232
3/24/69

721
KY-551

AEC RESEARCH AND DEVELOPMENT REPORT

MASTER

DEMONSTRATION FUEL ELEMENT SHIPPING CASK

FROM

LAMINATED URANIUM METAL

PART II

FABRICATION AND COSTS

V. A. SMITH
C. W. LOVELAND

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
PADUCAH GASEOUS DIFFUSION PLANT

UNION
CARBIDE

PADUCAH GASEOUS DIFFUSION PLANT
P. O. Box 1410
Paducah, Kentucky 42001

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

Printed in the United States of America

Available from

Clearinghouse for Federal Scientific and Technical Information

National Bureau of Standards, U. S. Department of Commerce

Springfield, Virginia 22151

Price: Printed Copy \$3.00; Microfiche \$0.65

Date of Issue: March 20, 1969

Report Number: KY-551

Subject Category: UC-2

GENERAL, MISCELLANEOUS,
AND PROGRESS REPORTS
(TID-4500, 53rd Ed.)

DEMONSTRATION FUEL ELEMENT SHIPPING CASK

FROM LAMINATED URANIUM METAL

PART II

FABRICATION AND COSTS

V. A. Smith

C. W. Loveland

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Report Number: KY-551

Subject Category: UC-2

GENERAL, MISCELLANEOUS,
AND PROGRESS REPORTS
(TID-4500, 53rd Ed.)

Authors: V. A. Smith
C. W. Loveland

ABSTRACT

This report describes the work performed by the Paducah Gaseous Diffusion Plant operated by Union Carbide Corporation, Nuclear Division, for the U. S. Atomic Energy Commission relative to the fabrication of a demonstration fuel element shipping cask utilizing laminated depleted uranium as shielding material. A detailed presentation is given of the fabrication, machining, cleaning, and heat treating operations followed in producing the cask. Machining characteristics of uranium are described and special control measures together with equipment requirements are presented.

Emphasis is placed on distinctive techniques used with uranium materials, and discussion of fabrication used with other, more common construction materials is minimized. Cost experience is detailed to permit its extrapolation to conventional industrial experience.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	ii
LIST OF FIGURES	iv
LIST OF TABLES	v
INTRODUCTION	1
SUMMARY	5
FABRICATION	6
Material Procurement	6
Protection of Uranium from Oxidation	6
Forming Uranium	13
Cleaning Uranium	18
Welding Uranium	18
Heat Treatment of Cask	20
Final Machining	24
Handling of Scrap Uranium	24
HEALTH PHYSICS ASPECTS OF URANIUM FABRICATION	26
COST EXPERIENCE	27
ACKNOWLEDGEMENTS	30
REFERENCES	31

LIST OF FIGURES

	<u>Page</u>
Figure 1 - Types of Uranium Shielded Casks Fabricated at Paducah	3
Figure 2 - Demonstration Fuel Element Shipping Cask from Laminated Uranium Metal	4
Figure 3 - Fabrication and Test Procedures for Cask	7
Figure 4 - Design Details of Cask	8
Figure 5 - Plasma Spraying Stainless Steel Cavity Envelope with Tungsten	12
Figure 6 - End Forming of Uranium Plate Prior to Rolling	14
Figure 7 - Uranium Plate Being Started Through Roll. . .	15
Figure 8 - Rolling Operation Nearing Completion	16
Figure 9 - Shims Being Used During Rolling to Prevent 'Belling' of Cylinder Ends	17
Figure 10 - Axial Weld Being Made on Uranium Plate. . . .	21
Figure 11 - Machining Uranium Cylinder	22
Figure 12 - Partially Completed Cylinder After Abrasive Cleaning	23
Figure 13 - Lid Being Installed on Completed Cask	25

LIST OF TABLES

	<u>Page</u>
Table 1 - Detailed Material Requirements for Demonstration Cask	9
Table 2 - Procedure for Silver Plating Uranium Rods . .	19
Table 3 - Quantity and Cost of Material Used to Build Demonstration Cask	27
Table 4 - Functional Breakdown of Labor Used to Build Demonstration Cask	28
Table 5 - Summary of Fabrication Costs for Demonstration Cask	29

INTRODUCTION

A demonstration fuel element shipping cask utilizing laminated uranium metal as the shielding material has been designed, fabricated, tested, and evaluated at the Paducah Gaseous Diffusion Plant. The project was authorized by the AEC Division of Reactor Development and Technology.¹ This report, covering the fabrication and costs of the demonstration cask, is one of a series of three reports covering the overall project. Emphasis is given to specific uranium fabrication techniques, and description of conventional material fabrication is minimized. Other reports in this series will cover (a) background and design aspects of the demonstration cask² and (b) the nondestructive and destructive tests performed on the cask.³

The rapidly growing nuclear power industry will require economical methods for transporting spent fuel components from reactors to reprocessing sites. Truck and rail transport appear to offer the most advantageous methods for moving the materials, and utilization of the most efficient, safe shielding material for transport offers long-term economies warranting investigation and analysis.

Depleted uranium, because of its high density and high melting point, has certain advantages not common to conventional shielding materials. Consideration of methods for utilizing uranium in large shielded assemblies led to the development of the laminated plate concept and to the proposal for the fabrication of the demonstration cask.

The nominal function of the gaseous diffusion plant is the production of isotopically enriched uranium. However, the maintenance and shop facilities required for process equipment led to the establishment of well integrated and equipped machine and fabrication facilities. The size of process equipment necessitated installation of large machine tools and fixtures capable of handling cascade components weighing in excess of 25 tons.

