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Integrated Equipment Test (IET) Facility Summary of Operations for FY 1985

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T. W. Burgess
B. B. Spencer
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CONSOLIDATED FUEL REPROCESSING PROGRAM

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Consolidated Fuel Reprocessing Program

INTEGRATED EQUIPMENT TEST (IET) FACILITY SUMMARY OF OPERATIONS FOR FY 1985

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ABSTRACT

The Integrated Equipment Test (IET) facility, now fully operational, provides an excellent place for the development and demonstration of advanced nuclear fuel reprocessing technology by the Consolidated Fuel Reprocessing Program (CFRP). One of the two unique capabilities of the IET facility provides for complete remote maintenance demonstrations on process equipment sized for actual plant service using state-of-the-art remote maintenance systems. The second feature of this facility is an experimental engineering pilot plant that can be operated with unirradiated uranium-bearing feed materials. This chemical plant enables the development of operating parameters and control procedures for existing process equipment during integrated process demonstrations and promotes the development of new process concepts through participation by the CFRP technical staff in its program. A descriptive summary of IET process equipment capabilities, IET operations during FY 1985, and IET program planned for FY 1986 is presented.

1. INTRODUCTION

The current operational status of the Integrated Equipment Test (IET) facility culminates a 10-year effort by the Consolidated Fuel Reprocessing Program (CFRP) and the U.S. Department of Energy (USDOE) to establish an experimental engineering program for the development and demonstration of advanced nuclear fuel reprocessing technology. The conceptual design of the facility began in December 1975. This study projected cost estimates that led to a funds request (construction project data sheet, schedule 44) for $16 million during the first quarter of FY 1977.[1] As implemented, this request for funds provided Title I design, beginning February 1, 1977, with $600,000 of authorized construction planning and design funds. An allocation of $3 million in FY-1978 funding was provided for Title II design and procurement of those equipment items that would require long lead times. The remaining $12.4 million was authorized for construction beginning in FY 1979. Title II design began in January 1978, and actual construction on the General Plant Facility (GPF) portion of the project began in January 1979 with a fixed-fee prime contractor.[2] Construction by the GPF contractor was completed in June 1980. Major equipment installation was scheduled by contracts that were first awarded in February 1981. Beneficial occupancy of the IET facility was attained during the first quarter of FY 1982. The following period through FY 1984 was required for completion of equipment acceptance tests, operational checkout of process units and maintenance equipment, and preparation of equipment operating procedures.[3]

The preconceptual design studies for what was to become the IET facility had stressed the importance of an experimental engineering capability for the development of nuclear fuel reprocessing technology. The simulation of an integrated equipment line would provide not only the simultaneous operation of the various process units but also an unusual opportunity to explore process control procedures and to address process interface conditions between operating systems. By sizing the IET facility with full-scale equipment, the hydraulic characteristics of each process unit could be assessed, and, more importantly, each process unit fabricated for actual service with irradiated fuels could be tested under realistic, but simulated, process operating conditions.

The early recognition of the importance of remote maintenance technology to increased plant availability and reduced radiation exposure was manifest in the conceptual design of the IET facility. The inclusion of this feature as a separate but related part of the experimental engineering plant provides a unique capability for the development of remote maintenance disciplines that exploit the capabilities of available maintenance tools and optimize the configuration of in-cell process equipment. This capability can have a direct impact on the layout design of engineering systems that require remote operating and maintenance procedures.

Although the IET facility has required almost ten years for its active design and construction, the direct association of this project with the engineering development programs of the CFRP has provided continuous renewal of equipment criteria and process principles as they emerged from the several conceptual production plants that were studied during this period. The equipment and services recommended for the IET facility were prototypical of the 0.5-metric-ton/d fuel reprocessing plant that had been proposed for support of the Clinch River Breeder Reactor (CRBR) Project. The conceptual design of this proposed Hot Experimental Facility (HEF) introduced totally remote operating and maintenance procedures within the highly radioactive environment of the process cells to upgrade operator safety standards, to support international guidelines for nonproliferation of nuclear materials, and to resolve public concern for the ecological impact of the facility on the surrounding geographical area. In addition, the HEF concept also endorsed low air-flow ventilation techniques to curtail the emission of volatile components from the reprocessing plant. Both the technical and fiscal justification for construction of the IET facility dedicated its operation to these principles of advanced fuel reprocessing technology.

Although plans for experimental reprocessing facilities for fast reactor fuels are inactive, the IET facility maintains the advanced equipment concepts proposed for these programs for further development. This capability represents a major commitment by the CFRP as an engineering research laboratory for its process and equipment development activities. During FY 1985, the IET Facility Operations was budgeted at about $2.53 million or about 17.5% of the Breeder Fuel Reprocessing Program allocation to the CFRP by the USDOE. Approximately $1.76 million of this budget provided direct technical support of actual IET operations. A similar budget allocation for FY 1986 is anticipated.

2. IET FACILITY DESCRIPTION

To address all phases of nuclear fuel reprocessing technology, the design layout of the IET facility embodied two principal work areas to simulate the constraints of remote procedures on both the maintenance and the process operations of a nuclear fuel reprocessing plant. The Remote Operations and Maintenance Demonstration (ROMD) area provides for the development of mechanical operating and maintenance procedures for process equipment under conditions that simulate constraints anticipated for actual plant service. The Integrated Process Demonstration (IPD) area provides for the development of remote process control procedures and for the demonstration of equipment components developed within the CFRP. As illustrated in Figs. 2.1 and 2.2, these work areas are multilevel and separated by a single wall. Because of the size of equipment in the head-end process, some functional overlap of the two work areas was required. The control room for the ROMD area was located at ground level near the main test area. The control room for the IPD area is on the second level and overlooks the solvent extraction area. Title I design of the IET facility was based on the modification of the two contiguous high-bay areas within the existing CFRP building complex. Descriptions of the functional status of systems located in the two work areas and their associated process and equipment control systems are appended (See appendixes A through C).

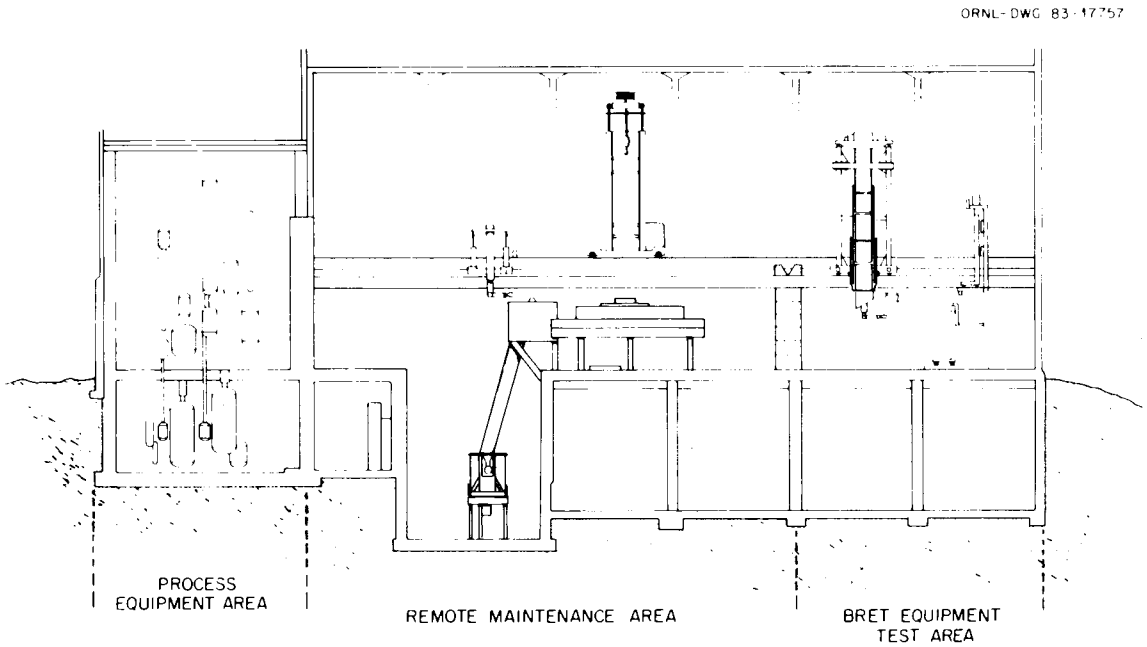

Fig. 2.1. Schematic of IET facility.

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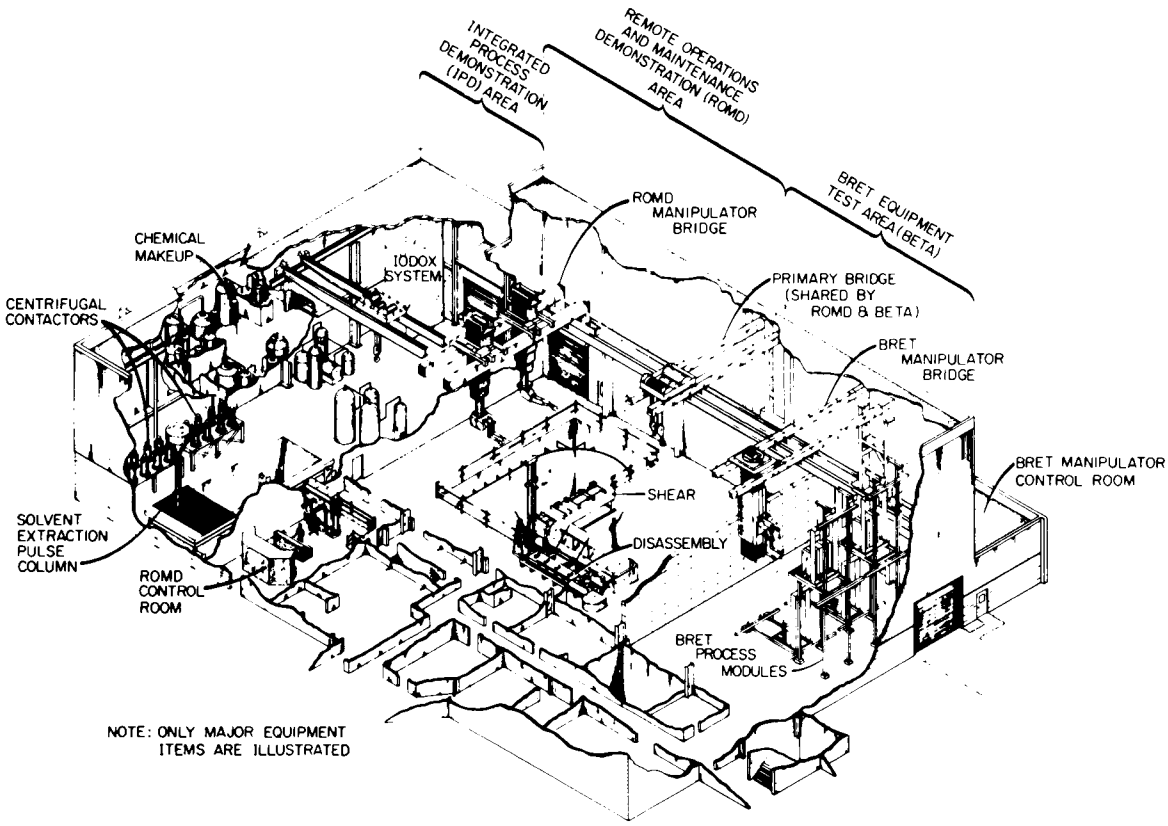

Fig. 2.2. Isometrics of IET facility.

The IET facility can utilize uranium-bearing feed materials for integrated equipment tests under simulated process operating conditions. Additionally, remote maintenance capabilities can be demonstrated on all major process equipment units designed for installation in the IET facility and on all process equipment modules fabricated for actual fuel reprocessing plant service. This area is being extended by current construction to mock up the process cell features of the proposed Breeder Reactor Engineering Test (BRET) at Hanford Engineering Development Laboratory; remote maintenance demonstrations on BRET process modules with BRET service equipment will be available. Construction of a third test area will be completed during FY 1986. This area, the Environmental Test Chamber, will provide further engineering development and demonstration of the low-flow ventilation concept. Following this demonstration, the facility will be used to test equipment components for compatibility with corrosive process cell atmospheres.

3. PROGRAM PLAN

With respect to the programmatic commitment of the CFRP, the IET facility attained functional status as an experimental engineering pilot plant during late FY 1984. Although a number of important development tasks had been accomplished in the facility during prior years, these were largely restricted in scope because of equipment availability or because of the inaccessibility of the IET during major facility construction projects. Program activities in the ROMD area were directed toward the development of operating procedures for the various remote maintenance equipment components while demonstrating the remote maintainability of available process equipment units. This period also provided for the performance of extensive acceptance tests of the various IPD process systems, for operator training programs, and for the familiarization and further development of the sophisticated process control instrumentation. In late FY 1984, uranium was introduced into the process equipment for the first time during an integrated campaign of available process systems in the IPD area.

Planning exercises for the FY-1985 IET operations schedule recognized the importance of operator training to a successful experimental engineering program. Additionally, prior operating experience had emphasized the necessity of continued investigations for determining specific operating characteristics of the unit process equipment. A third factor of particular importance to the CFRP was the introduction of its professional staff to the capabilities of the IET facility for conducting experimental programs. The response to this feature is partially reflected in the FY-1985 IET program and, more specifically, in the program outlined for FY 1986.

Although operations in both the ROMD and IPD areas are conducted by the IET operations staff, the professional direction of experimental programs for these areas is augmented by separate technical disciplines within the CFRP. Consequently, the planned operations for the IET facility consist of two separate programs that are scheduled according to the availability of the operating staff. This approach provides the operating staff with work experience that will realistically simulate that required of their counterparts in an actual fuel reprocessing facility. Experimental proposals from the CFRP technical staff promote the development of specific task objectives and stimulate staff interest in the exploration of new concepts for advanced fuel reprocessing technology.

3.1 REMOTE MAINTENANCE PROGRAM

Activities planned for operations in the ROMD area during FY 1985 were directed toward two principal objectives. As a continued assignment, methods and procedures for conducting remote maintenance routines on process equipment have been developed from

the application of existing maintenance equipment on simulated process modules, on IET process equipment components, and the remote maintenance tools themselves.[4,5] A second important feature of the ROMD program has pursued basic engineering development objectives.[6] Two major studies in this category were conducted during FY 1985. One test program provided comparative evaluations of existing remote maintenance systems as support for related maintenance equipment development programs and as a controlled test for evaluating the performance of skilled operators on each maintenance system. The second program examined the serviceability and reliability of commercially available electrical and tubing connectors during repetitive remote handling operations under simulated hot-cell conditions.

3.2 PROCESS DEVELOPMENT PROGRAM

The scope of the program plan for projected operations within the IPD area reflects the considerable effort that has been required to bring the chemical process plant to its current on-line status. The documentation of IPD equipment operating procedures and the attributes of its process control system are of fundamental importance to an experimental engineering program. While this development effort will continue as an integral part of IPD operations, the current status of most of the process systems warrants the support of intensive process and equipment component development activities.

The overall program plan for IPD operations during FY 1985 represents a period in which major objectives were directed toward determinations of operating characteristics of specific process units and the exploration of potential experimental engineering projects during continued staff training exercises. The IPD schedule for FY 1985 was based upon two major process campaigns during which selected portions of the plant were operated on a continuous basis for periods up to two weeks. Interim periods were used for preparing for campaigns, for conducting independent component tests, and for maintaining the operational status of the facility. A specific test plan describes each of the activities that is proposed for demonstration in the IPD area.

