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BORAX-IV REACTOR: MANUFACTURE OF FUEL
AND BLANKET ELEMENTS

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FOREWORD

This report describes the development of methods for and the fabrication of the fuel elements used in the reactor employed in the Borax-IV tests.

Fuel in the reactor is U^{235} supplied by high-fired ThO_2 -6.35 w/o UO_2 right cylinders, approximately 0.225 in. in diameter, and varying in length from 5/16 in. to 5/8 in. Blanket material, Th^{232} , is supplied by high-fired ThO_2 right cylinders of approximately the same dimensions. The cylinders are sealed within tubes in aluminum-1 w/o nickel (Alcoa M-388) alloy tube-plates. These are extrusions containing eight tubes, which are spaced and separated by integral webs as shown in Figure 1, in the same plane. In the interests of manufacturing economy, the tube-plates are not sized after extrusions; nor are the fuel or blanket cylinders sized after firing. Large clearances between cylinders and tubes are therefore provided to permit easy assembly. The resultant annular space of about 0.012 in. (per side) is filled with lead which does not wet but is in good mechanical contact with the tube and ceramic surfaces.

Each fuel (or blanket) subassembly contains six loaded tube-plates arranged in an MTR-type array. The tube-plates are electric-resistance spot-welded at their edges to 0.046-0.056 in. thick aluminum alloy (M-388) side-plates as shown in Figure 2. Blanket subassemblies contain blanket material (ThO_2) only. Fuel cylinders (ThO_2 - UO_2) are used exclusively in the fuel subassemblies. A single tube in one plate of each fuel subassembly is empty and open at one end to permit insertion of a boron (2 w/o) - stainless-steel rod if desired. Such a plate is shown in its specified location, second from the top, in the photograph, Figure 2.

Cast-and-machined aluminum alloy (356) end-fittings are welded to the fuel subassembly by plug welds made by hand with the inert-gas tungsten arc method. Aluminum (M388) wire, hand fed into the joint, supplies the necessary filler metal. Photographs of an assembly in exploded section and after plug welding are shown in Figures 3 and 4, respectively.

Division of Responsibility

The ANL Metallurgy Division through its Ceramics Group and Coating and Jacketing Group was responsible for:

1. The development of manufacturing and inspection techniques for:
 - a. Fuel and blanket cylinders.
 - b. Loading, lead filling, and sealing fuel and blanket tube-plates.
2. Manufacture of the above items.

Central Shops (ANL) performed all of the machining operations and manufactured the fuel subassemblies and assemblies using procedures adapted from those previously followed for the Borax-III fuel loading.

This report will not describe the making of the fuel and blanket bodies. It will discuss in detail the preparation, sealing, and testing of the fuel and blanket tube-plates. Only a brief description of the subassembly and assembly manufacturing operations will be given because the techniques employed are well known.

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BORAX-IV REACTOR: MANUFACTURE OF FUEL AND BLANKET ELEMENTS

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ABSTRACT

This report describes the procedures used in fabricating the core loading for the natural water-cooled Borax-IV reactor. Manufacturing of the fuel plates and blanket plates, which contain fissile (U^{235}) and/or fertile (Th^{232}) material in ceramic form, lead-bonded within tubes in aluminum-1 w/o nickel extrusions, is described in detail. A brief description of the assembly and welding of the finished plates into subassemblies and assemblies is given. Preparation of the ceramic bodies has been described by others in ANL-5669 and ANL-5678.

INTRODUCTION

A group of tests, the Borax-IV series, is to be run in the ANL Borax facility at Arco, Idaho. Their purpose is to determine the response of a boiling water reactor to a low-thermal conductivity fuel having a long thermal time constant. A ceramic, thoria (ThO_2) containing 6.35 w/o urania (UO_2 -highly enriched) in solid solution, has been selected as the fuel material because of its interesting properties and simple fabricability. The material is single phase, melts at a high temperature, undergoes no phase changes up to its melting point, and is inert to high-temperature water. Bodies of this general composition which have been irradiated to various burn-up levels have been rather stable dimensionally, according to Kittel and Handwerk.(2)

A process developed at ANL permits the use of U_3O_8 as the uranium-bearing starting material.(1) Thus, furnaces equipped with potentially dangerous or expensive atmospheres are not required for firing. All the ingredients necessary to manufacture the bodies, including the ThO_2 and U_3O_8 , are readily available at relatively moderate cost. The finished ware can be made to fairly high fractions (85 to 90%) of theoretical density by simple, economical means, and the ware is not overly fragile.

An aluminum-nickel alloy (M-388) was used as cladding for the ceramic bodies and for all of the side plates in the fuel and blanket subassemblies. The choice of this alloy was governed by a considerable amount of corrosion data,(3) much of it obtained in water at temperatures and pressures higher than those at which the Borax reactors are usually operated

(300 psia - 215°C Max). Use of M-388 is expected to furnish additional useful information on the behavior of this material under boiling reactor conditions.

The core loading contains both fuel and blanket assemblies; all were fabricated at ANL from components made here with only a few exceptions. Eighty-one assemblies were produced; seventy-two contained fuel, while the remainder were blanket assemblies. This required the manufacture of 430 fuel tube-plates and 54 blanket tube-plates. In 72 of the former, one fuel tube was left vacant to provide for the insertion of a poison (boron steel) rod, as has been described. These will be referred to as poison tube-plates. With the one exception noted, all tube-plates were identical in external appearance and dimensions. Every filled tube in each tube-plate contained 24 to $24\frac{3}{4}$ inches of ceramic material. All other pertinent dimensions are given in the drawing of a typical finished tube-plate, Figure 5. Note the 0.004 to 0.006-in. high ribs on the inside of each tube. Their function was to roughly center the pellets by limiting the minimum annulus to the order of the rib height.

Fabrication of the fuel and blanket plates consisted essentially of (1) sealing one end of the tube plates; (2) loading these with the appropriate ceramic bodies; (3) filling the annular space with lead, and; (4) sealing the second end to effect the final closure. To fabricate the entire core loading it was necessary to develop dependable techniques for the performance of these major operations and for a number of minor steps, including those necessary for the acceptance testing of the final product. Because time was limited, development work was performed concurrent with the manufacturing effort by the same personnel. As a result, process refinements which affected the ultimate quality of the product or the production rate were constantly being developed. These refinements affected almost all manufacturing operations.

MANUFACTURING PROCEDURE; FUEL-PLATES AND BLANKET-PLATES

A flow sheet which summarizes the operations required to fabricate the fuel-plates and blanket-plates is included as Figure 6. A more detailed description is as follows:

Tube-Plate Extrusion

The tube-plate extrusions were obtained from the Precision Extrusions Corporation in Bensenville, Illinois. Extrusion was done at 425°-450°C on a 1500-ton horizontal extrusion press. The die was a porthole type, designed and built by the Moczik Die and Tool Company, Detroit, Michigan. Because of the width of the section, 6-inch diameter billets were used. It is

of interest that in extruding these sections, personnel of Precision Extrusions reported the extrusion characteristics of M-388 to be superior in their estimation to those of alloy 1100.

After extrusion the sections were stretch-straightened while still in long lengths. The straightened sections were cut into 36-inch lengths prior to shipment to Argonne.

Upon receipt at Argonne, the extruded sections were checked on a spot-check basis to determine their conformity with the dimensional specifications shown in Figure 1. No rejections were made on this basis after the first series of die corrections.

To provide a means of handling the plates in process, the first operation was to punch a 1/4-inch diameter hole in each flange at one end of every plate.

Fuel and Blanket Plate Loading

First End Closure; General Discussion

The end closure was achieved by a high-temperature pressure brazing technique developed by Noland and Walker at ANL. This process employs elemental silicon in granular form; the silicon is applied as a suspension in glycerin and alcohol to both faces of the sections to be joined. The coated faces are brought into intimate contact with each other and are then placed under pressure in press-mounted dies maintained at a temperature above the melting point of the aluminum-silicon eutectic (571°C). Pressures of the order of 1000 to 2000 psi are exerted on the work until it reaches the desired temperature, generally 595°-600°C. After being at temperature a suitable length of time, the work is cooled under pressure to a temperature of the order of 500°C, the press opened, and the work removed. Joints made in this manner were sound, and the process was reproducible as determined by examination of a rather large number of samples. As is shown in the photomicrograph of a typical joint (Figure 7), little or no residual aluminum-silicon eutectic remained, the excess having been squeezed out during pressing. It should be noted that no fluxes of any type were used. Cleaning before the closure operation consisted of degreasing only.

Explanation of the mechanism underlying the process is the fact that silicon powder is hard and sharp. Thus, under pressure, it is able to perforate the oxide film on the aluminum to establish an oxide-free aluminum to silicon diffusion interface, as is shown schematically in Figure 8. Because the joint surfaces are under pressure, no oxygen can reach the joint for reoxidation to occur. When a sufficiently high temperature is reached, the silicon reacts with the bare aluminum with which it is in contact.

locally forming aluminum-silicon eutectic (Figure 9). Upon melting, the eutectic alloy undermines the oxide on both sides of the joint, and the applied pressure forces the liquid alloy and oxide out of the joint area, completing the joint.

Preparation for Closure

Steps in effecting the first end closure are illustrated pictorially in Figure 10.

Flattening of the tube ends was a prerequisite for a hot-pressed closure. To allow uniform flattening to take place, the separating webs between the tubes were removed from the first 1/2 inch of each plate. Removal of all the webs was done simultaneously in a gang-mill operation employing 7 milling cutters (Figure 11). An actual operation in progress is shown in Figure 12.

After machining was completed the tube plates were degreased with trichloroethylene in a vapor-spray-vapor-type degreaser. In order to provide intimate joint contact the internal rails were next removed from the top half inch of each of the tubes, as is shown in Figure 13. This operation was performed by hand with a stainless-steel bristled wire brush (Osborn No. 42-K-8) mounted in a high-speed grinder. Because the brush was slightly wider than the inside diameter of the tubes, an interference fit was obtained, which automatically applied radial pressure against the tube ribs. Thus, rib removal was accomplished by pushing the rapidly spinning brush into the open tube and withdrawing it; one insertion and removal cycle was sufficient.

