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Consolidated Fuel Reprocessing Program

# CONCEPT FOR A SMALL, COLOCATED FUEL CYCLE FACILITY FOR OXIDE BREEDER FUELS[*]

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# CONCEPT FOR A SMALL, COLOCATED FUEL CYCLE FACILITY FOR OXIDE BREEDER FUELS*

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## ABSTRACT

As part of a United States Department of Energy (USDOE) program to examine innovative liquid-metal reactor (LMR) system designs over the past three years, the Oak Ridge National Laboratory (ORNL) and the Westinghouse Hanford Company (WHC) collaborated on studies of mixed oxide fuel cycle options. A principal effort was an advanced concept for a small integrated fuel cycle colocated with a 1300-MW(e) reactor station. The study provided a scoping design, capital and operating cost estimates, and a basis on which to proceed with implementation of such a facility if future plans so dictate. The facility integrated reprocessing, waste management, and refabrication functions in a single facility of nominal 35-t/year capacity utilizing the latest technology developed in fabrication programs at WHC and in reprocessing at ORNL. The concept was based on many years of work at both sites and extensive design studies of prior years.

## INTRODUCTION—PURPOSE OF SCOPING STUDY

An advanced concept for a mixed oxide fuel cycle facility colocated with an LMR generating station was developed as one of several options examined under a USDOE program to seek appropriate future LMR and fuel cycle strategies. This work was done primarily in 1985 and early 1986 by an ORNL-WHC team to support reactor design studies done concurrently by Rockwell International Corporation and General Electric Company. The concept addressed the needs of a single 1300-MW(e) generating station and was applicable to any of the specific reactor designs being developed. The initial capacity chosen (35 t/year) later turned out to be larger than that needed (20 t/year) with the refined core management schemes developed.

The concept integrated reprocessing, refabrication, and fuel cycle waste management functions in a single facility physically on the generation station site. This paper presents the general design features of both the facility and processing equipment as the basis from which the capital and operating costs were developed. Because of the advanced state of development programs at WHC and ORNL as well as past design and facility activities, the concepts were based on sound, well-understood principles.

## PRIOR WORK BY PARTICIPANTS

This study was undertaken immediately following a collaborative effort by ORNL and WHC in the conceptual design of a proposed major addition to a WHC facility, the Breeder Reprocessing Engineering Test (BRET),[1] which had similar requirements to the "colocated" facility. This provided a wealth of background directly applicable to this study. Of all the systems in the facility, the fabrication equipment was probably most fully developed. For the past decade, WHC has been developing fabrication techniques and producing mixed oxide fuels. The recently completed Secure Automation Fabrication (SAF) line in the Fuels and Materials Examination Facility (FMEF) at WHC with the capability of making 5 to 10 t/year of core fuel has been undergoing tests. (Recent USDOE decisions will indefinitely delay actual startup.) With the excellent fuels performance experienced in the Fast-Flux Test Facility (FFTF) and the capability of producing follow-on cores, the U.S. technology in mixed oxide refabrication is largely developed. Actual operation would have permitted further refinements and, undoubtedly, cost reductions.

Breeder reprocessing development has been in progress at ORNL through the Consolidated Fuel Reprocessing Program (CFRP). The background information from the extensive development activities in mechanical head-end

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disassembly and shearing, solvent extraction contactors, off-gas retention, and other related reprocessing functions was utilized in the scoping design in this study.

## FACILITY FUNCTIONS AND REQUIREMENTS

The facility was designed to handle the normal recycle requirements of the on-site reactors, which had electrical generating capacity of 1300 MW(e). All fuel cycle logistics were defined by the reactor vendors. Initial capacity requirements, which formed the basis for the study, were 35 t/year. Later refinements showed this to be considerably oversized, with capacity needs of only 20 t/year. The facility was a free-standing building on the reactor site but with no common walls with any other facility. Normal services such as water, power, and steam were provided by the site. The major functions and requirements are listed in Table 1.

**Table 1. Function and requirements of the colocated facility**

1. Receive sodium-wetted fuel and blanket assemblies
2. Remote external sodium contamination
3. Provide surge storage for 100 spent fuel elements and other in-process surge where needed
4. Reprocess up to 35 metric tons of heavy metal (MTHM)/year to recover and decontaminate uranium and plutonium
5. Process all wastes by packaging in final form
6. Fabricate up to 130 subassemblies/year
7. Provide all safeguards requirements for such facilities
8. Provide support services such as analytical chemistry and maintenance

## OVERALL FACILITY FEATURES

The design features chosen were largely a result of the past development programs at ORNL and WHC. Many features were devised as part of the earlier BRET project, but they could be further refined when applied to a completely new facility. Technology ranged from well-proven processes and equipment for the most part to some innovative concepts under development that would be available in the near future. The overall facility cross section depicted in Fig. 1 shows the general arrangement. Reprocessing, fuel fabrication, and waste management are combined into a continuous, integrated process housed in a facility tailored to meet space and operational needs. A key feature of the reprocessing system is the remote maintenance concept shown schematically in a cross section of the reprocessing cell (Fig. 2). Servomanipulators mounted on an overhead bridge system are moved throughout the cell to permit replacement or maintenance of any failed process component. Process equipment is mounted on racks or modules positioned adjacent to either wall. A hot maintenance cell located above the cell provides capability for repair of major equipment removed from the process cell. This arrangement of the hot maintenance cell and its interfaces with the reprocessing cell is an updated concept developed from previous facility designs and layouts.

The reprocessing equipment is similar to that described in many prior papers reporting work of the ORNL's Consolidated Fuel Reprocessing Program. Key technologies employed are listed in Table 2.