The IPD campaign, which was planned for April 15–26, 1985, was based on the sustained operation of both the rotary dissolver and the solvent extraction systems on uranium-bearing feed materials. The operation of these major process units also included the supporting operations of the accountability and feed adjustment system, the uranium product system, the organic treatment system, and the liquid waste system under simulated reprocessing plant conditions. The primary function of this campaign was to provide operating experience on the various IPD systems under simulated process conditions. In this respect, all materials transfer operations were monitored for conformance with safeguards procedures for uranium accountability. This surveillance provided a measure of system integrity both for expanded safeguards applications and for the fundamental research and development projects that will follow.

The IPD campaign, which was planned for September 15–20, 1985, was based on the simultaneous operation of the rotary dissolver and the solvent extraction system on uranium-bearing feed materials. As in previous integrated process demonstrations, the sustained operation of these major process systems also required the concurrent operation

of their support systems. This campaign was the first IET demonstration of the fully integrated operation of the rotary dissolver system and the solvent extraction system at matching process rates. The rotary dissolver was also operated under conditions that simulated the shearing of CRBR blanket assemblies. All materials transfer operations were monitored for conformance with safeguards procedures for established uranium accountability. This surveillance capability was also utilized by the Safeguards Task during this campaign to demonstrate new and improved techniques that had been developed for the recognition of process stream diversions.

3.3 SAFEGUARDS FOR NUCLEAR MATERIALS

One of the major factors that has influenced the development of nuclear fuel cycles in the United States and other countries has concerned the effectiveness of safeguards methods for monitoring reprocessing plant materials accountability procedures. Because these concerns have involved both technical and institutional questions, they are of fundamental interest to program commitments of the CFRP. Consequently, an active technical program on nuclear materials safeguards has been supported by the CFRP through the USDOE and the U.S. Nuclear Regulatory Commission. Some advanced safeguards techniques have been developed, but demonstrations of their effectiveness have been limited by the availability of adequate plant facilities.

The IET facility is well suited for safeguards demonstrations although its materials-handling limitations restrict the use of certain detection and measurement devices for plutonium and the radioactive fission products. This facility features equipment that is prototypical for commercial reprocessing plants; its process control instrumentation represents current technology and will accommodate experimental objectives. The presence of depleted uranium in the IET flowsheet together with its computerized data acquisition system permits demonstrations of heavy-metal loss-detection capabilities that are required for advanced safeguards techniques.

The CFRP Safeguards Task maintains a capability for the direct electronic transfer of process data from the IET Distributed Data Acquisition and Control System (DDACS) to the Component Development Data Acquisition and Control System (CODEDACS) data base. This system permits real-time evaluation of process measurements using computer software developed by the Safeguards Task. Because of the sophisticated control systems that are available in the IET facility, a comprehensive safeguards program can be conducted on IPD activities with relatively few chemical analyses of samples from selected process streams. This capability for direct access of IPD process data for safeguards analyses promotes the use of each IPD campaign as an experimental program for materials accountability methods. As an additional benefit, the IPD operating staff remains continually aware of the importance of safeguards practices to the operation of a fuel reprocessing plant.

4. REMOTE MAINTENANCE OPERATIONS

The operation of the ROMD area is characterized by the technical expertise that is demonstrated by its staff for conducting complex maintenance operations with specialized equipment and tools that require skilled operator performance. The alliance of the ROMD operations staff with associated engineering development groups of the CFRP provides a unique capability for both the development and the demonstration of remote maintenance technology. These activities are engaged as separate task plans that are developed and implemented as discrete test programs.

4.1 MANIPULATIVE SYSTEMS COMPARATIVE TESTS

The application of the ROMD area as an experimental test facility was demonstrated for the first time with the manipulative systems comparative test program. The purpose of this test program was to evaluate and document the performance of selected manipulator systems in typical remote applications. The program was endorsed by the USDOE as a cooperative effort of Martin Marietta Energy Systems, Inc., and the Power Reactor and Nuclear Fuels Development Corporation (PNC) of Japan. The test procedure assigned six identical tasks to each of three manipulator systems: the Central Research Laboratory (CRL) Model M-2, the Meidensha Model BILARM 83A, and the PaR Model 6000.

Test conditions for each manipulator system were held constant with respect to the general placement of the manipulator system (for comparable range of motion to the task) and the use of a common viewing system. The six manipulator tests consisted of a bolt-engagement task, a peg-in-hole task, a motor/mount task, a start-a-bolt task, a transuranium processing plant (TRU) connector-tubing jumper task, and a component module task that was composed of several basic operations. These tasks were representative of current remote maintenance technology. Four experienced manipulator operators were used for the test program. Five test blocks were needed to evaluate all the experimental parameters for statistical significance.

The Meidensha BILARM manipulator system, shown in Fig. 4.1, was obtained on loan from PNC. This manipulator could be operated in either a "switchbox" control mode or, as shown in Fig. 4.2, a "position" control mode by use of an 8-D.F. (degree of freedom) exoskeletal master control arm with three force-reflecting joints. Operation of the BILARM in both control modes provided performance comparisons to the master-controlled CRL Model M-2 and the switch-controlled PaR Model 6000 power manipulator. In so far as was possible, tests of these manipulator systems were conducted under the same working conditions.

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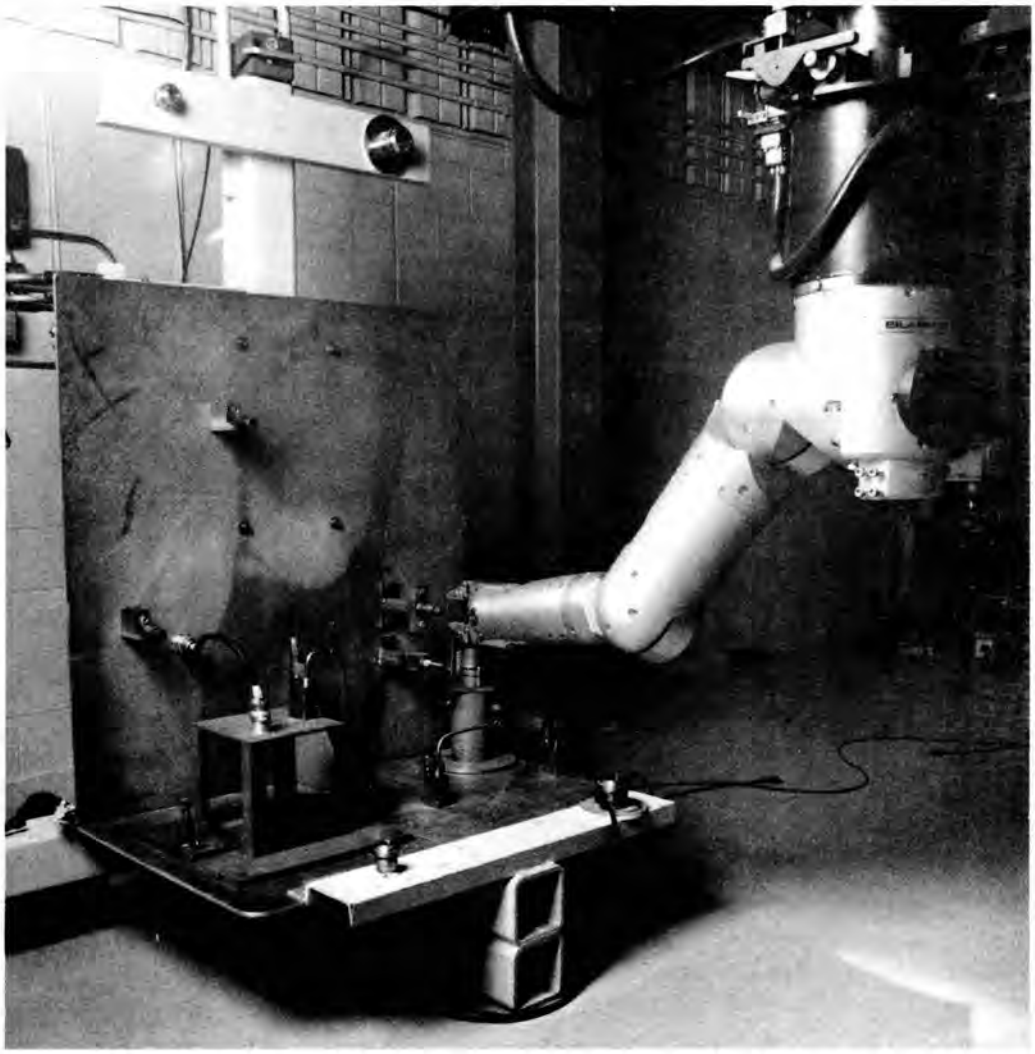

Fig. 4.1. Meidensha Model 83A BILARM manipulator.

Because only two manipulative systems could be installed on the ROMD transport bridge at one time, the test program was divided into two parts to accommodate comparative tests of the three manipulator systems. The test program was further divided to group the relatively simple test tasks into the first two test blocks. The more difficult test tasks were accomplished in the two test blocks that followed. This arrangement also allowed revision of the test procedures and changes in the test sequence for the two remaining test blocks. After experience with the first two test blocks, a fifth test block was planned. The four original test blocks were conducted from a fixed-bridge position; the added test block relieved this restriction and was used as another comparative test variable for the three manipulator systems.

The experimental program was organized for accommodation of statistical methods for evaluation of the test results. Experimental data that were collected for test evaluation included: (1) time-to-task completion, (2) number of errors (collisions, dropped items, or

ORNL/PHOTO 8737–84

Fig. 4.2. Meidensha Model 83A control station.

other critical incidents), (3) operator opinions on manipulator performance and on operator fatigue, and (4) simultaneous video recording.

Results of the experiments showed that operators using the Model M-2 in master/slave mode had significantly faster "times to completion" than did operators using the BILARM in master/slave mode; both groups of operators had about the same error rate per trial. The operators were slower using the BILARM with force reflection than without it, and they committed more errors. There was no statistically significant difference between force-reflection and nonforce-reflection conditions for the Model M-2 manipulator for any of the performance criteria. The BILARM manipulator system in switchbox control mode and the PaR Model 6000 system had significantly slower "times to completion" than did any other system in master/slave mode, with about the same error rate per trial. There were no significant differences between the BILARM in switchbox mode and the PaR arm. On average, tasks performed manually with television took twice as long to perform as with direct viewing.

4.2 REMOTE CONNECTOR TESTS

The second major demonstration of remote maintenance development capabilities in the IET facility consisted of a test program that examined conventional tubing and electrical connectors for potential service in a remotely maintained process plant.[7] Compared with earlier remote process cells, those equipped with the currently developed servomanipulator systems have vastly improved capabilities in dexterity and force-feedback features. The purpose of these tests was an examination of inexpensive, off-the-shelf connectors for potential use, either directly or with slight modifications, as replacements for connectors that have been specifically designed for remote handling applications.

The selection of suitable electrical connectors and tubing fittings for extended service in remotely maintained facilities has been limited to those of custom design and, in general, from custom fabricators. The requirements have reflected not only the limited remote-handling ability of the manipulator systems but also the rugged construction required for remotely maintained equipment. However, the increased dexterity of currently available servomanipulators and their force-reflection features should alleviate some of these requirements for customized hot-cell equipment components. The remote connector test was devised to examine the capability of these state-of-the-art servomanipulators (i.e., the CRL Model M-2) for performing maintenance tasks on selected electrical connectors and tubing fittings that are readily available from domestic and European commercial sources. The specific objectives of the tests were to qualify various types of connectors for service in areas maintained by the Model M-2 manipulator or its equivalent and to identify practical modifications that could extend their service life or enhance their remote-handling characteristics.

As shown in Fig. 4.3, the various electrical and tubing connectors and their associated jumpers that were selected for this program were mounted in multiple locations and configurations on a test panel. Comparable flareless tube fittings from three manufacturers and electrical connectors from five vendors were examined. Three sizes of tube fittings from each source (a total of 28 different fittings) and an assortment of some 24 electrical connectors were subjected to 25 repetitive connect/disconnect operations by the Model M-2 manipulator. An additional task that used 2-in. pipe connectors from a separate manufacturer was also added to the test sequence. Three operators with varied previous experience with the Model M-2 manipulator were used for all test operations. The sequence of tests was arranged to minimize bias in the evaluation of each connector. The experimental data characterized each electrical or tubing connector according to type, size, panel location, test configuration, tool requirements, and operator identification. The times required to disconnect and to reconnect the test jumper for each of the 25 repetitions were recorded along with results of systematic checks of connector integrity and video recordings of test operations.

With the exception of two coaxial connectors, all electrical connectors were remotely operable at all configurations on the test panel with the Model M-2 servomanipulator. After repeated operations, the serviceability of the connectors varied with the size and type of connector and was related to the breakage of either the housing or the alignment tab. There were no mechanical failures of the pins or changes in the electrical resistance of the connection on any of the connectors chosen for this test program. Average remote-handling

ORNL/PHOTO 6294–85

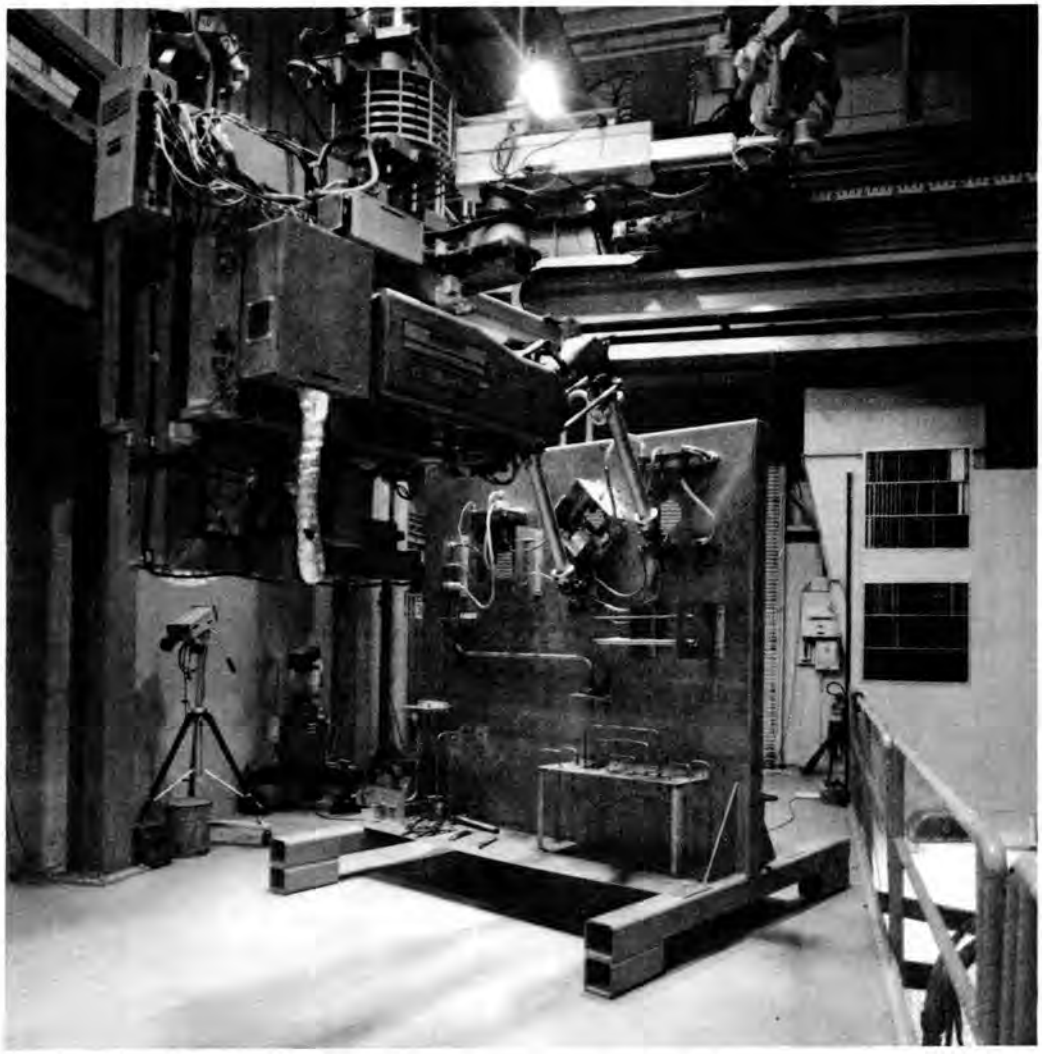

Fig. 4.3. Electrical and tubing connector remote handling tests using the Model M-2 servomanipulator.

times required to make and break a connection ranged from less than a minute to about 10 min and varied with connector type and location. Connectors that were designed for operation by a simple push-or-pull motion along the connector axis showed more favorable test results for remote maintenance applications.

