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**ADVANCED CONCEPTS UNDER DEVELOPMENT
IN THE
UNITED STATES BREEDER-FUEL-REPROCESSING PROGRAM**

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For Publication in Proceedings,
Conference on Fast Reactor Fuel Cycles,
November 9-12, 1981
The Institution of Civil Engineers
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As part of the overall U.S. Department of Energy program to develop technology for liquid-metal fast breeder reactors, advanced concepts and techniques for the fuel reprocessing step are being developed. These concepts have been incorporated into the conceptual design of a Hot Experimental Facility (HEF), which is intended to demonstrate reprocessing of the first U.S. breeder demonstration reactor. These advanced concepts include both equipment and facility features and have the objectives of achieving improvements in process and system reliability, material recoveries, safeguards and diversion resistance, and safety while substantially reducing occupational doses and off-site emissions. To achieve system reliability and reduce occupational doses, a concept of totally remote operation and maintenance (termed Remotex) has been conceived and is being developed. In this concept, maintenance and mechanical operations are accomplished with remotely operated bilateral force-reflecting electronic master/slave manipulators. Suitable transport systems, coupled with remote closed-circuit television viewing, are provided to extend man's capabilities into the hostile cell environment.

The concept for the HEF is an extension and sophistication of the state of the art for total remote reprocessing systems. The complex design of power reactor fuels and the requirement for waste solidification and packaging dictate the requirements for carrying out a variety of mechanically intensive operations, thus the need for more versatile remote techniques. Although requirements for such versatility are paramount in the mechanical operations, the concept has been extended to provide maintenance and equipment replacement capabilities throughout the chemical operations.

New equipment concepts are being developed for the fuel dismantling and shearing step, a high-temperature dry process termed "voloxidation" to remove tritium, a continuous rotary dissolver, and for an improved centrifugal solvent contactor. Techniques have been developed, using engineering-scale equipment with active tracers for retention of the gaseous radioisotopes ^{85}Kr , radioiodine, ^{14}C , and ^3H . Retention of these isotopes coupled with effective filtration of particulates can reduce maximum off-site doses to as low as 1 mrem/year.

Development of these advanced techniques is being carried out over a 10- to 15-year period leading to the expected engineering-scale demonstration in the HEF in the mid-1990s, concurrent with the operation of the first U.S. breeder reactor. Prototypic demonstration of many of these concepts in a nonactive Integrated Equipment Test (IET) facility will begin late in 1981. This paper will summarize the goals of the program and review the present status of the advanced techniques being developed.

INTRODUCTION

As part of the overall U.S. Department of Energy Program to develop technology for the liquid-metal fast breeder reactor, advanced concepts and techniques for the fuel reprocessing step are being developed. These concepts have been incorporated into the conceptual design of a pilot-demonstration facility, called the Hot Experimental Facility (HEF), which would be capable of reprocessing fuel from the first four to six U.S. breeder reactors. At this stage, commitments to the Clinch River Breeder Reactor appear to be firm; however, decisions have not yet been made to begin active implementation of this reprocessing project. Further examination of the timing of this project, an assessment of how breeder reprocessing might be integrated with light-water reactor reprocessing in the United States, and related matters involving the back-end of the fuel cycle are being studied in an effort to resolve these issues. The research and development programs focused on the HEF concepts are expected to ultimately provide the basis for engineering-scale recycle of breeder fuels in the United States. The overall goals of the program are to develop reliable, cost-effective advanced technology

for reprocessing spent breeder fuel in order to achieve high recovery of fissile material (goal 99.9%), minimize environmental emissions and doses to plant workers, and protect the fissile material with effective, workable safeguards systems.

Process flowsheets use the conventional chop-leach Purex decontamination and recovery system. Minor improvements in the chemistry are being sought in areas such as feed clarification and solvent cleanup with small-scale hot-cell tests using fully irradiated material from EBR-II and in the near future from the Fast-Flux Test Facility. Our major work in off-gas treatment directed toward retention of all the fission gases has been reported previously^{1,2} and will not be repeated here.

