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A CLOSER LOOK AT URANIUM METAL PRODUCTION

03/01/88

WEMCO/DOE
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REPORT

A CLOSER LOOK AT URANIUM METAL PRODUCTION

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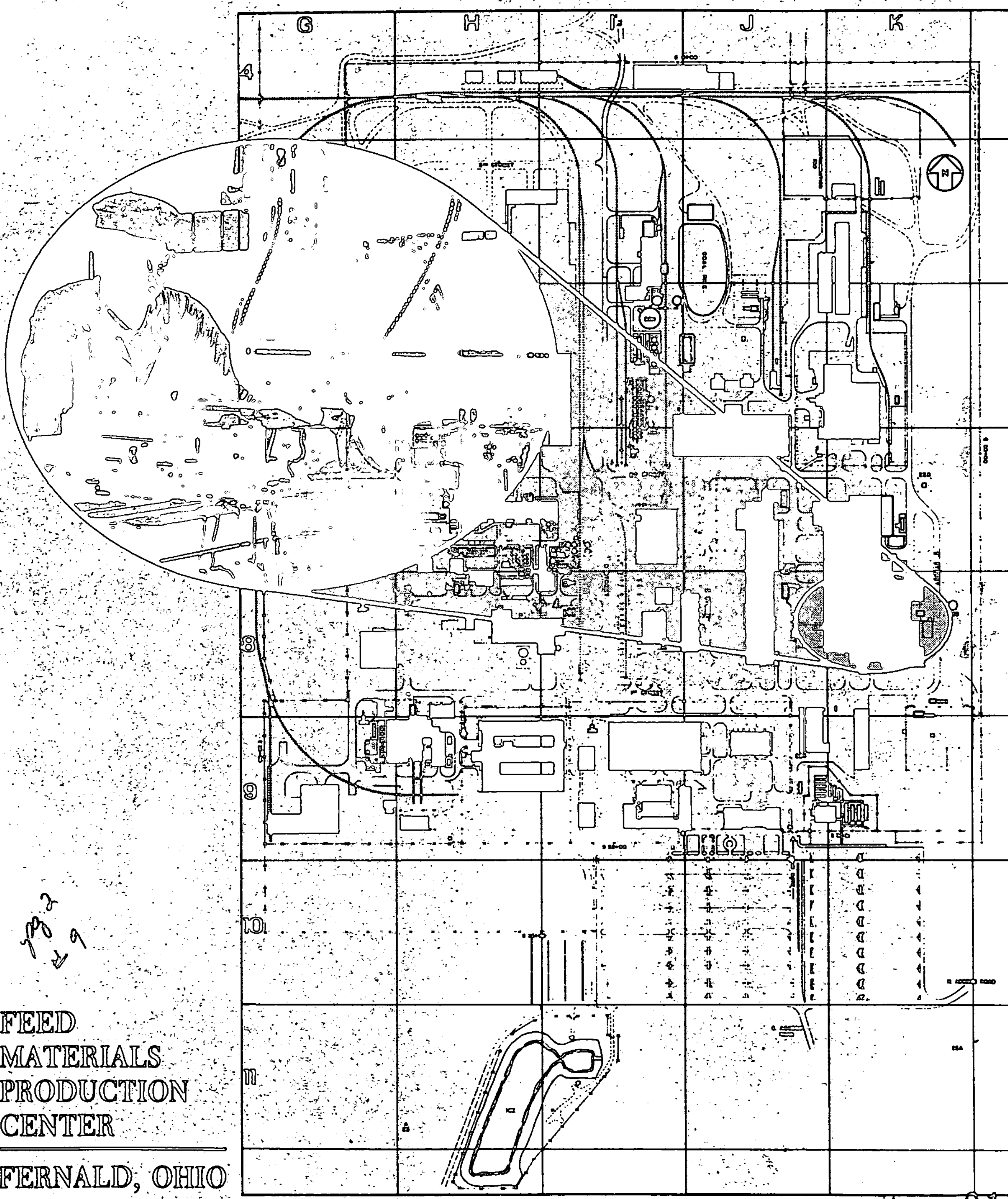
A TECHNICAL OVERVIEW



FEED MATERIALS PRODUCTION CENTER

FERNALD, OHIO

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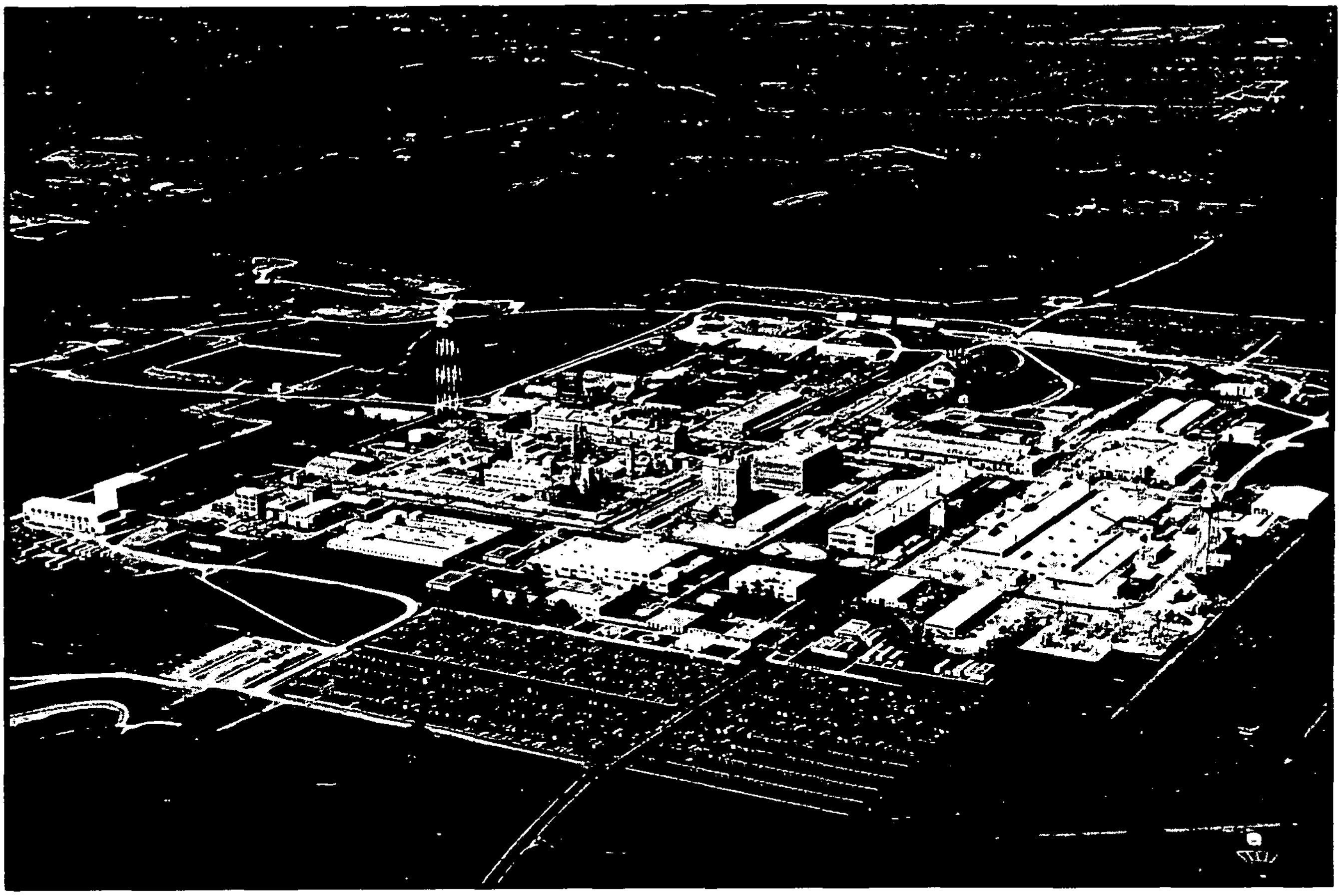
NOTICE

Date of Issue: March 1988



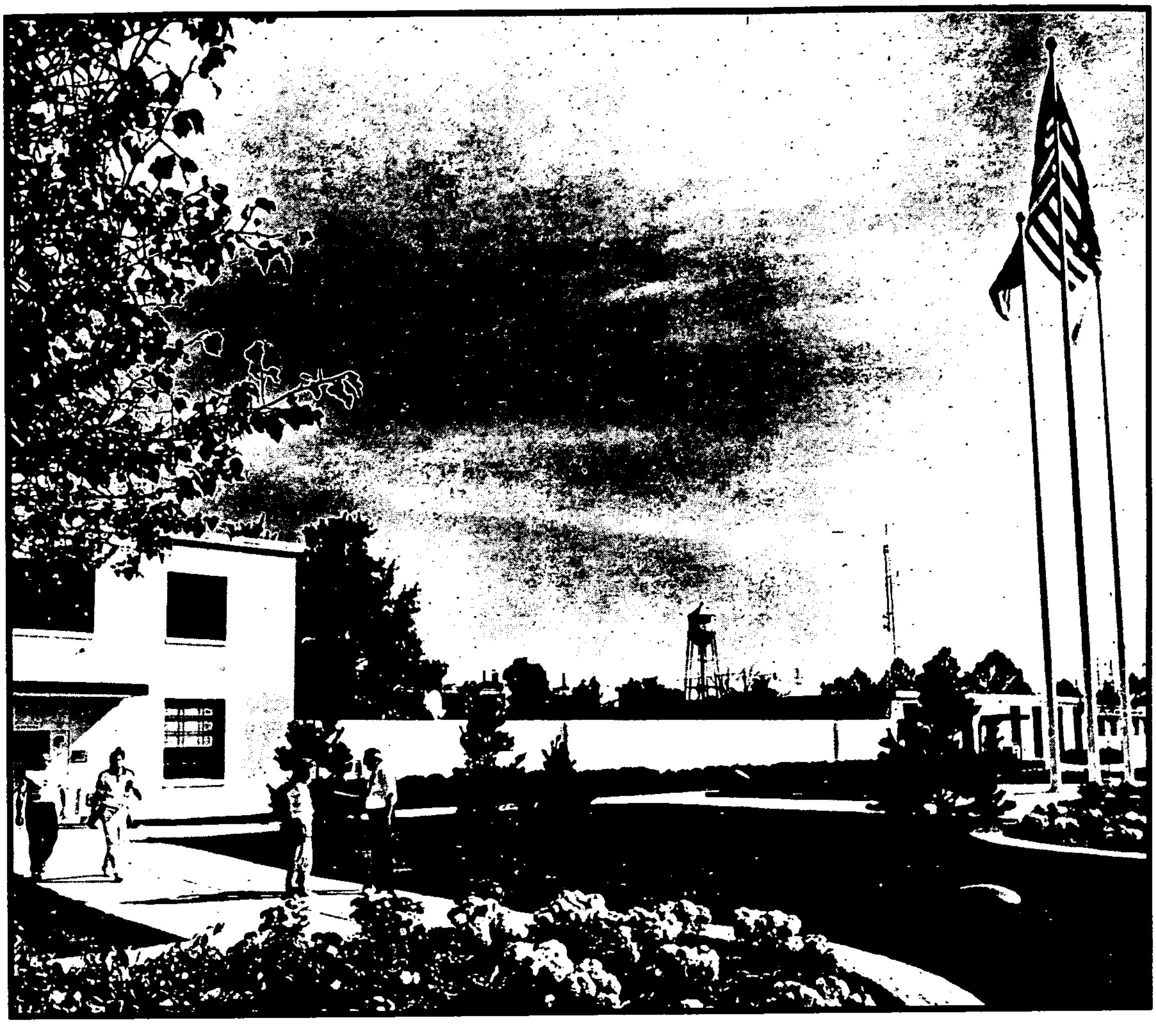
The Feed Materials Production Center, located 17 miles northwest of Cincinnati, is a government-owned, contractor-operated facility for producing uranium metal products. Production plants and administrative buildings cover 136 acres of the 1,050-acre site.

The Feed Materials Production Center

The Feed Materials Production Center (FMPC) is a large-scale, integrated facility that produces uranium metal products used as feed materials in U.S. Department of Energy (DOE) defense programs. These products include derbies, ingots, billets, and fuel cores. FMPC does not produce or handle explosive devices, nuclear weapons, or highly radioactive materials. Since January 1, 1986, the Westinghouse Materials Company of Ohio (WMCO) has operated the facility under prime contract for DOE.

Making uranium metal is a complex process. The purpose of this booklet is to provide a technical overview of FMPC's production process and to outline the role of each specialized plant in the process.