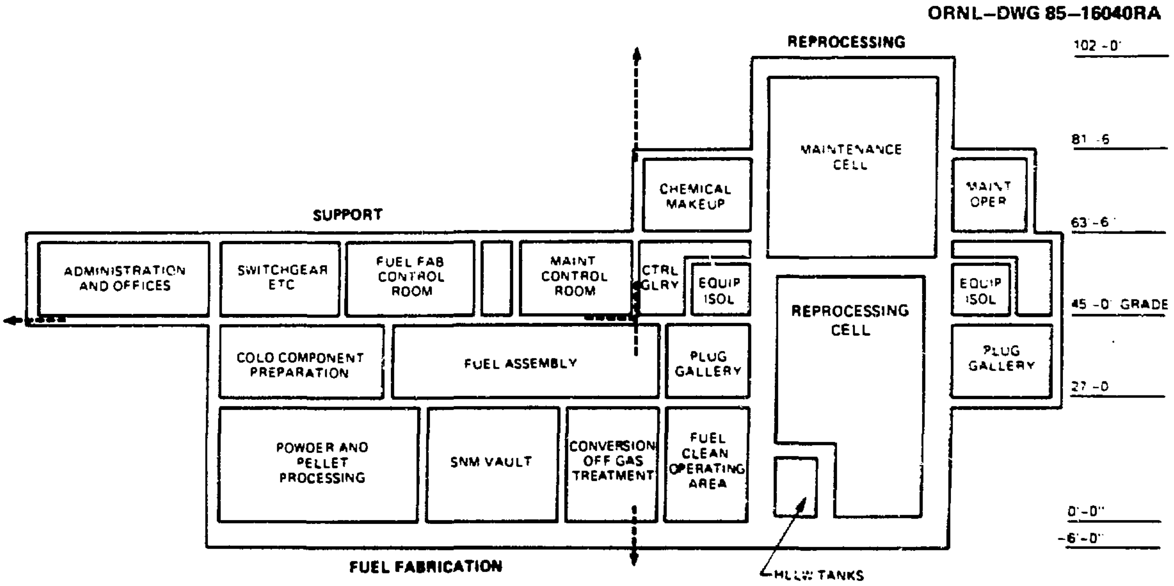

Fig. 1. Overall facility cross section.

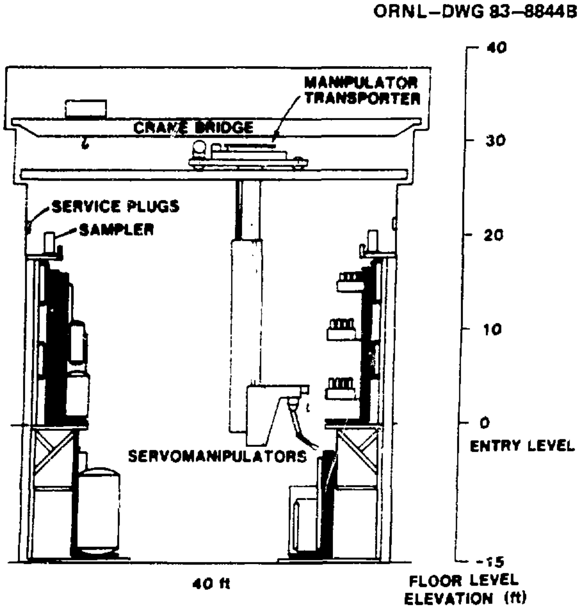

Fig. 2. Cross section of the reprocessing cell.

**Table 2. Key reprocessing technologies developed in the CFRP**

1. Integrated mechanical head-end
    Laser disassembly
    Bundle shear
2. Continuous rotary dissolver
3. Solvent extraction using centrifugal contactors
4. Near-total acid and water recycle
5. Automated sample collection vehicle
6. Sealed cell cooling and ventilation system

Similarly, mixed oxide refabrication development at WHC has produced several key equipment systems that reflect the advanced state of technology deployed in the SAF line. These key equipment systems are listed in Table 3.

**Table 3. Key refabrication technologies in the SAF line**

1. Automated pellet sintering in a continuous furnace
2. Sinter to size pellet fabrication
3. Automated pellet weighing and inspection
4. Solid-state pulsed magnetic welding of fuel pins
5. Extensive use of robots
6. State-of-the-art remote control systems
7. Rapid chemical analysis of fuel pellets

## REPROCESSING—WASTE MANAGEMENT SYSTEMS

Some of the main reprocessing components are pictured in the accompanying photos from the development programs that are described below.

### Integrated Head-End System

The initial steps in reprocessing involve mechanical subdivision of the fuel element subassembly into small pieces that can then be routed through several chemical separation steps. The hexagonal shroud is removed using a laser to make cuts both circumferentially and longitudinally. The laser is also used to cut off the end fixtures. Following this, the entire bundle of pins is fed to a hydraulic-actuated shear where pins are cut into 1-in.-long segments for subsequent dissolution. The multikilowatt unfocused laser beam is directed with mirrors to the location to be cut where it is focused to a 0.030-in. beam which can cut the 0.125-in.-thick metal at a rate of several feet per minute. Figure 3 is a photo of a laser cut using the 10-kW carbon dioxide laser at the ORNL facilities.

### Centrifugal Contactors for Solvent Extraction

An improved model of the centrifugal contactor has been developed over the past five years in work involving ORNL, Savannah River Laboratory (SRL), and Argonne National Laboratory (ANL). These small contactors, which are similar in some ways to the well-proven plant models at SRL, are pictured in Fig. 4 in a single cycle of solvent extraction. In this test system, 14 individual units are arranged in banks to provide extraction, scrub, and strip functions; over 100 of the individual units are required in a complete plant, but they are more compact than alternate contactors. One of their major advantages is the small holdup volume that both minimizes solvent damage from radiation and provides for very rapid start-up and shutdown.

### Center-Aisle Maintenance System

The key equipment component in the maintenance system shown earlier in Fig. 2 is the servomanipulator. These newly developed devices provide much the same capability as do standard through-the-wall manipulators, but, on the over-head crane system, they can be moved throughout a large reprocessing cell and be used to maintain equipment in any position. In addition, the new developments have increased reliability and maintainability through use of modular design and gear and torque-tube drives; such manipulators can be repaired in-cell with another manipulator. Ongoing tests show the capabilities of these systems to meet all needs and development goals. A close-up view of the slave arms is shown in Fig. 5 and of the control station in Fig. 6.

## REFABRICATION EQUIPMENT SYSTEMS

Many of the fuel fabrication components included in the design study were based upon highly automated and remotely controlled equipment developed as part of the SAF Program. Some of these are described below.

### Powder Handling Systems

The initial steps in fuel fabrication involve mixing fuel-grade $PuO_2$ powder with ceramic grade $UO_2$ powder. Mixing is accomplished in a vee-shell blender (shown in Fig. 7) followed by jet-milling to break up agglomerates to ensure microhomogeneity. The milled powder is thoroughly mixed with binder and pore former and sent to pellet forming.

