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FABRICATION OF RESEARCH REACTOR FUEL ELEMENTS

G. M. Adamson, Jr.

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ABSTRACT

A discussion is presented on the fabrication techniques used to fabricate fuel elements for research reactors. Such fuel elements are aluminum base with fuels of either uranium-aluminum alloy or dispersions of powdered U_3O_8 or UAl_3 in aluminum powder. Emphasis is on the latter types which are the ones used in the advanced high performance reactors such as HFIR and ATR.

The primary operation or design problem affecting fabrication is control of hot spots. This requires close control of uranium loading and distribution, core thickness, quality of bonds, absence of blisters, and uniform water-channel thickness. Control of each factor is discussed.

The fabrication of the dispersion plates is divided into the following areas: powder preparation, core fabrication, plate rolling, and inspection. Techniques for both U_3O_8 and UAl_3 are presented. Assembly operations are included for elements joined both by the mechanical roll swaging technique and by welding. The latter represents the technique now being used to fabricate the HFIR elements.

INTRODUCTION

The characteristics of research reactors and how they differ from power reactors have been discussed.[1] In this paper we will discuss the fuel elements for these reactors and how they are fabricated. The fuel elements for the research reactors are almost always aluminum-base flat-plate elements rather than the pellets in tubes used for power reactors.

In this discussion we will group the research reactors into two categories: the low-performance cores such as MTR, ORR, ETR, plus the various pool reactors, and the high-performance cores which will include

[1]W. C. Francis, Idaho Nuclear Corporation, "Fuel Elements for Thermal Test Reactors — Performance at NRTS," paper presented at the AEC Industry Meeting, Water Reactor Fuel Element Technology, January 29–30, 1968, Washington, D.C.

HFIR, ATR, and A^2R^2. Plate-type fuel elements for research reactors have been fabricated for over 20 years, being preceded only by the canned uranium slugs. The high-performance dispersion systems are, however, of a much more recent vintage, being only a few years old.

The low-performance systems have used a single type of fuel — that is, a core of uranium-aluminum alloy with uranium concentrations usually less than 20 wt %. While limited in uranium content these fuels are relatively cheap and simple to fabricate and fit in well with commercial equipment. Their technology is well understood by the commercial producers and they have been well tested over their 20 years of use.

Two new types of dispersion fuels are now being developed. These are U_3O_8 powders and powders of uranium-aluminum intermetallics, nominally UAl_3. While the intermetallics cover a range of uranium concentrations, we will, for this discussion, identify them all as UAl_3. The new fuels are capable of yielding very high fuel loadings with good homogeneity but are more expensive and difficult to fabricate than is the alloy. The dispersion fuels have another advantage over the alloy in that it is quite simple to add a burnable poison by adding another powder to the blend. The boron compounds have a very low solubility in the alloy and their density differences make segregation a major problem in those systems.

A dispersion fuel plate is one in which a powdered fuel is dispersed within an aluminum powder matrix with the core being completely enclosed or clad with aluminum. A variety of sizes and shapes of fuel particles are present and they are distributed in a far from ideal manner. Fuel powder fracturing and stringering are common.

The processes used for fabricating all these compounds into fuel plates are essentially the same. They consist of the following major operations: core preparation, plate fabrication and cladding, plate inspection, plate forming, element assembly, attachment of hardware components, and final machining. The greatest divergences in the procedures for the various systems are in the core preparation step.

All the plate fabrication procedures make use of the picture-frame, hot-rolling technique. The major components used in such an operation are two flat covers, a frame of the same width and length, with one or two cavities, and the fuel fillers which are the same size as the frame cavity. Hot rolling such a billet bonds all contacting surfaces and sizes the plate. For the low-performance reactors, all aluminum components are generally of type 1100, while types 6061 or 2219 are used where the higher strengths are required for HFIR and ATR. In these cases, all bonding surfaces contain a thin layer of type 1100 which has been clad to the base stock.

REACTOR PROBLEMS

Before discussing the fabrication sequence in more detail, let us discuss some of the problems encountered with these systems. In the high-performance reactors, the major problem is avoiding hot spots within the plates during operation. With such plates, the burnout margin is quite low, so hot spots can result and have resulted in plate melting. Factors in plate fabrication affecting hot spots and which must therefore be controlled are uranium loading, uranium distribution, core thickness, quality of heat transfer bonds, and the uniformity of plate curvature.

The most serious of these, and especially with the UAl_3 fuels, is the control of core thickness. If the properties of the core and frame material are not closely matched, an end phenomenon known as dogboning results (see Fig. 1). A thickening of the fuel cores at each end is found which causes both an increase in amount of fuel and a thinning of the cladding. The problem is circumvented by better matching of the properties of the frame and cores by varying the alloy or the heat treatments or by using small tapers at the core ends so less starting material is available in these areas.

As the fuel loadings are increased or the cores become thinner, problems in fuel homogeneity increase. Fuel concentrations usually result from clumping, a very severe example of which is shown in Fig. 2. Such fuel concentrations are usually the result of poor material preparation or blending practices.

A most serious problem in fabricating aluminum is the formation of blisters or nonbonds between the various components. Either a nonbond

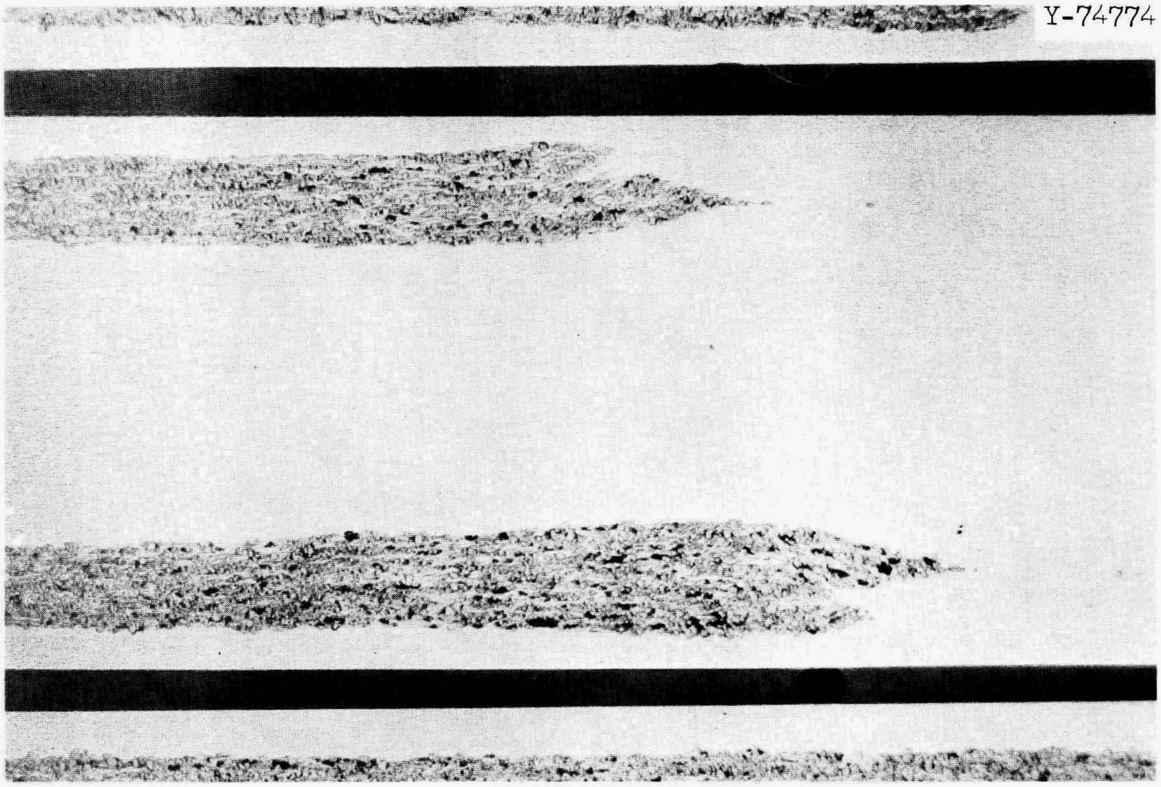

Fig. 1. Example of Dogboning at End of UAl_3 Dispersion Plate. 10X. As polished.

