Paper 24

MANUFACTURE OF THE FUEL PLATES AND FUEL SUBASSEMBLIES FOR THE ARGONNE LOW-POWER REACTOR

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Before I begin my discussion on the Argonne Low-Power Fuel Elements, I would like to give credit to David Walker of Argonne, who has been a colleague of mine for many years and who in a great measure is responsible for having done and done well most of the work on which I will report to you today.

The Argonne Low-Power Reactor, ALPR, is a light water-cooled and -moderated boiling reactor. It is rated at 3 Mw thermal output, a figure which is achieved by operating with a bulk coolant temperature of 216°C maximum at 300 psi gage. The water in the reactor is high-purity water of ~ 1-megohm resistivity and the water purity is maintained by continuous re-purification through a mixed resin bed. The production of useful power and heat are the sole purposes of the reactor. Fissionable material is supplied by highly enriched uranium in an aluminum-17.5 wt % uranium-2.0 wt % nickel alloy. This material is clad on all sides with aluminum-1 wt % nickel alloy (X8001) cladding, metallurgically bonded to the core material and to itself at all interfaces.

The reactor core grid plate can accommodate up to 59 parallel plate-type fuel assemblies, each of which contains nine fuel plates spot welded in an MTR array to aluminum side plates. The fuel plates are spaced 0.310 in. apart. All of the exposed surfaces on the fuel assembly including the top and bottom end fittings are wrought aluminum-1 wt % nickel alloy, the same alloy as that used for cladding each of the individual fuel plates. Figure 1 gives an idea of the size of the fuel assembly. Not shown in Fig. 1 is an aluminum-0.4 wt % $boron^{10}$ poison strip which will be attached to the outer face of one of the side plates of a number of fuel assemblies. These are 0.020-in. thick and are made by extruding (hot) a mixture of X8001 aluminum powder and high-purity elemental $boron^{10}$ powder into an oversize plate (0.250) which is next rolled to size and sheared to dimension.

One of the requirements that the fuel element is required to meet is that it survive a service period of three years minimum without failure for any reason, a fairly rigorous requirement.

Figure 2 is a drawing of an ALPR fuel plate in finished form and gives the over-all and internal dimensions of the fuel. A total of 531 of these plates will be required for a full reactor-core loading. Each of them in addition to meeting the drawing requirements, must demonstrate adequate resistance to corrosion by high-purity water at 290°C for two weeks, and must also exhibit no detectable unbonded areas as indicated by examination for blisters after