An adjunct of the Paducah Plant is a uranium metal processing plant. Here, depleted uranium hexafluoride gas, having been stripped of its ^{235}U isotope fraction, is reduced to uranium metal by a magnesium reduction process. The output of the metals plant is principally in the form of uranium derbies, each weighing approximately 1100 pounds and sized 18 inches round and about 6-1/2 inches thick. Large vacuum remelt furnaces are installed in the metal processing plant for melting derbies and casting the uranium into graphite molds. These furnaces have the capacity to produce castings weighing 3000 pounds having a maximum diameter of 24 inches and a maximum height of 55 inches.

Availability of uranium materials and fabricating facilities led to investigation of methods for utilizing depleted uranium. Fabrication of small shielding devices and ballast materials emphasized the requirement for protective external coating of the uranium to limit surface oxidation. Nickel plating of uranium required elaborate cleaning and surface activation procedures, and with existing limitations of equipment, it was decided that encapsulation of the uranium in a stainless steel envelope would be the most advantageous method to develop at the Paducah Plant. Applicable regulations for shipping

casks require the covering of uranium with a material suitable for high temperature service, and the stainless steel jacket would fulfill this requirement. Simultaneously, experience with castings pointed out the limitation of available furnace equipment, the involved graphite mold equipment requirements for each size casting, and the difficulties in measuring or detecting porosity or voids within a relatively thick uranium casting. Observation and experience with varying fabrication techniques led to selection of a laminated uranium plate structure enclosed in stainless steel as being the most compatible with available equipment and personnel craftsmanship. In addition, this technique could be used to fabricate containers of varying shielding thickness and length. In February 1967, a prototype isotope shipping cask for shielding 150,000 curies of ^{60}Co was produced by using the laminated structure. Minor revisions were made, and a second cask was produced which was designed to transport 400,000 curies of ^{60}Co . A proposal was submitted to the AEC at the end of FY-1966 that a cask utilizing laminated uranium as the radiation shield be constructed and tested to evaluate uranium as a material for spent fuel element shipping cask construction. A primary objective of the program was to demonstrate the improved safety aspects of the uranium cask with cost relegated to a secondary role; however, costs of all operations were carefully determined. It was felt that the mechanical properties of uranium would enhance the structural integrity of the cask. The physical properties would yield a cask with good fire resistance and built-in economic advantages such as shipment of a higher temperature core with shorter decay time and reduced weight per shipment.

The AEC approved the proposal, and design work was initiated late in 1966. Design and fabrication experience gained during the production of isotope casks was utilized in planning for the demonstration cask. Figure 1 compares the sizes of two isotope casks with that of the demonstration cask. The design concept for the demonstration cask treated the uranium as a structural unit providing support for stainless steel external members which were considered sacrificial under accident load conditions. The cask was dimensioned to carry four Indian Point core A fuel elements, except that the cavity length was shortened to 51 inches (approximately one-fourth the length of the Indian Point fuel element) to provide all necessary fabrication and cost data with minimum expense. Figure 2 presents a view of the cask design.

DEMONSTRATION CASK

HEAT SOURCE SHIELD

ISOTOPE SHIPPING CASK

TYPES OF URANIUM SHIELDED CASKS FABRICATED AT PADUCAH					
TYPE	OVERALL SIZE		CAVITY SIZE		CASK WEIGHT, LBS
	DIA.	HEIGHT	DIA.	HEIGHT	
HEAT SOURCE SHIELD	22"	21"	4.3"	7.9"	2,000
ISOTOPE SHIPPING CASK	35 $\frac{5}{8}$ "	43 $\frac{3}{16}$ "	11"	17.5"	10,000
DEMONSTRATION CASK	36"	84 $\frac{1}{2}$ "	17"	51"	25,260

TYPES OF URANIUM SHIELDED CASKS FABRICATED AT PADUCAH

Figure 1

DEMONSTRATION FUEL ELEMENT SHIPPING CASK **FROM LAMINATED URANIUM METAL**

Figure 2

SUMMARY

The sequence for fabricating a laminated uranium cask does not require massive manpower employment. Each welding operation for a lamination is followed by grinding, cleaning, and sequential forming operations. The entire sequence is characterized by repetitive actions performed by a small group of people. In general, only three or four individuals were required to work on the cask at any one time. Cask fabrication began May 15, 1967, and continued through January 19, 1968. During this period, design changes were made which limited fabrication progress. It should be noted that this cask, being a prototype, required greater time than would established production types.

Equipment requirements for cask fabrication are relatively simple. Fabrication requires a press brake, a large capacity roll, and a single rectifier type Heliarc welding machine. Machining requirements are fulfilled by a planer, a large high capacity vertical lathe, and a conventional horizontal lathe. An abrasive cleaning facility and appropriately-sized furnace equipment complete general requirements.

The laminated cask construction method has been shown to be feasible for production with conventional shop equipment. This method of fabrication can be readily utilized to produce large casks, and it is limited only by capacity of machining and auxiliary handling equipment. Fabrication costs appear sufficiently low that, when added to the cost of the uranium metal, the total cost of uranium shielded casks should prove competitive with the cost of lead or steel shielded casks. This is particularly true in situations where cask weight is limiting, as in the case of utilizing motor freight, and where it is desirable to maximize the cavity volume.