All tubing connectors, as configured on the test panel, were remotely operable with the Model M-2 servomanipulator using conventional, manually operated wrenches. With respect to remote-handling characteristics, all three types of connectors were essentially equivalent. Isolated incidents of connector damage from thread galling were experienced; however, these were usually related to connector mounting orientation. Connectors that were mounted vertically were self-supporting and provided better alignment conditions for jumper installation. Leak-tight connections were consistently easier to achieve with connectors having two-piece ferrules than with those having one-piece ferrules. Average

remote-handling times of 4 to 25 min were required for each jumper removal and replacement operation. The gear-driven pipe connectors (2-in. IPS) that were examined in this test were all remotely operable, but their drive mechanisms were susceptible to galling.

4.3 REMOTE SHEAR SYSTEM MAINTENANCE OPERATIONS

The remote shear system housing has two hinged covers that allow access to the shear mechanism. The cover located above the shear slides provides structural support to the slides during shearing operations and weighs about 7.5 metric tons. The other cover is located above the slide's hydraulic actuators; it weighs approximately 2 metric tons. A lifting eye is provided on each cover for opening and closing the covers by pivoting them 180° about their hinges with a 9-metric-ton hoist of the primary bridge system. A diagram of the in-cell component of the shear system with the hinged covers in the open position is shown in Fig. 4.4.

During installation of the remote shear system in ROMD, the procedure for opening and closing the housing cover was reviewed, and potential problems that concerned personnel and equipment safety were recognized. First, the opening and closing of the hinged cover would subject the primary bridge hoists to significant horizontal loading. These vertical lift hoists were not specifically designed for this type loading. Secondly, the bridge hoist could be easily overloaded at the peak of hinged cover travel without any indication to the

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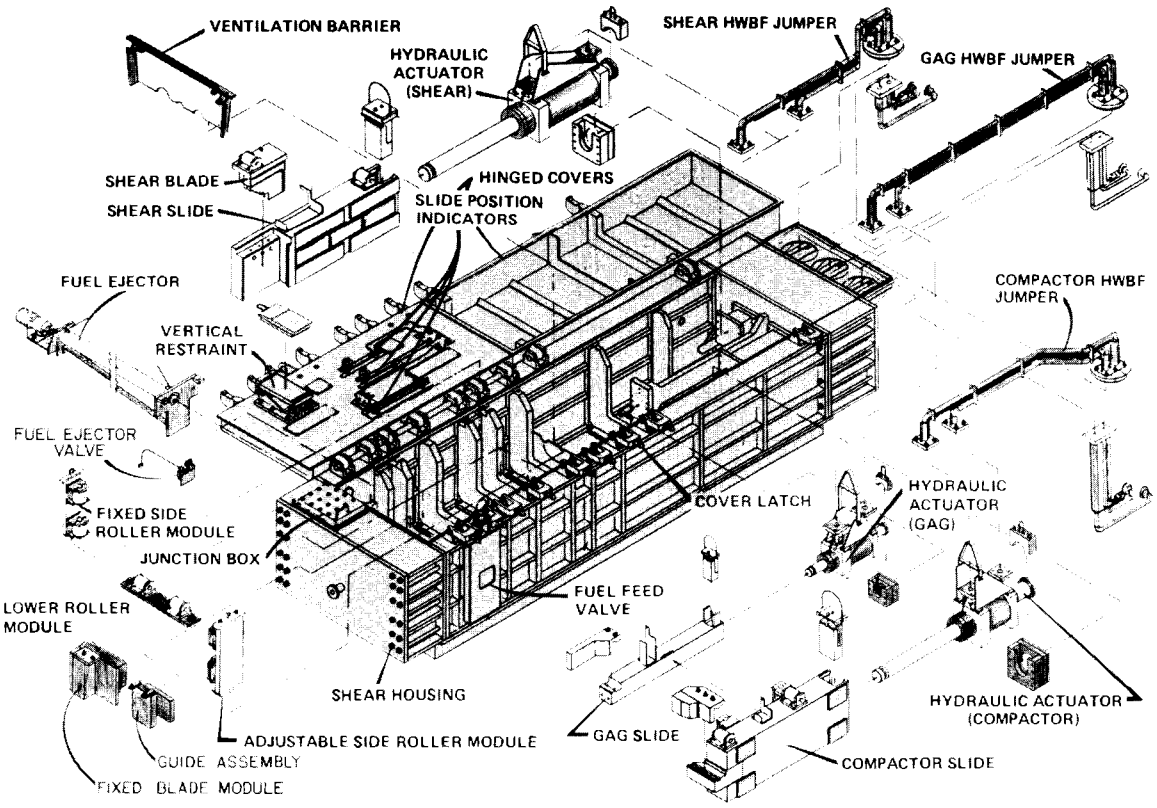

Fig. 4.4. Remote shear system.

system operators. Because the covers are rigidly fastened to the shear housing, there is no mechanical compliance. In addition, the location of the center of gravity of each cover with respect to its opening and closing line of action results in a flopping action when the cover reaches its overcenter, vertical attitude. Because of the large mass of each cover, this action could result in dangerously high vertical and horizontal shock loads on the hoist system. Finally, any uncontrolled movement of the bridge and hoist system (i.e., control system faults) while rigged to a cover could result in a catastrophic failure of the hoist and/or tipping of the gantry bridge.

A thorough analysis of these concerns was conducted before the test procedure could be prepared for demonstration of the cover opening and closing operations by the IET staff. This procedure was based on the use of a spring-loaded lifting device of special design that had been recommended and subjected to a safety analysis. The cover operation was successfully demonstrated, but it used local control of equipment. If remotely controlled operations are required, the design criteria for future remote shear installations should consider this cover-closure mechanism in greater detail.

4.4 REMOTE OPERATION OF A SATELLITE REFUELING COUPLING

The Model M-2 servomanipulator was used to demonstrate remote operation of a satellite refueling coupling for the Langely Research Center of the National Aeronautics and Space Administration (NASA). This demonstration was performed at the request of CFRP staff members who were actively engaged in conceptualizing teleoperated manipulators for space applications for Langely Research Center. The coupling was being developed by NASA for manual operation by astronauts for refueling satellites. The refueling operation has since been identified by NASA as a potential candidate for development as a remote operation. The objective of the demonstration was to illustrate the capabilities of existing remote handling technology.

As may be noted in Fig. 4.5, the coupling operation required the dexterous manipulation of both servomanipulator arms. This task was also more intricate than those normally encountered in fuel reprocessing applications for which the design of the Model M-2 was optimized. However, the bayonet-type mount on the coupling halves was engaged and disengaged without incident. The valves used to start and stop fuel flow were operated using a standard ratchet-type wrench that had not been modified for the remote-handling operation. Proper seating of valves was remotely determined using the force-feedback feature of the Model M-2 servomanipulator. Valve torques in the range of 20 to 30 in.-lb were experimentally detected. Operation of a relatively fragile mechanical lockout device that prevented uncoupling of the device with the fuel valves open was also demonstrated.

Complete operation of the coupling was successfully demonstrated in accordance with NASA criteria and without modification for the remote-handling operation. An edited video recording of the demonstration was produced and distributed to NASA organizations.

ORNL/PHOTO 6353–85

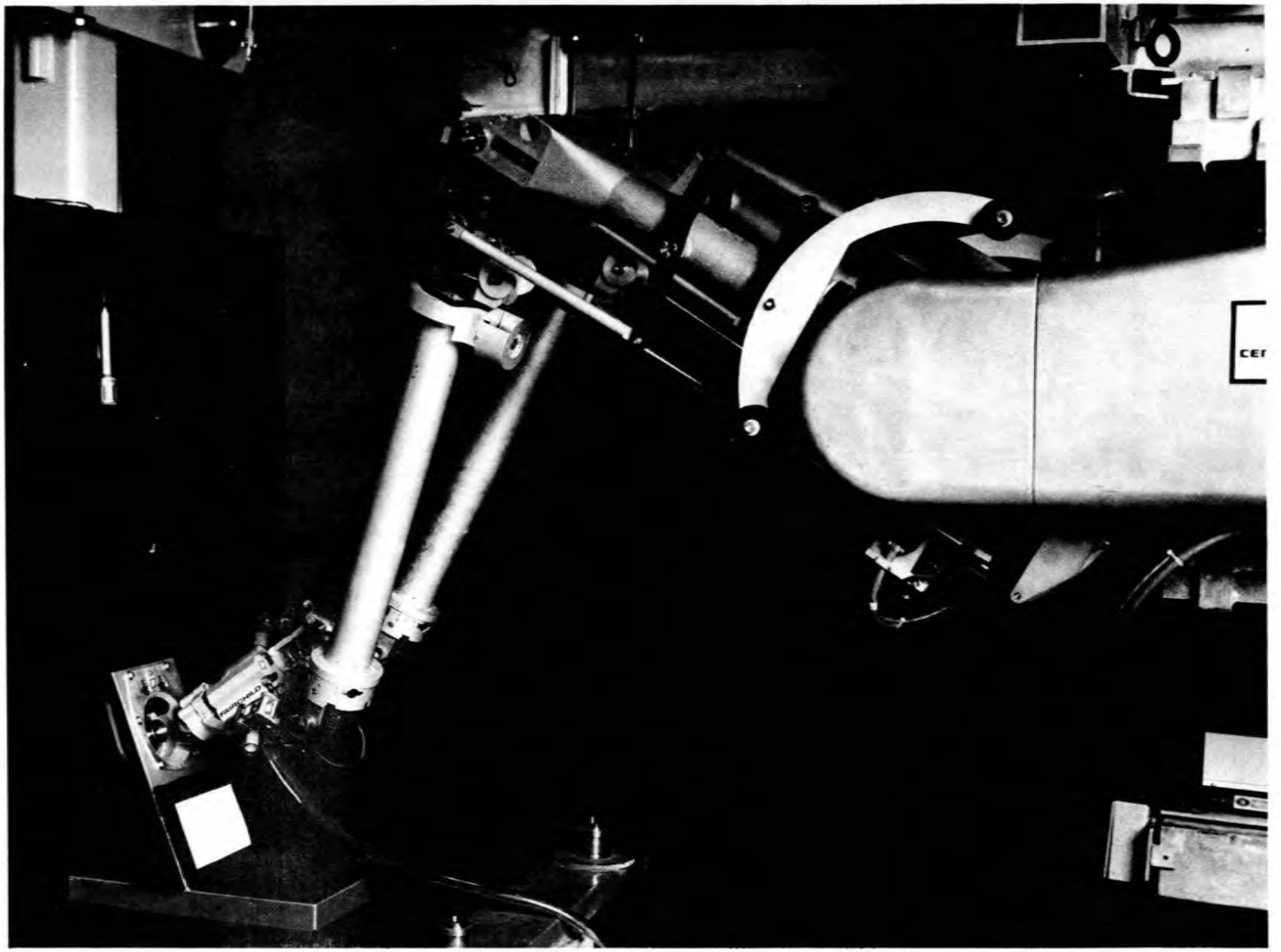

Fig. 4.5. Remote handling demonstration of a satellite refueling coupling.

5. PROCESS DEVELOPMENT OPERATIONS

The operation of the IPD facility embodies all functions of a dedicated chemical process plant. The installed equipment provides a production capability that is prototypical of a nuclear fuel reprocessing plant with a throughput capacity of 0.5 metric ton of heavy metal per day. Solid feed materials corresponding to this capacity can be simulated in the IET feed station as uranium oxides that are depleted in ^{235}U plus an appropriate quantity of fuel-pin hulls. As an alternate and a preferable source, solid feed materials can be sheared from dummy fuel-pin bundles in the remote shear system. Uranium from either source is transported to and dissolved in the completely equipped rotary dissolver system as a simulated production operation. The fuel-pin hulls are washed, dried, and recycled through the feed station. The uranyl nitrate dissolver solution is digested and fed through a clarification centrifuge to the accountability and feed adjustment system for makeup as feed for a complete cycle of solvent extraction. This system utilizes two banks of eight centrifugal contactors each for uranium extraction and scrubbing and a pulse column for final stripping of uranium from the organic phase into an aqueous product stream. The uranium product system then concentrates the uranium in the product stream in a single-stage evaporator before it is transferred through a materials accountability tank and discharged as feed to a simulated product conversion process. In the IPD system, this stream is diverted to the dissolver product surge tank for recycle through the solvent extraction system. The operation and maintenance activities required for these process units and their associated support systems are comparable to those of a small industrial chemical plant. However, effective operation of the IPD facility has been achieved with a limited staff using pilot-plant procedures because there have been no incentives for demonstrating plant productivity.

Process development operations during FY 1985 focused on a primary objective for demonstrating improved process operating and control procedures while supporting concurrent CFRP programs in two major categories. Frequent revisions of the equipment operating procedures for this relatively new plant were anticipated and reflect the developing interest and experience of the operating staff.

Demonstrations of coordinated operation of two or more process systems, as they are brought on line for plant service, were conducted as integrated process campaigns. Operations in this category have required full shift coverage for demonstrations of continuous operation over extended time periods and have been associated with the major milestone objectives of the IET facility. A second category represents the participation of the CFRP staff in utilizing the IPD facility for engineering research and development studies. When possible, these experimental programs have been combined with the IPD integrated campaigns or coordinated as separate experimental campaigns.

5.1 INTEGRATED PROCESS CAMPAIGNS

Uranium was first introduced into an integrated IPD process demonstration during September 1984 as a preliminary shakedown of the dissolver and solvent extraction systems. Although this activity prompted a number of changes in process piping and control procedures, the capabilities of the facility as a test site for demonstrating safeguards materials accountability procedures were recognized. Operating procedures for subsequent integrated process campaigns have conformed to these materials accountability standards and have supported the active participation of Safeguards Task personnel for development purposes. During FY 1985 two major integrated process campaigns were conducted.

5.1.1 IPD Campaign—April 1985

The initial IPD campaign of FY 1985 was completed during the period of April 15–26, 1985; it demonstrated the sustained operation of both the rotary dissolver system and the solvent extraction system as consecutive exercises. During the first week, the rotary dissolver and dissolver off-gas systems were operated along with the dissolver feed station, the digesters, and the accountability and feed adjustment system to prepare feed for the solvent extraction system. The automated sampling vehicle was used to obtain liquid samples of dissolver solution from the two digesters. The second part of the campaign demonstrated continuous operation of the solvent extraction system and supporting operation of the uranium product system, the organic treatment system, and the liquid waste system. The concentrated uranium product stream was recycled through the accountability and feed adjustment system to provide continuous operation of these process units.

The design for the campaign flowsheet was based on the following criteria:

1. Batch transfer of complete tank inventories (except for feed tanks) for all uranium-bearing materials.
2. An aqueous solvent extraction feed that contained 150 g of uranium per liter (150 g U/L) and a free acid concentration of 3.5-*M* nitric acid.
3. A maximum uranium concentration of 275 g U/L at a nominal acid content of 3-*M* nitric acid in the dissolver product solution.
4. Except for uranium accountability tanks, tank fill volumes were limited to 80% of their overflow capacities.