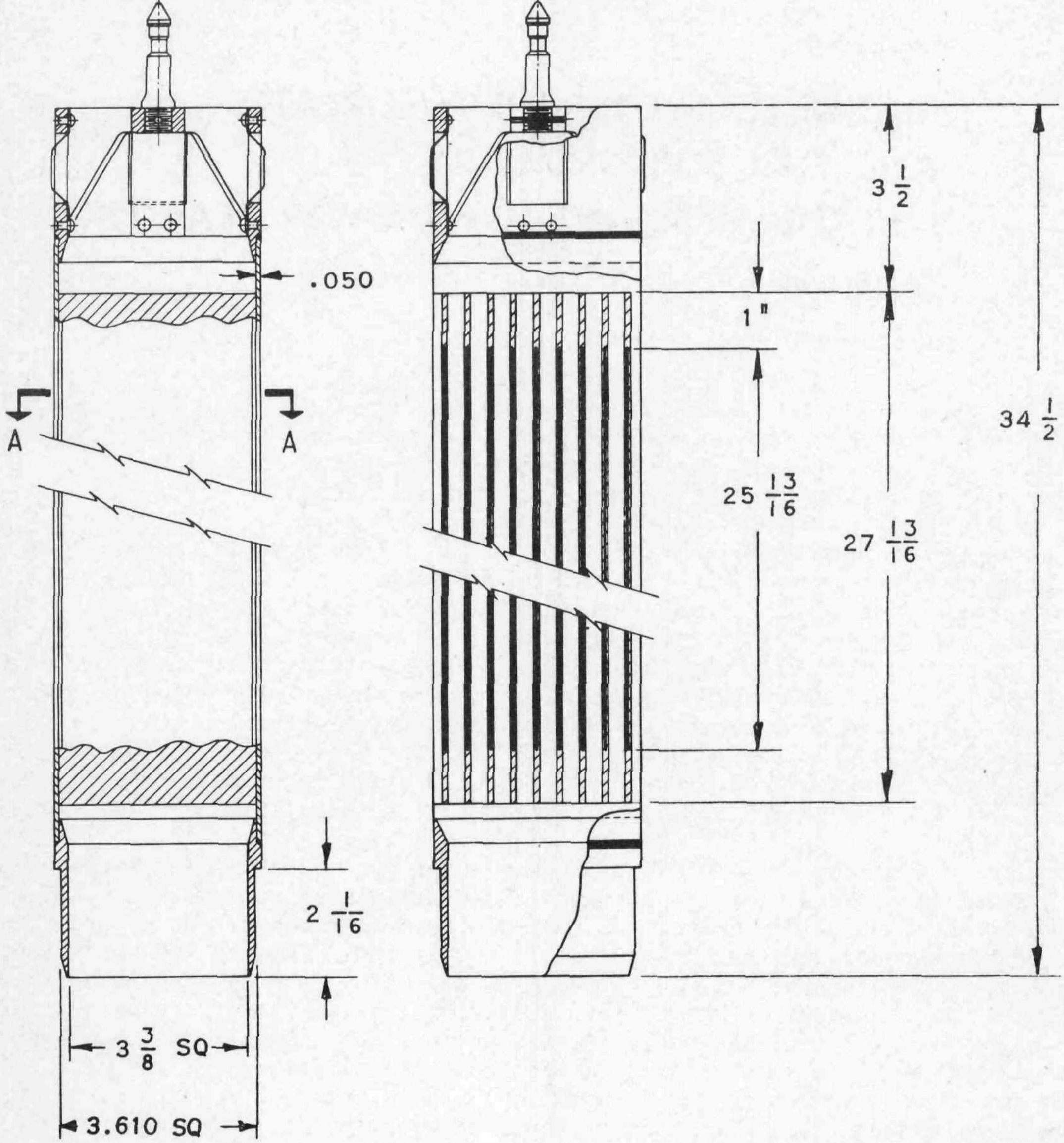


Fig. 1—ALPR fuel element.

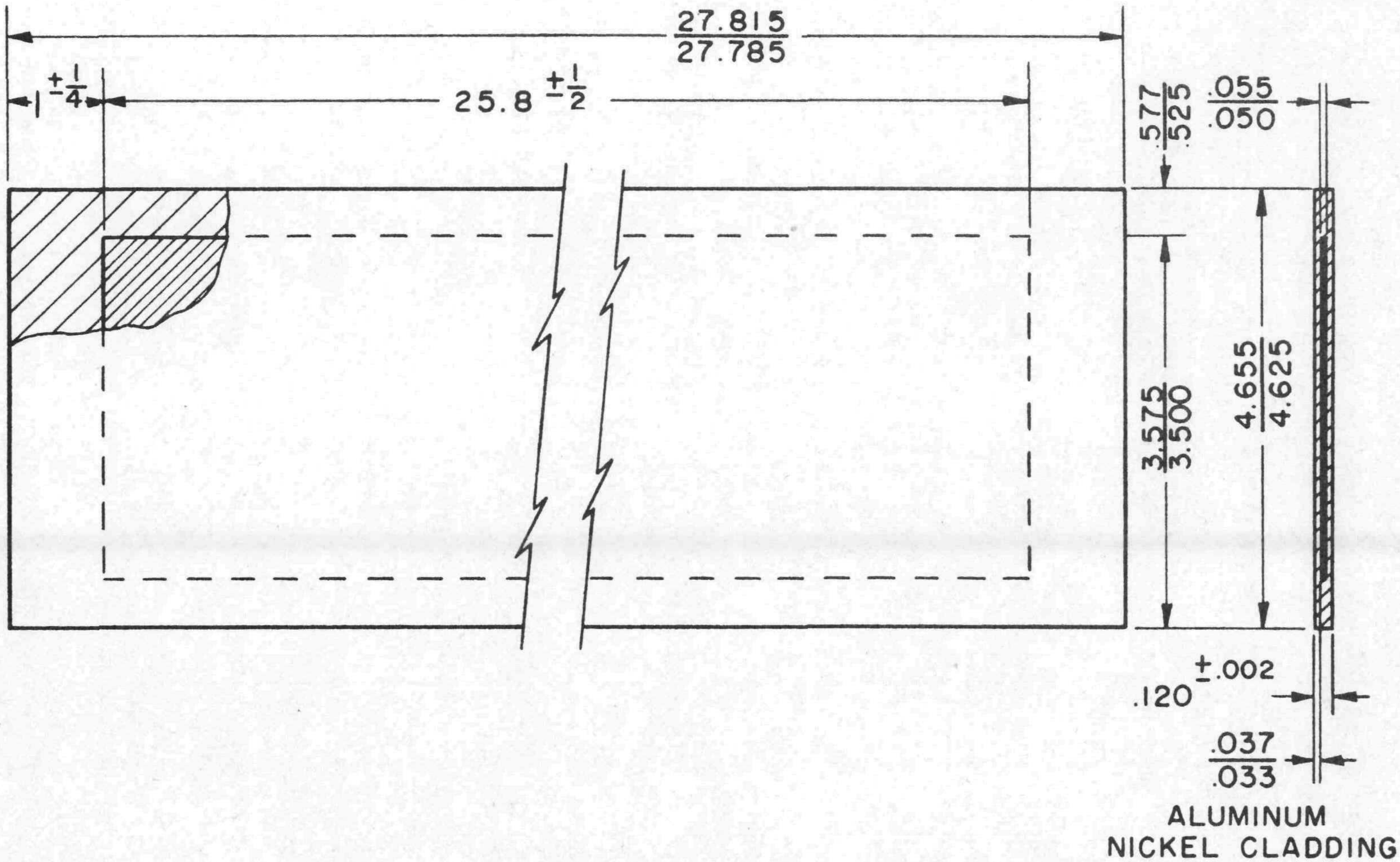


Fig. 2—ALPR fuel plate.

annealing at 550°F for one hour and by ultrasonic transmission inspection. The ultrasonic-transmission test is considered to be by far the more rigorous of the two bond tests mentioned.

