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AEC RESEARCH AND DEVELOPMENT REPORT

MASTER

DESIGN AND FABRICATION OF A
PROTOTYPE LAMINATED URANIUM
METAL SHIPPING CASK FOR LARGE
SHIPMENTS OF COBALT-60

C. B. CLIFFORD

**UNION
CARBIDE**

UNION CARBIDE CORPORATION
NUCLEAR DIVISION

Operating the

OAK RIDGE GASEOUS DIFFUSION PLANT	• OAK RIDGE NATIONAL LABORATORY
OAK RIDGE Y-12 PLANT	• PADUCAH GASEOUS DIFFUSION PLANT

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DESIGN AND FABRICATION OF A PROTOTYPE
LAMINATED URANIUM METAL SHIPPING CASK FOR
LARGE SHIPMENTS OF COBALT-60

C. B. Clifford

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SHIPMENTS OF COBALT-60

Author: C. B. Clifford

A B S T R A C T

This report presents the design standards, engineering drawings and the manufacturing techniques used in fabricating a prototype laminated depleted uranium metal shipping cask for transporting 150,000-curie lots of cobalt-60.

The cask design was based on criteria furnished by the Oak Ridge National Laboratory and the latest drafts of the proposed 10 CFR 71 regulations and Chapter AEC-0529. Emphasis was placed on reducing the weight and volume of the cask in order to minimize the problems associated with transporting and handling the cask in the cells located at ORNL and their customer's facilities.

Heat transfer test data are presented to show the temperatures obtained by dissipating up to 1.8 times the design heat load of electrical energy inside the cask.

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INTRODUCTION

The prototype shipping cask was designed and fabricated for the Oak Ridge National Laboratory by utilizing technology developed at the Paducah Plant for fabricating large laminated uranium metal structures. The cask will remain dimensionally stable over a large number of heat cycles, and it is capable of dissipating more than the required heat load without exceeding the design temperature specification.

The cask internal cavity is 11 inches in diameter by 17.5 inches deep, and all of the internal and external uranium shielding surfaces are clad in stainless steel.

A cask shield has been provided to protect personnel from thermal burns, and the cask and shield are mounted on a skid to facilitate handling the assembly in transit. The use of uranium shielding allowed a less bulky cask to be designed than would have been possible if a more conventional shielding material was used. The total weight of the cask, personnel shield and skid is approximately 11,400 pounds and the uranium shielding weighs 8,110 pounds. The cask is appreciably more resistant to fire and impact type accidents than the lead shielded casks which are being used for radioisotope and spent fuel element shipments.

The laminated uranium fabrication technology may be used to fabricate radiation shielding or shipping casks of virtually any size by using flat or rolled uranium plates. This technology utilizes relatively unsophisticated methods and conventional shop equipment; however, uranium metal possesses a number of unique properties which require it to be treated chemically and metallurgically in order to produce dimensionally stable structures that will possess high heat transfer rates over a large number of heating cycles.

SHIPPING CASK DESIGN STANDARDS

1. General

The design of the cask is based on proposed standards presented in the May 11, 1964 draft of Chapter AEC-0529, the January 12, 1966, 10 CFR 71 proposal for the "Transport of Licensed Material" and ORNL-TM-681, "A Guide to the Design of Shipping Casks for the Transportation of Radioactive Material."

2. Structural

a. Cobalt-60 Loading Capacity

The cask was designed for 150,000-curie lot shipments of cobalt-60.

b. Cavity Size

The internal cavity is 11 inches in diameter by 17.5 inches deep.

c. Cask Shielding

The cask shielding was fabricated from flat and rolled depleted uranium metal sheets in order to exploit the physical properties of uranium metal which favor a cylindrical type cask.

d. Radiation Shielding for 150,000-Curie Lots of Cobalt-60

Radiation shielding was provided to prevent the radiation dose rate originating from the container from exceeding 10 mr/hr. at a distance of one meter from the center of the shipping container and 200 mr/hr. or equivalent at any point on the external surface of the cask.

e. Cask Temperatures for the Design Heat Load

	Cask Exposed to Direct Sunlight In 100°F. Still Air
Maximum Fin Temperature	250°F.
Maximum Shield Temperature Accessible to Personnel	180°F.

