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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 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 capacity chosen initially and that on which the design was based was 35 t/year. Later, more refined core management schemes by the reactor designers showed that the actual capacity needed for the station was only 20 t/year.

The concept integrated reprocessing, refabrication, and fuel cycle waste management functions in a single facility physically on the generation station site. As far as we are

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aware, this is the first study that fully integrated all fuel cycle process and facility functions in this manner. The study focused on the facility characteristics, but all process flowsheets were prepared in detail to properly integrate the material flows and processes to the degree possible. This paper presents the general features of the process flowsheets and the facility and processing equipment as well as the facility configurations. Because of the advanced state of development programs at WHC and ORNL, 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 many requirements similar to the "colocated" facility. 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.

Breeder reprocessing development has been in progress at ORNL through the Consolidated Fuel Reprocessing Program (CFRP) for over a decade. The background information from the extensive development activities in flowsheet chemistry, mechanical head-end disassembly and shearing, solvent extraction contactors, off-gas retention, and other related reprocessing functions was utilized 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.

PROCESS CHEMISTRY AND FLOWSHEETS

The processes chosen are quite similar or variations on those used in all breeder fuel cycle facilities or designs worldwide for oxide fuels. These are shown in block flowsheet form in Fig. 1. Major emphasis in this study was in the integration of process and waste streams to minimize the overall processing systems and equipment. Steps in which those considerations were important are described briefly:

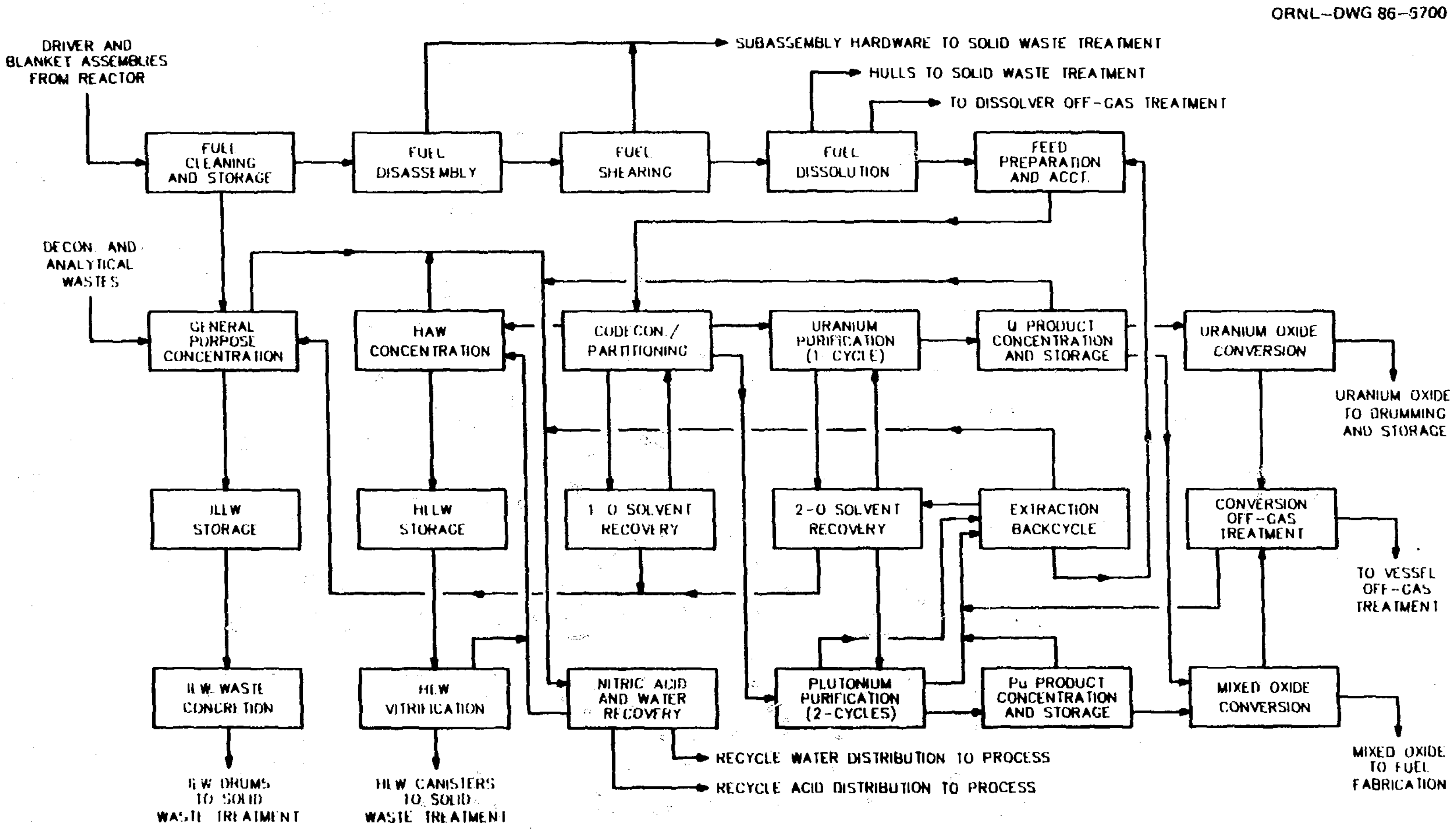

Fig. 1. Flowsheet of processes used in breeder fuel cycle facilities.

