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ABSTRACT

The preparation of typical fuel elements is briefly described.

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FUEL RESOURCES, TYPES OF FUELS, AND FABRICATION

By

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for the

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FUEL RESOURCES, TYPES OF FUELS, AND FABRICATION

INTRODUCTION

(Slide 1)

The first slide is for purposes of orientation as to what topics are going to be covered in this particular lecture of the series. We see here schematically the entire fuel cycle connected with a nuclear powered reactor. It begins with the mining of uranium ore and continues with the ore being concentrated to provide a reactor feed material. In the feed plant, the concentrate is converted to any desired compound (or possibly metal) of the exceedingly high purity required for the nuclear application. If desired, the feed material can be sent to a unit such as a gaseous diffusion plant, in which the ratio of fissionable U-235 to fertile U-238 is adjusted. In other fuel cycles which do not use a gaseous diffusion plant, the fertile to fissionable adjustment is made by blending of various streams. After any desired adjustment, the fuel material is manufactured into the elements which are placed into the reactor. After a period of residence in the reactor, which is limited by either economics or materials limitations, the residual fuel is discharged and usually sent to a radiochemical plant for recovery of any valuable materials still in the fuel element or produced in it. From the radiochemical plant are discharged fission products which have been produced in the reactor.

Tonight we will briefly discuss the sources of uranium and thorium, the preparation of reactor feed materials, and, in slightly greater detail, typical operations in the fabrication of fuel elements. We will not discuss the gaseous diffusion process tonight.

SOURCES OF NUCLEAR RAW MATERIAL

(Slide 2)

The next slide shows a recent estimate of the uranium and thorium available in the free world which is recoverable at current prices. You will note that in round numbers there are approximately one million tons of contained uranium available at \$10 per pound U₃O₈, or less, and comparable quantities of thorium. The main distinction between the uranium and thorium reserves are: (1) uranium contains fissionable U-235, whereas thorium does not; and (2) the United States is not as rich in thorium as it is in uranium. The picture may change in the future if we institute as extensive an exploration for thorium as we have had for uranium in the past few years.

(Slide 3)

The next slide shows some typical sources of uranium, the first of which is rather high grade material--the material typified by the Belgian Congo resources--and is rapidly being exhausted; the second represents the bulk of the uranium now being produced in the United States. The fourth is a large and important source of uranium at present. The content of the tailings is low, but they are available in a form which is economical to process. The next three sources are our future supply of uranium several decades hence in this country. The quantities of this

material are not known with any confidence, but it is clear that the total tonnages of uranium are exceedingly large. Estimates vary as to how much more uranium will cost to recover from these low grade sources than we are currently buying. In his Geneva paper, Jessie Johnson suggests a factor of perhaps three to six times as much. The largest two sources of uranium are too dilute for consideration at the present time. In fact, the very largest does not provide enough heat to raise the temperature of the source more than about 1°F.

FUEL ELEMENTS - GENERAL CONSIDERATION

(Slide 4)

The next slide shows the principal functions of a fuel element. In any reactor, we burn fissionable material and generate heat and a neutron and gamma flux. The heat is of interest, since we can convert it to electricity if it is available at a sufficiently high temperature; and the radiation is of interest for research and potentially for new chemical reactions. If we do not place pure fissionable material in the reactor, we can capture some neutrons in a fertile material and generate some fissionable material from it. If the reactor is suitably designed, it is possible to capture so many neutrons in fertile material that we can produce more fissionable material than we have consumed. This, of course, occurs at the expense of fertile material.

(Slide 5)

The basic requirements of a fuel element are listed in the next slide. Obviously, it must contain fissionable material to sustain a chain reaction. It should not contain excessive quantities of materials which will poison the chain reaction or render it less efficient. If the reactor is a power producer, we must provide adequate heat transfer. For conservation of materials and cost reasons, we wish to keep the fissionable material tied up in the reactor at a reasonable level. The element must stand up mechanically and corrosion-wise to environment; that is, to the coolant in particular, for a sufficient length of time to be of economic interest. Finally, if the power reactor is to compete with coal, the fuel element fabrication costs must be kept within bounds consistent with the other costs of the reactor.