Process equipment development focuses on HEF-scale components in the mechanical head-end portion of the process. Following testing as individual process steps, a major portion of these steps will be brought into a single line in the Integrated Equipment Test (IET) facility, now under construction in Oak Ridge. The IET is a nonradioactive

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simulated reprocessing cell in which both the facility concepts and prototype equipment will be tested over the next four to six years. The status and progress of a remote modular whole-element shear, a disassembly feed machine, a continuous rotary dissolver, and an advanced centrifugal solvent extraction contactor will be described.

The Remotex concept used in the HEF is a concept for the complete remote operation and maintenance of all active portions of the reprocessing complex employing servomanipulators and closed-circuit television (CCTV) systems for in-cell operation and viewing. This concept will be described along with its present status and development activities. Two other features of the HEF are sufficiently new and innovative to warrant a discussion in this paper. The low-flow ventilation system employed is based on a semisealed cell to hold leakage to only a few hundred cubic feet per minute. One advantage of this system is that the low flow permits extensive treatment of the off-gas system with relatively small equipment that will be both more economical and more reliable. A second "new" feature being developed is a robot sampler vehicle which traverses the inside of the cell collecting samples from conventional

double-needle sample stations. Cost savings and reductions in worker exposure are both obvious advantages in this idea.

ADVANCED FACILITY CONCEPTS

For the past several years, conceptual design activities have focused on a major new pilot-demonstration scale facility which addresses the problems of reprocessing breeder fuel at a scale sufficiently large to examine prototypic engineering problems. This facility, called the Hot Experimental Facility, evolved from principles employed in the canyon-type U.S. production facilities. This concept was chosen because of the inherent belief that reliable, cost-effective reprocessing, which could ensure low exposure to workers, can be best achieved in such a concept. However, many potentially significant improvements were envisioned, and an extensive effort to understand the potential for improving the state of remote technology within the next decade was examined as part of this conceptual design effort. About two years ago, a major decision was made to employ servomanipulators and CCTV viewing as the primary remote handling system.³ The concept that evolved is depicted in Figs. 1 and 2. Figure 1 is a cross-sectional view of one process

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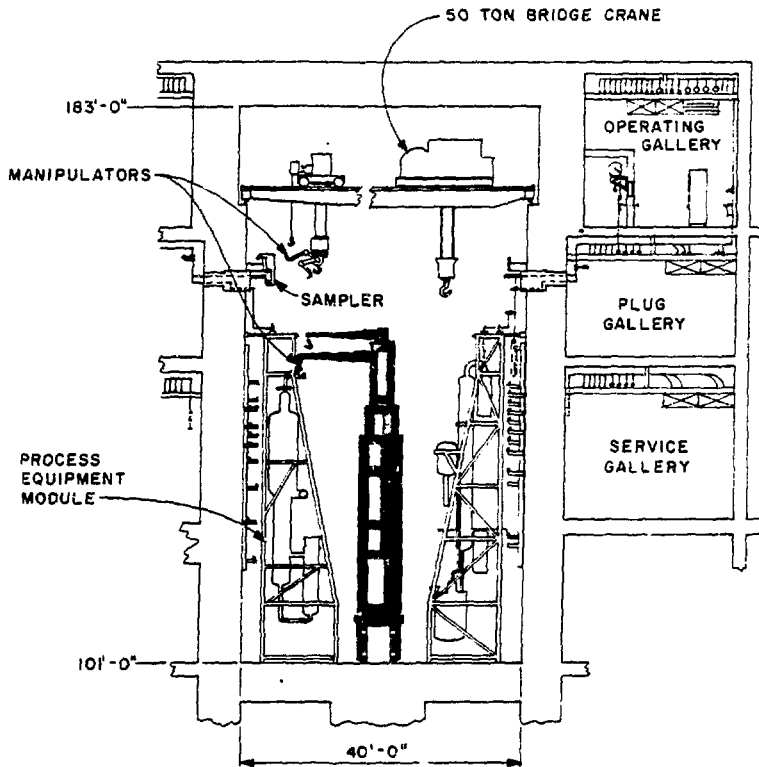