The maximum shipping cavity temperature shall not reach the melting point of aluminum.

f. Lid Closing Mechanism

The cask was provided with a positive fastening lid closure to prevent inadvertent opening.

The lid bolts and flanges are capable of withstanding a force in any direction of 60 times the weight of the lid plus the contents of the cask.

g. Pressure Testing Facilities

A 1/4-inch diameter pressure testing tap and pipe plug were provided in the cask lid.

h. Working Pressure

The cask was designed for a maximum allowable working pressure of 125 pounds per square inch.

i. Lifting Lugs

A safety factor of ten was used in determining the maximum allowable tensile stress in any lifting lug.

j. Lid and Personnel Shield Lifting Devices

The lid and personnel shield lifting devices were designed in such a way that they will be covered by the shield when it is bolted to the shipping cask to prevent anyone from accidentally trying to lift the cask with these devices.

k. Load Resistance

The cask is capable of withstanding a static load of over five times its fully loaded weight, without stressing any material in excess of its yield strength, when the cask is considered as a single beam supported at the ends of any major axis.

l. Floor Loading

The total weight of the unloaded cask, skid and personnel shield will not exceed a floor loading of 350 pounds per square foot.

m. Cask Tie-Down System

The tie-down system is capable of withstanding a static force applied to the center of gravity of the cask, without generating stress in any member of the cask in excess of its yield strength, with a vertical component of two times the weight of the cask and its contents; a horizontal component in the

direction of the cask travel of ten times the weight of the cask and its contents; and a horizontal component in the transverse direction of five times the weight of the cask and its contents.

CONSIDERATIONS ASSOCIATED WITH THE DESIGN AND FABRICATION OF URANIUM SHIELDED CASKS

The factors considered in using depleted uranium metal for fabricating the cask's shielding are presented in the following discussions:

1. Safety

The shipping cask design was based on the criteria set forth in the January 12, 1966 draft of 10 CFR 71, Chapter AEC-0529 and ORNL-TM-681, "A Guide to the Design of Shipping Casks for the Transportation of Radioactive Materials."

In order to provide the ultimate in public safety, emphasis was placed on designing the cask to withstand severe fire and impact accidents, and to prevent chemical, galvanic or other types of reactions from occurring between the materials of construction and the package contents.

2. Shielding Material

Depleted uranium metal was used for the radiation shielding due to its high density, strength, melting point, radiation absorption efficiency and its availability. The material also has adequate thermal conductivity and expansion properties to withstand heat cycling operations when it is clad in stainless steel.

3. Shielding Design

A detailed comparison of the chemical and physical properties of uranium, the thickness of shielding materials required for various broad beam gamma ray attenuations, the uranium to lead ratios required for typical shielding applications and the effect of temperature on the corrosion of uranium in air are presented in tables 1, 2, 3 and 4, respectively.

