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SUBJECT: Manufacturing U-1 Fuel Plates Clad with an
Intended 99.90 w/o Al - 0.10 w/o B Alloy

TO: J. H. Frye, Jr.

FROM: R. J. Beaver

Ref: (a) ORA: AWL ltr. dated March 15, 1956 from H. M. Roth
to J. A. Swartout

Classification cancelled (or changed to) **UNCLASSIFIED**
by authority of *Ltr. from Dabon, Branch*
dated May 23, 1956.
by *R. R. K. 3/31/56* TLE, date *5-31-56*

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To: J. H. Frye, Jr. Subject: Manufacturing U-Al Fuel Plates
Clad with an Intended 99.90
Copies: Listed Distribution w/o Al - 0.10 w/o B Alloy
Ref: (a) ORA:AWL ltr. dated March 15, 1956 from H. M. Roth
to J. A. Swartout

1. The 99.90 w/o Al - 0.10 w/o B alloy as air induction melted with an addition of a master Al-B alloy containing approximately 3 w/o B exhibits top and bottom segregation in the as-cast slab. This observation is based on only one result at the present time. However, on this basis, the alloy cover plate material for the simulated ETR plates was cropped prior to receipt of analytical results with the assumption that slabs, prepared in the exact manner as the first slab would exhibit a similar segregation pattern. This risk was necessitated because of the limited time available and the urgency to obtain plate fabrication results for GE APED by April 1, 1956. As a result of the end cropping, the yield of presumably acceptable material was merely 64%. However, with further development, it is believed that this yield may be improved to 81% and possibly higher.
2. Further efforts should be made to obtain improved homogeneous master alloys in the range of 2.5 to 3.5 w/o B-Al alloys from Cooper Metallurgical Associates. Another source of Al-B master alloys may be the Niagara Smelting and Refining Division of Continental Copper and Steel Company, Buffalo, New York. Improvement of homogeneity of master alloys should improve the homogeneity of the 0.10 w/o B-Al alloy.
3. Further efforts should be made to develop melting and casting techniques to overcome the top and bottom segregation pattern in the 0.10 w/o B-Al alloy and thus improve the yield of cover plate material.
4. Considerable care must be exerted to air-induction melt the 0.10 w/o B-Al alloy in an atmosphere with a relative humidity of less than 35%. By "flux-annealing" this material after melting and casting in a low relative humidity atmosphere, blistering of the material was reduced considerably. However, fuel plate rejections for this defect were 25%.

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5. Hot and cold breakdown of the 0.10 w/o B-Al slabs reveal that the material rolls much like high purity 99.99 w/o Al.
6. The 0.10 w/o B-Al cover plates can be roll bonded to the 11.0 w/o U-Al fuel alloy with the conventional practices utilized in MTR fuel plate fabrication.
7. In cladding with the 0.10 w/o B-Al alloy, the results reveal that the alloy clad reduces more than the fuel core. A statistical analysis of the cladding thickness shows that a 0.050 inch thick plate will contain a clad with a thickness of 0.0150 in. $\pm$ 0.0006 in.
8. The uncertainty of boron in a fuel plate clad with the 0.10 w/o B-Al alloy appears to be $\pm$ 19.5%. At the present writing, this uncertainty figure is based on only one result for uncertainty due to segregation. Further results will be available in the near future.
9. Difficulty was experienced in fabricating plates with straight cores because of the 36 inch length of the core, and the specification that the nominal inactive edge of the fuel plate be 0.150 inches. Results revealed that 22.5% of the 40 plates measured would be rejected for this defect. A decrease in the designed core width of the ETR plate core from 2.474 in. to 2.416 in. would increase the nominal inactive edge width to 0.179 which would permit a larger maximum core boundary. The results indicate that if such a change was made, rejections for "rainbowing" should decrease to 5.0%. Further experience in rolling these long plates, and the addition of guides on the mill table to assure straight away entrance into the rolls, might possibly reduce this rejection still further.
10. Difficulty was experienced in shearing these plates in the same manner as MTR fuel plates because of the additional length. Simultaneous shearing or slitting of both edges may be the solution to this problem.

Detailed information and results obtained are attached.

