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Consolidated Fuel Reprocessing Program

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# SAF-BRET-FMEF: A DEVELOPMENTAL LMR FUEL CYCLE FACILITY[1]

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[2]Operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy.

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# SAF-BRET-FMEF: A DEVELOPMENTAL LMR FUEL CYCLE FACILITY

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## 1.0 INTRODUCTION

Previous papers in this special session on "Fuel Cycle for New-Generation Small Reactors" have dealt with the fuel cycle for future Liquid Metal Reactors (LMRs). This paper discusses a developmental LMR fuel cycle facility which, if constructed, could serve as a transition facility for processing fuel from the first generation of LMRs before they are mature enough to support their own fuel cycle. The developmental fuel cycle facility described consists of existing as well as conceptual capabilities and is presented as an option not ignoring the option of a free-standing facility at the LMR site.

The Fuels and Materials Examination Facility (FMEF) at Hanford near Richland, WA was completed in 1984. The facility is currently undergoing acceptance and startup testing. A fuel fabrication line called the Secure Automated Fabrication (SAF) line(1) for LMR fuel is currently being installed in the FMEF with expected startup in 1987. Conceptual design of a fuel reprocessing capability, called the Breeder Reprocessing Engineering Test (BRET)(2) was recently completed which defines a fuel reprocessing capability which could be installed in the FMEF. Although BRET is currently deferred, integration of these functions into a single facility would provide a practical demonstration of the LMR fuel cycle by closing the cycle for FFTF and possibly the first generation of LMRs. The FMEF-SAF-BRET complex would provide a demonstration of a fuel cycle plant similar to that required for a new LMR site.

## 2.0 DESCRIPTION

The FMEF, the BRET, and the SAF, are described in the following sections.

## 2.1 Fuels and Materials Examination Facility (FMEF)

An overall view of FMEF, located in the Hanford 400 Area, is shown in Figure 1. The FFTF and the Maintenance and Storage Facility (MASF) are shown in the background. The FMEF Process Building is 76m (250 ft) long by 46m (150 ft) wide and extends from 11m (35 ft) below grade to 30m (98 ft) above grade at the roof level.

A cutaway view of FMEF is shown in Figure 2. The FMEF is composed of approximately 15,800$m^2$ (175,000 sq ft) of floor space on six different operating levels. Fuel pin fabrication in the SAF line is located on the top floor of the building, and the fuel assembly fabrication process is located in a portion of the ground floor. BRET would utilize many of the other areas of the building with the primary fuel reprocessing operations located in the large, shielded Main Process Cell (MP Cell) in the center of the building.

The FMEF is a Class I nuclear facility capable of withstanding the effects of a Design Basis Earthquake. It has four air ventilation zones established to confine hazardous materials within controlled areas of the facility. The FMEF is designed to confine radioactive material in the event of a design basis tornado or design basis earthquake, both of which are extremely low probability. Vital systems are designed to withstand all credible accidents or phenomena and include a 100% redundant emergency power supply.

## 2.2 Fuel Reprocessing

BRET, as conceptually designed, would process LMR fuel from the FFTF and from the CRBRP. However, processing requirements for advanced LMR fuel are expected to be about the same. Design throughput is for an initial rate of 6 MTHM/yr with expansion to 15 MTHM/yr, the primary difference being the number of processing campaigns per year. Instantaneous processing capacity of the equipment is 0.1 MTHM/day. The equipment is mounted on modules to enhance in-cell maintenance, to allow replacement of installed equipment as new and improved technology becomes available, and to facilitate the eventual decontamination and decommissioning of the process systems. Spent fuel is processed after one year of cooling and High Level Liquid Waste (HLLW) generated during reprocessing is vitrified in BRET. Subsequent discussions of BRET will be for the 15 MTHM/yr conceptual design case.

### 2.2.1 Facility Utilization

As mentioned previously, BRET was designed to utilize many portions of the existing FMEF. A cutaway of the FMEF showing the primary location of BRET operations is shown in Figure 3. Spent fuel is received in shielded casks in the FMEF Shipping and Receiving area. The cask is then transferred to the Entry Tunnel where it is loaded onto a transporter and located beneath the MP Cell. The cask is mated to the MP Cell transfer hatch, and fuel assemblies are transferred into the MP Cell.

The MP Cell is approximately 12m (40 ft) wide, 30m (100 ft) long, and 16m (56 ft) high with cell walls varying from 1.2m (4 ft) to 1.5m (5 ft) in thickness. Most of the fuel reprocessing operations are performed in the MP Cell, including: sodium cleaning, fuel disassembly, dissolution, solvent extraction, plutonium nitrate storage, HLLW vitrification, off-gas cleanup operations, and fuel and waste handling.

Directly above the MP Cell is the Upper Process Cell (UPC). This cell is used as a remote decontamination and maintenance cell. A large transfer hatch would be added between the MP Cell and UPC to enable transfer of equipment modules, failed equipment, or waste. The UPC is 12m (40 ft) wide, 18m (60 ft) long, and 7m (23 ft) high. The walls are 1m (40 in) thick reinforced normal concrete.

BRET also utilizes a series of process support hot cells located on the bottom level of the FMEF for sample preparation and analytical chemistry. The cells are arranged in two parallel rows separated by a horizontal transfer corridor. Sample transfers to the cells are accomplished by means of a pneumatic transfer system connected to the other processing cells.

### 2.2.2 Process Description

A conceptual layout of the MP Cell is shown in Figure 4. Spent fuel received in the MP Cell is placed in a sealed chamber where it is cleaned of residual sodium using a moist nitrogen atmosphere followed by water rinsing. Following cleaning, the assembly is moved to a dismantling area where the inlet nozzles and the shroud are removed. The fuel sections are placed in a special container and sent to a shear where they are cut into short sections (~2 to 5 cm long). The sheared pieces fall into a gaslock between the shear and dissolver, then are fed directly to the BRET dissolver.

The initial BRET dissolution system utilizes two batch dissolvers in a semicontinuous operation (i.e., one dissolver loading while the other is in a dissolution cycle). Later addition of a continuous dissolver is not precluded. The sheared pieces are placed in a basket and the fuel leached from the cladding using hot nitric acid. Following leaching, the basket is removed, and the cladding is rinsed and assayed, using nondestructive assay techniques prior to disposal of the cladding as a solid waste.

The dissolver solution is transferred to a feed clarification system to separate any undissolved fines and any fuel cladding material. Suspended solids are removed utilizing a solid-bowl centrifuge similar to one currently being used in the United Kingdom. After clarification, the solution is transferred to a feed adjustment and accountability tank prior to solvent extraction processing. The centrifuge bowls containing the solids are packaged and normally sent to retrievable storage. If assay of the bowls shows high plutonium content, the bowls could be set aside for recovery and recycle of the plutonium.

The solvent extraction process in BRET is a modified PUREX process using a mixture of 30% tri-n-butylphosphate and 70% dodecane diluent. The process consists of five cycles: a high activity (co-decontamination) cycle; a partitioning-uranium purification cycle; a uranium purification cycle; and two plutonium purification cycles. Plutonium nitrate product is concentrated to about 450 g/l and stored for subsequent product conversion.

Centrifugal contactors similar to those shown in Figure 5 were selected for use in the BRET solvent extraction system because they save space and because their low residence time reduces the process inventory, reduces organic solvent degradation, and enhances the system process control and response. The system has a short equilibrium time, so it can be operated for short cycles and then shut down. The contactor design, known as the annular centrifugal contactor, will be an adaptation of contactors currently in use in the Savannah River Plant.[3] The design being used facilitates simple unit replacement by remote maintenance techniques in the event of a failure.

Plutonium nitrate is converted to ceramic fuel grade $PuO_2$ powder in a glovebox operation using oxalate precipitation, filtration of the precipitate, and calcination to $PuO_2$. Because of the waste disposal capabilities available at Hanford, as originally conceptualized, the uranium product from BRET would be treated as a waste stream and not recycled to the process. Uranium recovery and recycle could be added later.

Handling of liquid waste streams in BRET is fully integrated with the reprocessing operations. The high-level aqueous waste stream from the first cycle of solvent extraction is concentrated, stored, then vitrified. The vitrification unit in BRET is the Liquid Fed Ceramic Melter currently being developed in the United States.

Offgases in BRET are treated to remove ruthenium, iodine, $NO_x$, and particulates prior to discharge. Ruthenium is removed using a metal mesh filter while iodine is removed using silver zeolite. During initial BRET operations, krypton-85 and carbon-14 are not recovered, although such retention capability could be added later. All gas streams are treated to meet acceptable DOE and Hanford Site release requirements prior to discharge.

### 2.2.3 Operation and Maintenance Description

The BRET operating and maintenance philosophy for the MP Cell is one of center-aisle maintenance using cranes and an advanced servomanipulator (ASM) system mounted on overhead bridges. The ASM, shown in Figure 6, utilizes a force-reflecting manipulative device with a 23 kg (50 lb) handling capacity. Two ASMs are attached to two separate transporter systems capable of covering the entire volume of the MP Cell such that full coverage of in-cell process equipment is provided. The ASM is remotely maintainable with modular design features that allow replacement of failed slave arm segments to minimize system downtime. The system is operated from an out-of-cell control station shown schematically in Figure 7.

The process equipment in BRET is arranged on equipment racks mounted along the walls of the MP Cell, accessible to the ASM and other maintenance equipment as shown in Figure 8. The process systems would normally be maintained by replacing a failed equipment rack or component with a spare and repairing or discarding the part as appropriate. However, the rack arrangement facilitates complete replacement of equipment and/or substitution of processing systems. Thus, BRET could serve as a test bed for demonstration of newly developed processes.

The other processing cells (i.e., UP Cell, Decon Cell, and Process Support Cells) use a combination of bridge-mounted Electromechanical Manipulators (EMMs), bridge cranes, and through-the-wall master slave manipulators.

An automated sampler is utilized in the MP Cell to remotely retrieve bottled process samples from sample stations mounted on the process modules. The track-guided, self-propelled sample vehicle remotely removes and replaces sample bottles at a sample station and delivers the samples to an unloading station where they are transferred from the MP Cell for laboratory analysis. Use of a remote sampling system eliminates the requirement for a sample gallery next to the MP Cell, reduces potential radiation exposure of operating personnel, and improves safeguarding of special nuclear materials.