Fig. 1. Process cell section of the Hot Experimental Facility.

cell which shows equipment mounted on two walls of the canyon in removable modules. A center aisle provides both the space required for removing the equipment modules and a track arrangement for a transporter-repair vehicle equipped with CCTV viewing and servomanipulators. This maintenance vehicle can reach virtually any area of the front and sides of the module to do limited or even extensive repairs to subassemblies of equipment on the module. The intent is to repair most failures by replacing small units rather than the entire module. The concept broadens considerably the kinds of equipment which can now be placed in-cell. Whereas the placement of certain types of pumps or instruments has been unthinkable in-cell in the past, it appears practical with this concept. Obviously, we still believe that all in-cell systems should (1) be extremely reliable, (2) minimize or eliminate moving parts, and (3) be intended for very infrequent maintenance or no maintenance. The overall concept, however, recognizes the large amount of mechanically intense equipment that must be employed in the head-end portions of the cell and is striving to provide a reliable set of tools to ensure that the maintenance that will be required on such systems can be done readily and reliably. Once such systems are available for the mechanical head-end, application to the rest of the plant is straightforward. In Fig. 2, the plan view shows the two parallel process cells interconnected by a special maintenance cell. Development work on servomanipulators is underway to improve reliability, provide modular and easily replaceable units for repair of failures on the manipulators, and to uncouple master and slave from hard wiring by using wireless or inductively coupled multiplexed signal transmission. The man-machine interface problem of providing an operator the optimum set of information and capability to carry out the task is being studied. A sketch of the servomanipulators is shown in Fig. 3.

An important improvement in the facility concept is the use of a low-flow (300-1000 cfm) ventilation system. Although this system requires a more leak-tight cell than normally employed, the advantages gained in reducing the size of off-gas components and in improving their efficiency and reliability seem to outweigh the special sealing requirements. In-cell cooling is provided by water-cooled units inside the cell. Chilled water is used for humidity and acid vapor control. All cell inleakage is either routed to the dissolver or vessel off-gas treatment systems. There is no separate cell ventilation system. Provisions for sealing include air-locks at all equipment access points and a stainless steel liner, although the need for the latter may be more for decontamination and decommissioning.

The concept for an automatic sampler system (Fig. 4) includes a robot vehicle for traversing the cell to collect solution samples in arrangements which use the conventional glass bottle, two-needle air jet with air-lift assist principles. The robot can be programmed to take samples wherever needed, and then return them to the analytical cell. Considerable savings are achieved over the normal hot-cell sample blisters now used. Final design of the robot vehicle is nearly complete, and a model should be ready for testing in less than one year.

The automatic sampler system concept incorporates many of the conventional safeguards principles for physical protection, material accountability and containment, and surveillance. Sensitive areas containing fissile materials free of fission products are zoned for special protection. Other features enhance the safeguards capability of the facility. All equipment in the massive shielding is remotely operated and maintained, thus denying direct access of fissile materials to the operators. Sampling operations are conducted