RJ Beaver
R. J. Beaver
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RJB:fwh

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Results Obtained in Manufacturing 40 Simulated
ETR Plates

A. Fabrication of Nominal 99.90 w/o Al - 0.10 w/o B Alloy.

1. Analysis of Al-B Master Alloy Containing Approximately
3 w/o Boron.

The master alloy used in this investigation was produced at Cooper Metallurgical Associates, Cleveland, Ohio. The alloys were analyzed at ORNL and as listed below showed appreciable deviation from the values submitted by Cooper. It was also observed that Cooper's analyses were based on one drilling from the center of the cast pig.

Cooper Master Alloy #1 was received as pieces. Approximately 15 to 20 samples were taken from these pieces, lumped together, and analyzed for boron.

Cooper Master Alloy #2 was received as a pig. Samples were drilled from both ends and the center.

Table 1

Analytical Results of Cooper Master Alloys

	<u>w/o Boron</u> <u>Alloy #1</u>	<u>w/o Boron</u> <u>Alloy #2</u>
Cooper Reported Value	2.96	3.04
ORNL Average Value	4.67 $\pm$ 0.02	2.60 $\pm$ 0.02
End #1	--	2.76
End #2	--	2.11
Center	--	2.94

The tolerance listed above represents precision from one analysis to the other made on the same sample. The accuracy of the analytical procedure itself appears to be less than 7%.

2. Amount of Pure Aluminum and Master Alloy Used in One Melt.

Seventeen (17) slabs of intended 99.9 w/o Al - 0.1 w/o B alloy were prepared during this investigation. Two of the slabs were analyzed thoroughly and the results are listed below. As noted, there appears to be definite top and bottom segregation; however, the majority of the slab shows uniform boron content. The first of these slabs was made from a nickel boride addition; the second from Cooper's Master Alloy.

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In both cases, the segregation pattern was similar. It is to be emphasized that ORNL would have preferred to have had additional supporting evidence before preparing the cover plate material. However, this was an impossibility due to the April 1st deadline. GE APED was made well aware of this risk, but felt that the deadline must be met. The irradiation-corrosion samples were prepared from this material. In view of the urgency to establish ETR fabrication procedures, fifteen (15) additional slabs were prepared as cladding stock for the ETR irradiation test assembly and the forty (40) ETR plates containing depleted uranium. Two of these slabs were prepared from Cooper Master Alloy #1, the charge totaling 1957 grams of 99.99 w/o Al and 43.1 grams of the master alloy. The balance of the slabs were prepared from Cooper Master Alloy #2, the charge totaling 1923 grams of Al and 77.0 grams of the master alloy.

Table 2

Analytical Results of Intended 99.90 w/o Al -
0.10 w/o B Alloys Prepared by ORNL

<u>Master Alloy</u>	<u>Distance from Bottom of Rolled Slab (in.)</u>	<u>Analyzed w/o Boron</u>
Cooper #1	0	0.112
	4.5	0.073
	9.0	0.072
	13.5	0.071
	18.0	0.071
	22.5	0.066
	27.0	0.062
	31.5	0.063
ORNL Nickel-Boride #3	0	0.126
	4.5	0.075
	9.0	0.082
	13.5	0.076
	18.0	0.078
	22.5	0.076
	27.0	0.066
	31.5	0.152

3. Casting Conditions.

All melting was accomplished in a 20 KW open air induction furnace powered by an Ajax Spark-gap Converter. The aluminum and the master alloy were simultaneously charged into the crucible and heated to 1075°C to insure complete solution of the master alloy. This melting and super heating required approximately 15 minutes. The melt was then cooled to 900°C and poured into a dried graphite mold whose mold wall temperature was slightly above ambient. Cooling to 900°C was accomplished in approximately 13 minutes. The relative humidity varied from

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20 to 35% during the course of casting the fifteen slabs.

The inside dimensions of the graphite crucible were $3\frac{1}{2}$ in. dia. at the bottom, $4\frac{1}{2}$ in. dia. at the top, and $15\frac{1}{2}$ in. in length. The wall thickness along the sides was $\frac{1}{2}$ in. and at the bottom, 1 in.

4. Geometry of the Mold.

The graphite mold was rectangular in cross-section with a taper of $\frac{1}{4}$ in. in $10\frac{1}{2}$ in. along the length. The inside dimensions were 3 in. in width x 1 to $1\frac{1}{4}$ in. in thickness x $10\frac{1}{2}$ in. in length. The total length, including the head, was 12 in. The cross-section at the end of the head was $3 \times 4\text{-}3/4$ in. Wall thickness of the mold was 1 in.

