Appendix F

Supplemental Information on Hanford Fuel Fabrication

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F.1 Single Pass Reactor Fuel Fabrication

F.1.1 Fuel Canning

The original fuel canning process implemented at Hanford involved the use of an electric heater press, known by workers as the "whiz-bang," to heat and bond the uranium fuel cores to their aluminum jackets. However, the heaters burned out frequently, did not heat the elements and cans to consistent temperatures, and did not produce a uniform bonding. This problem was serious because non-uniform bonding caused thin places in the jacketing which were subject to localized heating during irradiation. These "hot spots" could cause fuel element ruptures in the reactors. By August 1944, the uranium fuel cores were being jacketed in a triple-dip method that consisted of bathing them in molten bronze, tin, and then a molten aluminum-silicon mixture. The bronze used in this process at Hanford was relatively high in tin content (53% tin and 47% copper), and the bronze bath itself had a flux cover composed of barium chloride, potassium chloride, and sodium chloride. As fuel cores were dipped into this mixture, they acquired trace coverings of all of these substances.

Initially, the bare uranium cores were cleaned by passing them through a trichloroethylene vapor degreaser. They were then passed through a nitric acid pickling tank, two rinse tanks, and a hot air dryer. Meanwhile, a steel "sleeve" that would surround each can during the dipping process was cleaned in sodium hydroxide; and aluminum end caps and cans were cleaned in a sodium dichromate solution followed by a methanol rinse. The bare uranium cores were dipped in a bronze bath to heat them to a uniform temperature within the uranium beta phase (660 °C to 770 °C). Then they were placed in a tin bath to: (1) cool them into the uranium alpha phase (less than 660 °C) and (2) to remove any excess bronze. Next they were centrifuged to throw off excess tin. Then the cores were immersed quickly in an aluminum-silicon brazing bath while in the uranium alpha phase, and water quenched. The various heating and cooling procedures were done to randomize the uranium grains, thus inhibiting the uranium "growth" (expansion under irradiation) problem. After water quenching, the steel sleeve was pulled away and cleaned with sodium hydroxide and soap to remove any remaining aluminum-silicon. The sleeve then could be reused many times. The thickness of the residual end cap on the element was then measured with a fluoroscope and marked with a punch to indicate the amount that needed to be removed in subsequent end machining. Identification numbers were stamped on the can base end, and the braze line on the end cap was tungsten inert gas welded to seal the porous braze to the end cap and can. A final etching in nitric acid completed the procedures.

Three tests followed the canning process. The first, was the frost test, which consisted of spraying the can with acenaphthene mixed with carbon tetrachloride (CCl_4). The canned element was then placed into an induction coil to heat its surface. If there was a gas bubble or a non-bonded spot, this spot would become shiny, and the element then would be rejected and sent back through a recycling process. If the bond was good, the acenaphthene was removed with trichloroethylene, and the element was heated in one

of several autoclaves located in the 314 Building. In that step, the canned element was placed into a steam autoclave, which operated at about 100 pounds per square inch gauge (psig) and 175 °C for more than 20 hours, to reveal any pinholes or incomplete welds. Water from the steam would be conducted through any such openings, and the uranium core would expand rapidly, resulting from the formation of a uranium oxide compound known as U_3O_8, and split the aluminum can. If an element passed the autoclave test it then underwent a final radiograph (X-ray) test in the 314 Building, to detect porosity in the end weld bead. Any porosity could have become a pathway for water to contact the uranium fuel and cause the element to rupture during irradiation.

F.1.2 Single Pass Fuel Fabrication Changes

In 1948, the extrusion press in the 314 Building was excessed, and Hanford began receiving rolled uranium rods from an offsite commercial mill. The rolling process seemed to offer metallurgical advantages, because the uranium could be processed at lower temperatures, which induced less oxidization and produced smaller and more random grains within the metal. From 1950 to 1951, a rolling mill was procured and installed in the 314 Building, to save the costs of shipment to offsite mills. However, this mill was relatively small, and the rolling operation was transferred to a large facility constructed at the Feed Materials Production Center (FMPC), an Atomic Energy Commission (AEC) site in Fernald, Ohio, in 1952. Thereafter, no extruding or rolling operations were conducted at Hanford in connection with the fabrication of fuel elements for single-pass reactors. The 314 Building process continued to operate for the purposes of straightening uranium rods, providing autoclave and radiograph testing of canned elements, and providing uranium scrap processing operations.