FMPC is implementing strict modern standards for health, safety, and environmental protection. All upgrades and planned improvements are designed to bring the 35-year-old facility in line with new operating standards. FMPC has been working hard not only to meet these standards for production safety and waste management but also to surpass them whenever possible. In conjunction with State and Federal officials, FMPC is committed to producing high-quality uranium metal safely and efficiently.



The Feed Materials Production Center is owned by the U.S. Department of Energy and operated by Westinghouse Materials Company of Ohio. For additional information about FMPC, contact either DOE or WMCO.

Addresses

U.S. Department of Energy
Feed Materials Production Center
P.O. Box 398705
Cincinnati, OH 45239-8705
Phone: (513) 738-6357

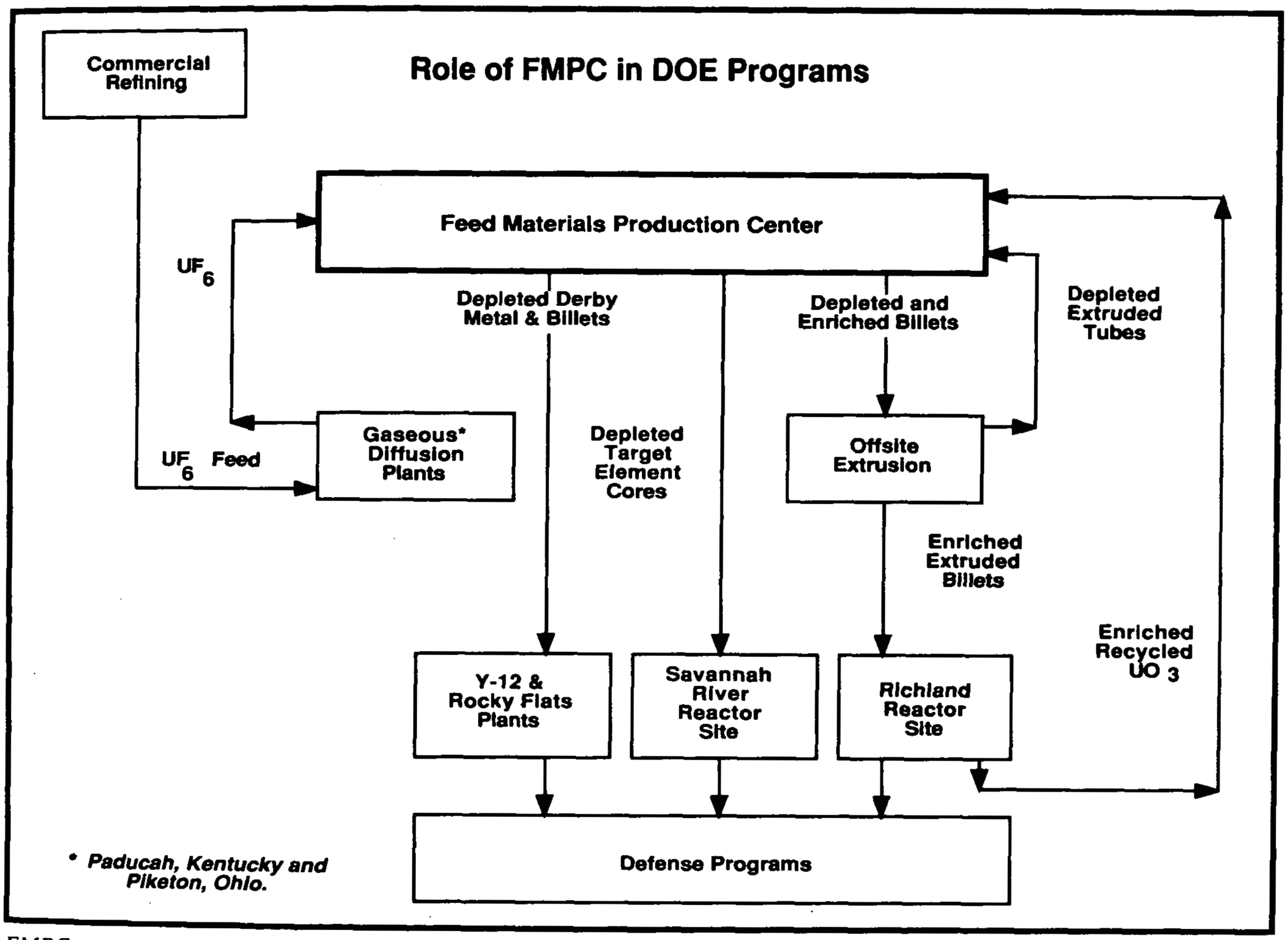
Westinghouse Materials Company of Ohio
P.O. Box 398704
Cincinnati, OH 45239-8704
Phone: (513) 738-6200

Contents

Principal Products

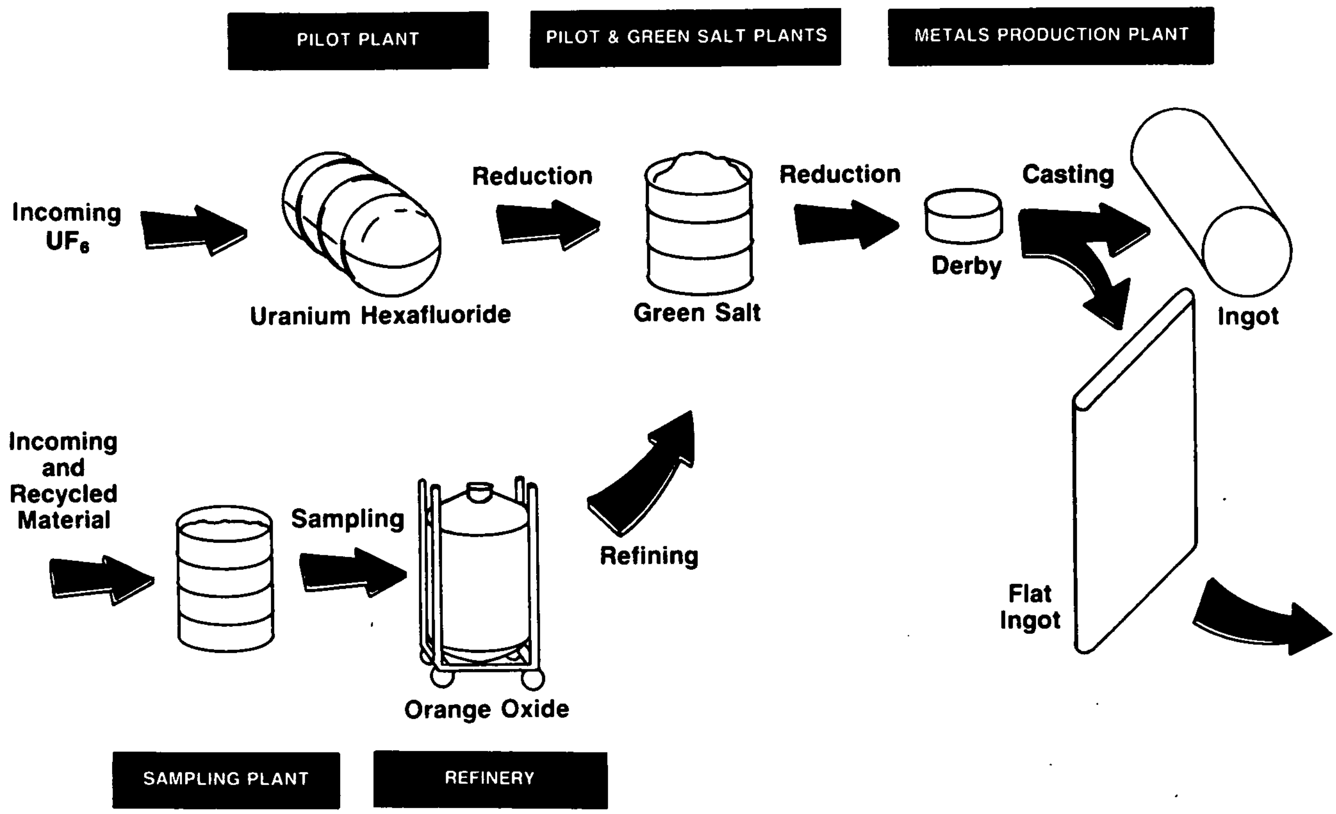
FMPC's principal products are variously sized, highly purified uranium metal forms of assorted standard isotopic assays. Producing uranium metal requires a series of chemical and metallurgical conversions that occur in nine specialized plants onsite. The finished metal products are then shipped to Rocky Flats, Colorado; Savannah River, South Carolina; Oak Ridge, Tennessee; and Hanford, Washington, for DOE use.

Fuel cores, one of several FMPC finished products, are carefully inspected before shipment to other DOE sites. Other products include derbies and cylindrical and flat billets.



FMPC manufactures uranium metal products for use in DOE's national defense programs.

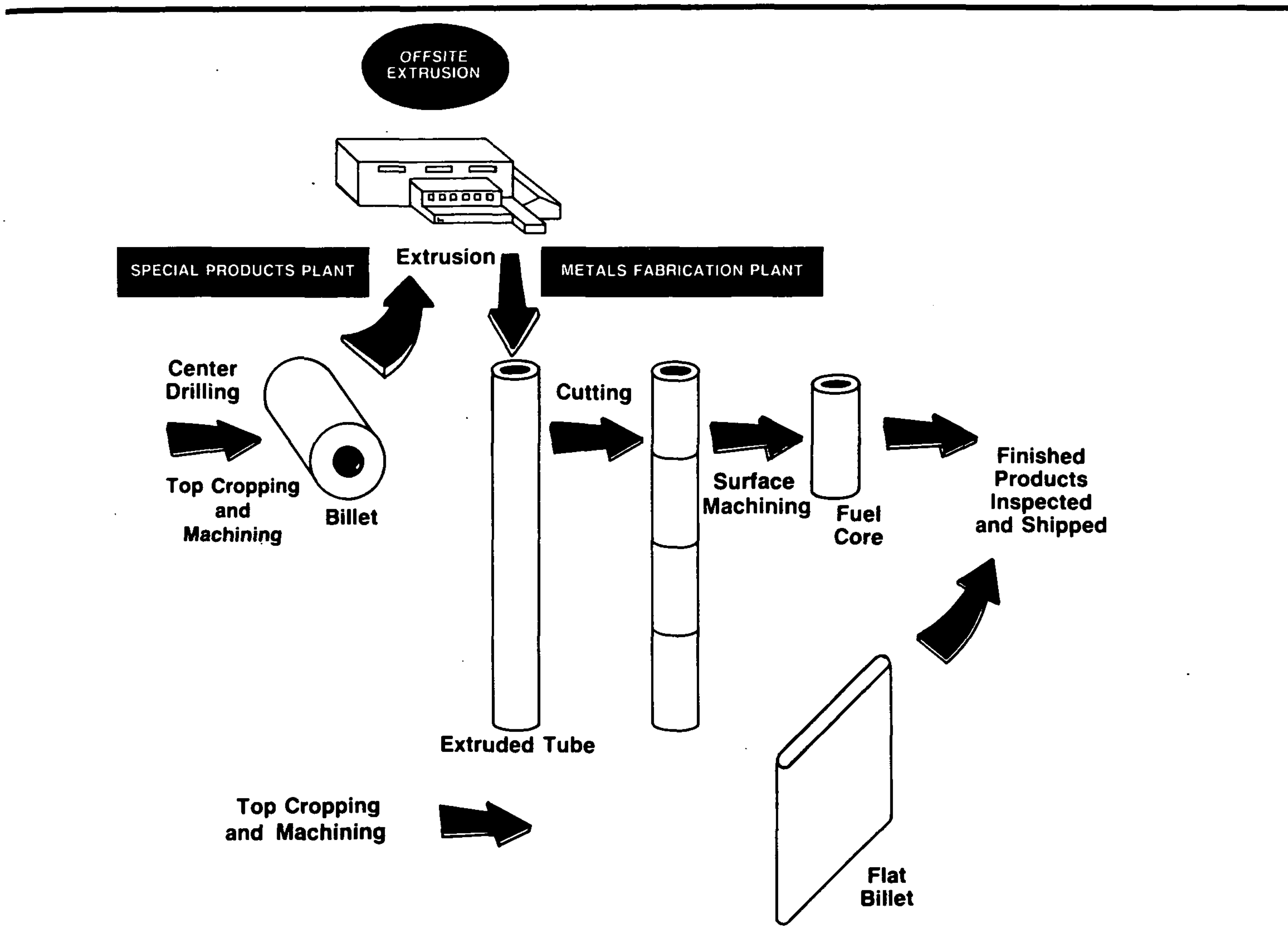
Production Process at FMPC



The Production Process

The production process at FMPC begins with the purification of uranium contained in materials that are recycled from production and are received from other DOE sites. Scrap metals generated onsite or received from other sources are also refined for production. Heating the materials in a furnace upgrades them to chemical processing requirements.