## 2.3 Fuel Fabrication

The fuel fabrication capabilities within the FMEF include the SAF line which processes uranium and plutonium dioxide powders into fuel pins and a Fuel Assembly Area in which fuel pins are inspected and fuel assemblies are built. Figure 9 shows a simplified process flow diagram for fuel fabrication in the FMEF.

Both the SAF line and the Fuel Assembly Area equipment are designed to fabricate fuel of the following description.

| | |
|---|---|
| Fuel Pin Length | 93-114 inches |
| Fuel Pin Diameter | 0.23-0.27 inch |
| Fuel Assembly Length | 168 inches maximum |
| Fuel Pins Per Assembly | 217 |
| Fuel Composition | 37 w/o $PuO_2$ |
| Isotopic Composition | 20 w/o $^{240}Pu$ in Pu |

The design throughput is six metric tons of mixed oxide (MOX) fuel per year, or 36,000 fuel pins and 160 fuel assemblies per year. This throughput is based on a one-shift per day, 5-day per week schedule, except for certain continuous operations such as sintering which would operate around the clock. The capacity could be significantly increased and plutonium with up to 25 w/o $^{240}Pu$ could be processed with few equipment changes, depending upon fuel enrichments, fuel configuration, operating mode, and the time since separation of the plutonium.

The SAF line is highly automated and remotely controlled while the Fuel Assembly Area is highly mechanized. Gamma and neutron shielding are used in both areas to maintain the whole body exposure of workers to less than one rem per year. Both areas incorporate major advances in the technology of mixed oxide fuel fabrication which are directed toward improving worker safety, safeguarding of special nuclear material, process control, and reduced costs.

Nearly all SAF process equipment has been fabricated and installation in FMEF is ~50% complete. Start of fuel production for FFTF is scheduled to begin in 1987. The current schedule for installation of neutron shielding and mechanization of pin inspection and assembly fabrication processes coincides with the need to utilize high exposure plutonium for FFTF fuel beyond 1990. This paper describes the fully shielded and mechanized equipment as it would exist to supply fuel to a commercial-sized LMR generating station.

### 2.3.1 Secure Automated Fabrication (SAF) Line(1)

The SAF line will receive uranium and plutonium oxide powders, process these into sintered pellets, and load the pellets into cladding tubes which are welded to form sealed fuel pins. Figure 10 shows an isometric view of the SAF line on the 70-foot level of FMEF. The SAF line operations may be organized into five major groupings as follows:

#### Powder Operations

In the powder operations, $PuO_2$ is received in canisters from the FMEF vault. The canisters are remotely weighed, identified and emptied into a batching station where the proper amounts of $PuO_2$ are introduced into a remotely-operated blender. The blended powders are processed through a jet mill to break up agglomerates to assure microhomogeneity. The milled powder is thoroughly mixed with binder and pore former. The next process steps produce a free-flowing powder by pressing the powder into compacts and crushing the compacts to form granules, which are then blended with a small amount of lubricant for pellet pressing.

#### Pellet Operations

Granules are transferred in canisters to the pellet pressing stations. Two hydraulic presses are used to press pellets, a fraction of which are automatically inspected for process control. The pellets are loaded into sintering boats at the pressing stations and transferred to a low temperature, continuous belt furnace for removal of the organic binder and lubricant. The boats are then transferred to a high-temperature, continuous sintering furnace, shown in Figure 11, to produce dense, sintered pellets with the proper oxygen-to-metal

(O/M) ratio. An automatically controlled boat transport system moves containers of pellets from the pellet presses to the various furnaces and to a boat unloading station.

Pellets are sampled at the boat unloading station for measurements and analyses to verify conformance with specifications. If required by specifications, pellets are ground and inspected for weight-per-unit-length and surface condition before being transferred to Pin Operations.

<u>Pin Operations</u>

Pellets are made into fuel columns which are automatically weighed and measured. Clad tubes with the bottom-end closure weld and lower-end non-fuel pin internals are introduced into the pin operations in preloaded magazines. The fuel columns are inserted into the clad tubes, the upper pin internals loaded, and the weld area decontaminated. The top end cap is welded into place by a solid-state pulsed magnetic welding process. The completed fuel pin is loaded into a container for transfer to the pin inspection area. An entire container full of pins (115) is helium leak tested before leaving the pin operations area.

<u>Process Automation/Instrumentation and Control</u>[4]

The automation techniques used by the SAF Line are similar to those in other manufacturing plants, and many commercially available components are used. The SAF Line incorporates 24 robots in its design, most performing single, relatively straightforward tasks. Robots were selected over alternative automation techniques generally due to:

- Overall compactness.
- Standardization of equipment and controls among several different unit operations.

- Design simplicity.

- Ability to accommodate product changes without expensive retooling.

Commercially available pneumatic pick-and-place robots are used to handle individual fuel pellets and sample vials for the analytical chemistry system while other robots were selected to perform more complex functions. The greatest difficulty was finding commercial robots able to handle moderate payloads in the 9 to 23 kg (20 to 50 lb) range in the tight confines of a plutonium process enclosure. An example is shown in Figure 12.

Hard automation (i.e., nonprogrammable, limited function) is used for many SAF subsystems. These applications include both commercially available automatic machinery and custom-designed equipment. The sintering boat transport conveyor and the fuel pin loading system are examples of single-purpose hard automation.

SAF utilizes a state-of-the-art remote control system which employs a three-level control hierarchy. These are the local control, remote control, and supervisory control levels. The local control panels are located in the direct vicinity of the process equipment. They include only the simplest components which are needed for maintenance, testing or upset recovery; or they include equipment which, for technical reasons, must be located near the process equipment. Remote control equipment is located up to 76m (250 ft) away and includes the primary process control microprocessors and the input/output conditioners and interfaces for all sensors and effectors. Each of the process subsystems can be operated from the remote control racks but this does not represent the normal point of operation. The supervisory control level provides the centralized coordination and operator interface necessary for efficient operation of the fabrication line. The merging of control requirements and interactions between the unit process subsystems is controlled from redundant central processors at this level which concurrently provide data storage, report preparation and efficient, interactive operator interface with the process. Figure 13 shows a schematic of the control system.

### Analytical Chemistry[5]

A system for very rapid chemical analysis of fuel pellets has been developed and is being installed to support the SAF line. The operation of the system is totally automated from the selection and transfer of sample pellets to the reporting of results to the SAF line operatiors. The single analysis turnaround times are 10-15 minutes. The analyses included in the system are plutonium/uranium ratio, oxygen-to-metal ratio, moisture content, offgas volume, halide content, carbon and sulfur content.

### 2.3.2 Fuel Assembly Area[6]

The fuel assembly area includes two main functions 1) inspection of fuel pins from the SAF line and 2) assembly of pins into completed fuel assemblies. The operations in this area employ shadow shielding and mechanization as necessary to meet the one-rem-per-year whole body exposure limit. Figure 14 shows the details of an FFTF fuel assembly. Figure 15 shows the arrangement of equipment in this area. The process line is a series of individual stand-alone stations at which inspection or assembly operations are performed.

Fuel pins are received from the SAF line contained in a 115-tube bundle which has been placed in a shield cask to provide neutron and gamma shielding over the fuel column region. The cask is transported from the SAF line on a motorized cart. In the fuel assembly area, the cask is lifted from the cart by a monorail hoist and transported to the required process station. At the process station, the cask is lowered onto a support table to provide alignment of the station's fuel pin insertion/withdrawal mechanism.

Process stations for inspection of fuel pins consist of a fuel pin internal inspection station which uses fissile assay, densitometer, and eddy current nondestructive methods, an ultrasonic examination station for the cladding-end cap pulsed magnetic (PM) welds, and a fuel pin visual inspection station for external examination and measurements.

When fuel pins are ready for final assembly operations, the pins are transported in the cask, using the monorail system, to the wire wrap/strip layer station.

At this station, wire is wrapped around and welded to the fuel pins and the pins are assembled into strip layers. The strip layers are placed in a strip layer cart as they are assembled. The motor-driven strip layer cart then is moved across the building to the final assembly station. Figure 16 shows the wire wrap/strip layer station with the cask in place as an example of the use of mechanization and shadow shielding in these operations.

At the final assembly station, the strip layers are laid horizontally to produce the fuel bundle and are attached to the shield-inlet subassembly. The bundle is tilted to the vertical position, and the duct-handling socket subassembly is lowered over the bundle using the bridge crane. After the duct-handling socket subassembly is in place, the assembly is returned to the horizontal position and the duct welded to the shield inlet assembly. This completes fabrication of the Driver Fuel Assembly (DFA).

To inspect the driver fuel assembly, the assembly is removed vertically from the final assembly station using the bridge crane and moved to the final assembly inspection station. After inspection, the assembly is moved to and lowered into the fuel and assembly storage array with the bridge crane. The assemblies are stored in this area until needed at the reactor.

## 3.0 CONCLUSIONS

The SAF-BRET-FMEF complex represents a versatile fuel cycle facility for processing LMR fuel. While originally conceived for processing FFTF and CRBRP fuel, it represents a facility where LMR fuel from the first generation of innovative LMRs could be processed. The cost of transporting fuel from the LMR to the Hanford site would have to be assessed when the LMR site is identified.

The throughput of BRET was set at 15 MTHM/yr during conceptual design of the facility, a rate which was adequate to process all of the fuel from FFTF and fuel and blanket material from CRBRP. The design is currently being reevaluated to see if BRET could be expanded to ~35 MTHM/yr to process fuel and blanket material from ~1300 MWe generating capacity of the innovative LMRs. This expanded throughput is possible by designing the equipment for an instantaneous throughput of 0.2 MTHM/d, and by selected additional modifications to the facility (e.g., expansion of shipping and receiving area, and addition of a second entry tunnel transporter), and by the fact that the LMR fuel assemblies contain more fuel than the FFTF assemblies (therefore, fewer assemblies must be handled for the same throughput). The estimated cost of such an expansion is also being assessed.

As stated previously, the throughput of SAF and Fuel Assembly could be made to support typical LMRs at little additional cost. The throughput could be increased to support the fuel fabrication requirements for 1300 MWe generating capacity of the innovative LMRs. This added capacity may be achieved by increasing the number of operating shifts, and is affected by variables such as fuel design, fuel enrichment, and plutonium isotopic composition.