The operating schedule for the rotary dissolver was based on eight digester batch loadings having controlled uranium inventories of 95 kg U (112 kg U_3O_8 in the dissolver fuel) each and volumes within the range 345 to 475 L. In actual practice, about 1200 kg of depleted U_3O_8 powder was processed in ten digester batches. Very few equipment problems were encountered, and the sampling vehicle demonstrated a 93% sampling mission success rate in withdrawing liquid samples of dissolver product solution from the digester tanks. The drum drive, steam generator, and bearing-water-lube subsystems all performed satisfactorily, and there were no unscheduled dissolver shutdowns. The wash/dry station for

recycling fuel-pin hulls from the dissolver to the feed station generally required an overnight period for drying. This unit was identified for further improvement.

The discrepancy in digester batch loadings was traced to an inconsistency in the software used for feed station operation. Initial attempts to predict accurately the uranium and acid concentrations in the digester solutions from solution conductivity, density, and temperature values were biased because of an incorrect signal from the conductivity probes. This condition was corrected during early dissolver operations.

The safeguards test program that was conducted as part of the integrated campaign was based on the near real-time evaluation of process data for uranium accountability. The primary objective of this activity was the accumulation of data during steady-state operation of the overall IPD plant to establish a data base for subsequent development and refinement of accountability methods and procedures. These results will be applied in later IPD campaigns to evaluate advanced safeguards under more complex process conditions. The safeguarded system for this campaign was bound by accountability tank 09F23 for the uranium feed materials, tank 19F07 for the uranium product, and tank 32F11 for the liquid waste.

The solvent extraction system, as well as its supporting systems, were operated without difficulty while processing about 2000 kg of uranium. After operating for 48 h at steady state, the acid concentration of the feed (HAF) stream was decreased to about 0.5-*M* nitric acid to establish conditions for measuring stage efficiencies in the HA contactor bank. Samples of both the organic and aqueous phases from each stage were withdrawn after new steady-state conditions were achieved.

The extended solvent extraction operation also provided for additional tests of the uranium photometer for controlling the operation of the pulse column as a scrubbing (HC) column.[8] This effort was moderately successful, but additional modifications to the control loop were indicated.

Considering the complexity of the operations program and the limitations with both the number and experience of the operating staff, this campaign successfully demonstrated sustained operations of the various process systems and established the viability of the IPD facility for engineering research and development applications.

5.1.2 IPD Campaign—September 1985

The second integrated IPD campaign for FY 1985 was completed during the week of September 15–20, 1985, and featured the simultaneous operation of both the rotary dissolver system and the solvent extraction system on uranium-bearing feed materials. As in the previous campaign, the sustained operation of these major process units also required the concurrent operation of their support systems. The campaign simulated "warm" startup conditions in that solvent extraction feed for about 30 h of operation was prepared during the preceding week to reduce the lag time for startup of the solvent extraction system.

Feed solids to the rotary dissolver consisted of U_3O_8 powder and fuel-segment hulls and wires from the feed station as in the previous campaign. However, the rate at which these solids were added to the dissolver was regulated as two different modes. The first corresponded to the uninterrupted shearing of a complete CRBR blanket assembly and was

followed by a second period of no solid feed while the shear was reloaded. Nitric acid and water additions to the dissolver were based on the complete dissolution of uranium in an excess of about 3-*M* nitric acid during the shearing cycle. These flows were reduced during shear reloading to control the concentration of uranium in the digester tank solutions. This simulation of an integrated operation of the shear and the dissolver required digester batch cycles of 12 h each (6-h fill period). Each digester batch contained a nominal 125 kg of uranium for a feed rate corresponding to 500 kg U/d. Other features of the process flowsheet for this campaign were similar to that of the earlier campaign except that the concentration of uranium in the solvent extraction feed was increased to 160 g U/L at the same solution acidity to compensate for changes in the digester operating cycle.

A change in process equipment configuration was also installed in the IPD facility to alleviate the constraint imposed by the feed clarification centrifuge on process capacity. This process unit has a maximum throughput capacity of about 4 L/min. As originally installed, the centrifuge was alternately fed by steam ejectors mounted on each digester tank. These jets had capacities of about 38 L/min and frequently flooded the centrifuge. Smaller jet transfer units were subsequently installed, but they could not be satisfactorily operated because of the unusual length and configuration of the transfer line and the significant liquid head that exists between the digesters and the centrifuge. The change in process equipment configuration utilized tank 09F21 as the digester surge tank and the original jets for rapid transfer of dissolver solution from each digester. The clarification centrifuge was moved downstream of this tank so that it could be supplied by a single low-volume jet and discharged directly into the accountability tank, 09F23. This jet was later replaced with a fluidic pump.

The use of tank 09F21 as a digester surge tank required that adjustments to solvent extraction feed conditions be made in a single step. Additionally, each accountable batch measured in tank 09F23 represented about 2.07 digester batches and corresponded to an operating cycle of about 12.4 h. With a flow constraint for feed clarification of about 5-h/tank, the remaining batch cycle time allowed about 7 h for batch certification after routine sampling.

Safeguards tests that were included in the integrated campaign provided overall surveillance of materials transfers within the uranium accountability tank system. As in the previous campaign, the solvent extraction system and its supporting systems were operated at steady state on once-through feed for the bulk of the campaign. Solvent extraction conditions were varied at the end of the campaign to accommodate an additional test of the efficiencies of the HA contactors and further tests of the uranium photometer installation. The safeguards test program also requested the planned diversion of materials from within the accountability system on 17 occasions by 6 different methods to test the capability of detecting these events on a near-realtime basis. This phase of the program was satisfactorily accomplished and provided a test of computer software developed by the Safeguards Task.

The dissolver demonstration planned for this campaign was based on 12 digester batch preparations during 72 h of continuous operation. The total materials inventory required for the dissolver operation corresponded to about 1500 kg of uranium as U_3O_8, about 3400 L of 11-*M* nitric acid, and about 2550 L of recycle water. Adjustments of the dissolver solutions to compositions suitable for solvent extraction feed required an additional 1100 L of 11-*M* nitric acid and about 600 L of recycle water.

5.2 EXPERIMENTAL DEVELOPMENT PROGRAMS

Demonstrations of engineering research and development programs in the IPD facility during FY 1985 represented the continued interest of the CFRP in the development of improved equipment components for nuclear fuel reprocessing plants. Although each operation of the facility is examined for potential improvements in equipment design or configuration and in operating procedures, four separate studies were defined for detailed experimental evaluation.

5.2.1 Purge Air Flows to Solvent Extraction Contactor Spindle Motors

The motorized spindle drives, as installed on the IPD 12-cm centrifugal contactors, are subject to bearing degradation and motor damage if corrosive liquids or gases penetrate the seals on the motor housings. The protection of these units depends on the delivery of an adequate supply of purge air to each motor and its discharge through the front labyrinth seal into the cavity above the rotor assembly. The specification of purge-air requirements for these spindle drives was based on appropriate values for the linear velocity of purge gas through the seal during operational and nonoperational periods. This experimental program provided measurements of purge-air velocities as functions of purge-air pressure applied to the motor cases of each of the contactors installed in the IPD facility. During the first part of the tests, the contactors were operated without process fluids at rotor speeds of 1200 and 1750 rpm. The concluding tests examined purge-air discharge from the system during solvent extraction operations that used dilute nitric acid (without uranium) as the aqueous feed stream.

5.2.2 Gadolinium Monitor Tests

Engineering design of head-end process equipment for the conceptual BRET facility proposed the use of gadolinium as a soluble neutron poison for nuclear criticality control.[9] According to this control scheme, gadolinium will be dissolved to prescribed concentrations in all fluids entering the head-end process. A part of the basic acceptance criteria for this method requires the demonstrated ability to continuously monitor these dissolver input streams for their gadolinium content and to render an immediate alarm signal if the neutron poison concentration drops below a limiting value. The objectives of tests conducted within the chemical makeup area of the IPD facility were to (1) examine the operational stability of a gadolinium monitor proposed for this application, (2) demonstrate on-line calibration procedures, and (3) evaluate the characteristics of safety signal generation by the monitor when low gadolinium concentrations were encountered. The monitor chosen for this study had been subjected to extensive laboratory development tests.[10,11]

The gadolinium monitor designed for this program consisted of a vessel through which process solution could be passed between a neutron source and a neutron-sensitive detector. A monitor station would be located downstream of each cold chemical makeup point for dissolver inlet streams and provide a continuous electrical signal that was proportional to the gadolinium concentration in the dissolver inlet stream. Periodic instrument calibration

would be accomplished by diverting the process stream and substituting a standard gadolinium solution for comparison of signal magnitude. Alarm limits for the monitor would be selected and could be tested by similar procedure. The mock-up of a gadolinium monitor station in the IPD facility provided realistic process conditions for extended monitor tests. However, small closed-loop installations were used to recycle these test solutions to conserve gadolinium and reduce waste solution volume.

The gadolinium monitor demonstration test utilized a simulated process stream that contained 11 g of gadolinium per liter (11 g Gd/L), an on-line calibration stream that contained 13 g Gd/L, and a series of standard solutions that contained from 0 to about 17 g Gd/L. Standard solutions that contained less than 11 g Gd/L were also used to create signal alarm conditions. The output monitor signal was connected to the DDACS control system for data collection.

The initial test of this program provided a total of 237 h total operation on the simulated process stream at flow rates of 5 and 35 L/h. The on-line calibration test was conducted on ten occasions, and the safety signal test was performed twice. The stability of the monitor signal could not be satisfactorily determined during this test period because of excessive noise in the electrical circuit used to power the monitor. The sources of noise were determined and corrected in preparation for additional tests on the monitor system.

5.2.3 Steam Ejector Tests

Steam jets provide a convenient means for transferring aqueous solutions between tanks and are readily adaptable to service in a nuclear fuel reprocessing plant. The primary features of these devices are their simple design with no moving parts and their reliable performance over a wide range of process conditions. However, this method for transferring solutions has certain drawbacks that are associated with the addition of water to the process stream by dilution with condensed steam. This condition can be particularly significant when solutions containing plutonium are transferred by steam jet. The localized dilution of these streams can contribute to the formation of insoluble plutonium oxide polymers under specific solution conditions of concentration, acidity, and temperature. The injection of steam into the process solution can also result in significant increases in solution temperature. These factors are both related to the efficiency of the steam jet during solution transfer.

A standard dilution factor of 5% as condensed steam is usually assumed during flowsheet studies for commercially available jets but could be larger at the low flow rates required for certain process steps. Accordingly, operational tests with a commercial low-flow steam jet were devised to (1) evaluate the feasibility of low-flow applications, (2) determine dilution levels for various pumping rates, and (3) measure the temperature rise of the pumped solutions. Test conditions established requirements for the suction lift, the horizontal length of transfer line, and the discharge head.[12] The steam supply pressure was held constant for each test over the range of 10 to 80 psig. The initial tests provided for jet calibration data at various steam pressures and solution temperatures for transfer of a relatively dense solution of uranyl nitrate. Further tests refined these calibrations by varying the motive steam pressure as required to achieve a specified pumped-liquid flow rate.

5.2.4 Fluidic Pump Tests

Fluidic pumps are being developed by the CFRP as alternate devices for supplying gravity-flow metering tanks with process solutions, for transferring solutions between process tanks, and for mixing solutions contained in product slab tanks.[13,14] The absence of packing glands, mechanical seals, and moving parts in these pumping systems promotes their use for transporting hazardous or corrosive fluids that may also carry suspended particulate matter. In support of this program, a bottom-loading slab-tank pulsatile pump was designed and fabricated for pump development. The purpose of the test program conducted in the IPD facility was a demonstration of product mixing under conditions proposed for the BRET facility.

These pulsatile pumping devices use compressed air to force liquid from the pumping chamber to a receiver tank. The pumping chamber is filled by gravity flow from its feed tank during a timed interval without compressed air flow. The critical component in the pumping system is the reverse-flow diverter, a generic name for a three-port device that provides a forward-flow mode where liquid is transported from the feed tank to the pumping chamber and a reverse-flow mode that diverts fluid through a jet to the outlet port. The properly designed reverse-flow diverter should carry fluid over the relatively short gap distance to the receiver/diffuser with sufficient static pressure to force the fluid through some vertical distance to the receiver vessel and without diverting an appreciable amount of fluid back to the feed tank.

The fluidic pump used for this test was made from a 4-ft. length of 4-in. 304L stainless steel pipe with a rigid air line of 0.5-in.-diam stainless steel tubing and a rigid liquid discharge line of 0.75-in.-diam stainless steel tubing. To demonstrate the BRET application, the pump needed, at least, an 8-ft refill head and a 14-ft vertical head to pump against. A uranyl nitrate–nitric acid solution having a measured density of about 1.4 g/L represented the product solution.

The fluidic pump was installed in the solvent extraction feed tank (11F03) and required temporary piping changes to provide solution return from the catch tank (11F01) and for auxiliary storage of the uranyl nitrate solution. The test program provided performance data over the complete volume range of the tank. Repetitive tests were conducted at air supply pressures over the range 25 to 40 psig at 5-psig intervals. At the beginning of each test, the pump time cycle was selected and then adjusted for optimum conditions that would not produce audible blowout of air into the tank. All data required by the test program were generated by on-line instrumentation and stored in the DDACS system at 4-min intervals. The results of the tests compared favorably with those obtained from a predictive computer model that had been developed from laboratory test data.[15]

6. ENGINEERING SUPPORT

Engineering support for the IET facility, and that for the entire CFRP building complex, is provided as a dedicated activity of the CFRP. This process engineering function began during the inception of the IET facility to exercise primary responsibility for planning and supervision of its detailed engineering design. This activity was extended for supervisory and quality control during the fabrication and subsequent installation of the various equipment components in the IET facility. The preparation of detailed design descriptions and associated acceptance test procedures for each process system were a part of this process engineering activity.

Although all major equipment integration projects for both the IPD and ROMD areas have been completed, dedicated engineering support is essential for the continued operation of the IET facility and for projected demonstrations of advanced fuel reprocessing technology.

6.1 IET FACILITY SUPPORT

Significant engineering efforts in the IPD area during FY 1985 were devoted to process equipment modification and repair following the IPD milestone campaign at the end of FY 1984. The rotary dissolver system required a major maintenance effort to correct materials and design discrepancies in the drum support and rotation mechanism. An improved method was also developed for washing and drying fuel-pin hulls after their discharge from the rotary dissolver. A system change was necessary to alleviate restrictions from the low capacity of the feed-clarifying centrifuge on process throughput rates. The centrifuge is now fed from the surge tank, 09F21, and discharges directly into the feed-accountability tank, 09F23. Dissolver solution from each digester can be jetted without flow restriction directly to the surge tank.

Additional process-sampling points and instrumentation capabilities were installed throughout the IPD area. Piping changes were also made to provide simulated product diversions for safeguards test demonstrations. A temporary system for conducting stability tests on the gadolinium monitor was installed in the chemicals makeup area.

Maintenance activities in the ROMD area included modifications to the secondary bridge crane to extend its travel over the remote shear system and remote disassembly system for performing remote maintenance demonstrations. This work included switching the east and west trolley positions, shortening the cable-handling device, and raising the operating level of the telescoping tube used for suspension of the Model M-2 servomanipulator.

6.2 ENVIRONMENTAL TEST CHAMBER

Detailed design of the Environmental Test Chamber was completed, and capital equipment funding for the project was approved. A contract for the construction of the chamber was awarded at midyear for scheduled completion by the third quarter of FY 1986. Contracts were awarded for fabrication of the in-cell cooling and purification unit and for procurement of analytical instrumentation.

A mathematical model of the low-flow ventilation system was developed to predict atmospheric concentrations of corrosive materials that would result from various plant operating conditions.[16] The model can also be used to study pressure and temperature transients that may result from system upsets and to evaluate system design.