5. Cropping of the Ingot.

The entire slab, including the head, was hot rolled to approximately 0.102 in. in thickness. Sixteen inches of material was cropped from the top and bottom of this plate and discarded. The remainder was considered to be satisfactory cover plate stock.

6. Procedure for Fabrication of Cover Plates.

- a. Preheat 45 minutes at 565°C .
- b. Roll to 0.225 in. thickness with 20% reduction per pass and reheat 3 minutes between each pass.
- c. Flux anneal (process same as detailed under flux annealing of fuel plates). During fabrication of the first slabs processed, it became apparent that slabs cast in air in which the relative humidity was high, blistered during fabrication. Flux annealing plates from slabs cast in relatively high humidity decreased the number of blisters, but the two factors together; namely, casting in air with a relative humidity of less than 35%, and flux annealing the plate during fabrication, drastically reduced any rejected material due to blisters.
- d. Preheat 1 minute at 565°C .
- e. Roll to 0.155 in. thickness with 20% reduction per pass.
- f. Cold roll to 0.102 in. in thickness in 4 passes.
- g. Crop, shear to cover plate length, and section samples as tabulated below.

Table 3

Cropping, Shearing and Sampling of
Alloy Cover Plate Stock

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Lower Half of Original Slab

1. Total length of plate	47 inches
2. Cropping loss at bottom	16 inches

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(Table 3 continued)

3.	Sample	$\frac{1}{2}$ inch
4.	Cover plate	15 inches
5.	Cover plate	15 inches
6.	Sample	$\frac{1}{2}$ inch

Upper Half of Original Slab

1.	Total length of plate	46 $\frac{1}{2}$ inches
2.	Cropping loss at top	16 inches
3.	Sample	$\frac{1}{2}$ inch
4.	Cover plate	15 inches
5.	Cover plate	15 inches

- h. Yield of satisfactory material (pending analytical results) -- 64 %

This yield may have been improved to 81% by cropping only 8 in. from ends of plates. The final sheared cover plate size was 0.102 in. thick x 14 in. long.

i. Sampling

Three samples, presumably within the boundaries of the material considered homogeneous, were sheared as $\frac{1}{2}$ inch wide pieces sheared transversely across the plate. Approximately 4 grams of each piece were sent to Analytical Chemistry and the balance reserved for an emergency.

j. Cleaning

After shearing to size, the plates were degreased in trichlorethylene vapor.

- k. Accuracy in which the boron content in 19 cover plates can be determine:

The accuracy in boron content is determined by

- (1) assumed density of the 0.10 boron alloy,
- (2) assumed homogeneity, based on one slab,
- (3) assumed precision of analysis,
- (4) basic uncertainty in analytical procedure,
- (5) assumption that the average cladding thickness is .015 in. thick.

Density. Because of the small addition of boron to this alloy, the density of the alloy was assumed to be the same as the commercial type 1100 aluminum; namely, 2.7 gms/cm³.

Homogeneity. Based on the results of one slab listed in

Table 2, and cropping of the segregated ends of the slab, the uncertainty due to segregation appears to be $\pm 7\%$.

Precision of Analysis. The precision from one analysis to the other made on the same sample appears to be $\pm 1.5\%$.

Uncertainty in Analytical Procedure. In order to obtain precise data to ascertain the accuracy of the analytical method, samples of boron and aluminum powder were carefully weighed to various concentrations and delivered to Analytical Chemistry for determination of boron content. The results are listed below. Samples 1 through 5 were weighed on an analytical balance. Samples 6 and 7 were weighed on a microbalance.

Table 4

Determination of Accuracy of Analytical
Method for Al-B Alloys

Sample	Intended B Content w/o	Analyzed B Content w/o	Deviation of Analyzed from Intended B Content w/o
1	0.136	0.116	-15
2	0.200	0.183	- 8
3	0.286	0.243	-15
4	0.507	0.450	-10
5	0.220	0.182	-17
6	0.080	0.080	0
7	0.120	0.112	- 7

As may be noted, the results are scattered, but there seems to be a trend toward improvement. It appears that present accuracy of the procedure lies somewhere below 7%.

Effect of Volume of Cladding. The boron content in each plate is extremely dependent on the cladding thickness, assuming the length and width are machined to tolerances specified. In establishing fabrication procedure for the ETR plates, metallographic measurements were made on the finished plate and the results of a statistical analysis are listed below.