## 4.0 REFERENCES


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## FIGURES

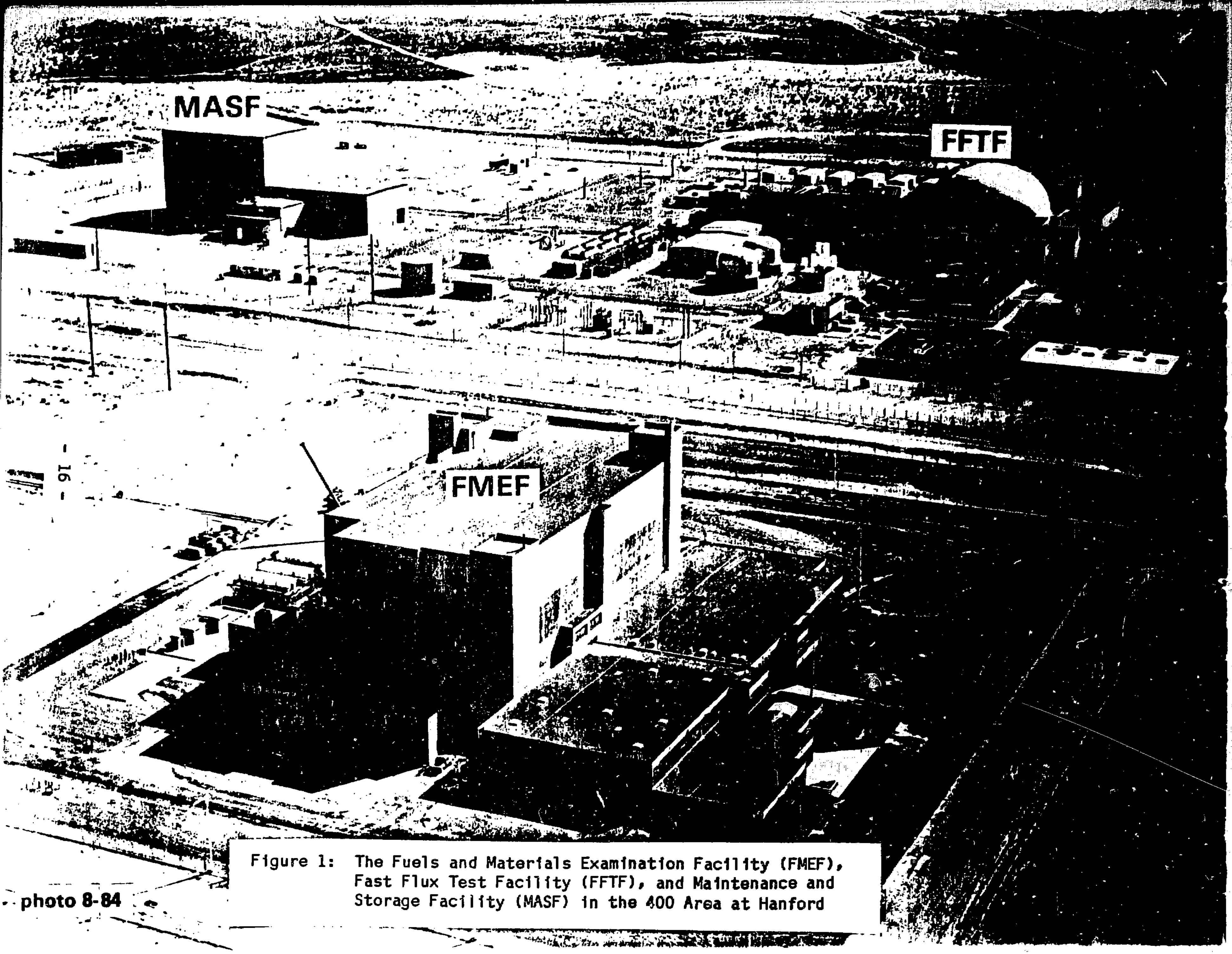


Figure 1: The Fuels and Materials Examination Facility (FMEF), Fast Flux Test Facility (FFTF), and Maintenance and Storage Facility (MASF) in the 400 Area at Hanford

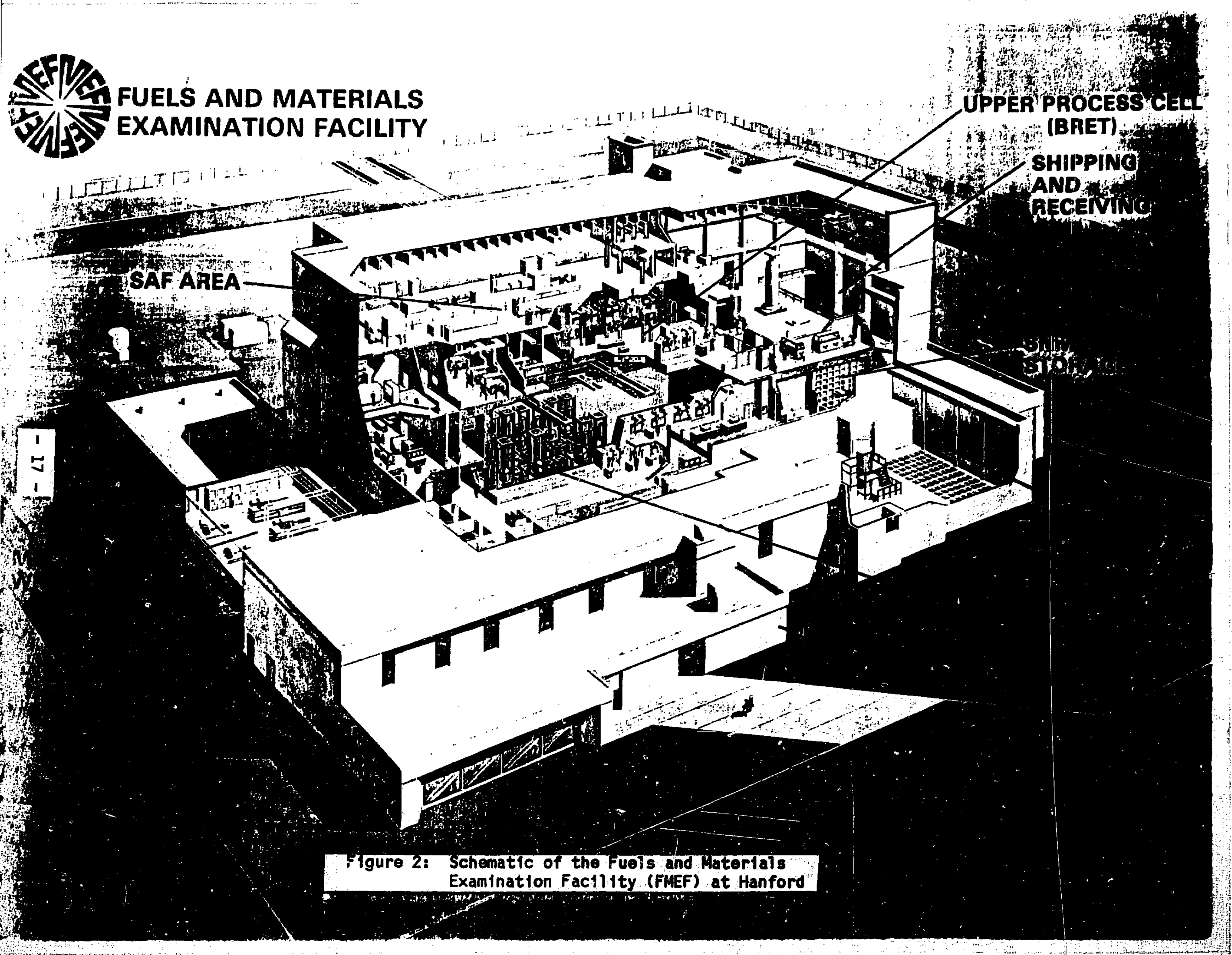


Figure 2: Schematic of the Fuels and Materials Examination Facility (FMEF) at Hanford