FABRICATION

MATERIAL PROCUREMENT

Final engineering design of the cask was completed in May 1967. Figures 3 and 4 are two of the detail drawings of the cask. A material recapitulation from the drawings is detailed in table 1. Arrangements were made to obtain the necessary uranium rolling and plate production from the Y-12 Plant at Oak Ridge, an AEC plant operated by Union Carbide Corporation - Nuclear Division. All other material was procured from conventional supply sources. Thirty-six regular purity isotopically depleted derbies having a nominal assay of 0.22 ± 0.02 weight per cent ^{235}U were shipped to the Y-12 Plant for rolling. Each derby weighed approximately 1100 pounds, a total shipment of nearly 40,000 pounds. Rolling operations were initiated in April 1967 and were completed shortly thereafter.

The uranium rolling is performed in the high alpha range, at a temperature of about 1000°F, without intermediate anneals. A neutral salt bath is used for heating the uranium before and during rolling. Final cooling upon completion of rolling is performed in the salt bath, and a water quench facilitates removal of residual salt. Care is taken to avoid overheating which can occur from a combination of mechanical work and oxidation accompanying the rolling operation. Rolling is performed on a Bliss 66-inch slab mill which controls plate thickness to ± 0.050 inch, and deviation from mean surface is limited to less than 0.015 inch. The plate is rolled with different traverse passes to minimize directional fiber development. All plates are tested ultrasonically for soundness; no slag inclusions, impurity inclusions, or folds are acceptable in the finished plate. Following inspection, the plates are sheared to desired size. A nominal tolerance of 1/8 inch was permitted on the uranium plate length and width measurements.

PROTECTION OF URANIUM FROM OXIDATION

Uranium is a reactive metal which, under normal conditions, oxidizes rapidly. It can be pyrophoric when finely divided. Freshly machined uranium begins to discolor immediately, changing from a metallic silver color to bronze as oxidation occurs. Oxidation protection for uranium in the cask was provided by enclosing the uranium in a stainless steel envelope. Under normal conditions, the oxidation would be confined to a very thin surface layer. Heat transfer and shielding properties of the uranium would be unaffected. The stainless steel cover also prevents any possibility of contamination from uranium. The installation of the stainless covering created another problem, for it has been established that under fire conditions, with accompanying high temperature, the interface between the uranium-stainless steel will form a low-melting alloy.² A 5-mil thickness of tungsten sprayed on the surfaces of stainless steel, which would otherwise be in contact with uranium, has been demonstrated to act as an effective barrier and deterrent to the formation of the low-melting alloy. Cask fabrication at Paducah began with the rolling, welding, and machining of the cladding material for the cask cavity. This fabrication was conventional in all respects. The stainless steel cylinder which was formed was coated with a 5-mil layer of tungsten using plasma spraying. Figure 5 shows the plasma spraying apparatus being used to coat the stainless steel inner envelope. A temporary support mandrel, with appropriate handling appurtenances fabricated from mild steel, was installed in the stainless steel sleeve, and the process of installing the uranium laminates was initiated.

Table 1

DETAILED MATERIAL REQUIREMENTS FOR DEMONSTRATION CASK

Item	Quantity	Units	Description
1	1	ea	Plate, stainless steel, 304L, 6"x 31" o.d. x 25" i.d.
2	1	ea	Plate, stainless steel, 304L, 3"x 12"x 12".
3	1	ea	Plate, stainless steel, 304L, 2-1/4"x 12" dia.
4	1	ea	Plate, stainless steel, 304L, 1-1/4"x 18" dia.
5	1	ea	Plate, stainless steel, 304L, 4-1/2"x 22" dia.
6	1	ea	Plate, stainless steel, 304L, 1"x 48"x 48".
7	1	ea	Plate, stainless steel, 304L, 3/4"x 54"x 30".
8	1	ea	Plate, stainless steel, 304L, 1/2"x 76"x 96".
9	1	ea	Plate, stainless steel, 304L, 1/2"x 24"x 72".
10	1	ea	Plate, stainless steel, 304L, 3/8"x 22" dia.
11	1	ea	Plate, stainless steel, 304L, 3/8"x 3"x 54".
12	1	ea	Plate, stainless steel, 304L, 1/4"x 56"x 76"
13	10	ea	Plate, stainless steel, 304L, 3/16"x 48" x 96".
14	1	ea	Bar, stainless steel hex, 304L, 1/2" hex x 1" long.
15	1	ea	Plate, hot rolled carbon steel, ASTM A-285, 1"x 70"x 111".
16	1	ea	Plate, hot rolled carbon steel, ASTM A-285, 1"x 48"x 48".
17	4	ea	Bar, stainless steel, ASTM A-107, 1/2"x 1-1/4"x 125".
18	1	ea	Plate, stainless steel, ASTM A-285, 3/4"x 8"x 16".
19	2	ea	Plate, stainless steel, ASTM A-285, 1/2"x 5" dia.
20	1	ea	Plate, stainless steel, ASTM A-285, 1/4"x 16"x 70"
21	1	ea	Bar, cold rolled carbon steel, ASTM A-108, 2" dia x 20".
22	1	ea	Bar, cold rolled carbon steel, ASTM A-108, 3" dia x 4".
23	48	lineal ft	Beam, carbon steel 4 wide flange 13, ASTM A-36.
24	30	lineal ft	Channel, carbon steel 4 channel 5.4, ASTM A-36.
25	16	lineal ft	Angle, carbon steel, 5"x 5"x 3/4", ASTM A-36.
26	10	ea	Screw, socket hd.cap, stainless steel, 5/16"- 18 UNC x 1-1/4".
27	4	ea	Screw, socket hd.cap, stainless steel, 1/2"- 13 UNC x 1".
28	4	ea	Screw, hex hd.cap, alloy steel, 1-1/2"- 6 UNC x 4".
29	4	ea	Nut, hex, alloy steel, 1-1/2"- 6 UNC.
30	2	ea	Seal-O-Ring No. 20000-7-3-NP-PF, Advanced Products Co., 33 Defco Park Rd., North Haven, Conn. 06473.
31	1	ea	Pipe, 1/4" sch. 80S, stainless steel, 304L, 18".
32	1	ea	Pipe, 1/2" sch. 80S, stainless steel, 304L, 24".
33	1	ea	Nipple, pipe, sch. 80S, stainless steel, 304L, 1/4"x 3".
34	3	ea	Nipple, sch. 80S, stainless steel, 304L, scr'd., 1/4"x close.
35	1	ea	Nipple, sch. 80S, stainless steel, 304L, scr'd., 1/4"x 1-1/2".
36	2	ea	Nipple, sch. 80S, stainless steel, 304L, scr'd., 1/2"x 1-1/2".
37	3	ea	Ell, 90° scr'd., 1/4", 2000 lb, stainless steel, 304L.
38	1	ea	Tee, scr'd., 1/4", 2000 lb, stainless steel, 304L.
39	1	ea	Ell, 90° scr'd., 1/2", 2000 lb, stainless steel, 304L.
40	1	ea	Safety head, Black Sivalls and Bryson No. 1S - 1/2" - 1/4 NPT - free, all stainless steel with 250 psi rupture disc, 375°F.
41	2	ea	Valve, ball, Worcester No. 1/2 - F466, RTSE.