Silicon Application

Silicon powder, suspended in an alcohol-glycerin vehicle, was applied to the inner faces of each tube with a small artist's brush as shown in Figure 14. Application of this suspension was not especially critical, but its composition had a direct effect on the leak-tightness of the finished joints. An overabundance of silicon resulted in the retention of unreacted amounts of this element in the hot-pressed joint. The unreacted material remained in loose powder form (Figure 15) and prevented the joint from being consummated, permitting leaks. To achieve satisfactory, leak-tight joints on a reproducible basis it was necessary to: (1) control to a moderately close degree the amounts of silicon powder, glycerin, and alcohol which made up the mixture, and (2) control the silicon powder particle size fractions. The most satisfactory results were obtained with a suspension containing 0.25 gram of silicon per cc of a vehicle made up of 67 w/o glycerin, 33 w/o ethyl alcohol. The particle size range of the silicon was as follows:

<u>Mesh Range</u>	<u>wt %</u>
-200 + 325	84.0
-100 + 200	16.0

Table I lists 2 different suspension compositions and the percentage of leak rejection which was obtained on leak testing tube-plates employing each composition. In almost all cases where leaks were found they were present in only one of the eight tubes in each tube-plate. Because eight tubes were sealed at once with this process, it might not be considered unfair to multiply the number of test pieces by the factor of 8. On this basis, even the highest rejection rate is reduced to a rather reasonable figure. Note that by far the best results were obtained with the composition given above, which was used on 341 plates of which only 2 were found to contain leaks. The leaks could be detected at only the highest sensitivity available with the Consolidated mass-spectrometer leak detector used. Every one of these plates was produced after the suspension had been in use for six to eight hours; the composition and/or viscosity of the suspension had been altered somewhat by the combined effects of drag-out and selective evaporation of the alcohol in the vehicle. Replacement of the questionable suspension with a fresh supply invariably resulted in the production of tight closures.

Table I

FINAL CLOSURE; EFFECT OF SILICON CONCENTRATION

Suspension No.	Glycerin, v/o	Alcohol, v/o	Si, grams/cc of Vehicle	Plates Tested	Leaks
6	67	33	0.35	135	14
8	67	33	0.25	339	2*

*Not in Closures.

Following the application of silicon, the vehicle was driven off by heating the end of the tube-plate with an oxy-acetylene welding torch, as shown in Figure 16. For this purpose, a slightly oxidizing, soft flame was used. Removal of the vehicle was judged to be complete when a blue-yellow flame and/or light smoke no longer issued from the tube ends.

Cold Flattening

To put the joint surfaces in intimate contact, the silicon-coated tube ends were cold flattened for about 1/2 inch of their length. This was done in hardened tool steel dies mounted in a Riehle hydraulic-powered

universal testing machine. A photograph of this setup is shown in Figure 17. Note that the bottom die has mounted to it a back-stop which prevents the tube-plate from being inserted too far. A length of angle iron fastened to the bottom die shoe was used as a side guide to assure positive, correct alignment between the tube-plate and the dies. The full capacity of the 60-ton universal testing machine was used for this operation; this gave a flattening pressure of the order of 2.5 tsi. Selection of the specified pressure was arbitrary; no attempts were made to demonstrate that lower pressures were sufficient. The thickness throughout most of the flattened section averaged 0.047 inch; thus an increase of about 0.005 to 0.010 inch in section thickness occurred in this operation.

At some locations in every flattened section, however, no increase in thickness occurred, and the local thickness was as low as 0.037 inch. Because of these thin spots it was necessary to use sufficient pressure in the subsequent hot-pressing operation to reduce the final thickness after hot pressing to 0.030 to 0.032 inch.

Hot Pressing

To prevent the hot dies from sticking to the aluminum surfaces, the flattened faces were painted with a suspension of polishing grade alumina (Linde B) in water. This coating was allowed to dry before proceeding to the next step.

To effect the seal, the joint was put under a pressure of about 2000 psi in heated stainless steel dies mounted in a small universal testing machine. A photograph of the die setup in place is shown in Figure 18. Two dies were used: a top die and a bottom die, both identical. The dies, machined from solid blocks of Type 304 stainless steel, were made to conform with the drawing shown in Figure 19. Essentially each was a heavy slab, 2 inches thick x 3 inches wide x 6 inches long, which had as a working face a tongue-like projection, 1/4 inch thick x 1/4 inch wide x 6 inches long. Heat was supplied to each die by a group of four 250-watt cartridge-type electric resistance heaters which were fitted closely to the 0.501 to 0.503-inch diameter holes shown. The temperature of each die was independently controlled by means of a variable transformer and an automatic temperature controller. A chromel-alumel thermocouple buried in the geometrical center of the projecting tongue of each die acted as the temperature-sensing element. Insulation against excessive thermal losses was provided by a suitable insulating material held in place by a thin stainless steel can. A closeup photograph of the dies in the open position with a workpiece in place is shown in Figure 20.

The pressing sequence used was:

1. Place tube-plate in hot dies.
2. Close dies, and immediately raise pressure to 2000 pounds total (2000 psi effective on joint).

At the conclusion of step 2, the control of the operation (except for maintenance of pressure) was assumed by an automatic control circuit. This circuit was mounted on the right-hand panel in the photograph of the control equipment (Figure 21). The automatic control circuit was responsible for (1) controlling the length of time the workpiece was above the aluminum-silicon eutectic melting temperature; (2) opening a solenoid valve which permitted a blast of cold compressed air to be directed at the workpiece and the die fingers upon the conclusion of hot bonding; (3) and turning off the air blast when the temperature of the workpiece in the dies reached 500°C. At the conclusion of the hot-pressing operation, the automatic device signalled the press operator, who opened the press and inserted a fresh workpiece. As indicated, the die fingers and work were cooled down to 500°C at the conclusion of the pressing stage. This step was arbitrarily selected. Its purpose was to prevent the joint from being pulled apart in the event the work adhered to both dies. Although adhesion to the tools did not occur, the cycle was not changed to eliminate the cooling period.

Trimming

No attempt was made to hot seal the tubes to their very ends; thus a small section at the end of the flattened area remained unbonded. This section was trimmed off by hand with an ordinary photographic print trimmer, as is shown in Figure 22. The operation consisted of trimming the end of the plate and a 45° chamfer at each edge to provide an end similar to that shown in Item 5, Figure 10.

Leak Detection

After each plate was stamped with a suitable identification number, the closures and the tube-plates were tested for leaks with a helium-sensitive mass-spectrometer leak detector, using the setup illustrated in Figure 23. The tube-plates were first evacuated to a pressure of the order of 50×10^{-3} mm Hg by means of an accessory vacuum system powered by a single roughing pump. Connection of each tube-plate to the inlet of the accessory system was accomplished by means of a fitting which permitted all eight tubes to be evacuated simultaneously. A photograph of such a fitting by itself, and mounted in place on a tube-plate is shown in Figure 24. Upon reaching the aforementioned pressure, the leak detector (Consolidated model 24-101A) was valved into the vacuum system, its controls set for maximum sensitivity, and the plate end was bathed in helium, using the bag technique (Figure 22). If the closure was found to be leak-tight, the operator sprayed helium on both sides of the tube-plate from top to bottom to check the rest of the plate. None were found to contain leaks at places other than the closure. To check the performance of the leak detector, it was calibrated several times during each eight-hour shift by means of a

calibrated standard leak permanently attached to the equipment. To speed up production, the valving on the accessory vacuum system was devised to permit simultaneous evacuation and testing of up to four tube-plates.

Loading with Fuel or Blanket Pellets

Loading of the tube-plates with fuel or blanket material was done by members of the Ceramics Group of the Metallurgy Division under the direction of Mr. J. H. Handwerk. The apparatus used is shown in Figure 25, a photograph taken in process. The loading device consisted essentially of a flat steel plate, approximately 6 feet long, arranged at an angle of about 20-30° to the horizontal and attached at its center to a Syntron Vibrator. To the top end of this plate was fixed a stainless steel magazine which contained grooves machined to line up with the tubes in the tube-plates. A clamping and alignment device was located at the bottom end of the magazine at a point just above the Syntron Vibrator. By means of this device the open ends of the tubes in the tube-plates were positively aligned opposite the grooves in the magazine and were held in place during the loading operation. A slot was cut in the alignment device at a point coincident with the end of the magazine to allow the insertion of a thin sheet metal gate. This gate prevented the pellets from sliding into the tube-plates while the magazine was being loaded.

The operation was performed as follows:

1. Assemble empty tube-plate to loading fixture and clamp in place.
2. Insert pellet gate.
3. Load each groove in loading magazine with $2\frac{1}{4}$ to $24\frac{3}{4}$ inches of pellets. Place a single 0.230-inch diameter by $1\frac{1}{2}$ inch long aluminum (M-333) slug at the top end of each row of pellets.
4. Remove pellet gate and vibrate charge into place, using small diameter gauging-and-pushing rod to assure that proper filling is achieved.
5. Gauge distance between top of last pellet and tube and in each of the eight tubes with Go-no-go-type gauge. Continue to vibrate until correct distance is obtained.
6. Indent each tube just above the aluminum pellet to prevent pellets from floating out in subsequent lead-filling operation.

During vibration it was possible to increase the amplitude of the Syntron Vibrator in order to free pellets which had become jammed. When jamming occurred, the operator pushed by hand a small diameter stainless steel rod against the jammed column to assist the pellets into place.

Because the greatest amount of work was done with the loading of pellets containing highly enriched uranium, measures were taken to insure close accountability for this material. In the photograph of the loading fixture (Figure 25), note that the table on which the fixture is mounted is covered with a plastic material to catch and retain any ceramic fragments. To determine the exact fuel charge, each plate was weighed to a precision of 0.1 gram before and after loading. These weights were logged in a bound notebook and are recorded in ANL-5678.

Following filling and weighing, the plates were coated on their outside surfaces with a mixture made up of 0.18 gram of polishing grade alumina (Linde B) per cubic centimeter of a liquid composed of 40 v/o glycerin, 60 v/o methyl alcohol. When in use, the liquid was stirred continuously.

This coating was intended to discourage adhesion of lead to the aluminum surfaces in the lead-filling operation. It was applied by hand with a soft camel's hair brush, and the material was thoroughly brushed onto the aluminum surfaces. Application by spraying and dipping was investigated, but the resultant coats were not satisfactory. To dry the coating, it was necessary to bake the plates at 240°C for 30 minutes.