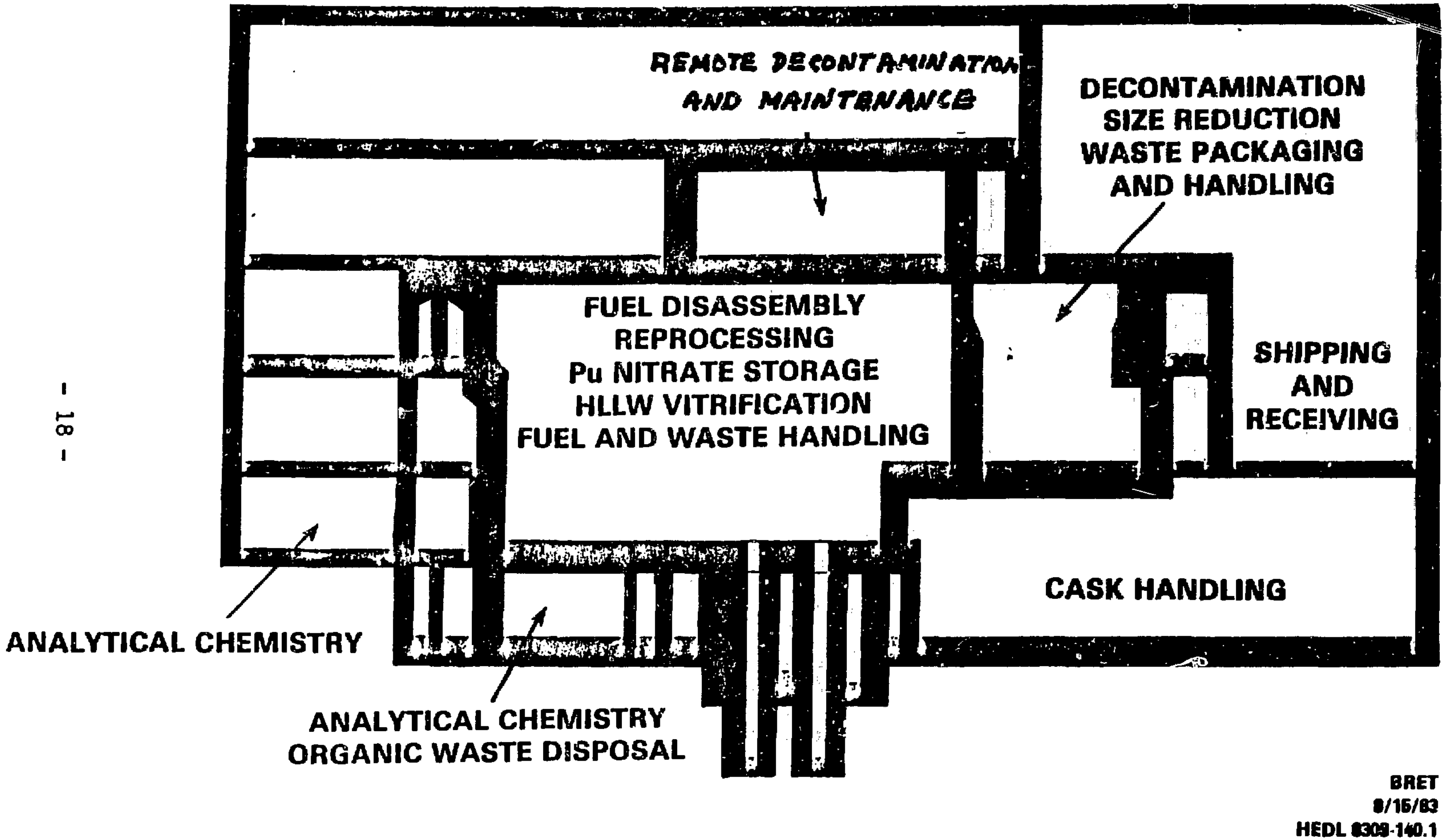


Figure 3: Breeder Reprocessing Engineering Test (BRET) activities in the FMEF

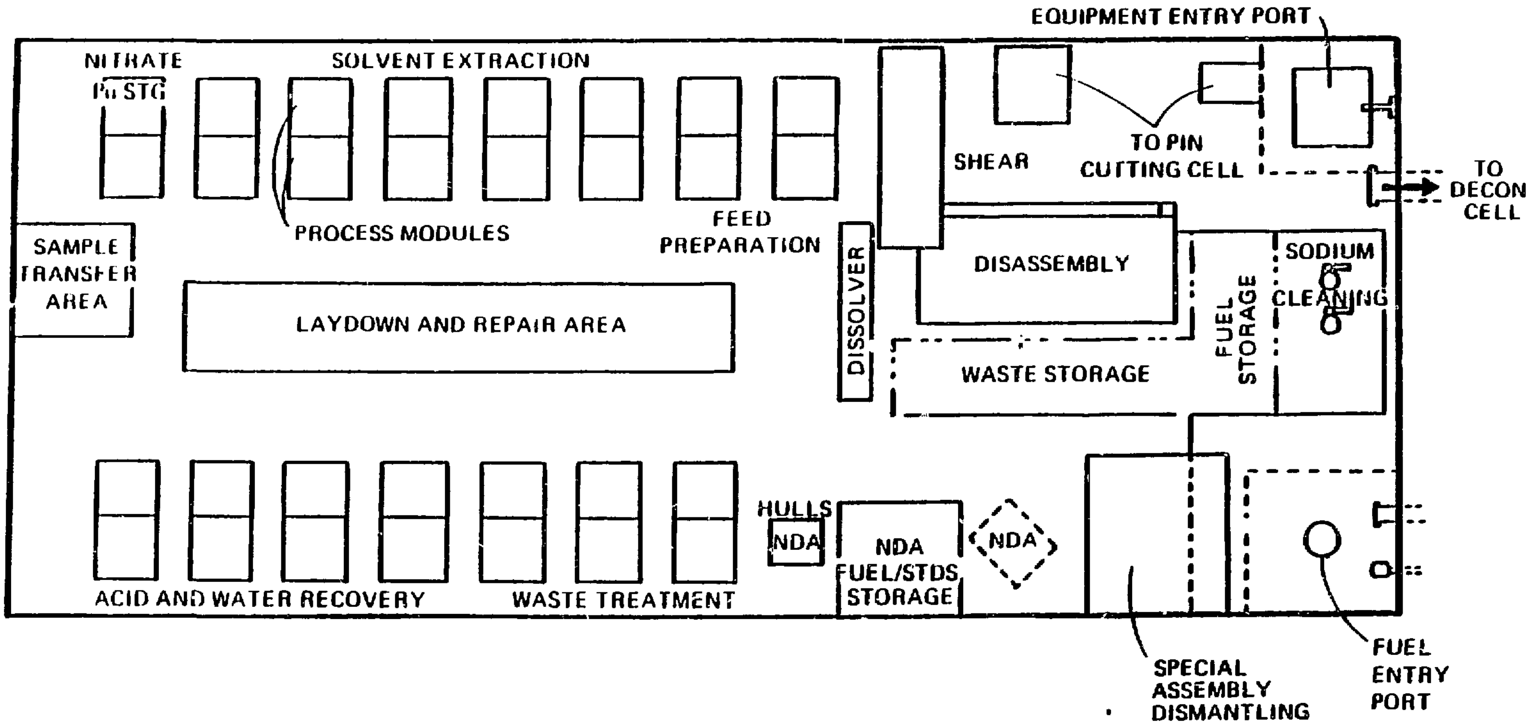


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Figure 4: Conceptual Layout of Main Process Cell in BRET