TABLE 1
PHYSICAL AND CHEMICAL PROPERTIES OF SOME SHIELDING MATERIALS

	Uranium	Lead	Iron
Atomic weight	238.03 ⁽¹⁾	207.19 ⁽¹⁾	55.847 ⁽¹⁾
Atomic number	92 ⁽¹⁾	82 ⁽¹⁾	26 ⁽¹⁾
Density at 20°C., g/cc	19.05 ⁽²⁾	11.34 ⁽²⁾	7.86 ⁽²⁾
Color	Silvery Metal	Silvery Metal	Silvery Metal
Melting point, °C.	1132 ⁽²⁾	327 ⁽²⁾	1535 ⁽²⁾
Melting point, °F.	2071	621	2795
Boiling point, °C.	3927 ⁽¹¹⁾	1515 ⁽²⁾	3000 ⁽²⁾
Boiling point, °F.	7101	2759	5432
Oxidation states	+3, +4, +6, +5 (unstable)	+2, +4	+2, +3
Thermal conductivity Cal/(cm ²)(sec.)(°C.)/cm. at 100°C.	0.063 ⁽³⁾	0.082 ⁽⁹⁾	0.19 ⁽¹⁰⁾
at 330°C.	0.078 ⁽³⁾	0.039 ⁽⁹⁾	---
Coefficient of thermal expansion, Temperature interval - °C. 25-125	14.47 x 10 ⁻⁶ /°C. ⁽¹²⁾		
18-100		29.40 x 10 ⁻⁶ /°C. ⁽²⁾	
40			12.10 x 10 ⁻⁶ /°C. ⁽²⁾
Specific heat, cal/(g)(°C.)	0.028 ⁽⁵⁾	0.031 ⁽⁹⁾	0.108 ⁽⁸⁾
Electrical conductivity, (ohm-cm) ⁻¹	2 to 4 x 10 ⁴ ⁽⁶⁾	4.6 x 10 ⁴	17 x 10 ⁴
Hardness, Brinell scale	185-385* ⁽¹¹⁾	5 ⁽⁷⁾	90-310* ⁽⁸⁾
Ultimate tensile strength, psi	50-200,000* ⁽⁴⁾	2,500 ⁽⁷⁾	38-135,000* ⁽⁸⁾
Minimum yield strength at 0.2% offset, psi	25,000 ⁽⁴⁾		

*Varies with treatment

TABLE 1

Table 1 (continued)

Physical and Chemical Properties of Some Shielding Materials

REFERENCES

- (1) Fisher Scientific/Periodic Chart of the Elements, Cat. 5-702, 1962.
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- (7) Perry, R. H., et al., Chemical Engineers' Handbook, pp. 23-43 4th Edition, McGraw-Hill Book Co., Inc., 1963.
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- (10) Ibid., p. 20
- (11) Donahue, J. E., and Higinbotham, A. E., Uses of Depleted Uranium, Massachusetts Institute of Technology Engineering Practice School, Oak Ridge, Tenn. (MIT-OR-5).
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TABLE 2
SHIELDING MATERIAL
BROAD BEAM GAMMA-RAY ATTENUATION
(With Buildup)*

Isotope	Shield Material	Inches of Shield Material					
La ¹⁴⁰	Water	26	46	62	83	106	---
	Aluminum**	10.5	19	28	35	43	50
	Iron	3.6	6.6	9.6	12.2	15.2	---
	Lead	1.8	3.7	5.5	7.4	9.4	---
	Uranium	1.1	2.1	3.2	4.2	5.3	6.3
Co ⁶⁰	Water	26	44	62	77	98	---
	Aluminum**	10.6	18	26	32	39	46
	Iron	3.6	6.2	8.8	11.1	13.7	---
	Lead	1.8	3.4	4.8	6.5	8.3	---
	Uranium	1.0	1.9	2.7	3.5	4.4	5.2
Ba ¹⁴⁰ + La ¹⁴⁰	Water	25	45	65	82	105	---
	Aluminum**	9.7	19	27	35	43	50
	Iron	3.4	6.4	9.2	12.0	14.9	---
	Lead	1.6	3.6	5.3	7.2	9.2	---
	Uranium	.96	2.1	3.1	4.1	5.2	6.2
Ra ²²⁶ (in equilibrium with dtrs.***, encased in 0.5 mm Pt-Ir)	Water	25	44	64	81	104	---
	Aluminum**	9.8	18	27	35	44	51
	Iron	3.4	6.4	9.2	11.8	14.8	---
	Lead	1.6	3.4	5.2	7.1	9.0	---
	Uranium	.87	2.0	3.0	4.1	5.2	6.3
Attenuation Factor		10	10 ²	10 ³	10 ⁴	10 ⁵	10 ⁶

*Calculated from data of Fano (as plotted in AERE HP/I23) and recent values for spectra energies, relative intensities, and attenuation coefficients. Figures are probably conservative as buildup values were calculated for inside an infinite shield.