The inner faces in the empty zone of each tube were next coated with a suspension of colloidal graphite in alcohol.

This suspension was applied by hand with a swab made from an oversized pipe cleaner. The purpose of this coating was to simplify subsequent removal of lead from the free volume above the charge.

Lead Filling

Loading Plate-Racks

The devices which carried the tube-plates in the lead-filling operation are called plate-racks. These were made of type 302 stainless steel and were capable of holding as many as six tube-plates; an unloaded rack is also shown in Figure 26. Five tube-plates were suspended in each plate rack on a pair of 3/16-inch diameter stainless steel rods passed through the mounting holes in the tube-plate flanges. These rods can be seen in Figure 26.

Lead-pulling cables, twelve-inch lengths of 1/8-inch diameter stainless steel cable, were next installed. These were inserted inside every tube and extended down to the indentation in each tube. To prevent fraying, the cables were inert-gas tungsten-arc welded at both ends. One strand was left free from the mass at the bottom end of each cable. This was done to provide the cable a better grip on the lead in the subsequent

lead-removal operation and to prevent it from floating out in the lead-filling operation. A lead-pulling cable is held by the operator in Figure 27. Perforated metal strips and various types of screening were tried as substitutes for the cables. None of the substitutes were satisfactory.

Lead Filling

Lead filling of the annulus between the ceramic pellets and the tubes was accomplished by submerging the tube-plates, in groups of five, into molten lead held at a temperature of 490° -500° C. The lead was held in a resistance-heated carbon-steel pot, 12½ inches I.D. by 6 feet deep. Prior to complete submersion, the tube-plates were inserted into the bath to a point just below their open ends. They were held in this position for 10 minutes to allow their contents to reach the temperature of the lead before filling. After lead filling, the loaded plate-rack was slowly inserted into a tank of cold water to force directional solidification from bottom to top, thus minimizing shrinkage porosity, etc.

In sequence, the lead-filling operation was as follows: The plate-rack was first fastened to a long vertical arm by means of a quick-acting bayonet-type connector. The vertical arm was fixed to a movable cross-head mounted on rollers connected to an elevator driven by an air cylinder controlled with a four-way valve. Two steel pipes, mounted to a base plate which was bolted to the furnace top, guided the elevator. The photograph, Figure 28, taken just prior to the start of the lead-filling operation, illustrates this equipment. From this point the operating sequence is as follows:

1. Lower the group of tube-plates into the lead to a point 1 inch below their open ends (Figure 29). Hold in this position ten minutes to allow complete preheating to take place.
2. Lower tube-plates approximately 1 inch below the surface of the molten lead. Retain in this position until bubbling of gas is no longer evident.
3. Lower fixture 3 feet to bottom of lead pot. Hold until bubbling ceases.
4. Raise fixture so that the tube ends are just below surface of the lead. Hold in place until bubbling stops. Up-and-down oscillation is continued until no bubbling is observed when the tube-plate ends are just beneath the surface of the lead. This indicates that all of the air in the annuli has been replaced with lead.
5. Raise fixture completely out of lead to a point sufficient to allow clearance beneath bottom of tube-plates and furnace top.

6. Grasp vertical arm, and slide crosshead and fixture into position above water-quench tank (Figure 30). Lower fixture slowly into water to a point 2 inches below the top of the tube-plates. Do not allow water to enter the open ends of tube-plates.
7. Raise plate-rack out of water and remove it from vertical arm.

Steam produced on the surfaces of the hot plates during quenching created sufficient agitation in the water to remove essentially all of the alumina barrier-coating from the tube-plate surfaces. Continuity of the lead layer was excellent with the above procedure, as indicated by radiography and/or autoradiography. During the development period all lead-filling procedures were evaluated for lead continuity by stripping the aluminum jacket in a solution of dilute hydrochloric acid, thus exposing the lead film to open view. During the production runs, stripping samples were periodically run as a check on process performance. Also, one plate selected at random from each plate-rack load was radiographed before the rack load was accepted. None were rejected for this reason. Cross sections of a loaded and lead-filled tube-plate are shown in Figures 31 and 32.

Annular clearances of less than 0.002-0.004 inch could not consistently be filled with lead. Consequently, the extrusion die was altered to permit extrusion of 6 evenly spaced longitudinal ribs, 4 to 6 mils in height, around the inner periphery of each tube. However, it is of interest that extremely small crevices within the ceramic bodies were filled with lead; for example, lead was found between the butted ends of the pellets in many of the samples which were stripped for examination. Also, lead was found to have permeated many of the lower-density pellets used in the development runs. This suggests the possibility that superior thermal-conductivity might be achieved if such pellets are deliberately used. The exact density of the latter pellets is not known.

Lead Removal

Removal of the lead from the space above the pellets was necessary in order to provide a free volume within each tube and to permit an end closure to be made. Lead removal was done in two steps:

1. With the plate upside down, approximately the top 6 inches of each tube-plate was submersed in molten lead for 3 minutes, leaving a 2-inch slug of lead in place above the aluminum pellet.

2. Each tube-plate was then mounted in a holding fixture attached to a small tensile-testing machine, and the remainder of the lead was physically pulled from within each tube. In pulling, each lead slug fractured in the annulus at the top of the aluminum slug at the head of each column of charge. Removal of the lead in this fashion acted to broach dross and other loose films from the inner surfaces of the tubes; thus somewhat of a cleaning operation was provided. A photograph taken at the conclusion of a lead removal operation is included as Figure 33. Note the plastic bag around the lower end of the holding arrangement. Its purpose was to catch any loose fragments of enriched uranium which had become dislodged into the lead.

Final Closure

Prior to final closure the tube-plates were cut to a length of $28\frac{1}{2}$ inches using the power saw set-up shown in Figure 34. The separating webs were removed in the same manner as for the first closure. No lubricants or coolants were used in either of these operations.

Next, as a precaution, the plates were baked in groups at 300°C for a minimum of 1 hour to drive off volatile materials which might have accumulated within the tubes. Such volatiles were known to be capable of severely deforming or even rupturing the closed tube ends during final hot sealing.

Preparation of the tube-plate for final closure and the final closure operation itself resembled closely that necessary for the first closure, except for a few minor changes. The process steps were as follows:

1. Wire brush inside of tube walls.
2. Apply elemental silicon suspension.
3. Drive off vehicle in suspension by hand with oxyacetylene torch.
4. Bake in groups of 12 for 30 minutes at 300°C to guarantee complete removal of glycerin and alcohol.
5. Cold flatten ends, filling free space above pellets with helium during flattening operation.
6. Apply alumina separating compound to flattened faces.
7. Hot press.

Of the above steps, note in Step 5 that reference is made to the filling of the free space above the pellets with helium. This was done to supply a source of helium in each tube for subsequent leak detection. Filling

was automatically accomplished during the cold-flattening step by employing a manifolded stop at the back edge of the bottom die, as shown in open view of the die arrangement, Figure 35. Eight holes were drilled into the face of this backstop to coincide with the tube-plate ends. These holes communicated to a manifold connected to a cylinder of helium. A solenoid in the supply line between the manifold and the cylinder controlled the gas flow. In operation, the press operator pushed the end of the tube-plate tightly against the face of the backstop and started the press in motion. At about the time the top die made contact with the tube-plate, the microswitch shown on the left-hand side of the photograph was operated by descending head of the press, thus causing the gas-flow solenoid to open. As the press head continued its downward stroke, the tube ends were flattened as the helium flowed into place. When the section was completely flat, a second microswitch was contacted, closing the solenoid, and stopping the flow of gas. A number of tests using a mass-spectrometer leak detector definitely confirmed that the technique was effective in filling the free space with helium. It was also shown that the helium remained in place in a cold-flattened sample at atmospheric pressure for at least a week, and probably longer. Methods other than the above were considered as means of incorporating the helium supply. Among these were the use of short lengths of helium-filled polyethylene or fusible metal tubing, pinch or heatsealed at their ends to retain the gas. None of these approaches were investigated.

The hot-pressing cycle for the final closure differed from the initial hot-closure step in only two respects. First, the length of time the work-piece was in the die was increased from 4 minutes 15 seconds to 6 minutes 30 seconds because of the additional mass of the ceramic pellets, the lead, and a chill. Use of a chill was the second change. It consisted of a small water-saturated cellulose sponge which was held against the upper face of the tube-plate at a point as close to the dies as possible. Its function was to prevent the lead from melting and running out of its annular position into the free space. The sponge was satisfactory in all respects and completely prevented melting of the lead. Sponge life was indefinite, averaging approximately 100 pieces. A photograph illustrating the tube-plate and chill in position for hot pressing is shown in Figure 36. A small tray located beneath the sponge and tube-plate served to catch any water dripping from the sponge and held water to wet the sponge between operations. Solid metal chills and precision-machined water-cooled metal chills were found to be unsuitable.

Poison-Plate Fabrication

The poison plates were fabricated in a fashion similar to that described for the fuel tube-plates, except that provision was made to provide an empty tube open at one end in each plate. This was done by not loading fuel pellets into one of the tubes adjacent to the plate center (tube 4 or 5). Prior to loading with pellets, a 1/8-inch diameter hole was drilled through

the empty tube section adjacent to the flattened area at the bottom of each poison plate. While the lead was still molten after the lead-filling operation, the lead was allowed to drain out through this hole before proceeding with the directional-quenching step. To ensure that no lead remained at the bottom of the empty tube, the subject area was carefully heated with a gas torch, and a 3/16-inch diameter rod was used to force out any remainder. The final end closure was effected in the same manner used for all other tube-plates: the entire section was flattened and then hot-pressed. To provide an opening to permit insertion of the stainless steel-2 w/o boron rod, the empty tube was machined open for a short distance on a milling machine equipped with a 5/16-inch diameter end mill. A poison plate with the open tube clearly visible is shown in the photograph of a typical fuel subassembly, Figure 2.

Final Closure; Leak Testing

Leak testing was done with a helium mass-spectrometer leak detector using a modification^(a) of the evacuated chamber technique.^(b) In general, this method involves treating articles to be tested so as to put helium in any voids present. The articles so treated are then placed in a chamber which is next sealed and evacuated to a predetermined pressure (vacuum). The atmosphere remaining within the chamber is then sampled for helium by noting the leak rate over a short-time interval. Leak-rates in excess of a certain value fixed by prior experiments are taken as an indication of the presence of leaks.