Initially, the materials from the Sampling Plant are dissolved in nitric acid to produce a crude uranyl nitrate solution (UNH) for solvent extraction purification. Purified UNH is concentrated by evaporation and is thermally denitrated to uranium trioxide (UO_3), or orange oxide. Orange oxide is then converted to uranium tetrafluoride (UF_4), or green salt, for reduction to metal. Green salt is also produced at FMPC from uranium hexafluoride (UF_6) received from other DOE sites.



To begin metal production, UF_4 is blended with magnesium granules and placed in a closed reduction pot. The reduction pot is heated in a furnace until the contents react to produce uranium metal shaped in forms called derbies, weighing 136 to 168 kg. Some derbies are sent directly to other DOE sites; most, however, are cast into ingots at FMPC.

Ingots are formed by melting derbies, along with metallic scrap and briquettes recycled from earlier production and fabrications, in a graphite crucible in a vacuum induction furnace. When the molten metal reaches the proper temperature, it is bottom poured into a graphite mold to form ingots.

Ingots vary in weight, size, and shape according to how they will be used. Since the late 1960s, all cylindrical ingots have been center drilled at FMPC and sent offsite for extrusion (the process of forming metal into tubes). Most of these extruded tubes are returned to FMPC for heat treatment and final machining before they are again shipped offsite for use at other DOE sites.

Plant by Plant Process Flow

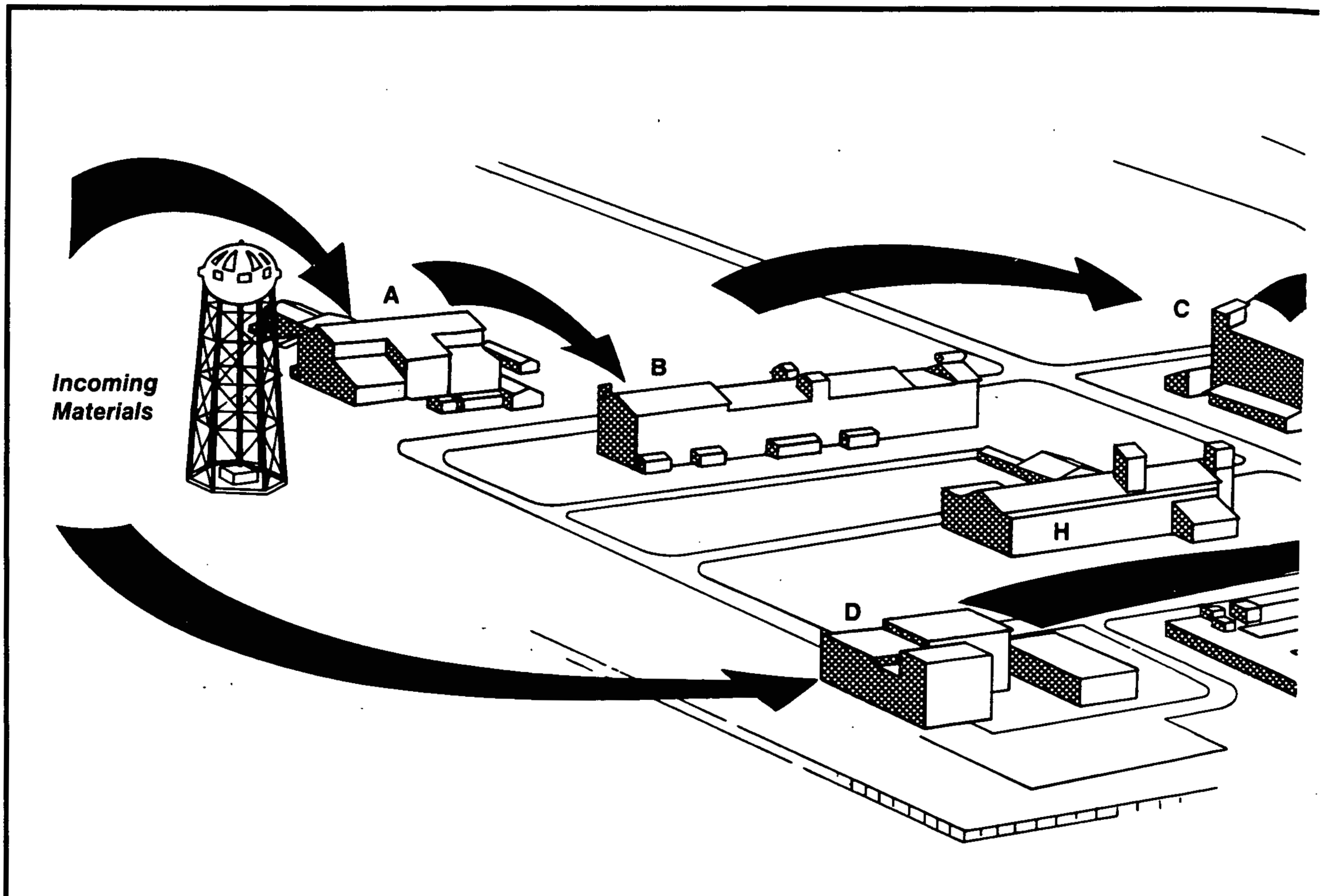
A. **Plant 1 – The Sampling Plant:** Incoming materials are sampled and analyzed for uranium content.

B. **Plant 2/3 – The Refinery:** Uranium is recovered from recycled materials and converted to high-purity UO_3.

C. **Plant 4 – The Green Salt Plant:** The UO_3 is treated to form uranium dioxide (UO_2), or brown oxide. The UO_2 is converted to UF_4.

D. **Pilot Plant – The UF_6 to UF_4 Reduction Plant:** As an alternative method of producing UF_4 (green salt), incoming UF_6 from other DOE facilities is reduced to UF_4.

E. **Plant 5 – The Metals Production Plant:** The UF_4 is converted to uranium metal derbies. Some derbies are melted to form ingots.

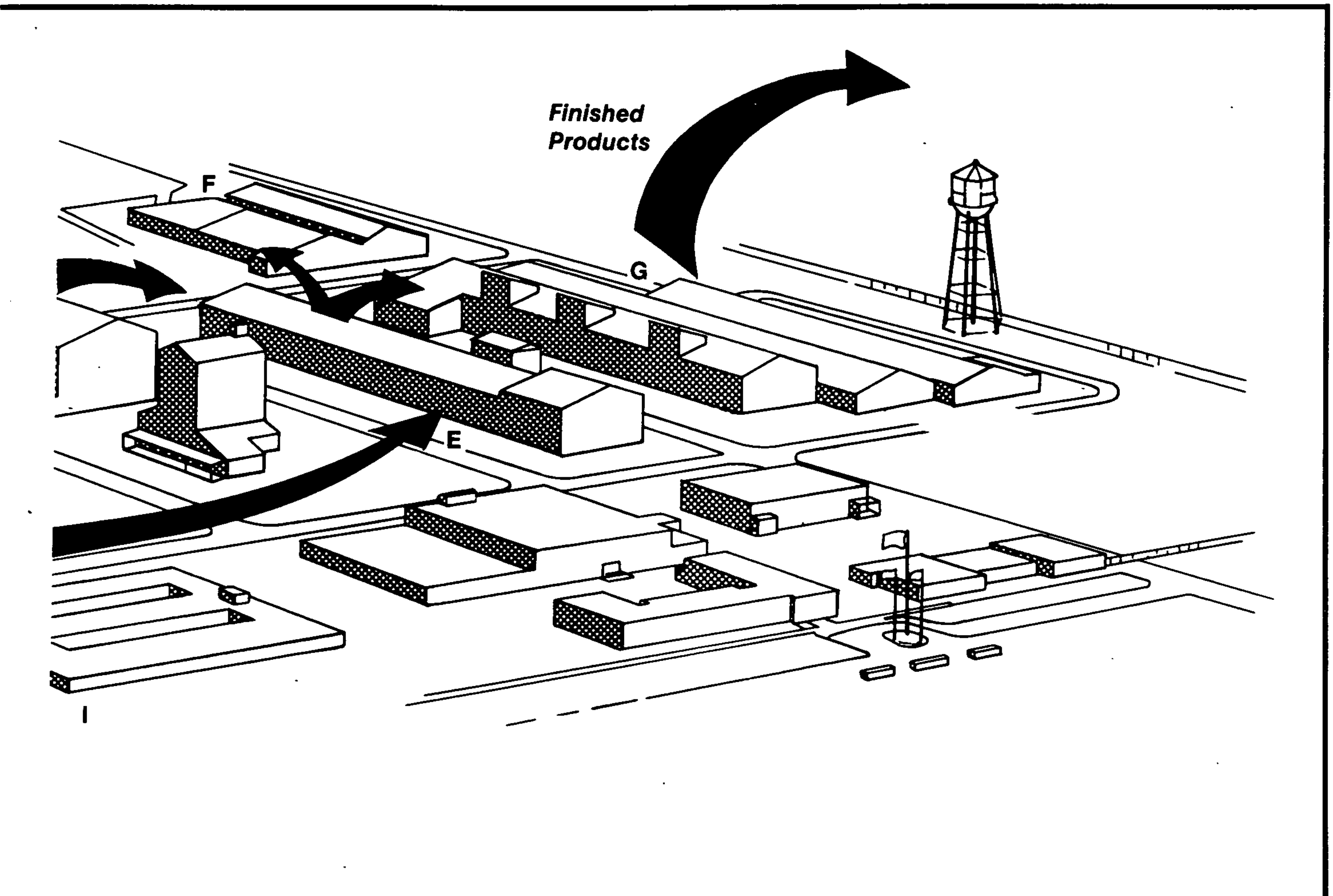


F. **Plant 9 – The Special Products Plant:** Special oversized ingots are cast from derbies and recycled metal. Ingots are machined into billets.

G. **Plant 6 – The Metals Fabrication Plant:** Billets are heat treated for offsite extrusion. Final machining, inspection, and shipping of finished products are carried out.

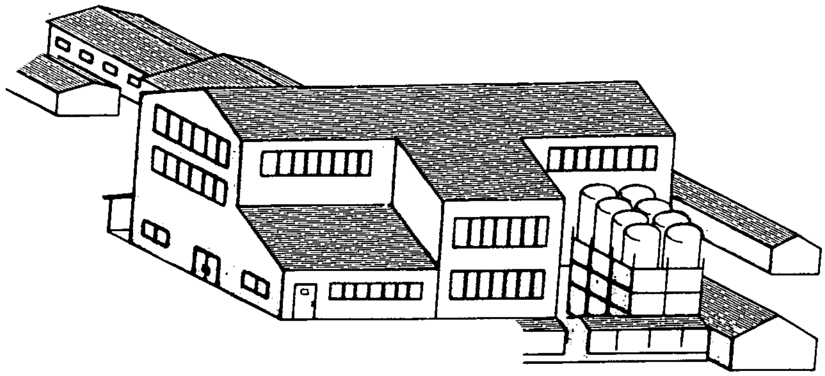
H. **Plant 8 – The Scrap Recovery Plant:** Metal scraps remaining from production are recycled by roasting and filtering.

I. **Analytical Laboratory:** Samples of materials are tested and analyzed throughout the production process to ensure that final products are of the highest quality.



