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GROUP I

TECHNICAL DIVISION


PLANT PLATE BOND PURCHASE REPORT

No. 3

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SUMMARY

Further experience with the uranium high alpha-rolled at Superior Steel continues to confirm generally the satisfactory quality of metal so fabricated for making into flat plate fuel elements. Only a limited dimensional change takes place during beta transformation and the as-rolled surface serves as a satisfactory base for nickel-electroplating without other treatment than etching and the normal preparation for plating. It was found, however, that treatment after rolling introduced cracks into a substantial percentage of the metal. These were both transverse cracks, apparently produced in roller straightening, and longitudinal cracks, apparently resulting from shearing, and were not removed in the edge machining.

Additional suppliers of aluminum components were obtained in Harvey Machine Co. and Revere Copper and Brass, and some of the required sheath and process tube shapes previously programmed with ALCOA were undertaken by these companies. Some aluminum sheathing of both unribbed and ribbed designs required for MTR irradiation were obtained. Harvey provided the ordered ribbed sheaths. ALCOA provided a limited supply of unribbed sheaths and progressed toward eliminating fabrication difficulties with these shapes.

Processes for attachment of aluminum ribs to the sheaths of bonded fuel elements received some attention and will continue to do so until the bonding and non-destructive testing of elements made with ribbed sheaths is proved satisfactory. Of most interest, on a long-term basis, was the initial showing by Aeroprojects of the ability to weld aluminum ribs to sheaths by ultrasonics. Of greater short-term interest was the marked improvement by Aeroprojects in quality and reproducibility of ultrasonically soldered ribs and the further production by Metals & Controls of adherent ribs rolled onto smooth sheathed fuel elements.

The various processes for the making of wrought metal bonded elements for MTR irradiation and for testing these elements were established at the Savannah River Laboratory. Smooth sheathed pieces are in preparation for MTR irradiation.

Twenty additional powder metallurgy MTR-size elements were provided by Sylvania. These incorporated improvements indicated desirable by the initial lot of 14 elements. From the 2 lots, 6 elements were selected as satisfactory for MTR irradiation based on a series of tests made at Savannah. Failure of the majority of pieces to pass the tests occurred in autoclaving and was due to defects at the aluminum weld between the end plug and the tube at the lower end of the uranium cores. One piece out of 6 is under irradiation test, with the remainder rejected at MTR due to pitting of the aluminum sheaths. An additional lot of 20 Sylvania powder metallurgy plates is in preparation employing conditions believed likely to avoid the imperfections occurring in the first 2 lots.
I. URANIUM COMPONENTS

A. Metal Supply and Surfacing

The wrought metal used in the flat plate research work for the period consisted primarily of plate stock from the August Superior Steel high-alpha rolling, although a limited amount of work was carried out with metal cast and rolled at Savannah. Some evaluation was made of uranium produced at Sylvania by powder metallurgy techniques. (Most of the metal from Sylvania was received in the form of bonded fuel element cores, and results with this are covered under "Powder Metallurgy Techniques"). The metal from Superior Steel continued to appear to have fundamentally satisfactory characteristics for irradiation use, although examination of individual pieces disclosed that handling after rolling had resulted in gouges and in transverse and longitudinal cracks in a substantial percentage of the total stock. The transverse cracks, apparently less than 0.030" deep, are believed to have been produced in handling and roller-leveling straightening operations and the longitudinal cracks entirely in the shearing operation. It is believed that steps can be taken in future rollings to eliminate these and certain other defects, such as pits, pinhole porosity and scales, which may have resulted from ingot quality.

From the August Superior Steel plate stock a total of 334 MTR-size plates were machined at AM&F. Of these, 117 were as-rolled and the remainder were beta-treated. Superior Steel stock was also used at Savannah for: machining to MTR plates directly for beta transformation studies, and for electroplating and other surface characterization work. Finally, beta-treated August Superior metal was supplied, as bare uranium and after having been nickel-plated, to Battelle and Metals & Controls for various bonding and sheathing researches in the fabrication of bonded fuel element stock.