### Pellet Operations

The mixed powder is pressed into pellets using hydraulic presses. The pellets are loaded into sintering boats and transferred to a high-temperature, continuous sintering furnace (shown in Fig. 8) to produce dense, sintered pellets. The sintering process is controlled to produce sinter-to-size pellets (i.e., no grinding of pellets is necessary) and pellets with the proper oxygen-to-metal ratio. An automatically controlled boat transport system moves containers of pellets to subsequent operations in fully contained stainless steel enclosures. Pellets are sampled at a boat unloading station for measurements and analyses to verify conformance with specifications; then, they are sent to be loaded into fuel pins.

### Fuel Pin Operations

Pellets are made into fuel columns that are automatically weighed and measured. Clad tubes with the bottom-end-closure weld and lower-end nonfuel components in place are introduced into the pin loading equipment (shown in Fig. 9). The fuel column is then inserted into the clad tube, the upper pin internals are loaded, and the weld area is decontaminated. The top end cap is then welded into place using a new technique called pulsed magnetic welding. The completed fuel pin is located into a container and transferred to final pin inspection and final assembly. The final assembly operations are also highly mechanized.

### Computer Control and Process Automation

The SAF line utilizes a state-of-the-art remote control system with capability for both local control and totally remote control. The local control panels, located in the direct vicinity of the process equipment, are used for maintenance, testing, or recovery from process upsets. The totally remote control equipment (shown in Fig. 10) is used to operate all processes from a remote location. This permits isolation of the operators from the on-going operations, thereby reducing exposure to personnel.

The SAF line also makes extensive use of robotic equipment throughout the processes. Because many of the robots used perform pick-and-place operations, commercially available equipment was used. An example of this is the robot, shown in Fig. 11, used for handling canisters of fuel in the Special Nuclear Materials (SNM) storage vault. The same type of demonstrated capability was used in the LMR fuel cycle scoping study.

## TRADE-OFF STUDIES AND OPTIONS EXAMINED

Over the initial 12-month period of the study, the scoping design and cost estimates were done. In a short follow-on period, a few trade-off studies were made to examine options that would reduce costs. These studies were quite nondetailed, focusing on such concerns as reducing space requirements, alternate conversion methods, and requirements for process surge volume. Among other features, these studies produced changes that reduced the process cell length by 10 ft and the overall cost by about 10%. The team felt intuitively that further such studies might reduce costs another 10 to 15%, but the studies were not done.

## CAPITAL AND OPERATING COSTS

A primary purpose of the scoping design was to develop the basis for capital and operating costs and to produce cost estimates. Following the limited trade-off studies, final estimates for capital costs were determined. These estimates are shown broken down by major functions in Table 4. These estimated costs represent all facility capital costs including all design, construction, fabrication, installation, and a contingency of about 30%. All costs are in 1985 dollars.

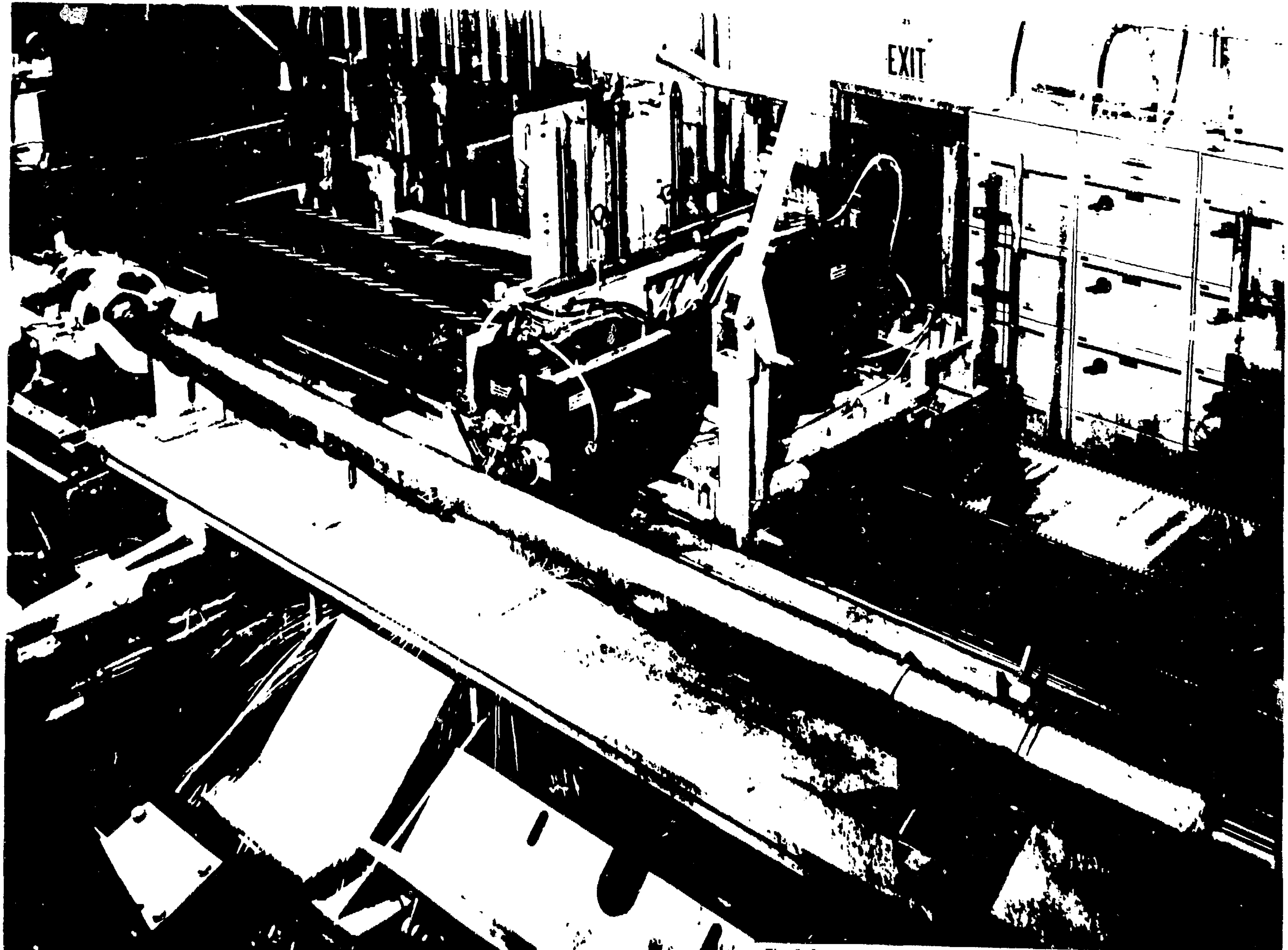

Fig. 3. Laser cut using the 10-kW carbon dioxide laser at the ORNL facilities.