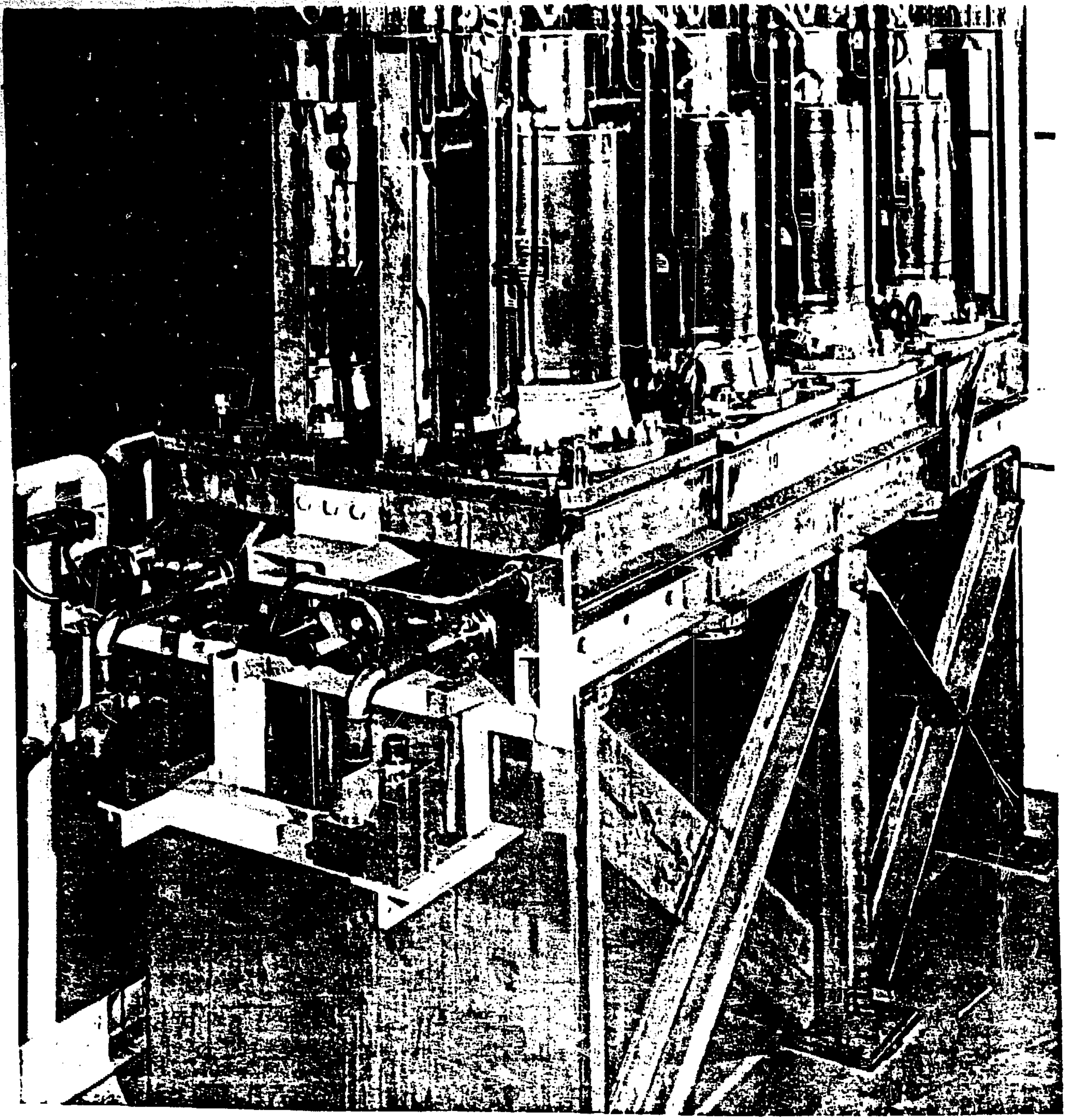

Figure 5: Eight-Stage Centrifugal Contactor Being Tested at ORNL

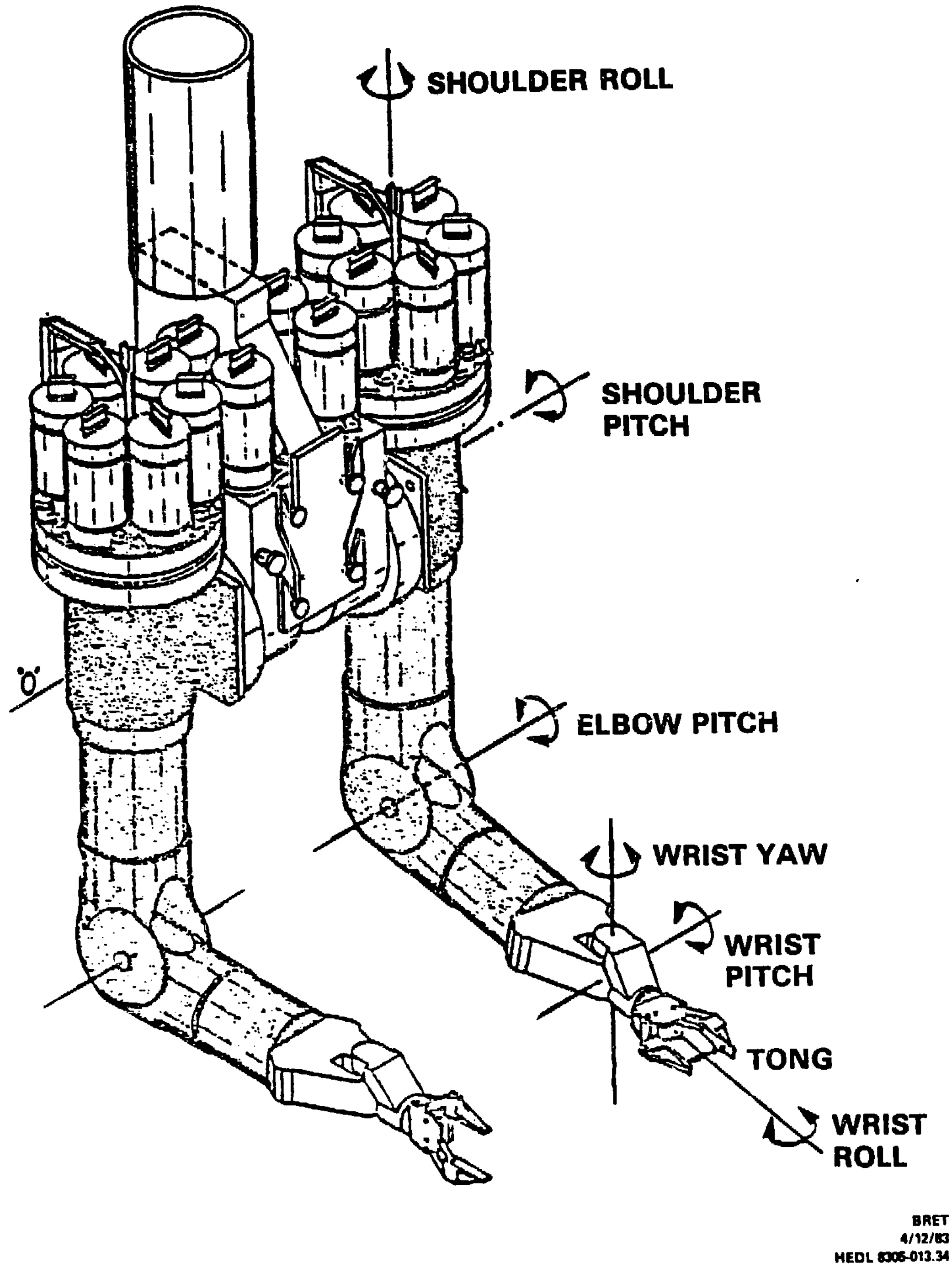


Figure 6: Advanced Servomanipulator (ASM) Design Proposed for Use in BRET

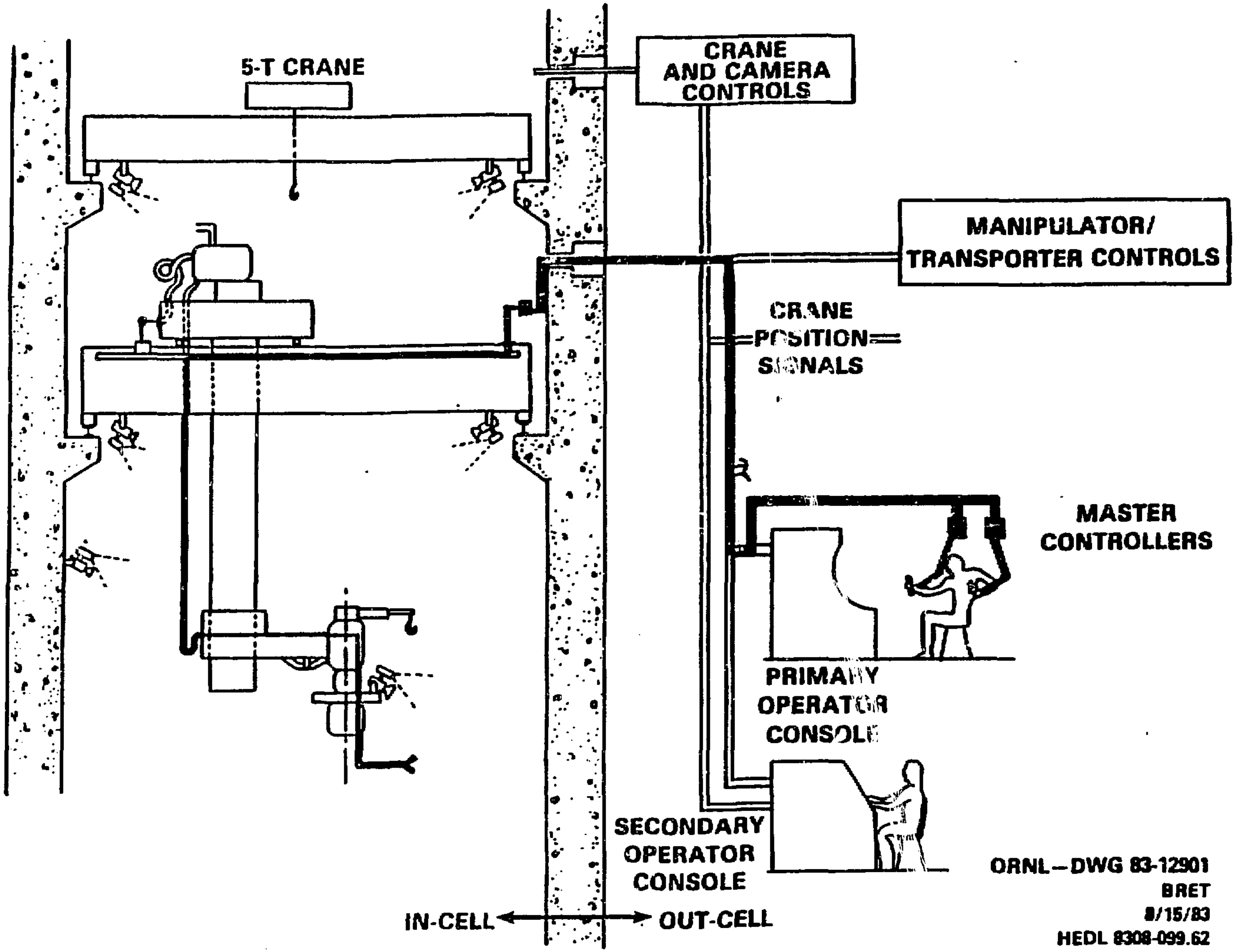


Figure 7: MP Cell Maintenance System Schematic

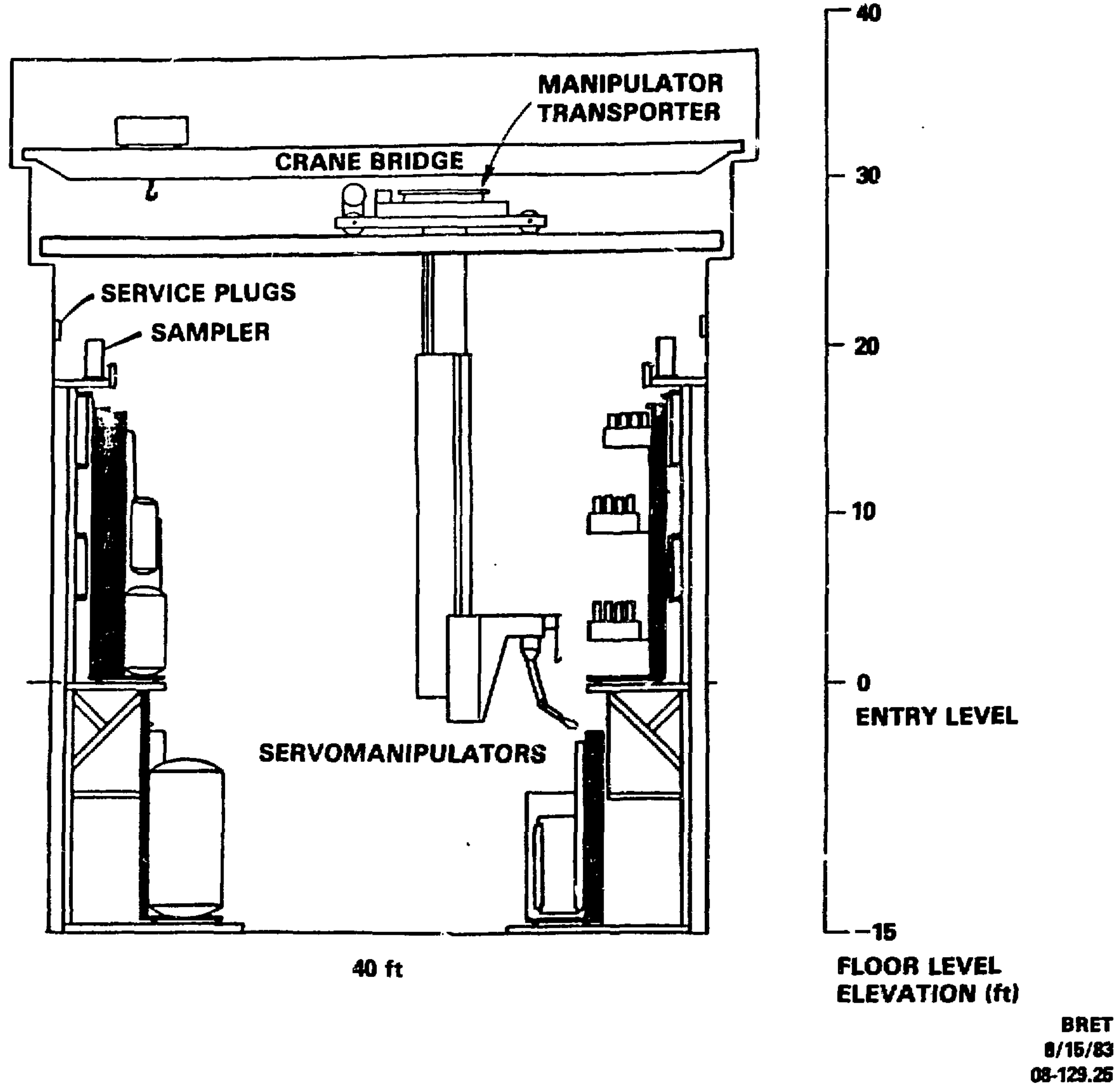


Figure 8: End View of MP Cell Showing Equipment Racks Along Walls and Center Aisle Maintenance