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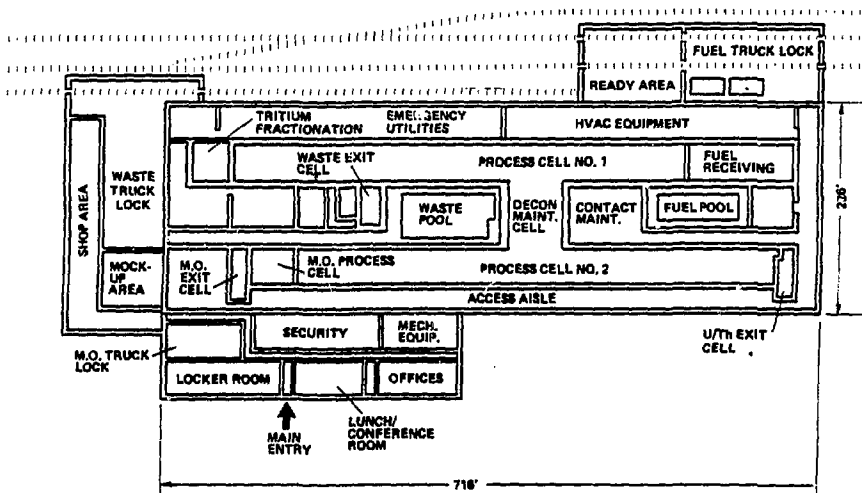


Fig. 2. Hot Experimental Facility plan view.

entirely within the shielding; thus, no sample lines, which might provide access to material, penetrate the shielding. Concepts for near real-time accountability are being studied, and other computer-monitoring systems are being developed which use continuously available process instrument signals to trigger alarms if sensitive material transfers appear abnormal. Many of these safeguards systems will be further developed as the facility design is undertaken.

FLWSHEET IMPROVEMENTS

The process employs the conventional chop-leach Purex process commonly used worldwide for all nuclear fuel processing. Process development thus is directed toward a variety of improvements to a reasonable well-understood process. Flowsheets containing the much higher plutonium content of breeder fuels have been studied in "cold" coprocessing solvent extraction systems to determine conditions for obtaining a uranium-to-plutonium product ratio of 3:1. Similar tests are being carried out with kilogram quantities of fully irradiated fuel in the Solvent Extraction Test Facility.⁴ In other activities, alternate methods for feed clarification and for solvent cleanup are being studied to minimize the chemical sodium wastes from the latter step.

A major program is in progress to develop an advanced co-conversion process as feed to produce a pellet fuel form.

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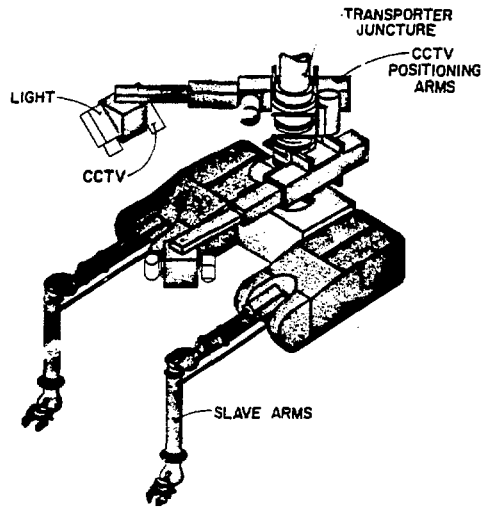


Fig. 3. Industry standard servomanipulators (slave end).

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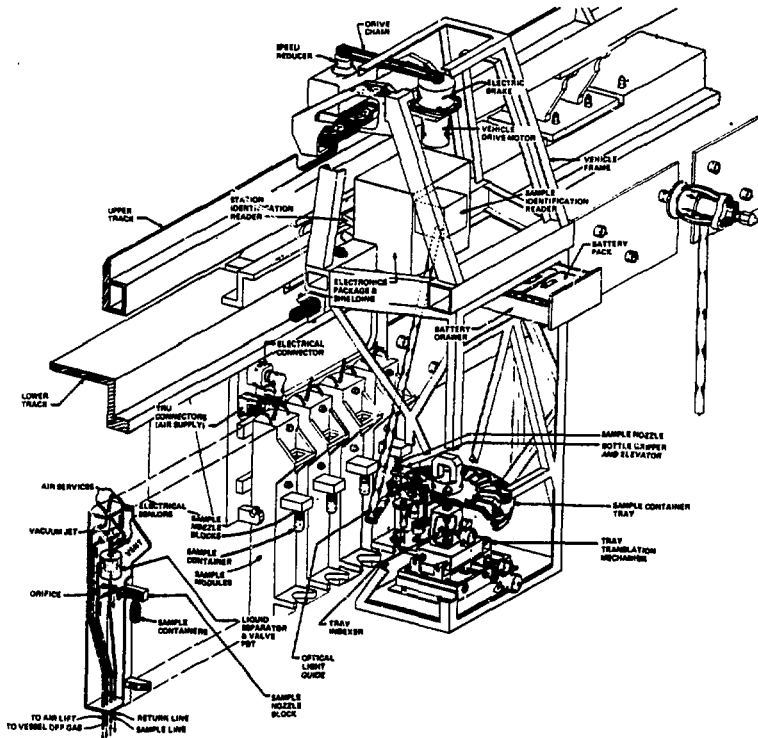