Table 1 (Cont.)

DETAILED MATERIAL REQUIREMENTS FOR DEMONSTRATION CASK

Item	Quantity	Units	Description
42	1	ea	Bar, rd., stainless steel, Type 17-4PH, hot rolled annealed, 1-1/8"dia x 72".
43	1	ea	Plate, stainless steel, 304L, 4"x 10"x 11".
44	1	ea	Bar, cold rolled, 1/4"dia x 12".
45	1	ea	Plate, hot rolled steel, USS T-1, 1/2"x 48"x 72", U. S. Steel (constructional alloy steel).
46	1	ea	Bar, hot rolled steel, USS T-1, 1"x 4"x 36", U.S.Steel.
47	1	ea	Bar, cold rolled steel, USS T-1, 4"dia x 36", U.S.Steel.
48	1	ea	Bar, cold rolled steel, USS T-1, 3"dia x 8", U.S.Steel.
49	25	ft	EB insert, 5/32"dia, stainless steel, 308L, Electric Boat Division, General Dynamics Corp.
50	4	ea	Nut, hex, stainless steel, 1/2"-13 NC.
51	8	ea	Screw, cap, hex socket head, stainless steel, 1/2"dia, 1/2 -13 NC x 1-1/4".
52	4	ea	Screw, cap, hex socket head, steel, 3/4"-10 NC x 3-1/4".
53	1	ea	Bar, stainless steel, 304L, 1/2"dia x 12".
54	2	ea	Bushing, reducing, screwed stainless steel, 304L, 1/2" x 1/4".
55	1	ea	Nipple, pipe, sch. 80S, stainless steel, 304L, screwed 1/4"x 2-1/2".
56	4	ea	Seal-O-Ring, Viton, 18.233"o.d.x 0.139"dia, No.2-284, compound 77-545, Parker Rubber Division.
57	50	lb	Welding rod, E-9016, 1/8"dia.
58	50	lb	Welding rod, E-9016, 5/32"dia.
59	100	lb	Welding rod, stainless steel, 308L, 3/32"dia x 36"(cert).
60	1	ea	Plate, stainless steel, 304L, 6"x 32"o.d.x 18-1/2"i.d.
61	1	ea	Plate, stainless steel, 304L, 1"x 48"x 48".
62	1	ea	Plate, stainless steel, 304L, 1/2"x 24"x 96".
63	1	ea	Plate, stainless steel, 304L, 3/4"x 12"x 20".
64	1	ea	Plate, stainless steel, 304L, 1-1/2"x 7"x 7".
65	1	ea	Plate, stainless steel, 304L, 3-1/2"x 27-1/2"o.d.x 16"i.d.
66	1	ea	Bar, hex, stainless steel, 17-4PH, cond.A, 2-1/4"x 26".
67	1	ea	Bar, rd., stainless steel, 17-4PH, cond.A, 1-5/8"dia x 100".
68	28	lineal ft	Bar, rd., stainless steel, 304L, 1"dia.
69	1	ea	Pipe, stainless steel, 304L, sch. 80S, 1/2"x 12".
70	1	ea	Ell, 90°, scr'd., stainless steel, 304L, 1/2", 2000 lb.
71	1	ea	Plate, hot rolled steel, USS T-1, 1/2"x 24"x 48".
72	1	ea	Plate, hot rolled steel, ASTM A-285, 1"x 24"x 48".
73	1	ea	Plate, hot rolled steel, ASTM A-285, 1/2"x 18"x 36".
74	1	ea	Plate, hot rolled steel, ASTM A-285, 1/4"x 11"x 12".
75	2	ea	Uranium disks, 4-3/4" x 21" dia.
76	2	ea	Uranium disks, 3-1/4" x 29-1/2" dia.
77	1	ea	Uranium plate, 1/2" x 24-5/8" x 62".
78	1	ea	Uranium plate, 1/2" x 30" x 62".
79	1	ea	Uranium plate, 1/2" x 24-5/8" x 65".
80	1	ea	Uranium plate, 1/2" x 30" x 65".
81	1	ea	Uranium plate, 1/2" x 24-5/8" x 62".
82	1	ea	Uranium plate, 1/2" x 30" x 62".
83	1	ea	Uranium plate, 1/2" x 24-5/8" x 71".