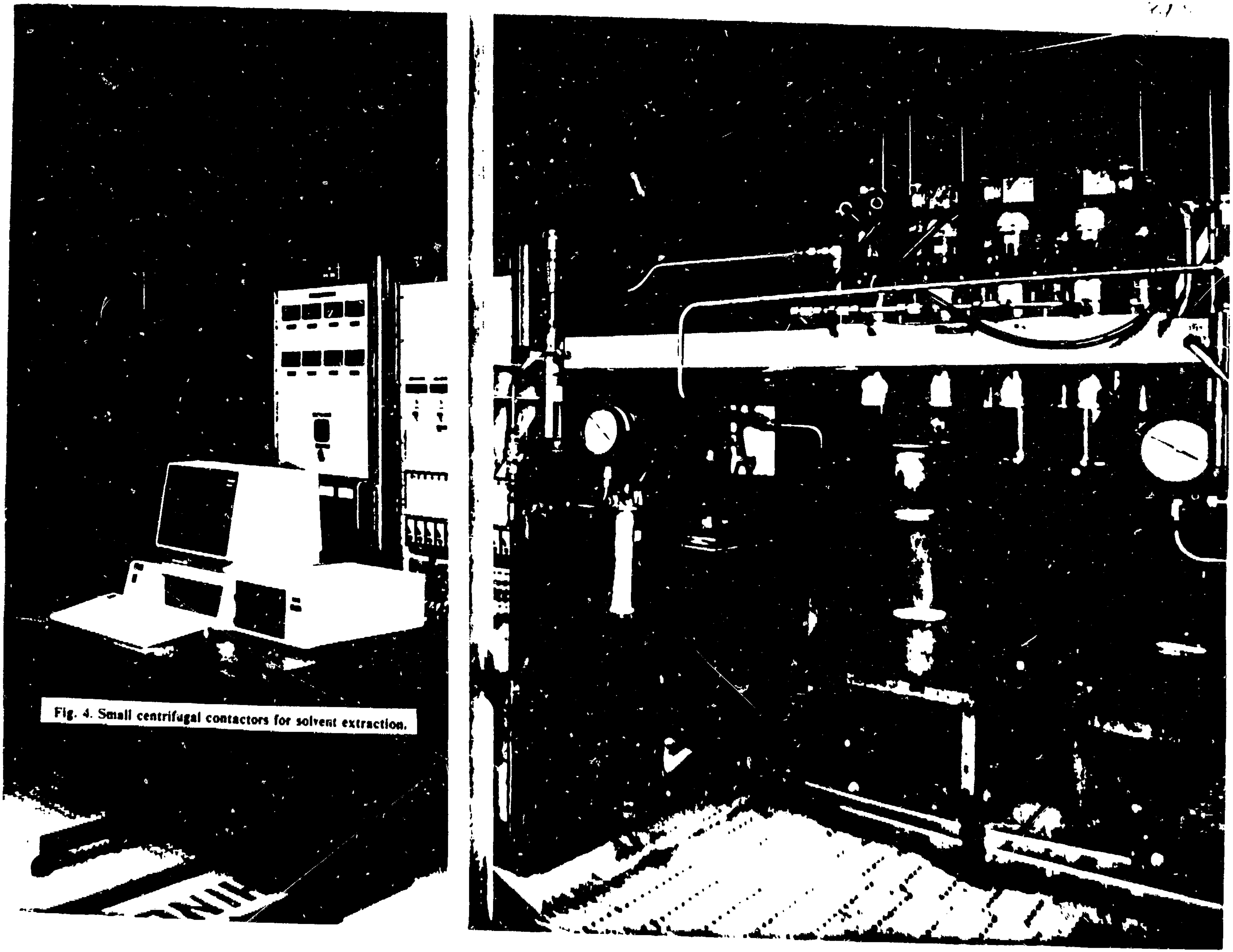

Fig. 4. Small centrifugal contactors for solvent extraction.