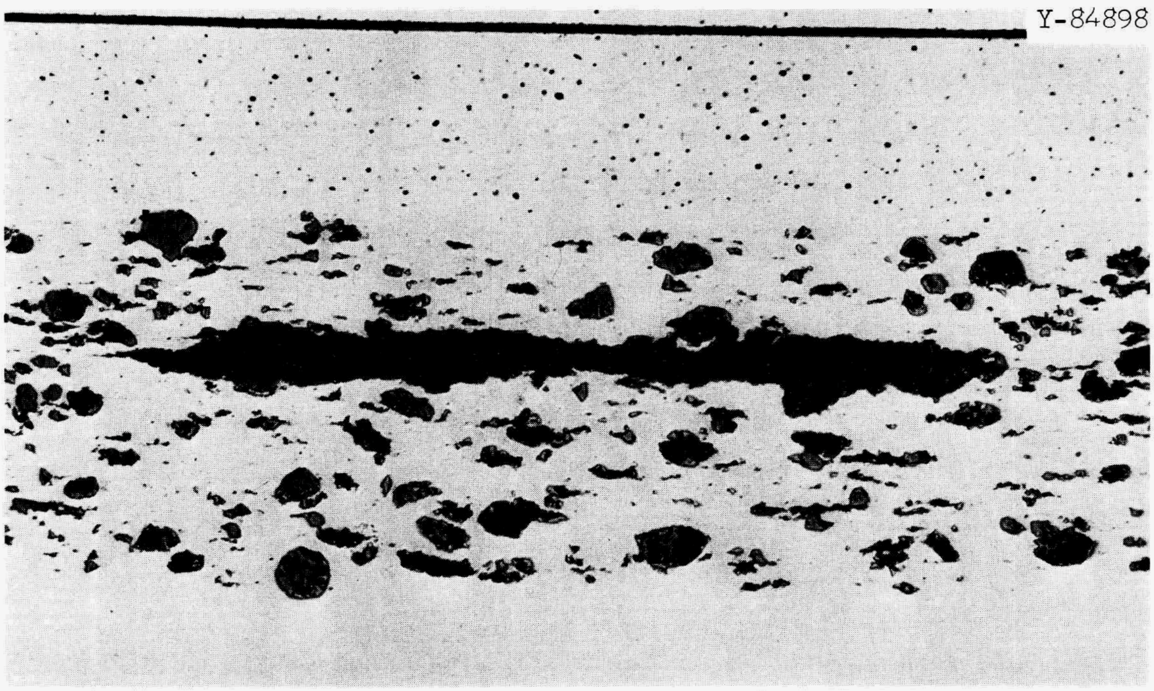

Fig. 2. Fuel Clumping in Dispersion Plate. 100X. As polished.

or blister anywhere within a fuel plate may be a barrier to proper heat transfer. Since most inspection techniques do not differentiate between these two defects, they will be discussed together. The principal types of blisters are shown in Fig. 3. They may originate from (1) improper end or side fits of the core and frames; (2) laminations, clumping, or impurities within the core; (3) nonbonds at various interfaces; (4) incipient melting of segregated areas within the alloy; or (5) an alloy containing excessive hydrogen.

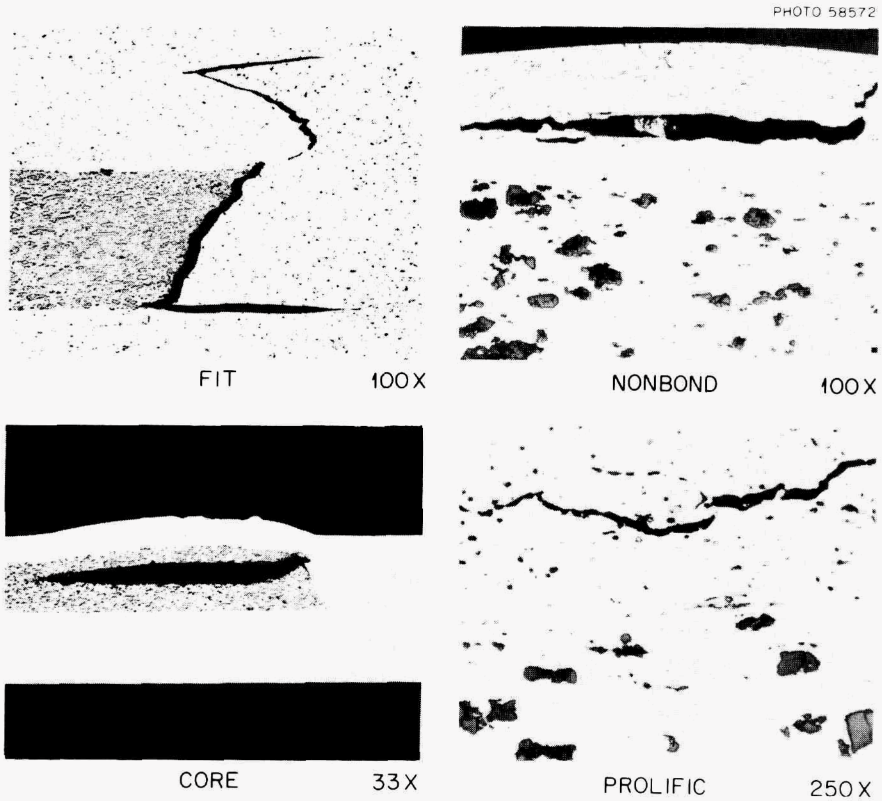

Fig. 3. Illustration of Blister Types Observed in HFIR Fuel Plates. As polished.

Another problem is the dimensional control required of the cores. These requirements result from several considerations: (1) providing assurance that no fuel is exposed; (2) keeping fuel away from areas in which adequate cooling is not available such as within the side plate slots; (3) assuring sufficient cladding thickness for corrosion resistance; and (4) avoiding fuel extending beyond specified limits and entering a region in which flux peaking occurs, such as excessive lengths.

As mentioned previously, a big contributor to this problem is core thickening caused by dogboning. A second problem in this area is maintaining the specified end tolerances for core length. The rolling operator can control core length only indirectly and, for most of the research reactor plates (0.050 in. thick × 24 in. long), a change in thickness of 0.001 in. will cause a length change of 0.5 in. While plate length control can be achieved, other more difficult to control parameters also affect these core lengths. As shown in Fig. 4, the core ends are far from straight or sharp; fuel particles may stringer out for considerable distances and often tapers are present at the ends. Defects of these types result from improper rolling practice, usually poor guides, improper roll lubrication, or low-density cores.

