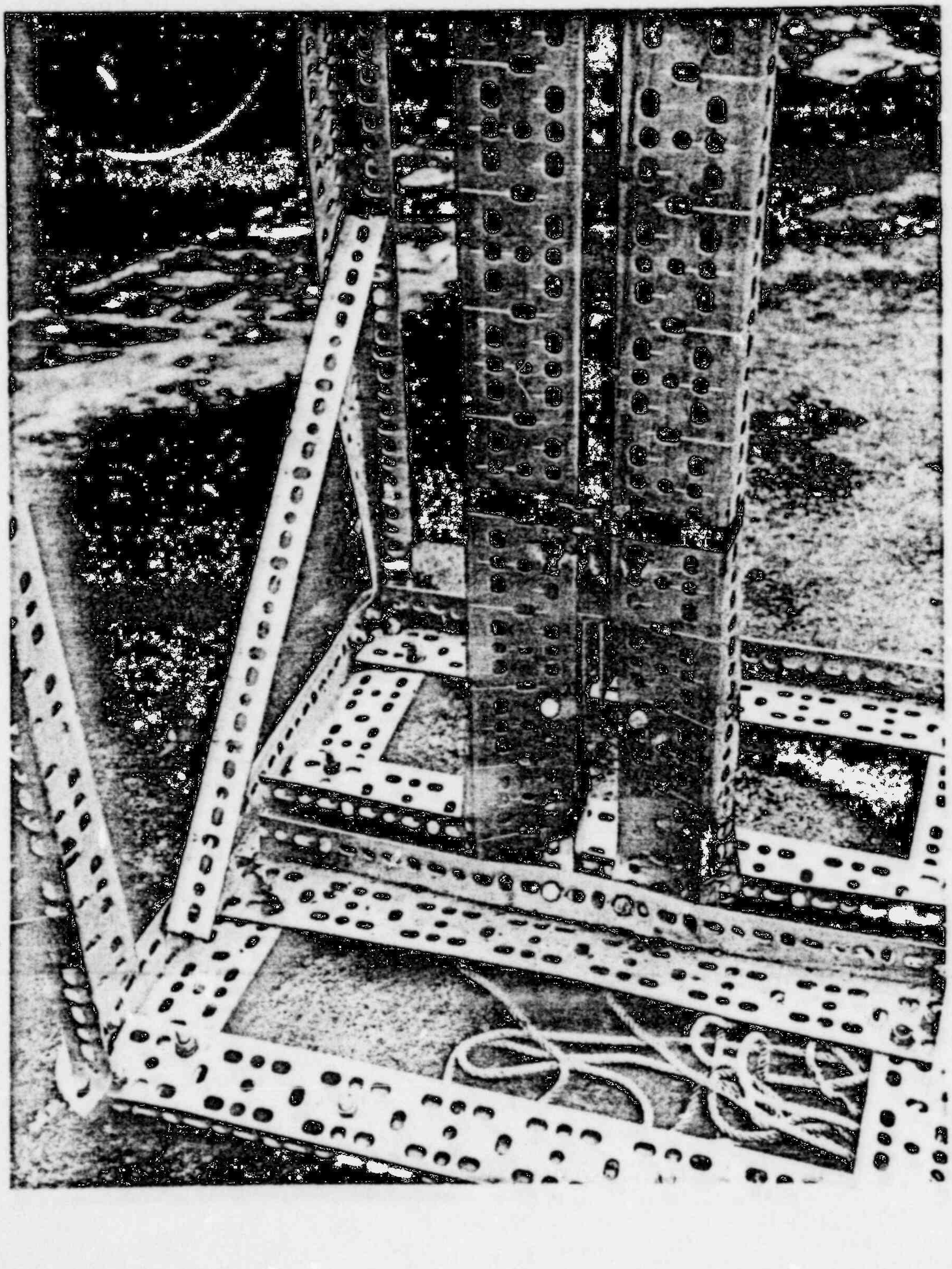


Figure D-14

Drop #7: No Loss of Containment After 30' Foot Drop



SECTION E. - BAPL 5910 BIRDCAGE NUCLEAR SAFETY ANALYSIS

1. Introduction

The BAPL 5910 birdcage was re-examined for compliance with the nuclear safety criteria of Chapter 0529 of the AEC Manual. The evaluation was not based on the original container limits but rather on new, simplified limits. Under these new limits, the amount of ^{235}U per container is increased while the number of containers per shipment is decreased. These new limits are shown here to comply with the 0529 requirements.