From the surface characteristics of the Superior Steel August alpha-rolled metal it is expected to use this material, as-rolled, as a standard for all further operations directed toward wrought metal flat plate fuel elements. Nothing has developed which would indicate that, aside from the necessary machining, other surface treatment need be given to the plate stock than etching to put it in proper condition for electroplating and bonding. About one per cent of the stock as received is removed in the etching operation as used to date. A good part of the weight removed, however, is believed to be oxide and scale rather than uranium metal. Studies are under way to determine whether less extensive etching will still provide a satisfactory base for electroplating and bonding.
B. Uranium Characterization

Characteristics of Superior as-rolled material by determining mechanical properties has been completed with the exception of certain impact samples now in preparation.

1. Impact tests yield values of 1.00 ft/lbs. for transverse specimens and 1.50-2.00 ft/lbs. for longitudinal specimens.

2. Bend test results of transverse specimens show tensile elongations of 1-1/2% with deflections of 5-10 degrees (total angle). Longitudinal specimens exhibit tensile elongations of 3 - 6-1/2% with deflections of 20-55 degrees.

3. Ultimate tensile strengths for longitudinal specimens are 15-25% higher than those for corresponding transverse specimens.

Yield strengths (0.2% offset) for transverse specimens from three ingots (734, 738, and 739) are 65-80% higher than for corresponding longitudinal specimens. The moduli of elasticity for these longitudinal and transverse specimens are respectively 15-22 x $10^6$ psi and 36-39 x $10^6$ psi.

Yield strengths for transverse specimens from other ingots (741, 742, and 747) are 30-50% higher than for corresponding longitudinal specimens. The moduli of elasticity for these specimens are: (a) longitudinal, 22-28 x $10^6$ psi and (b) transverse, 37-40 x $10^6$ psi.

4. The average hardness varies between 94 and 97 on the Rockwell B scale. No significant difference in hardness is observed from different locations in a given ingot or between ingots.

II. ALUMINUM COMPONENTS

A. Fuel Element Sheath and Process Tube Procurement

Requirements of the research program call for procurement of: a "B" process tube to contain ribbed sheaths of two different widths and also unribbed sheaths; a "C" process tube to hold ribless sheathed elements; a "D" process tube to hold ribbed and ribless sheathed elements but permitting greater tolerance in assembly than can be obtained with the "B" design. In addition, aluminum sheaths with and without ribs are required for the irradiation experiments in the MTR. During the report period the Harvey Machine Company and Revere Copper & Brass have agreed to fabricate certain of the required aluminum components. In consequence, ALCOA has been relieved of the responsibility for some of the . . .
components. Status of the procurement of the aluminum components required for the flat plate fuel element program is indicated below:

<table>
<thead>
<tr>
<th>Component</th>
<th>Vendor</th>
<th>Fabrication Process</th>
<th>Expected Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTR Sheaths</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain sheath</td>
<td>ALCOA</td>
<td>Mandrel extrusion &amp; drawing.</td>
<td>Feb 1, 1954</td>
</tr>
<tr>
<td>Ribbed sheath</td>
<td>Harvey</td>
<td>Porthole extrusion</td>
<td>Completed</td>
</tr>
<tr>
<td>&quot;D&quot; Process Tube Design</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tube</td>
<td>ALCOA</td>
<td>Extrusion</td>
<td>Feb 1, 1954</td>
</tr>
<tr>
<td>Sheaths (ribbed narrow width)</td>
<td>ALCOA</td>
<td>Porthole extrusion</td>
<td>Feb 1, 1954</td>
</tr>
<tr>
<td>Sheaths (ribbed larger width)</td>
<td>Revere</td>
<td>Porthole extrusion</td>
<td></td>
</tr>
<tr>
<td>Sheaths (plain)</td>
<td>No procurement necessary for current experimental work.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;C&quot; Process Tube Design</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Tube (2-piece)</td>
<td>ALCOA</td>
<td>Extrusion</td>
<td>Feb., 1954</td>
</tr>
<tr>
<td>(2) Tube (alternate welded 2-piece channel)</td>
<td>Revere</td>
<td>Extrusion</td>
<td>----</td>
</tr>
<tr>
<td>&quot;D&quot; Process Tube Design</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Sheaths</td>
<td>No procurement necessary for current experimental program.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An order for the ribbed tubing for MTR irradiations was placed with Harvey early in November and completed at the end of this report period. Examination of representative samples of material indicates that the sheaths equal or better specifications. With a normal wall thickness of 30 mils, tolerance is to ± 2 mils. End thickness, widths, rib design and surface characteristics meet specifications. The placement of the ribs is slightly off the positions now preferred, but it is believed this will not interfere with use of the sheaths in the experimental program of bonding and of testing the bonded fuel elements. The weld of metal from flowing around the spider of the porthole extrusion die is sound without evidence of oxide or other defect. The welds are in the heavy edges of the extrusion, and the only evidence of their positions in the samples examined is a slight grain enlargement.
ALCOA has submitted several trial lots of unribbed MTR sheaths produced by mandrel extrusion and drawing but has continued to experience a variety of difficulties preventing production of a satisfactory sheath. Major defects are poor surfaces on both the inside and outside of the sheaths and lack of proper positioning of the heavy edge sections.