7. PROGRAM FOR FY 1986

The IET program for the FY 1986, which began in October 1985, represents a significant escalation in process development activities, the continued scheduling of major demonstrations of remote maintenance technology, and the expansion of the experimental capability of the CFRP with the addition of the Environmental Test Chamber. This program also reflects the increased participation of the CFRP technical staff in IET operations and will place additional demands on engineering support for the IET facility. The coordination of these activities for execution by the IET operating staff will follow guidelines used for the FY-1985 program.

7.1 PROGRAM PLAN FOR THE ROMD FACILITY

The remote maintenance program for FY 1986 will support two major demonstrations and additional smaller tasks as they can be accommodated by the IET operations schedule. One demonstration will examine the force-reflection feature of the CRL Model M-2 servomanipulator and the impact of its use on operator performance. The second major ROMD task will demonstrate the remote maintainability of the remote shear system. Less extensive tasks that have been scheduled include selected remote maintenance operations on the remote disassembly and the dissolver systems.

7.1.1 Force-Reflection Evaluation Tests

The principal source of information for operators of most currently available servomanipulator systems is based on a television monitoring system that shows visual images of the field of operation of the manipulator. The operator may also have indicators that register the amounts of force applied by the joints of the manipulator arm. Other indicators may provide information about the movement of the slave arm and its position relative to the servomanipulator transporter. If the manipulator system provides force reflection, the operator also receives information concerning the inertia of arm movement, its contact with objects, and the amount of force that it applies. Evaluations of operator response to these available information sources and their impact on the performance of remote-handling tasks have been beneficial to the development of remote maintenance technology by the CFRP. The experimental program proposed for execution in the ROMD facility during FY 1986 will continue this investigation by an examination of the force reflection capabilities of the CRL Model M-2 servomanipulator system for their effect on task performance.

The experiment has been designed to test the impact of force feedback on the performance of experienced operators during the execution of novel remote-handling tasks and on performance in the presence of degraded visual conditions. A second set of tests will elevate the effect of force feedback on the performance of unskilled operators.

Four manipulator tasks will be rigidly mounted to a six-axis load-sensing table so that forces and torques exerted on the tasks will alter the output signals from the load table. The test program will also utilize right-arm signals from the Model M-2 tachometers for obtaining velocity data on manipulator movements. Similar outputs from three accelerometers and electrical currents from four joints will be recorded. Data from these sources will be collected as the manipulator tasks are executed by an electronic data collection system based on a Hewlett-Packard Model 9000-236 desk-top computer with hard-disk storage. The test observer will input test identification and critical incident data by keyboard interface with the computer.

7.1.2 Maintenance Demonstration of the Remote Shear System

The remote shear system is one of several major activities that serve as an important precursor to the ultimate demonstration of advanced fuel reprocessing technology. A nuclear fuel reprocessing plant must provide for the mechanical segmentation of spent liquid metal fast breeder reactor fuel assemblies as preparation for subsequent chemical processes. Prior to shearing, the metallic hardware (such as the shroud and end fittings that are associated with these fuel assemblies) will be removed by a companion remote disassembly system. A demonstration of the remote maintainability of the remote shear system has been planned for FY 1986; the corresponding maintenance demonstration for the remote disassembly system has been scheduled for FY 1987.

The remote shear system that has been installed in the IET facility consists of three mechanical systems and an associated control system. The hydraulic power system consists of conventional fixed-displacement oil pumps, valves, and accumulators that can be located outside the process cell. The fluid/mechanical coupler system consists of tandem hydraulic cylinders that isolate the out-of-cell, oil-based fluid circuits from the potentially contaminated in-cell, water-based fluid circuits. The in-cell system is a sealed mechanical structure that interfaces with the disassembly system and contains the essential components that perform the shearing operation. This in-cell system was designed for maintenance by totally remote procedures.

The in-cell shear system is driven by three adjacent hydraulic cylinders that operate on water-based fluids. The driven parallel slides are horizontal and are supported by mechanical rollers. These slides engage fixtures that compact the fuel-pin bundle, hold (gag) the compacted bundle, and shear the fuel into short segments for direct loading into the dissolver system. The in-cell shearing system is totally enclosed within a massive steel housing. Vertical access to all internal components is available through large covered ports in the top of the housing structure. Remote maintenance and tooling changeout procedures would be accomplished between process campaigns using hoists and manipulators transported by the overhead bridge system.

The remote maintenance demonstration planned for execution in the ROMD facility during FY 1986 will consist of opening the shear lids and removing jumpers, slides, activators tooling, and supports down to the bare box structure. After removal, these components will be replaced by similar remote procedures. The shear will be readjusted and machine operated to verify proper installation. The documentation of these tests will describe lifting fixtures developed for specific maintenance tasks, detailed procedures and sequence of all maintenance tasks, execution times, and evaluation of the engineering design of the shear system.

7.1.3 Changeout of Fuel Adapters in the Remote Disassembly System

The remote disassembly system receives intact fuel and blanket assemblies as they are scheduled for fuel reprocessing operations. The specific function of this system is the removal of metallic shroud and end fittings from the assemblies that might impede the subsequent shearing process or introduce excessive metallic scrap into the dissolver. The in-cell components of this system must rely on remote procedures for operation and maintenance. Although a complete remote maintenance demonstration for this system has been scheduled for FY 1987, a preliminary test was planned for FY 1986 to verify the design of some replaceable components of the system.

To accommodate the disassembly of different fuel types, replaceable positioning and support fixtures must be designed for each fuel-element configuration. Remote changeout of these fixtures must be conducted for each different fuel type as a routine operation. This test program was designed to examine the capability of removal or replacement of all CRBR core fuel-specific adapters on the remote disassembly system and replacement with specific adapters for CRBR blanket assemblies. Documentation of test results will include a listing of tools and procedures developed for this maintenance task, a record of the execution time needed for each operation, and an evaluation of design criteria used for the fabrication of these fixtures.

7.1.4 Maintenance of Rotary Dissolver Steam Chest Lid Seal

The steam chest surrounding the rotary dissolver drum has a removable lid to allow access to the drum and other components within the chest. Because the pressure in the chest is maintained slightly below atmospheric pressure, an airtight lid seal is desired to minimize the leakage of cell air into the dissolver off-gas (DOG) stream. The seal currently in use is established by placing the edges of the lid in a trough containing a molten metal eutectic mixture (Cerrobase; melting point is 123.9°C) and allowing the metal to freeze.

Component development tests of the lid seal identified potential problems that might preclude its use within the process cell of a nuclear fuel reprocessing plant. The test program scheduled for FY 1986 will examine remote maintenance procedures that will be required to restore this seal following simulated maintenance operations on the dissolver drum.

7.2 PROGRAM PLAN FOR THE IPD FACILITY

Planned operations of the IPD facility during FY 1986 will probably support three major campaigns. Where possible, these campaigns will coordinate relevant experimental engineering projects with major process demonstrations that are associated with CFRP milestone objectives. One of the primary objectives of the FY 1986 program will be the integrated operation of the remote shear system with the dissolver system and with the balance of the IPD plant at matching process rates. A second objective will be an intensive engineering evaluation of the dissolver off-gas system and the checkout and operation of the Iodox system. A third objective will be the installation of 5.5-cm. centrifugal contactors in the solvent extraction system. The completion of this objective during FY 1986 would provide a basis for the third major campaign. Each process demonstration will reflect the significant improvements in process control technology that are being developed by the IPD operating staff. As with the FY-1985 program, other engineering research and component development activities will be scheduled as they are proposed by the CFRP technical staff and accomplished as individual experimental programs.

7.2.1 Process Automation and Control

The versatility of the computerized IET control system (see Appendix C) provides a capability for the development of automated process control schemes that can be effective for advanced nuclear fuel reprocessing applications. Although this technology has been actively pursued for industrial process applications, its general use has been limited by the diversity and reliability of on-line process sensors that can be "read" by advanced computerized control systems. Accurate measurements of process parameters were first available from on-line sensors for temperature, pressure, and liquid/gas flow rates and have now been supplemented by sensors that can indicate liquid levels in calibrated tanks and solution properties such as acidity, density, and electrical conductivity. When these property measurements can be utilized to infer chemical concentrations of specific process streams, more effective designs for automated process control schemes can be installed.

Experience gained from integrated operations of the IPD system during FY 1985 has been utilized to establish the precision and reliability of installed on-line sensors. Additionally, tests of a mathematical correlation of solution physical properties to infer the chemical concentrations of uranyl nitrate solutions have yielded satisfactory results and have been complemented by the direct photometric measurement of uranium concentrations by adaptation of an on-line sensor. During FY 1986, a major emphasis will be placed on the further development and testing of automated process control schemes that will utilize these developments. Near-term plans have been established for controlling batch compositions and volumes in digester tanks and for automated operation of the accountability and feed-adjustment system to prepare and deliver uranyl nitrate feed solution to the solvent extraction system. The development of an automated control scheme for operation of the solvent extraction system was begun during FY 1985 and will continue in FY 1986. The current scheme utilizes on-line photometric measurements for uranium in solvent extraction process streams. A control scheme for the automated operation of the uranium product system will begin during FY 1986.

7.2.2 IPD Experimental Campaign—March 1986

An integrated operation of the IPD systems during March 1986 will provide process conditions for a preliminary review of current safeguards materials accountability procedures in preparation for an integrated IPD campaign in April 1986 that will support the coincident CFRP Safeguards Workshop. This experimental campaign will also provide for the continued development of process control methods. The application of on-line photometer cells for continuous indication of uranium concentrations in solvent extraction streams has been investigated as a potential method for process control of that system. The sustained operation of the solvent extraction system during this campaign will be utilized for further development tests of this control scheme. Equipment modifications, which may become necessary for integration of the BRET-scaled 5.5-cm centrifugal contactors into the IPD solvent extraction system, will be identified during test operations of airlift transfer devices at the lower flow rates that have been anticipated for these contactors. An experiment will be conducted during solvent extraction operations to test a new control scheme for the uranium product evaporator system.

7.2.3 IPD Integrated Campaign—April 1986

The IPD campaign, planned for April 1986, will feature the first integrated operation of the remote shear system with the rotary dissolver and the balance of the IPD process systems. The shear will be used to segment 24 bundles of simulated fuel pins that contain sintered uranium dioxide pellets (depleted in ^{235}U) clad in Zircaloy tubing. The sheared fuel will be fed directly as it is produced to the rotary dissolver during sustained operation of the IPD plant. This integrated operation of the shear with the rotary dissolver represents a major milestone accomplishment for the CFRP.

As a second feature, this campaign will directly support the CFRP Safeguards Workshop by providing simulated process conditions for demonstrating current materials accountability procedures. The surveillance capability that has been developed for monitoring materials transfer operations in the IPD facility provides a unique opportunity for demonstrating new and improved techniques that have been developed within the Safeguards Task. These techniques will be demonstrated for routine materials accountability applications and for the recognition of process stream diversions.

This integrated operation of the IPD systems will be utilized to examine potential improvements that will be installed in the IPD plant for process operation and/or control purposes. An automated control scheme will become available for solvent extraction feed makeup and for all solution-transfer operations in the accountability and feed adjustment system. The fluidic pump developed within the CFRP and previously tested in IPD operations will begin routine service for transporting dissolver solution from the digester surge tank, 09F21, to a head tank that supplies the feed-clarification centrifuge. The automated sampling vehicle will be linked with the DDACS process control system for demonstration of automated sampling capabilities by routine withdrawal of analytical samples from the two digester tanks.

A limited study of the DOG composition and NO_x scrubbing efficiency will be conducted for preliminary evaluation of the effects of increased NO_x concentrations from UO_2

dissolution on the IPD systems. Data obtained during this campaign will be utilized for planning an experimental program for processing dissolver off-gas through the Iodox system.

7.2.4 Performance of Condensers in the Dissolver Off-Gas Stream

In addition to certain dissolver reaction products, the noncondensable component in the off-gas is augmented by purge and sparge gas streams and by the inleakage of cell air at significant rates through the rotary dissolver and the feed chute from the shear (or feed station). Because the dissolver and digesters are operated at temperatures of about 95 to 100°C, an excessive quantity of liquid can be discharged to the off-gas system by evaporation. At the relatively high gas inleakage rate of the IET system, the considerable evaporation rate could further complicate the design of off-gas process units or compromise iodine transporter properties.

The design for the BRET primary dissolver system recognized these potential off-gas problems and specified double overhead condensers in the off-gas line to return condensed nitric acid to the dissolver at minimal iodine recycle rates. The first condenser would be operated at an elevated temperature to reduce iodine condensation while removing the bulk of water vapor and nitric acid from the off-gas stream. The second unit could then be operated with chilled water without condensing a significant quantity of iodine from the relatively dry off-gas stream. Laboratory experiments have confirmed design calculations that both iodine recycle and nitric acid losses would be minimized. An engineering research program has proposed the installation of double overhead condensers in the off-gas system and a test plan that will verify the effectiveness of this process configuration.

This experimental program will begin a detailed examination of the off-gas stream to evaluate the performance of the double overhead condenser design and to measure off-gas saturation levels and concentrations of noncondensable components (i.e., iodine and nitrogen oxides) at various air purge rates. Repetitions of the experimental procedure will be conducted as necessary for adequate characterization of the off-gas system.

7.2.5 Operational Tests of the Iodox and Acid Concentration Systems

Acceptance test procedures for the Iodox and acid concentration systems have been completed, and preliminary operating procedures for the two systems have been prepared. The operational tests that will precede startup of these systems provide for the investigation of the operational status of the equipment, the verification of operating procedures, and the determination of operating parameters. Initial tests will use only water as the process fluid and will continue until system operating characteristics have been established and operator training objectives have been achieved. The test program will lead to a demonstration of the operational capability of the acid concentration system for preparing hyperazeotropic nitric acid (>68% HNO_3) by the magnesium nitrate extractive distillation process. Tests that will introduce iodine into the feed gas stream to the Iodox column will be conducted at a later date when iodine transport through the DOG system has been demonstrated.

7.2.6 Gadolinium Monitor Stability Tests

The conceptual BRET facility provides for the use of gadolinium as a soluble neutron poison for nuclear criticality control. According to this control scheme, gadolinium will be dissolved to prescribed concentrations in all fluids entering the head-end process. A part of the basic acceptance criteria for this method will be the demonstrated ability to continuously monitor these dissolver input streams for their gadolinium content and to render an immediate alarm signal if the neutron poison concentration drops below a limiting value. Thus, the qualification of an analytical instrument for monitoring gadolinium concentrations in these aqueous process streams is a primary requisite for approval of this criticality control concept.

Tests conducted during FY 1985 on this program examined the operating characteristics of the gadolinium monitor. On-line calibration procedures were demonstrated, and the response of the monitor to low-gadolinium concentrations satisfied criteria for safety signal generation. The tests revealed that the electronic detection circuits of the monitor were sensitive to electrical interference and that the instrument required atmospheric isolation from corrosive gases. These deficiencies have been corrected. Tests will be conducted during FY 1986 to examine the long-term stability of the gadolinium monitor.

7.2.7 Solvent Extraction Contactor Operations in Extract—Strip Mode

Centrifugal contactors have been used in the Savannah River Plant since 1966 for extraction and scrubbing in the codecontamination step of the Purex solvent extraction process. The design of future fuel reprocessing plants and possible major renovations of existing plants will also consider the application of centrifugal contactors for the back extraction (stripping) step of the process. This proposed experimental program will determine some of the operating characteristics of the two banks of 12-cm centrifugal contactors currently installed in the IET facility during their operation in an extract-strip mode.