(Slide 6)

The possible parts of a typical fuel element are: (1) the fuel itself; (2) fuel diluent may be added to lend stability or reduce the damage due to the fission fragments; (3) there may be a gas gap between the fuel and its clad, or the gap may be filled with some other material; namely, (4) the heat transfer bond, (5) the clad which has been used in all solid fuel elements to date to protect the fuel against the corrosive action of the coolant and to contain the fission products; and finally, a fuel conceivably could contain (6) moderator material to make the nuclear reaction more efficient or (7) its own coolant, as is the case with any fluid fuel reactor.

(Slide 7)

The next slide shows a schematic of some of these portions of a fuel element.

The fuel itself within, surrounded by some sort of layer which conducts the heat from the fuel to the clad; and finally, the clad, which contains the element and separates it from the coolant.

(Slide 8)

The next slide shows that a great variety of fuel materials is possible. Under solids, we may have metal, a compound, or a dispersion of a fuel compound in another material. Under liquid, we may have molten metal, molten salt, or a solution. Gaseous fuel reactors have not been operated in this country but have been proposed at various times. Solid-liquid fuel is typified by slurry reactors and solid-gas fuel for gas phase dispersion such as a dust fuel reactor. Finally, there has even been some discussion of plasma-filled reactors.

The next three slides briefly outline the path we take in going from uranium ore as it is found in the ground to the starting materials from which we manufacture fuel elements.

(Slide 9)

The first slide shows that we mine a typical Colorado ore at a concentration of $\sim 0.2\%$ uranium. The material is ground and leached and the uranium values recovered from the leached liquor by precipitation, solvent extraction, or ion exchange. The material is then precipitated and possibly calcined to U_3O_8 and shipped as a concentrate, which typically may be 70% uranium with metallic impurities of perhaps 5 to 10% . In a refinery, the concentrate is purified by solvent extraction and converted to UO_3 of exceedingly high purity. By hydrogenation and hydrofluorination, the UO_3 is converted first to UO_2 and then to UF_4 , which is known in the trade as "green salt." "Green salt" is the starting material either for manufacturing metal or for manufacturing uranium hexafluoride, which is the gas used in the gaseous diffusion process. Fluorination of green salt yields UF_6 , while a thermite type reduction of green salt with calcium or magnesium yields the metal.

(Slide 10)

On the next slide is repeated the sequence of reactions we just mentioned for making uranium metal, which would be normal uranium metal, since we have not gone through any isotope separation plant. If we wanted normal UO_2 , as was used, for example, in the Shippingport Reactor, we could simply withdraw the UO_2 from the usual chain for making metal. If, however, we wanted enriched uranium metal or oxide, we would send the UF_6 we had made to a diffusion plant, and would then convert the enriched UF_6 to metal (as is shown in this slide) via conversion to green salt first.

(Slide 11)

If we wanted enriched UO_2 , we would proceed, as is shown schematically in the next slide, by precipitating ammonium diuranate with ammonium hydroxide and filtering off and then calcining in a hydrogen atmosphere the ammonium diuranate to yield desired UO_2 powder.

FABRICATION OF SAMPLE FUEL ELEMENTS

In the bulk of slides to be shown from this point on, we are going to try to give you a picture of what a variety of fuel elements look like and some idea of how we go about manufacturing them. Please do not get the idea that all the steps are shown. The slides were selected with the idea of giving you typical views of what is done; and many steps, some of them quite costly, have been omitted in order to avoid boring you.

1. Oak Ridge Graphite Fuel Element

Historically, the first reactor to operate at any appreciable power was the Graphite Reactor at Oak Ridge. The fuel element it used and, incidentally, is still using at the present time, is shown in the next slide.

(Slide 12)

It consists of a slug of normal uranium metal of approximately 1 in. diameter by 4 in. long. The uranium slug is canned in aluminum to protect it against the coolant, which in this case was air. In order to provide a good path for heat transfer from the fissioning uranium to the air outside the can, an aluminum-silicon bond fills up the gap between the fuel and the can.