In 1954, the 313 Building underwent a major remodeling and expansion, reaching a total size of 182.5 feet by 486 feet, with a total area of 76,633 square feet. At that time, much contaminated equipment and other solid wastes from this building and its immediate surrounding area and from the 303 fresh fuel warehouses were buried. The remodeling occurred at the time that fuel canning technology in the 313 Building switched from the triple-dip process to the new lead-dip process. Lead-dip consisted of immersing the uranium fuel cores in a duplex bath (molten lead covered with molten aluminum-silicon) to preheat the cores in the uranium alpha phase. This step formed an intermetallic compound of uranium and lead (UPb or UPb_3) on the core. It was followed by a molten aluminum-silicon bath (also in the uranium alpha phase) to braze and bond the cores to the aluminum cans and caps. This process allowed the first canning bath to occur at a lower temperature (lower than 660 °C) because the uranium cores already had been beta heat treated in a molten salt bath at the FMPC. However, the new method introduced a great deal more lead and other heavy metals into 313 Building waste streams. At about the same time that the lead-dip process replaced the triple-dip method, an ultrasonic test replaced the frost test, which eliminated the use of acenaphthene and CCl_4. Concurrently, the majority of testing autoclaves were removed from the 314 Building and placed in the north end of the 313 Building.

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In the early 1960's, just before the eight single-pass reactors at Hanford began to close, experiments were under way in the 304, 3716, and 313 Buildings with a new canning procedure known as the Hot Die Size Process. Also termed the "nickel-plate" procedure, this operation plated uranium fuel cores with nickel, using nickel sulfate, nickel chloride, and boric acid. It included standard fuel fabrication cleaning, degreasing, etching, and testing chemicals and processes. Although the Hot Die Size method was tested successfully, it was not implemented on a large scale because of the impending closures of Hanford's eight original reactors.

F.2 N-Reactor Fuel Fabrication Processing

Fuel element preparation activities for the single-pass reactors ended in the 313 and 314 Buildings in 1971, when the last of these reactors closed. The 314 Building was modified in the 1970's and was used for a variety of research projects and crafts services. The majority of the fabrication equipment for single-pass reactor fuel elements was removed from the 313 Building between the mid-1970's and the mid-1980's. However, the south end of the 313 Building continued to house major functions in support of N-Reactor fuel production. Among these functions were: (1) the receiving and inspection of uranium billets and other components used to make N Reactor fuel elements, (2) the chemical passivation of spacers from N-Reactor, (3) the casting and machining of copper-silicon pre-shape components used in N-Reactor fuel elements (beginning in 1973), and, (4) the neutralization and handling of non-uranium-bearing acid wastes from N-Reactor fuel fabrication processes in the 333 Building. Finished N-Reactor fuels and fabrication components, tools, and miscellaneous supplies were stored in the north end of the 313 Building from 1971 to 1987, and an Engineering Development Laboratory, including facilities for working with uranium, was established in this structure in the 1970's.

F.2.1 N-Reactor Fuel Fabrication

The fuel-making process for the New Production Reactor (N-Reactor) was very different from that used to make fuel for single-pass reactors. Soon after funding was secured for N-Reactor in 1958, a high-pressure heat transfer apparatus was emplaced in the 189/190-D Building, a converted World War II pumphouse in the Site's 100-D Area. Its purpose was to test a new, N-Reactor fuel concept being developed in the 306 Metallurgical Pilot Plant, a 300 Area building dedicated to fuel manufacturing experimentation. The concept first tried for N-Reactor fuel was a wire-wrapped, seven-element cluster of long, thin fuel rods spaced together in a horizontal flow tube. Each individual element was only 0.625 to 0.704 inches in diameter, and was 35 to 45 inches long. However, attention soon turned to yet another new concept developed in the 306 Building. This idea, of a co-extruded tube-in-tube fuel element design, eventually was adopted for N-Reactor.

F.2.2 Co-Extrusion Process

The co-extrusion process began with inspection and cleaning of copper and copper-silicon pre-shapes and backing plates used in the process. The cleansing agents were nitric acid, nitric hydrofluoric, and chromic nitric sulfuric acid. Next, cladding components made from Zircaloy-2™ were degreased, rinsed in nitric and hydrofluoric acid, and dried with forced-air heating. In the meantime, uranium billets were degreased with perchloroethylene, etched with nitric acid, rinsed, dried and inspected. Next, the copper, copper-silicon, Zircaloy-2™, and uranium components were assembled and welded into a billet assembly. This assembly was evacuated of air, leak tested, sealed preheated, and then co-extruded (squeezed together) in the Loewry Press. As the process specifications for this step emphasized: "The quality of the extruded tube is dependent upon many things, not the least of which is skill, care, effort, and precision that are put into the co-extrusion operation."