B. Attachment of Ribs to Sheathed Fuel Elements

Despite the success by Harvey in making apparently satisfactory ribbed sheaths, attention continued to be given to possible methods of attaching aluminum ribs to ribless sheathed fuel elements and will continue to be given until it is determined whether there will be difficulties in bonding and non-destructively testing elements made with ribbed sheaths. Work on methods of attaching bonds continued to be done by Metals & Controls Corporation (M&C) and by Aeroprojects.

M&C showed earlier that it was possible to attach ribs to aluminum sheathing by rolling, but this was accomplished with ribs of lower height and differing otherwise from the required design conformation. Following favorable corrosion resistance tests with the first M&C ribbed pieces, this company is concentrating on rolling on ribs of the required design and number and on doing so without deformation of the uranium cores.

The initial ribbed samples fabricated by M&C by rolling a round rib under conditions of heavy deformation onto a flat plate showed no failures in corrosion tests in flowing de-ionized water after 500 hours in 95°C.

A significant development by Aeroprojects has been the initial ultrasonic welding of small aluminum ribs to aluminum sheaths. Bond strength and corrosion resistance appear excellent. The favorable initial results resulted in a request to Aeroprojects to carry forward the development of the design configuration with ribs. The attractiveness of this process is somewhat reduced by the amount of development work likely to be necessary on ultrasonic equipment for production use. Aeroprojects has also continued work on ultrasonic soldering of solid ribs to aluminum sheets with favorable results. Improvements have been made in the cleaning of aluminum, in solder compositions, and in the ultrasonic and temperature conditions. Periods of much longer corrosion resistance have been obtained and samples have been prepared with an assuringly greater degree of reproducibility. Aeroprojects has forecast the probability of considerably greater rib life under service conditions than would be required for the irradiation periods expected.
An extension of the research is, accordingly, programmed. Earlier samples of ribs ultrasonically soldered to aluminum sheath and then spray-coated with aluminum did not fail in 1000 hours of test at 95°C in flowing de-ionized water.

III: BONDING

Attention continued, as in the previous report period, to be given to bonding systems and to processes for employing the systems. Work on bonding systems in this period has been concentrated largely on nickel applied electrolytically, with limited research at Battelle on other electroplates, such as copper, and at National Research on non-electrolytic methods, especially with chromium. Processes for bonding continued to receive attention in the following order: mechanical pressing, including step-pressing; hydrostatic pressing; rolling; and extrusion. All initial samples of either wrought or powdered metal for MTR irradiation are being prepared by mechanical pressing employing nickel bonding layers and aluminum sheaths. The hydrostatic pressing process is receiving increased attention because of its potential applicability to a variety of shapes including, for example, pieces of irregular outside conformation with which it would be difficult to employ mechanical pressing.

A. Bonding Systems

1. Nickel Plating

Attention has been concentrated on obtaining optimum conditions for the making of reproducible electroplates satisfactory for bonding and also on securing higher production rates primarily by increasing current density of plating baths. Investigations have included anodization with hydrochloric and with phosphoric acid; etching with nitric acid; and study of plating bath composition with respect to pH, nickel sulfate, boron and chloride content.