Figure 3 is a photograph of the plate components. The outer dimensions of the two cladding plates and the picture frame are identical being 6-in. wide by 9-7/16-in. long. The cores and the matching rectangle in the picture frame are 3-5/16-in. wide by 6-7/8-in. long and are obtained by blanking both picture frames and cores on the same punch and die. Each of the components at this stage is four times the finished thickness, thus the cladding stock is 136-mils thick, and the picture frames and cores are 0.200 mils in thickness. Bonding of the plate components is not achieved entirely if at all by hot rolling, but is instead achieved by a process developed at ANL by Noland and Walker called silicon bonding. This is an extension of the puncture bonding method which is adapted to aluminum as follows: first, the articles to be joined are coated on one or both sides of the interface with elemental silicon powder. The coated faces are next brought into intimate contact with each other and are placed under pressure in press-mounted dies maintained at a temperature above the melting point of the aluminum silicon eutectic; in other words above 577°C. Pressures of the order of 1000 to 2000 psi are exerted on the work until it reaches the desired temperature which is generally in the neighborhood of 595 – 600°C. After being at temperature a minute or so, the work is cooled under pressure to about 550°C, the press is opened and the work removed. Figure 4 schematically illustrates the mechanism.

In Fig. 5 is shown a photomicrograph of a section which was deliberately underheated which tends to support the proposed mechanism.

After the work in the dies has exceeded the melting point of the eutectic formed by solid-phase processes, the alloy formed, being under pressure, is largely squeezed out of the joint. This is indicated by the photomicrograph next shown in Fig. 6 in which you will notice a nearly complete absence of second-phase silicon in the joint area.

Flow sheets showing the process steps (somewhat simplified) in the making of ALPR plates are shown in Figs. 7 and 8.

The manner in which the components are assembled after silicon coating the cladding pieces is shown in Fig. 9.

The hot pressing set-up is shown in Fig. 10. A 60-ton capacity tensile testing machine is used for this operation. The top and bottom dies are identical, both being stainless steel blocks heated by cartridge-type heaters. Each die is equipped with an automatic temperature control which is wired into a control system whose function is to control the process sequence automatically.

After the hot pressing operation the compacts are processed as indicated in the flow sheets. This consists of hot rolling to near size, cold finishing, blister annealing, radiographic-core location, shearing, sonic-bond inspection, etc.

The plates are fixed in fuel subassemblies in the same way as followed in manufacturing the fuel elements for the Borax-III and Borax-IV reactors, both of which have been described in the past.[1] For those who may be unfamiliar with the method employed, it involves first forming 3/8-in.-wide flanges at right angles to the plate surface at both long edges of each plate. After forming, both flanges are milled to reduce their thickness to the order of 55 mils, and the plates are assembled one at a time with side plates and are spot welded in place. Figures 11 and 12 illustrate this procedure.

To date we have made about 100 practice plates to develop the bonding procedure parameters. Normal uranium rather than enriched uranium was used

(Text continues on p. 244.)

