48. Plants for the Fabrication of Fuel Elements

A "plant for the fabrication of fuel elements" includes the equipment:

48.1. Which normally comes in direct contact with, or directly processes, or controls, the production flow of nuclear material; or

48.2. Which seals the nuclear material within the cladding; or

48.3. Which checks the integrity of the cladding or the seal; or

48.4. Which provides for the finishing surface treatment of the sealed fuel.

Typical Appearance

A fuel element fabrication plant will be housed in one or more low-rise buildings that have no particular distinguishing features from other industrial buildings when viewed from the outside. Building size can vary, and entry and exit may or may not be controlled. The layout of a typical fuel fabrication facility is shown in Figure 48.1. Typically, a line or suite of glove boxes (Figure 48.2) is dedicated to fuel fabrication including (for oxide fuels) powder treatment, pressing, sintering, grinding, and dimensional measurements. Other characterization, such as density, pore size and distribution, stoichiometry, and grain size measurements are conducted in another line or set of boxes. Gas filling and welding are carried out in yet another set of boxes. However, the extent to which glove boxes are used and other safe practices are followed may be considerably less. For metal fuels, melting and casting and other fabrication processes are performed in a suite of boxes such as the one shown in Figure 48.3. If recycled fuel is used, remote operations in a hot cell or gamma shielding of all glove boxes at a minimum will be required.

Parts of the facility's interior may resemble a smelting shop and foundry in the metals industry with large (2000-tonne) presses, extrusion machines and rolling mills. Other parts may house high-temperature furnaces, associated control systems, and glove boxes for fuel preparation. Welding equipment, with associated power and gas supplies, will be evident. Supplies of shiny tubing of varying diameter and in 1- to 4-m lengths, extrusion

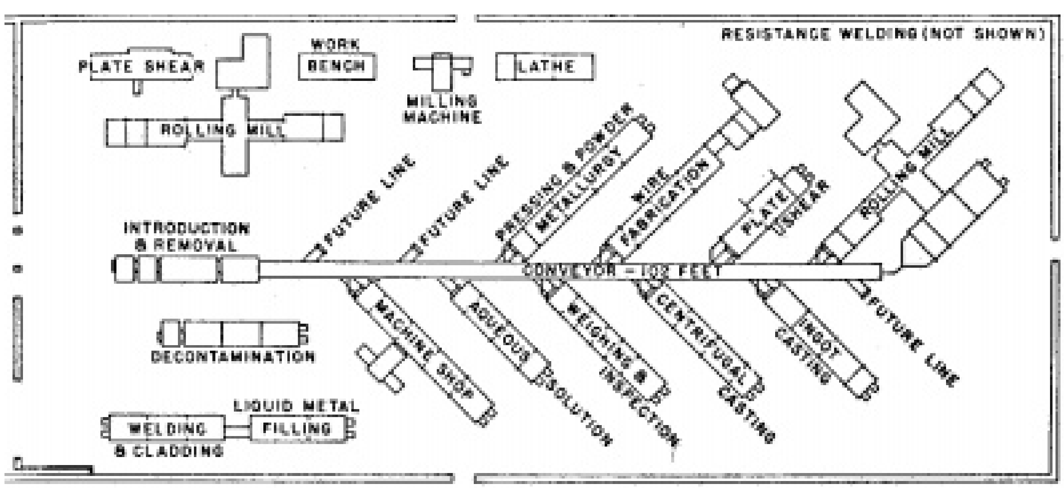

Figure 48.1. Fuel fabrication facility showing glove-box arrangement.

dies, solid bar and plate stock, and limited access areas for element storage are also likely to be encountered.

As Manufactured: Fuel fabrication plants, and the equipment they contain, vary widely according to the type and form of fuel produced. The primary types of nuclear reactor fuel are metals and oxides. The primary forms are rods, rod assemblies, tubes, and plates, which are then assembled into fuel assemblies. The type of nuclear reactor in which the fuel is to be used determines the type, form, and size of the fuel. Each permutation of type and form requires different fabrication processes and imposes its own requirements on the fuel fabrication plant used to produce it.