Table 5

Results of Statistical Analyses of Core-Clad
Thicknesses in Simulated ETR Plates

Plate	Mean Thickness (in.)	Ave. Deviation from Mean (in.)	Maximum Thickness (in.)	Minimum Thickness (in.)	Number of Readings
1-B Core	0.0218	± 0.0007	0.0248	0.0201	30
Clad	0.0143	± 0.0008	0.0162	0.0096	50
2-B Core	0.0203	± 0.0007	0.0217	0.0180	30
Clad	0.0148	± 0.0006	0.0161	0.0130	60
3-B Core	0.0197	± 0.0011	0.0255	0.0170	30
Clad	0.0150	± 0.0008	0.0179	0.0107	50
4-B Core	0.0198	± 0.0007	0.0213	0.0187	15
Clad	0.0152	± 0.0004	0.0163	0.0136	30
5-B Core	0.0202	± 0.0006	0.0217	0.0192	15
Clad	0.0148	± 0.0004	0.0162	0.0134	30

The average cladding thickness obtained from the results of plates 3-B, 4-B, and 5-B is 0.0150 in. with an average deviation of ± 0.0006 in. The possible error, based on this average deviation, appears to be $\pm 4\%$.

A summary of the uncertainty of the boron content is listed in Table 6.

Table 6

Accuracy in Which it Appears that the Total Boron Content
in 19 Fuel Plates Can Be Determined

- (1) Assuming a 99.90 w/o Al - 0.10 B alloy
- (2) Assuming an 0.0150 in. cladding thickness
- (3) Uncertainties

(a)	Homogeneity	$\pm 7\%$ *
(b)	Precision of Analysis	$\pm 1.5\%$ *
(c)	Accuracy of Analytical Method	$\pm 7\%$
(d)	Effect of Cladding Deviations	$\pm 4\%$

Total $\pm 19.5\%$

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(Table 6 continued)

(4) Boron content (to be completed when analyses become available)

Nominal
High
Low

*Note that this is based on one result. Table 6 will be revised when further results become available.

B. Fabrication of Fuel Core Slugs.

1. Amount of Al and U for One Melt.

Al - 5498.16 gm
U - 70.84 gm

Two slabs are poured from this charge.

2. Casting Conditions.

- a. Melting was accomplished in a 20 KW open air induction furnace powered by an Ajax Spark-gap Converter.
- b. The inside dimensions of the graphite crucible were $3\frac{1}{2}$ in. dia. at the bottom, $4\frac{1}{2}$ in. dia. at the top, and $15\frac{1}{2}$ in. in length. The wall thickness along the sides was $\frac{1}{2}$ in. and at the bottom 1 in.
- c. The melting procedure is itemized below:
 - (1) High grade (99.99%) Al was selected as the working stock and melted in a graphite crucible.
 - (2) Small pieces of uranium approximately 100 to 300 grams total weight were added to the molten Al at a temperature of 800°C.
 - (3) After the desired addition was made, the bath temperature was increased to 900°C, and stirred gently at 2 minute intervals until the metal was in solution.
 - (4) The bath was permitted to cool to 800°C, while stirred thoroughly and continuously.
 - (5) The molten alloy was held at 800°C for 10 minutes to alloy for degassing.
 - (6) The power was shut off, and the bath permitted to cool to 760°C for drossing and sampling prior to pouring.

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- (7) Immediately after sampling, the alloy was poured in a mold inclined at an angle of 15 degrees from its vertical axis. As pouring progressed to completion, the mold was gradually rotated to a vertical position.
- (8) The thermocouple protection tube, stirring rod, sampling spoon and molds are of graphite. The sampling spoon has the capacity of a teaspoon.

3. Material and Geometry of the Mold.

The mold was of AGOT graphite, rectangular in cross-section, with inside dimensions of 1-1/4 x 3-3/4 x 9 in. The mold was not tapered, but allowance was made at the top for a shrinkhead. Wall thickness was 1 in.