The following experiments were carried out in the study to obtain higher production by increasing the current density:

<table>
<thead>
<tr>
<th>Description</th>
<th>Time (Min.)</th>
<th>Temp. (°C)</th>
<th>Current AMPS/dm²</th>
<th>Volts</th>
<th>Sol. Conc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degreased</td>
<td>8</td>
<td>74</td>
<td>8.1</td>
<td>5.2</td>
<td>Trichlor. Vapor 8N nitric acid H₃PO₄-HCl 8 nitric acid Std. solution &quot;  &quot; &quot;  &quot;</td>
</tr>
<tr>
<td>Pickled</td>
<td>10</td>
<td>44</td>
<td>3.2</td>
<td>3.5</td>
<td>&quot;</td>
</tr>
<tr>
<td>Anodized</td>
<td>0.5</td>
<td>70</td>
<td>1.6</td>
<td>2.1</td>
<td>&quot;</td>
</tr>
<tr>
<td>Etched</td>
<td>10*</td>
<td>38</td>
<td>6.2</td>
<td>5.5</td>
<td>&quot;</td>
</tr>
<tr>
<td>Hi-SO₄ (Plated)</td>
<td>20**</td>
<td>34</td>
<td>3.2</td>
<td>3.2</td>
<td>&quot;</td>
</tr>
<tr>
<td>Watts</td>
<td>10*</td>
<td>46</td>
<td>1.6</td>
<td>2.1</td>
<td>&quot;</td>
</tr>
<tr>
<td>(Plated)</td>
<td>20**</td>
<td>45</td>
<td>6.2</td>
<td>5.5</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

* Conditions for high current density resulting in about 0.4 mil Ni.
**Conditions for low current density resulting in about 0.4 mil Ni.
The plated specimens were studied by (1) spot tests for indication of plating porosity, (2) bend tests for indication of plating adherence, (3) metallographic examination for interface characteristics, plating thickness, porosity, and grain structure, (4) post hot-pressed and stripped metallographic examination for relative adherence after pressing and for diffusion and interface studies.

Spot Tests - no correlation between plating conditions and apparent porosity of the plate.

Bend Tests - specimens about 1/2" wide and 3" long were taken from each specimen and subjected to bend tests. The specimen was examined after a crack appeared on the side in tension. No flaking or spalling of the nickel plate was observed on any specimens. This indicates a relatively adherent plate.

Specimens were hot-pressed by the sandwich technique using 2S aluminum cover plates (0.030 inches thick).

The bonding strengths resulting from either plating condition were equally very high as evaluated by stripping. If the aluminum did not tear, separation occurred at the uranium-nickel interface. These results are in agreement with the quantitative bond strengths determined at ANL for SRL hot-pressed specimens. ANL reports similar separations for bonds of high strengths.

Metallographic examination of as-plated specimens yielded results similar to those reported above for the combination specimens plated at ANL. Examination of the hot-pressed specimens show two Al-Ni diffusion zones and three zones at the U-Ni interface. Of these latter zones, the inner dark region appeared on the as-plated specimen and is assumed to be an oxide. The other two zones at the U-Ni interface are presumably diffusion zones.

It is of interest to note that in some regions of the U-Ni interface a very dark brittle layer was observed. These regions are adjacent to the sides where oxidation occurs during pressing. Furthermore, since such a region was not observed in the as-plated condition it is assumed that the brittle layer is an oxidation product. Samples of this brittle layer have been submitted for X-ray diffraction studies. Further study is being conducted to determine the nature and occurrence.
Uranium surface metallographic examination was completed using a variety of surfacing methods and then nickel-plated at Argonne National Laboratory. Results confirm the previous conclusion that as-rolled and etched surfaces are as satisfactory for nickel-plating as liquid-honed, ground, and machined. The general roughness of the uranium surface after the final steps of preparation for electroplating by etching and anodizing appears independent of previous surface treatment.