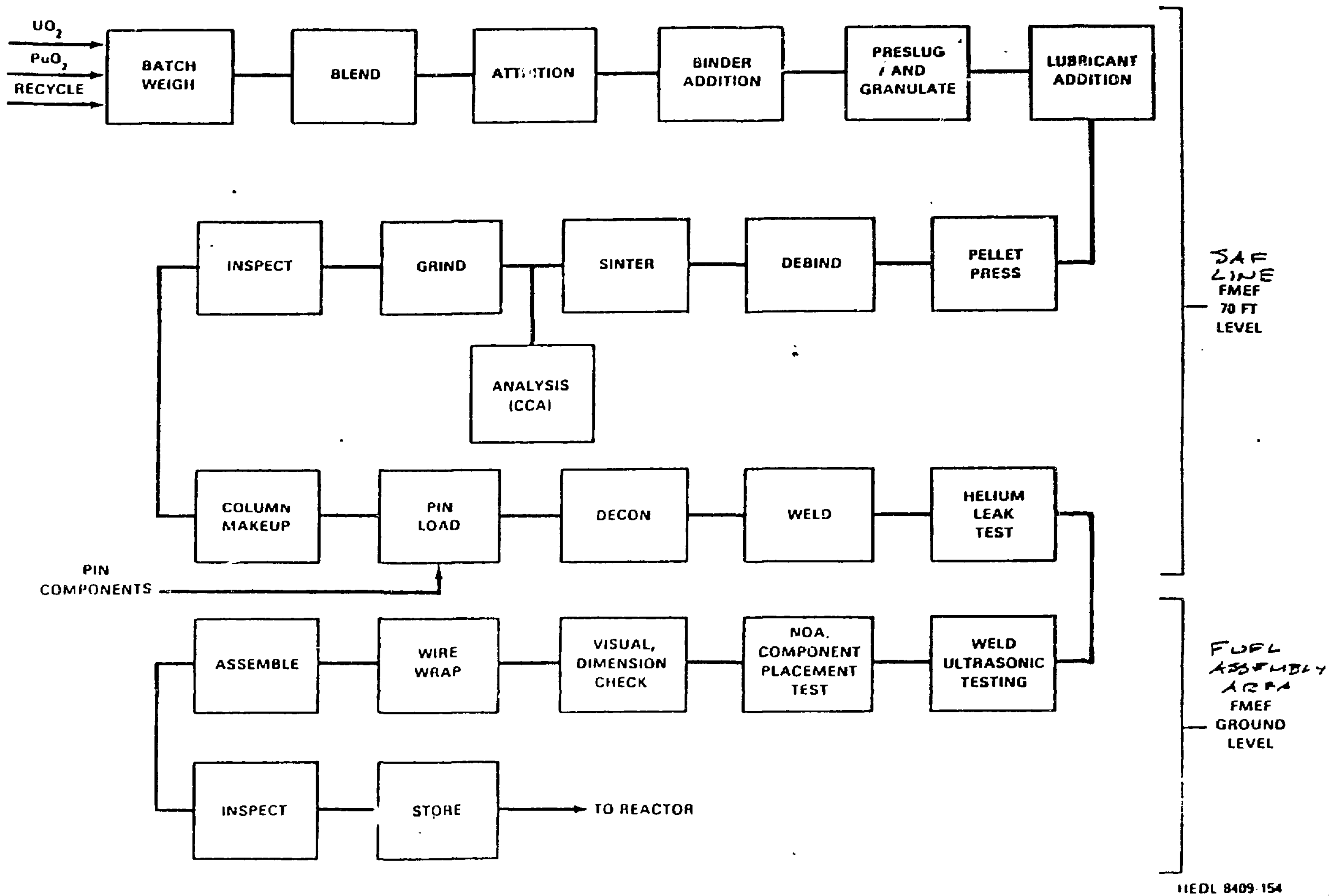


Figure 9: Simplified Process Flow Diagram for Fuel Fabrication in the FMEF

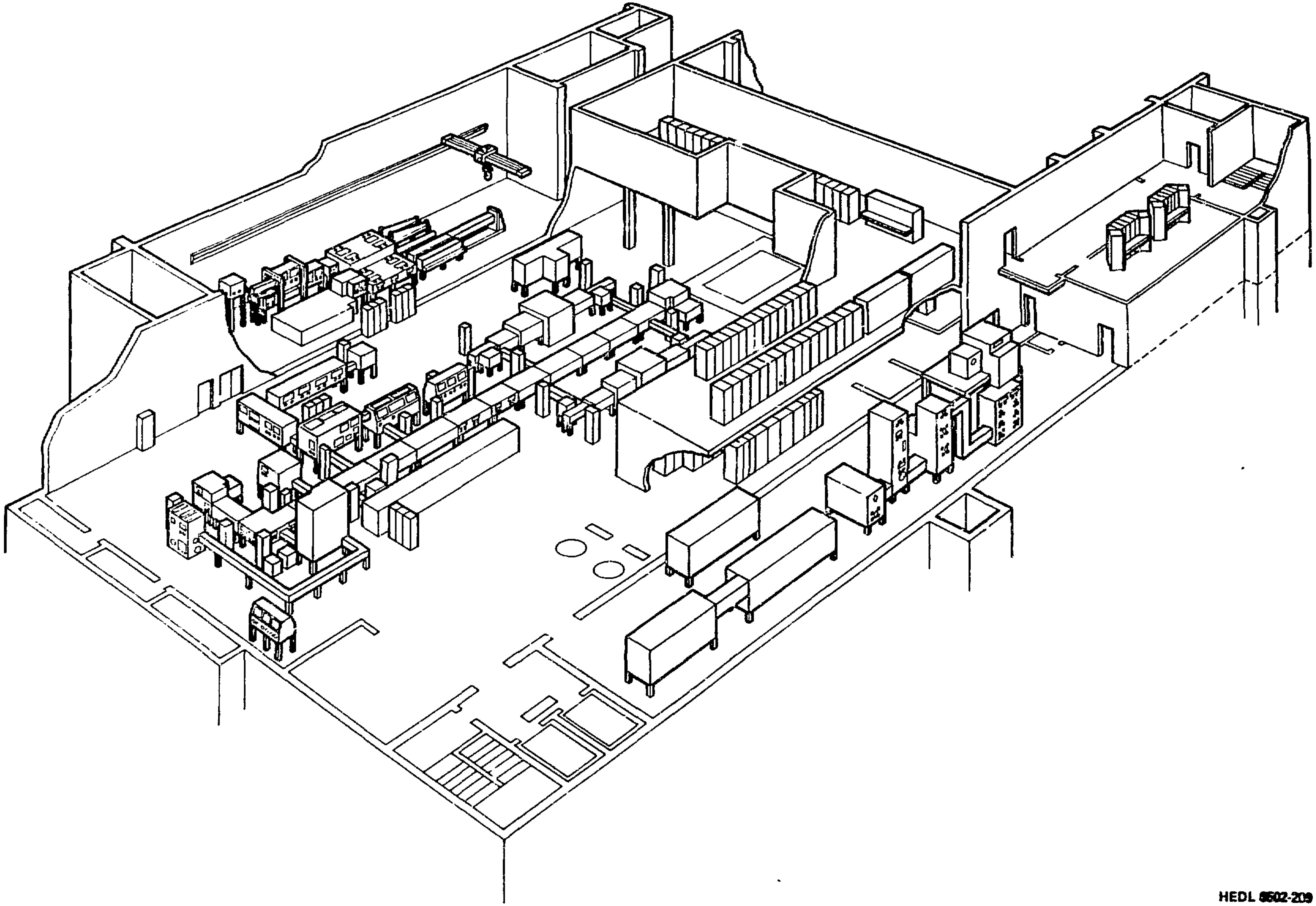


Figure 10: Isometric View of the Secure Automated Fabrication (SAF) Line

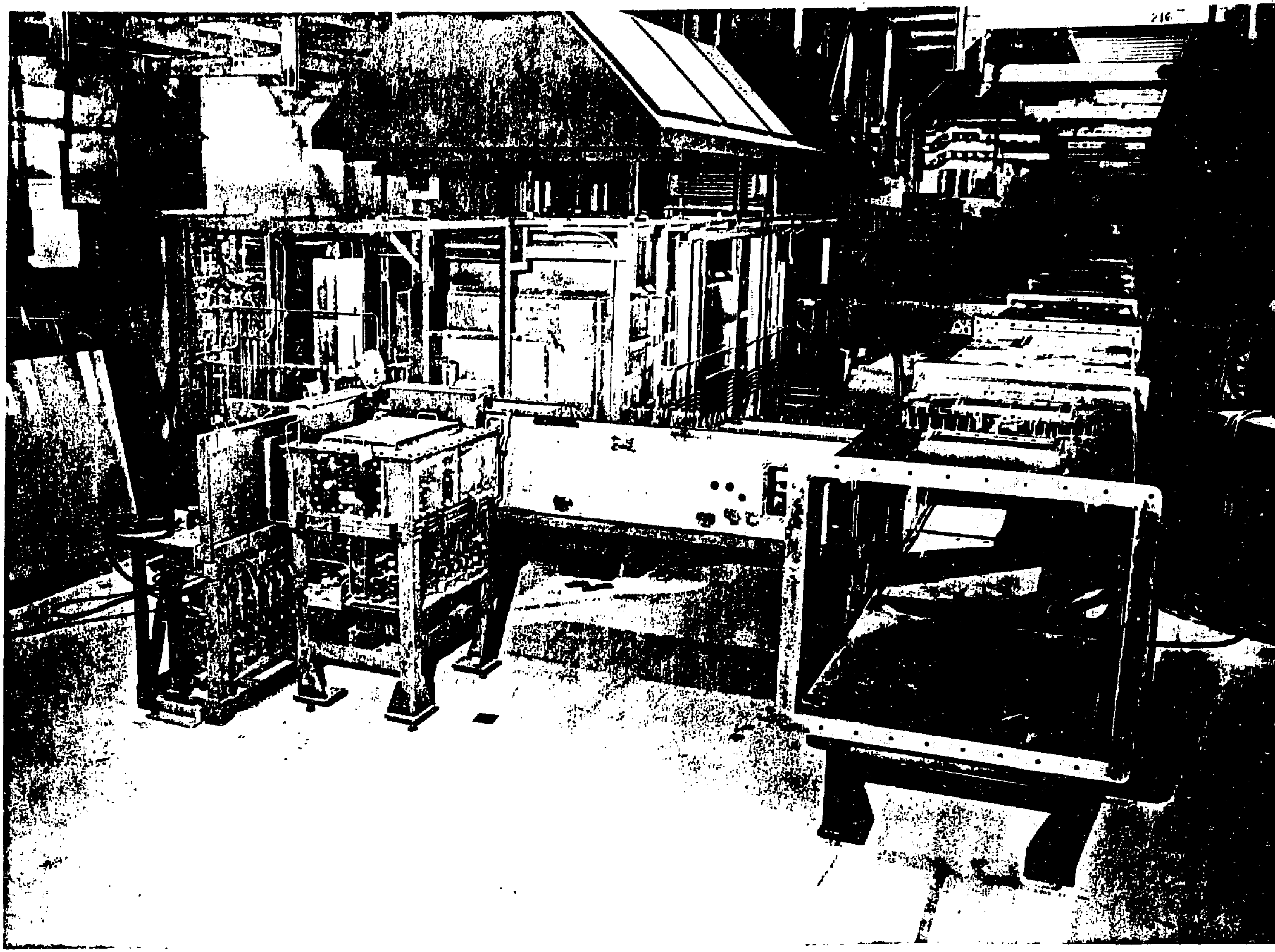