Plant 1

The Sampling Plant



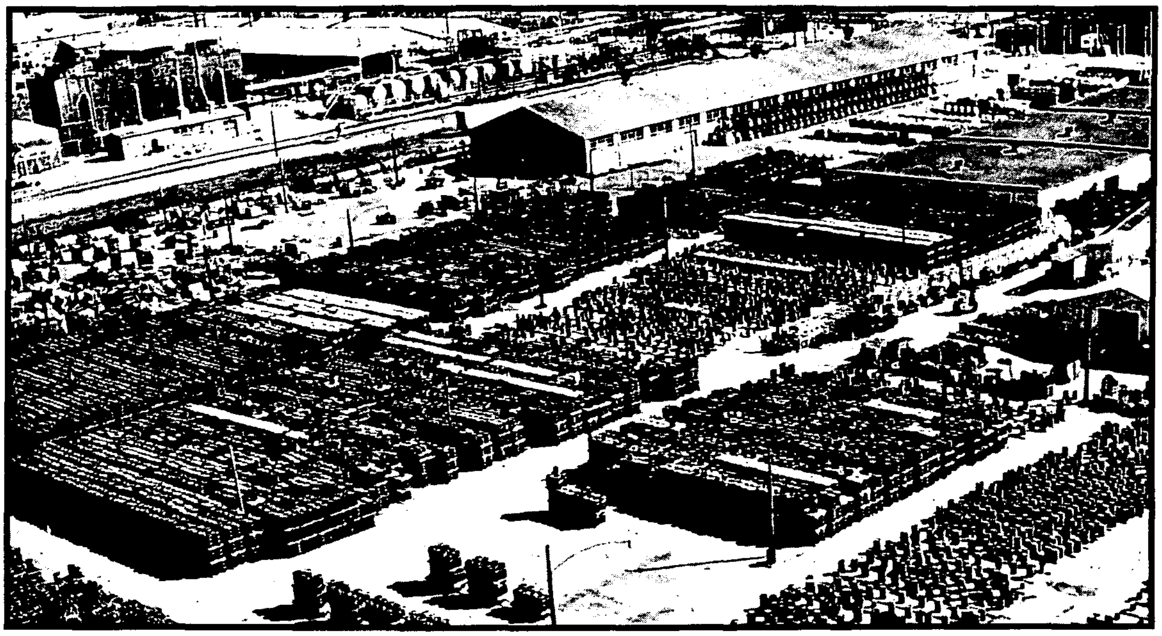
The **Sampling Plant** supports operations throughout the site. Today, personnel in the Sampling Plant weigh and sample recycled material generated at FMPC and received from offsite. These samples enable personnel to establish nuclear materials control data for accountability and control of fissionable materials processed at FMPC. The Sampling Plant also houses nondestructive isotopic verification equipment developed by FMPC. This equipment determines the assay of materials for long-term storage and eventual processing and verifies the nuclear materials control data.

Sampling Plant functions include the following:

- shipping, receiving, sampling, and storing large amounts of depleted, normal, and enriched uranium materials in open and covered storage areas
- drying, crushing, milling, grinding, and classifying feed materials for FMPC processing
- reconditioning steel drums for reuse and baling deteriorated drums
- digesting enriched feed materials assaying up to 5% uranium-235 (U-235) in geometrically safe equipment.

At one time, the principal function of the Sampling Plant was to obtain representative samples of the large quantities of incoming ore concentrates. Recently, however, the primary function of the Sampling Plant has been to store recycled materials until they are needed by the production plants. In addition, the Sampling Plant grinds enriched-uranium-contaminated slag and selected recycled materials in a ring-roller mill for chemical processing to UO_3 in the Refinery (Plant 2/3).

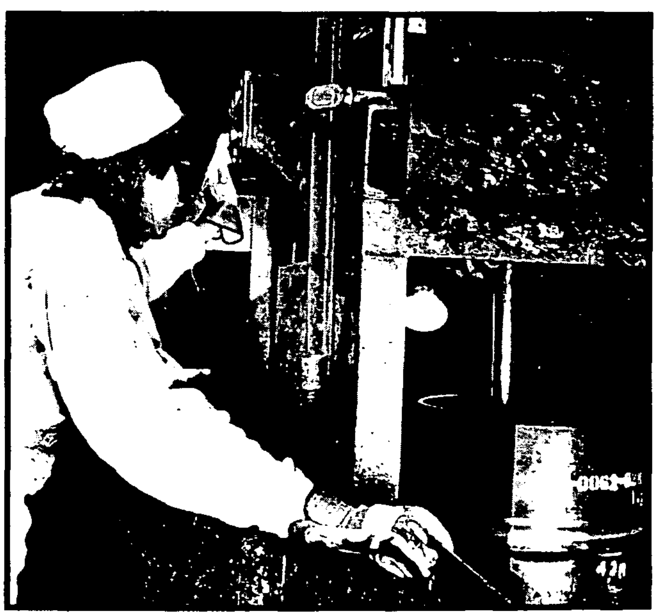
The Sampling Plant has over 19,045 m^2 of storage space, of which 3,879 m^2 is under roof. The remaining area is open-pad and fenced in for storage. Several large-scale systems, still present in the plant from its early days of operation, have



Depending on their uranium content, drummed materials like these will be recycled in production or processed for offsite disposal.

a combined capacity for crushing, grinding, and blending more than 9.1 metric tons/hr. of solid material.

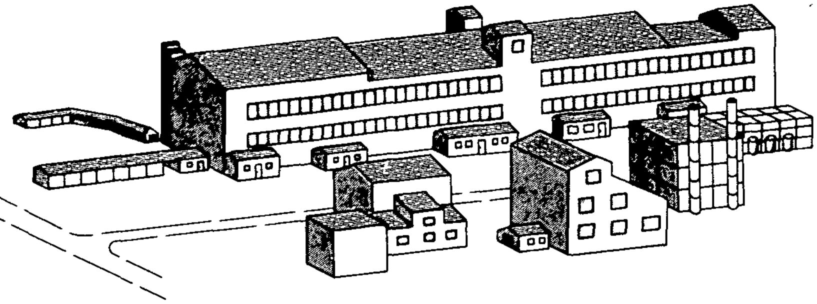
In 1970, FMPC installed a safe-geometry digestion system to process enriched uranium materials assaying up to 5% U-235. The system, employing the safe-diameter concept for all process vessels, has operated intermittently during the last several years.



Samples are analyzed to determine the uranium content of the materials in each drum.

The Sampling Plant also reconditions 30 and 55 gallon drums that are used to transport and store process materials onsite. First, dents are removed, and the chimes, the ring-like protrusions around the barrels, are regrooved. Drums are then sent to the shot blaster where they are bombarded with small pieces of steel shot to remove rust, paint, and other materials down to the bare metal. Afterward, drums are visually inspected for holes, rims out-of-round, or dents that could cause later structural failure. Drums that fail this inspection are scrapped. If a drum can be reconditioned, its exterior is painted with a water-based paint and its interior with a clear water-based lacquer. Newly painted drums are dried in a furnace, after which they are ready for the onsite transportation and storage of process materials. Only new drums are used to ship waste offsite.

Plant 2/3
The Refinery



At one time, the **Refinery** converted the Government stockpile of natural uranium ore concentrates to UO_3. Today, the Refinery operates intermittently on a sequential campaign mode to convert enriched recycled materials to oxide. The primary functions of the Refinery include the following:

- digesting recycled materials in nitric acid, using large stainless steel tanks and conveying equipment
- recovering uranium from internal process wastes, including uranium-contaminated slag
- performing liquid-liquid countercurrent solvent extraction in stainless steel, perforated-plate columns for purification
- recovering nitric acid from nitrogen oxide (NO_x) discharges from the digestion and denitration operations
- calcining the concentrated uranium liquor to UO_3 in denitration pots.

The three steps in the process of converting recycled materials to UO_3 are digestion, extraction, and denitration. In the digestion step, the recycled materials are conveyed into agitating tanks for digestion in nitric acid. The resulting slurry consists of acid insolubles and a digest liquor of impure uranyl nitrate and excess nitric acid. Following a check for proper concentration of the solution, the slurry is analyzed and pumped to the extraction system. Low-grade uranium slurries must be filtered and evaporated before they are transferred into pulsed, perforated-plate extraction columns that are 33 cm in diameter and 7.6 m high with 5.1 cm plate spacing. The plate perforations are 0.5 cm, and the columns are 5.1 cm on center and have 23% void space.

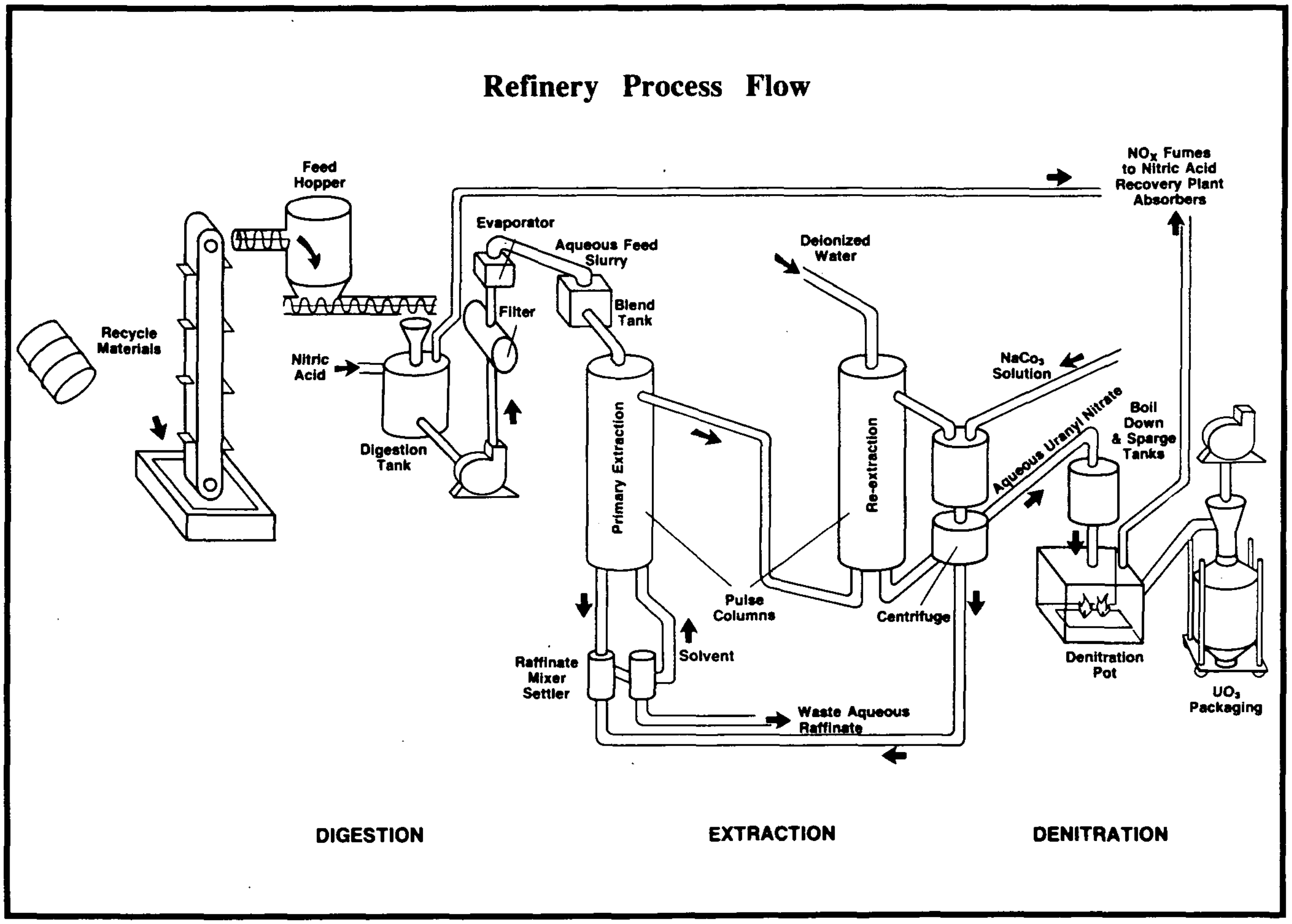
In the primary extraction step, the aqueous feed slurry and an organic solvent — a mixture of tributyl phosphate and kerosene — enter the first column from opposite ends. They are pumped countercurrent to one another in a pulsating manner through a large number of perforated plates. This plate arrangement increases the turbulence within the column, forcing the two liquids to mix thoroughly. In the presence of nitric acid, the uranyl nitrate in the feed slurry is preferentially attracted to the organic solvent. Most of the nitric acid and impurities are left behind in what is called the aqueous raffinate. A raffinate mixer-settler is used in series with the primary extraction columns to further reduce the uranium content of the aqueous waste stream leaving these columns.

The purified uranyl nitrate is recovered from the organic solvent stream by re-extraction with deionized water in parallel columns (56 and 66 cm inner diameter). Inside the columns are perforated plates with 0.32-cm-diameter holes. In the absence of nitric acid, the uranyl nitrate contained in the solvent is preferentially attracted to the water phase. After the solution is treated with a sodium carbonate solution to remove degradation products, the stripped solvent stream is reacidified and recycled to the primary extraction columns. Employes sample and analyze the aqueous uranyl nitrate product to ensure that it conforms to strict chemical specifications.