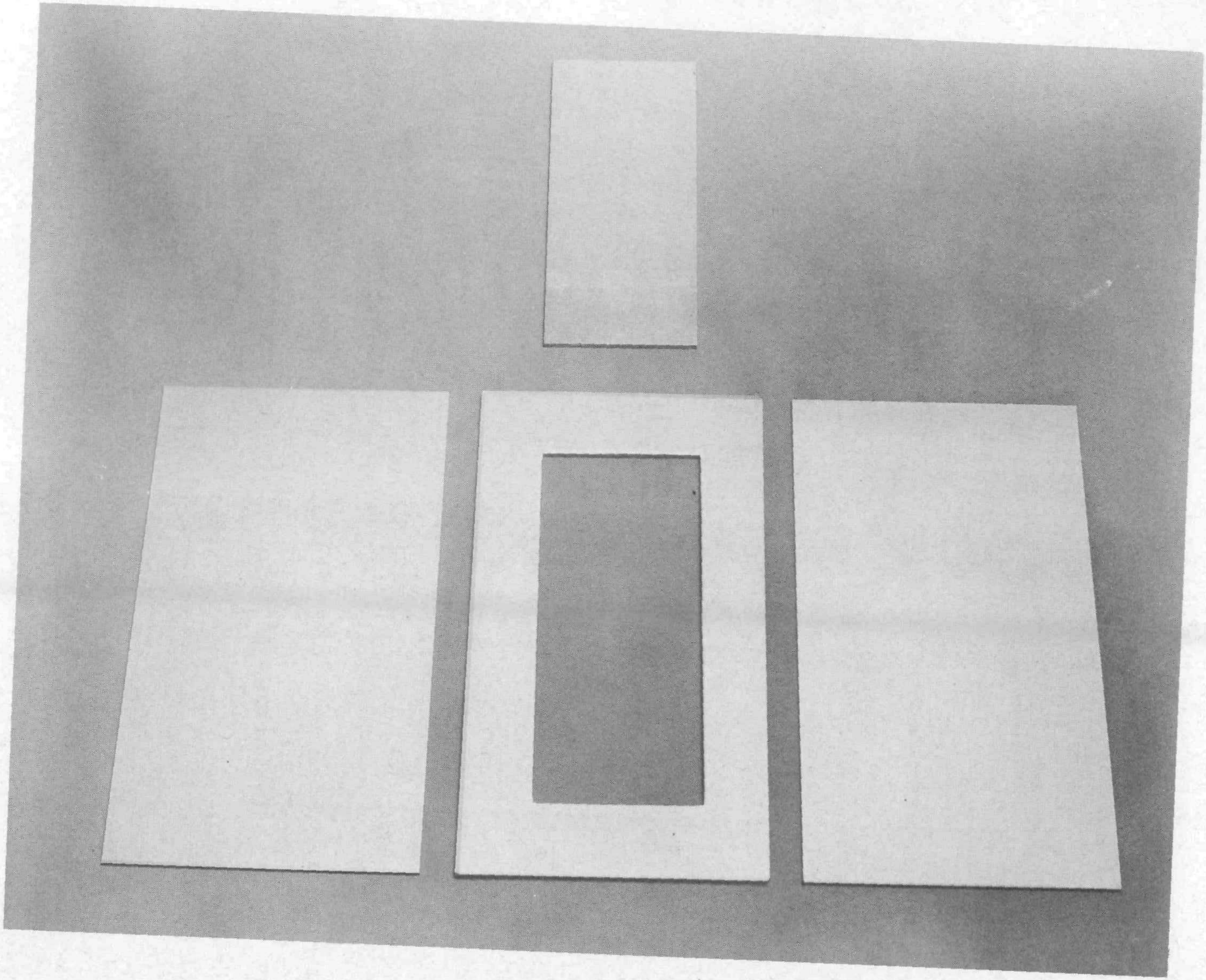


Fig. 3—Plate components.

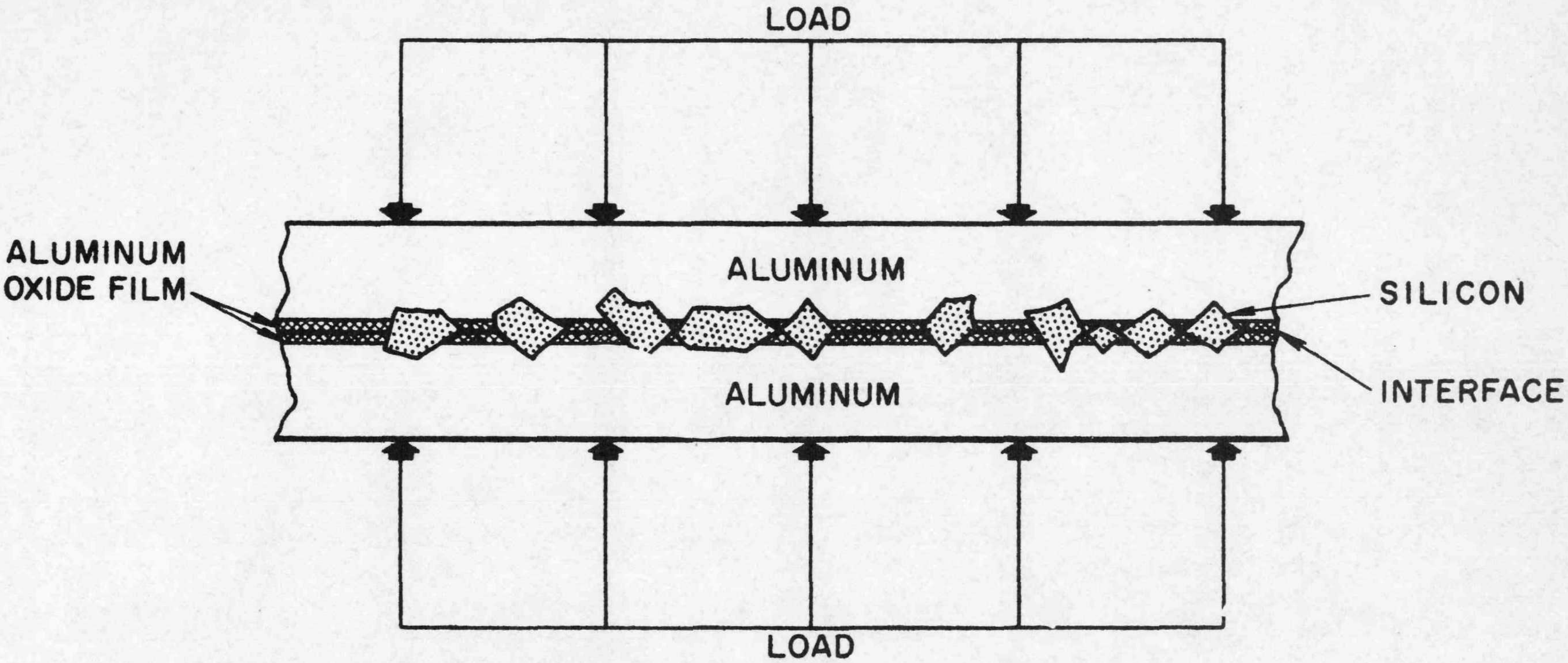
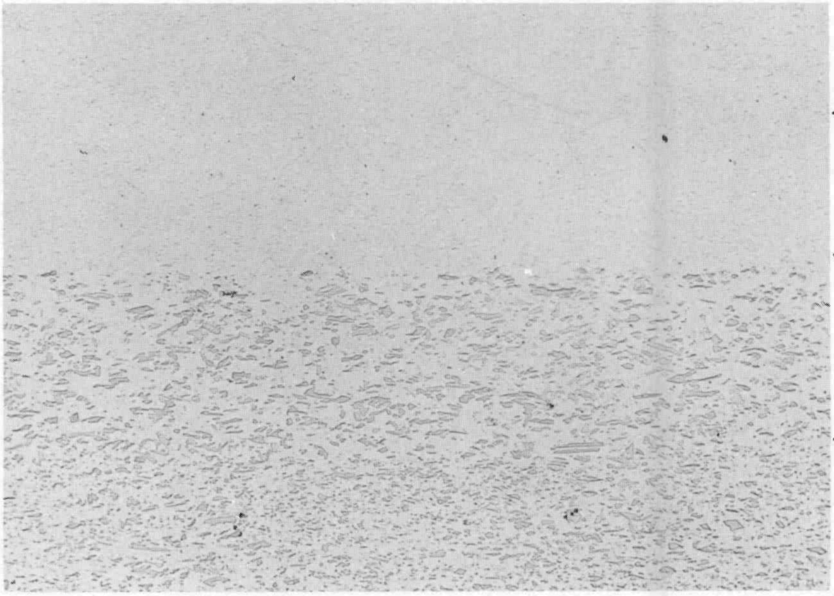