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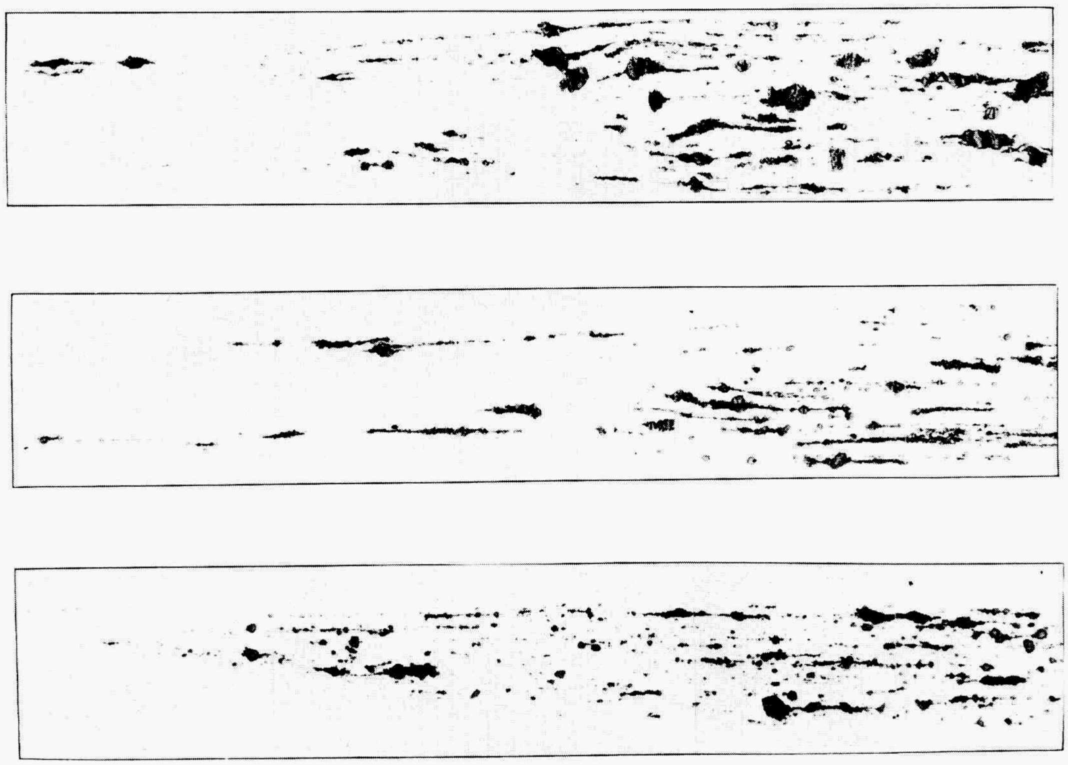

Fig. 4. Dispersion Fuel Plate End Characteristics. As polished. 150×.

One of the difficult problems encountered in fuel plate fabrication has been surface defects. If deep scratches or gouges are present, they may compromise cladding thickness. The aluminum plates are so soft that if they are dragged over any surface a scratch will result. All mills and shop equipment must be kept clean and free of any chips. One technique for minimizing these problems is to cover all working surfaces with rubber floor mats that have pointed nubbins.

HFIR DESIGN

With all these problems, is it possible to fabricate plates? Since the answer is obviously yes, the next question is how? To discuss the fabrication procedures in more detail, we will start with the procedures being used in the commercial production of HFIR elements.

The HFIR core assembly (shown in Fig. 5) is made up of only two elements; the entire assembly is about 18 in. in diameter and about 30 in. long with an active fuel length of 20 in. Note the unusual circular side plates and the involute curvature for the fuel plates. The pins for irradiating the isotopes, which is the prime function of this reactor, are located in the center hole of the inner element.

A cross section of a fuel plate is shown in Fig. 6. These plates are unusual in that the fuel core is not rectangular, as is found in other research reactors. The white area within the aluminum envelope represents fuel with varying thicknesses, helping to produce a flat flux profile and reducing the peak-to-average power density, thereby permitting a higher average power. To simplify fabrication, an aluminum powder filler section (black area) is added to make a rectangular core. In the inner annulus, the B_4C powder used as a burnable poison is located in the filler section. The fuel core is a dispersion of U_3O_8 powder in aluminum powder.

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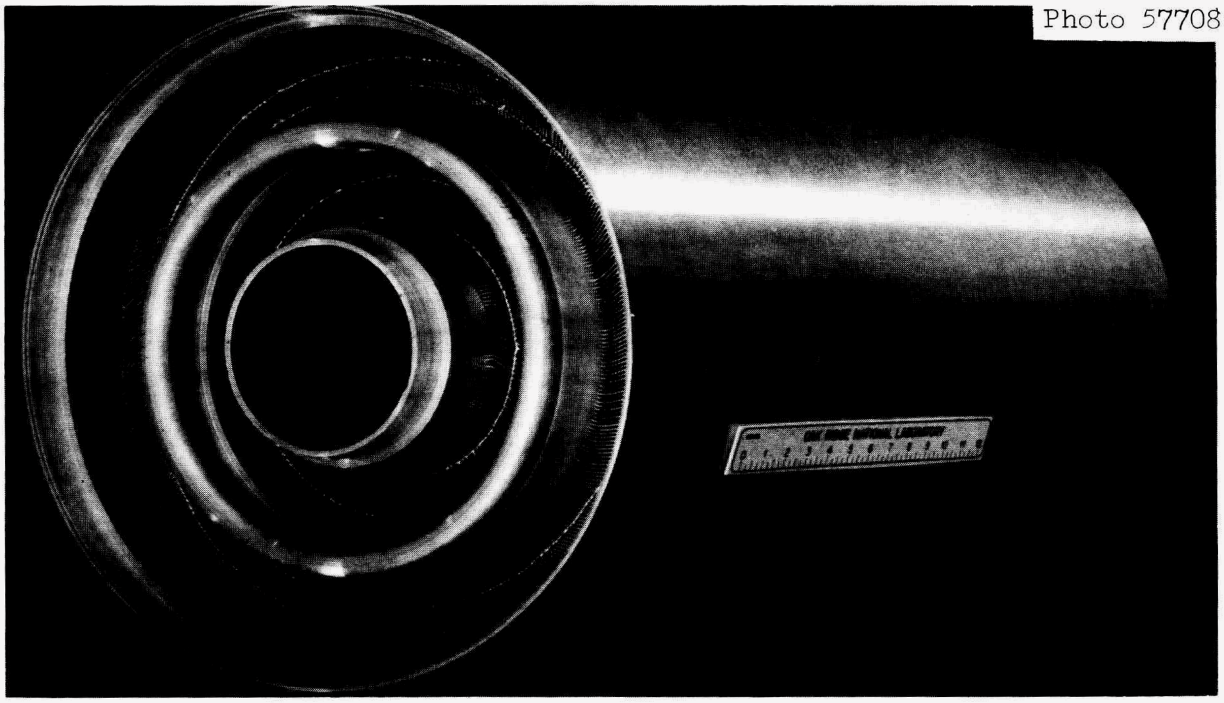

Fig. 5. HFIR Core Assembly

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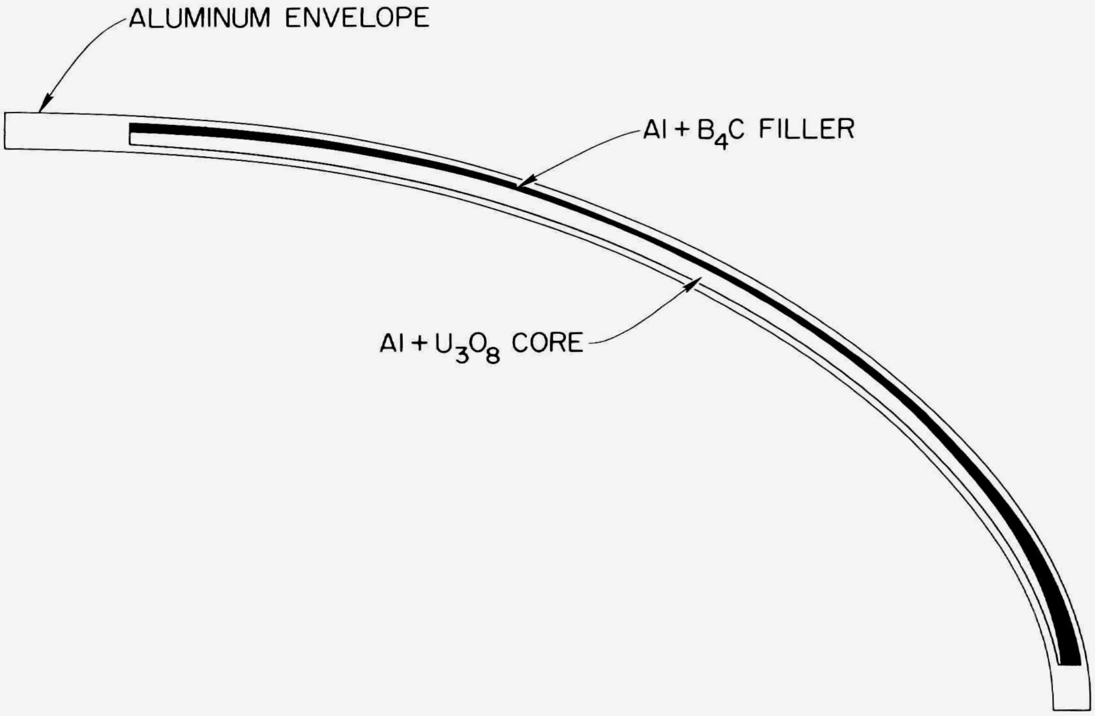

Fig. 6. HFIR Inner Annulus Fuel Plate Cross Section.