B. Bonding Processes

Primary attention at the Savannah River Laboratory was given to mechanical hot pressing employing conditions which had been developed earlier at Battelle and the Savannah River Laboratory. Thirty-four prototype or MTR plates were hot-pressed. Eighteen were the plain picture-frame sandwich type, six had "C"-shaped covers, and ten were made with MTR sheaths. In the course of the period a satisfactory lubricant-and-parting compound was developed, eliminating the earlier problem of parting compounds which adhered to the sheaths and produced detrimental results in corrosion tests. The material consists of levigated alumina and "Tide" in hot water. The "Tide" prevents agglomeration of the alumina and aids in wetting of the assembly surfaces. The slurry is sprayed on the work with conventional paint spray equipment. Pressing cycles evaluated were:

1. Two step - 10 min. 2000 psi plus 10 min. 5000 psi
2. Two step - 10 min. 2000 psi plus 10 min. 8700 psi
3. One step - 10 min. 8700 psi.

Severe blistering was found with the one step cycle, probably due to entrapped air. Occasional blisters were found with the two step cycles, indicating, perhaps, that a cold sizing operation is necessary to remove all air. No correlation has been found between blistering and other variables.

Six of the assemblies have been hot pressed with nickel plated end fittings. After mechanical stripping, indications are that a weak bond is obtained.

Undersize MTR tubing received from ALCOA required a 3" wide core. The edges of this tubing were not indexed well; however, these assemblies presented no new problem and hot pressed well.

Results are not sufficient at this time to make a statement concerning destructive testing.
Facilities now available are suitable for pressing in a single step specimens having the 18" long x 3" wide uranium cores required for MTR tests. Investigation of satisfactory dies for step pressing is under way as a result of the obvious problems in handling plates several feet long at the pressure and temperature conditions required for bonding. Active experimental work on step pressing is expected to begin after the first of the year.

Initial studies of hydrostatic pressing of uranium-nickel-aluminum, uranium-copper-aluminum, and uranium-AlSi-aluminum have been carried out at the Engineering Research Laboratories, Wilmington. Pressures up to 20,000 lbs. have been investigated using helium gas. Temperature investigations have ranged from 400 to 600°C. Good bonds up to an indicated strength of 10,000 psi have been obtained on a number of samples. There has been no indication of core deformation. The advantages of this type of pressing for handling a number of plates at the same time and for handling plates several feet long and with ribbed sheaths have warranted a considerable stepping-up in activity on hydrostatic pressing, and this is being undertaken. The work will include careful investigation of surface preparation of the materials to be bonded together, partly as a result of evidence that in the initial researches certain areas of the surfaces appear to act as nuclei initiating bonding under less severe conditions than required by the remaining areas. Proposed facilities will be centered around a high pressure autoclave approximately 3 feet long inside and having 4 inches inside diameter. Until larger facilities are available work will continue on pieces 1 inch wide and up to 9 inches long.

Roll cladding continued to receive attention at Battelle, Metals and Controls, and the Savannah River Laboratory, with efforts directed toward the bonding of plates of dimensions suitable for MTR irradiation, i.e., having uranium cores approximately 3 inches and up to 18 inches long. Researches are utilizing uranium plate from the Superior Steel rolling. Nickel plate is employed as a bonding layer with aluminum sheath of approximately 30 mils final thickness. Preliminary work has been performed with welded aluminum plate, but pieces for final tests, including irradiation, will employ Harvey or ALCOA wrought aluminum sheaths. A requirement in all the roll cladding work is that deformation of uranium, likely to produce dimensional instability on irradiation, be held to a minimum. Available information indicates that this should be less than 5%.
Continued scouting work at Battelle has shown the feasibility of direct extrusion cladding of aluminum on solid cores. Work to date has employed considerably greater thicknesses of aluminum than the desired 30 mils. This lead to an ultimate low cost cladding method has, however, been encouraging. Using a nickel-plated core a good bond was obtained in hot extruding 1/4" aluminum sheaths over 1/4" diameter uranium cores at 900°F, 50,000 psi, at an extrusion rate of 1/2" per minute.