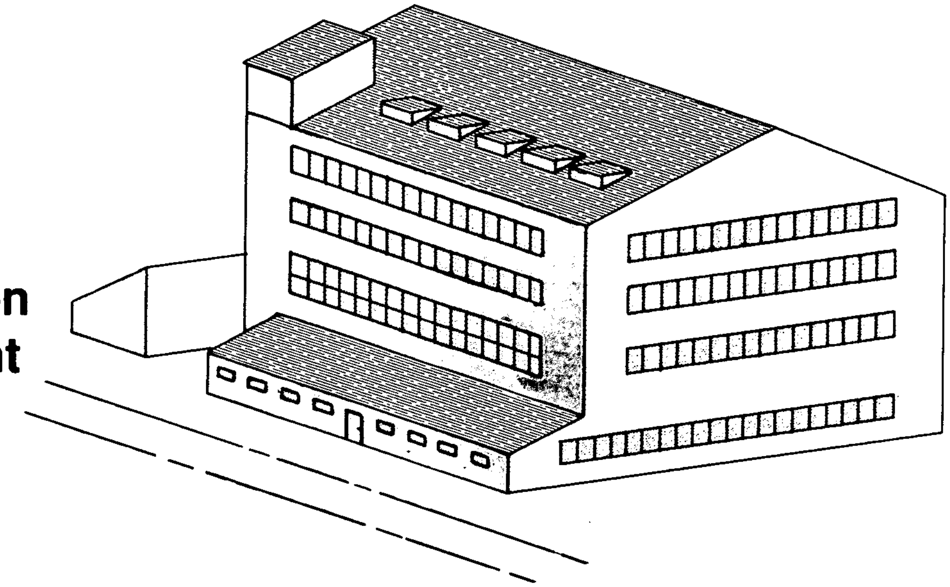
This aqueous uranyl nitrate product begins the denitration step at a concentration of about 100 g/l U. The aqueous product is then concentrated by boiling and evaporation to about 1,350 g/l U. The product is calcined in batches in nominal 1,900 liter denitration pots to yield UO_3, the end product of the Refinery. The UO_3 is milled and packaged into hoppers with a capacity of 3.6 metric tons each or into 55 gallon drums.

The Nitric Acid Recovery Plant operates in conjunction with the Refinery to recover nitric acid from the NO_x fumes generated in digestion, denitration, and other Refinery processes. The acid is returned to the digestion area for reuse, which reduces operating costs by saving acid and also reduces the potential for environmental damage.

Uranium in the aqueous waste streams from the solvent treatment and cleanout operations is precipitated with magnesia and reclaimed. Extraction raffinate and other low-level uranium wastes are neutralized with lime before they are processed for disposal.



Refining uranium involves three steps: digestion, extraction, and denitration. Orange oxide (UO_3) is the resulting product.



Plant 4
The Green Salt Plant

The **Green Salt Plant**, the common name for Plant 4, produces green salt (UF_4) from UO_3. Green salt is the key intermediate compound in the overall process of producing uranium metal. The UO_3 is either produced in the Refinery or recycled from other DOE sites. The primary functions of the Green Salt Plant include the following:

- converting UO_3 to UF_4 in continuous-flow reactor banks designed and staged for gas-solids reactions
- blending and packaging depleted green salt for the Metals Production Plant (Plant 5).

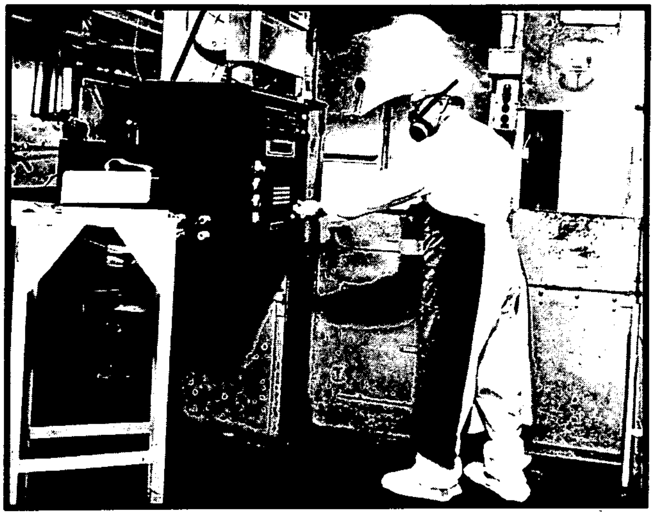
In the Green Salt Plant, UO_3 is first converted to uranium dioxide (UO_2), or brown oxide, by reducing it with hydrogen. The UO_2 is then reacted with anhydrous hydrogen fluoride (AHF) to produce UF_4. The UO_3 recycled from the reactor sites undergoes double pass reduction-oxidation-reduction (R-O-R) processing to yield high purity UF_4.

At the beginning of the process, UO_3 is delivered in mobile hoppers to stainless steel fluid bed reactors. These reactors are heated in the range of 529° to 593°C. Dissociated ammonia (H_2 and N_2) enters the bottom of the reactor through a gas diffuser.

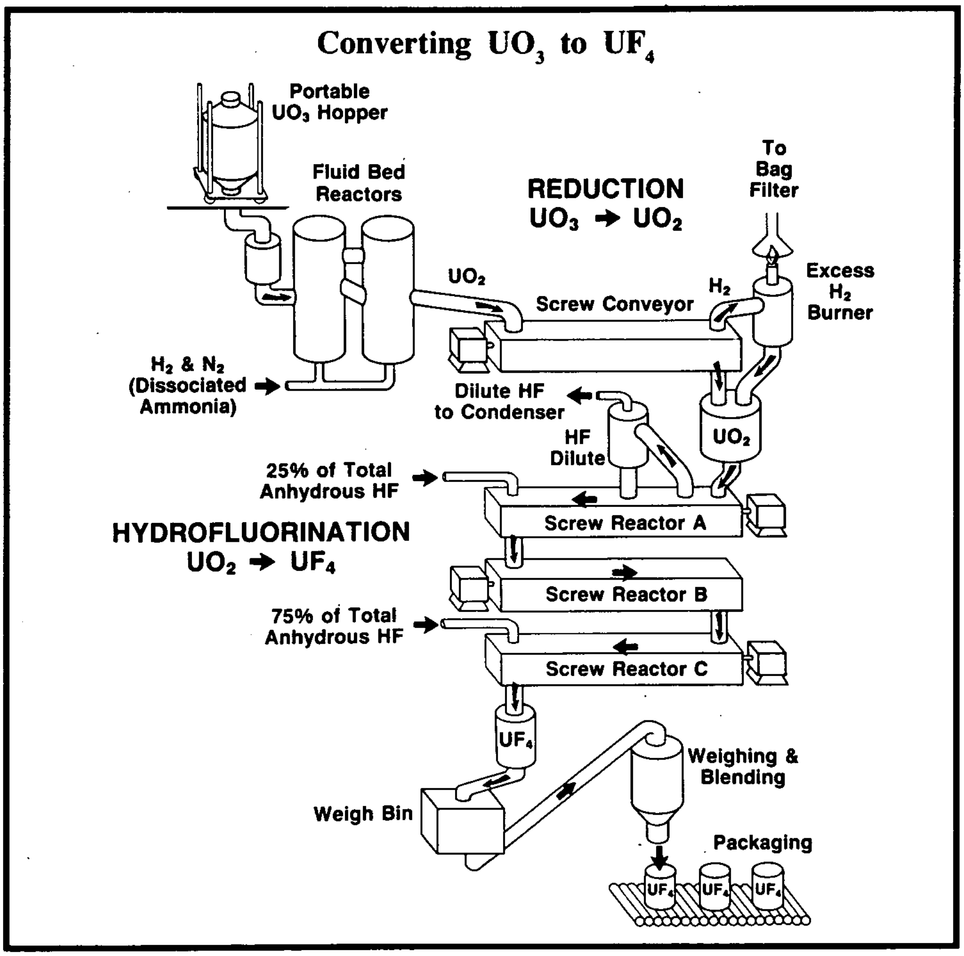
The dissociated ammonia holds the UO_3 powder in suspension so that it behaves much like a liquid (hence the name "fluid bed"). Partially converted UO_3 overflows from the first fluid bed reactor into the second, where the reaction with the hydrogen is completed. A computer monitors and controls, within specified limits, the feed rate (by weight) of UO_3 fed to each reactor bank.

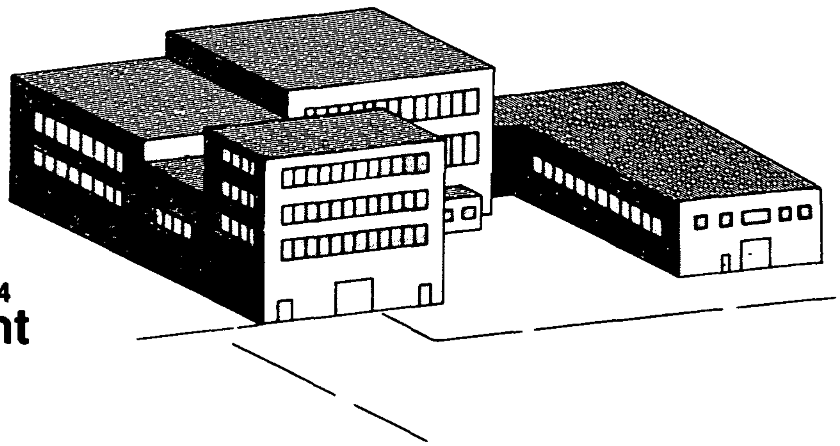
Hydrofluorination occurs in a group of three heated, horizontal ribbon screw reactors arranged in vertical stacks. Each reactor tube is 40.6 cm in diameter, 5.9 m long, and is constructed of Inconel. The operating temperature of each reactor is progressively higher than the previous one — starting at about 149°C for the first reactor and ranging up to 649°C for the third. The UO_2 enters at one end of the top reactor and is conveyed slowly to the other end as it is stirred by a power-driven ribbon screw constructed of Hastelloy. Of the total AHF, 75% enters at the discharge end of the bottom reactor and flows countercurrent to the UO_2 up through all three reactors. The remaining 25% of the total AHF enters the top reactor and mixes with the UO_2. The resulting product, UF_4, is weighed, blended, sampled for chemical analysis, and packaged in 38 liter cans for transportation to Plant 5, the Metals Production Plant.

Excess hydrogen fluoride (HF) is vented from the top reactor and is condensed to form a dilute HF solution (ranging from 20% to 35%) for reuse at FMPC.



At an automated packaging station, green salt (UF_4) from Plant 4 is weighed, blended, and packaged into 38 liter cans.





Pilot Plant
The UF_6 to UF_4 Reduction Plant

The principal function of the Pilot Plant is to convert uranium hexafluoride (UF_6) to UF_4 for use in the metal production process. The Pilot Plant also has the capability of coating by plasma spray the crucibles used for casting uranium metal. The primary functions of the Pilot Plant are:

- reducing UF_6 to UF_4
- coating crucibles by plasma spray.

A considerable part of the metal produced at FMPC is depleted uranium. The principal source for depleted uranium is the UF_6 tails, the by-product from uranium enrichment at the DOE-owned gaseous diffusion plants.

Uranium hexafluoride arrives in solid form in large cyclinders at the Pilot Plant. To produce UF_4, the UF_6 is first heated to form a gaseous compound and is then reduced to UF_4. The reduction occurs in a reaction with hydrogen from dissociated ammonia at approximately 538°C.

In 1984, FMPC installed new equipment at the Pilot Plant to convert UF_6 to UF_4. The equipment includes three autoclaves for heating solid UF_6 to a gaseous form. Twin reduction reaction vessels with a computerized distributive control system reduce the gaseous UF_6 to solid UF_4. The UF_6 flow rate from an autoclave to the reduction system is approximately 1,000 kg/h at 50 psig and 110°C. Both reduction reactors are constructed of Monel and are about 5.9 m long. They operate at a range of 480° to 650°C. The facility is designed to produce solid UF_4 equivalent to 16 metric tons of uranium per day. The equipment is geometrically safe for low-enriched materials and can process UF_6 assaying as much as 2.5% U-235.

The Pilot Plant also has equipment to coat metal-casting crucibles by plasma spray to minimize carbon pickup in uranium metal products.