FUEL PLATE FABRICATION

The flow chart of the plate fabrication operation is shown in Fig. 7. It consists of two major areas, the group of operations on the left being those involved in the core fabrication with those in the center on plate fabrication. Note the large number of inspection operations.

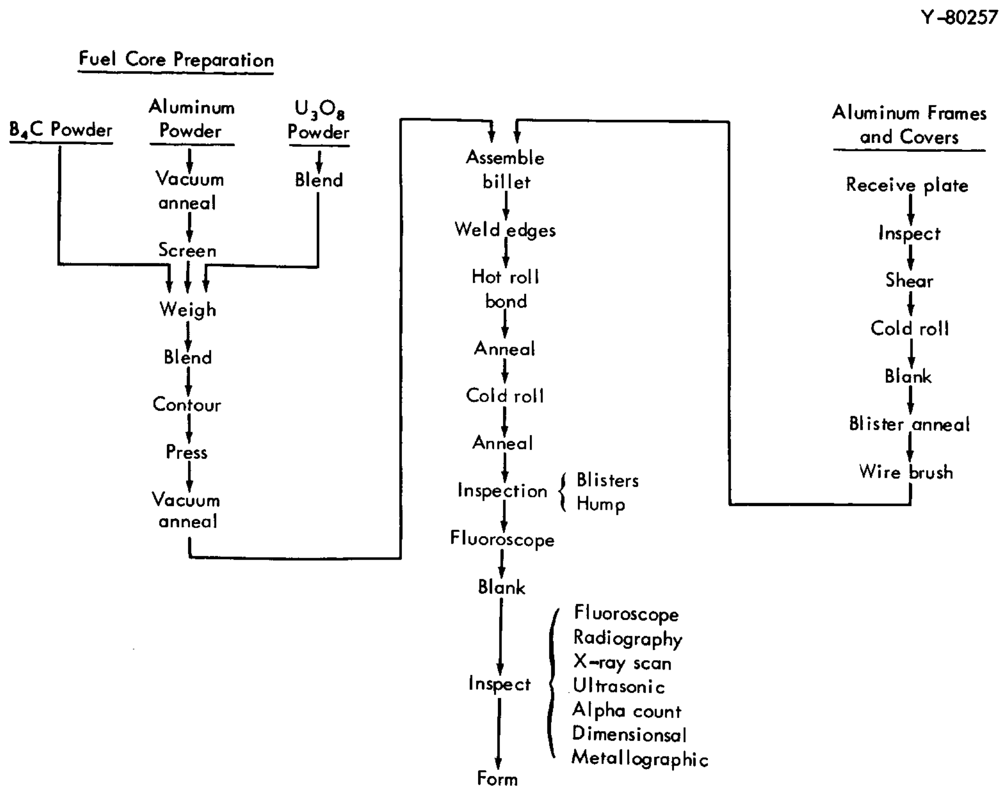

Fig. 7. Major Operations for HFIR Fuel Plate Fabrication.

HFIR Fuel Core Fabrication

The U_3O_8 must be a high-fired or dead-burned oxide. Since the uranium oxide—aluminum system is not a thermodynamically stable system, the tendency is to react and form uranium-aluminum intermetallics. Therefore, we desire an inert oxide rather than an active oxide such as is used in pellet fabrication for power reactors. If an active oxide is used it reacts during fabrication, resulting in badly warped plates.

The procedure presently used to produce such an oxide requires both a low- and a high-firing operation. The fired oxide is ground and screened to produce a −170 +325 mesh fraction for use. For fabrication, important properties of the oxide are density, surface area, and particle shape and size. Density and surface area have been shown to be indirect indexes of how much particle fracturing and stringering will occur during fabrication, with a low-density high-surface-area particle showing more fracturing. They would, however, produce a core of a lower density which is an advantage.

The key to successful dispersion plate fabrication, at least for HFIR, is in the powder handling and pressing operations. Excellent blending must be achieved if segregation is to be minimized. To provide a maximum control of the uranium and boron concentrations, it was required that each core be weighed and blended individually.

The complex fuel cores are formed in a single cold-pressing operation. The various components used in the pressing are shown in Fig. 8. Shown are the two punches, a die block, and two shaped die tops. The powder for the fuel section is gently poured into the die with the first die top in place. The upper surface is leveled by gently working a straight edge over the die top until all powder has been added and no cavities are present. The bottom punch is gently raised or lowered to assist in this operation. The second die top is then added and the procedure repeated with the filler powder. The powders are then gently lowered into the die and pressed at a pressure of about 30 tsi. The pressed compacts are heated to 590°C in vacuum to remove any moisture or pressing lubricant. Thicknesses are then measured and must be within ±3 mils of the specified value.

Items in pressing which affect the quality of the final plate and therefore must be controlled are:

1. powders must be well blended,
2. neither classification nor tamping can occur as the die is filled,
3. all powder must be added,
4. leveling must be good and be with a reproducible technique,
5. compaction or tamping of small areas must not occur during leveling,

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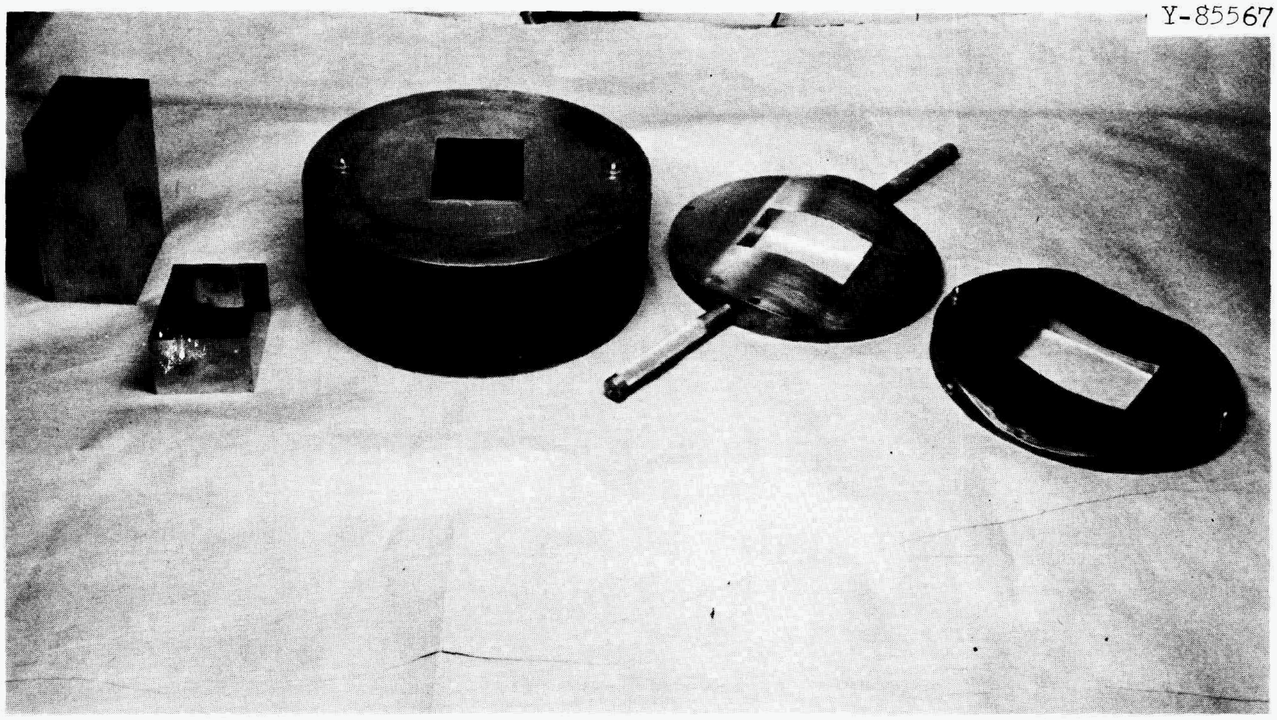

Fig. 8. Die Components — HFIR Fuel Core Preparation.