IV. TESTING PROGRAM

The program of tests for bonded flat plates covers methods for both destructive and non-destructive examination. Destructive examination will include: mechanical tests on uranium (impact, bend, ultimate tensile, yield, hardness); corrosion tests under expected reactor temperature and water conditions on the components of the flat plate assembly and on the completed assembly and autoclaving of the completed assembly in steam at 125 psi for 40 hours. Non-destructive tests to be employed include: the completeness of the alpha-to-beta transformation of uranium by ultrasonics; the thickness of nickel plate; the soundness of bonding by frost test and by ultrasonics; the thickness of sheath by auto-radiation of uranium and by X-ray reflection; and the soundness of welds by radiography.

Information on these test methods are given here only as new developments were made in the methods during the report period. The results using the tests are given under the sections dealing with the uranium component and with powder metal or wrought metal fuel elements.

Ultrasonics tests for alpha-to-beta transformation - The laboratory test equipment for determining completeness of alpha-to-beta transformation on flat plate uranium cores by detection of change in grain size has been completed. Using alpha-rolled plates which were then beta treated at one end, clear demarcation of the beta-treated end was evident.

Bonding by frost test and by ultrasonics - Comparative results indicate that with the present coil design and the frequency employed, the frost test equipment developed for 1 to 1-1/2" diameter uranium cylinders is not nearly as sensitive a method for the determination of unbonded areas of plates as is the ultrasonic test. This is true with both wrought metal and powder metal cores. On the powder metal cores, ultrasonics detected readily unbonded areas of 1/8 - 1/4" in diameter. With the wrought metal plates there was wide variance in the amount of agreement between the ultrasonic map of bonding and the evidence obtained from mechanical stripping. Agreement in the latter case was improved considerably by adjustment of the pulse height of the ultra sound. The correct setting was established by running a series of pulse heights on each of several plates, then stripping mechanically to ascertain the proper pulse height setting to agree with the mechanical stripping results.
Employment of auto-radiation of uranium to determine the thickness of cladding was found to be inapplicable near the edges of uranium plate. This is a serious deficiency since the most probable place for lack of bonding on a press-clad plate is near an edge. Moreover, in the case of plates having a bonding layer of nickel, it is proving necessary to know either the thickness of the nickel or the ratio of nickel-to-aluminum. Improvement of the method is being undertaken.

It was found possible to measure the thickness of aluminum over nickel by X-ray reflection from the nickel, employing for the tests nickel and aluminum foils and using available X-ray equipment. However, the maximum thickness of aluminum which could be measured is 11 mils. A series of specimens is being prepared to find out (a) whether the diffusion-bonded layer of nickel present in a bonded fuel element reflects in a different manner than an equal thickness of foil and (b) whether the method can be extended to measurements of at least 15 mils of aluminum by use of harder X-rays.

V. FLAT PLATE FUEL ELEMENTS PRODUCED BY POWDER METALLURGY TECHNIQUES.

In addition to the 14 MTR-size flat plate fuel elements provided by Sylvania in September, 20 elements were provided in this report period. The 20 elements incorporated modification of fabrication conditions indicated desirable by preliminary examination of the initial lot of 14 elements. Changes included reduction in the thickness of nickel electroplate employed on the inside of the aluminum sheaths, reduction in the amount of nickel at the ends of the uranium core, and the replacement by alumina of the graphite parting agent employed in the pressing operation. In addition to these changes, steps were taken to make improvements quality-wise on various points, such as range and uniformity of core thicknesses. All powder metallurgy plates were completed into pieces of the required MTR fuel element design by the welding-on of solid aluminum ends. Evaluation of all elements was then carried out.