Fig. 5

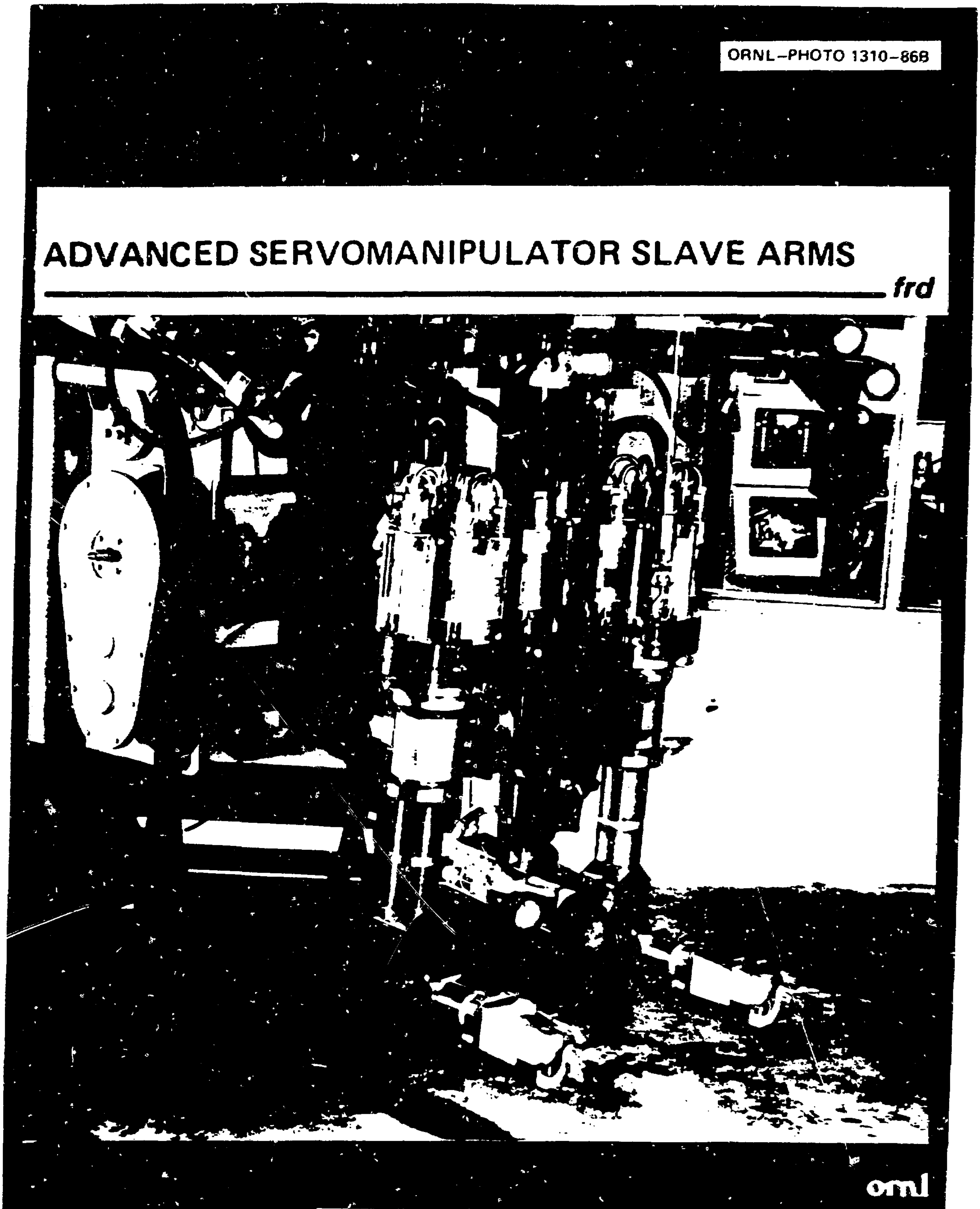

Fig. 5. Advanced servomanipulator slave arms.

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# ADVANCED INTEGRATED MAINTENANCE SYSTEM CONTROL ROOM

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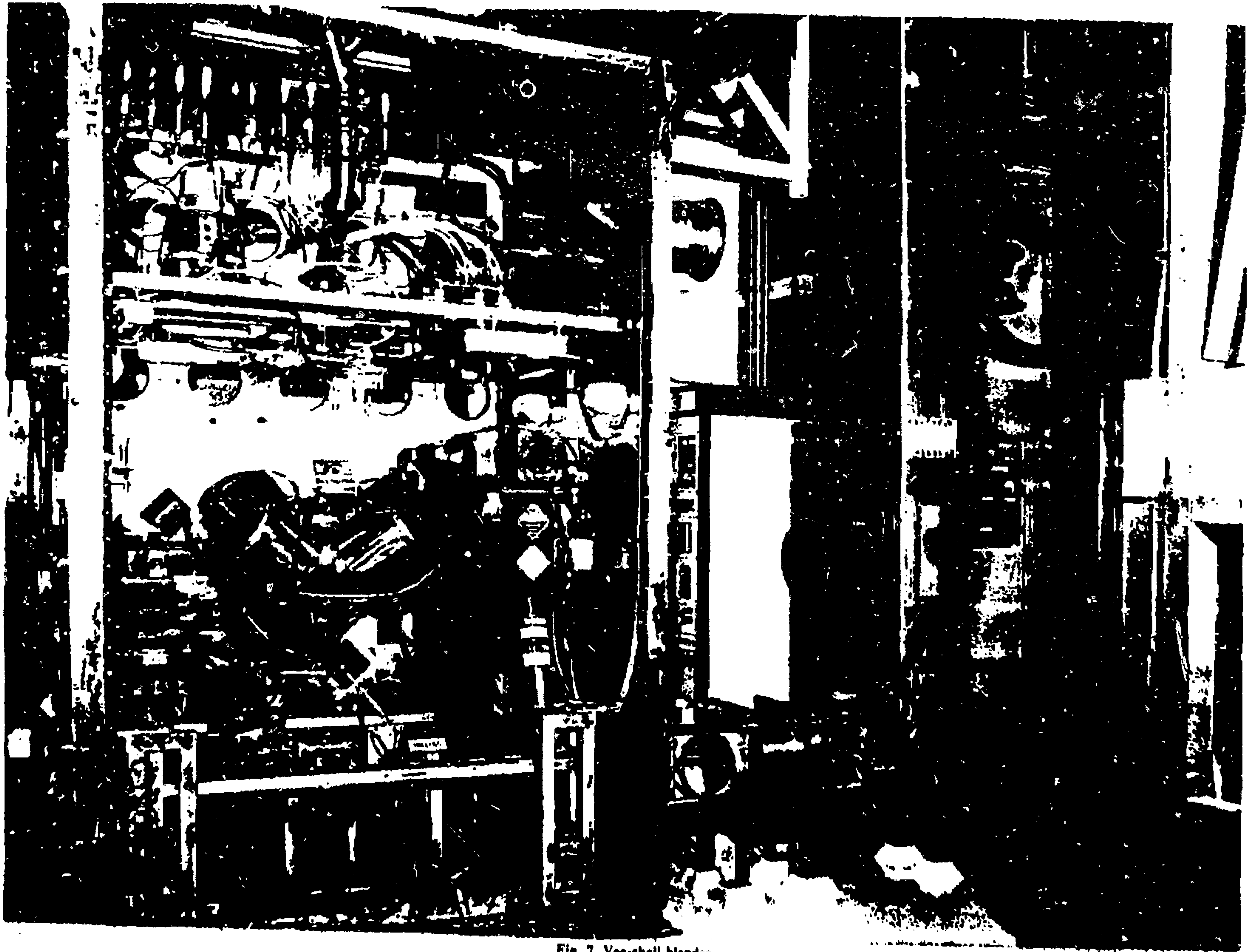
Fig. 6. Advanced integrated maintenance system control room.



Up

Fig. 7. Vee-shell blender.