6. edges and corners must be completely filled,
7. rollup cannot occur as powders are lowered into the die,
8. a good fit must exist between the die and punches,
9. a minimum of lubricant should be used.

A similar technique is used for other type fuel plates using U_3O_8 fuels except the simple rectangular cores do not require as close a control as do the duplex ones. In these cases, the fuel core is pressed as an individual piece.

HFIR Plate Rolling

The next phase of the operation to be discussed is the hot- and cold-rolling operations used to size the plate and to bond the various components. The fuel cores are assembled with the frames and covers into the roll billets. For HFIR, tight tolerances are set for the frame dimensions and parallelism; this requires punching and broaching as the fabrication technique. The covers are individual pieces and, after assembly, are welded to the frame so no relative movement is possible during rolling. For the low-performance reactors, the frames are usually only sheared and the covers are a single piece bent around the frame.

Just before billet assembly, all bonding surfaces are thoroughly cleaned and either scratch brushed or etched, and all handling is with white gloves. Cleanliness is a major problem and all parts must be immaculate. To minimize the possibility of fit blisters, the cores are larger and thicker than the frame cavity and a shrink fit is used.

The major portion of the fuel plate reduction is done hot by rolling at temperatures between 475 and 500°C. To avoid blistering, either because of a nonbond or from incipient melting, the temperatures must be controlled within the limits specified.

The parameters controlling the rolling operations are:

1. To avoid fragmentation, use as low a total reduction as possible and all rolling should be hot.

2. To assure bonding, the total reduction should be a minimum of 8:1.

3. To seat the various components and help avoid flash or flaking, small reductions should be used at the start.

4. Once the billet is set, individual reductions of 25:1 may be used.

5. The hot-rolling temperature must be between 475 and 500°C.

6. To avoid end effects, the roll surface and amount of roll lubrication must be carefully controlled.

7. For flat uniform plates, use as large diameter rolls as possible.

8. For surface and dimensional control, the final reduction should be done cold.

9. For best forming, a minimum of 20% cold reduction is necessary.

10. Either very close gage control or individually tailored final passes are required for core length control.

Contradictory requirements were listed for total reduction and for amount of cold work. With the specified cleanliness and core frame fits, reductions of about 10:1 appear to be optimum. Good bonding with acceptable fragmentation results. Using all hot rolling would also reduce fragmentation, but the required dimensional control and formability could not be achieved.

While the importance of the fuel core lengths has been stressed, it is obvious that the roller can only follow these changes indirectly. Two control techniques are possible: The first consists of rolling to a gage which is held within sufficiently close limits that proper core length is also achieved. To use this method, the HFIR technique, plate thicknesses must be controlled within 0.0005 in. and preferably within 0.0002 in. A more common technique is to fluoroscope every plate before the last two or three reductions and tailor them to give the desired length. With the latter technique, variations in gage result which cause variations in forming.

If the plates have been rolled and heat treated properly, forming is not usually a problem. Fuel plates are formed using either a conventional metal-metal pressing or more commonly by a modified marforming in which a shaped punch presses the plate into a rubber or plastic pad.

During HFIR development, more than 50% of the plates were being rejected for not meeting the forming tolerances. These plates had been cold rolled 7.5% for dimensional control and annealed 2 hr at 500°C as a blister test. The forming rejection rate was reduced to essentially zero by increasing the cold work to 20%; this gave a more uniform structure, even after annealing by minimizing local variation in cold work.

UAl_3 Plate Fabrication

The second fuel system whose fabrication will be discussed is the dispersion of UAl_3 in aluminum. Fabrication techniques for UAl_3-bearing plates are very similar to those just discussed. The fabrication is more difficult and not as well developed as it is for U_3O_8. The major differences occur in the powder preparation steps.

Two techniques are available for producing the UAl_3 powder: melting and powder metallurgy. The former is cheaper and more suitable for commercial operation and will be the only one discussed. For use in the ATR, powders containing 69 wt % U with a size range of −100 +325 mesh are being specified. The major constituent must be UAl_3 with no unalloyed uranium being permitted. The powders are usually produced by arc melting.

In fabricating the UAl_3 by casting, metallic uranium and aluminum are melted together usually with the addition of scrap UAl_3 powder material. Procedures must be used which minimize segregation which may arise either from incomplete melting or during cooling. To obtain a UAl_3 structure, the melts must be quenched since this is not the stable form at low temperatures. If induction melting is used, it must incorporate a provision for adequate stirring and the ingots must be rapidly cooled. With arc-melting several melting operations are usually required. In the melting operations, some material is volatilized so uranium control and stoichiometry problems must be faced. The intermetallics are more difficult to grind to fine powder than are the oxides. Attempting to grind this powder into the desired size range results in the production of a high proportion of fines that must be recycled in the melts.

Procedures used to fabricate the UAl_3 powder into plates are identical to those discussed for U_3O_8. However, the fuel cores containing UAl_3 are stronger than the oxide cores and do not match the properties of the type 6061 aluminum frames as well. Severe dogboning and end defect problems are encountered with these plates. Work is still in progress to minimize these difficulties.

Alloy Fuel Plate Fabrication

The third type of fuel to be discussed is the one which has been used the longest — that is, the uranium-aluminum alloy cores. With this fuel the entire core consists of the alloy and is therefore of a relatively low uranium concentration. This fuel has been and still is the one used in the majority of the research reactors. The cores are fabricated by conventional induction melting of metallic uranium and aluminum with alloy scrap. Fairly large melts producing several ingots are possible. A major advantage of this system is that, since relatively large amounts of aluminum are added, even scrap fuel plates may be easily recycled into the melting operation. The cast ingots are hot rolled, usually bare, to the thickness desired for the fuel plate cores. The cores are mechanically punched from the rolled alloy. From this point on, the fabrication sequence is identical to that used for the dispersions.

FUEL ELEMENT ASSEMBLY

Assembly of ATR

The next major area to be discussed is that of element assembly. While brazing and mechanically pinning techniques have been used in the past, at present only a mechanical technique, called roll swaging, or welding is being used. We will first discuss the assembly of ATR elements which uses the roll swaging technique. This procedure is also representative of the techniques used for the low-performance reactors.

In the ATR elements each plate has a different width and therefore must be formed to an individual radius. This means that any variations in forming one plate will probably not be found in the adjacent plates as would be the case if they were all formed with the same die. Assembling the independently formed plates makes it more difficult to obtain plate spacing control. The angles for the longitudinal edges of every plate are also different, which necessitates varying the angles for the slots in the side plates so a match may be obtained.

To use the roll swaging technique, the two side plates are mounted in a backup fixture and the first plate is slid into place. The technique used for making the joint is shown in Fig. 9. The upper land of the side plate slot is mechanically deformed into the upper fuel plate surface, locking the plate in place. This deformation is accomplished by wheels running down small grooves cut in the lands, both sides being done simultaneously. For critical applications such as ATR, spacers such as Teflon are inserted in each channel to assist in achieving the required plate spacing. The critical parameters in achieving sound joints follow.