Fig. 4. Automatic sampler system.

The process produces 200- to 400- μ spherical particles using an internal gelation process in semiconventional sphere-forming and drying columns. A significant advantage sought and apparently achievable is a completely nitric-acid-soluble fuel. In collaboration with the Hanford Engineering Development Laboratory and Pacific Northwest Laboratories, preliminary drying and calcination conditions for producing fuel-quality pellets with densities in the range of 90% of theoretical are being determined. The objective is to produce the partially calcined oxide at the end of the conversion process, which is completely stable but can be pressed into pellets and sintered by the fuel fabricator to give a pellet equivalent to those produced previously with active mechanically blended powders. Excellent results have been achieved in these early tests.

PROTOTYPE PROCESS EQUIPMENT DEVELOPMENT

Development of the mechanically-intensive head-end components has been underway for a number of years. The following is an update on the status of these developments. Whole element shear tests which define compacting conditions, blade configurations, and forces required are now essentially complete. Although whole element shearing of breeder fuel subassemblies appears feasible, removal of the sheath and shearing of the entire bundle of tubes (excluding the sheath) was desirable because of the excess metal and potentially irregular shape of the sheath pieces routed through the dissolver. A remote modular shear (Fig. 5) is now being designed and procured. This shear incorporates three in-cell hydraulic pistons for compacting, gaging, and shearing with through-the-wall water hydraulic lines instead of the

usual wall-mounted concept where the pistons penetrate the wall. This design prevents activity from being moved across the primary shield wall by the reciprocating action of the pistons and simplifies the seismic design of the shear. All parts are assembled with simple accessible hold-down bolts that permit replacement and repair of worn or failed parts. A disassembly-feed system (Fig. 6) is being designed after earlier development work had fixed certain concept parameters. The sheath will be removed after longitudinal slitting with a laser. The end piece will be cut off with a laser, and gas plenums will be sheared and removed in the shear.

Development work with the rotary-continuous dissolver² has essentially been completed, and engineering-scale work with the voloxidation process for retention of tritium has continued.

Improvements to solvent extraction performance in the initial codecontamination cycle is being sought through a simpler designed centrifugal contactor. This type of contactor will minimize solvent radiation damage, and it has other features, such as rapid and easy start up, which make it attractive for fuel reprocessing. The system will incorporate connected groups of single-stage units similar to the one shown in Fig. 7. The rotor is suspended from the drive motor in such a way that the rotating parts can be simply withdrawn and exchanged should failures occur. Tests with single-stage units have been completed, and multistage systems are now being tested. A major feature of this unit is the capability of handling reasonable quantities of solids without plugging or gross changes in contactor efficiency. Although