**Reasonable approximation for ordinary concrete.

***Daughters

TABLE 3

COMPARISON OF LEAD AND URANIUM
CYLINDRICAL CASK SHIELDS*

(Based on an inside radius of 5.9 inches and
a radial thickness of 11.8 inches of lead)

<u>Gamma Ray Energy, Mev</u>	<u>Uranium-To-Lead Ratios</u>		
	<u>Shield Thickness</u>	<u>Shield Volume</u>	<u>Shield Weight</u>
1	0.539	0.416	0.698
2	0.564	0.442	0.741
3	0.566	0.444	0.745
4	0.568	0.446	0.748
5	0.571	0.449	0.754
6	0.571	0.449	0.754
8	0.571	0.449	0.754
10	0.571	0.449	0.754

*Calculated from attenuation coefficients and dose buildup factors
published in ANL 6000.

TABLE 4

EFFECT OF TEMPERATURE ON CORROSION
OF URANIUM IN AIR*

<u>Temperature, °F.</u>	<u>Penetration, Inches/Year</u>
68	nil
212	0.10
280	0.20
392	1.98
572	3.96
752	21.38
932	28.54

*Paducah Plant Laboratory data.

3. Shielding Design (continued)

The high density, high radiation absorption efficiency and the thermal conductivity properties of uranium at elevated temperatures make it possible to design lighter and less bulky casks capable of transporting larger quantities of radioactive material than can be shipped in a similar size cask of a more conventional design.

The thermal conductivity of uranium is about the same as lead for normal shipping cask temperature conditions; however, uranium has a much higher melting point than lead and about twice the thermal conductivity of lead near its melting point.

The laminated uranium shielding was also used for cask structural members in order to simplify design and fabrication problems.

The cask shielding was clad with a 400 class stainless steel on the outside and a 300 class stainless steel on the inside in order to utilize the thermal expansion properties of the metals to form tighter cladding joints as the cask temperature increases. The shielding and internal surfaces of the stainless steel cladding were vacuum outgassed and backfilled with helium to prevent uranium oxide films from forming on the laminated uranium surfaces and to improve the heat transfer properties of the cask. The shielding joints were seal welded to prevent foreign materials from accidentally being deposited between the uranium laminations. This type of construction eliminated the need for perfect metal to metal contact in the laminated joints, and it will prevent large quantities of air or water from filling the joints if a cladding failure should develop.

4. Thermal Cycling Growth of Uranium Metal

Figure 1 shows the effects of thermal cycling temperature ranges on the growth of as-rolled alpha uranium metal.

THERMAL-CYCLING RANGE AND TEMPERATURE
EFFECT ON GROWTH OF URANIUM

(From Trans. Am. Soc. Metals, 50, 926 (1958))

FIGURE 1

4. Thermal Cycling Growth of Uranium Metal (continued)

All uranium plates were beta heat treated and oil quenched to prevent thermal cycling growth from splitting the stainless steel cladding on tightly laminated shielding structures. Extensive failures of this type would lead to high uranium oxidation rates and progressively lower heat transfer rates.

5. Uranium Oxidation

Uranium oxidizes rapidly in air at elevated temperatures (see table 4); however, cladding uranium with stainless steel prevents air from contacting the uranium and eliminates further oxidation problems. Experimental work has shown that small cracks or openings in the stainless steel cladding of a uranium shield will seal themselves in a short time due to small quantities of uranium oxide forming a non-porous deposit in the area of the opening.

6. Reaction of Uranium with Other Metals

Either 300 or 400 class stainless steels will alloy with uranium at approximately 1450°F. to form a low melting point material that will melt and flow away from the base metals. The formation of low melting point alloys was prevented by copper flame spraying the stainless steel cladding in contact with the uranium. Paducah Plant development work has shown that this type shielding will withstand the 1450°F. fire test regulations specified in the latest draft of 10 CFR 71, and it will prevent catastrophic alloying up to 1750°F.