(Slide 13)

In the next slide are shown the main steps required to assemble this element. The slide shows us starting with a manufactured uranium slug. The slug was manufactured from the metal by first converting it into an ingot, then rolling rods, and, finally, cutting and machining the rods into slugs. The slug is cleaned, inspected, and coated with aluminum-silicon. The can, the cap, and the sleeve are similarly cleaned. The can is inserted in the sleeve, the slug is inserted into the can, and the combination is again dipped in aluminum-silicon to provide the coating. The combination is removed from the bath, the can is stripped off, and the cap is welded on. This is actually quite a ticklish operation because the bath must be at just the right temperature and the components held in the bath for just the right time.

2. MTR Type

(Slide 14)

The next slide shows a development of a new type of metallurgical fuel element. First, it contains highly enriched uranium rather than the normal uranium in the ORNL slug. Second, in order to provide greater heat transfer area, the single massive slug has been broken down into thin plates which are curved for structural reasons. If you look closely, you can see within each plate a dark band within each cross section which consists of the fuel material, namely, uranium-aluminum alloy. All the lightly colored material you see is simply aluminum. The fuel plates are fitted into the side plates by brazing.

(Slide 15)

The next slide shows schematically what we mean by the "picture frame" technique by which elements of this type are manufactured. We begin by making a roughly square piece of fuel alloy. This is then dropped into a frame of aluminum and covered top and bottom with additional sheets of aluminum. The assembly is then welded, closed on all edges, and rolled into the fuel plates we saw in cross-section in the previous slide. In the rolling process, we achieve a heat transfer bond by a metallurgical bonding between the fuel alloy and the clad of aluminum.

3. APPR Type

The MTR type we have just described is widely used in research reactors which operate below the boiling point of water. A logical development has been the substitution of stainless steel for aluminum, in order for us to operate at elevated temperatures with pressurized water.

(Slide 16)

The APPR element shown in this slide contains UO_2 dispersed in stainless steel instead of uranium-aluminum alloy, and the cladding material and side plates are stainless steel instead of aluminum. The element is still made by brazing the fuel plates to side plates, and in this case the plates are straight instead of curved by virtue of their having greater rigidity built in.

4. PWR Seed Type

Another variation of our basic MTR idea is the use of zirconium instead of aluminum, since zirconium has excellent corrosion resistance to pressurized water, and in its hafnium-free form it has very low poisoning for thermal neutrons.

(Slide 17)

The next slide shows that we again utilize our old friend the picture frame. The fuel material is a uranium-zirconium alloy with highly enriched uranium. It is placed inside a frame of zircaloy. Any gases are evacuated by this tube; and then the assembly is clad in steel to protect the zircaloy during the rolling operation, since zirconium, as all of you know, I am sure, is an excellent "getter" for oxygen and is therefore used in the manufacture of vacuum tubes. I hope this item of electrical engineering picked up years ago hasn't already been out-dated.

(Slide 18)

The next slide shows how the fuel plates, after they have been rolled and their protective steel cover removed, are stacked, separated by steel spacers in preparation for, in this case, not brazing but welding.

(Slide 19)

The next slide is intended to give you some glimpse at the special care with which zirconium fuel elements are welded, namely, in a special box with an inert atmosphere.

(Slide 20)

The next slide shows a cluster which is made up of four boxes of plates of the type we saw previously. The cross-shaped hole in the center provides space for a cruciform control rod which makes the nuclear reactor increase or decrease in power in accordance with the electrical demand on the reactor.

5. EBWR Type

A variation on the previous element is a zircaloy-clad plate fuel which utilizes, instead of highly enriched, slightly enriched uranium.

(Slide 21)

Shown here is the completed experimental boiling water reactor assembly and its parts. The plates are again made by the picture frame technique, the fuel material in this case being a uranium-zirconium-niobium alloy containing mostly slightly enriched uranium. The fuel plates are spot-welded to the side plates through the slots you can see.

The next series of slides shows a few of the steps in the manufacturing.

(Slide 22)

This slide shows the fuel induction furnace in which the alloy is cast.

(Slide 23)

This slide shows another furnace in which the plate was treated after the rolling operation.

(Slide 24)

This slide shows an inspection step in which the plates are radiographed to locate exactly where in the plate the fuel alloy is.

(Slide 25)

This slide shows how the operator trims the plate to length.

(Slide 26)

This slide shows another inspection. This one is an ultrasonic test to determine the quality of the bond between the fuel alloy and the clad.