Specifically, the following practice was used in testing the subject plates. The plates were first placed in the cylindrical chamber shown in Figure 37, which was then sealed and evacuated to 150×10^{-3} millimeter Hg (absolute) by an auxiliary roughing pump. At this point, the auxiliary pump was isolated from the system, and a throttle valve on the leak detector was opened slightly to draw a continuous sample of the chamber atmosphere into the spectrometer. With the pressure in the leak detector maintained at 0.1×10^{-3} mm Hg by hand adjusting the throttle valve, the leak rate on the leak detector was noted over a period of about 1 minute. If the leak rate value fell to 0.4^(c) or lower by the end of a minute, the plates under test were considered to be leak-tight. A leak rate significantly higher than 0.4^(c) was due to (1) helium absorbed on the plates, or (2) one or more closure leaks. To differentiate between absorbed helium and leaks, the throttle valve on the detector was closed, the chamber re-filled with air, and the above evacuation and detection cycle repeated. Repetition of the

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- (a) Modification developed by C. C. Stone, ANL.
 - (b) STP-223, Helium Leak Detector Test for Nuclear Reactor Welds, by W. J. McGonnagle, to be published by ASTM.
 - (c) Std. cc/sec air at 15 psi differential across leak. Exact value requires calibration with standard leak.

evacuation-and-leak detection cycle more than three times was seldom required, because the leak rate reached a steady value, either high or low, which permitted a definite conclusion to be reached. The number of cycle repetitions necessary was shown to be an inverse function of the length of time intervening between the time the final closure was made and leak testing; the longer the intervening time, the smaller the number of repetitions. The relationship thus indicated was shown to be related to the amount of helium which remained on the plate surfaces when the plates were introduced into the leak-testing chamber. To determine whether it was possible for helium (at room temperature-atmospheric pressure) completely to leak out of a faulty closure over an interval of a few hours to a day, an exaggerated leak was simulated by making a sample plate in which the final hot closure was omitted; e.g., the helium was sealed in place by a cold-flattened closure only. This plate was put through several evacuation-leak testing cycles a day for two weeks. Constant, high leak-rate values were obtained at the end of every cycle for the entire period. It was thus concluded that insignificant leakage was likely to occur.

Leak-rate values of plates with tight closures were found to be lower than those with faulty closures by a large factor, regardless of the sensitivity level used for detection. In addition, the initial leak-rate values were almost always significantly lower for tight closures, and the rate dropped exponentially either as sampling continued or in subsequent testing cycles. Leak-rate values of plates containing leaks remained at a constant high value regardless of the number of testing cycles employed.

The plates were leak tested in groups of 12. If a high leak-rate value was obtained, after two or three cycles, half of the plates were removed from the chamber and the remainder checked. If the value remained high, half of the plates were again removed and the remainder checked. This process of grouping and then splitting in halves continued until the faulty plates were isolated. Examination of the plates in groups as indicated was possible largely because of the very low number of faulty closures found.

Of the first 135 plates tested, 14 were found to contain leaks. As had been the case in the first closure, all of the leaks were shown to have been caused by an excess of silicon in the joint. After these plates had been run, stringent controls were put in force to maintain the composition of the silicon suspension within the range previously specified as optimum. After these measures were taken, 339 plates were sealed. No leaks were found in the closures of the plates which made up this group, again emphasizing the importance of closely controlling the composition of the silicon suspension.

Plates rejected for leaks were repaired by cutting off the flattened tube section on a circular saw, followed by carrying the salvaged plates through the same process steps originally employed. All but 2 of the rejected plates were repairable with this technique. The plates which could not be repaired were found to leak away from the closure in an area which had been perforated accidentally in process.

Another test which was designed as a proof test for leaks was performed on a small number of plates which had successfully passed mass-spectrometer leak detection. This test involved placing 10 to 12 tube-plates in a water-filled pressure vessel. The pressure vessel was sealed and additional water was pumped into it with a high pressure hand pump until the internal pressure of the system reached 500 psi. This pressure remained on the system for one hour, following which the pressure was reduced to atmospheric and the vessel opened. After the plates were dried, they were inserted, final closure end first, into oil at 300°C. It was expected that any water which had been forced into the free space within the tube-plate would be rapidly converted into steam, thus developing sufficient pressure to severely deform the section. Only a few dozen plates were tested in this manner. None failed the test. When it was found that plates known to leak when tested by the helium mass-spectrometer method invariably passed the proof test, the test was discontinued. As a further check for the presence of volatile materials within the tubes, the immersion of the final closure ends of the tube-plates into 300°C oil or lead was continued. All plates tested were satisfactory.

To prepare the plates for subsequent processing it was necessary to remove small amounts of lead which had adhered in isolated spots on the external surfaces of almost all of the plates. Lead removal was a tedious, slow operation. The fact that it was necessary indicated the inadequacy of the alumina barrier compound. A number of methods, such as coating with colloidal graphite, chemical oxidation of the aluminum, etc., were investigated in attempts to prevent adhesion. None were found to be completely satisfactory; most were found to be rather unsatisfactory. Among the latter were removal by means of power-driven wire brushes, fibre-bristled brushes, and cloth buffs. All of these spread the lead over a broader area, causing it to adhere more tightly to the aluminum surfaces. Almost all of the plates were cleaned of lead by using hand methods employing stainless steel wool, aluminum wool, metal-bristled hand brushes, and thin metal-bladed scrapers. Toward the end of the production run, two methods under concurrent development and use were found promising. One method involved immersion of the tube-plates in a solution containing 3 parts of glacial acetic acid and 1 part of 30% hydrogen peroxide maintained at 50°C in a stainless steel (Type 304) tank. After exposure to this solution for 10 - 15 minutes the lead was sufficiently undermined to permit its removal by hand or in subsequent processing operations. The second method involved immersion of the tube-plates in molten lead-bismuth alloy

eutectic maintained at 250°C for five minutes. The lead-bismuth alloy reacted with lead to form a low melting-point material which was readily wiped off the aluminum surfaces with a rag or cellulose sponge. Use of palm oil on the rag or sponge added significantly to the ease of lead removal.

Final cleaning of the plates consisted of etching them in a hot (70°C) 10 w/o sodium hydroxide solution for 20 seconds. This was followed by two cold water rinses, immersion in 50 volume per cent nitric acid (70%) for a minimum of 1 minute, two cold running water rinses and a hot water rinse. The etched and rinsed plates were dried in a stream of moving hot air.

Fuel Subassembly Fabrication

A completely welded fuel subassembly is shown in Figure 2. It is made up of six tube-plates arranged in an MTR-type array with the plates spaced 0.307 inch from each other. To hold the plates in place, they were welded at their outside edges to 1/16-inch thick M-388 aluminum side-plates. To provide a suitable welding-joint geometry, each plate was formed into a channel-like section by bending the flanges adjacent to the end tubes 90° to the lateral plane of the tube-plate. This was done with dies mounted in a 100-ton hydraulic press. The dies are shown unloaded in the open position in Figure 38. The working sections of the dies were sufficiently long to accommodate a full-length plate, and flattened the tube-plate in addition to bending the flanges. The die was of the double-action type, i.e., the central section was spring loaded. In operation, the work piece was loaded onto the die (Figure 39). As the punch descended it made contact with the workpiece in the die, thus flattening the workpiece. Continued downward motion of the punch compressed the die springs, permitting relative motion to occur between the movable section of the die and the stationary die rails mounted on each side. This motion caused the plate flanges to be wiped upward, thus forming the channel section desired. A clearance of 0.040 inch existed between the punch side faces and the stationary die rails so that a reduction in thickness of 0.003 inch took place in the aluminum flanges. This was done to smooth the surface and slightly cold work the material to improve its characteristics in spot welding. A photograph of the punch and die set-up in place with the punch at the bottom of its stroke and a simulated workpiece in position in the dies is shown in Figure 40.

Subassembly; Spot Welding

The tube-plates and the side-plates were assembled into subassemblies and electric resistance spot welded in agreement with drawing No. RE-1-18170 C, Figure 41. Plate II in the Appendix lists all subassemblies and identifies the plates contained in each. Assembly and spot-welding

of the tube-plates to the side-plates was done one tube-plate at a time, starting at a center plate and adding the plates outward until 6 plates were in place. Spot welds were made at 1-inch intervals along the length of each welding flange. Correct spacing between the plates was achieved in the assembly operation by inserting a 0.307-inch thick cloth-filled phenolic plastic spacer between a plate already welded in place and the next plate to be welded (Figure 42). This arrangement was temporarily held in place by means of three special rectangular-section clamps spaced uniformly apart along the length of the piece-part. The unwelded plate was then spot welded on each flange at several locations adjacent to the clamps as shown in Figure 43. Next, the clamps were removed, and the remainder of the welds were made (Figure 44). This process was repeated until all six plates had been welded in place. To permit the use of a full width welding flange on each of the two outer tube-plates, the side plates were deliberately sheared oversize to a width of 5 inches. After all the plates were welded in place, the side-plate width was machined to 3.828 inch to conform with design specifications. This was the only machine operation performed upon the subassembly.

Spot welding was done on a Sciaky Model PMCRIT-75 KVA 3 Phase Spot Welder equipped with water-cooled class 1 electrodes. No difficulty was encountered in spot welding, largely because of the 0.504-inch wide welding flange permitted by the broad plate spacing. No preparation of the surfaces prior to welding was required other than vapor degreasing (trichloroethylene).

No work to develop the spot-welding technique beyond the welding of one or two practice subassemblies of design consideration was required. As soon as a production rhythm was established, a three-man assembly-and-welding crew consistently attained a production rate of 14 to 16 subassemblies per eight-hour shift. Final weld quality was good as judged by free-bend tests made on specimens of the same configuration employed in the subassemblies.

Completing the Assembly

To complete the assembly (Figure 45), cast-and-machined aluminum alloy (ALCOA 356) end fittings were plug welded in place. The inert-gas tungsten-arc method was used for this operation. Addition of aluminum alloy (M-388) filler rod was necessary to complete the weld. As final operations the excess plug weld material was removed by milling, and the outer face of each side-plate was buffed with a stainless steel-bristled power-driven scratch brush.