2. Packaging Description

The 5910 birdcage consists of a metal inner container mounted in an open steel angle framework. The inner container, or box, may be of any configuration provided that its cross-section does not exceed 20 square inches. The framework is 2' square and can be from 5 to 12 feet long. A detailed description is provided in Section B.

3. Package Contents

a. Previous Limits

DOT Special Permit 5910 limited the 5910 birdcage to Fissile Class III shipments of not more than 51 birdcages. Each birdcage was limited to one of the following quantities of ^{235}U based on the cross-section of the inner container:

Container Cross-Section	grams ^{235}U
10 in^2	800
13 in^2	430
20 in^2	300
20 in^2	1900*

*provided that 50% or more of the box is filled with metal which is reasonable uniformly distributed along the box length

b. Proposed Limits

It is proposed to change this limit to permit up to 1900 grams ^{235}U (at any volume percent metal) in inner containers with a cross-section not to exceed 20 in^2. The 20 in^2 restriction on the cross-sectional area of the inner container would then apply to all uses of the birdcage. However, eliminating the volume percent metal requirement necessitated a reduction in the number of packages permitted per shipment from 51 to 36. With this new limit, the number of birdcages per Fissile Class III shipment will be limited to 36 birdcages.

4. Computer Program

All calculations were done with the Bettis RCP Monte Carlo neutron transport program, which is based on the RECAP-12 program described in Reference (a). The cross-sections used were prepared by RECAP-0, Reference (b), and were qualified by comparing calculations to critical experiment data.

The uncertaintities quoted for each value of k_{eff} are at the 95% confidence level.

5. Analytical Model

For the purposes of this calculation the birdcage was considered to consist only of the contents of the inner container. That is, neither the steel angle framework nor the metal walls of the inner container were included. This omission is justified since 1) the only purpose of the framework is to maintain the necessary spacing of the inner containers, and 2) the nominally .075" thick walls of the inner container would be a thermal absorber, decreasing reactivity slightly and making the present calculations correspondingly conservative.

The fuel was assumed to be uniformly distributed throughout the volume of the inner container. No clad material or other metals were included. These two assumptions were necessary since there are no restrictions on the materials, shape, or distribution of the fuel elements. Since the metal would in fact absorb some fraction of the neutrons, this does not result in non-conservative results. In all cases, the inner container was assumed to be flooded with water, since the container seals were not demonstrated to be leak proof under either the normal or accident conditions. The water was assumed to occupy the entire volume of the inner container, taking no credit for the volume of the fuel elements, since this was shown to be the most reactive case.

The inner container was shown as a 4.5 inch square box. This results in a cross-section of 20.25 in^2, which is just over the 20 in^2 limit. The square configuration was chosen to provide maximum reactivity, since any other rectangular shape with the same cross-sectional area would increase leakage and thus be less reactive.

The length of the box was varied from 5" to 100" in demonstrating the nuclear safety of a single package, to ensure that the most reactive length was considered. For the array evaluations, the box was considered to extend the full length of a 5' long birdcage, which is the smallest permitted. The smallest birdcage was used because this would result in the highest ^{235}U density in the array; the larger birdcages would result in a larger array with greater leakage and would therefore be less reactive. The fuel was assumed to homogeneously distributed throughout the 5' long box. This was judged to be most reactive since it would provide the greatest interaction between the fuel in adjacent birdcages.