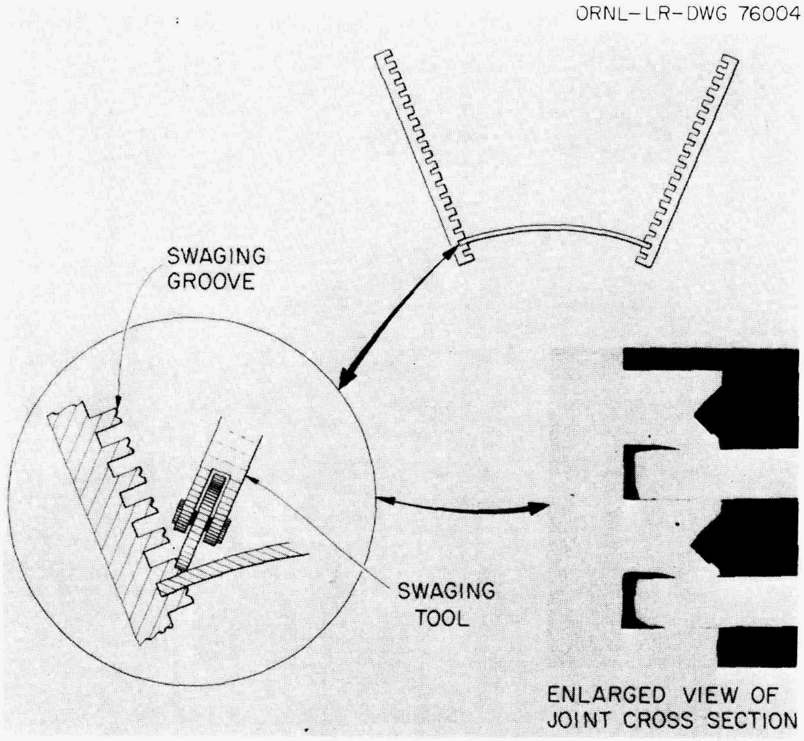

Fig. 9. Technique Used to Fabricate Roll Swaged Joint.

1. proper fit of fuel plate into the side plate slot,
2. depth of penetration of fuel plate into groove,
3. all surfaces must be clean — grease or oil is especially detrimental,
4. proper guiding of swaging rolls,
5. uniform swaging pressure.

If proper control is exercised over these parameters, joint strengths in excess of 200 lb/in. may be obtained.

After all plates are in place, the spacers are removed and combs and end boxes are attached by welding. The elements are then machined to final size.

HFIR Assembly

As would be expected from the geometries involved and as shown on the previous flow chart, Fig. 7, the assembly of the HFIR elements is considerably more involved than for other reactors. It was shown previously that the entire core consists of only two annular elements.

The assembly procedure used for HFIR is unusual and is unique to that element. The attachment technique is to cut a series of grooves into the opposite surface of the side plate from the fuel plate slots; the grooves are cut deep enough so that the edges of the fuel plates are exposed (see Fig. 10). These exposed edges are then fused to the side plate by MIG welds. Achieving welds of the required strength depends upon having sufficient fuel plate edge exposed to make a proper tie-in. If one stops and thinks, it is readily apparent that the amount of fuel plate penetration is affected by the tolerances on both the side plates and the fuel plates.

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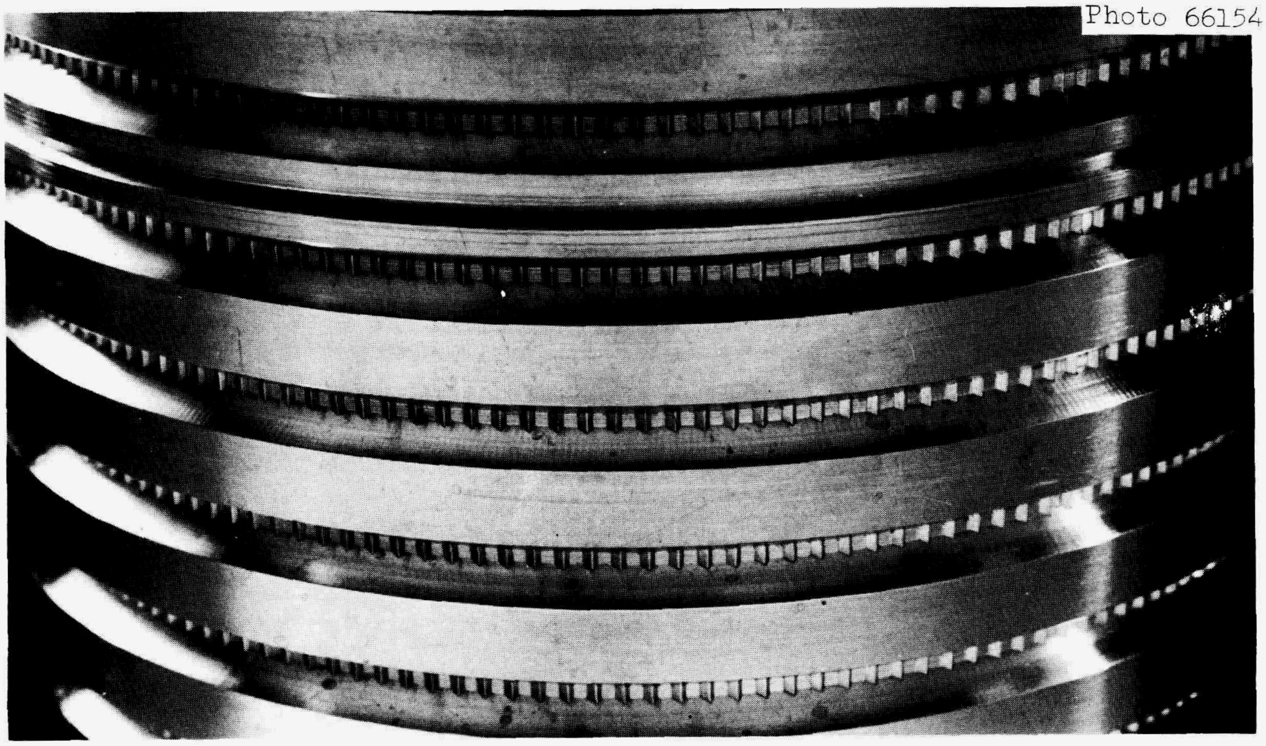

Fig. 10. Typical Weld Joint — HFIR Fuel Element.

The first and one of the more difficult operations in the HFIR assembly sequence is the machining of the side plates. The slot dimensions, including parallelism, must be controlled to about 0.001 in. The machining is complicated by the fact that the wall thickness-to-diameter ratio of the larger tubes is such that they are not self-supporting within the machining tolerances required. If laid on their sides, they are no longer cylindrical. For all machining operations, they must be held in the proper shape by mandrels or backup cylinders.

After machining, the side plates are placed in positioning jigs and the fuel plates inserted in the slots as shown in Fig. 11. A problem here is that, unlike conventional elements, there is no simple way to index or position the side plates relative to each other. This is accomplished by trial and error insertion of the fuel plates and revolving the side plates until the plate edges are well bottomed in the slots. Plates are divided equally among three or four sectors rather than inserted in order around the circumference.