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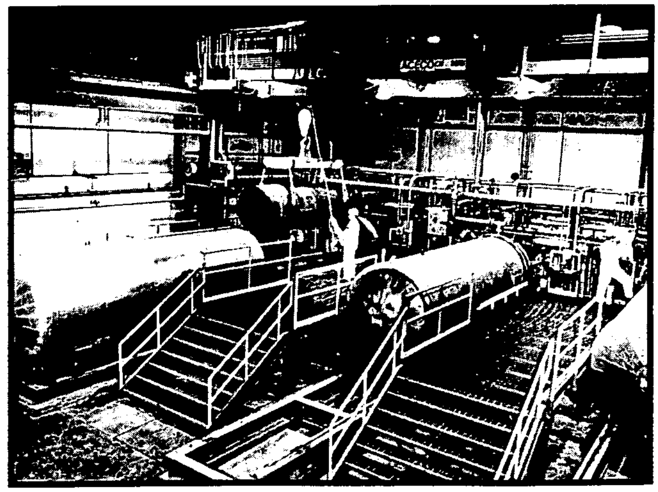
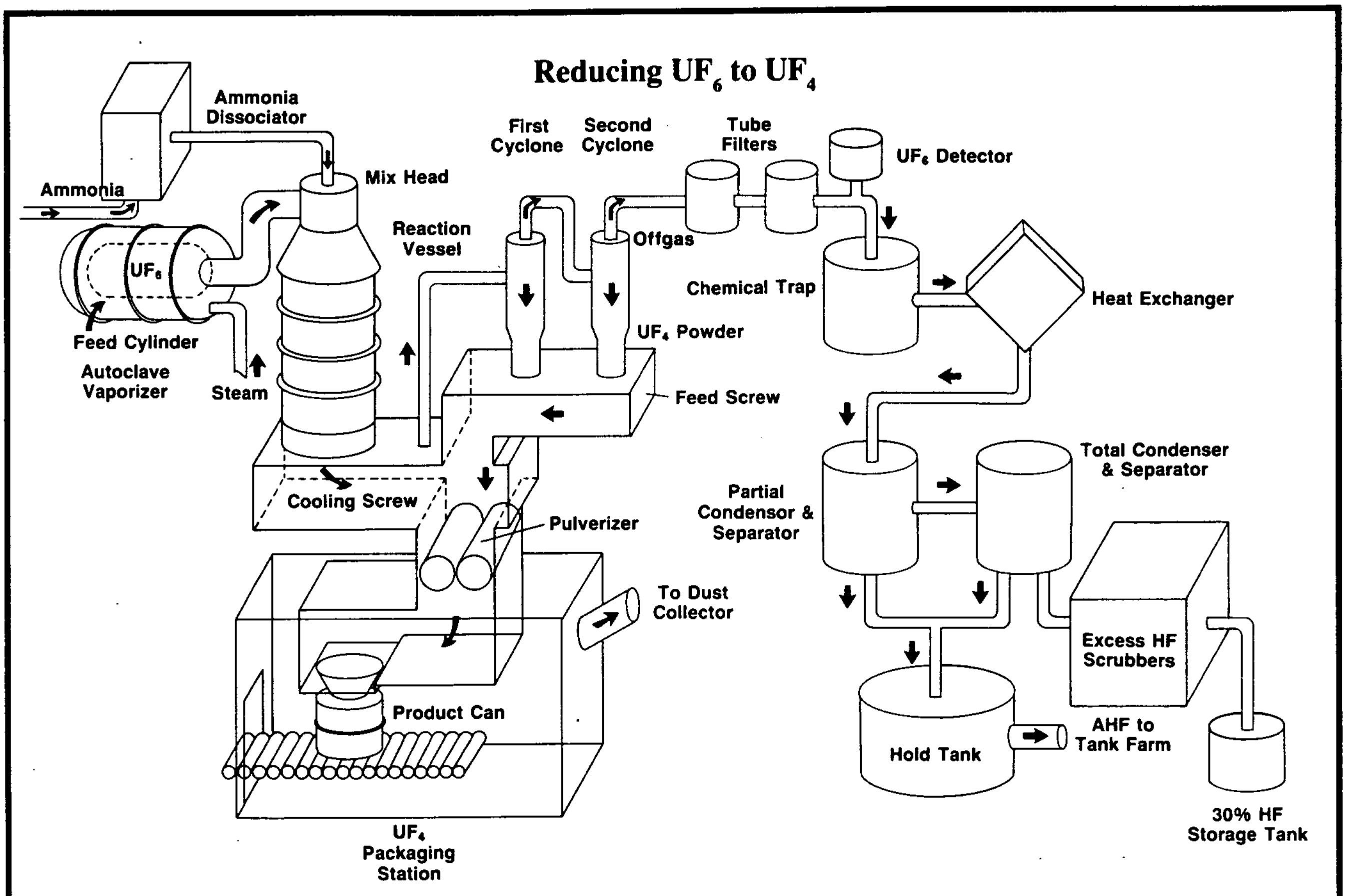
Casting crucibles are coated by plasma spray to control carbon pickup.



Solid UF_6 is vaporized in autoclaves, the first step in the UF_6 to UF_4 process.



The Pilot Plant contains specialized equipment to reduce UF_6 to UF_4.

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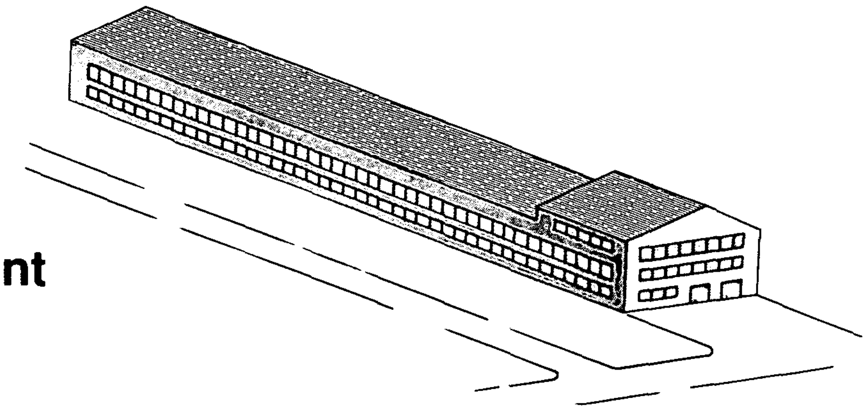
Plant 5
The Metals Production Plant



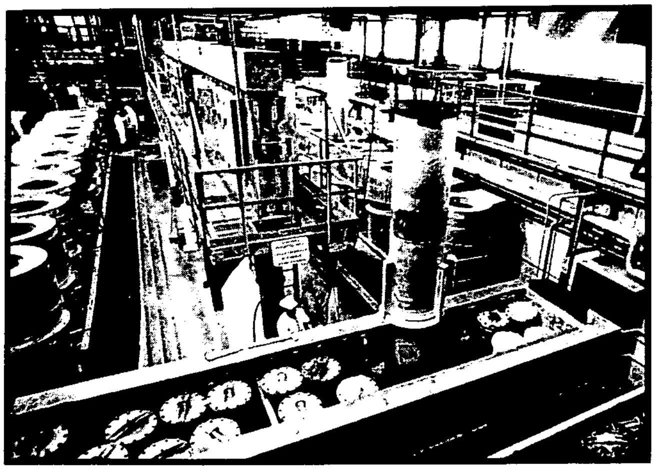
At the **Metals Production Plant,** UF_4, the product of Plant 4 and the Pilot Plant, undergoes a thermite-type reaction with magnesium to produce uranium metal. The primary functions of Plant 5 include the following:

- reducing UF_4 to high-purity depleted, normal, and enriched uranium derby metal
- remelting derby and recycled metals in vacuum induction furnaces for casting into ingots
- sawing ingots to size
- sampling metal products for quality
- machining graphite into various shapes using lathes, saws, milling machines, routers, and grinders
- milling magnesium fluoride (MgF_2) slag by-product for reuse in lining reduction pots.

To begin the reduction process that produces uranium metal, UF_4 and magnesium granules, totalling about 263 kg, are blended and charged into a steel pot lined with magnesium fluoride slag. The pot is capped with slag to protect it from the intense heat of the reaction, fitted with a steel cover, and heated in a Rockwell resistance furnace at 649° to 816°C for three to four hours until the contents react. At this point, the internal temperature of the pot may reach 1,649°C. A minimum of 20 minutes after the contents react, employes remove the pot from the furnace and store it in an air cooling tank for at least one hour. The pot is then removed to a water cooling tank for several hours. After the pot cools, employes remove the resulting uranium mass, called a derby, and clean and separate it from the slag.

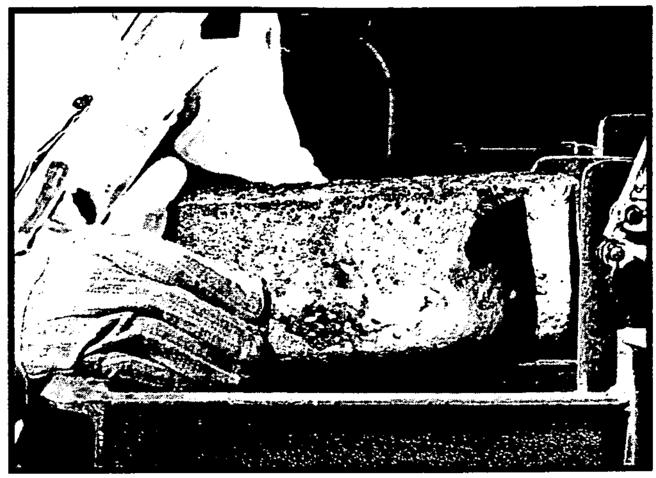
Standard depleted and normal production derbies weigh about 168 kg; enriched derbies weigh about 136 kg. Some derbies are transferred to the casting area in Plant 5 or to the Special Products Plant (Plant 9); others are shipped to various DOE sites for use in related research and development programs.

In the process of casting ingots, cleaned derbies are charged along with uranium recycled metals into a graphite crucible. The loaded crucible is placed in a vacuum induction furnace and heated for about 95 minutes at 130 kilowatts input. When the contents of the crucible reach 1,482°C, a shear plug in the bottom of the crucible is broken, allowing the molten metal to flow into a heated graphite mold directly under the crucible. After cooling, the newly formed ingot is removed from the mold. The mold is cleaned and prepared for reuse, and the crucibles are flame treated to oxidize any residual uranium.

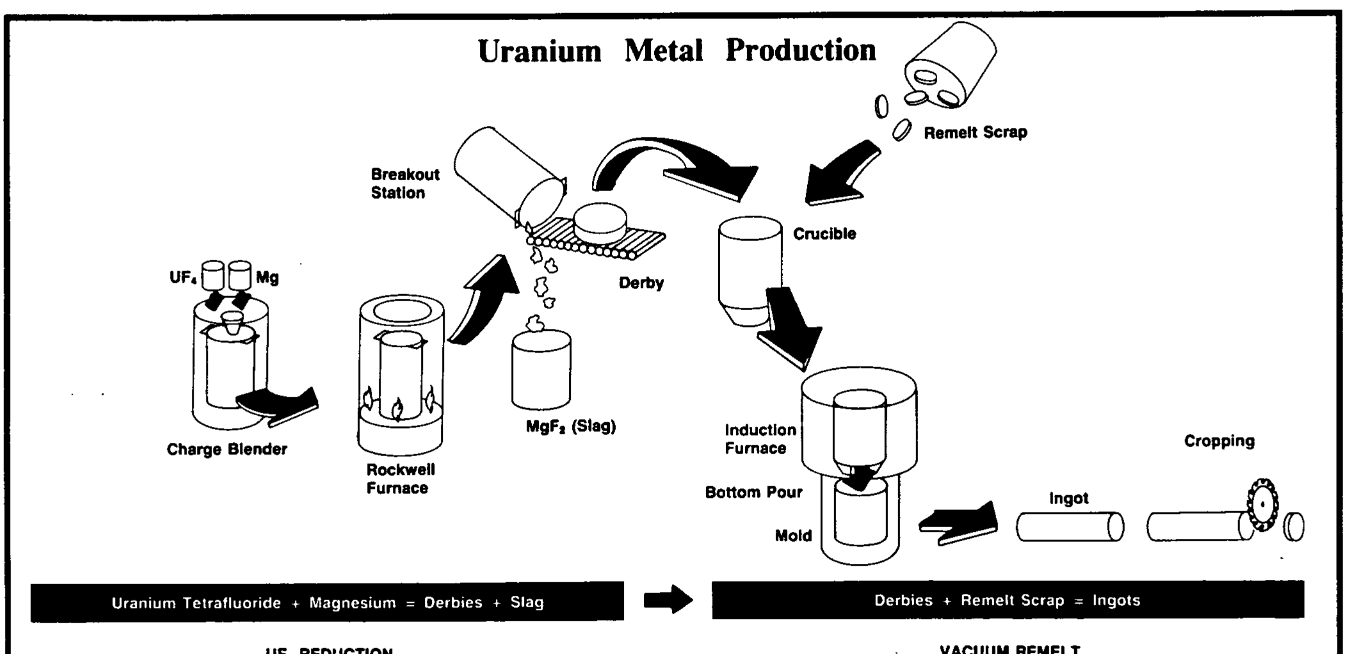


Reduction pots are removed from the Rockwell furnaces and cooled in tanks before derby breakout.