Six elements (3 from each lot) were selected for shipment to MTR for irradiation on the basis of X-radiography, ultrasonic bond tests, auto-radiography, weld examination, autoclaving tests, flow tests, and surface inspection. However, the sheaths of all but one plate surviving the autoclaving tests showed "pitting". As a result, only one piece was considered acceptable at MTR for irradiation, and this was accepted for an exposure of only approximately six weeks. Results of the various tests performed at the Savannah River Laboratory for the purpose of eliminating faulty material and characterizing materials submitted to MTR for irradiation are given below.
It should be pointed out that the problems arising from examining and testing the 34 powder metallurgy pieces are not an indication of dissatisfaction or difficulty with the powder uranium core itself but rather with various aspects of the sheathing system. Modifications which appear likely to eliminate these difficulties seem probable and a third lot of plates incorporating the changes has been requested in order that the irradiation evaluation of the sheathed and bonded cores made by powder metallurgy can be carried out. It is expected that these may be produced by the production of a preform, having a density between 17 and 17-1/2 and the insertion of this into a nickel plated aluminum sheath for cladding and bonding. The preform process has received considerable attention by Sylvania Electric in connection with the investigation of means of making much longer fuel elements than the 18-inch cores required for MTR test. The process appears to have attractive features and advantages over the initial non-preform process which was adopted originally in the interest of speed in obtaining pieces for MTR irradiation.

Radiography of the plates in the as-received condition was performed at two intensity levels. The first set of exposures was made at 40 kv, 10 ma., for 100 seconds. This level delineated aluminum, nickel, and uranium. The higher intensity, 150 kv, 10 ma., 1 min., completely outlined the uranium core and did not show the nickel powder or nickel plating on the sheath interior. Examination of the radiographs showed that the nickel and aluminum powders were mixed in the top plug. In most cases the nickel was piled in a mound at the center of the plug, and aluminum was in contact with the uranium at the outer portions of the plug. Nickel patches, or islands, existed in several of the top plugs. The aluminum-nickel layer was slightly irregular at both ends of the core. Crevices, about 1/4 to 1/2" long, into which nickel and some uranium have penetrated, extend from the end of the core, along the edge of the bottom plug, towards the end of the plate. High intensity X-ray exposures indicate that the crevices are primarily filled with nickel.

Projection shots were made at a magnification of 2x after final machining of the end fittings. These radiographs were made by setting the distance between target and sample equal to one-half of the distance between the sample and film. It was observed that the nickel plating on the interior of the sheath was folded; however, there was no observable area of U-Al contact along the edges.

The average uranium core length was found to be about 12-3/4" with some irregularity in the centering of the cores. Near the mid-point of many of the plates a projection of uranium occurred which extended much closer to the edge than did the remainder of the core. This may have been due to an imperfection in the die. Core thicknesses were of the order of 150 mils. Aluminum sheath walls varied in thickness from about 15 to about 70 mils.
All plates were tested for bonding by ultrasonic transmission. The entire surface area was scanned with an ability to detect non-bonds of as little as 1/8 to 1/4" in diameter. Several plates were found with non-bonded areas. Two areas of 1" and 1/2" in diameter were found on each of two plates on the powder plug at the top of the plate. Nearly all plates showed the core uranium on the ultrasonic test record. It was thought that this indication of apparent lack of bond was due to a refraction phenomenon and that sound was reflected from the irregular end folded surfaces of the pressed core edges. Mechanical stripping provided support for this assumption. Frost test of the degrees of sensitivity possible with available equipment did not detect the unbonded areas as found by ultrasonics.

Aluminum end fittings were welded to the clad cores with some difficulty in making the welds at the upper end. Radiographs of all welds were taken. One plate of the second lot and two plates of the first lot could not be welded, possibly because of impurities, such as nickel, in the powder end. All other plates welded, but the weld joints were generally porous and the porosity was more severe at the top end than at the bottom wrought plug end. The bottom welds showed in most cases only a hairline trace of pinholes, but on the other hand, some of the top welds had voids up to 1/8" in diameter.

Auto-radiography was used to test for sheath thickness and uniformity. It was found that this method could not tell the exact sheath thickness unless a suitable correction for the nickel layer was made. Nickel plating on the first 14 plates was about 2-3 mils, and on the second group the plating was about 1/2 mil. It was found that the absorption of radiation of 2.3 mils of nickel was equal to that absorbed by 16 mils of aluminum. Auto-radiographic results were correlated with metallography, and it was found that the average sheath thickness was about 23 mils. It must be noted, however, that auto-radiography tests were valid only at the center of the plate. The test is not valid near the edges of the plate because of non-symmetrical radiation.