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FIGURE 1
BORAX IV· TUBE PLATE

FIGURE 2
BORAX-IV FUEL SUBASSEMBLY

FIGURE 3
FUEL ASSEMBLY, END FITTINGS NOT FIXED; BORAX IV

FIGURE 4
FUEL ASSEMBLY; BORAX IV

FIGURE 5
FINISHED TUBE PLATE; BORAX IV

FIG. 6. FLOW SHEET; FUEL AND BLANKET TUBE-PLATES FABRICATION; BORAX IV

FIGURE 7
HOT-PRESSED CLOSURE INTERFACE

FIGURE 8
MECHANISM: ALUMINUM OXIDE PERFORATION IN
SILICON BONDING (IDEALIZED)

FIGURE 9
SILICON BONDING; DIFFUSION OF SILICON INTO
ALUMINUM AT SILICON PARTICLE LOCATIONS

FIGURE 10
PROCEDURE FOR CLOSING BORAX-IV FUEL PLATES

FIGURE 11
WEB REMOVAL; MACHINE SET-UP

FIGURE 12
WEB REMOVAL; OPERATION IN PROGRESS

FIGURE 13
REMOVAL OF INTERNAL RIBS

FIGURE 14
APPLICATION OF SILICON SUSPENSION

FIGURE 15
EFFECT OF SILICON EXCESS IN SUSPENSION
ON INTERFACE MICROSTRUCTURE

FIGURE 16
REMOVAL OF ALCOHOL-GLYCERIN VEHICLE

FIGURE 17
COLD-PRESSING OPERATION

FIGURE 18
HOT-PRESSING OPERATION

FIGURE 19
HOT-PRESSING DIE; CONSTRUCTION DRAWING

FIGURE 20
CLOSE-UP; HOT-PRESSING TOOLS

FIGURE 21
TEMPERATURE AND CYCLE -CONTROL PANELS

FIGURE 22
TRIMMING END AFTER HOT-PRESSING

FIGURE 23

FIRST END CLOSURE; LEAK DETECTION

FIGURE 24

END-FITTINGS; FIRST END-CLOSURE
LEAK-DETECTION

FIGURE 25
FIXTURE FOR LOADING FUEL PELLETS

FIGURE 26
PLATE-RACKS; LOADED AND EMPTY

FIGURE 27

INSTALLATION OF LEAD-REMOVAL CABLES

FIGURE 28

LEAD-FILLING OPERATION; TUBE-RACK
ON CANNING ELEVATOR PRIOR TO FILLING

FIGURE 29

LEAD-FILLING; WORK PRE-HEATING
IN LEAD BATH

FIGURE 30

LEAD-FILLING; DIRECTIONAL QUENCHING
IN WATER AFTER FILLING

FIGURE 31
CROSS SECTION: LOADED AND LEAD-FILLED TUBE-PLATE

FIGURE 32
PARTIAL SECTION: LOADED AND LEAD-FILLED TUBE-PLATE

FIGURE 33
LEAD REMOVAL

FIGURE 34
CUTTING LOADED AND LEAD-FILLED PLATE
TO FINAL SAWED LENGTH

FIGURE 35
FINAL CLOSURE; COLD FLATTENING TOOLS

FIGURE 36
FINAL HOT-PRESSING OPERATION IN PROGRESS

FIGURE 37
FINAL CLOSURE LEAK-DETECTION APPARATUS

FIGURE 38
FLANGE-FORMING DIES; OPEN IN PLACE ON PRESS

FIGURE 39
FLANGE-FORMING DIES; WORK PIECE IN POSITION

FIGURE 40
FLANGE-FORMING DIES IN CLOSED POSITION;
SECTIONED TUBE-PLATE IN PLACE

FIGURE 41
SUBASSEMBLY-BORAX IV
RE-1-18170-C

FIGURE 42
ASSEMBLY OF TUBE-PLATE WITH PARTIAL SUBASSEMBLY
IN WELDING FIXTURE

FIGURE 43
TACK AND SPOT-WELDING ADJACENT TO FIXTURE-CLAMPS

FIGURE 44
SPOT-WELDING AFTER REMOVAL OF FIXTURE-CLAMPS

FIGURE 45
BORAX IV FUEL ASSEMBLY
RE-1-18167-D

APPENDIX

PLATE I: Procedure for Leak Detecting

- (1) Evacuate system to 150 microns; this includes chamber, manifold and external cold trap on leak detector. Throttle valve on leak detector is closed during this operation.
- (2) Close valve to external vacuum pump.
- (3) Crack throttle valve to leak detector until pressure in spectrometer reaches 0.1 micron. Maintain pressure in spectrometer at 0.1 micron by manipulating throttle valve.
- (4) Check helium leak rate. Leak rate should be 0.4^(a) or less.
- (5) If leak rate is greater than 0.4, refill chamber with air and repeat steps 1 through 4.
 - a) An exponentially falling leak rate upon repeating steps 1 - 4 indicates absorbed helium on surfaces and step 5 should be repeated until a stable leak-rate value is obtained. If stable leak rate is greater than 0.4 a leak is present.

^(a) Std. cc/sec air at 15 psi differential across leak. Exact value requires calibration with standard leak.

PLATE II

THORIA SUBASSEMBLIES

(Further detailed Accounting is given in Appendices of ANL-5678)

<u>Subassembly Number</u>	<u>Plate</u>	<u>ThO₂ (grams)</u>	<u>Thorium (grams)</u>
T-1	497	1082.8	951.6
	540	992.3	872.0
	491	944.2	829.8
	434	1063.6	934.7
	481	940.0	826.1
	468	<u>1083.1</u>	<u>951.8</u>
		6106.0	5366.0
T-2	439	1025.8	901.5
	455	1097.0	964.0
	451	1085.4	953.8
	465	1085.4	953.8
	472	1088.4	956.5
	431	<u>1084.1</u>	<u>952.7</u>
		6466.1	5682.3
T-3	433	1064.7	935.7
	467	945.7	831.1
	456	1069.9	940.2
	480	934.9	821.6
	498	965.3	848.3
	478	<u>952.9</u>	<u>837.4</u>
		5933.4	5214.3
T-4	488	981.8	862.8
	438	1046.5	919.7
	464	1038.2	912.4
	430	1054.2	926.4
	448	1099.6	966.3
	489	<u>976.2</u>	<u>857.9</u>
		6196.5	5445.5
T-5	450	973.8	855.8
	471	963.0	846.3
	496	973.5	855.5
	461	1090.1	958.0
	462	968.4	851.0
	552	<u>989.7</u>	<u>869.7</u>
		5958.5	5236.3

THORIA SUBASSEMBLIES (Cont'd.)

<u>Subassembly Number</u>	<u>Plate</u>	<u>ThO₂ (grams)</u>	<u>Thorium (grams)</u>		
T-6	483	986.1	866.6		
	484	961.5	845.0		
	485	963.8	847.0		
	453	1059.8	931.4		
	490	962.1	845.5		
	436	950.3	835.1		
		<u>5883.6</u>	<u>5170.6</u>		
T-7	511	980.5	861.7		
	475	958.6	842.4		
	443	1053.2	925.6		
	437	1106.1	972.0		
	487	969.8	852.3		
	494	908.7	798.6		
		<u>5976.9</u>	<u>5252.6</u>		
T-8	435	1099.9	966.6		
	463	1082.3	951.1		
	446	1079.4	948.6		
	477	983.2	864.0		
	449	973.5	855.5		
	495	917.2	806.0		
		<u>6135.5</u>	<u>5391.8</u>		
				<u>First Shipment Total</u>	
				48,656.5	42,759.4
				(48.66 kg)	(42.76 kg)
T-9	458	1042.2	915.9		
	466	1082.5	951.3		
	473	979.7	861.0		
	444	945.8	831.2		
	454	1043.6	917.1		
	482	970.9	853.2		
		<u>6064.7</u>	<u>5329.7</u>		
T-10	537	987.0	867.4		
	442	1054.0	926.3		
	445	1070.0	940.3		
	486	981.6	862.6		
	479	984.0	864.7		
	440	1044.4	917.8		
		<u>6121.0</u>	<u>5379.1</u>		
				<u>Second Shipment Total</u>	
				12,185.7	10,708.8
				<u>NET</u>	<u>THORIUM</u>
GRAND TOTAL -				60,842.2	53,468.2

FIRST SHIPMENT

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES

<u>Sub- assembly Number</u>	<u>Plate</u>	<u>Batch 212M5-8- 1475-1</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
1	790	-1A	919.0	756.3	51.4	47.9
	874	1B	823.4	677.7	46.0	42.9
	730	1C	928.0	763.7	51.9	48.4
	733	1D	909.3	748.4	50.8	47.3
	681	1E	943.4	776.4	52.7	49.1
	507	1F	956.5	787.2	53.5	49.9
			5479.6	4509.7	306.3	285.5
<u>212M5-8- 1475-2</u>						
2	731	-2A	929.9	765.3	52.0	48.5
	852	2B	816.6	672.1	45.6	42.5
	536	2C	928.6	764.2	51.9	48.4
	624	2D	924.0	760.5	51.7	48.2
	524	2E	918.5	755.9	51.3	47.8
	516	2F	920.4	757.5	51.5	48.0
			5438.0	4475.5	304.0	283.4
<u>212M5-8- 1475-3</u>						
3	530	-3A	913.5	751.8	51.1	47.6
	841	3B	809.0	665.8	45.2	42.1
	793	3C	921.5	758.4	51.5	48.0
	534	3D	918.6	756.0	51.3	47.8
	591	3E	937.8	771.8	52.4	48.8
	623	3F	923.6	760.1	51.6	48.1
			5424.0	4463.9	303.1	282.4
<u>212M5-8- 1475-4</u>						
4	626	-4A	927.1	763.0	51.8	48.3
	424	4B	835.9	687.9	46.7	43.5
	574	4C	929.0	764.6	51.9	48.4
	569	4D	933.9	768.6	52.2	48.6
	547	4E	922.5	759.2	51.6	48.1
	518	4F	919.2	756.5	51.4	47.9
			5467.6	4499.8	305.6	284.8