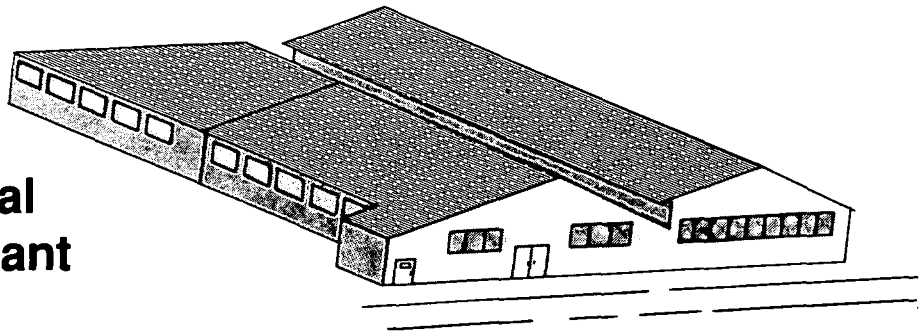
Ingots range from 58.4 to 101.6 cm long. As-cast ingots weigh up to 653 kg. Employes saw about 5 cm from the top section of each ingot to remove shrinkage cavities and impurities that rise to the top of the melt during solidification. The longer ingots are sawed in half, producing two billets for extrusion. The cropped billets are sampled and transferred to the Special Products Plant for center drilling and surface machining. Machined billets weigh as much as 520 kg and are heat treated in Plant 6, the Metals Fabrication Plant, before they are moved to another site.



Uranium metal derbies, weighing between 136 kg and 168 kg, are the initial forms used to make final products.



In the Metals Production Plant, green salt (UF_4) is reacted with magnesium to produce a uranium metal form called a derby. Derbies can be cast into ingots for machining into final products.



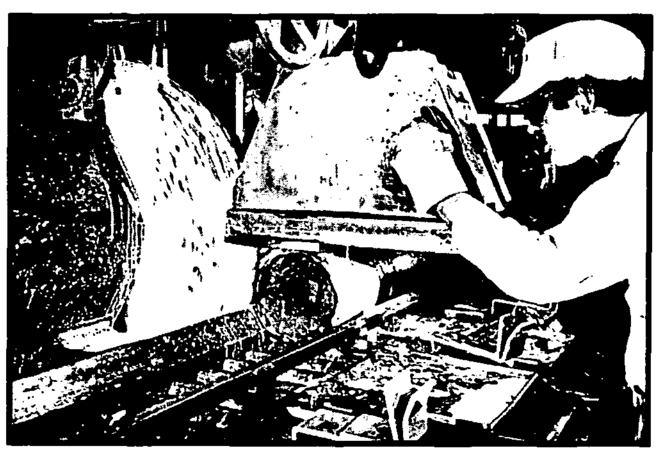
Plant 9
The Special Products Plant

In the **Special Products Plant**, larger ingots than those produced in Plant 5 are cast, and uranium metal pieces are machined for extrusion. The primary functions of Plant 9 include the following:

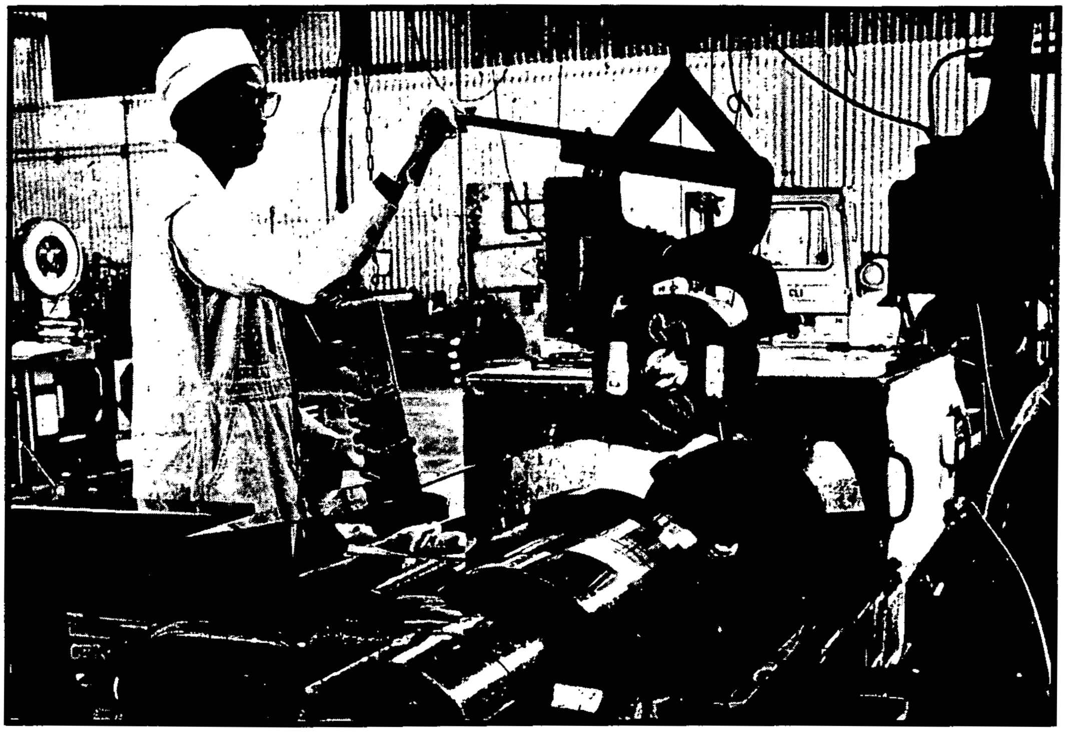
- machining ingots for extrusion
- casting derbies and high-grade recycled metals into large-diameter ingots
- chemically decladding unirradiated fuel elements.

Ingots cast in Plant 9 measure up to 33 cm in diameter, 63.5 cm long, and weigh up to 900 kg. Employes crop the top section of each ingot to remove shrinkage cavities and impurities as they do on the smaller ingots of Plant 5. Cropped billets from both plants are center drilled on a rapid boring machine and are surface machined on standard lathes. Machined billets are heat treated in the Metals Fabrication Plant (Plant 6) before they are inspected and shipped offsite for extrusion and additional processing.

A chemical decladding process called Zirnlo is also performed in Plant 9. In this process, rejected coextrusion sections from the cladding operation at the Hanford reactor site are immersed in dilute nitric acid to remove the outer copper layer that serves as a lubricant during coextrusion of Zircaloy-2 and uranium. The decoppered coextrusion sections are then treated with dilute HF to remove the Zircaloy-2 cladding that encases the uranium metal fuel core. FMPC recycles the decladded uranium metal cores to the casting operation for remelting to ingot form.



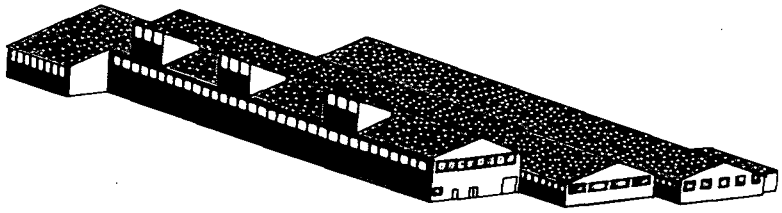
Ingots are top cropped to remove impurities.



Cropped billets are center drilled on a rapid boring machine.

All FMPC products must meet exact specifications.

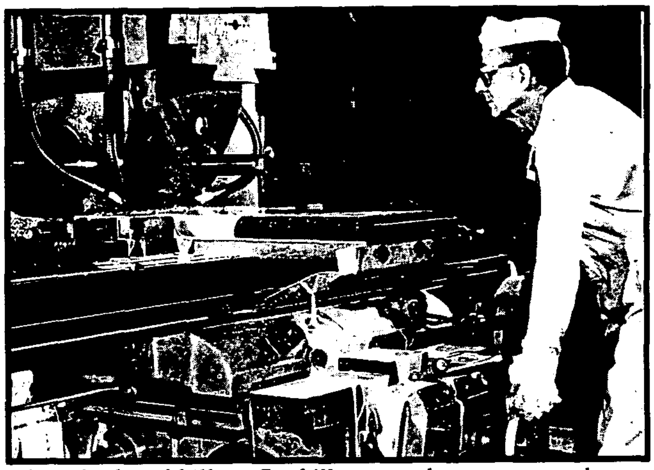
Plant 6
The Metals Fabrication Plant



At the **Metals Fabrication Plant**, uranium metal products are heat treated to improve their strength and grain structure. Some of these products are shipped offsite for extrusion. The extruded tubes are returned to the Metals Fabrication Plant to be machined into final products. After inspecting the products to ensure the highest quality, FMPC ships them to other DOE sites. The specific functions of Plant 6 include the following:

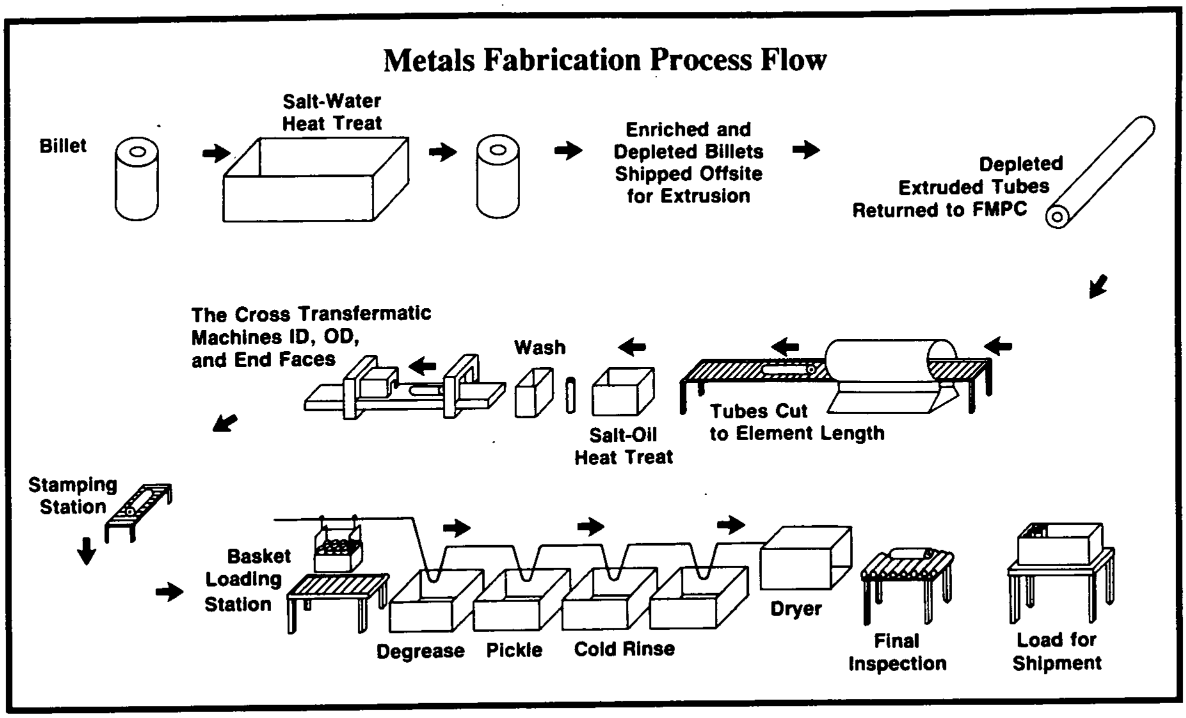
- heat treating products in neutral salt (NuSal) and salt-oil baths
- performing final machining of target element cores
- cropping, surface milling, and inspecting products for shipment
- performing metal pickling and chip briquetting operations
- inspecting finished target element cores and final products before shipment.

After heat treating is completed, FMPC ships the billets offsite for extrusion into tubes of various inner-diameter (ID) and outer-diameter (OD) dimensions. Some of these tubes are returned to FMPC for further fabrication.



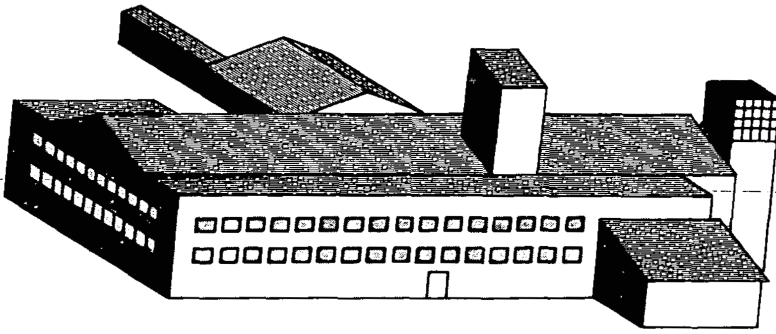
Like cylindrical billets, flat billets are also top cropped to remove impurities.