Fig. 4—Mechanism: Aluminum oxide perforation in silicon bonding (Idealized).

500X

Etched

Fig. 5—Silicon bonding: Unreacted silicon particles surrounded by rejected silicon in underheated section.



100X

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Fig. 6—Typical microstructure at core to clad interface.

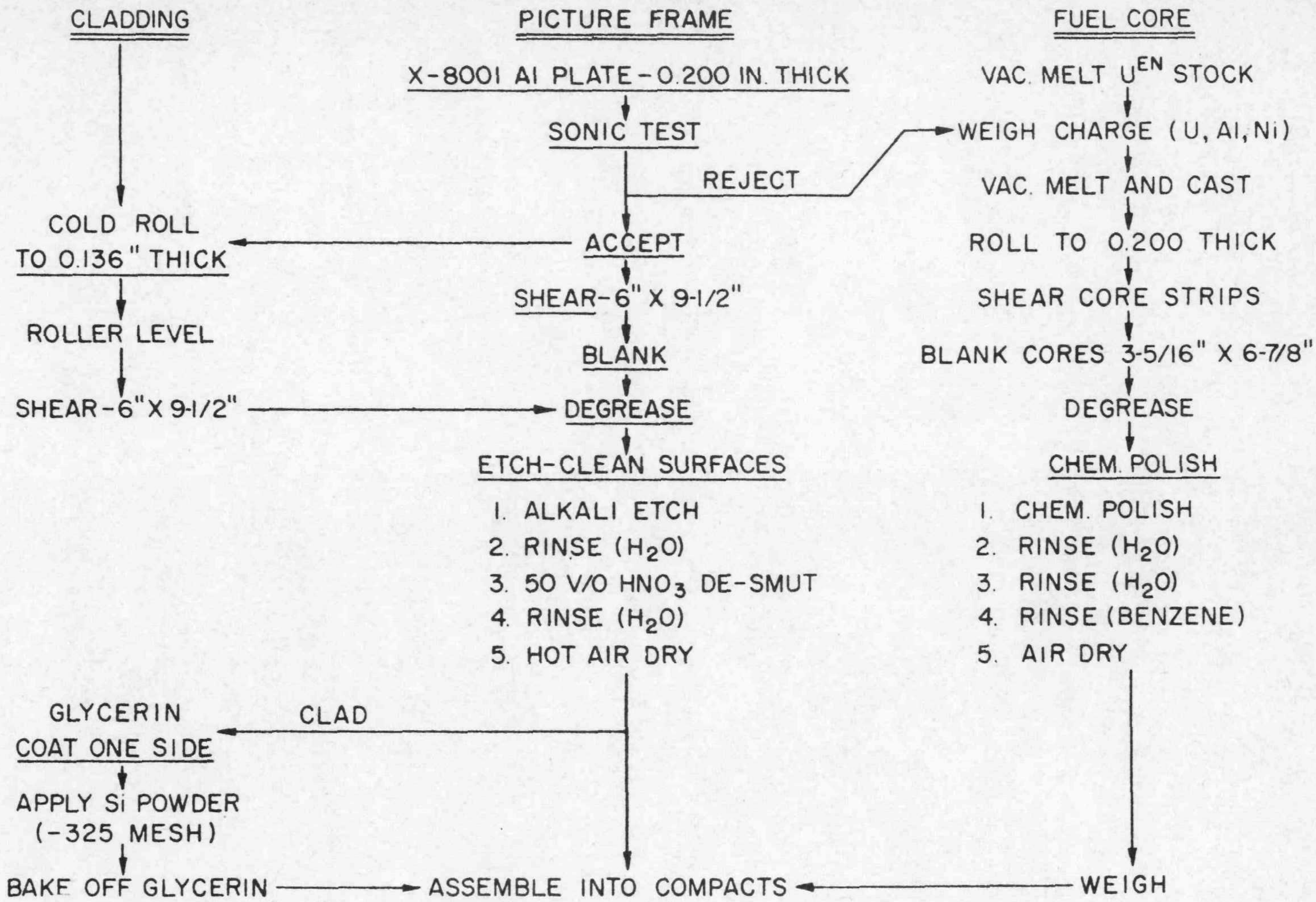

Fig. 7—ALPR fuel plates: Preparation of compact components.