Fuel element fabrication plants turn purified uranium oxides or uranium metal into finished fuel elements. Processes for the production of the uranium oxides and metal are discussed in Chapter 6.

Oxide Fuels. A plant for the fabrication of uranium dioxide (UO_2) pellets is shown in Figure 48.4. Generally, the UO_2 powder is reduced in size by grinding in rod or ball grinders. The powder is then mixed with a binder and fed into hydraulic or mechanical pellet presses. The resulting pellets, generally in the form of right cylinders, are machined to the appropriate approximate size. They are inspected and sorted into dies on trays and placed into a sintering furnace for heating. Sintering drives out air and eliminates pores within the pellets. Sintering furnaces can be continuous, in which case the pellets are conveyed on molybdenum boats. Sintering furnaces also can be discontinuous, in which case batches of pellets are loaded onto molybdenum racks and sintered sequentially. The final product is machined to the desired tolerances with pellet grinders, reinspected, and sorted into holding trays (Figure 48.5) to be fed into cladding tubes. These trays can be over 10 m long. The line of fuel pellets is inserted into zirconium or stainless steel tubes (Figure 48.6). These tubes are prefabricated and sealed at one end. Once a tube is filled with pellets, the end is welded shut, typically using

Figure 48.2. Glove box.

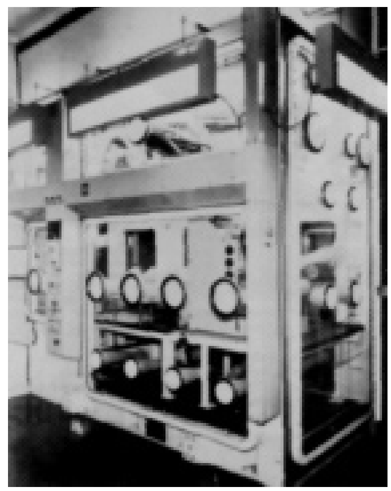

Figure 48.3. Melting and casting unit.

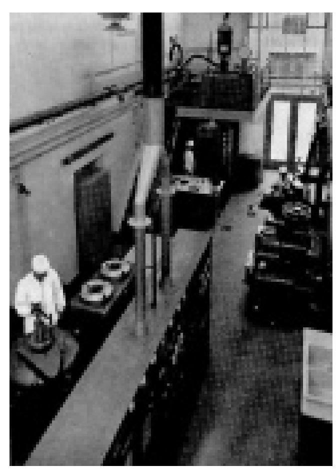

Figure 48.4. Plant for the fabrication of uranium dioxide (UO_2) pellets. Picture shows equipment for powder preparation, a hydraulic press, a sintering furnace (lower left), and pellet grinding machines (right).

an electric arc process. The closing of the open end of the tube is often done in large glove boxes under a helium atmosphere. Smaller chambers (Figure 48.7), which accommodate only the open end of the tube, can also be used; the tube is inserted into the chamber through a vacuum seal. The finished tube is inspected for leaks (using a helium leak test),

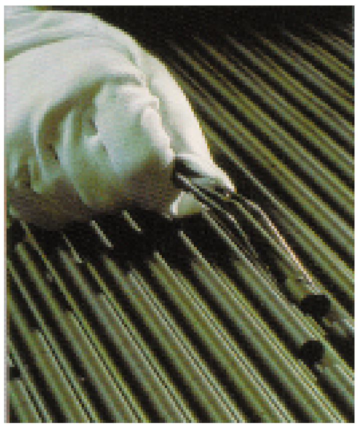

Figure 48.5. Pellets in trays.