(a) SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub-assembly Number</u>	<u>Plate</u>	<u>Batch 212M5-8- 1475-5</u>	<u>Net</u>	<u>Th</u>	<u>SS^(a)</u>	<u>U²³⁵</u>
5	521	-5A	996.4	820.0	55.7	51.9
	410	5B	760.9	626.2	42.5	39.6
	767	5C	909.7	748.7	50.9	47.4
	758	5D	913.6	751.9	51.1	47.6
	776	5E	916.1	753.9	51.2	47.7
	593	5F	932.4	767.4	52.1	48.6
			<u>5429.1</u>	<u>4468.1</u>	<u>303.5</u>	<u>282.8</u>
<u>212M5-8- 1475-6</u>						
6	786	-6A	917.3	754.9	51.3	47.8
	835	6B	814.4	670.3	45.5	42.4
	616	6C	928.6	764.2	51.9	48.4
	799	6D	913.4	751.7	51.1	47.6
	728	6E	924.3	760.7	51.7	48.2
	742	6F	911.5	750.2	51.0	47.5
			<u>5409.5</u>	<u>4452.0</u>	<u>302.5</u>	<u>281.9</u>
<u>212M5-8- 1475-7</u>						
7	585	-7A	915.2	753.2	51.2	47.7
	844	7B	819.0	674.0	45.8	42.7
	802	7C	906.5	746.0	50.7	47.3
	504	7D	909.1	748.2	50.8	47.3
	598	7E	908.0	747.3	50.8	47.3
	674	7F	915.5	753.5	51.2	47.7
			<u>5373.3</u>	<u>4422.2</u>	<u>300.5</u>	<u>280.0</u>
<u>212M5-8- 1475-8</u>						
8	607	-8A	924.3	760.7	51.7	48.2
	857	8B	818.3	673.5	45.7	42.6
	680	8C	921.0	758.0	51.5	48.0
	390	8D	887.3	730.2	49.6	46.2
	653	8E	943.2	776.3	52.7	49.1
	691	8F	927.7	763.5	51.9	48.4
			<u>5421.8</u>	<u>4462.2</u>	<u>303.1</u>	<u>282.5</u>

^(a)SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub-assembly Number</u>	<u>Plate</u>	<u>Batch 212M5-8- 1475-9</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
9	670	-9A	912.1	750.7	51.0	47.5
	876	9B	832.1	684.9	46.5	43.3
	687	9C	931.8	766.9	52.1	48.6
	635	9D	927.5	763.3	51.8	48.3
	729	9E	927.1	763.0	51.8	48.3
	604	9F	907.0	746.5	50.7	47.3
			<u>5437.6</u>	<u>4475.3</u>	<u>303.9</u>	<u>283.3</u>
<u>212M5-8- 1475-10</u>						
10	734	-10A	921.6	758.5	51.5	48.0
	840	10B	813.2	669.3	45.5	42.4
	620	10C	925.1	761.4	51.7	48.2
	565	10D	989.2	814.1	55.3	51.5
	632	10E	929.9	765.3	52.0	48.5
	634	10F	942.6	775.8	52.7	49.1
			<u>5521.6</u>	<u>4544.4</u>	<u>308.7</u>	<u>287.7</u>
<u>212M5-8- 1475-11</u>						
11	777	-11A	918.6	756.0	51.3	47.8
	513	11B	793.6	653.1	44.4	41.4
	416	11C	902.6	742.8	50.5	47.1
	785	11D	916.8	754.5	51.2	47.7
	627	11E	929.6	765.1	52.0	48.5
	602	11F	916.1	753.9	51.2	47.7
			<u>5377.3</u>	<u>4425.4</u>	<u>300.6</u>	<u>280.2</u>
<u>212M5-8- 1475-12</u>						
12	806	-12A	917.6	755.2	51.3	47.8
	789	12B	787.5	648.1	44.0	41.0
	782	12C	905.6	745.3	50.6	47.2
	411	12D	884.4	727.9	49.4	46.0
	566	12E	1000.1	823.1	55.9	52.1
	560	12F	974.0	801.6	54.4	50.7
			<u>5469.2</u>	<u>4501.2</u>	<u>305.6</u>	<u>284.8</u>

(a) SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub- assembly Number</u>	<u>Plate</u>	<u>Batch 212M5-8- 1475-13</u>	<u>Net</u>	<u>Th</u>	<u>SS^(a)</u>	<u>U²³⁵</u>
13	583	-13A	926.2	762.3	51.8	48.3
	836	13B	812.3	668.5	45.4	42.3
	557	13C	923.3	759.9	51.6	48.1
	606	13D	893.1	735.0	49.9	46.5
	418	13E	957.2	787.8	53.5	49.9
	414	13F	903.9	743.9	50.5	47.1
			<u>5416.0</u>	<u>4457.4</u>	<u>302.7</u>	<u>282.2</u>
<u>212M5-8- 1475-14</u>						
14	803	-14A	914.8	752.9	51.1	47.6
	409	14B	829.3	682.5	46.4	43.2
	508	14C	913.7	752.0	51.1	47.6
	525	14D	907.6	747.0	50.7	47.3
	671	14E	920.1	757.2	51.4	47.9
	546	14F	905.9	745.6	50.7	47.3
			<u>5391.4</u>	<u>4437.2</u>	<u>301.4</u>	<u>280.9</u>
<u>212M5-8- 1475-15</u>						
15	523	-15A	935.2	769.7	52.3	48.7
	855	15B	823.7	677.9	46.0	42.9
	519	15C	914.9	753.0	51.1	47.6
	517	15D	913.6	751.9	51.1	47.6
	543	15E	936.2	770.5	52.3	48.7
	794	15F	915.1	753.1	51.2	47.7
			<u>5438.7</u>	<u>4476.1</u>	<u>304.0</u>	<u>283.2</u>
<u>212M5-8- 1475-16</u>						
16	419	-16A	959.5	789.7	53.6	50.0
	155	16B	798.4	657.1	44.6	41.6
	515	16C	922.4	759.1	51.6	48.1
	553	16D	929.4	764.9	52.0	48.5
	514	16E	921.9	758.7	51.5	48.0
	503	16F	918.6	756.0	51.3	47.8
			<u>5450.2</u>	<u>4485.5</u>	<u>304.6</u>	<u>284.0</u>

(a) SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub- assembly Number</u>	<u>Plate</u>	<u>Batch 212M5-8- 1475-17</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
17	532	-17A	910.2	749.1	50.9	47.4
	877	17B	801.7	659.8	44.8	41.8
	562	17C	905.8	745.5	50.6	47.2
	159	17D	941.8	775.1	52.6	49.0
	796	17E	930.5	765.8	52.0	48.5
	805	17F	920.7	757.7	51.5	48.0
			5410.7	4453.0	302.4	281.9
<u>212M5-8- 1475-18</u>						
18	531	-18A	915.5	753.5	51.2	47.7
	830	18B	808.8	665.6	45.2	42.1
	818	18C	909.9	748.8	50.9	47.4
	798	18D	924.4	760.8	41.7	48.2
	779	18E	882.4	726.2	49.3	45.9
	502	18F	927.5	763.3	51.8	48.3
			5368.5	4418.2	300.1	279.6
<u>212M5-8- 1475-19</u>						
19	826	-19A	934.5	769.1	52.2	48.7
	866	19B	782.8	644.2	43.8	40.8
	819	19C	928.8	764.4	51.9	48.4
	775	19D	913.5	751.8	51.1	47.6
	833	19E	947.4	779.7	53.0	49.4
	787	19F	912.7	751.2	51.0	47.5
			5419.7	4460.4	303.0	282.4
<u>212M5-8- 1475-20</u>						
20	158	-20A	934.2	768.8	52.2	48.6
	827	20B	808.5	665.4	45.2	42.1
	319	20C	959.0	789.3	53.6	50.0
	763	20D	897.4	738.6	50.2	46.8
	825	20E	905.7	745.4	50.6	47.2
	816	20F	905.5	745.2	50.6	47.2
			5410.3	4452.7	302.4	281.9

(a) SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub- assembly Number</u>	<u>Plate</u>	<u>Batch 212M5-8- 1475-21</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
21	764	-21A	939.3	773.0	52.5	48.9
	850	21B	808.2	665.1	45.2	42.1
	795	21C	917.4	755.0	51.3	47.8
	597	21D	931.1	766.3	52.0	48.5
	770	21E	910.8	749.6	50.9	47.4
	732	21F	918.4	755.8	51.3	47.8
			5425.2	4464.8	303.2	282.5
<u>212M5-8- 1475-22</u>						
22	559	-22A	910.3	749.2	50.9	47.4
	858	22B	819.1	674.1	45.8	42.7
	762	22C	920.4	757.5	51.5	48.0
	736	22D	928.3	764.0	51.9	48.4
	595	22E	948.9	780.9	53.0	49.4
	592	22F	948.3	780.5	53.0	49.4
			5475.3	4506.2	306.1	285.3
<u>212M5-8- 1475-23</u>						
23	601	-23A	909.0	748.1	50.8	47.3
	847	23B	807.8	664.8	45.2	42.1
	860	23C	931.1	766.3	52.0	48.5
	528	23D	920.2	757.3	51.4	47.9
	596	23E	911.2	749.9	50.9	47.4
	548	23F	944.3	777.2	52.8	49.2
			5423.6	4463.6	303.1	282.4
<u>212M5-8- 1475-24</u>						
24	804	-24A	920.8	757.8	51.5	48.0
	824	24B	798.9	657.5	44.7	41.7
	527	24C	919.6	756.8	51.4	47.9
	839	24D	926.6	762.6	51.8	48.3
	621	24E	917.6	755.2	51.3	47.8
	535	24F	914.5	752.6	51.1	47.6
			5398.0	4442.5	301.8	281.3