Plutonium Storage. The major plutonium storage as pure, decontaminated plutonium was placed in the reprocessing cell with only operational quantities transferred to the conversion facility as needed.

Conversion Process. Direct thermal denitration based on some preliminary work at ORNL was chosen as the conversion process to minimize overall waste streams. Uranium and plutonium solutions were mixed in the quantities needed as the initial conversion step. Additional studies and development work would be required to fully prove this overall method.

High-Level Wastes. Solidification by a liquid-fed ceramic melter was done directly in the reprocessing cell. This permitted coupling of the off-gas treatment systems and more direct integration of the whole liquid waste treatment system.

Safeguards and Physical Security. With all fuel cycle functions within one building, physical protection of fissile material transfers between steps was simplified. Pipeline transfers were used between reprocessing and conversion steps, and a single overall protection boundary could be defined for all fissile materials.

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 layout depicted in Fig. 2 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. 3). 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 Prgram. Key technologies employed are listed in Table 1.

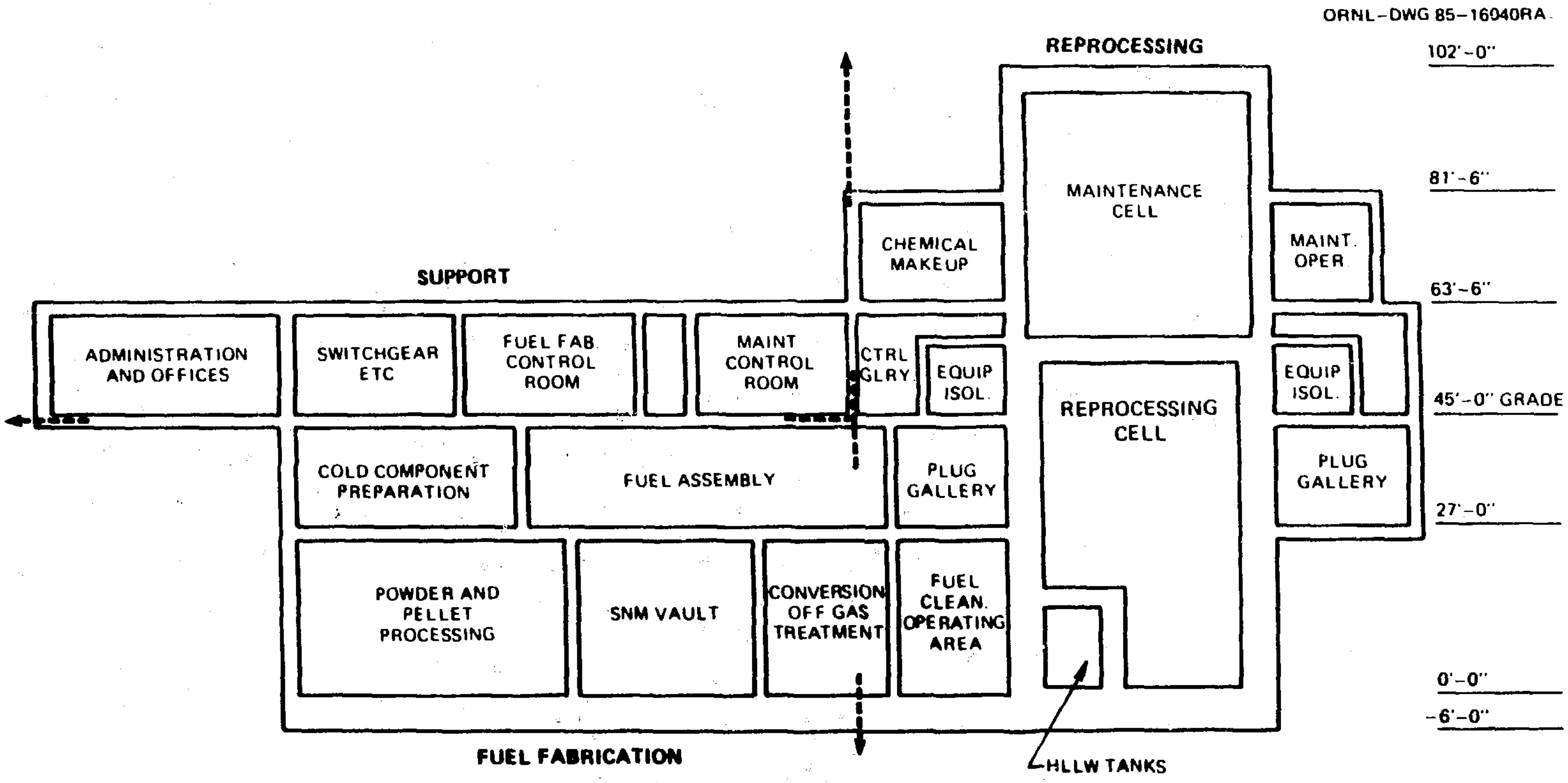

Fig. 2. Overall facility cross section.

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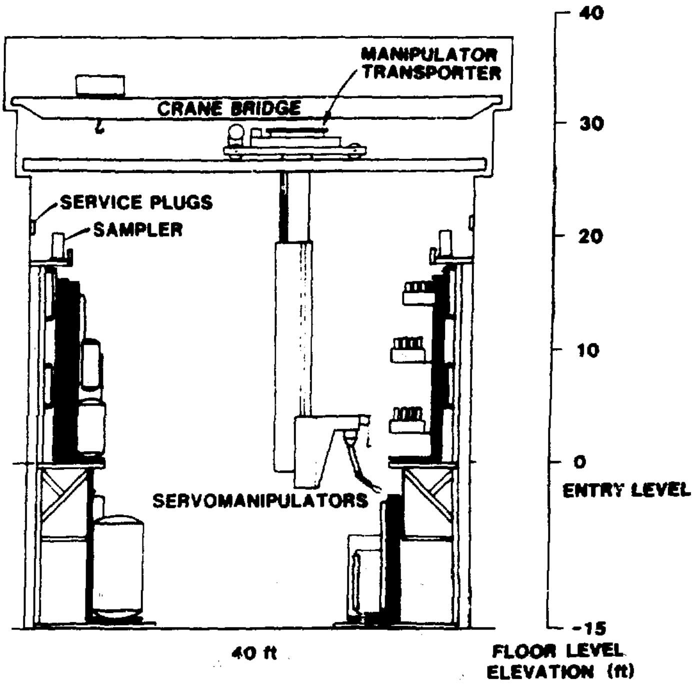

Fig. 3. Cross section of the reprocessing cell.

Table 1. Key reprocessing technologies developed in the CFRP

1. Integrated mechanical head-end
   Laser disassembly and 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 2.

Table 2. 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.

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

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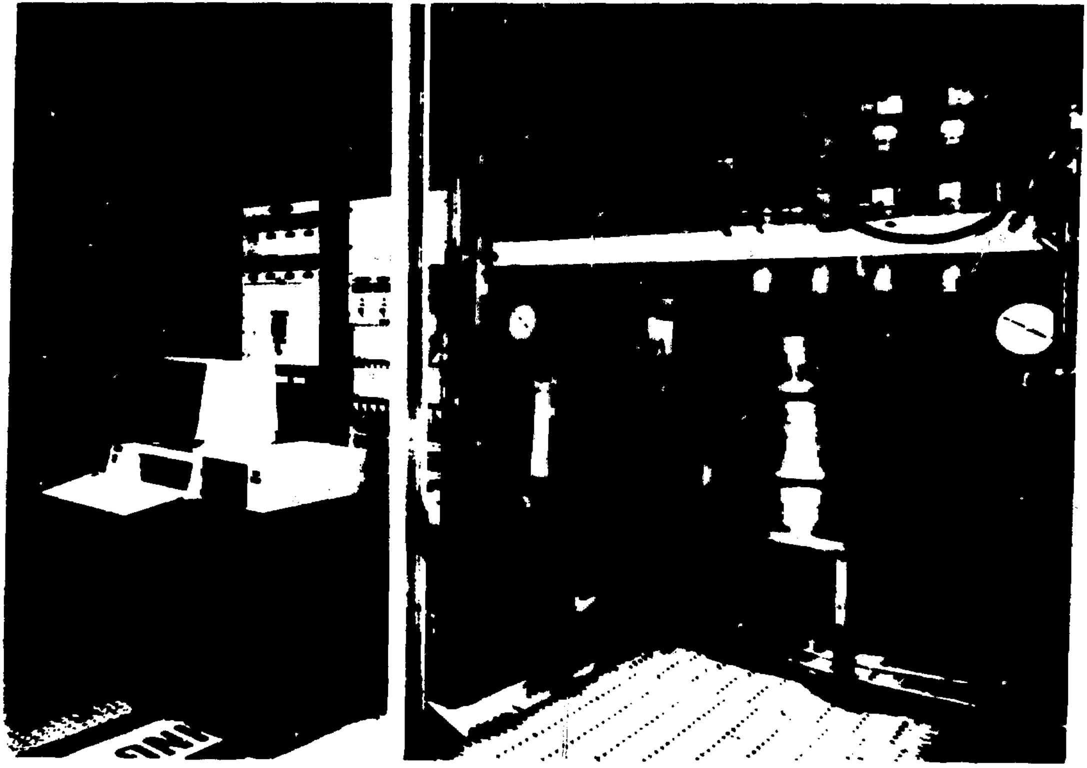

Fig. 4. Small centrifugal contactors for solvent extraction.

alternate contactors. One of their major advantages is the small holdup volume which 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. 3 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.