7. Fabrication of Uranium

Paducah Plant experience has shown that uranium metal may be cut, sheared, formed, machined, or welded by utilizing the basic fabrication techniques used on more common metals, and that radiation shielding of any desired thickness may be built up by laminating as many plates as required. Cylindrical shields may be fabricated by warm rolling uranium plate and weld shrinking successively larger

rolled plates over a preassembled section of the shield. All of the shielding was vapor degreased and dry honed with alumina shot immediately before each new lamination was welded in place. The removal of uranium oxide from the laminated metal surfaces made it possible to produce a tightly laminated structure possessing an appreciably higher heat transfer rate than could have been realized from a similar structure containing uranium oxide on the joint surfaces.

SHIPPING CASK FABRICATION TECHNOLOGY

The design drawings used in fabricating the shipping cask are presented in figures 2, 3 and 4, and the critical features of the fabrication technology are as follows:

1. Uranium Shielding Material

The uranium plates used in the cask shielding were rolled from depleted virgin uranium billets, made from regular purity Paducah Plant derbies. The shielding plates were rolled to meet the following specifications:

Plate Analysis - A complete spectrographic analysis was run on each of the billets used for rolling the shielding plates.

Plate Thickness - The thickness of all uranium plates was held to plus or minus 0.050 inches.

Surface Roughness - Deviations from the mean surface were no more than 0.010 inches. No visible slag or impurity inclusions were imbedded in the rolled plate.

Plate End Cuts - All end cuts were square with the longitudinal axis of the plates.

2. Heat Treatment of Uranium Plate

The uranium plates used in the fabrication of the cask shielding were beta heat treated for 25 minutes at 1350°F. in a 47% BaCl₂, 25% KCl and 28% NaCl salt bath, and quenched in a Houghton-Quench K oil bath. This procedure was used to produce random grain orientation in the uranium plates, to eliminate subsequent problems due to

FIGURE 3

FIGURE 4

2. Heat Treatment of Uranium Plate (continued)

thermal cycling growth and to produce a material having a predictable coefficient of thermal expansion. This heat treating procedure was established after no measurable thermal cycling growth was obtained from 110 150°F. to 700°F. heat cycling tests which were run on a 1/2" x 1" x 10" uranium test piece which was heat treated according to the above procedure. The test piece was obtained by cutting its long axis parallel to the rolling axis of a heat treated plate. (See table 5 for the heat treating cycles used on the uranium shielding plates.)

3. Forming Uranium Cylinders

The cylindrical sections of shielding were formed by preheating half-inch thick beta annealed uranium plates to 400° to 600°F. in an electrically heated oil bath, and by flame heating the plates as required to maintain them above the brittle transition temperature for uranium. The plates were maintained in the ductile state during all press end forming, rolling and shearing operations to prevent the metal from breaking, cracking, or tearing. (See photographs 1 and 2 on press end forming and rolling operations.) The use of low tensile strength alpha rolled and beta annealed plates allowed more concentric cylinders to be produced with smoother surface characteristics.

Preheating the uranium plates in a hot oil bath reduced the amount of uranium oxide dust produced during the plate forming operations, and localized contamination to small areas that were easily policed to meet Health Physics standards.

4. Uranium Welding

All uranium welding was done utilizing 3/16" single V-butt joints and inert D.C. tungsten arc welding. The welding was done in a helium atmosphere, free from air disturbances, by using 3/16 ± 1/32-inch square rods sheared from sheets rolled from virgin uranium billets.