(a) SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

Sub-assembly Number	Plate	Batch 212M5-8- 1475-25	Net	Th	SS ^(a)	U ²³⁵
25	864	-25A	929.4	764.9	52.0	48.5
	682	25B	922.5	759.2	51.6	48.1
	781	25C	900.9	741.4	50.4	47.0
	810	25D	920.6	757.7	51.5	48.0
	801	25E	925.4	761.6	51.7	48.2
	533	25F	918.4	755.8	51.3	47.8
			5517.2	4540.6	308.5	287.6
<u>212M5-8-1475-26</u>						
26	811	-26A	933.5	768.3	52.2	48.7
	829	26B	803.7	661.4	44.9	41.8
	788	26C	891.0	733.3	49.8	46.4
	412	26D	895.0	736.6	50.0	46.6
	773	26E	920.4	757.5	51.4	47.9
	522	26F	924.6	760.9	51.7	48.2
			5368.2	4418.0	300.0	279.6
<u>212M5-8-1475-27</u>						
27	197	-27A	967.1	795.9	54.1	50.4
	584	27B	809.8	666.5	45.3	42.2
	387	27C	930.9	766.1	52.0	48.5
	130	27D	912.7	751.2	51.0	47.5
	361	27E	905.0	744.8	50.6	47.2
	166	27F	934.0	768.7	52.2	48.6
			5459.5	4493.2	305.2	284.4
<u>212M5-8-1475-28</u>						
28	352	-28A	897.4	738.6	50.2	46.8
	831	28B	809.1	665.9	45.2	42.1
	376	28C	897.8	738.9	50.2	46.8
	358	28D	925.1	761.4	51.7	48.2
	362	28E	909.8	748.8	50.9	47.4
	209	28F	970.7	798.9	54.3	50.6
			5409.9	4452.5	302.5	281.9

^(a)SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

Sub-assembly Number	Plate	Batch 212M5-8- 1475-29	Net	Th	SS ^(a)	U ²³⁵
29	868	-29A	931.1	766.3	52.1	48.6
	872	29B	821.9	676.4	45.9	42.8
	611	29C	975.5	802.8	54.5	50.8
	695	29D	910.8	749.6	50.9	47.4
	505	29E	930.9	766.1	52.0	48.5
	196	29F	918.3	755.8	51.3	47.8
			5488.5	4517.0	306.7	285.9
<u>212M5-8-1475-30</u>						
30	704	-30A	981.8	808.0	54.9	51.2
	417	30B	837.1	688.9	46.8	43.6
	501	30C	936.4	770.7	52.3	48.7
	637	30D	915.4	753.4	51.2	47.7
	869	30E	928.4	764.1	51.9	48.4
	367	30F	930.2	765.6	52.0	48.5
			5529.3	4550.7	309.1	288.1
<u>212M5-8-1475-31</u>						
31	791	-31A	937.5	771.6	52.4	48.8
	499	31B	828.4	681.8	46.3	43.2
	355	31C	921.7	758.6	51.5	48.0
	368	31D	924.0	760.5	51.7	48.2
	385	31E	916.2	754.0	51.2	47.7
	386	31F	920.9	757.9	51.5	48.0
			5448.7	4484.4	304.6	283.9
<u>212M5-8-1475-32</u>						
32	697	-32A	928.4	764.1	51.9	48.4
	420	32B	848.0	697.9	47.4	44.2
	363	32C	911.5	750.2	51.0	47.5
	163	32D	916.6	754.4	51.2	47.7
	172	32E	945.5	778.1	52.9	49.3
	506	32F	937.1	771.2	52.4	48.8
			5487.1	4515.9	306.8	285.9

^(a)SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub-assembly Number</u>	<u>Plate</u>	<u>Batch 212M5-8- 1475-33</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
33	374	-33A	940.6	774.1	52.6	49.0
	404	33B	809.2	666.0	45.2	42.1
	774	33C	910.5	749.3	50.9	47.4
	544	33D	923.7	760.2	51.6	48.1
	149	33E	921.5	758.4	51.5	48.0
	218	33F	981.3	807.6	54.9	41.2
			<u>5486.8</u>	<u>4515.6</u>	<u>306.7</u>	<u>285.8</u>
<u>212M5-8- 1475-34</u>						
34	379	-34A	891.3	733.5	49.8	46.4
	423	34B	832.9	685.5	46.6	43.4
	615	34C	918.3	755.8	51.3	47.8
	778	34D	917.3	754.9	51.3	47.8
	373	34E	927.2	763.1	51.8	48.3
	353	34F	917.4	755.0	51.3	47.8
			<u>5404.4</u>	<u>4447.8</u>	<u>302.1</u>	<u>281.5</u>
<u>212M5-8- 1475-35</u>						
35	692	-35A	926.1	762.2	51.8	48.3
	422	35B	847.8	697.7	47.4	44.2
	757	35C	912.2	750.7	51.0	47.5
	646	35D	924.8	761.1	51.7	48.2
	649	35E	918.4	755.8	51.3	47.8
	745	35F	937.8	771.8	52.4	48.8
			<u>5467.1</u>	<u>4499.3</u>	<u>305.6</u>	<u>284.8</u>
<u>212M5-8- 1475-36</u>						
36	756	-36A	933.4	768.2	52.2	48.7
	614	36B	811.6	667.9	45.4	42.3
	577	36C	915.0	753.0	51.1	47.6
	769	36D	904.5	744.4	50.6	47.2
	772	36E	886.5	729.6	49.6	46.2
	648	36F	924.5	760.9	51.7	48.2
			<u>5375.5</u>	<u>4424.0</u>	<u>300.6</u>	<u>280.2</u>
<u>First Shipment Total</u>			<u>195718.4</u>	<u>161076.3</u>	<u>10940.6</u>	<u>10196.5</u>

(a) _{SS} = Total Uranium

SECOND SHIPMENT

THORIA-URANIA WEIGHTS(GRAMS)IN REACTOR SUBASSEMBLIES

<u>Sub- assembly Number</u>	<u>Plate</u>	<u>Net</u>	<u>Th</u>	<u>SS^(a)</u>	<u>U²³⁵</u>
37	633	917.1	754.8	51.3	47.8
	875	818.1	673.3	45.7	42.6
	867	925.2	761.4	51.7	48.2
	622	897.6	738.7	50.2	46.8
	579	922.9	759.5	51.6	48.1
	625	937.2	771.3	52.4	48.8
		<u>5418.1</u>	<u>4459.0</u>	<u>302.9</u>	<u>282.3</u>
38	538	907.6	747.0	50.7	47.3
	690	832.9	685.5	46.6	43.4
	372	923.0	759.6	51.6	48.1
	759	926.5	762.5	51.8	48.3
	863	933.6	768.4	52.2	48.7
	643	920.4	757.5	51.5	48.0
		<u>5444.0</u>	<u>4480.5</u>	<u>304.4</u>	<u>283.8</u>
39	792	941.9	775.2	52.7	49.1
	843	819.3	674.3	45.8	42.7
	765	934.2	768.8	52.2	48.7
	838	929.4	764.9	52.0	48.5
	554	918.4	755.8	51.3	47.8
	630	926.2	762.3	51.8	48.3
		<u>5469.4</u>	<u>4501.3</u>	<u>305.8</u>	<u>285.1</u>
40	771	922.2	759.0	51.6	48.1
	873	817.7	673.0	45.7	42.6
	260	916.9	754.6	51.3	47.8
	310	967.5	796.2	54.1	50.4
	153	912.5	751.0	51.0	47.5
	629	925.0	761.3	51.7	48.2
		<u>5461.8</u>	<u>4495.1</u>	<u>305.4</u>	<u>284.6</u>

^(a)SS = Total Uranium

THORIA-URANIA WEIGHTS(GRAMS)IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub-assembly Number</u>	<u>Plate</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
41	344	934.9	769.4	52.3	48.7
	427	833.4	685.9	46.6	43.4
	161	929.4	764.9	52.0	48.5
	179	934.5	769.1	52.2	48.7
	168	942.5	775.7	52.7	49.1
	768	928.7	764.3	51.9	48.4
		<u>5503.4</u>	<u>4529.3</u>	<u>307.7</u>	<u>286.8</u>
42	366	945.9	778.5	52.9	49.3
	871	817.1	672.5	45.7	42.6
	347	932.8	767.7	52.1	48.6
	784	907.2	746.6	50.7	47.3
	340	907.2	746.6	50.7	47.3
	300	957.7	788.2	53.5	49.9
		<u>5467.9</u>	<u>4500.1</u>	<u>305.6</u>	<u>285.0</u>
43	346	931.2	766.4	52.1	48.6
	832	817.7	673.0	45.7	42.6
	375	933.5	768.3	52.2	48.7
	364	916.7	754.4	51.2	47.7
	348	916.7	754.4	51.2	47.7
	766	894.7	736.3	50.0	46.6
		<u>5410.5</u>	<u>4452.8</u>	<u>302.4</u>	<u>281.9</u>
44	619	916.4	754.2	51.2	47.7
	845	829.4	682.6	46.4	43.2
	722	935.6	770.0	52.3	48.7
	167	918.2	755.7	51.3	47.8
	349	931.4	766.5	52.1	48.6
	377	902.7	742.9	50.5	47.1
		<u>5433.7</u>	<u>4471.9</u>	<u>303.8</u>	<u>283.1</u>

(a)SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

Sub-assembly Number	Plate	Net	Th	SS ^(a)	U ²³⁵
45	164	922.9	759.5	51.6	48.1
	408	810.3	666.9	45.3	42.2
	666	939.9	773.5	52.5	48.9
	679	926.8	762.8	51.8	48.3
	169	937.1	771.2	52.4	48.8
	240	929.0	764.6	51.9	48.4
		<u>5466.0</u>	<u>4498.5</u>	<u>305.5</u>	<u>284.7</u>
46	739	988.1	813.2	55.2	51.4
	834	818.5	673.6	45.8	42.7
	703	950.1	781.9	53.1	49.5
	699	939.4	773.1	52.5	48.9
	694	913.7	752.0	51.1	47.6
	700	976.2	803.4	54.6	50.9
		<u>5586.0</u>	<u>4597.2</u>	<u>312.3</u>	<u>291.0</u>
47	581	954.0	785.1	53.3	49.7
	817	799.0	657.6	44.7	41.7
	740	905.4	745.1	50.6	47.2
	701	966.4	795.3	54.0	50.3
	457	931.8	766.9	52.1	48.6
	738	974.2	801.8	54.5	50.8
		<u>5530.8</u>	<u>4551.8</u>	<u>309.2</u>	<u>288.3</u>
48	378	889.2	731.8	49.7	46.3
	854	800.4	658.7	44.7	41.7
	350	942.0	775.3	52.7	49.1
	151	932.0	767.0	52.1	48.6
	365	922.4	759.1	51.6	48.1
	669	945.8	778.4	52.9	49.3
		<u>5431.8</u>	<u>4470.3</u>	<u>303.7</u>	<u>283.1</u>