A cut-off lathe is used to cut the extruded tubes into blanks of appropriate length. After the blanks are treated in a hot salt bath and quenched in oil, the Cross Transfermatic machine automatically machines them to specific tolerances. The machined elements are then individually stamped for identification and degreased. Chips and lathe turnings from machining are crushed, pickled, rinsed, dried, briquetted, and recycled to the casting operations. Cleaned, finished elements are then conveyed to the final inspection area where they are carefully checked for quality and are packaged and shipped to other DOE production sites. Salvageable fuel cores are returned for processing, and all rejects are recycled through the Metals Production Plant.



Some billets produced at FMPC are heat treated in Plant 6 and shipped offsite for extrusion. The extruded tubes are returned to Plant 6 where they are cut to length, machined, treated, and inspected before shipment.

Robotics expedite fuel core packaging for offsite shipment and reduce employe exposure to radiation.



Plant 8

The Scrap Recovery Plant

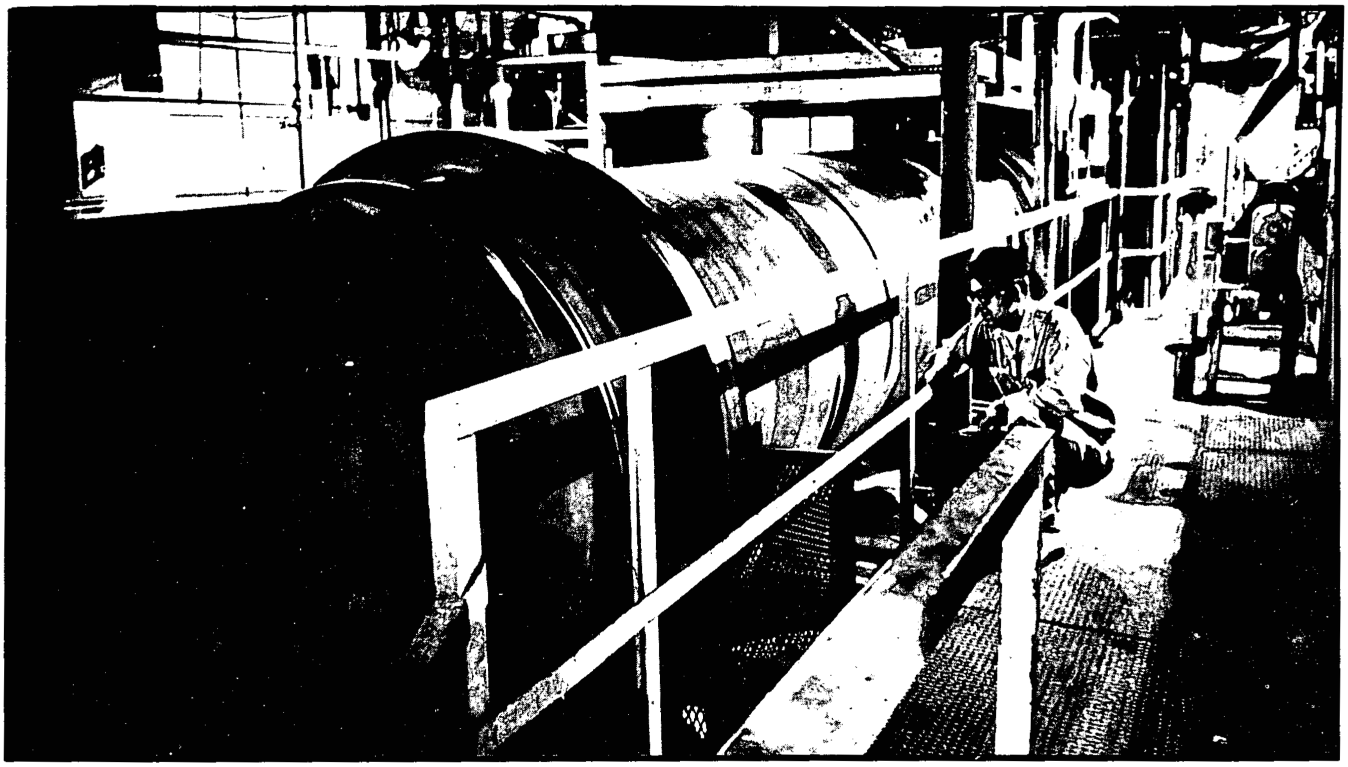
In the **Scrap Recovery Plant**, recycled residues and scrap from uranium processing are upgraded before they are sent to the Refinery for uranium extraction. Besides its recycle functions, the plant equipment is used to achieve waste management objectives and, on occasion, to treat enriched uranium residues. The primary operations in the Scrap Recovery Plant include:

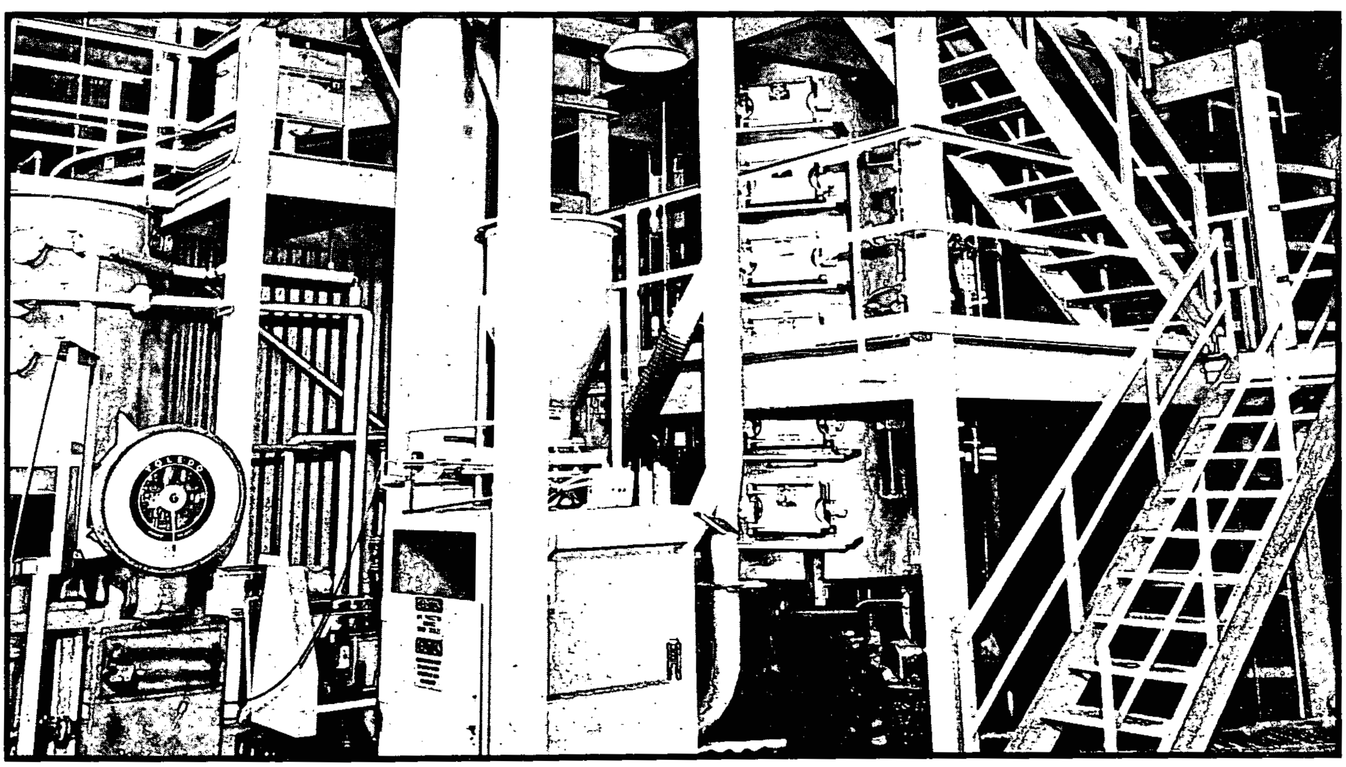
- screening recycled materials
- heating uranium-containing residues in a furnace to dry them and oxidize impurities
- drying and heating in a furnace waste materials for offsite disposal, including contaminated filter cakes from neutralized process waste streams and Refinery slag leach operations
- drum washing
- filtering contaminated water for recovery and waste operation.

At Plant 8, scrap materials prepared for the Refinery digestion cycle include uranium metals, black oxide, furnace salts, dust collector materials, and floor sweepings. Recycled or scrap materials containing metallic impurities, oil, graphite, or other contaminants are roasted to oxidize the impurities.

Oversized pieces of scrap are screened, and wet materials are dried in either a rotary kiln or three multiple-hearth vertical furnaces.

Recycled materials of significantly different isotopic assays must be segregated throughout processing and storage. The dimensions of the production equipment limit processing enriched materials to a maximum of 1.25% U-235.





The rotary kiln (top photo) and the vertical hearth furnace (bottom photo) roast wet, recyclable materials to remove moisture and impurities.

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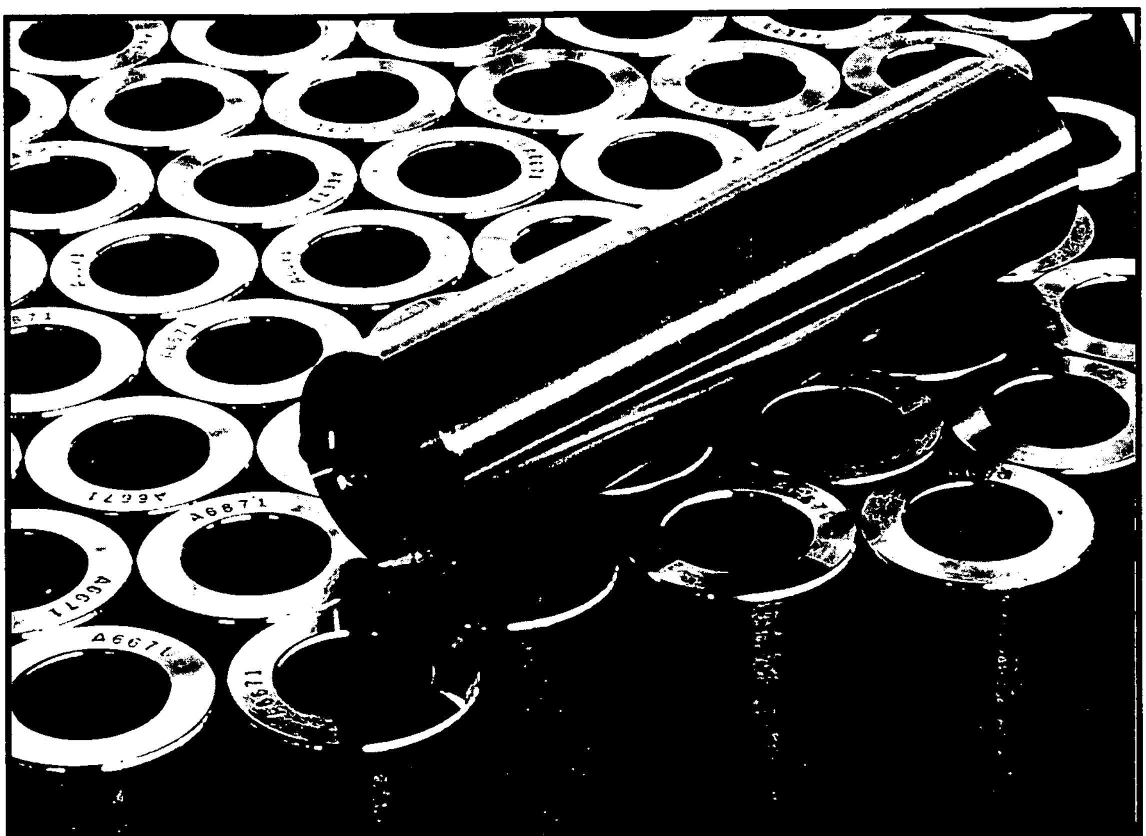
Conclusion

The Feed Materials Production Center is a unique facility that refines and casts tonnage quantities of high-quality uranium metal. This production capability is not available at any other facility in the United States.

The uranium metal manufactured at FMPC is essential as a feed material for defense programs carried out at Department of Energy facilities.

Ongoing improvements in production efficiency and waste management technology will enable FMPC to fulfill its role in DOE defense programs and to enhance safety and environmental protection at and around the facility.

Additional information is available from the FMPC Public Affairs Department at (513) 738-6185.



FMPC's production capability is not available at any other plant in the United States.

Notes

Feed Materials Production Center
Operated for the U.S. Department of Energy
by Westinghouse Materials Company of Ohio