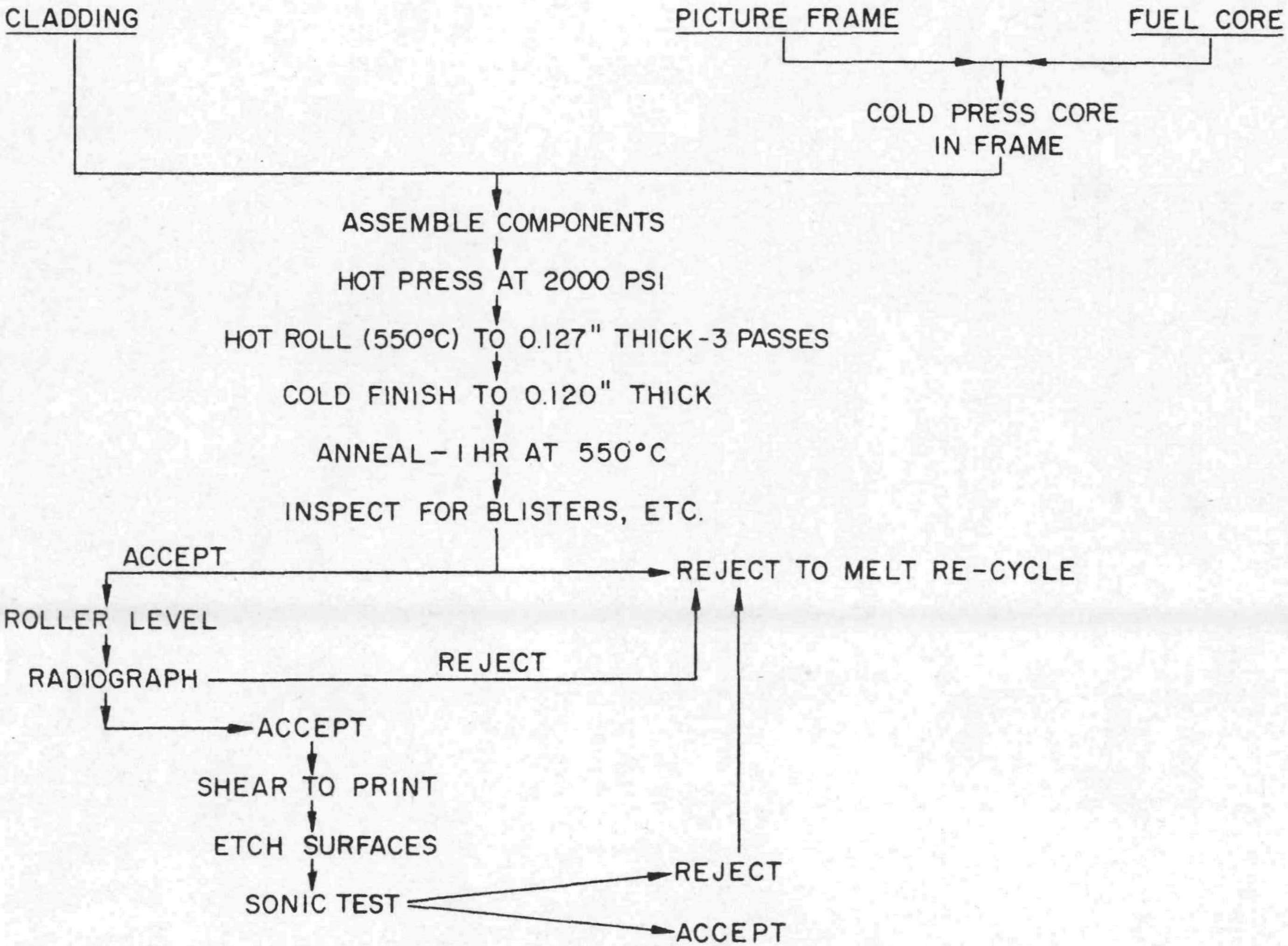

Fig. 8—Process steps.