Figure 11: High Temperature Continuous Sintering Furnace in SAF

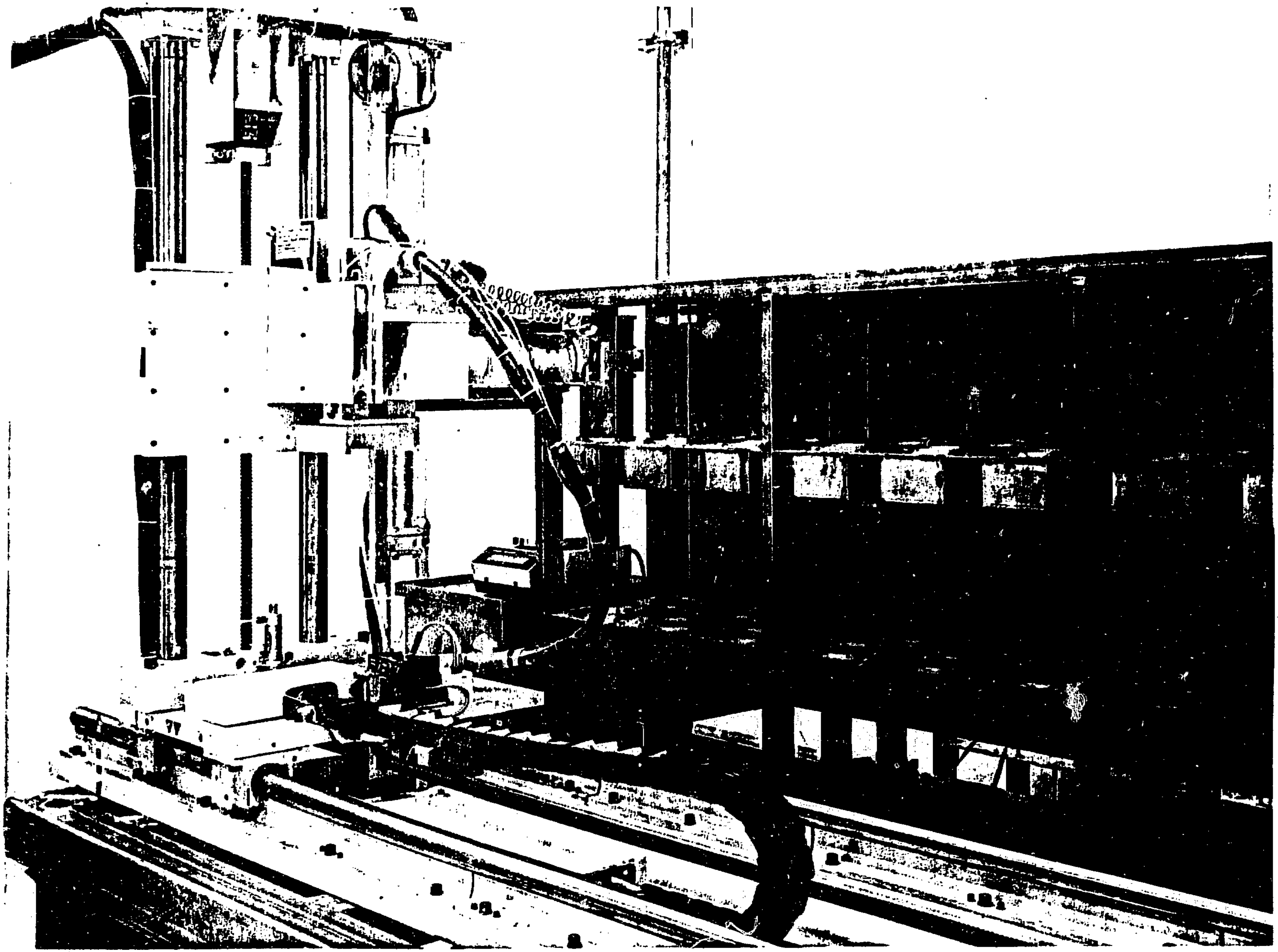

Figure 12: Robot Used in SAF

# CONTROL SYSTEM

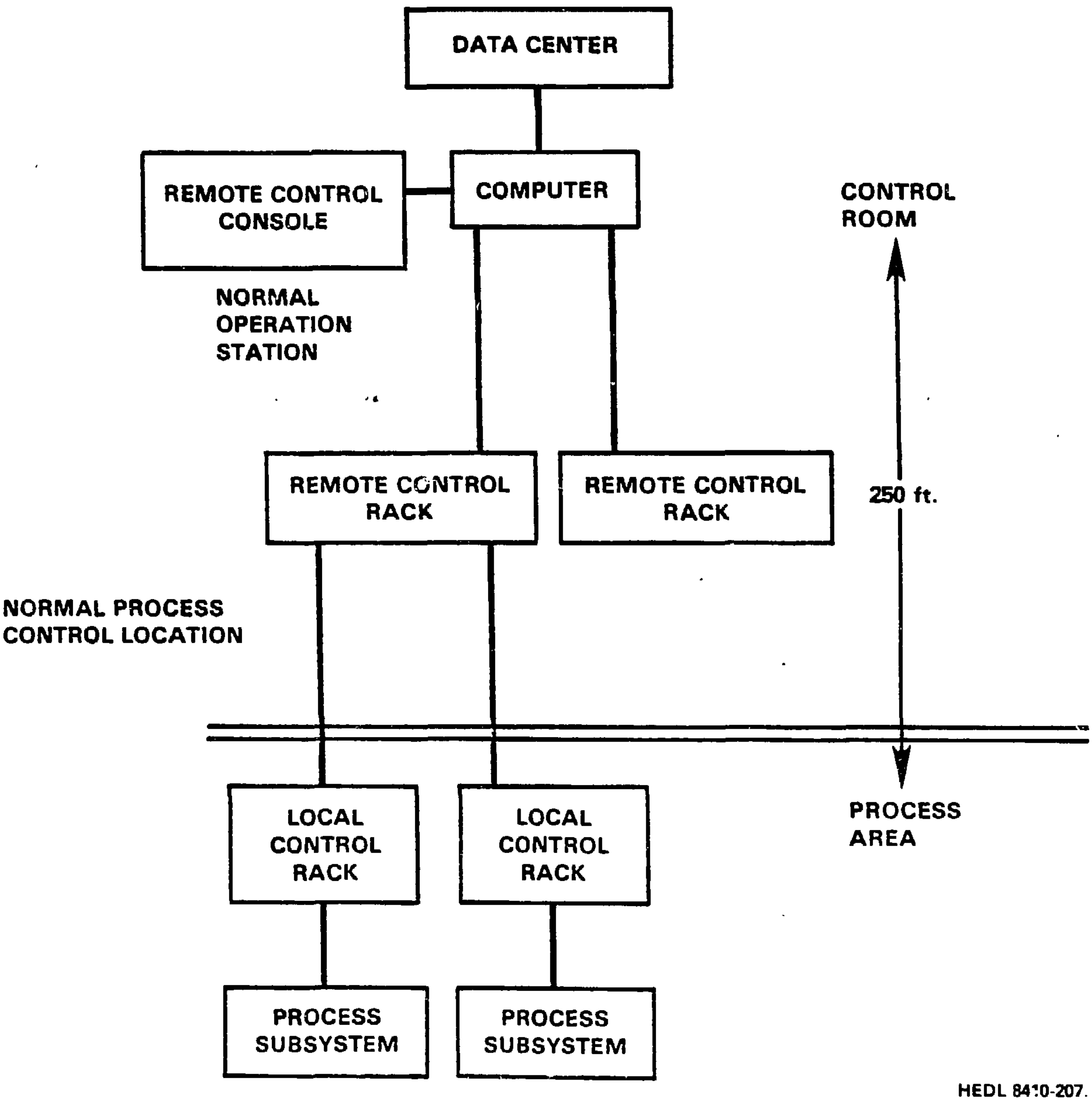


Figure 13: Schematic of SAF Control System