Figure 7

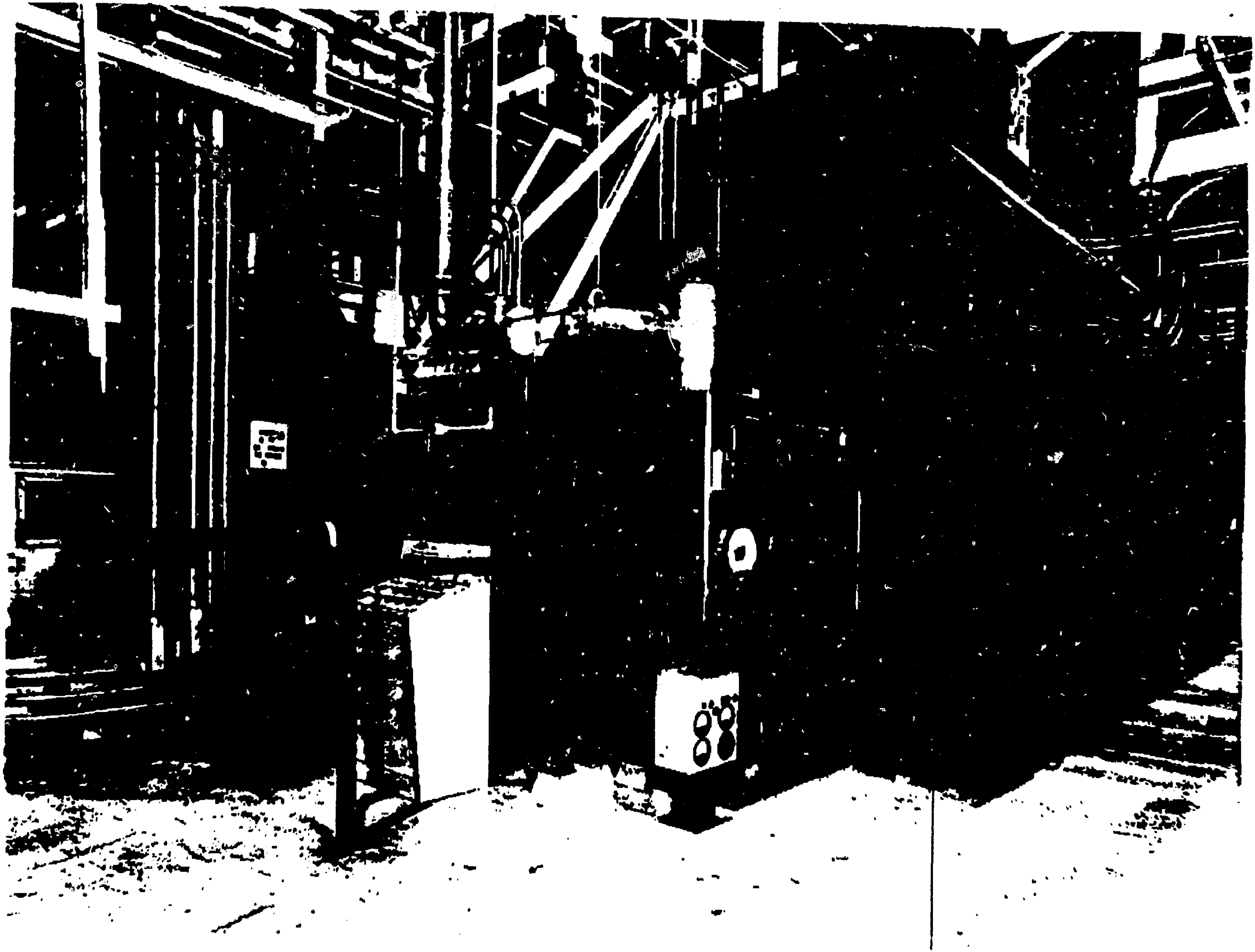


Fig. 8. High-temperature, continuous sintering furnace.