Table 1 (Cont.)

DETAILED MATERIAL REQUIREMENTS FOR DEMONSTRATION CASK

<u>Item</u>	<u>Quantity</u>	<u>Units</u>	<u>Description</u>
84	1	ea	Uranium plate, 1/2" x 30" x 71".
85	1	ea	Uranium plate, 1/2" x 24-5/8" x 71".
86	1	ea	Uranium plate, 1/2" x 30" x 71".
87	1	ea	Uranium plate, 1/2" x 20-1/4" x 75".
88	1	ea	Uranium plate, 1/2" x 40" x 75".
89	1	ea	Uranium plate, 1/2" x 20-1/4" x 78".
90	1	ea	Uranium plate, 1/2" x 40" x 78".
91	1	ea	Uranium plate, 1/2" x 20-1/4" x 81".
92	1	ea	Uranium plate, 1/2" x 40" x 81".
93	1	ea	Uranium plate, 1/2" x 20-1/4" x 84".
94	1	ea	Uranium plate, 1/2" x 40" x 84".
95	1	ea	Uranium plate, 1/2" x 20-1/4" x 87".
96	1	ea	Uranium plate, 1/2" x 40" x 87".
97	1	ea	Uranium plate, 1/2" x 20-1/4" x 90".
98	1	ea	Uranium plate, 1/2" x 40" x 90".
99	1	ea	Uranium plate, 1/2" x 20-1/4" x 93".
100	1	ea	Uranium plate, 1/2" x 40" x 93".
101	1	ea	Uranium plate, 1/2" x 20-1/4" x 97".
102	1	ea	Uranium plate, 1/2" x 40" x 97".
103	1	ea	Uranium plate, 1/2" x 20-1/4" x 97".
104	1	ea	Uranium plate, 1/2" x 40" x 97".
105	1800	ea	Uranium rod, 1/8" sq x 24" long.
106	600	ea	Uranium rod, 3/16" sq x 24" long.
107	200	lbs	Powder, tungsten, Metco.

PLASMA SPRAYING STAINLESS STEEL
CAVITY ENVELOPE WITH TUNGSTEN

Figure 5

FORMING URANIUM

Before rolling uranium into cylindrical shapes, the edges of the uranium plate were machined to provide optimum weld joints. The weld joints used were single vee butt joints, and preliminary machining of the uranium plate called for edge beveling at a $37\frac{1}{2}$ degree angle. Wherever possible, the edge beveling was performed using a large hydraulically driven openside Rockford planer with a 6-foot by 14-foot bed. The uranium, having a BHN hardness of 200-230, was planed by using a heavy duty Kennametal HBR tool holder with a sintered carbide insert. The HD125K25 insert with an L-shaped cross section had a composition of 85% tungsten carbide, 10% cobalt, 1% tantalum carbide, and 4% titanium carbide. This tool proved less susceptible to breakage and cratering than conventional tungsten carbide tools. The cutters showed good wear resistance and toughness, and they could be sharpened several times. A table speed of 125 feet per minute with approximately 0.060 inch feed per stroke with single cut planing action was established as the optimum machining rate. The chips produced were relatively thick and were generally thrown clear of the planer. The tool was engaged about 75% of the time, and the intermittent contact eliminated some problems normally associated with tool cooling. A vapor mist of soluble oil and water sprayed directly on the tool proved effective in extending tool life by providing some cooling and by facilitating particle removal from the tool surface. Planing proved to be the optimum method for preparing the uranium plate for welding. Plate edges which could not be beveled by planing were machined by using conventional vertical milling cutters with oil cooling. In the course of assembly, some weld preparation had to be performed by hand grinding on edges inaccessible to machine tools.

Machining of uranium at room temperature closely resembles that of stainless steel. However, forming of uranium must be done hot to provide requisite ductility. Rolling of uranium plate is performed by heating the uranium to 650°F and hot working the material. At this temperature, uranium handles very much like copper at room temperature. The uranium plates were heated in an open electric resistance furnace. The plate was first coated with a silicone material, Dow Corning 200 Fluid - a dimethylpolysiloxane, to prevent excessive oxidation during the heating cycle.

The ends of each plate were formed on a press brake before rolling to eliminate any flat area near the welding seam. This preliminary forming operation is shown in figure 6. The uranium was rolled on two large sheet pinch-type rolls - a Smith-Courtney 12 foot by 1 inch and a Webb Model 7L1006S 6 foot by $1\frac{1}{2}$ inch. The cylindrical sections were rolled slightly oversize and then removed from the roll for welding.

Typical roll-forming operations are illustrated in figures 7 and 8. Shims of thin steel $1/16$ -inch thick are used (figure 9) to overcome a tendency of the uranium to "bell" at the ends during rolling. Oxyacetylene torches provide supplementary heat during the rolling operation, and temperature of the plate is maintained above 400°F to provide desired ductility. Plate temperature is measured during forming by using Tempilstiks.