^(a)SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub-assembly Number</u>	<u>Plate</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
49	370	942.5	775.7	52.7	49.1
	849	810.8	667.3	45.3	42.2
	371	946.0	778.6	52.9	49.3
	360	922.4	759.1	51.6	48.1
	150	922.7	759.4	51.6	48.1
	760	926.7	762.7	51.8	48.3
		<u>5471.1</u>	<u>4502.8</u>	<u>305.9</u>	<u>285.1</u>
50	638	930.6	765.9	52.0	48.5
	821	786.2	647.0	43.9	40.9
	865	928.2	763.9	51.9	48.4
	617	866.6	713.2	48.4	45.1
	640	928.2	763.9	51.9	48.4
	706	934.9	769.4	52.3	48.7
		<u>5374.7</u>	<u>4423.3</u>	<u>300.4</u>	<u>280.0</u>
51	716	939.7	773.4	52.5	48.9
	809	792.8	652.5	44.3	41.3
	813	931.8	766.9	52.1	48.6
	576	969.1	797.6	54.2	50.5
	712	926.2	762.3	51.8	48.3
	708	933.3	768.1	52.2	48.7
		<u>5492.9</u>	<u>4520.8</u>	<u>307.1</u>	<u>286.3</u>
52	814	923.9	760.4	51.6	48.1
	820	790.2	650.3	44.2	41.2
	655	970.4	798.6	54.2	50.5
	570	917.6	755.2	51.3	47.8
	837	925.5	761.7	51.7	48.2
	861	843.5	694.2	47.2	44.0
		<u>5371.1</u>	<u>4420.4</u>	<u>300.2</u>	<u>279.8</u>

(a) SS = Total Uranium

THORIA-URANIA WEIGHTS(GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub- assembly Number</u>	<u>Plate</u>	<u>Net</u>	<u>Th</u>	<u>SS^(a)</u>	<u>U²³⁵</u>
53	815	937.5	771.6	52.4	48.8
	529	792.3	652.1	44.3	41.3
	812	937.0	771.2	52.4	48.8
	688	921.5	758.4	51.5	48.0
	761	914.9	753.0	51.1	47.6
	696	917.5	755.1	51.3	47.8
		<u>5420.7</u>	<u>4461.4</u>	<u>303.0</u>	<u>282.3</u>
54	650	964.8	794.0	53.9	50.2
	652	821.1	675.8	45.9	42.8
	571	971.1	799.2	54.3	50.6
	610	973.7	801.4	54.4	50.7
	587	968.2	796.8	54.1	50.4
	684	975.5	802.8	54.5	40.8
		<u>5674.4</u>	<u>4670.0</u>	<u>317.1</u>	<u>295.5</u>
55	717	939.0	772.8	52.5	48.9
	639	818.3	673.5	45.7	42.6
	656	927.0	762.9	51.8	48.3
	613	964.8	794.0	53.9	50.2
	726	972.0	800.0	54.3	50.6
	663	946.0	778.6	52.9	49.3
		<u>5567.1</u>	<u>4581.8</u>	<u>311.1</u>	<u>289.9</u>
56	667	914.5	752.6	51.1	47.6
	853	808.1	665.1	45.2	42.1
	750	937.2	771.3	52.4	48.8
	642	917.2	754.9	51.3	47.8
	659	966.8	795.7	54.0	50.3
	724	939.2	773.0	52.5	48.9
		<u>5483.0</u>	<u>4512.6</u>	<u>306.5</u>	<u>285.5</u>

(a)SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub- assembly Number</u>	<u>Plate</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
57	662	905.0	744.8	50.6	47.2
	657	814.0	669.9	45.5	42.4
	748	930.8	766.0	52.0	48.5
	698	953.6	784.8	53.3	49.7
	665	934.1	768.8	52.2	48.7
	707	944.9	777.7	52.8	49.2
		<u>5482.4</u>	<u>4512.0</u>	<u>306.4</u>	<u>285.7</u>
58	549	925.5	761.7	51.7	48.2
	842	817.0	672.4	45.7	42.6
	723	933.0	767.9	52.2	48.7
	797	913.7	752.0	51.1	47.6
	162	916.9	754.6	51.3	47.8
	689	970.5	798.7	54.3	50.6
		<u>5476.6</u>	<u>4507.3</u>	<u>306.3</u>	<u>285.5</u>
59	660	935.7	770.1	52.3	48.7
	870	818.0	673.2	45.7	42.6
	618	930.7	766.0	52.0	48.5
	568	923.7	760.2	51.6	48.1
	715	933.4	768.2	52.2	48.7
	862	925.3	761.5	51.8	48.2
		<u>5466.8</u>	<u>4499.2</u>	<u>305.5</u>	<u>284.8</u>
60	751	924.3	760.7	51.7	48.2
	526	790.6	650.7	44.2	41.2
	672	940.1	773.7	52.6	49.0
	705	912.1	750.7	51.0	47.5
	675	982.2	808.3	54.9	51.2
	741	929.1	764.6	51.9	48.4
		<u>5478.4</u>	<u>4508.7</u>	<u>306.3</u>	<u>285.5</u>

(a) SS = Total Uranium

THORIA-URANIA WEIGHTS (GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub-assembly Number</u>	<u>Plate</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
61	673	900.5	741.1	50.3	46.9
	406	804.6	662.2	45.0	41.9
	686	923.5	760.0	51.6	48.1
	755	925.1	761.4	51.7	48.2
	647	922.7	759.4	51.6	48.1
	749	930.9	766.1	52.0	48.5
		<u>5407.3</u>	<u>4450.2</u>	<u>302.2</u>	<u>281.7</u>
62	752	909.1	748.2	50.8	47.3
	823	793.3	652.9	44.3	41.3
	737	920.4	757.5	51.4	47.9
	743	930.1	765.5	52.0	48.5
	744	914.2	752.4	51.1	47.6
	727	930.9	766.1	52.0	48.5
		<u>5398.0</u>	<u>4442.6</u>	<u>301.6</u>	<u>281.1</u>
63	747	933.8	768.5	52.2	48.7
	425	838.6	690.2	46.9	43.7
	589	916.4	754.2	51.2	47.7
	754	936.5	770.7	52.4	48.8
	753	912.8	751.2	51.0	47.5
	510	909.0	748.1	50.8	47.3
		<u>5447.1</u>	<u>4482.9</u>	<u>304.5</u>	<u>283.7</u>
64	195	976.4	803.6	54.6	50.9
	846	824.5	678.6	46.1	43.0
	578	977.7	804.6	54.7	51.0
	677	968.7	797.2	54.2	50.5
	174	971.1	799.2	54.3	50.6
	693	915.4	753.4	51.2	47.7
		<u>5633.8</u>	<u>4636.6</u>	<u>315.1</u>	<u>293.7</u>

(a) SS = Total Uranium

THORIA-URANIA WEIGHTS(GRAMS) IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub-assembly Number</u>	<u>Plate</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
65	582	981.6	807.9	54.9	51.2
	407	777.8	640.1	43.5	40.5
	588	943.2	776.3	52.7	49.1
	160	966.1	795.1	54.0	50.3
	156	936.1	770.4	52.3	48.7
	612	920.5	757.6	51.5	48.0
		<u>5525.3</u>	<u>4547.4</u>	<u>308.9</u>	<u>287.8</u>
66	645	992.6	816.9	55.5	51.7
	426	836.9	688.8	46.8	43.6
	676	989.3	814.2	55.3	51.5
	636	998.3	821.6	55.8	52.0
	685	930.2	765.5	52.0	48.5
	718	935.7	770.1	52.3	48.7
		<u>5683.0</u>	<u>4677.2</u>	<u>317.7</u>	<u>296.0</u>
67	654	974.9	802.3	54.5	50.8
	859	804.1	661.8	45.0	41.9
	564	921.7	758.6	51.5	48.0
	567	814.3	670.2	45.5	42.4
	563	997.9	821.3	55.8	52.0
	711	930.1	765.5	52.0	48.5
		<u>5443.0</u>	<u>4479.7</u>	<u>304.3</u>	<u>283.6</u>
68	651	947.0	779.4	52.9	49.3
	851	812.0	668.3	45.4	42.3
	599	944.8	777.6	52.8	49.2
	800	900.0	740.7	50.3	46.9
	594	937.6	771.6	52.4	48.8
	808	929.5	765.0	52.0	48.5
		<u>5470.9</u>	<u>4502.6</u>	<u>305.8</u>	<u>285.0</u>

(a)SS = Total Uranium

THORIA-URANIA WEIGHTS(GRAMS)IN REACTOR SUBASSEMBLIES
(Continued)

<u>Sub-assembly Number</u>	<u>Plate</u>	<u>Net</u>	<u>Th</u>	<u>SS(a)</u>	<u>U²³⁵</u>
69	580	978.5	805.3	54.7	51.0
	828	817.9	673.1	45.7	42.6
	668	935.8	770.2	52.3	48.7
	590	942.9	776.0	52.7	49.1
	555	913.6	751.9	51.1	47.6
	575	955.4	786.3	53.4	49.8
		<u>5544.1</u>	<u>4562.8</u>	<u>309.9</u>	<u>288.8</u>
70	683	912.2	750.7	51.0	47.5
	780	906.0	745.6	50.7	47.3
	207	972.0	800.0	54.3	50.6
	359	929.5	765.0	52.0	48.5
	822	797.2	656.1	44.6	41.6
	138	924.9	761.2	51.7	48.2
		<u>5441.8</u>	<u>4478.6</u>	<u>304.3</u>	<u>283.7</u>
71	586	955.1	786.0	53.4	49.8
	641	966.7	795.6	54.0	50.3
	250	929.9	765.3	52.0	48.5
	225	788.9	649.3	44.1	41.1
	600	932.8	767.7	52.1	48.6
	783	905.6	745.3	50.6	47.2
		<u>5479.0</u>	<u>4509.2</u>	<u>306.2</u>	<u>285.5</u>
Second Shipment Total		<u>191855.9</u>	<u>157897.9</u>	<u>10725.0</u>	<u>9996.2</u>

THIRD SHIPMENT

72	710	933.0	767.9	52.2	48.6
	713	991.8	816.2	55.4	51.6
	721	948.7	780.8	53.0	49.4
	735	925.7	761.8	51.7	48.2
		<u>3799.2</u>	<u>3126.7</u>	<u>212.3</u>	<u>197.8</u>

(a) SS = Total Uranium