4. Amount of Cropping on the Casting.

None

5. Chemical Analysis.

- a. Samples were taken from the molten alloy just prior to pouring.
- b. Three samples, approximately 5 gram total weight, were taken, two of which were sent for analyses, the other reserved for emergency.
- c. Analytical chemistry claims $\pm 0.5\%$ accuracy of the sample analyzed. Accountability is based on accounting for the product level uranium in each fuel element to this accuracy. In other words, a 19 plate 200 gram element is predicted to contain 200 grams ± 1.0 gram. This prediction is based on analytical results and the average weight of the core determined from weighing 76 cores in one operation.
- d. The 40 simulated ETR plates contained 9.530 grams of uranium instead of 9.737 later requested by GE APED. This difference is negligible insofar as the melting and casting procedure is concerned.

6. Preheating.

- a. Furnace temperature - 595°C.
- b. Time - 60 minutes.

7. Hot Rolling.

- a. Reduction per pass - 15%.
- b. Reheat time between passes - 3 minutes.
- c. Number of passes - 10.

d. Dimensions of hot rolled slab - $0.410 \times 5\frac{1}{4} \times 30$ in.

8. Cold Rolling.

- a. Reduction per pass - approximately 1% with continuous thickness measurement.
- b. Number of passes - 8 to 12.
- c. No intermediate annealing.
- d. Dimensions of finished slab - $0.381 \times 5\frac{1}{4} \times 32$ in.

9. Punching.

- a. Dimensions of MTR punch - 2.000×2.300 in.
- b. Dimensions of core slugs - $2.000 \times 2.300 \times 0.381$ in.
- c. Dimensions of picture frames - $6.375 \times 4 \times 0.370$ in.

10. Insertion of Core Slugs in Frame.

Two cores are pressed into a double picture frame in one operation under approximately 20 tons.

11. Rolling Prior to Applying Cover Plates.

- a. Furnace temperature - 595°C .
- b. Preheat time - 30 minutes.
- c. Reduction per pass - 17%.
- d. Reheating time between passes - 5 minutes.
- e. Number of passes - 6.
- f. Dimensions after rolling - approximately $4\text{-}1/3 \times 19 \times 1/8$ in.
(finished thickness varies between 0.124 and 0.128 in.)

12. Cleaning.

No cleaning prior to applying cover plates.

C. Fabrication of Plates.

1. Selection of Cover Plates.

The proper cover plate thickness was determined experimentally as shown in Table 7, utilizing a core 2 in. in length, 2.3 in. in width and 0.381 in. in thickness.

Table 7

Determination of Proper Cover Plate Thickness
to Produce 15-20-15 Fuel Plate

Expt.	Initial Cladding Thickness (in.)	Finished Cladding Thickness (in.)	Finished Core Dimensions (inches)			Reduction Ratios		
			Thickness	Length	Width	Thickness Clad	Core	Length Core
1	.094	.0143	.0218	33.375	2.5 $\frac{1}{32}$ ₀	6.57	5.73*	16.69
2	.098	.0148	.0203	34.500	2.5 $\frac{1}{32}$ ₀	6.62	6.15	17.25
3	.102	.0150	.0197	35.250	2.5 $\frac{1}{32}$ ₀	6.80	6.34	17.63
4	.102	.0152	.0198	35.375	2.5 $\frac{1}{32}$ ₀	6.71	6.31	17.69
5	.102	.0148	.0202	35.375	2.5 $\frac{1}{32}$ ₀	6.89	6.19	17.69

*Based on intermediate core thickness of 0.124/0.128 in.

2. Applying Covers.

Scratch brush mating surface of cover plate with a stainless steel wire brush, bend in a sheet metal brake and close over frame in a small, 500 pound air press. As shown in Table 7, experiment 3 resulted in acceptable core and clad thickness dimensions and was substantiated in experiments 4 and 5. It is also noteworthy that the cladding reduces more than the core during the process by a factor of 1.07. The cover plate material during hot rolling reduced in thickness in a manner similar to high purity 99.99 w/o Al.

3. Preheating Furnace.

- a. Temperature - 595°C.
- b. Time - 30 minutes.

4. Hot Rolling.

- a. Reduction per pass - 32%.
- b. Reheating time - 4 minutes for two passes; balance 2 minutes.
- c. Number of passes - 5.
- d. Dimensions after hot rolling - approximately 4-1/8 x 51 x 0.065 in.

5. End Cropping.

Shear ends square to approximately 38 in. length.

6. Cleaning.

None

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7. Flux Annealing.