ORNL–PHOTO 1310–86

Fig. 5. Advanced servomanipulator slave arms.

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 UO2 powder. Mixing is accomplished in a vee-shell blender 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 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 which 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, which is shown in Fig. 6. 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 loaded into a container and transferred to final pin inspection and final assembly. The final assembly operations are also highly mechanized.

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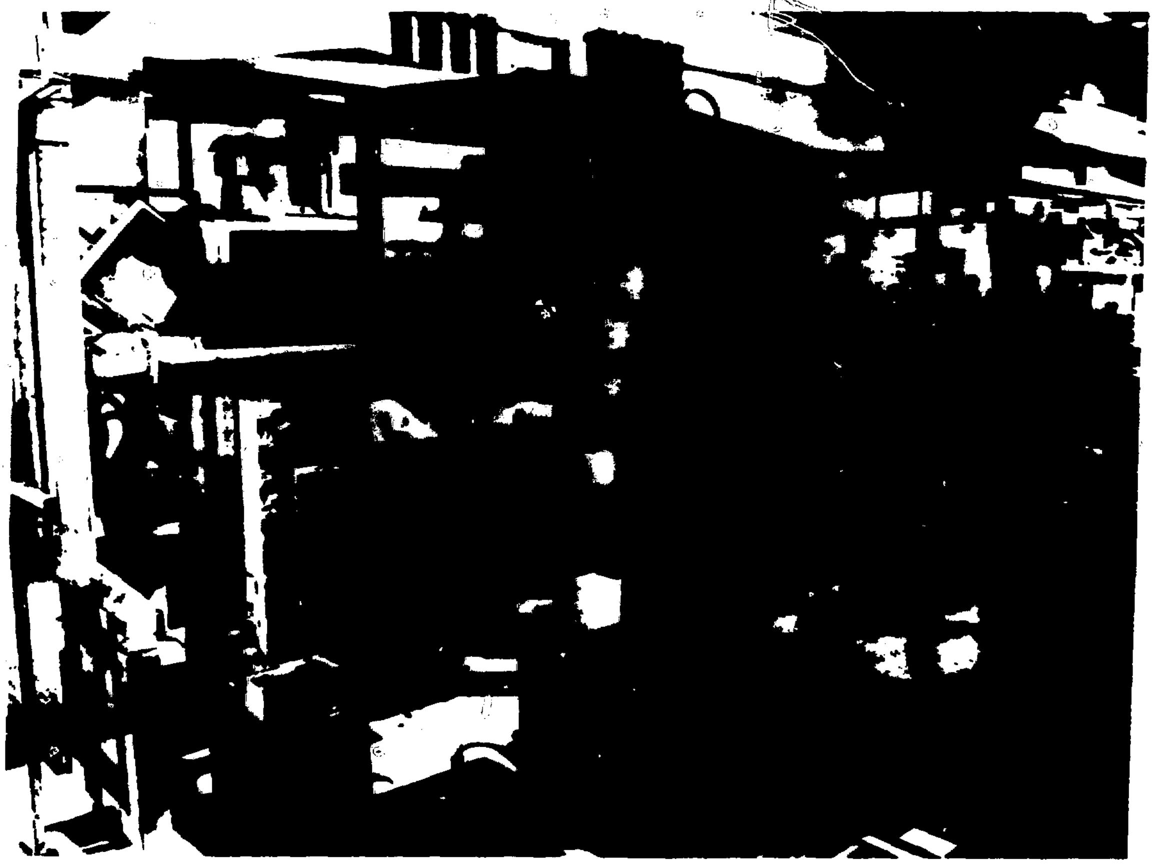

Fig. 6. Fuel pin loading equipment and enclosures in SAF.

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 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. 7, 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.

ORNL–PHOTO 3829–87

Fig. 7. Fuel handling robot in SNM storage facility.

OVERALL RESULTS OF THE STUDY

While this study must be recognized as a scoping study, not a detailed conceptual design, the broad base of past work of WHC and ORNL provided the background information needed to cast a reasonable and clear picture of the process systems and facility configurations. In future papers capital, operating and fuel cycle cost estimates will be provided.

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