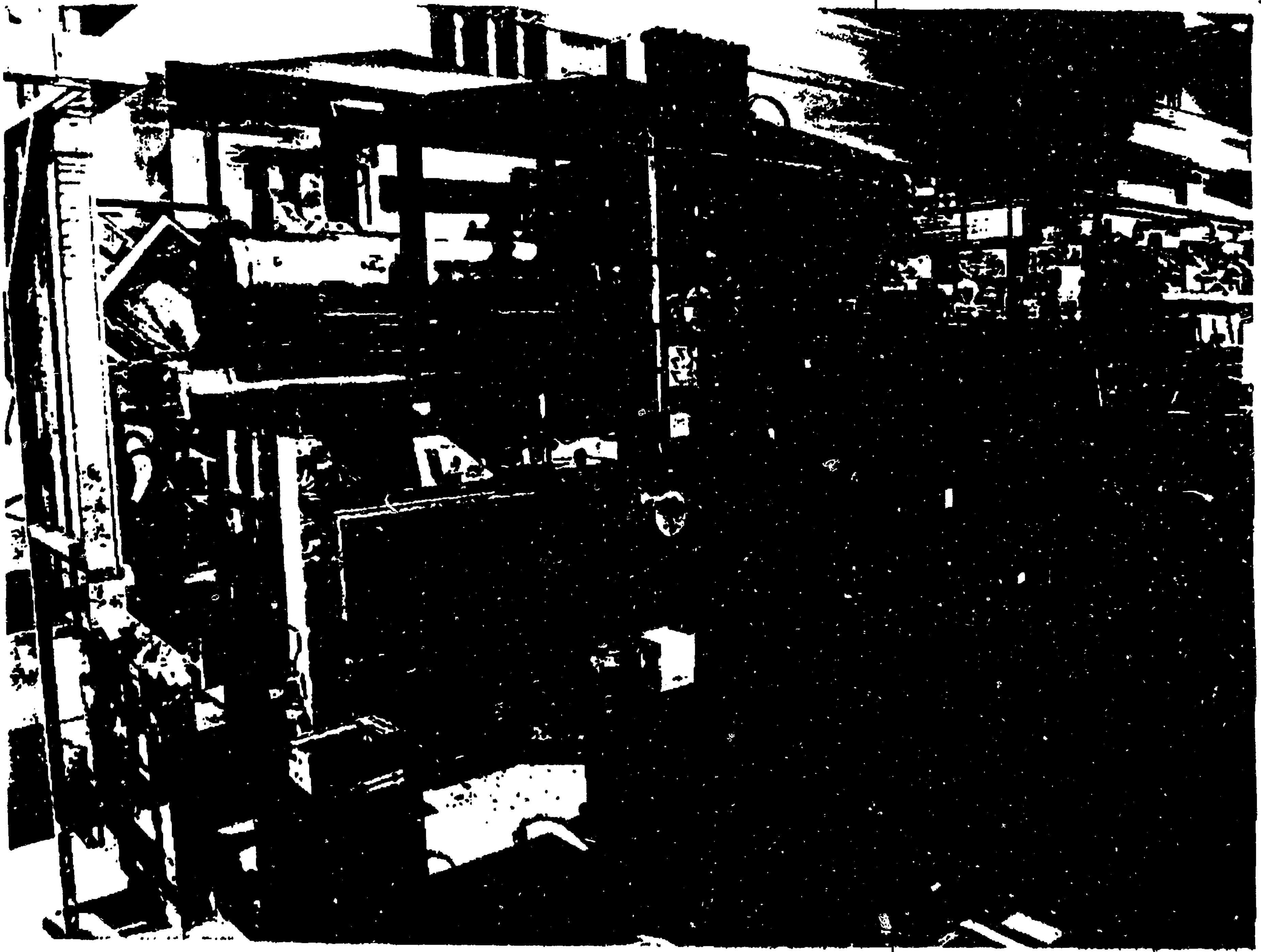


Fig. 9. Fuel pin loading equipment.

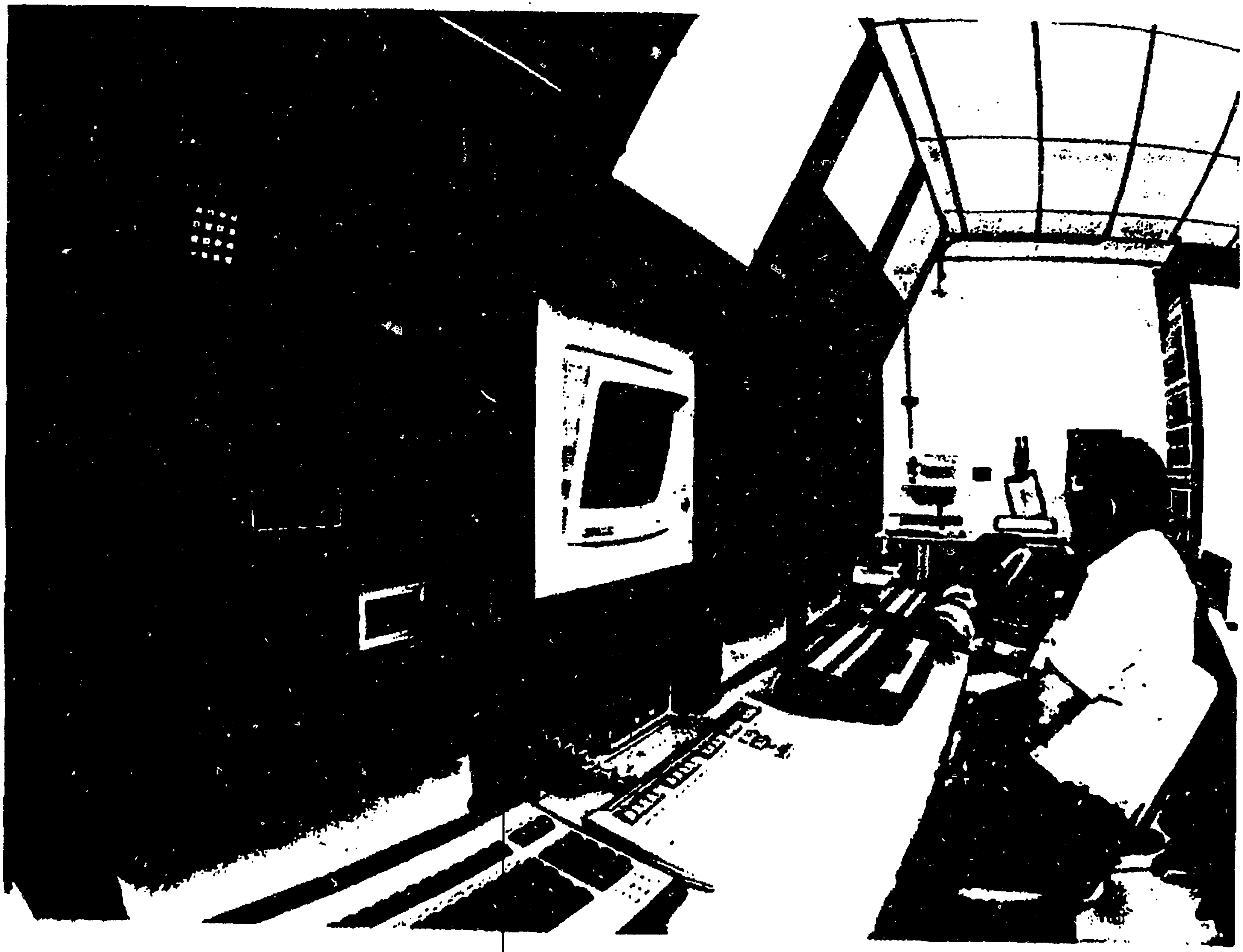


Fig. 10. Remote control console with touch screen controls.