- a. Flux in a Eutectic 190-Methyl Alcohol slurry of 2 parts flux and 1 part alcohol by weight.
- b. Slurry is applied by brushing on both sides of plate.
- c. Plates are dried in a drying oven, at 165°C for 60 minutes.
- d. Plates are removed from drying oven, transferred to a furnace heated to 600°C, and heated for 60 minutes.
- e. Plates are removed from furnace, quenched separately in hot water, scrubbed thoroughly and pickled in a 10% HNO₃-2% HF aqueous solution by volume.
- f. The plates are not inspected for blisters after this treatment.

8. Cold Rolling.

- a. Reduction per pass - approximately 5% with continuous thickness measurement.
- b. Number of passes - 4 to 5.
- c. Dimensions after cold rolling - 4-1/8 x 47 x 0.050 in.

9. Annealing.

- a. The plates are stacked in batches of ten on an aluminum plate in a resistance wound furnace.
- b. Furnace temperature - 600°C.
- c. Annealing time - 60 minutes.
- d. Removed from furnace and air quenched.
- e. Inspected for blisters.

10. Cleaning.

None

D. Rejections.

The two major sources for rejection in fabrication of aluminum fuel plates are (1) rainbowing of the core caused by the plate curving during the rolling sequences, and (2) blistering of the fuel alloy or clad material during hot rolling or in subsequent heat-treatment.

The tolerances as interpreted for the inactive aluminum edges on ETR fuel plates are 0.150 inch nominal inactive edge, with a 0.100 inch minimum. Since ORNL did not machine the plates to size, measurements were made from sheared edges, and as observed fluoroscopically. Inasmuch as the core width rolled at ORNL was 2.5 ± 1/32 inches and the sheared plate width was 3.0 inches, the nominal inactive edge is 0.234 inches. Those plates with a width boundary

greater than 2.631 inches were considered as rejects, as listed in Table 8 and were based on the following procedure:

1. Examine plates fluoroscopically.
2. Scribe a mark on one edge of the core tangent to the maximum convex curvature in the rainbow of the core.
3. Scribe two marks at the extreme end points on the opposite side of the core.
4. Draw a penciled line through the two marks scribed in 3 above.
5. From this reference line to the mark scribed in 2 above, represents the maximum width in which the core lies.
6. Measuring this width value from the reference line described in 4 above, scribe marks on the boundary of the opposite edge of the core, as determined in 2 above.
7. Draw a penciled line through the three marks scribed as in 2 and 6 above. This represents the boundary of the core on that side.
8. Scribe marks at the core ends, and mark off length boundaries of the core.
9. Ink in all lines representing the core boundaries.
10. Measure the total width of inactive edge aluminum, to shear to 3 inch width; split the difference; scribe reference marks on one edge of the plate; shear along a line drawn through the marks; shear other side of the plate utilizing the 3 inch location stops on the shear table.
11. Nominal core width boundary of plates fabricated at ORNL is 2.531; therefore, extrapolating to ETR plate specifications, the maximum core width boundary for "rainbowed" cores is 2.631 inches. (Theoretically .050 inches less on each inactive edge). Rejections for rainbowing are based on this criteria.

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Table 8

Rejections Due to Rainbowing of Fuel Core and
Blister Rejections in Alloy Clad

Plate No.	Boundary Core Width (in.)	Length (in.)	Rejector		% Total Rejection
			Core Rainbow	Blistered Core	
S-5	2.500	35-3/8	none	none	
N-3	2.500	35-1/2	none	none	
P-1	2.500	35	none	none	
R-3	2.562	36-1/8	none	none	
R-4	2.578	35-25/32	none	none	
O-1	2.562	35-1/8	none	reject	
N-4	2.440	35-15/16	none	none	
O-3	2.562	35-7/8	none	reject	
J-3	2.656	35-3/16	reject	none	
N-1	2.686	36-5/16	reject	reject	
P-4	2.625	35-9/16	none	none	
Q-3	2.609	35-3/4	none	none	
M-2	2.625	35-13/16	none	none	
M-4	2.641	35-13/16	reject	reject	
Q-1	2.594	36	none	reject	
L-1	2.625	35-31/32	none	none	
K-2	2.594	35-17/32	none	reject	
K-1	2.562	35-3/4	none	none	
S-1	2.750	35-9/16	reject	none	
Q-2	2.625	35-13/16	none	none	
P-2	2.687	35-21/32	none	none	
J-4	2.594	35-3/4	none	none	
L-3	2.594	35-1/2	none	none	
R-6	2.562	35-1/2	none	none	
M-3	2.672	35-9/16	reject	none	
N-2	2.625	35-11/16	none	none	
K-4	2.610	35-5/16	none	none	
S-3	2.625	36-11/16	none	none	
M-1	2.640	35-23/32	reject	none	
Q-4	2.625	35-3/8	none	reject	
S-4	2.594	35-15/16	none	reject	
O-2	2.594	35-21/32	none	reject	
L-2	2.625	35-13/16	none	none	
O-4	2.625	36	none	none	
S-2	2.687	35-25/32	reject	reject	
L-4	2.655	36	reject	none	
S-6	2.750	36-11/32	reject	reject	
R-5	2.531	35-7/8	none	none	
R-2	2.500	36-3/32	none	none	
R-1	2.531	35-13/32	none	none	