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For the undamaged array calculations, the 4.5 inch square inner containers were shown at the nominal 24 inch center-to-center spacing since the testing for the normal transport conditions had shown no significant changes in the birdcage integrity or in the inner container spacing. For the damaged array calculations, a spacing less than nominal to reflect the effects of the drop tests is required. The 30 foot drop test showed a decrease of less than 2 inches between the inner container and the side of the birdcage. Applying this to all sides of the birdcage results in a CTC spacing of 20 inches, which is the value used in the damaged array calculations.

6. Results of the Calculations

a. Single Package

Parts IIC, IIE2a, and IIF2 of AECM Appendix 0529 require that an individual package be subcritical under specified conditions. These requirements can all be met by showing that a single inner container flooded and reflected is subcritical under these conditions.

As stated above, the inner container was assumed to be a 4.5 inch square and the ^{235}U - water mixture to be homogeneously distributed throughout the inner container. However, the inner container length at which the maximum k_{eff} will occur is not apparent. Accordingly, several problems were run, showing an inner container varying in length from 5 to 100 inches immersed in water. The fuel content was assumed to be 1900 grams ^{235}U mixed with water at 100% of normal density. The results of these calculations are plotted in Figure 1, which shows k_{eff} as a function of container length. The maximum k_{eff} is estimated as $0.89 \pm .03$ and occurs at a container length of approximately 20 inches.

b. Two Undamaged Arrays

Part IIJ1 of Appendix 0529 requires that "the undamaged shipment would be subcritical with an identical shipment in contact with it and with the two shipments closely reflected on all sides by water".

Since fissile Class III shipments of 36 birdcages are proposed, it is necessary to show that 72 birdcages are subcritical. Since the birdcages were assumed to be 2' x 2' x 5', this results in a 6 x 6 x 2 array of 192 birdcages; the overall dimension of the array is 12' x 12' x 10'. The array is reflected with water and each inner container is filled with water to the extent noted above. The space between the inner containers was assumed to contain air only. The calculated k_{eff} for this case is $0.94 \pm .01$.

c. Single Damage Array

Part IIJ2 of Appendix 0529 requires that a shipment of packages, each of which has been damaged to the extent resulting from the hypothetical accident conditions and then re-arranged in the most reactive array, is subcritical.

Since the Fissile Class III limit is 36 birdcages, it is necessary to show that a damaged array of 36 birdcages is subcritical. The array was depicted as a 5 x 5 x 1 array of 20" x 20" x 86.4" long birdcages, with each birdcage containing ^{235}U at a density equivalent to 1900 grams per 60". This is equivalent to a 5 x 5 x 1.44 array of 60" long birdcages, for a total of 36 birdcages. This was the simplest method of depicting a reasonably cubic array (100" x 100" x 86.4") without increasing the number of birdcages beyond 36. As in the two-undamaged-array case, the array was water reflected with water moderation in the inner containers and with air between the inner containers. The resulting k_{eff} was determined to be 0.95 ± .01. This result is considered to be on the conservative side due to the assumed condition of the birdcages--that is, the 2" deformation noted after the 30' drop test was applied to all four sides of the birdcage. In fact, however, the inner container was displaced in the birdcage rather than the birdcage being deformed. It is judged that the 24" x 24" cross-section of the birdcage would be essentially unchanged even after 30' drops on each side, although the inner container would no longer be centered.

7. Summary & Conclusions

The proposed limits for the BAPL 5910 Birdcage have been shown to comply with AECM Appendix 0529. The values of k_{eff} for the various calculations are summarized as:

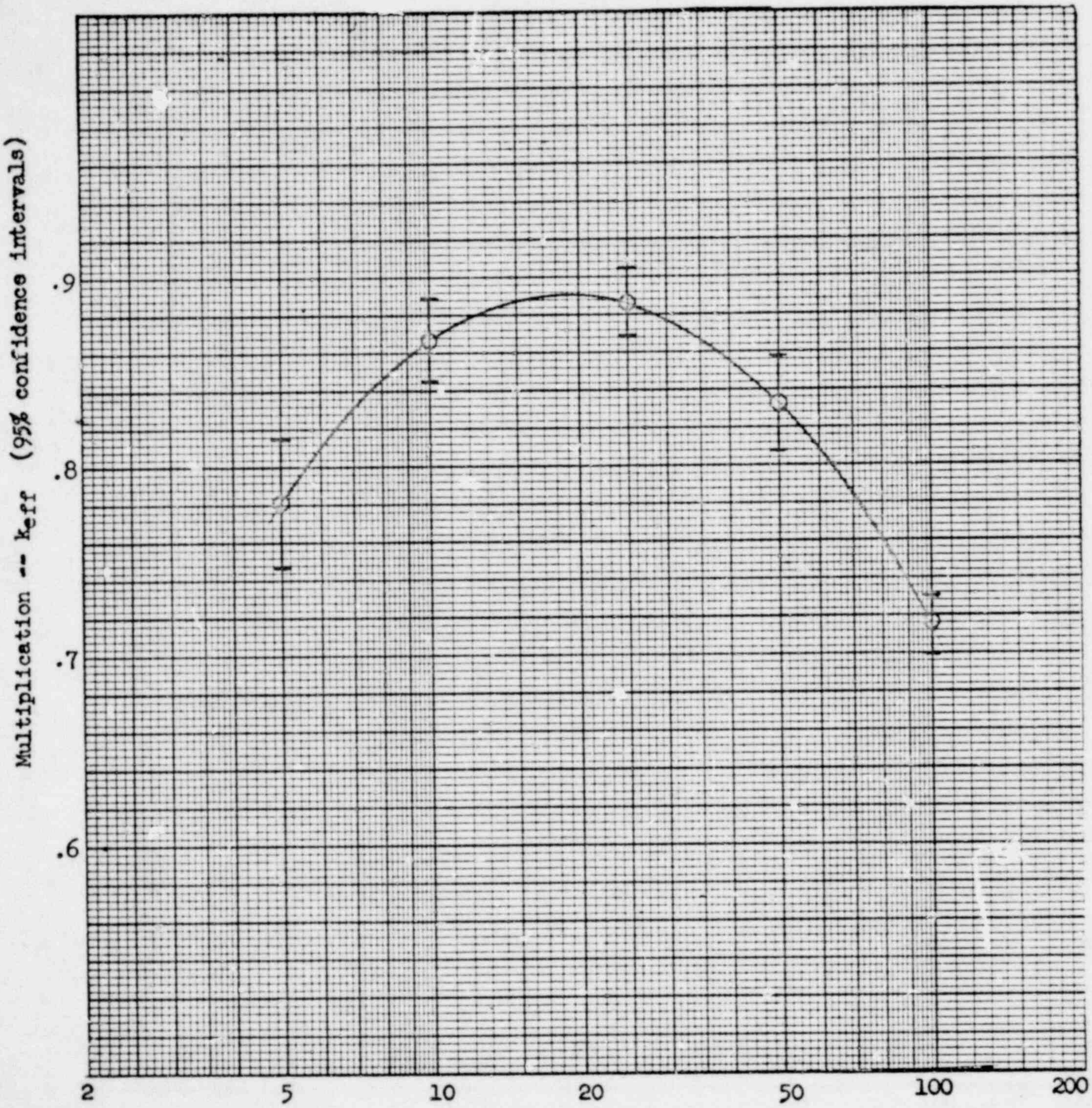
Calculation	k_{eff}
Single Inner Container	.89 ± .03
Two Undamaged Arrays	.94 ± .01
Single Damaged Array	.95 ± .01

8. References

(a) WAPD-TM-1139(L) Monte Carlo Techniques and Input Description for the CDC-7600 Program, Recap-12 dated October 1974

(b) WAPD-TM-1096(L) Recap-0: A CDC-6600 Program Which Prepares a Recap-12 Cross Section Library, dated October 1974

Multiplication of a Single Inner Container
loaded with 1900 grams ^{235}U
flooded and reflected



Inner Container Length - Inches

Figure 1

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