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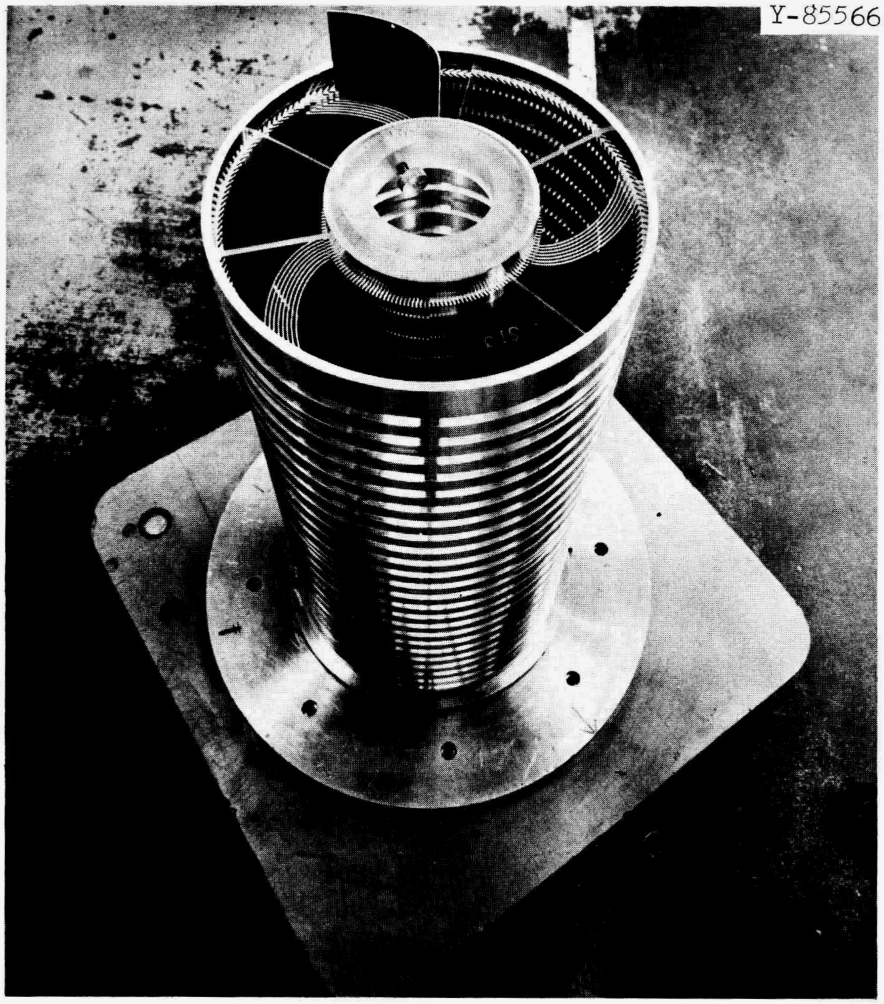

Fig. 11. HFIR Fuel Element During Assembly.

While close tolerances are maintained on plate curvature, differences in water-channel spacing are still found when the elements are assembled. To correct these differences and force the plates into the proper position for welding, strips of Teflon 48 mils thick are inserted into each channel as shown in Fig. 12. In production only single full-width strips are used. The Teflon has a natural lubricity and is fairly easy to add and to remove after welding.

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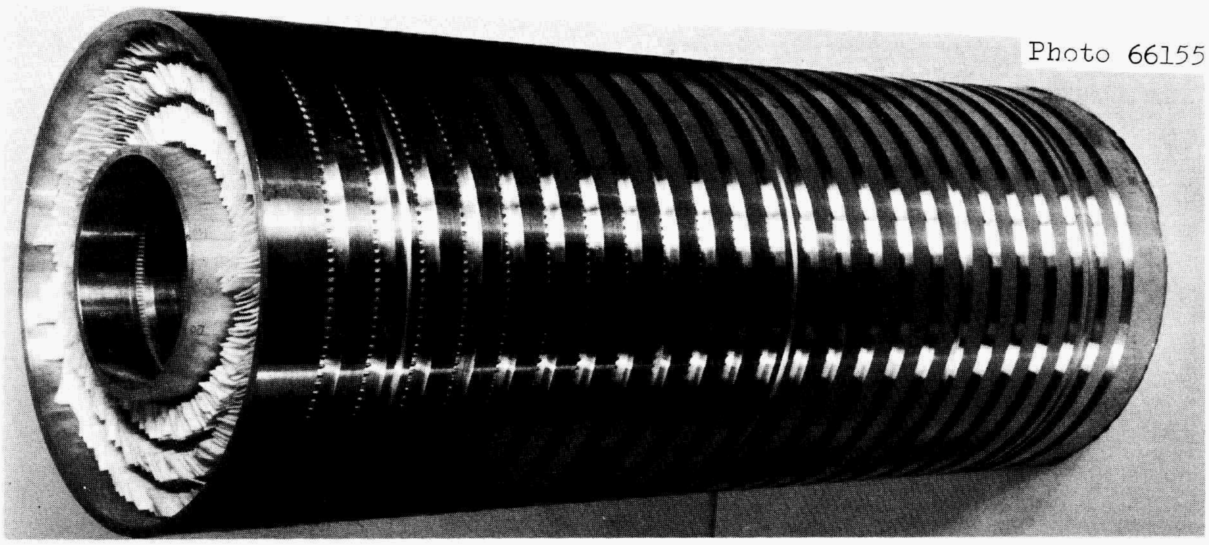

Fig. 12. Assembled Element Showing Inserted Teflon Spacers.

To provide the necessary control, a completely controlled welding machine was obtained, as shown in Fig. 13. The control is obtained by use of feedback systems. Separate conditions are established for starting, running, and stopping of the weld.

The actual control panel is placed right by the element-holding device. Note the small clearance between the end fittings, the side plate, the inner torch, and the massive holding fixtures. This torch was specially built for working inside the small tube of the inner element, but it is used for the inner welds of the outer elements. The outer welds are made with a standard MIG torch. In both cases the work moves under the torches.

The major problem with these welds, shown in Fig. 14, is obtaining the proper tie-in. The example on the left is a satisfactory weld. If

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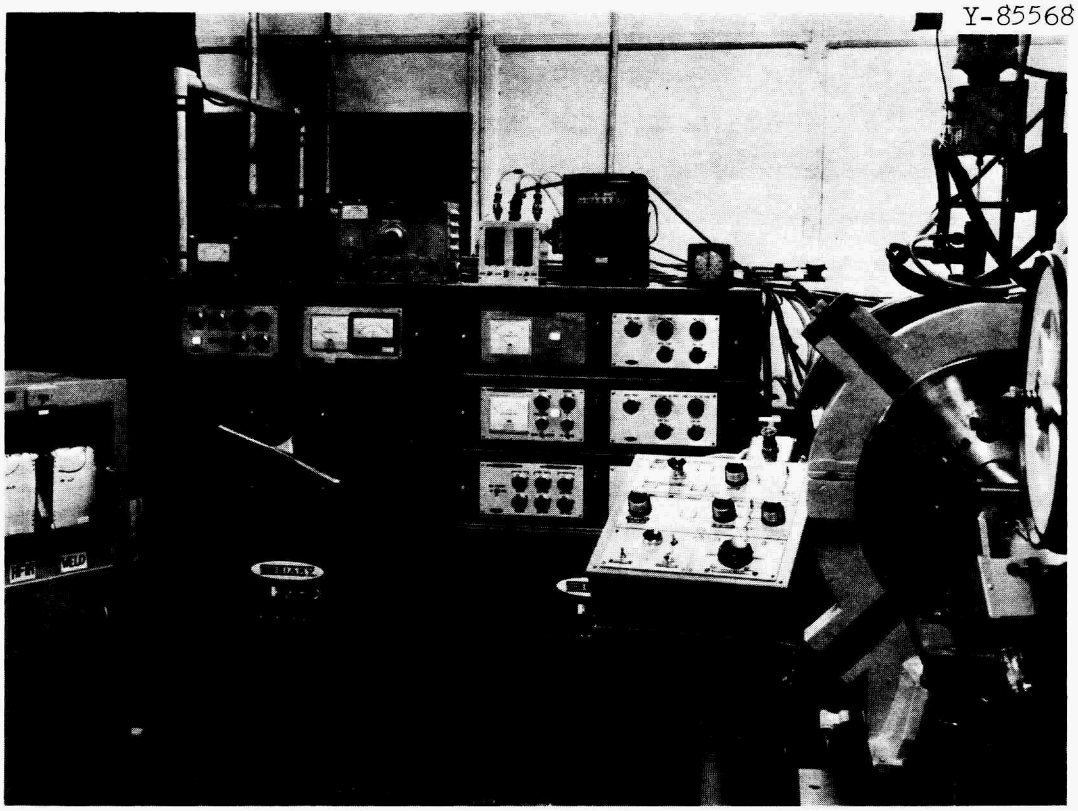

Fig. 13. Welding Equipment Used for HFIR Fuel Element.