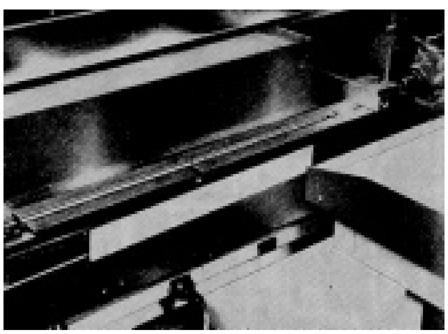

Figure 48.6. Loading a pellet column into a tube.

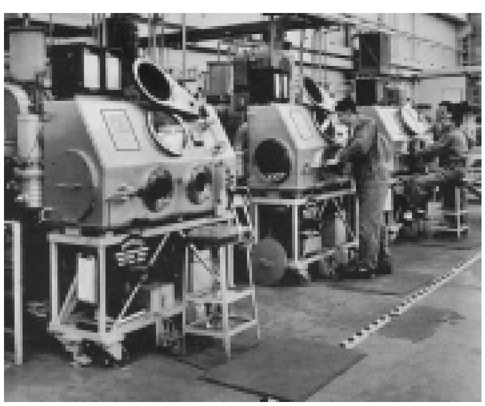

Figure 48.7. Hermetically sealed welding chambers.

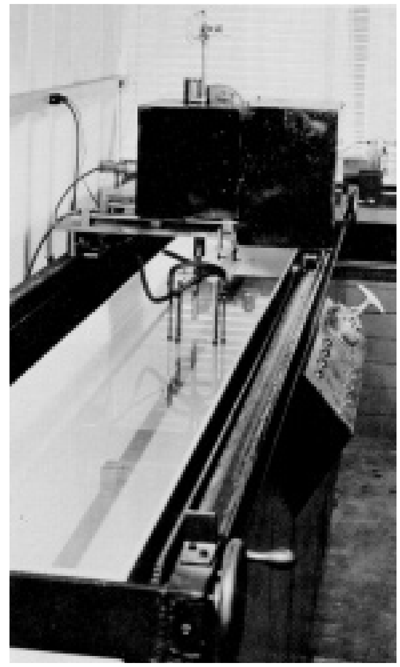

Figure 48.8. Ultrasonic inspection apparatus.

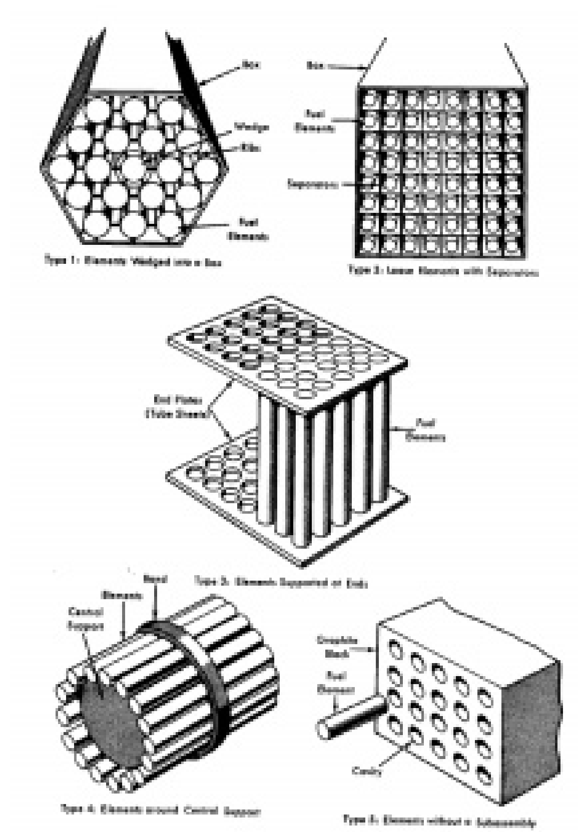

Figure 48.9. Various fuel element geometries.

corrosion resistance (using an autoclave), and/or differences in grain size and the presence of voids (using ultrasonic or X-ray testing). Ultrasonic testing apparatus is shown in Figure 48.8. Gross contamination of the outer surface of the tubes can be eliminated by surface treatment (such as pickling in sodium hydroxide or brushing in a citric acid solution). The rods, supported to prevent bending, are assembled into bundles of various geometries (Figure 48.9). Spacers are inserted and straps and end-pieces are put into place and locked together to form a complete fuel element. The fuel elements are typically enclosed in plastic and stored for shipment.