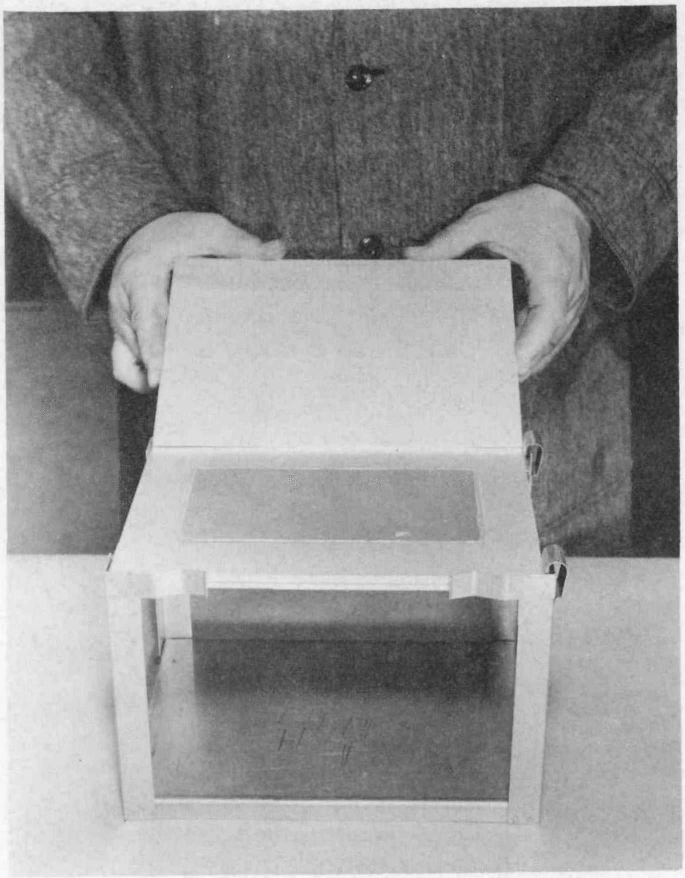

Fig. 9—Assembly of components after silicon coating the cladding pieces.

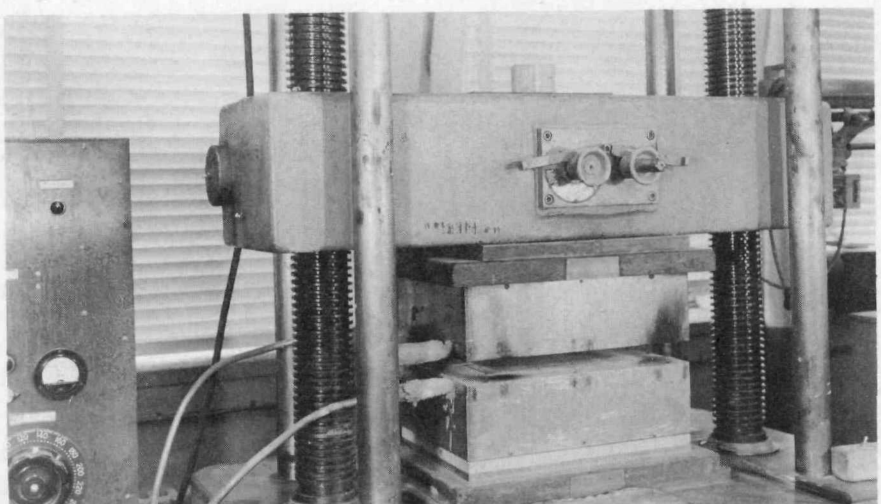

Fig. 10—Hot pressing set-up.

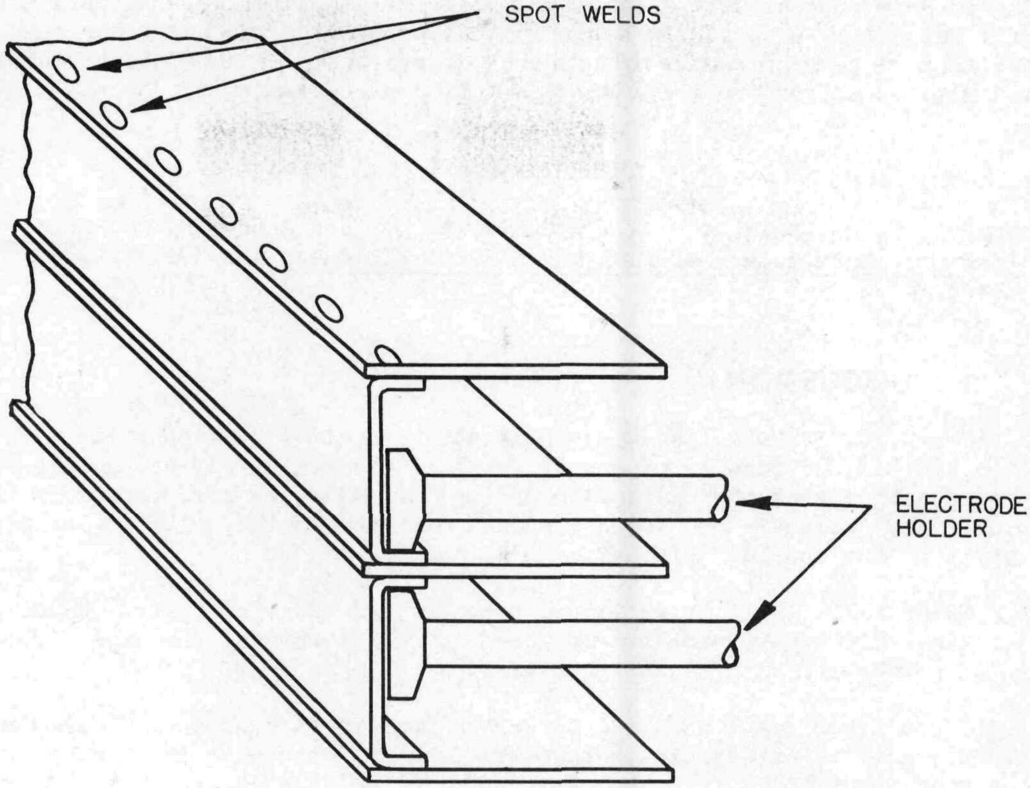

Fig. 11—Schematic illustration of assembly method.