(Slide 27)

In this slide the clad is shown being pickled in an acid vat.

(Slide 28)

This slide shows fuel plates being given a corrosion test in pressurized water, which would show up imperfections in the exterior of the cladding.

6. PWR Core 1 Blanket Type

(Slide 29)

Almost all the previous assemblies utilized plate fuel and most of them utilized enriched uranium. A major change in fuel elements was pioneered by Westinghouse in the PWR blanket. Instead of using uranium as metal, or oxide dispersed in metal, it uses pure uranium oxide. The reason is that uranium oxide has a very high melting point and radiation stability greatly superior to metal. Just in case you may think that it is a perfect fuel, let me remind you that its thermal conductivity and thermal shock resistance are poor. Another innovation is that the fuel is in the form of a rod in a plate, which perhaps harkens back to our first uranium slug, although the diameter of this rod is generally less than one-half that of a slug. The next slide shows how the UO_2 pellet was made.

(Slide 30)

UO_2 powder was taken from the metal manufacturing chain, prepared by adjusting its particle size and adding binder, pressed into a pellet, sintered at high temperature to raise the density of the pellet and to reduce the amount of voids, and ground in order to make the diameter to a tolerance of plus or minus 1/2 mil. The grinding step is indicated in dashed lines in this slide, since some reactor designers are going to try to get by with diameter tolerances of plus or minus 2 mils and save the expense of grinding.

(Slide 31)

The next slide shows a machine in an inert gas chamber welding the end cap on a PWR rod. The cap and clad material, namely, the tubing, in this case are zircaloy-2.

(Slide 32)

This slide shows a finished fuel rod bundle consisting of 120 rods. In between the rods are coolant holes drilled in the tube sheets which hold the bundle together.

(Slide 33)

This slide illustrates some of the pains that are gone to to avoid warping the tube sheet. The numbers at the top of the slide indicate the sequence of welds that are made in welding the rods to the tube sheet.

(Slide 34)

This slide shows how seven such bundles are assembled end-to-end in a zircaloy case to produce the final blanket assembly.

7. Yankee Fuel Assembly

(Slide 35)

The next slide illustrates a variation of the PWR blanket assembly, in that this assembly uses stainless steel instead of zircaloy for the cladding. The fuel assembly, incidentally, is the one on the right. This particular slide, besides its obvious attractions, is intended to illustrate the size of typical power reactor fuel bundles. We have come a long way from the 4-in.-long slug. A unit such as this assembly may weigh in the neighborhood of one-half ton. We cannot see it, but the rods containing UO_2 in this case are assembled by brazing ferrules or straps to the individual rods. We are waiting for the strapless design.

8. PWR Core 2 Blanket Type

(Slide 36)

Since almost all technology goes in cycles, future planning for the pressurized water reactor is to replace the rod bundle with a plate-type element. The next slide shows schematically how this will be done. It is reminiscent of our old friend the picture frame with its cut-out center portion and cover plates. In this case, the fuel will be small platelets of extruded UO_2 , and development work is underway on techniques of bonding the cover plates to the metal portion of the central fuel plate. The objective of this design is to take advantage of the short path that the heat has to flow in a thin plate (you remember the low conductivity of UO_2) and obtain increased power from the PWR.

9. BORAX-IV

The next sequence of slides illustrates various aspects in the manufacture of Argonne's BORAX-IV fuel element. This was chosen not only for its own merits but also because some excellent photographs are available of the manufacturing process, and many of the steps typify what you would see if you followed a fuel element manufacturing line from beginning to end.

(Slide 37)

The first slide shows the fuel itself, which consists of pellets of fully enriched UO_2 in ThO_2 . As you can see, the pellets are not very large and a power reactor loading may require millions.

(Slide 38)

The next slide shows the typical operation of pressing pellets. It is located in a glove box because of the hazard of ingestion of any dust particles which may be produced.

(Slide 39)

This slide shows how the pellets themselves are clad. Instead of individual tubes, of the type we have previously seen, BORAX-IV uses a tube plate which is really seven tubes side-by-side manufactured as one piece by extrusion.

This next slide shows an operation that typifies a very costly aspect of fuel element manufacture, namely, inspection. Incidentally, there is lead used in the BORAX assembly, but this slide should read "Leak Detection."