Metal Fuels. Uranium dingots ("direct ingots") are transformed into ingots by remelting in a high vacuum and by casting. Residual slag and impurities are removed during the remelting process, and the metal is given a form suitable for further processing. The melting furnaces are usually high-vacuum induction furnaces (Figures 48.10, 48.11, 48.12). Production of

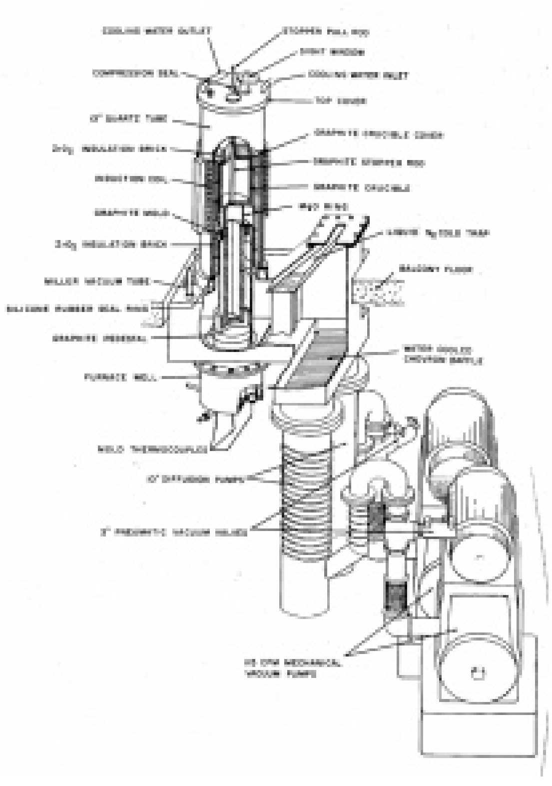

Figure 48.10. Schematic of vacuum induction furnace and associated equipment.

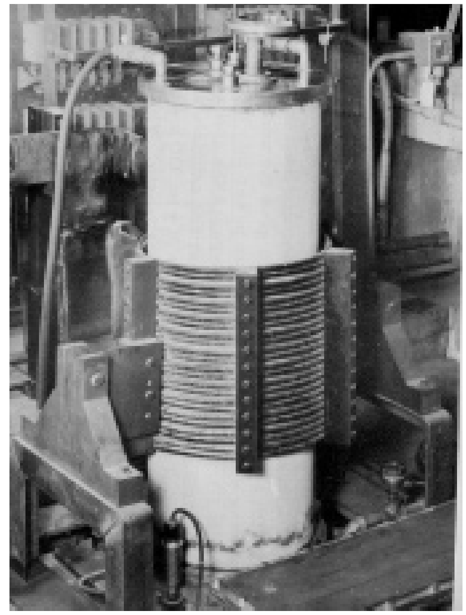

Figure 48.11. Vacuum induction furnace.

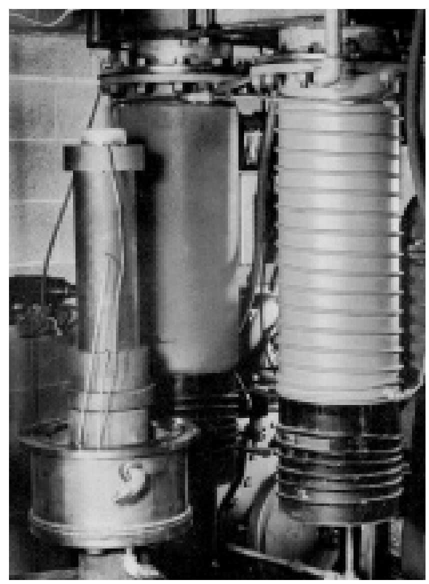

Figure 48.12. Vacuum induction furnace well and vacuum system.