Rejections 9
22½%

10
25%

47½%

Rejections for ETR
core width of 2.416 in.-----

2

10

Rejections for ETR
core width of 2.354 in.-----

5%

25%

30 %

0

10

25 %

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From the above information, it is quite apparent that under normal rolling conditions as utilized in MTR plate fabrication, the 22.5% rejections due to rainbowing are extremely high with the proposed ETR tolerances.

From ORNL's experience in fabricating the 40 simulated ETR plates, it is felt that the major difficulties are caused by (1) the 36 in. core length, and (2) the specification that the nominal core width be 2.474 inches. The "rainbowing" rejections are high because of the length. Assuming no change may be made in decreasing length, this condition can be minimized by allowing a wider nominal inactive edge of aluminum. The change can be made by either designing a narrower core, or a wider fuel element. From the results listed in Table 8, it appears that to minimize "rainbowing" rejections, extrapolating to the ETR specifications, the nominal inactive edge should be 0.179 inches, with a minimum inactive edge of 0.100 inches. The nominal ETR core width would thus change from 2.474 in. to 2.416 in. Based on the results shown in Table 8, and the modifications suggested above, rejections for "rainbowed" cores should decrease to 5.0%. It would appear that rejections for rainbowing would be eliminated with a decrease in core width to 2.354 in., which allows 0.210 in. wide inactive aluminum edges along the fuel plate.

In addition to the rainbowing condition, results of shearing these plates have revealed that it is extremely difficult to shear to exact parallelism in order to allow equal width of inactive aluminum along the edges. This condition appears to be due to the release of stresses during a shearing operation in which both edges are not sheared simultaneously. It is very probable that this condition may be eliminated or greatly minimized by shearing or slitting both edges simultaneously.

The results listed in Table 8 reveal that total rejections in rolling the 40 ETR plates were 47.5% of which 25% were a result of small isolated blisters on ten plates. A close examination showed that all blisters were confined to the alloy clad. The appearance of these blisters is generally associated with entrapped hydrogen during melting and casting of the alloy. The "flux annealing" treatment is designed to permit the hydrogen to escape. Inasmuch as there is no record of the aluminum-boron alloy rejected after flux annealing and prior to cladding the fuel plate, it is possible that either the material was not thoroughly inspected and suspicious portions rejected, or the procedure is not yet optimum.

The results of this work strongly indicate that if the core width of the ETR plate is decreased to 2.416 in., 70% of the plates fabricated will be satisfactory, with approximately 25% of the rejections due to blistering of the cladding. It is apparent that further development work is desirable in an effort to reduce rejections because of the faulty Al-B alloy. 666 017

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The maximum percent spread in core width during fabrication was 10%.

E. General Information.

Recommended punch size for ETR core is based on the following:

- a. MTR core width prior to fabrication 2.3 in.
- b. Maximum core width after ETR plate fabrication 2.531 in.
- c. Maximum percent spread 10%

- d. ETR core width prior to fabrication =

$$\frac{(2.3)(2.474)}{2.531} = 2.248 \text{ in.}$$

- e. ETR core length prior to fabrication:

$$\frac{35.250}{2} = \frac{17.67}{1} \text{ length ratio}$$

$$\frac{36}{17.67} = 2.037 \text{ in.}$$

- f. Recommended original core size - 2.248 in. width x 2.037 in. length x 0.381 in. thickness.

The above calculations are based on ORNL experience with ETR dummy plates and the assumption that the core ends will be square after fabrication. Another method which appears to be just as feasible is to design for a longer initial core length and fabricate from a thinner core than was done at ORNL.

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