END FORMING OF URANIUM PLATE PRIOR TO ROLLING

Figure 6

3373-10 (U)

URANIUM PLATE BEING STARTED THROUGH ROLL

Figure 7

3373-2 (U)

ROLLING OPERATION NEARING COMPLETION

Figure 8

3373-8 (U)

SHIMS BEING USED DURING ROLLING
TO PREVENT 'BELLING' OF CYLINDER ENDS

Figure 9

CLEANING URANIUM

After the rolling operation, the surface of the uranium plate exhibited some scaling from oxidation and residual silicone fluid. The cylinders were vapor degreased using a combination of liquid rinsing and the condensing action of hot trichloroethylene vapors to remove surface soil. Following degreasing, the cylinders were cleaned by using a dry abrasive. Equipment used was a Vacu-Blast Model 11-P employing a 150 mesh aluminum oxide abrasive. A measurement of surface condition following cleaning indicated that a typical surface was about 125 RMS. After the cleaning cycle, the uranium was wrapped in a 3-mil polyethylene envelope to await welding. The work schedule was arranged so that a minimum of time elapsed between cleaning and welding.

WELDING URANIUM

Welding utilizes heat with or without pressure and with or without filler material to join two pieces of metal. Variations of the thirty or so distinct methods have been investigated for adaptation to welding uranium. Oxyacetylene welding and carbon arc welding produce excessive oxide inclusions, cracks, and porosity. Sigma welding (shielded inert gas metallic arc) produces satisfactory welds with silver plated wire, but the high energy requirements create problems in controlling widespread dispersion of particulate uranium. Welding of uranium at Paducah has been performed almost exclusively by using a fusion welding process with inert gas shielding of a tungsten electrode. This process, commonly called "TIG," was originally developed and patented as the "Heliarc" process, and it has proved adaptable to welding many reactive metals, such as uranium, titanium, magnesium, and aluminum. These metals are intensely reactive at their melting point with atmospheric gases as well as with any flux material which might be used. TIG welding is shielded by inert mono-atomic gas - either helium or argon. Both shielding gases have been used in uranium welding, but helium has been used exclusively for cask construction at the Paducah facility since it produces wider, smoother beads than argon.

Basic equipment requirements for TIG welding are quite simple. No special welding chamber is required, and the cask welding is performed in an open front, covered booth equipped with a positive exhaust system. The electrode holder transmits current to the tungsten electrode, provides a gas shield to displace air around the electrode, and is moved and positioned manually. Current for the cask welding operation was supplied by a National Cylinder Gas rectifier welder with a high frequency response. The machine most commonly used was a Model 66A-BP rated at 600 amperes AC/DC, 60% duty cycle, 40 volts AC/DC, 38 KW, 47.9 KVA. Direct current, straight polarity was used with 400-500 amperes generally used for welding 1/2 inch thicknesses of uranium plate. Shielding gas was supplied in a compressed gas cylinder and regulated to constant low pressure and flow by a regulator and low capacity rotometer. A typical flow rate for helium shielding was 30 cubic feet per hour. Silver plated uranium rods are used for filler material in welding uranium. The silver plating prevents oxidation of the filler material, and the silver forms an insoluble layer which floats on top of the molten weld area preventing introduction or

inclusion of impurities in the weld zone. The filler material was produced by rolling uranium metal into a 1/4-inch thick sheet approximately 30 inches wide and then shearing the sheet to produce rods 1/4-inch square by 30 inches. Small quantities of rods were electroplated at one time to minimize atmospheric exposure, and a two-week supply was kept available for welding requirements. The plating cycle followed is shown in table 2.

Table 2

PROCEDURE FOR SILVER PLATING URANIUM RODS

Cleaning

1. Dry hone.
2. Immerse in a 50% volumetric nitric acid solution for 12 minutes.
3. Rinse in distilled water.

Plating

1. Composition of bath, ounces per gallon:

Silver cyanide	3.3 to 4.4
Free potassium cyanide	4.0 to 6.0
Potassium carbonate	3.0 to 12.0
 2. Operating conditions:

pH	Not controlled
Temperature	70 - 80°F
Current density	30 to 15 ASF
Strike plate for	30 sec at 30 ASF
Plate for	37 min at 15 ASF
-

The weld joint used throughout the cask construction was a butt joint made between two parts laying in the same plane. Edges were beveled to provide a single vee butt joint. The butt joint has been found to produce a weld joint which most closely resembles the base material. Extensive testing of this type joint has proved and demonstrated its superiority under varying conditions.

Certain precautions must be taken during the welding of uranium: the joint must be clean; shielding by inert gas must be complete; the welding area should be free of draft; and whenever possible, the uranium should be welded in the horizontal position. Welding in a vertical position is extremely difficult due to the tendency of the molten uranium to flow.

The welding sequence followed in the cask fabrication called for the welding of one laminate followed by grinding and dry abrasive cleaning of the external surface.

A typical welding operation is shown in figure 10. Heavy duty C-clamps were used to adjust the root gap to the optimum 1/16-inch to 1/8-inch opening. Each laminate was inspected closely at installation to ensure that annular space between adjacent laminates was minimal. Each laminate was composed of two cylindrical sections joined by a circumferential weld. It is noteworthy that this method of fabrication could allow the construction of a cask of any length, being limited only by the load carrying capacity of available equipment. The joints in the cask were staggered vertically and horizontally so that the number of joints in any plane is a minimum. After the first laminate was placed on the core mandrel, the uranium base was welded into position. The uranium base, machined from a massive uranium casting 29-1/2 inches in diameter and 3-1/2 inches thick, was turned on a large engine lathe. A typical lathe used for this operation is a Betts-Bridgeford with a 72-inch-diameter face and a 24-foot bed. After four laminates were installed and welded to the base, the welded top of the laminations was faced off, and the outer laminate was machined to a reference diameter to ensure concentricity. This machining operation is shown in figure 11. The vertical mill used was a Betts which has a 12-foot-diameter table with a 7-foot height under horizontal rail and 51-inch vertical travel of rail bar. The cutting tools used were single-point throw-away type with a groove chip breaker made from Rex AAA high-speed T4 tool steel having a composition of 0.7% carbon, 17.19% tungsten, 0.5% molybdenum, 4% chromium, 1% vanadium, 5% cobalt, and the balance iron. This phase of machining was performed without coolant to prevent the introduction of foreign material into the cask laminates, and it was performed using a slow table speed. The top portion of the stainless liner for the lid recess was installed, and additional uranium laminates were welded in position. The partially completed shield is shown in figure 12 being returned from abrasive cleaning. The silver streaks shown locate uranium seam welds. After the final uranium laminate was installed, the cask was again machined on the large vertical mill to ensure concentricity. Welding of the thicker uranium sections used for the cask lid followed the same general procedure established for welding the 1/2-inch laminates.