the metal (or alloy) is always followed by forming. Common methods of forming include casting, extrusion, co-extrusion, and rolling. Casting can be done with top-pouring or bottom-pouring induction furnaces. The crucibles and molds (Figure 48.13) are generally graphite. In co-extrusion (Figure 48.14), deformation and canning are carried out in one operation. Rolling (Figure 48.15) is commonly used for the fabrication of plate-type fuel. The material may be preheated to rolling temperature in a salt bath. In the picture frame technique (Figure 48.16), the fuel-bearing alloy (Figures 48.17 and 48.18) is fitted into a frame, cover plates are placed on both sides, and the resulting sandwich is hot-rolled. Following forming comes machining (using grinders or lathes) and straightening (using conventional straightening machines). Heat treatment is carried out in salt baths, vacuum furnaces, or protective-gas furnaces. Salt-bath crucibles can

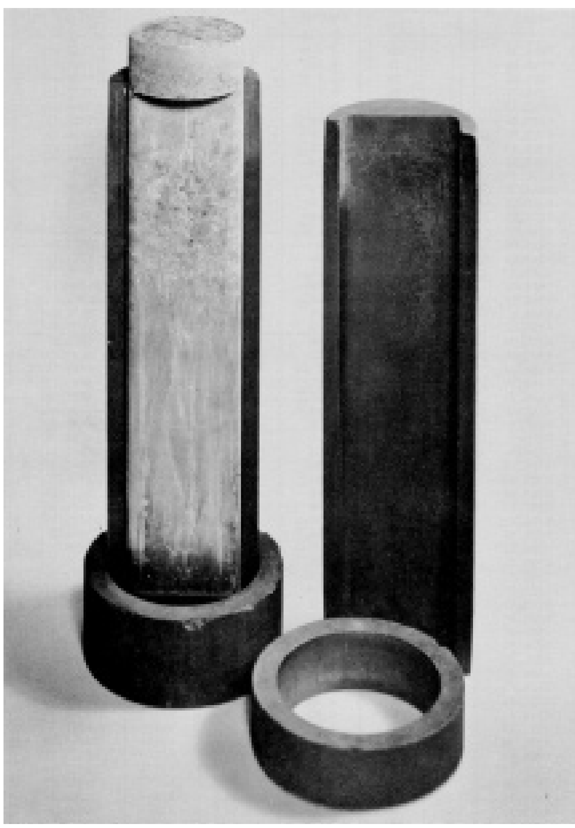

Figure 48.13. Partially disassembled mold with casting in place.

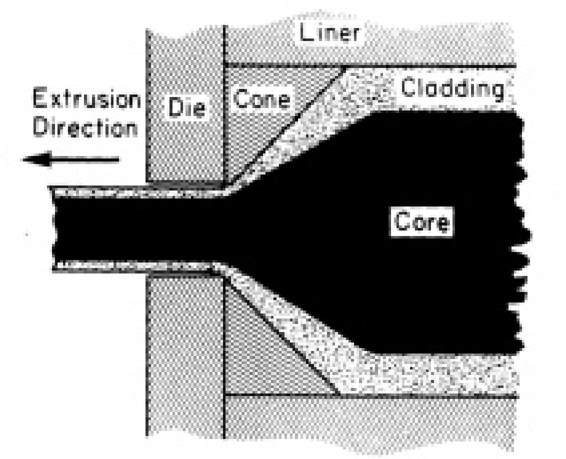

Figure 48.14. Schematic of co-extrusion process.