The experimental test program will investigate the hydraulic performance of the contactor banks using an acid HAF stream (no uranium) and a water HCX stream at increasing flow rates. The second part of the program will provide analyses of both the organic and aqueous phases of each contactor in the HC bank at steady state with typical uranyl nitrate feed solution and with consecutive HCX streams of 0.02-*M* nitric acid and water. Measurements at typical and at 95% of maximum permissible flow rates will be obtained. The third part of the proposed program will examine procedures for rapid startup of the contactors and recovery from process upset conditions using automatic control based on photometer values for the uranium content in the organic phase in the fifth contactor stage.

7.3 PROGRAM PLAN FOR THE ENVIRONMENTAL TEST CHAMBER

Future nuclear fuel reprocessing plants are expected to contain nitrogen enriched atmospheres having low oxygen concentrations and low humidities. Process leaks and spills (inevitable events in any plant operation) will result in contamination of the atmosphere

with nitric acid vapor and nitrogen oxides. The current design philosophy of the CFRP advocates the use of a low-flow ventilation system for removing excess heat and corrosive contaminants from the process cell atmosphere. Expected background concentrations of these corrosive contaminants will be slightly higher than those found in traditional once-through ventilation systems.

The low-flow ventilation concept requires discharge of only enough cell gas to compensate for the small inleakage of outside air. If an inert atmosphere is maintained in the cell, the cell discharge gas must also compensate for the inert gas that will be supplied to the cell to dilute the inleaking oxygen to an acceptable concentration. An in-cell cooling and gas purification unit will remove excess process heat and corrosive contaminants. This unit consists primarily of a blower, a chilled-water-operated cooling coil, and a steam operated reheating coil. Because the mass of gas in the cell will change very slowly, cell pressure can be controlled by altering the mean cell temperature within a narrow range and by manipulation of the inert gas feed rate to the chamber. During cooling, water will be condensed from the cell gas; simultaneously, water soluble contaminants such as NO_x and HNO_3 will be absorbed into the liquid condensate phase.

The Environmental Test Chamber has a floor area of 23.4 m^2 (252 ft^2) and a volume of 141.6 m^3 (5000 ft^3). All internal concrete and block surfaces have been sealed with an epoxy coating. Viewing windows were installed in two opposite walls to permit observation of the chamber interior. A pair of glove ports at one window site permits limited manipulation of in-cell equipment when corrosive test conditions prevail. An air lock system provides controlled entry into the chamber without serious perturbation of the enclosed atmosphere.

Process heat loads up to a maximum of 9.6 kW will be simulated with electrical resistance heaters that are mounted overhead within the chamber. Two experimental stations are located on a wall adjacent to the windowed sections and have been provided with outlets for electric power, steam, condensate, and compressed nitrogen and with cabling to the control computer. Shelving that can accommodate items weighing up to 136 kg (300 lb) has been installed along the opposite wall of the chamber for test equipment and specimens. A manually operated hoist has been installed on an overhead monorail to aid in positioning the heavier test components on the shelf unit.

Construction of the Environmental Test Chamber will be completed during the second quarter of FY 1986 and will be followed by a period of acceptance testing and demonstration of the low flow ventilation concept. The operation of the facility for experimental purposes will begin in FY 1987.

8. ACKNOWLEDGMENTS

The design, fabrication, and installation of the IET facility has required major contributions over its ten-year construction period from personnel of the Fuel Recycle Division, ORNL Engineering Division, Chemical Technology Division, Instrumentation and Controls (I&C) Division, and other divisions of Martin Marietta Energy Systems, Inc. The significant contributions by E. L. Nicholson, Fuel Recycle Division, began with the detailed design of the facility, continued through the early checkout and operational phases of IET construction, and have extended into its current operational program. The continued support of I&C personnel assigned to the IET operating staff is gratefully acknowledged.

Technical review of the manuscript was provided by E. L. Nicholson and W. S. Groenier. V. H. Wallace organized and prepared the document for final review.

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Appendix A

ROMD FACILITY DESCRIPTION

The ROMD program represents a major commitment by the CFRP for the development of maintenance concepts both for advanced fuel reprocessing technology and for potential applications in other programs of national interest. The technical development of remote operations and maintenance procedures for nuclear fuel reprocessing applications currently pursues the use of teleoperated devices that may have either specific or general task capabilities. This development strategy promotes the concept of complete isolation of the process cell environment and also recognizes the flexibility gained by manned control of maintenance equipment for unique work assignments. Thus, development activities in remote maintenance technology are generally directed toward examinations of remote maintenance procedures. This activity also supports associated research programs that have electromechanical development objectives or that investigate the impact of man-machine interactions on equipment design and operation. A complete state-of-the-art remote handling system has been assembled for these investigations.

As originally planned, the ROMD facility would consist of a simulated hot-cell structure with capabilities for equipment rearrangement to represent a mechanical head-end cell, a chemical processing cell, a maintenance cell, and a cell for metallic wastes. Mock shielding could be erected in a variety of arrangements to form a simulated shield wall between the operating area and the cell area. Special modular shielding units with windows, or windows and master-slave manipulators, would form work station areas and observation points. Vertical and horizontal transfer devices with 9-metric-ton (10-ton) load capacities would transport process equipment to these work stations, to decontamination facilities, and to a contact maintenance area. Although this original work station concept has specific applications in current maintenance schemes, more recent developments with servomanipulator systems support a central station concept for remote control of maintenance operations performed at the process equipment site. In accordance with this maintenance strategy, the current ROMD facility, as shown in Fig. A.1 demonstrates central station control of maintenance operations over all parts of a 500-m^2 (5,380-ft^2) high-bay area with a vertical working height of about 17 m (56 ft).

The centerpiece of the ROMD remote maintenance system is the CRL Model M-2 bilateral force-reflecting servomanipulator. This manipulator system was a joint development of CRL and ORNL. The balance of the IET remote maintenance system includes (1) a high-bay gantry bridge with two 9-metric-ton (10-ton) hoists, (2) a manipulator transport bridge with three telescoping-tube trolleys (two for manipulators and one for closed-circuit television cameras), (3) a vertical bridge for manipulator coverage in the dissolver pit area, and (4) two PaR 6000 manipulators.

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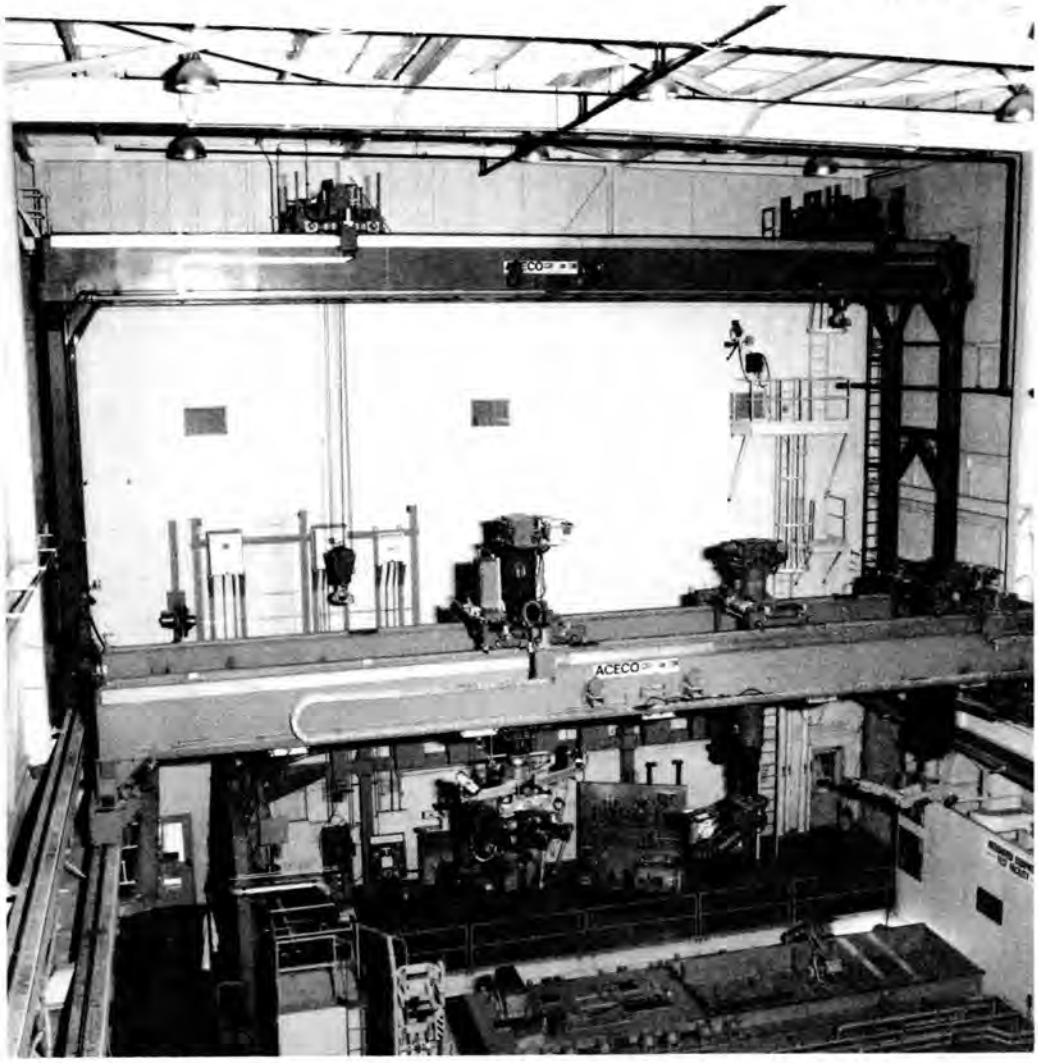

Fig. A.1. The ROMD facility.

A.1 ROMD CONTROL

Operator interface with the remote maintenance equipment of the ROMD facility is based on a centralized control room that houses a remote viewing system and the controls for the IET remote maintenance system. The television viewing system consists of eight television monitors and the associated controls for ten closed-circuit television cameras. Operation of the Model M-2 servomanipulator is performed from a separate control station within the ROMD control room. As shown by Fig. A.2, this station consists of the master manipulator control arms, control panel, and three closed-circuit television monitors. In addition, the control room houses the control panel and host computer for the automated sampling vehicle. Figure A.3 is a photograph of the Model M-2 servomanipulator and the prototypical sampling device that was fabricated and installed on the ground floor at the north end of the ROMD facility.

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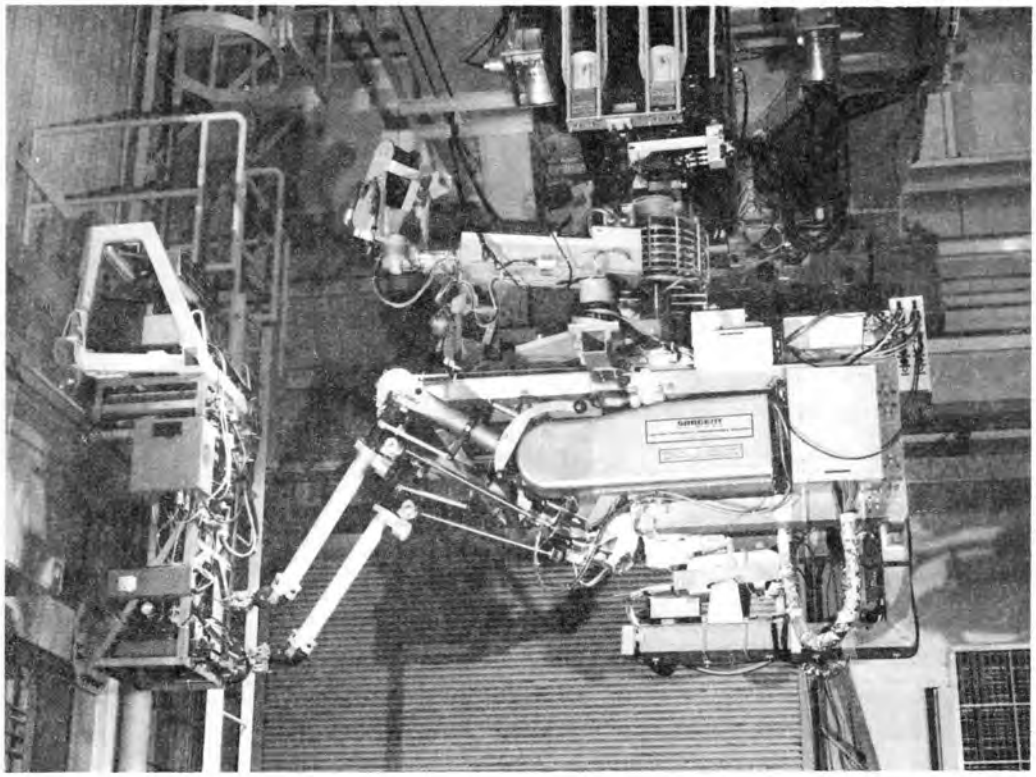

Fig. A.2. Control station for the CRL Model M-2 servomanipulator.

ORNL/PHOTO 5013-83

Fig. A.3. Remote maintenance of the automated sampling vehicle using the Model M-2 servomanipulator.

A.2 CRL MODEL M-2 SERVOMANIPULATOR

The CRL Model M-2 manipulator is a bilateral, force-reflecting servomanipulator system. The master arms are kinematic replica controllers with 7 D.F. The slave arms each have a handling capacity of 23 kg (50 lb) that is continuous in any position. The kinematics are in the typical "elbows-up" stance used by all the commercial vendors of servomanipulators that are currently available in the United States and Europe.

The M-2 slave joints are each driven by a brushless dc servomotor with integral position and velocity encoding. The output of the upper degrees-of-freedom are gear and lever driven. The lower 4 D.F. of master and slave are cable driven. The master controller lower degrees-of-freedom are tape driven. A standard position-position technique, implemented in digital control hardware, provides force reflection in ratios from 1:1 to 8:1 and operations without force reflection.

A.3 PaR MODEL 6000 MANIPULATOR

The PaR Model 6000 is a rate-controlled power manipulator of typical design for its class. The manipulator arm has seven joints and a 181-kg (400-lb) capacity for all arm attitudes. Permanent magnet dc motors with continuously variable speed control drive each joint. A switchbox controller with spring-returned potentiometers provides rate control of each arm joint. A magnetically coupled clutch in the end-effector drive allows adjustment of gripping forces from the control panel. However, this type of manipulator provides no feedback of information to the operator regarding forces exerted with the slave arm. Three types of end-effectors (parallel jaw, double hook, and single hook) are used by the arm and can be remotely changed.

A.4 THE AUTOMATED SAMPLING VEHICLE

The automated sampling vehicle, previously designated the advanced technology liquid sampling vehicle, was designed and developed by the CFRP as a mechanism for collecting liquid samples that have been withdrawn from process streams of a nuclear fuel reprocessing plant. Automated control of the battery-powered sampling device directs its travel along a track system installed on the hot-cell wall to sample stations that have been specifically designed for this service. The liquids are drawn from process vessels by air-ejector/air-lift systems into small bottles affixed to a needle block fixture at each sampling station. The sampling device can interface with each of the accurately positioned stations to identify and remove filled sample bottles and to install a prelabeled empty bottle for the next sampling event before the vehicle moves to the next scheduled sampling station.

Various diagnostic instruments are included on the sampling device to detect both normal and abnormal operating conditions. An on-board micro-processor is used to interpret data from these instruments for communication to an out-of-cell host computer. The vehicle can be remotely disassembled and reassembled from 12 basic modules that have been designed to minimize downtime.

A prototype of this vehicle has been designed, fabricated, and installed on the wall of the IET dissolver pit. Sample stations for the two digester tanks and the NO_x scrubber tanks have been located along the track system for demonstration of routine sampling service by this vehicle.