Five plates from the first group of 14 received were flow-tested in deionized water for 17 days. Ultrasonic tests revealed no signs of non-bonding which may have been caused by the continuous flexing of the plates by the water flow during the test.

Autoclave tests were carried out at 125 psi of saturated steam on a group of 27 plates which came through earlier tests. Ten of the first lot of 14 plates were tested and 3 failed. Seventeen of the second group of 20 were tested and 5 failed.
All but one of the plates surviving the autoclaving had sheath pits. The pits varied from rather minute and shallow ones to others of considerable area, apparently penetrating substantially through the complete depth of the sheath. It is assumed that the pits may have resulted from the quality of the aluminum, from some processing step or from pressing the parting compound or other solid in the sheath in the pressing and bonding step. Unidentified foreign bodies found in some instances in the surface of the plates corresponded to the size and shape of some of the pits. One plate from the second lot formed a blister approximately 1/2" in diameter and 10-12 mils high near the bottom end of the core. Failures occurred in less than 48 hours and without exception at the weld between the wrought plug and the aluminum tube.

Ultrasonic tests were re-run after welding, after machining, and after autoclaving. It was found that bonding had not been damaged during any of the above operations.

One plate was tested for sensitivity to thermal shock by heating to approximately 545°C and quenching in water at room temperature. The plate was cycled 5 times before any signs of blistering occurred. The sixth trial produced a 3/4" blister which steadily grew to about 2" by the nineteenth trial. Total length change was less than 1/32 inch.

Hardness measurements were taken at one inch intervals along the length of the core of one plate (149); the cladding had been removed by milling. Measurements were made at the center and at a distance of 1/2 and 1 inch from the center. The values obtained varied from Rockwell B 101 to 106.

Density of the core was determined at both ends and the center. Values of 18.70 to 18.91 were obtained on nine specimens.

Tensile strength of longitudinal sections and of transverse sections show no apparent preferred orientation: ultimate, 110,000 psi; yield, 75,000 psi.

### VI. FLAT PLATE ELEMENTS PRODUCED FROM WROUGHT URANIUM CORES

Uranium cores for the wrought metal MTR pieces were chosen from the crack-free sections of the Superior Steel high alpha-rolled metal. The material was beta-transformed and machined to dimensions at the ends and on the edges but the flat faces were not given special surface treatment. The as-rolled etched and anodized metal was nickel plated and pressed. Etching, anodizing, electroplating, mechanical hot pressing, and bonding procedures were employed as described earlier. Limitation on actual preparation of a substantial number of elements for evaluation of pieces with wrought metal cores has been prevented in this period by non-availability of aluminum sheaths. A sufficient stock of ALCOA unribbed sheaths is now available.
to provide 20 or more completed plates for MTR use by the end of the month. The information following on the wrought metal plates is based on the few hot-pressed pieces completed and tested with sheaths earlier available. Tests employed were the same as those applied for the powder metallurgy cores.

Strong nickel bonds were obtained between the uranium core and the aluminum sheath on parts of every plate pressed and, generally, bonding occurred on more than 90% of the plate surface. Nickel bonds between aluminum end plugs and aluminum sheaths were, however, always weak regardless of whether nickel was used as an electroplated deposit or as a foil. Time, temperature and pressure modifications are being made to secure bonding over the entire nickel-uranium areas and to improve the nickel-aluminum bond. Fracture of the bond is more frequent between the aluminum-nickel than between the uranium-nickel. Investigation is under way to clean and otherwise prepare surfaces of these components to assure stronger and more reproducible bonds. Sound, strong welds were easily and regularly obtained and were found to be satisfactory by non-destructive test procedures.

There is no evidence of thinning or penetration of the aluminum sheath in the pressing operation.

Three plates pressed using the ALCOA tubular sheaths were autoclaved in 125 psi steam for 72 hours. No evidence of failure was found in these plates. A second series of six plates is in test. Three of these were welded at the end in the usual fashion and three were as-hot pressed after 24 hours. One of the latter failed, apparently, because of penetration through the plate end.
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