HEAT TREATMENT OF CASK

Uranium develops preferred grain orientation during rolling, and in this condition it is subject to thermal cycling growth. Uranium with random grain orientation, such as cast or beta treated material, does not undergo thermal cycling growth. After assembly of all laminates, the cask was beta treated to prevent any growth which could result from thermal cycling. Lack of a sufficiently large vacuum or inert atmosphere furnace necessitated the fabrication of a mild steel container for use in an electric resistance furnace. The cask was placed in the thin-walled mild steel cylinder which was seal welded and pumped down to a vacuum of 0.02 inch of mercury. The vacuum was broken with helium gas, and the container was again pumped to a vacuum. This cycle was repeated several times to fill the voids between laminations with helium. The canned cask was placed in an electric resistance furnace, charged with a slightly positive atmosphere of helium, and heated to 1250°F.

AXIAL WELD BEING MADE ON URANIUM PLATE

Figure 10

3373-7 (U)

MACHINING URANIUM CYLINDER

Figure 11

3373-20 (U)

PARTIALLY COMPLETED CYLINDER
BEING RETURNED FROM ABRASIVE CLEANING

Figure 12

The cask was held at this temperature until all parts of the cask reached equilibrium. The heating cycle was followed by furnace cooling at 50°F per hour. The heat treatment serves to decrease the void space between the laminates and normalizes the coefficient of thermal expansion of the uranium to produce uranium having a lower coefficient of expansion than the stainless steel cladding.

FINAL MACHINING

After heat treatment, the joints at the top of the laminates were seal welded. Previous experience has shown that this action provides significant helium retention between laminates with accompanying improved heat transfer properties. The cask was machined to true up diameter and length. This machining action was performed dry to prevent any contamination of the uranium. Following application of the tungsten coating, the outer stainless steel jacket was installed, and the stainless steel cooling fins were welded in place with full penetration welds. A tungsten coated 'Electric Boat' insert was used behind the longitudinal weld of the stainless steel jacket to maintain integrity of the tungsten diffusion barrier and to facilitate installation of a sound weld. The stainless steel cladding welds were checked with dye penetrant. Pressure adapters were installed in the stainless steel skin, and the welds were soap tested by using helium to pressure the envelope to 2.5 psig. The fabrication of the cask lid followed the same general sequence used in producing the cask except large uranium castings were used rather than laminated uranium plates. Penetration of the uranium shield and stainless steel skin to provide for installation of pressure relief devices was performed using conventional high speed steel drills. A low rotary speed was used and extreme care was exercised to prevent drill breakage. The drilling was performed dry and was interrupted frequently to provide necessary cooling. Sandblasting of the external surfaces completed the cask fabrication. Assembly of the lid in the completed cask is shown in figure 13.

HANDLING OF SCRAP URANIUM

Finely divided uranium can be ignited by rough handling and can ignite spontaneously under certain conditions. The procedure adhered to during uranium fabrication specified that scrap uranium in the form of turnings and chips be removed from the shop daily. At no time was scrap uranium material left unattended in the work area. The uranium scrap generated is not recovered because it is not economical to process. The material is collected in 15-gallon capacity drums and covered with the least expensive hydrocarbon oil obtainable. Burning chips are rapidly quenched in oil, and appropriate Metal-X fire extinguishers are kept readily accessible to machining and fabrication areas. Absolute filters, installed in the exhaust system for the booth where grinding and welding were performed, are replaced periodically, and the exhaust lines are cleaned regularly to prevent accumulation of fines. When filled with scrap, the small drums are moved to a burial area and buried. Drum lids are fitted loosely to permit escape of any hydrogen which might be generated. Water has been used in some locations to cover scrap materials, but this practice has been avoided at Paducah to preclude the generation of hydrogen by water-uranium reaction.

LID BEING INSTALLED ON COMPLETED CASK

HEALTH PHYSICS ASPECTS OF URANIUM FABRICATION

The primary health hazard associated with depleted uranium is its heavy metal chemical toxicity which is similar to that of lead, tin, or cadmium. During fabrication of the demonstration cask, no action was taken to control exposure of personnel to the weak radiation field generated by the depleted uranium. Exposure was monitored by film badges worn by all Paducah Plant personnel. The highest level of exposure during any quarter was approximately one-third the maximum acceptable level set forth by the Radiation Protection Guides of the Federal Radiation Council. These exposures were recorded on the two people who assembled the laminated shield. Since the cask was assembled in Paducah's fabrication shop, there were other people in the area working on unrelated projects. None of these people received more than one-tenth of the acceptable level of exposure.