(Slide 40)

In this slide the man is checking the first end closure prior to loading of pellets.

(Slide 41)

This slide shows pellets being loaded into a tube plate. I don't think the Saran Wrap was there for the man's lunch.

(Slide 42)

The next slide shows a bunch of tube plates about to be immersed in a lead bath. The lead provides the heat transfer bond between the pellet and the aluminum cladding material of the plate.

(Slide 43)

This slide shows a cross-section of a lead-filled plate. The dark lines around the pellet are the lead bond.

(Slide 44)

The next slide shows a closeup in which you can probably see the bond better. The irregularities at these points are due to ribs which were extruded in the plate originally to ensure centering of the pellets.

(Slide 45)

The next slide shows the final assembly with the end fittings on each side. the tube plates are fastened to side plates by welding. Incidentally, it is of interest that a 1% nickel addition to aluminum is used in making this assembly, and it has been found that this results in a great improvement in the corrosion resistance of the aluminum to elevated temperature water.

10. APDA Core

(Slide 46)

For fast reactors, the loading of uranium is generally much greater than for thermal reactors. In order to keep the loading within bounds, the fuel pieces are generally made with a geometry which provides a very large heat transfer area per unit volume. In this slide the core of the fast reactor to be built in Michigan is schematically shown. The fuel is contained in 144 pins which are $\sim 1/8$ in. diameter. The pins are held in a bundle by end grids, and they are held apart from each other by wires, which allow a space for the coolant. The fuel is uranium-molybdenum alloy of intermediate enrichment. The clad is zirconium metallurgically bonded to the fuel during extrusion of the pin, and the coolant is sodium. The entire bundle is held in a thick outer can.

FABRICATION SCRAP

One unfortunate thing that goes with the manufacture of fuel elements, particularly metal fuel, is the generation of scrap. We have, first of all, very rigid specifications and frequent inspections. Therefore, we expect to pick up rejections. Second, in a long sequence of casting and machining operations, in each of which we keep only the best portions, we naturally generate a great amount of scrap.

(Slide 47)

This slide shows the three typical types of scrap generated by the fabrication of metal fuel elements. Remeltable scrap is material which is sufficiently massive and clean that it can simply be recycled to a casting operation. An example of this is material cropped off the ends of ingots or rods to ensure that the remainder is homogeneous. The second type of scrap is material which can be burned to U_3O_8 . In this category are impure pieces of metal, residues such as slag, used molds from casting operations, and a multitude of materials which contain uranium, such as floor sweepings, rags, etc. Finally, some scrap can be dissolved in nitric acid and purified by extraction. The principal material of this type is the U_3O_8 produced by burning the combustible scrap. In the case of a uranium oxide fuel element, scraps, such as ground UO_2 from grinding operations on a pellet, would probably be dissolved. Each unit of scrap that has to go through combustion, dissolution, and purification is in a sense going all the way back through the fuel cycle as though it were a raw material concentrate; and a small percent of such scrap can, therefore, substantially increase the cost of making a fuel element.

(Slide 48)

The next slide gives some typical numbers for what might be expected from fuel element scrap. You will notice that the uranium oxide type of fuel element gives the highest direct yield, but all of its scrap will probably have to be recovered chemically. The uranium-zirconium PWR type plate has a very low yield without recycle, but the majority of the scrap is potentially remeltable, and development work is underway to bring this into practice. Even the traditional uranium-aluminum alloy MTR plate has with it a considerable recycle to melting, and appreciable scrap would be sent to chemical recovery for salvage.

REFABRICATION OF FUEL ELEMENTS

You will remember that we began with the idea that fuel elements in a reactor are generally only incompletely burned. Unless the residue value is less than the cost of recovery, it is desirable to recover the valuable constituents of fuel and reuse them. Here comes the problem. Even if we remove all the radioactive fission products from our irradiated fuel, we still have left from side reactions in the reactor some radioactive isotopes.