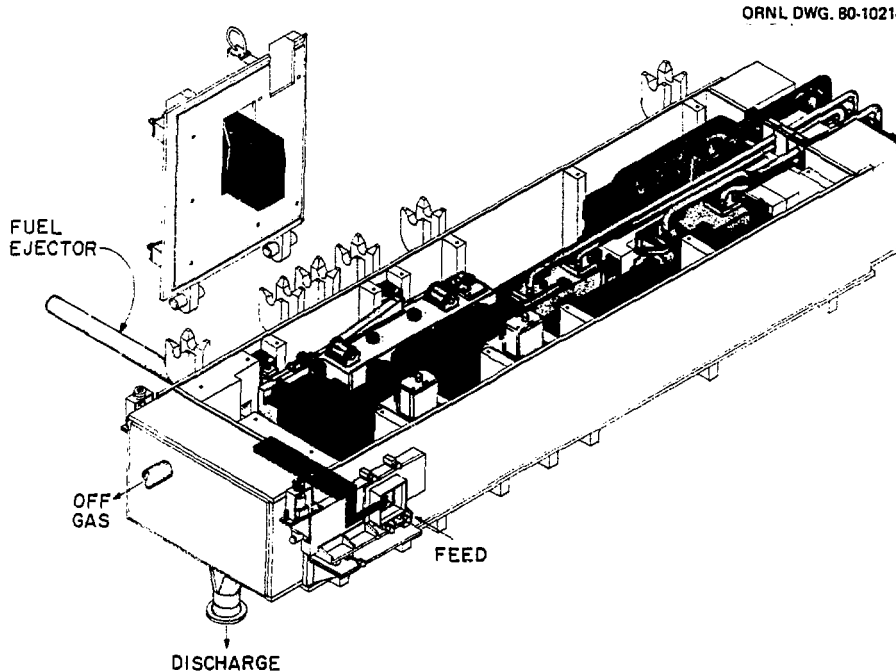


Fig. 5. Remote modular shear.

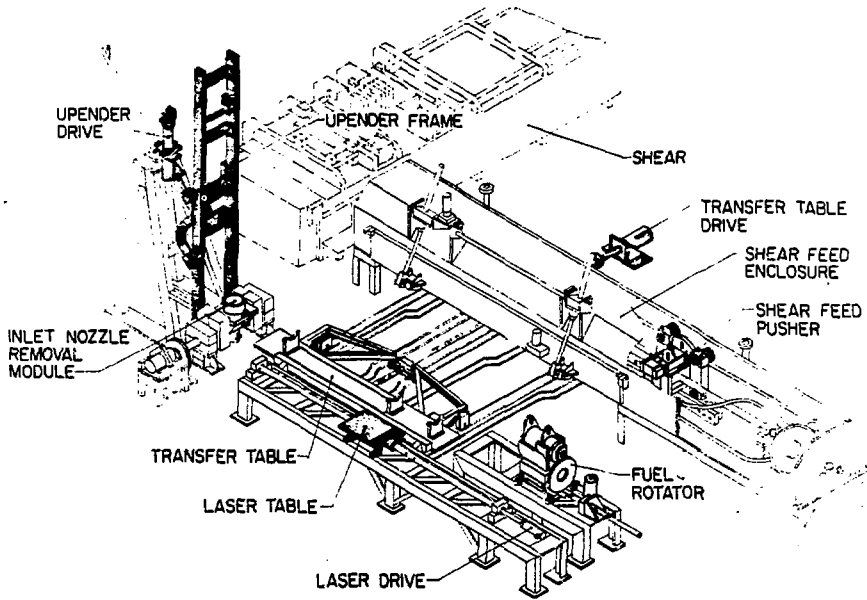


Fig. 6. Disassembly feed system.