The principal health problem associated with the fabrication of uranium metal is the control of airborne fumes or particulate matter. The precautions required to prevent ingestion of airborne particles when fabricating uranium are standard in any shop dealing with toxic metals. The fact that uranium is slightly radioactive simplifies atmospheric monitoring. Air samples are drawn through a filter which is then 'counted' to determine the contamination level. All operations were monitored.

Welding and grinding are the only fabrication operations that produce undesirable levels of airborne contamination. These activities must be confined to prevent spread of objectionable contamination. Silver, rather than uranium, was the primary health hazard during welding of the demonstration cask. The TIG welding process does not create large amounts of airborne uranium, but the silver coating on the rods created enough contamination to require respiratory protection. Grinding disperses large amounts of particulate uranium and also requires respiratory protection. Personnel performing welding and grinding were equipped with the Acme Protection Equipment "PUR-A-Weld" mask which incorporates a positive air supply, filters, and check valves to prevent recirculation of exhaust air. Grinding and welding were isolated from other work areas by performing these operations in an enclosed booth equipped with its individual exhaust system, and the exhaust system was equipped with absolute filters to positively confine fine particles generated by the fabrication operations.

Upon completion of cask fabrication, all machine tools which had been used were given routine cleaning and returned to conventional service. Monitoring of the equipment indicated no need for additional decontamination procedures.

COST EXPERIENCE

Quantities and costs of materials required for cask construction are detailed in table 3.

Table 3

QUANTITY AND COST OF
MATERIAL USED TO BUILD THE DEMONSTRATION CASK

<u>Material</u>	<u>Quantity, Lbs.</u>	<u>Cost, \$</u>
Uranium plate	26,000	8,690
Stainless steel	4,500	5,730
Carbon steel	5,500	825
Tungsten powder	100	1,000
Silver powder	10	210
Miscellaneous hardware	-	170
Fabrication materials	-	650
Total		17,275

The cost of uranium plate shown represents the charges for transporting and rolling the uranium from 1100-pound derbies into the required amount of rolled plate. The starting material, uranium derbies, was considered to have no value, and an extrapolation of cost data would have to make a provision for cost of uranium as metal. No credit for surplus material (e.g., scrap) was allowed.

Labor requirements are recapped in table 4. Where applicable, detailed cost factors such as cost per foot of weld are presented.

Total material and direct fabrication labor costs are summarized in table 5. The cost for cask construction amounted to \$1.36 per pound with the cost of the mild steel skid and lifting yoke included.

Table 4

FUNCTIONAL BREAKDOWN OF LABOR
USED TO BUILD THE DEMONSTRATION CASK

<u>Operation</u>	<u>Man-Hours</u>	<u>Unit Cost</u>
Shear and bevel uranium plate	167	0.4 man-hrs/ft
Form uranium plate	189	7.8 man-hrs/plate*
Abrasive clean uranium plate	197	8.2 man-hrs/plate*
Position uranium cylinders for welding	96	4.0 man-hrs/plate*
Weld uranium	88	0.25 man-hrs/ft
Dye check uranium welds	18	0.05 man-hrs/ft
Silver plate uranium welding rods	72	0.03 man-hrs/rod
Beta heat treat uranium	55	--
Machine uranium	910	--
Tungsten spray stainless steel	109	1.2 man-hrs/ft ²
Shear stainless steel plate	219	--
Weld stainless steel	176	0.28 man-hrs/ft
Dye check stainless steel welds	35	0.06 man-hrs/ft
Machine stainless steel	1,635	--
Sandblast stainless steel	18	--
Build skid	409	--
Build lifting yoke	177	--
Engineering inspection	116	--
Direct supervision	860	--
Total	5,546	

*The uranium plate was 1/2-inch thick and ranged from 24 inches by 58 inches to 40 inches by 92 inches.

All times noted in table 4 are the actual times to perform the operation. Auxiliary shop time is not shown in this breakdown.

Table 5

SUMMARY OF FABRICATION COSTS
FOR THE DEMONSTRATION CASK

Cask Description

Weight with skid	28,950 lbs
Weight without skid	25,260 lbs
Cavity size	17-in. diameter by 51-in. deep
Shielding	5-3/4 in. of uranium

Cask Fabrication Cost

Materials	\$ 17,275
Direct labor	22,029
	<hr/>
Total	\$ 39,304

Notes:

1. Materials include uranium metal derbies at zero cost.
 2. Labor includes direct supervision and inspection.
 3. The total cost includes \$3,015 for the skid and lifting yoke.
 4. Fabrication cost factor is \$1.36/pound of cask weight including skid and yoke. It must be remembered that this factor covers only fabrication. As such, it includes the cost to convert uranium derbies into plate, all materials used in the fabrication of the cask, and all direct labor costs including supervision and inspection.
-

ACKNOWLEDGEMENTS

The assistance and helpful comments of Messrs. F.H.Amonett, S.Bernstein, H.D.Bewley, C.B.Clifford, W.R.Golliher, B.P.King, D.H.Stitt, and G.O.West are gratefully acknowledged.

REFERENCES

¹ Schedule 189a, Justification for Operating Costs and Equipment Obligations for Reactor Development Progress; No. 24 0019 001, dated June 16, 1966.

² Loveland, C. W., Stitt, D. H., and Bernstein, S. Demonstration Fuel Element Shipping Cask from Laminated Uranium Metal. Part I - General Information, Background, and Design, April 1969, KY-550.

³ Clifford, C. B. Demonstration Fuel Element Shipping Cask from Laminated Uranium Metal. Part III - Tests and Demonstrations, March 1969, KY-552.