(Slide 49)

This slide illustrates the type of thing we have to contend with. It shows several materials and the radiation reading one foot from a kilogram sphere. Naturally, fuel elements are not made as kilogram spheres, but this is a convenient quantity to calculate and some idea may be obtained from the relative

numbers. You will see that, in fabricating a fuel the first time, we have numbers ranging on this table from 0.2 to 3.9 mr/hr. If we want to refabricate plutonium produced by the irradiation shown here into a fuel element, we have a reading perhaps 100-fold as great; and if we want to fabricate a U-233 fuel element, unless we do it very rapidly, we may have a reading which is intolerable for direct handling. Work, therefore, remains to be done and has been instituted at the various National laboratories on how to handle the material after radiation and for recovery. The future economics of nuclear fuel cycles will depend to a considerable extent on how well the problem is solved.

JWU:nr;mep

LIST OF SLIDES

1.	ORNL-LR-Dwg. 23760	26.	Photo 44921
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ORNL-LR-DWG 23760

THE FUEL CYCLE OF URANIUM, THORIUM AND PLUTONIUM

KNOWN AND INFERRED RESERVES

COUNTRY	THOUSANDS OF TONS METAL AT \$10/lb OXIDE	
	U	Th
SOUTH AFRICA	370-480	13
CANADA	320-480	160
U. S.	160	60
FRANCE	30	--
INDIA	--	440
BRAZIL	--	106
OTHER	1	32
TOTAL (NON-SOVIET)	880-1150	810

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URANIUM SOURCES

MATERIAL	% U
PITCHBLEND	1 - 4
WESTERN U. S.	0.08 - 1.0
SHALE (SWEDEN)	0.02 - 0.3
GOLD TAILINGS	0.006 - 0.05
PHOSPHATE ROCK	0.01 - 0.02
LIGNITES	0.005 - 0.02
SHALE (U. S.)	0.006
GRANITE	0.0005 - 0.01
SEA WATER	4×10^{-7}

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FUNCTIONS

BURN FISSILE MATERIAL (U^{233} , U^{235} , Pu^{239} , Pu^{241})
TO GENERATE HEAT AND RADIATION

ABSORB NEUTRONS IN FERTILE MATERIAL (Th^{232} , U^{234} ,
 U^{238} , Pu^{240}) TO GENERATE MORE FISSILE MATERIAL

PRODUCE NEUTRONS FOR ABSORPTION IN TARGETS

REQUIREMENTS

CONTAIN DESIRED FISSILE AND/OR FERTILE

NOT CONTAIN EXCESSIVE UNDESIRABLE

YIELD NECESSARY HEAT TRANSFER

YIELD REASONABLE FISSILE INVENTORY

STABLE TO CHEMICAL, RADIATION AND
MECHANICAL ENVIRONMENT

NOT COST TOO MUCH TO FABRICATE
(AND RECOVER RESIDUE)

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POSSIBLE FUEL ELEMENT PARTS

FUEL (FISSILE AND FERTILE)

FUEL DILUENT

GAS GAP

HEAT TRANSFER BOND

CLAD

MODERATOR

COOLANT

UNBURNED URANIUM
FISSION PRODUCTS
TRANSMUTATION PRODUCTS
(a) FISSIONABLE
(b) NON-FISSIONABLE
ADDITIVES

IRRADIATED FUEL ELEMENT

TYPES OF FUEL MATERIAL

SOLID:	METAL (U), COMPOUND (UO_2), DISPERSION (UO_2 -SS)
LIQUID:	MOLTEN METAL (U-Bi), MOLTEN SALT (UF_4 -NaF-ZrF ₄) SOLUTION (UO_2SO_4 -D ₂ O)
GAS	UF_6
SOLID-LIQUID:	UO_2 -ThO ₂ -D ₂ O
SOLID-GAS:	UO_2 -He

FEED MATERIALS

NORMAL U METAL

NORMAL UO₂

ENRICHED U METAL

CERAMIC GRADE ENRICHED UO₂

Schematic Section of Canned Fuel Slug.

Sequence of Operations for Canning ORNL Graphite Reactor Slugs by the Flux-Alpha Canning Process.

- A - STEEL COVER PLATE
- B - ZIRCALOY FLANGE STRIP
- C - STEEL SPACER
- D - ZIRCALOY RECESSED COVER PLATE
- E - FUEL ALLOY
- F - STEEL PICTURE FRAME
- G - STEEL EVACUATION TUBE

Fuel Plate Element Components Prior to Assembly (P-787).