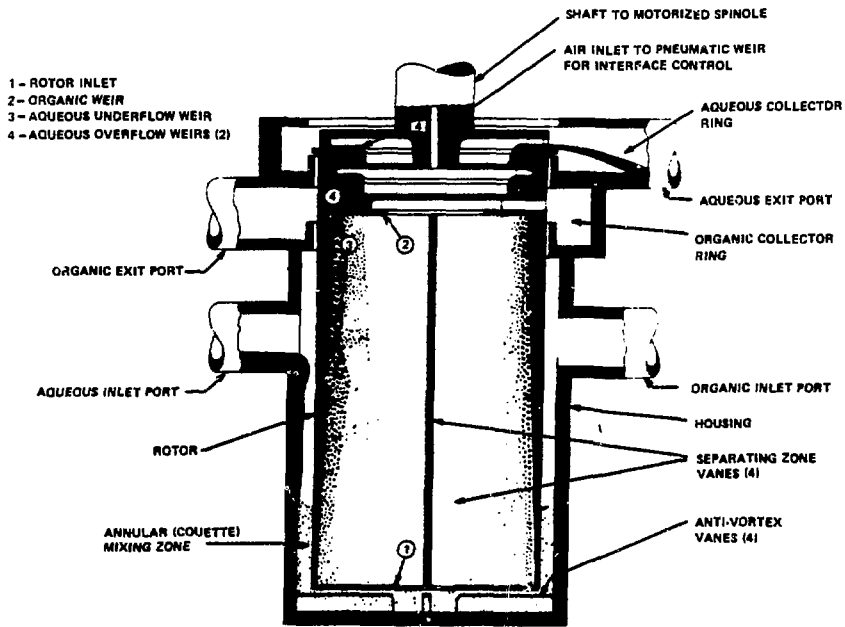


Fig. 7. Single stage centrifugal contactor.

the units appear to be capable of accepting some solids in the feed, the flowsheet will include good feed clarification preceding solvent extraction.

INTEGRATED EQUIPMENT TEST FACILITY

A facility now under construction at ORNL will be used to test the prototype head-end process equipment in an

integrated mode in a large simulated process cell. Initial operations in this facility, called the Integrated Equipment Test (IET) facility, will begin within a few months. An isometric view of the IET is depicted in Fig. 8. A major goal of this facility is to demonstrate the remote operating and maintenance features of the prototype process equipment as well as the operability and reliability of the remote features incorporated into the overall Remotex concept.

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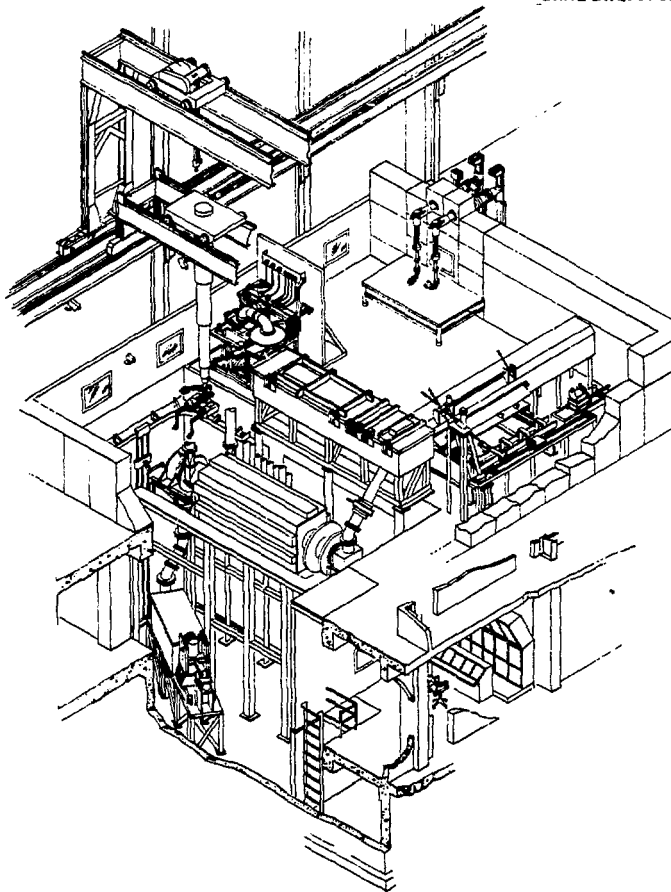


Fig. 8. Isometric sketch of the Integrated Equipment Test facility.

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