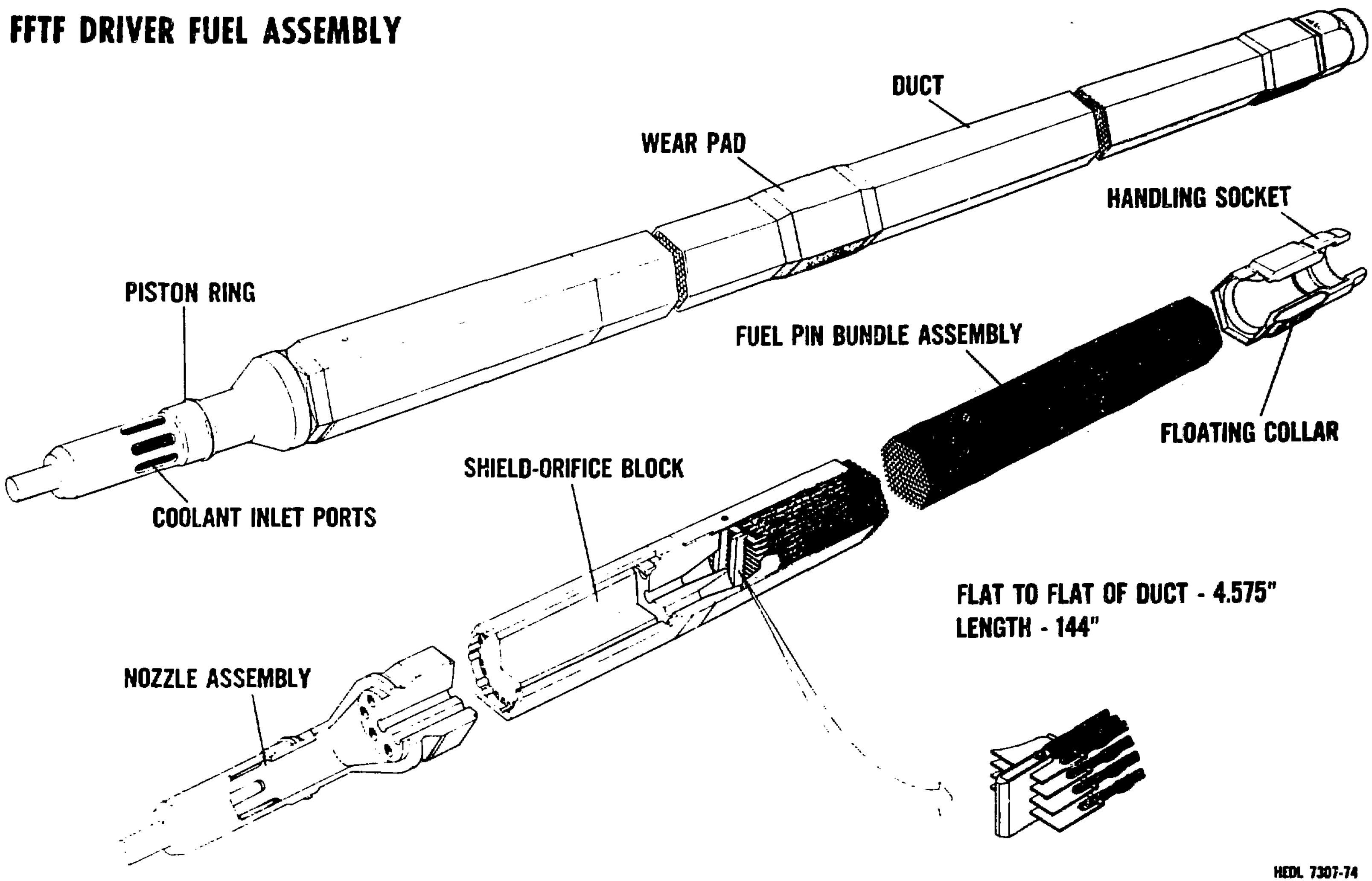


Figure 14: FFTF Fuel Assembly

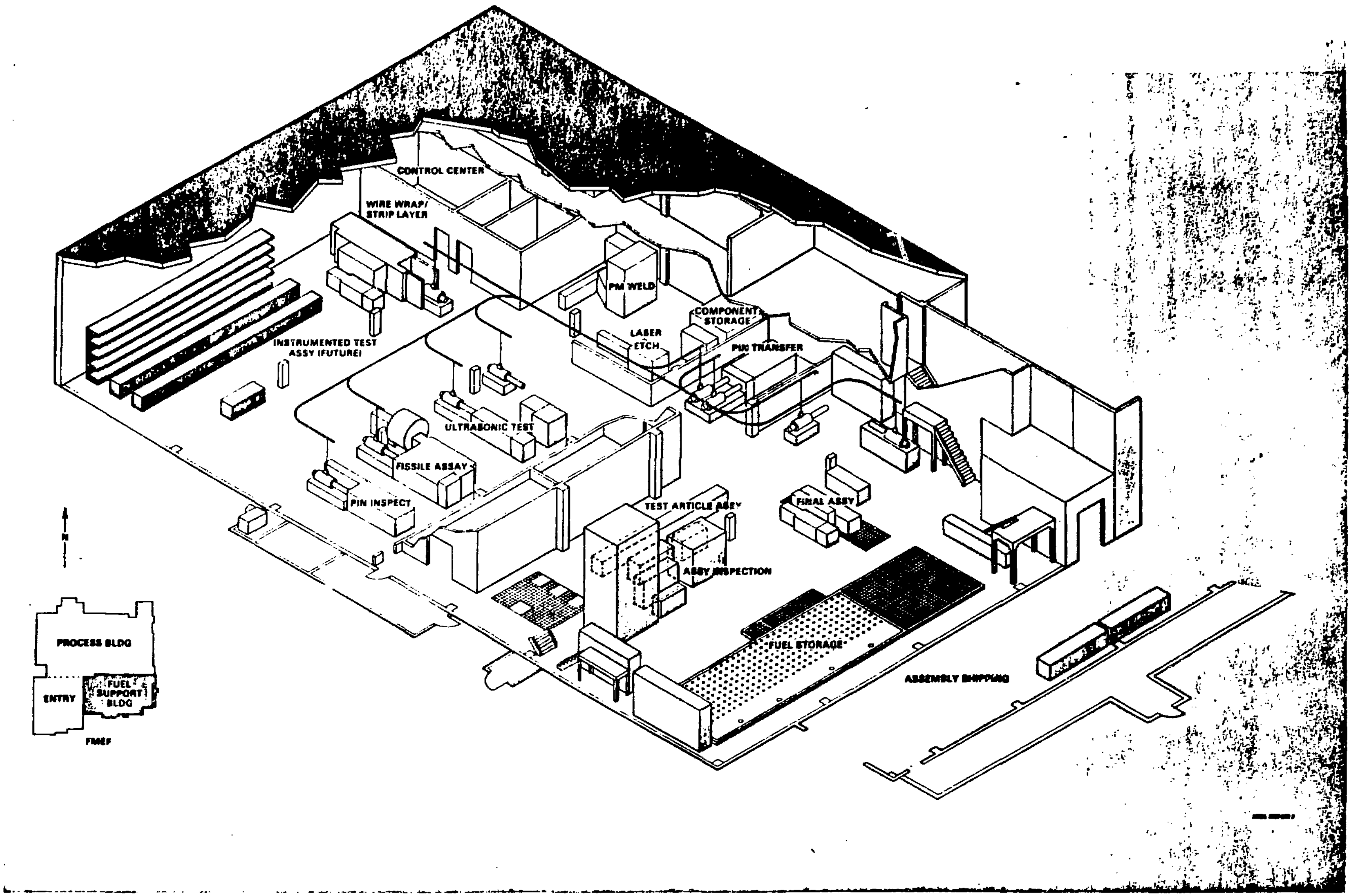


Figure 15: Isometric View of Fuel Assembly Area in FMEF

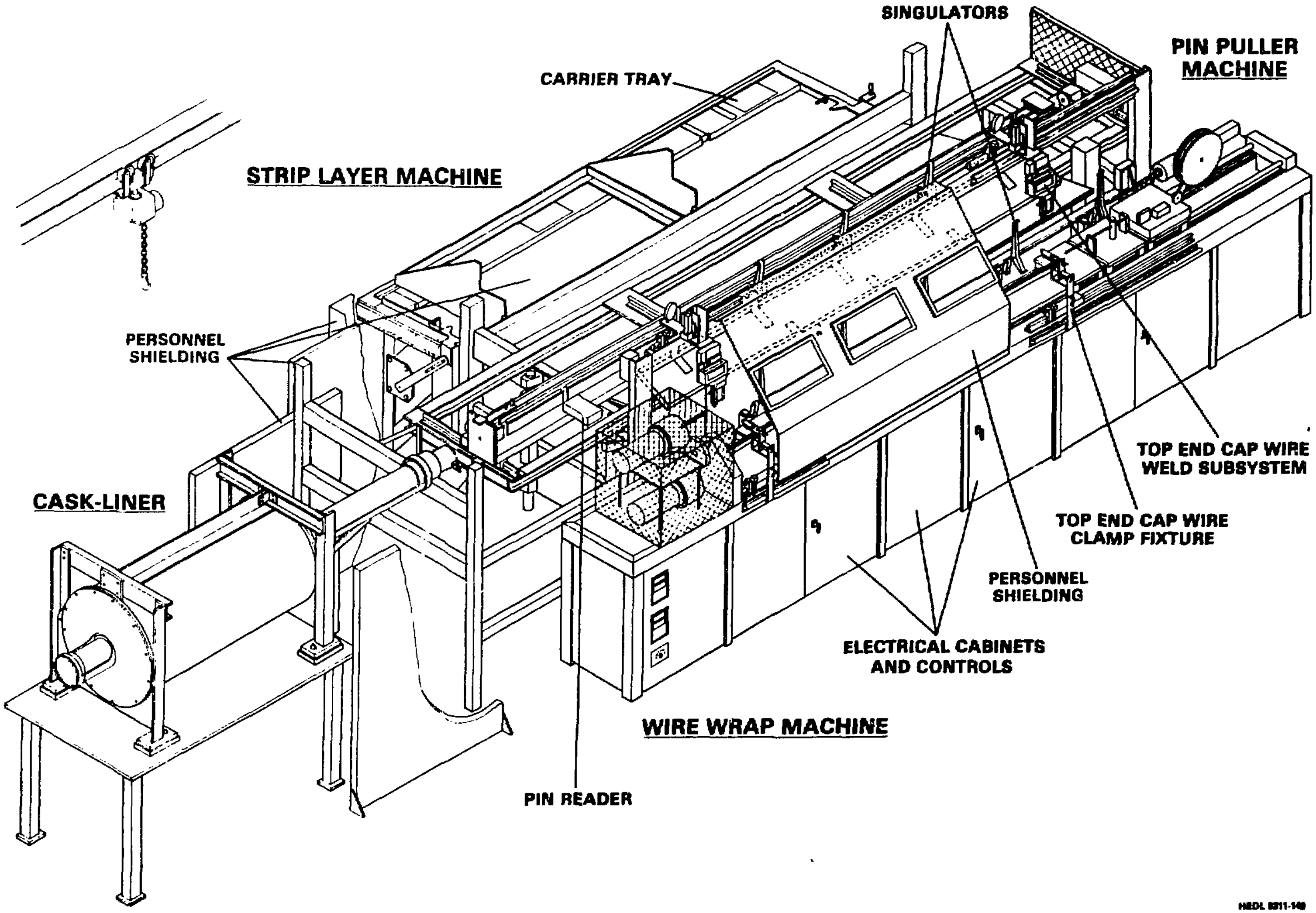


Figure 16: Fuel Supply Wire Wrap Strip Layer Station