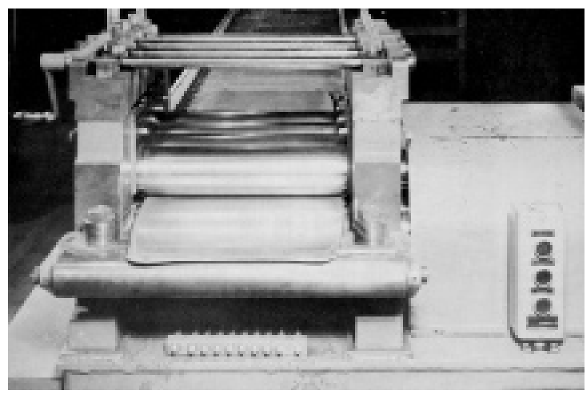

Figure 48.15. Roller leveler.

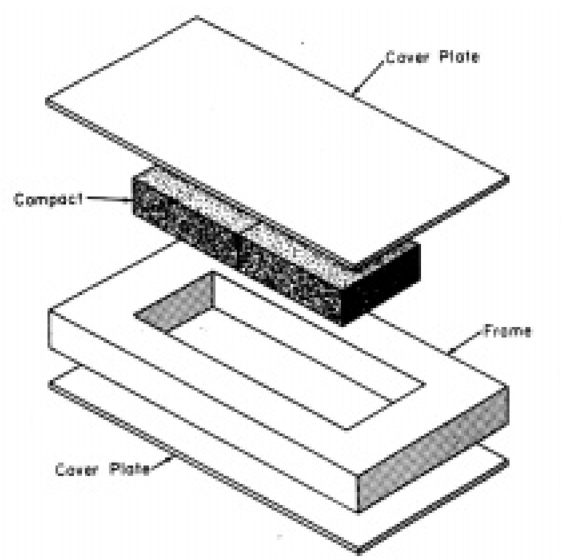

Figure 48.16. Picture frame assembly schematic.

be vertical for short (~1-m) work places, but would generally be horizontal. The surface of the fuel is then treated in preparation for canning and bonding. Electropolishing is often used for cleaning, and a bonding metal (copper or zinc) is applied to the surface by galvanic methods or by high-vacuum evaporation and deposition. Canning, testing, and surface treatment of metal rods is similar to the processes described for oxide fuels.

As Packaged: The finished fuel assemblies will be loaded into specially designed, shock-mounted shipping containers.

Glove boxes are unmistakable oblong metal skeleton structures that are bulky but not heavy. They are usually shipped apart from their panels in slatted wooden crates for assembly on-site. Internal equipment such as induction vacuum furnaces, sintering furnaces, small, cold presses, mixing devices, and the like, together with external-control and supply equipment is shipped in separate containers. They are not particularly heavy and can be hoisted by a forklift. Furnaces require external cabinets containing voltage, power and frequency control and display units. Other cabinets house monitoring and control devices for the glove-box atmosphere. These are likely to be shipped on pallets.

Cautions: Disassembly of process equipment or glove boxes presents a toxicity hazard from inhalation of uranium dust. In addition, the fine powders involved can be pyrophoric. Criticality is a concern if enriched uranium fuel is present. If recycled fuel is used, radioactivity presents a major hazard.

Nuclear Uses

Fuel-element fabrication facilities produce nuclear fuel for commercial, research, and weapons reactors.

Figure 48.17. Punching core blanks for a picture frame assembly from sheared strips.

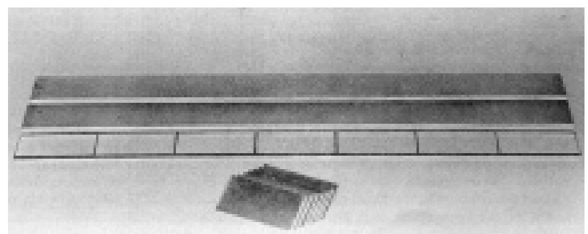

Figure 48.18. Punched core blanks and resultant trellis.

Go To Next Chapter

Back To Previous Chapter

Back To TOC