TABLE 5

DEPLETED URANIUM METAL - BETA HEAT TREATMENT DATA

<u>Uranium Plate Size</u>	<u>Oil Temp., °F. Before Quench</u>	<u>Salt Bath Starting Temp., °F.</u>	<u>Salt Bath Recovery Time To 1350°F.</u>	<u>Salt Bath Holding Time At 1350°F.</u>	<u>Transfer Time From Salt Bath To Quench</u>	<u>Oil Temp., °F. After Quench</u>
25" x 3.25" Disc	130	1400	1 hr. 40 min.	25 min.	30 sec.	170
25" x 4" Disc	110	1400	1 hr. 40 min.	25 min.	25 sec.	260
23" x 2.25" Disc	170	1400	1 hr.	25 min.	30 sec.	220
25" x 4" Disc	72	1400	1 hr. 40 min.	25 min.	30 sec.	174
42" x 21.75" x 0.5"	210	1400	30 min.	25 min.	30 sec.	260
45" x 21.75" x 0.5"	90	1400	30 min.	25 min.	25 sec.	210
48" x 21.75" x 0.5"	170	1400	30 min.	25 min.	29 sec.	260
52" x 21.75" x 0.5"	260	1400	30 min.	25 min.	32 sec.	276
55" x 21.75" x 0.5"	250	1400	30 min.	25 min.	33 sec.	280
58" x 21.75" x 0.5"	220	1400	30 min.	25 min.	30 sec.	294
61" x 21.75" x 0.5"	250	1400	30 min.	25 min.	30 sec.	272
64" x 21.75" x 0.5"	260	1400	30 min.	25 min.	32 sec.	284
67" x 21.75" x 0.5"	250	1400	30 min.	25 min.	32 sec.	308
70" x 21.75" x 0.5"	150	1400	30 min.	25 min.	34 sec.	220
74" x 21.75" x 0.5"	216	1400	30 min.	25 min.	35 sec.	276
77" x 21.75" x 0.5"	100	1400	30 min.	25 min.	34 sec.	220
80" x 21.75" x 0.5"	198	1400	30 min.	25 min.	38 sec.	260
83" x 21.75" x 0.5"	158	1400	35 min.	25 min.	35 sec.	240
46" x 19.25" x 0.5"	72	1400	40 min.	25 min.	40 sec.	174

PHOTOGRAPH 1
PRESS END FORMING URANIUM PLATE

3095-1

PHOTOGRAPH 2
ROLLING URANIUM PLATE

3095-2

4. Uranium Welding (continued)

The base metal and rods were cleaned with a dry honing system before each new pass was made and the final welds were inspected by using dye-penetrant. The welding standards specified no undercuts, over-laps, or lack of fusion in any weld. Full penetration root beads were used, with no lack of fusion.

5. Uranium Cladding

The outside surfaces of the uranium shielding was clad with 405 stainless steel and the shipping cavity was clad with 304-L stainless steel, in order to form cladding joints that would become tighter when the cask temperature is increased.

All cladding surfaces were sand blasted and the surfaces next to the uranium shielding were flame sprayed with 0.005 inches of copper to prevent low melting point alloys from forming between the cladding and the uranium if the cask is ever exposed to abnormally high temperature conditions.

6. Fabricating the Top and Bottom Radiation Shields

The top and bottom radiation shields were formed by machining two uranium disks to their desired shapes and vapor degreasing the parts immediately before they were welded together to form a shield. The welds were machined to their final dimension and the shields were vapor degreased and dry honed with alumina shot immediately before they were clad with 405 stainless steel. (See photograph 3 for the component parts used in fabricating the bottom shield.)

7. Fabricating the Cylindrical Radiation Shield

This shield was formed by welding a 304-L stainless steel cladding cylinder around a finned welding mandrel and by band clamping and weld shrinking successively larger half-inch thick uranium cylinders over the preassembled section of the shield. The mating surfaces between laminated cylinders were degreased and dry honed with alumina.

PHOTOGRAPH 3
COMPONENT PARTS USED IN FABRICATING THE BOTTOM SHIELD

3095-9

7. Fabricating the Cylindrical Radiation Shield (continued)

shot immediately before each lamination was added to the cylindrical shield. Each lamination was positioned flush with the bottom of the shield and it was welded in place under room temperature conditions. This procedure minimized the amount of uranium oxide in the laminated joints, increased the metal to metal contact between cylinders and subsequently improved the heat transfer properties of the cask.

The welding mandrel was fabricated by welding twelve 11-inch diameter by 1/4-inch thick steel plates on a 6-inch diameter pipe. The plates were spaced on 1-1/2-inch centers and the outer edge of each plate was slotted to facilitate removing the mandrel after the outside stainless steel cladding was installed on the cylinder. The mandrel was removed by cutting the plates from the pipe with an oxy-acetylene cutting torch. (See photographs 4 and 5 for the welding mandrel and the finished cylindrical shield.)