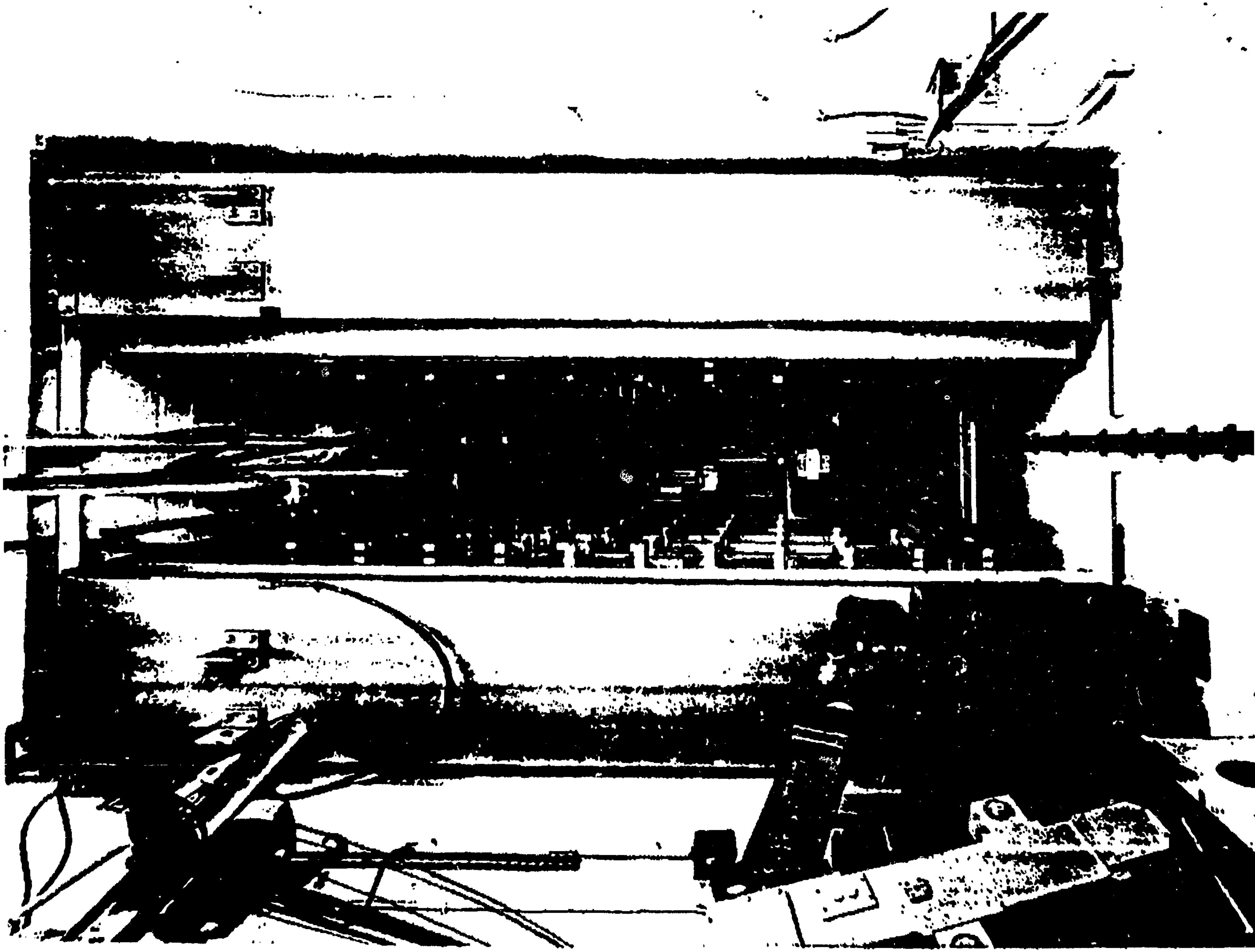


Fig. 11. Fuel handling robot in SNM storage facility.

**Table 4. Capital Costs for the Colocated Fuel Cycle Facility**

| Element | Costs ($000) |
|---|---|
| Facility design and construction | $110,300 |
| Fuel reprocessing | 116,200 |
| Fuel fabrication | 40,000 |
| Waste management | 29,900 |
| Total | $296,400 |

A minimal effort was spent in examining cost differentials for facilities of other capacities. This did not entail detailed designs and basic new cost estimates. For that reason the validity is not established. The estimates as made were as follows:

| Capacity (t/year) | Total Cost ($000) |
|---|---|
| 35 (base case) | 296,400 |
| 25 | 278,900 |
| 50 | 310,800 |

Subsequent reactor vendor studies showed a need for even smaller capacity–more nearly 20 t/year. It might be inferred that the facility cost for that capacity should be about $260 million to $270 million. No studies were made to confirm that.

Operating costs were estimated by making detailed estimates of annual operating manpower requirements (330 man-years), adding consumables, fuel element hardware, and other standard operating costs. These estimates totaled to about $30 million annually ($15.5 million for reprocessing and waste management, and $14.5 million for fabrication). Of the latter costs, nearly half was in fuel element hardware.

## TOTAL FUEL CYCLE COSTS

Total fuel cycle costs were estimated for a range of scenarios too detailed to reproduce here. One example, where financing is defined as regulated-high (fixed charge rate of 9.8%, equivalent to 4% interest rate and 8% return on equity), is shown in Table 5. These economic parameters followed the normal USDOE costing methods. Capital costs shown have been corrected to the final assumed capital cost of $265 million for a facility with throughput of 20 t/year. We recognized that operating costs represent a sizable value and are probably less well known than the capital costs. For this table, operating costs were reduced 20% from the prior estimates developed for a throughput of 35 t/year. For all cases, facility capital costs were broken down somewhat arbitrarily one-third to fabrication and two-thirds for reprocessing and waste management. Plutonium was assumed available for intial core loading at $25/g. Decommissioning costs equal to one-tenth initial capital were assumed.

**Table 5. Total fuel cycle costs**

| Element | Cost (mils/kWh) |
|---|---|
| Capital Costs | |
| Reprocessing and waste management | 2.68 |
| Fabrication | 0.92 |
| Operating Costs | |
| Reprocessing and waste management | 2.14 |
| Fabrication | 1.45 |
| Driver components | 0.79 |
| Blanket elements (purchased) | 1.41 |
| High Level Waste Disposal | 1.00 |
| Sub-total | 10.39 |
| Plutonium Inventory Charges | 2.10 |
| Overall Total | 12.49 |

It is quite clear that such fuel cycle costs are highly dependent on the economic parameters chosen and the scope of the fuel cycle costed. Various economic parameters can swing the costs by almost a factor of 2. Space does not permit adequate treatment of the cost estimates examined. In perspective, the total power costs for these systems are in the range of 50 mils/kWh. Fuel cycle costs of some 25% of the total do not appear unreasonable. While the scoping nature of this study might leave doubts as to the validity of the estimates, the substantial background from prior work adds greatly to the information developed in this study.

On the one hand, this estimate has been compared and found to be quite high relative to the metal fuel cycle costs produced and reported here and elsewhere by ANL. It was generally understood that a good comparison between these two studies has not been done nor could be done factoring in the different status of the technology. That will be a subject for other papers in the future. On the other hand, based on perspectives from other countries, the authors speculate that our costs might even seem low for such a small, colocated fuel cycle facility.

The study did not attempt any comparisons between the colocated fuel cycle and any centrally deployed scenarios. Hopefully, it provides another viewpoint on concepts and costs for advanced mixed oxide fuel cycle facilities sized appropriately for early stages of breeder demonstration and deployment wherever that might occur.

## REFERENCE

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