Stacking Fuel Plate Elements, Steel Spacers (Perforated) and End Plates Prior to Subassembly Welding (P-787).

Inert Atmosphere Welding Box for Subassembly and Cluster Welding (P-787).

PWR Cluster from Transition End (P-787).

EBWR Fuel Assembly and Fuel Assembly Components. Fuel Plates are 3-5/8" Wide x 54" Long (ANL-5629).

700-62

111-2930

View of 20" Quartz Tube Vacuum Induction Furnace from Balcony Floor (ANL-5629).

Steel Jacketed Fuel Plate being Entered into Reheat Furnace after Rolling (ANL-5629).

Radiographing Ends of Fuel Plates for Core End Location (ANL-5629) .

106-2791

Cutting Fuel Plate to Rough Length on Abrasive Wheel Saw (ANL-5629).

Ultrasonic Testing Equipment for Nondestructive Inspection of Fuel Plate Bonds.
Same Equipment Used for Soundness Inspection of Billet Cores (ANL-5629).

Pickling of EBWR Fuel Plate (ANL-5629).

Equipment Used for Corrosion Testing of Fuel Plates (ANL-5629).

111-3870

132 042

270

Large Autoclave Being Loaded with Fuel Plates

111-3871

Stainless Steel Fixture for Loading Fuel Plates in Autoclave

Rod Fuel Element Components (P-2380).

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UO₂ PELLET

Interior of Fuel Rod Welding Chamber (P-2380).

Finished Fuel Rod Bundle (P-2380).

Fuel Rod Bundle Welding Sequence (P-2380).

Cutaway View of Shell Assembly Showing Fuel Rod Bundle Placement (P-2380).

132 048

-64-

Compartmented Plate Fuel Element Components (P-2380).

Fired Thoria Pellets (ANL-5678).

View of Press in Glove Box (ANL-5678).

Tube Plate Closed on One End (ANL-5678).

Macro 21752

First End Closure; Lead Detection (ANL-5721).

Fixture for Loading Fuel Pellets (ANL-5678).

**Lead-Filling Operation; Tube-Rack on Canning Elevator
Prior to Filling (ANL-5721).**

138 057

Cross Section: Loaded and Lead-Filled Tube-Plate (ANL-5721).

Partial Section: Loaded and Lead-Filled Tube-Plate (ANL-5721).

Fuel Assembly; Borax IV (ANL-5721)

METALLIC FUEL ELEMENT SCRAP

TYPE	EXAMPLE
REMELTABLE	CROPS
COMBUSTIBLE	RESIDUES
DISSOLVABLE	U_3O_8

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ESTIMATED FABRICATION YIELD (% OF U)

ELEMENT	DIRECT YIELD	REMELTABLE	NONREMELTABLE
HIGHLY ENRICHED U-Al PLATE	60	30	10
HIGHLY ENRICHED U-Zr PLATE	21	27	52
SLIGHTLY ENRICHED UO ₂ ROD	88	0	12
SLIGHTLY ENRICHED U-Zr SLUG	39	43	18

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APPROXIMATE ACTIVITY LEVEL OF ONE KILOGRAM SPHERE IN AIR

MATERIAL	mr/hr AT ONE FOOT
NATURAL U IN SECULAR EQUILIBRIUM WITH DAUGHTERS	0.2
NATURAL Th IN SECULAR EQUILIBRIUM WITH DAUGHTERS	1.1
U^{235} IN SECULAR EQUILIBRIUM WITH DAUGHTERS	3.9
Pu WITH 9% Pu^{240} FROM SINGLE 100 DAY U IRRADIATION AT 5×10^{13} n/cm ² /sec	108
U^{233} FROM 3000 g/t Th AFTER 2 YEAR STORAGE (2-13 mb Th n, 2n cross-section)	750-4850
*RECOVERED Th FROM A SINGLE IRRADIATION TO 3000 g/t PROCESSED 60 DAYS AFTER IRRADIATION	1.6

*1.68 Kg slug, $\sigma_{02}(n, 2n) = 10^{-13}$

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- 200. Laboratory Records, RC
- 201- 202. Central Research Library
- 203. Document Reference Section

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