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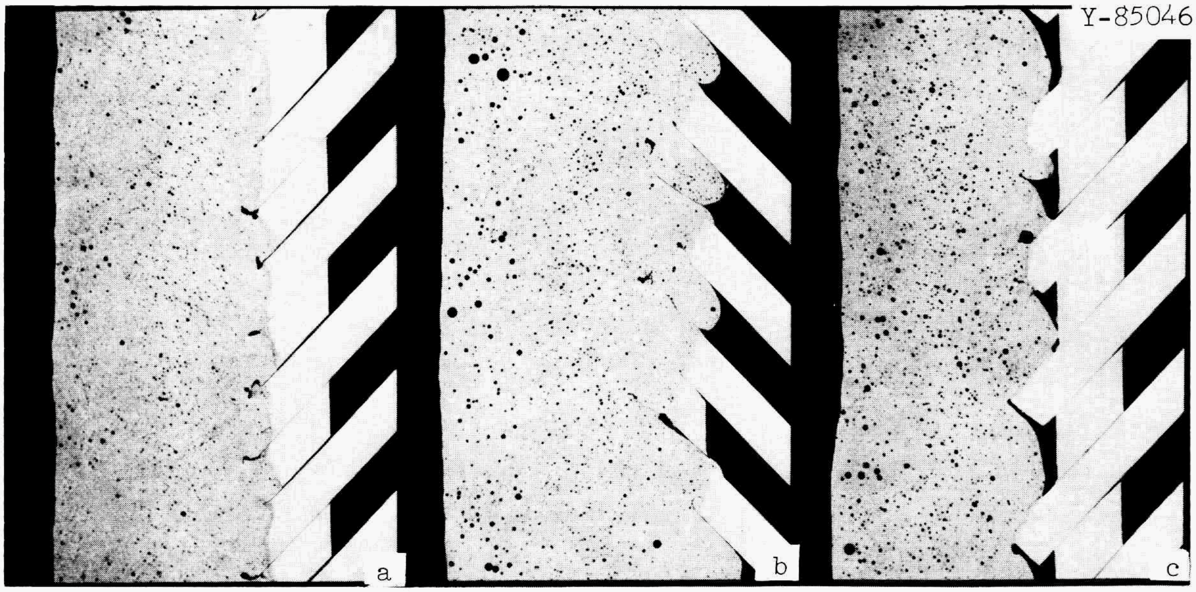

Fig. 14. Weld Penetration, HFIR Fuel Element. (a) Satisfactory, (b) excess penetration, (c) lack of tie-in. 5×. Etchant: 1% HF.

too much heat is present, it is possible to melt completely through the side plate as in the center and even into the fuel core. Also, with inadequate heat, as on the right, the plates are not fused in. The difference between these two conditions is very small; for instance, a change in side slot depth of 0.025 in. greatly assisted in eliminating burn-through. This problem is complicated by the fact that there is no nondestructive testing technique capable of inspecting the tie-in of these welds.

The second major problem is the porosity which may be noted in the welds shown in this figure. This is a function of excess heat and cleanliness. Fine- with an occasional spot of medium-size porosity is acceptable and is found in all welds.

With all of this welding, there is a considerable shrinkage for which the outer tube must compensate. Almost 0.5 in. of shrinkage is found in the side plate length. The original dimensions must allow for this and the welding sequence must start at the center and work out so that relative movement between fuel plates and side plates can occur. Diametral shrinkage is also a problem and varies with the side plate diameters. For the large tube, it amounts to 0.071 in. in the center where the maximum is found. Since the inner tubes shrink in the direction of the machining, the original dimensions must be large enough to allow for it. The outer tubes shrink away from the machining, so it results in a thicker wall. However, in both cases, the ends do not shrink as much as the center and very little occurs on the tabs to which the end fittings are to be welded. The end tabs and any portions of the element showing unusual shrinkage must therefore be either expanded or contracted to achieve the desired diameter.

FUEL PLATE INSPECTION

With the low-performance research reactors, simple and rudimentary inspection techniques were sufficient to furnish the required assurance. However, with HFIR, ATR, and A^2R^2, this is no longer true. Lack of suitable inspection procedures is now one of the limits on further advances.

Fuel Distribution and Homogeneity

With the low-performance reactors, concentrations of fuel were not desirable but, unless very heavy, do not cause problems. The commonly accepted technique for inspecting for such inhomogeneity has been a visual examination of the plates on a fluoroscope and, if questions existed, radiographing the plates. Other than a standard plate agreed to as being acceptable, no other standards were established.

With the high performances of HFIR and ATR, an appreciable fuel segregation could result in a hot spot. Previous inspection techniques did not have sufficient accuracy and reliability to prevent such an occurrence. For ATR homogeneity inspection, every plate is radiographed. Any questionable areas on the radiographs are inspected with a densitometer. Any spot 0.080 in. in diameter must be within 25% of the specified value and any 0.500-in.-diam spot within 8%. It is expected that eventually all plates will be inspected 100% with the densitometer.

For HFIR, further advances in inspection have been made and all plates are 100% inspected using a newly developed instrument which measures differences in x-ray attenuation of various locations on the plate surface. Such an inspection is greatly complicated by the curved fuel core cross section. This means that every longitudinal scan will have its own specified value of uranium content. This value will include batch variations in homogeneity and in fuel core thickness. The spot size currently being used for this inspection is 5/64 (0.078) in. in diameter. The tolerances which are being routinely met are: no single spot may deviate from the specified value for that trace by more than 27%, and no average over approximately a 1-in. length may vary by more than ±12%. This x-ray attenuation scanner has proven to be very effective and reliable. It has been shown to have sufficient accuracy to answer questions on total uranium content of a plate and on analytical accuracy.

Nonbonds

The standard commercial inspection technique for determining nonbonds is simply to heat the plates to 500°C and examine the surfaces for blisters. While crude, with the thin plates involved, this technique is surprisingly reliable.

To provide increased reliability, the current specifications are now also calling for a through-transmission ultrasonic inspection. The sensitivity must be such that a 1/16-in. standard nonbond will be rejected. All plates are 100% inspected. The reliability of this inspection appears to be excellent; however, especially if fuel clumping is present, it may reject an occasional acceptable plate. This rejection of acceptable plates is what has set the inspection level at the 1/16-in. spot.

Core Outline and Channel Spacing

While more care is used and more measurements taken, the basic processes used for inspecting core outline and water-channel spacing are the same for all research reactor elements. Core outlines are determined by comparing the plate to a template in a fluoroscopic examination. Doubtful plates are checked and spot checks made by measuring the outline from x-ray films of the plates. Such techniques have adequate sensitivity to meet present requirements.

Water-channel spacings are being measured with a variety of probes which are inserted in the channels, the most common being strain gage probes with eddy-current probes a second choice. The difference in inspection for the low- and high-performance machines is the number of measurements required. HFIR has developed an eddy-current probe which continuously records the spacing at five diameters down each channel and also records a continuous average of the five probes to give a continuous average for the channel cross section.

Critical Facilities

The final major inspection is usually made after the elements have been received at the purchaser's plant and is a measurement in a critical facility. Such a measurement determines the nuclear worth of the element. Initially, every element is measured but, as confidence is obtained in the fabricator, only spot checking is used.

CONCLUSION

Even though the research reactor fuel elements are aluminum based, they operate at heat and neutron fluxes well beyond the power reactors. Obtaining such performances has required development of flat-plate-type fuel elements with powdered fuel in a dispersion core and fabricated to exacting tolerances. Such elements are fabricated commercially using picture-frame-type procedures. They require a large number of carefully controlled inspection operations and a high inspector-to-operator ratio. Either mechanical or welding procedures are used for assembly, depending upon the geometry involved.

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