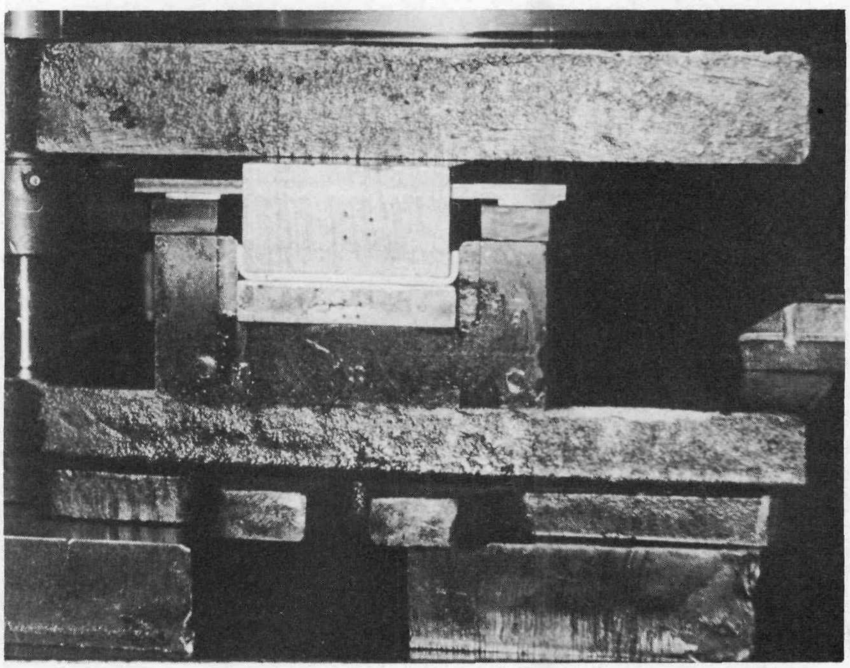

Fig. 12—ALPR: Fuel plate forming die.

in the cores of these. The last 70 of the practice plates were satisfactory in all respects. We are just beginning our production run using enriched cores, thus we have no production figures at present. We hope the production plates will be as good as the last 70 practice plates were.

REFERENCES

1. Walker, D. E., Noland, R. A., McCuaig, F. D., and Stone, C. C., Borax-IV Reactor: Manufacture of Fuel and Blanket Elements, ANL-5721 (1958) March.

DISCUSSION

MR. W. C. THURBER (Oak Ridge National Laboratory): I have two questions with regard to your bonding process. First is the reason for using this silicon bonding practice that the oxide film on the 8001 alloy is more tenacious than with ordinary aluminum; and second, about how thick is this silicon layer that you apply to the shoulder plates?

MR. NOLAND: Well, I will answer the second question first. Minus 325 mesh powder has maximum particle size of about 1.7 mils; so that the layer is a monolayer of powder. Its thickness then will be of that order.

I don't believe I know the answer to your first question, which was whether I believe that the oxide film on the 8001 is more tenacious than the ordinary. I rather doubt that it is. I think what you are really seeking may be an explanation as to why we would use a process like this. I think the reason is that we were trying to provide a fuel plate for a reactor employing aluminum-clad fuel at temperatures higher than such fuel had ever been subjected before. We felt that to do this we had to have a process which at least in theory could produce a 100% bond. We thought this might be the method.

MR. L. D. SCHAFFER (Oak Ridge National Laboratory): How do you incorporate your burnable poison core into the fuel element?

MR. NOLAND: We incorporate it by manufacturing a material by a powder metallurgical technique. We mix first X 8001 powder and elemental boron powder. We put this in an aluminum can and direct extrude to a strip about 1/4-in. thick. This is cold finished to size (0.020 in.) with intermediate anneals in the process.

MR. SCHAFFER: Where do you put it?

MR. NOLAND: We tack weld a strip on one side plate of each fuel subassembly that requires it. It is not in the fuel. It is attached instead to the subassembly.

MR. H. PEARLMAN (Atomics International): Why is it that the boron isn't in the meat?

MR. NOLAND: The reason that the boron is not in the meat is not a physics reason. It is not in the meat because we felt that in the time we had in which to do this work we did not want to introduce a process variable of which we knew very little.

CHAIRMAN KAUFMANN: Why do you have nickel in the meat?

MR. NOLAND: We have nickel in the meat to improve its corrosion resistance.

MR. S. SIEGEL (Metals and Controls, Inc.): You recycle, I presume.

MR. NOLAND: Yes.