The process of cleaning, degreasing, etching and drying components, then assembling and pressing them, was repeated for both the outer (larger) and inner (smaller) tubes that made up the tube-in-tube configuration. The extruded tubes then exited the press to a roll-out table where they were rolled continuously for at least six minutes to prevent tube deformation and non-uniform cooling. Next they were sectioned to the specified length, and the ends were machined to create fuel sections or elements. Nitric acid was used to remove copper silicon residues, and nitric sulfuric acid was used to chemically mill (i.e., dissolve away) excess uranium on fuel element ends. Elements then were etched with nitric hydrofluoric and nitric acid, and brazed with an etched braze ring material consisting of Zircaloy-2™ alloyed with about five percent beryllium. (This braze material previously had been degreased and etched.) The brazed elements were heat-treated in a molten salt bath to randomize the uranium grain structure to prevent preferential grain growth that could rupture the elements in the reactor.

The next step in the process was to weld projections or supports onto the fuel elements. Eight lengthwise protrusions were attached to the outer surface of each fuel element, evenly spaced around its diameter. This configuration allowed cooling water to circulate optimally around the elements, without creating hot spots where the sides of elements rested too close to the inner walls of the process tubes. After projections were welded onto the elements, the two tubes (inner and outer) had to be attached together. Support hardware was attached to the outer surface of the inner tube, and locking hardware was affixed to the inner surface of the outer tube. The two tubes were then given a final nitric hydrofluoric acid etch, separately tested in autoclaves, inspected, assembled and interlocked, and stored as finished fuel. The co-extrusion process was carried out continuously in the 333 Building from 1960 until December 1986, reaching a peak volume of approximately 250 finished fuel elements per week in the mid-1980s.

Worker exposure to uranium was controlled. Machining and other fines-producing fabrication activities were conducted within ventilated enclosures. Air exhausted from these enclosures was filtered. Uranium scrap recovery activities such as burning in a controlled atmosphere incinerator, while providing a higher potential for worker uranium

uptake, were limited in scope. Additionally, due to transportation issues with untreated scrap, much of the scrap was processed to a recoverable wet sodium diuranate cake before shipment offsite. Some low concentration liquid wastes were discharged to ponds and cribs for disposal. Dry wastes were packaged and sent to the Hanford waste burial sites for disposal.

F.3 Material Sources

A number of private contractors were involved with the early fuel fabrication operations. B&T Metals of Columbus, Ohio, extruded a large quantity of uranium metal rods for Hanford from April through August 1943. Copperweld Steel Company of Warren, Ohio out-gassed and straightened a large quantity of uranium rods for the reactors between May and August 1943. Revere Copper & Brass also out-gassed and straightened rods in Detroit. Hanford began out-gassing and straightening its own uranium fuel rods in September, 1944. Baker Brothers of Toledo, Ohio, manufactured unbonded uranium slugs for Hanford from early 1944 through July, 1944. The William E. Pratt Manufacturing Company turned and ground unbonded slugs in the spring of 1944. Between May and August of 1944, McKinney Tool and Manufacturing in Cleveland, Ohio turned and ground unbonded slugs. During the late 1940s and early 1950s, uranium rods were rolled or extruded by Vulcan Crucible Steel Company in Aliquippa, PA, Revere Copper and Brass, and the Brush Beryllium Company in Detroit, Joslyn Manufacturing & Supply Company in Fort Wayne, Indiana, Allegheny-Ludlum Steel Corporation in Watterville, New York, and Simonds Saw & Steel Co. of Lockport, NY.

Hanford stopped extruding uranium rods in 1948, switching to rolled rods on site. The AEC shifted the rolling work to the Fernald, Ohio Feed Materials Production Center and it supporting contractors in 1952.

Uranium slug machining was taken over by FMPC at Fernald Ohio, which opened in 1952, and the Weldon Spring plant which opened in 1956. FMPC and Weldon Spring produced ingots of natural, low enriched and depleted uranium to be extruded offsite into tubes and billets for further machining into uranium cores. The cores were then shipped to Hanford for cladding and assembly. The ingots were extruded into tubular billets by Bridgeport Brass Company in Adrian, MI from 1954 to 1961 and later by its corporate successor, Reactive Metals, Inc., in Ashtabula, Ohio. Fernald then shipped the billets to Hanford.

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F.4 References (This entire Appendix is supported by one or more of the following general references.)

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