A.5 HOIST AND MANIPULATOR TRANSPORT SYSTEMS

Heavy equipment transport and maintenance functions that require crane and impact wrench operations are remotely performed in the ROMD facility by use of an 18-metric-ton (20-ton) overhead gantry bridge equipped with two 9-metric-ton (10-ton) hoist and trolley assemblies. This gantry bridge provides primary access to the full north-south length (40 m) of the ROMD facility and full east-west access along its 18-m span with the two trolley assemblies. Special design features of this bridge system include the remote maintainability of the trolley-hoist assemblies, the motorized capability for continuous rotation of the load block hook, and the placement of electrical power outlets (dc voltage) on the load block for remote tool operation and control.

A second gantry bridge system, at an elevation lower than the primary bridge, is nested between the end-truck and girder supports of the primary bridge system and operates over about 27 m of the north-south length of the facility. The secondary bridge system is equipped with three telescoping tube and trolley assemblies that provide three-axis positioning of the two manipulator systems and a closed-circuit television camera boom. Currently, the bridge system supports and provides mobility for the Model M-2 servomanipulator, a PaR Model 6000 power arm, and two boom-mounted closed-circuit television cameras. The telescoping tube assemblies can be mounted at any one of three trolley support elevations. The telescoping feature of the tube provides a 10-m positioning range from the fully extended to fully retracted position.

The trolley and telescoping tube assemblies were also designed for remote maintainability, and the two supported manipulator systems can each be removed at the telescoping tube interface using a mechanical master-slave manipulator. Electrical power outlets (dc voltage) are located on the telescoping tube for operation and control of power tools. A special rotatable dual hook assembly can be installed on the tubes (i.e., in place of a manipulator system) for increased gripping and lifting capabilities.

A third bridge system provides manipulator coverage in the ROMD pit area for remote maintenance operations on the IPD rotary dissolver system. This 99-m^2 (1,050-ft^2) pit in the north end of the facility extends 9 m (30 ft) below the ground elevation of the ROMD facility. This vertical bridge can move along three walls of the pit on a double, U-shaped guide and support track. A trolley and boom assembly supports a PaR Model 6000 manipulator, which can be raised or lowered along the vertical axis of the bridge by means of an integral hoist. This bridge and trolley system was designed for remote maintainability, but it is not prototypical of transport systems currently considered for fuel reprocessing applications.

A.6 CLOSED-CIRCUIT TELEVISION VIEWING SYSTEM

Visual information for control of remote operations in the ROMD facility is based on the strategic placement of television cameras within the facility to provide comprehensive coverage of anticipated remote-handling operations. Four cameras are mounted on the secondary bridge, one on the primary bridge, and four on the facility walls. Two of the four secondary bridge cameras are mounted to a boom on the center telescoping tube trolley to provide flexible, close-up viewing of manipulator operations. An additional camera is mounted on a portable tripod for relocation to areas that may be hidden from the other camera positions. each camera is equipped with a fully motorized telephoto lens and pan-and-tilt mounting base. Camera control units are located in the remote maintenance console in the ROMD control room. Full camera view selection capabilities to eight 17-in. monitors are provided by this system. The three integral cameras of the Model M-2 servomanipulator system provide increased view selection at both the Model M-2 control station and the maintenance system console.

Appendix B

IPD FACILITY DESCRIPTION

The Title II design of the IPD area required the close coupling of the equipment line as an integrated process, but with the capability for supporting experimental engineering development studies of the program. As illustrated in Fig. B.1, process elements that could require hot-cell containment under plant operating conditions were chosen for demonstration. These elements were grouped as separate modular systems with capabilities for independent operation or for integrated operations with adjoining and/or supporting systems. The process demonstration begins with the disassembly of unirradiated fuel assemblies and extends through one stage of solvent extraction. The product from solvent extraction, after concentration of its actinide components, would be acceptable as feed for fuel refabrication in a separate plant.

Although the shear and disassembly systems will be available for integrated operations with the dissolver, their routine operations for general engineering development studies would require prohibitive costs for dummy fuel element fabrication. The limited supply of UO_2 fuel rods available to the program has been reserved for major process demonstrations of these two systems. Consequently, the operation of these two systems will be restricted to component development activities that have specific interests for the CFRP. As an alternative, the design of the IPD head-end process incorporated a feed station concept for simulating sheared fuel discharge to the dissolver. Solid oxides of uranium (depleted in ^{235}U) can be fed with simulated fuel-pin hulls and structural metal scrap at controlled rates and intervals.

B.1 DISSOLVER SYSTEM

As illustrated in Fig. B.2, the rotary dissolver (07L01) receives sheared simulated fuel directly from the shear or from the feed station through a sloped charging chute. Within the dissolver drum, solids are advanced batchwise through a feed stage, seven dissolution stages, and one rinse and discharge stage. Nitric acid (11 *M* HNO_3) introduced at the seventh stage, and sufficient feed water for dilution to about 7 *M* nitric acid is added at the hulls discharge/rinse stage. This continuous countercurrent flow of acid through the dissolver contacts and dissolves the depleted uranium fuel.

Agitation of the solids in nitric acid occurs during forward rotation of the dissolver drum. Transfer of solids from one stage to the next takes place upon reversing the drum rotation for 1.25 revolutions. By alternating agitation cycles with one transfer revolution, the rotary dissolver establishes a continuous dissolution process.

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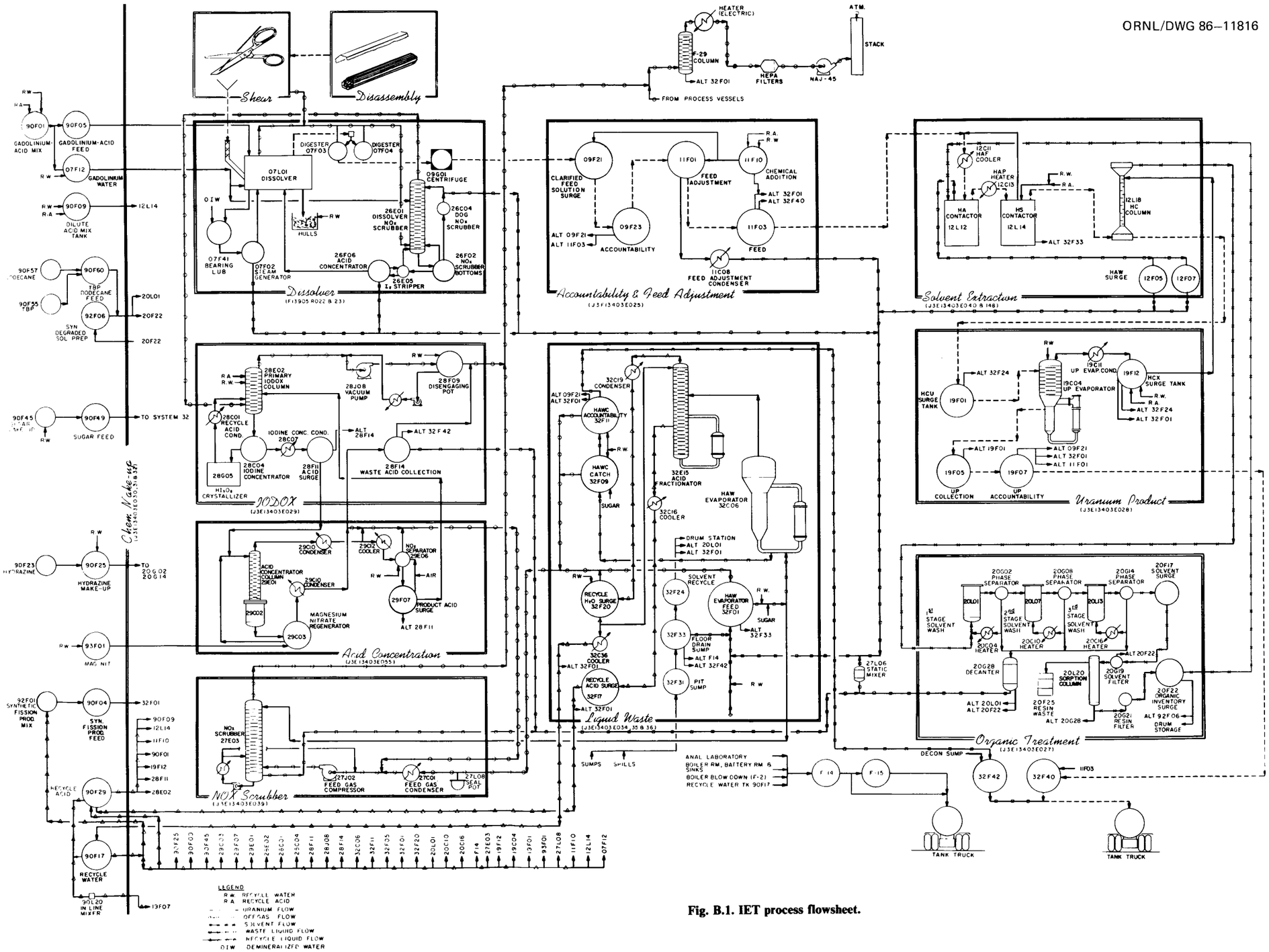

Fig. B.1. IET process flowsheet.

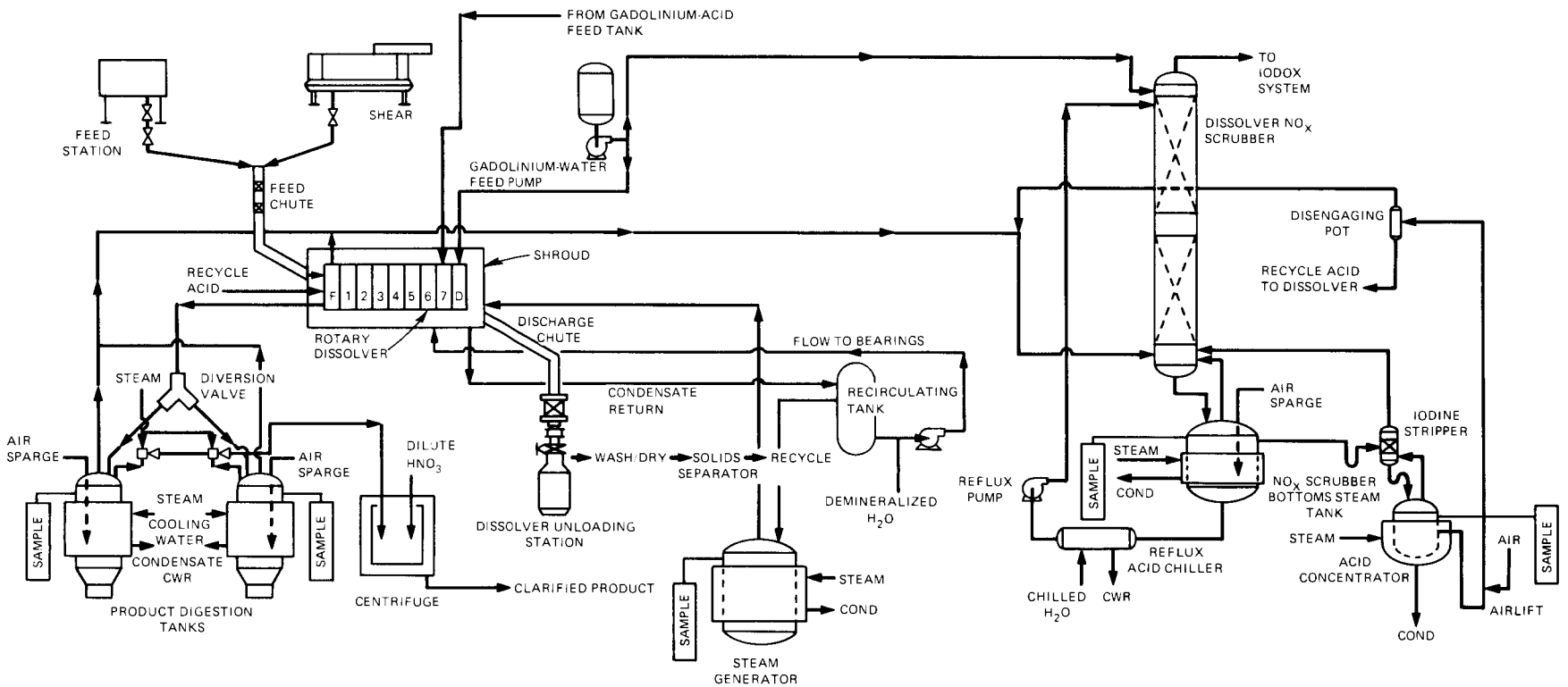

Fig. B.2. IET dissolver system.

The dissolver drum is enclosed in a tightly sealed stainless steel shroud and is maintained at a slightly negative pressure to prevent escape of gases and vapor to the atmosphere. A small, jacketed steam generator delivers steam at atmospheric pressure to the shroud enclosure to maintain dissolver temperature at about 95°C and to purge the dissolver drum seal gaps. Hulls and structural metal solids are discharged by gravity into an unloading canister for recycle through the feed station. The dissolver product solution (uranyl nitrate/nitric acid) is withdrawn from the feed stage near the drum periphery and piped through a diversion valve to one of two digester tanks. After digestion, the product solution is cooled and transferred by steam ejector to the feed solution surge tank.

Gases and vapors generated during shearing and dissolution are continuously removed from the drum interior at the feed stage. This off-gas stream is combined with the off-gas streams from the digester tanks and piped directly to the dissolver NO_x scrubbing system. The system consists of a packed scrubber column, a bottoms holding tank, an iodine stripper, a scrubber bottoms reflux loop, and an acid concentrator.

B.2 ACCOUNTABILITY AND FEED ADJUSTMENT SYSTEM

The dissolver product solution is transferred (jetted) as batch quantities (500 L) after each digester cycle by steam ejector to the dissolver product surge tank (09F21) in the accountability and feed adjustment system. Solids that may be suspended in the dissolver product stream are removed by centrifugation as the solution is pumped from 09F21 to the accountability tank (09F23). The configuration of tankage in the accountability and feed adjustment system and the geometrical shape of the accountability tank were designed for conformance with standards for safeguarding nuclear materials. The accountability tank provides accurate determination of solution volume (~ 1180 L) at constant temperature and at uniform composition. Chemical analyses of solution samples withdrawn under these conditions are combined with batch-volume measurements to record accurately the ingress of accountable materials into the process.

When materials accountability measurements have been confirmed, the entire contents of the accountability tank are jetted to the feed adjustment tank (11F01) for dilution with nitric acid or concentrated by evaporation to specified component concentrations for solvent extraction feed. When an acceptable feed composition has been attained, the solution can be jetted to the feed tank (11F03) for the solvent extraction system.