Band clamps were found to be superior to "C" clamps for obtaining tightly laminated cylinders since they did not immobilize the laminations as they were welded in place, and the band clamps forced the laminated joint to become tighter as the weld metal cooled. This type of fabrication produced laminated joints with a high percentage of metal to metal contact. In no case was it possible to run a 0.001 inch feeler gauge more than a fraction of an inch into a joint.

8. Seal Welding a Helium Atmosphere Between Laminations

The joints between the uranium laminations were seal welded at the bottom, after the last lamination was welded in place, and the bottom surface of the shielding was machined flat and degreased prior to installing the bottom and side cladding plates. The shield was vacuum outgassed and backfilled with one atmosphere of helium by seal welding the top of each laminated joint.

The cylindrical shield was machined to its design height by machining the top of the shield flat, and the unit was degreased prior to welding the top cladding plate in place.

PHOTOGRAPH 4

WELDING MANDREL AND SECTION OF THE CYLINDRICAL SHIELD

3095-4

PHOTOGRAPH 5

WELDING MANDREL AND COMPLETED CYLINDRICAL SHIELD

3095-8

8. Seal Welding a Helium Atmosphere Between Laminations (continued)

Apiezon "Q" was used to prevent cutting oil from seeping into the cladding to uranium joints during all machining operations, and the sealing material was removed before the machined surfaces were degreased to install the top and bottom cladding plates.

SHIPPING CASK HEAT TRANSFER TESTS

The heat transfer tests were run on the assembled shipping cask by dissipating known quantities of electrical energy inside of the cask, and by monitoring the skin temperatures of the unit with chromel-alumel thermocouples and a Speedomax temperature indicator. Table 6 presents the data on thermocouple locations and the equilibrium temperatures associated with dissipating approximately the design heat load and 1.8 times this heat load of electrical energy inside of the cask. Photographs 6 and 7 show various views of the finished cask and photograph 8 shows the cask and heat transfer testing equipment.

OAK RIDGE NATIONAL LABROATORY RADIATION SURVEY DATA

An Oak Ridge National Laboratory radiation survey was made on the cask when it was loaded with 204,592.7 curies of cobalt-60. This survey showed the following radiation readings:

<u>Type of Radiation Reading</u>	<u>Mr/Hr. of Gamma Radiation</u>
Background	6
Between Fins	14
1 foot from side of cask	11
2 feet from side of cask	10
3 feet from side of cask	8
4 feet from side of cask	6.5

FIN EDGE									HEATER WALL	SKID - UNDER CASK	AMBIENT	HEAT SHIELD			
N			SW			SE						C	T	M	B
T	M	B	T	M	B	T	M	B							
44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
145	139	135	141	136	129	135	133	125	711	90	75	115	95	84	81
182	172	162	180	176	162	170	159	147	902	101	76	140	107	95	86

Data # 2 is after 23 hours at the test heat input.
All Data in °F.

150,000 CURIE Co^{60} SHIPPING CASK

Table 6

PHOTOGRAPH 6
FINISHED CASK AND SKID

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PHOTOGRAPH 7

FINISHED CASK, SKID AND PERSONNEL SHIELD

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PHOTOGRAPH 8
HEAT TRANSFER TESTING FINISHED CASK ASSEMBLY

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CONCLUSIONS

The design, fabrication and heat transfer testing of the prototype laminated uranium metal shipping cask, and an Oak Ridge National Laboratory 204,593 curie cobalt-60 radioisotope loading test on the same cask, have shown that laminated uranium metal structures can successfully be fabricated and utilized for the radiation shielding in casks of this type by using conventional fabrication and heat treating equipment and procedures. The use of stainless steel clad uranium metal for both radiation attenuation and structural members has resulted in a less bulky cask and an appreciable reduction in the handling problems associated with shipping large quantities of radioactive isotopes.

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