B.3 SOLVENT EXTRACTION SYSTEM

The IET solvent extraction system, as illustrated in Fig. B.3, utilizes two 8-stage centrifugal contactors (8-packs) and a pulse column to simulate the codecontamination cycle of a fast breeder reactor (FBR) fuel reprocessing plant. Figure B.4 is a photograph of one of the centrifugal contactor banks that has been installed in the IET facility. The system design provides the flexibility for interchanging equipment functions with minimal piping changes. The primary configuration (HA-HS-HC) utilizes one 8-pack centrifugal contactor for the extraction (HA) function, a second 8-pack for the scrub (HS) function, and the

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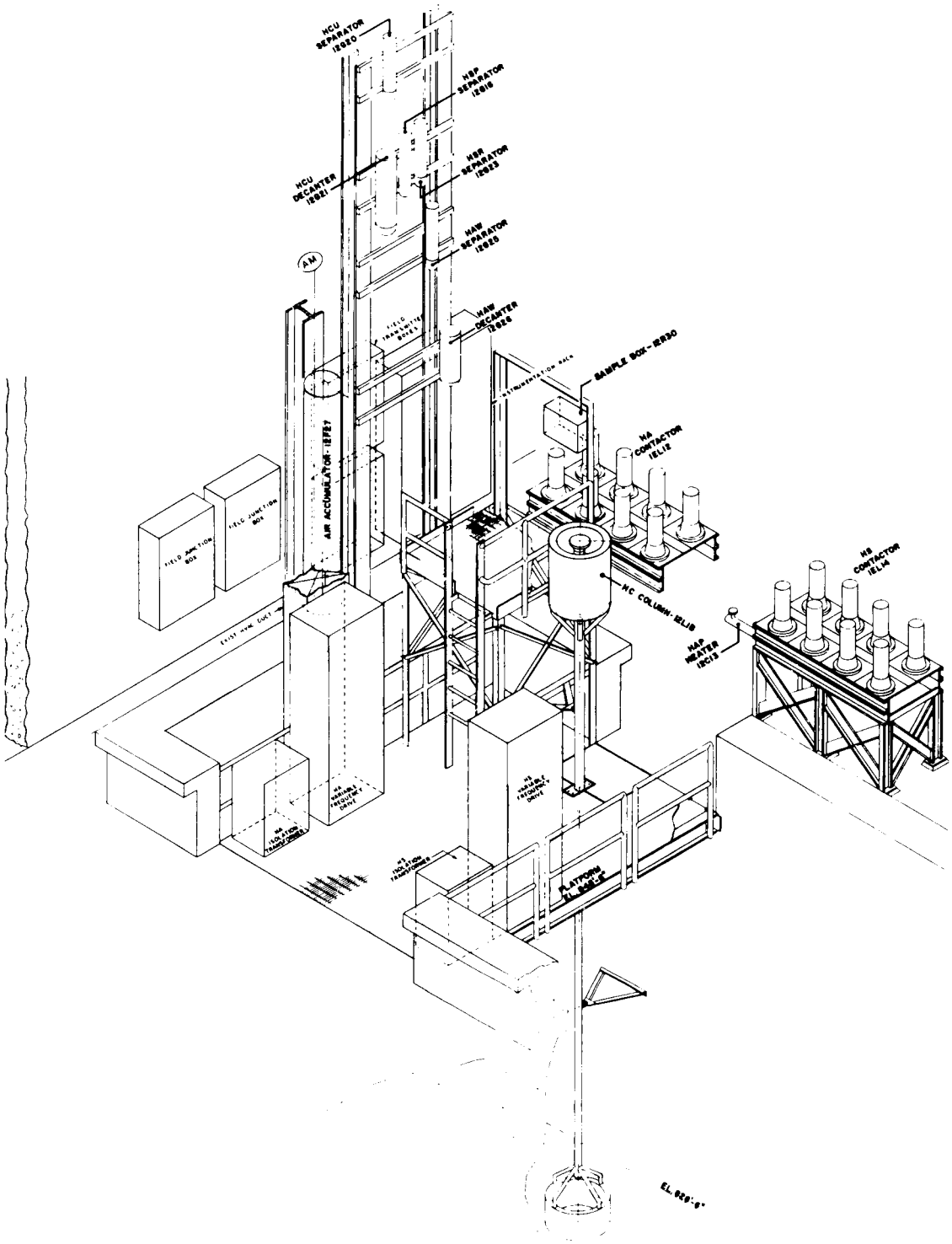

Fig. B.3. IET solvent extraction system.

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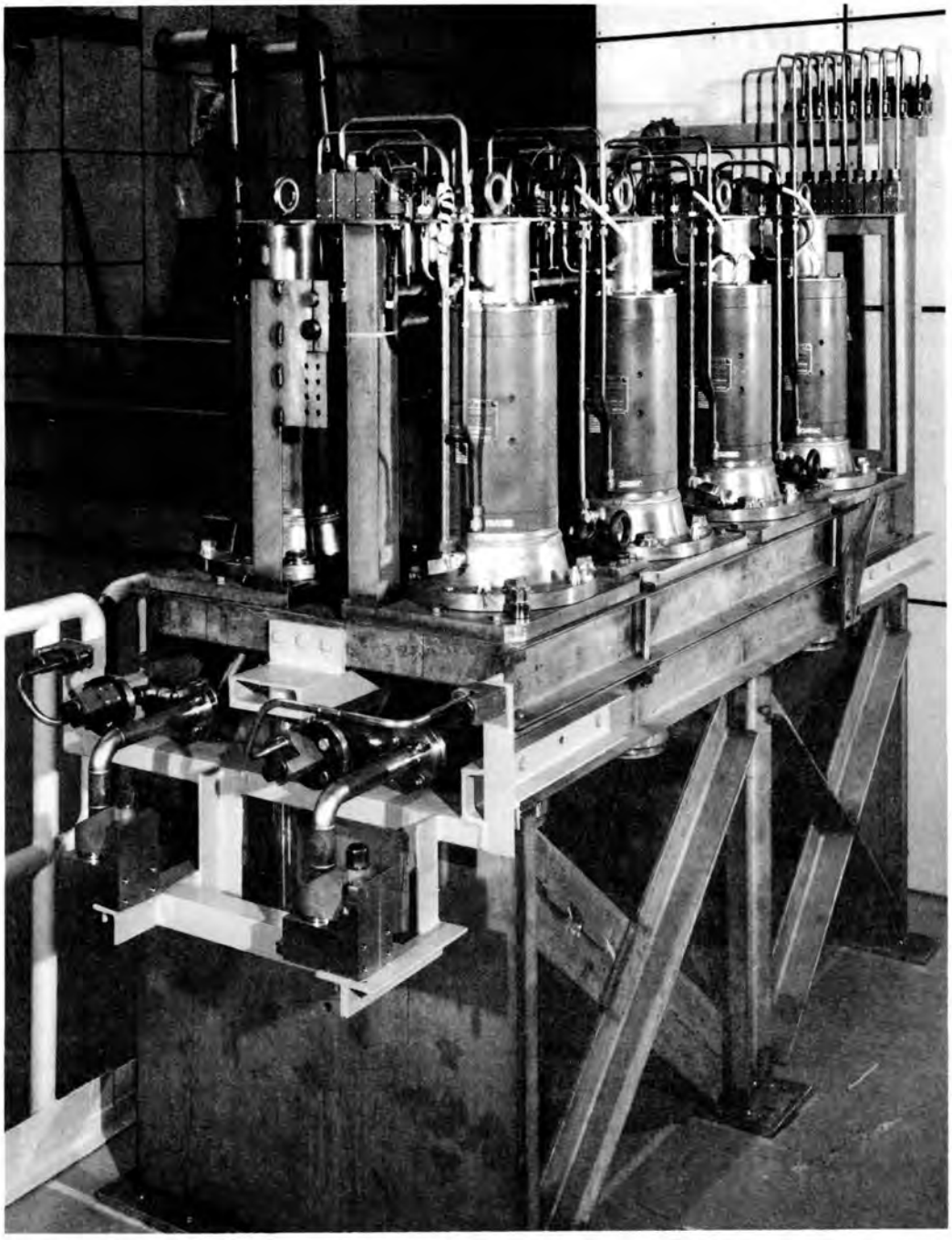

Fig. B.4. IET eight-pack centrifugal contactor bank.

pulse column for the stripping (HC) function. A second arrangement deletes the scrub function and uses one 8-pack for extraction and the pulse column for stripping. A third arrangement also deletes the scrub function, but it uses the second 8-pack in the stripping function in place of the pulse column.

The uranyl nitrate feed stream (HAF) for the solvent extraction system, as depicted in Fig. B.5, is fed continuously to the HA contactor (12L12) by means of a two-stage air

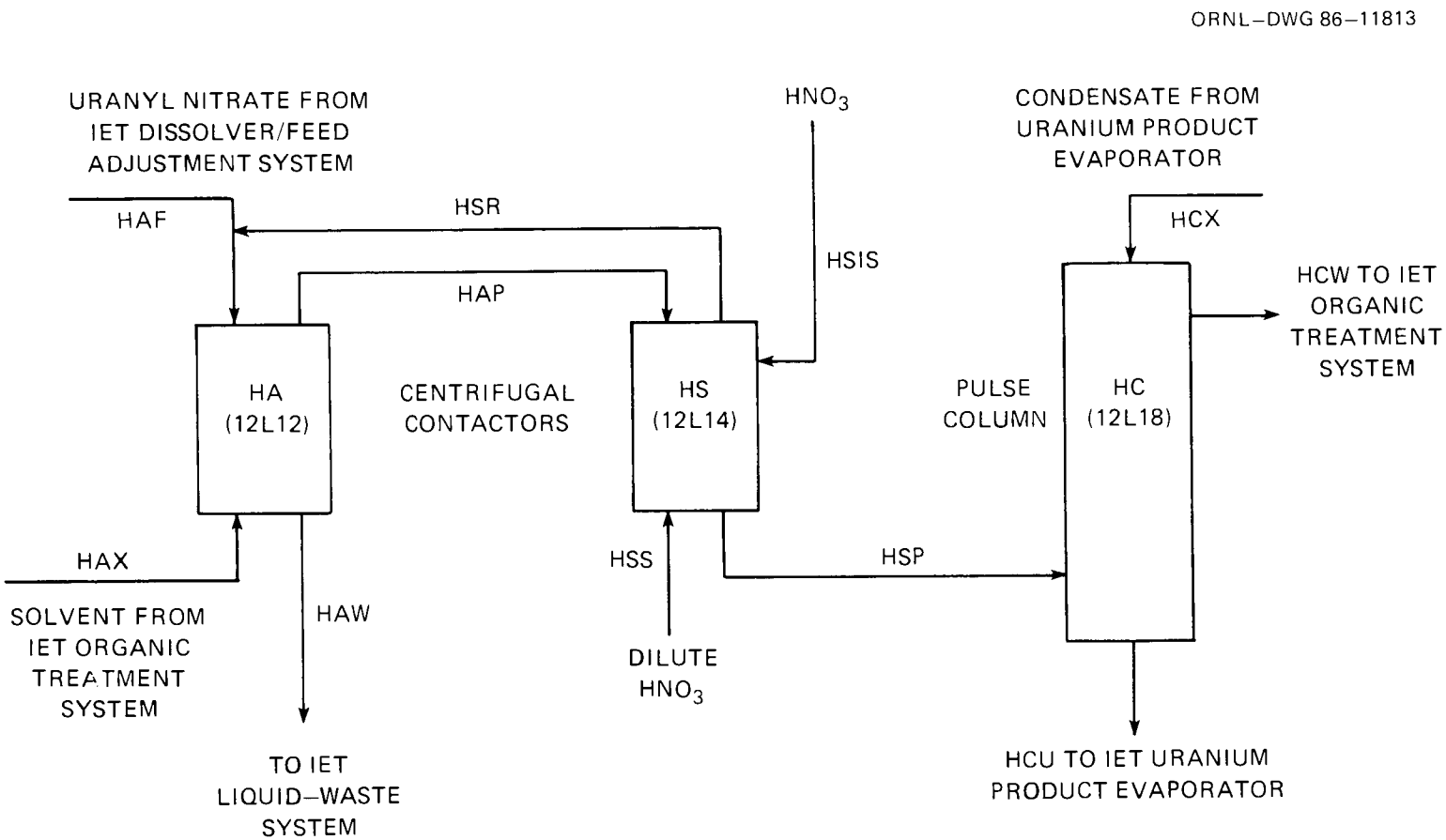

Fig. B.5. Flow diagram for IET solvent extraction.

lift. Contact of this stream with a countercurrent flow of the organic solvent containing tributyl phosphate (TBP) permits the extraction of actinide elements into the organic phase. The aqueous waste stream (HAW) from the HA contactor flows to one of two surge tanks (12F05 and 12F07) for processing through the liquid waste system. Each surge tank was sized to collect an 8-h batch of HAW and has a nominal volume of about 1740 L. A hydraulic jackleg connects the two tanks and acts as a diversion valve for redirecting the HAW stream from one surge tank to the other.

Actinides are stripped from the organic solvent into dilute nitric acid in the final step of the IET solvent extraction demonstration. The aqueous product stream (HCU) from solvent extraction flows continuously to the HCU surge tank (19F01) in the uranium product system for concentration and materials accountability procedures. After uranium stripping, the spent organic solvent (HCW) is processed through the organic treatment system before recycle to the HA contactor as the HAX stream.

B.4 URANIUM PRODUCT SYSTEM

The aqueous product stream (HCU) from solvent extraction flows continuously to a surge tank (19F01) and then to the uranium product evaporator (19C04). The nominal HCU stream contains about 70 g U/L in 0.04 *M* nitric acid. The concentrated uranium product contains about 375 g U/L in 0.2 *M* nitric acid. Because of the potential for entraining trace quantities of organic solvent with the feed stream, the maximum heating steam pressure for the uranium product evaporator is limited to 134°C. As an additional safety precaution, TBP and organic diluent contaminants are stripped from the evaporator feed solution (in 19F01) with steam.

The evaporator condensate is collected in the HCX surge tank (19F12) and adjusted to 0.02 *M* nitric acid for recycle as the HCX stream in the solvent extraction system. The bottoms product of the evaporator flows continuously by gravity to the collection tank (19F05), where it is cooled from the boiling point to ambient temperatures. The solution may then be jetted back to 19F01 for rework or transferred by airlift to the accountability tank (19F07) for final heavy-metal accountability in the product line of the current IET system.

B.5 ORGANIC TREATMENT SYSTEM

The recycle of the organic solvent, 30 vol % TBP in normal paraffin diluent, to the solvent extraction system necessitates the periodic removal of degradation products that may alter extraction properties or promote the retention of actinide elements in the organic phase. Solvent used in a "hot" facility is degraded both chemically and radiochemically; however, chemical degradation by hydrolysis is significant and does warrant the practical application of solvent cleanup procedures in the "cold" IET facility.

The organic treatment system uses three solvent washer stages set in series for concurrent contact of the solvent with aqueous wash solutions at controlled temperatures. Although solvent washing practices may vary according to specific application, the current practice for IET operations uses a dilute basic wash solution (0.25 *M*), such as hydrazine

carbonate or sodium carbonate in the first stage, which is followed by very dilute nitric acid (0.01 *M* HNO_3). The washed solvent flows through a cartridge filter and may also be passed through a bed of solid sorbents for further removal of degradation products as required. Clean organic solvent is returned to the solvent extraction system as the HAX stream, and the spent wash solutions are discharged to the liquid waste system.

B.6 LIQUID WASTE SYSTEM

The principal waste stream in a fuel reprocessing plant is the acidic fission product waste stream (HAW) from the first-cycle solvent extraction contactor. This stream goes directly to the continuous HAW evaporator for recovery of nitric acid and water. During actual "hot" plant operations, the concentrated waste (HAWC) from the evaporator would be batch-treated with a reducing agent, typically sucrose, to destroy excess nitric acid. In a large plant, the partially decontaminated acidic vapor from the HAW evaporator is condensed, combined with other low-radioactivity acidic waste streams, and sent to the intermediate-level waste (ILW) evaporator. The evaporator bottoms are recycled to the HAW evaporator feed tank, and the decontaminated acidic vapor from the ILW evaporator goes to an acid-fractionating tower yielding 10 to 12 *M* nitric acid and water streams for recycle to the process. Other waste collection and evaporator systems may be included to process other streams (e.g., solvent recovery wastes, equipment decontamination washes, and floor spills). The IET liquid waste system combines all the functions of the various radiochemical waste collection and evaporation systems in one evaporator system.

The contents of the HAW surge tanks, 12F05 and 12F07, are jetted alternately to the HAW evaporator feed tank (32F01) and diluted by automatic density control instrumentation to about 8 wt % nitric acid using recycle water. To eliminate organics from the feed to the HAW evaporator (32C06), a skimmer weir inside 32F01 is used to periodically remove the organic layer from the vessel. Additionally, an aqueous heel is always kept in the vessel to preclude drawdown of organic into the aqueous outlet. Provisions have been made for adding sugar solution to the 32C06 evaporator feed to demonstrate its use in the evaporation of highly radioactive wastes. The sugar reacts with nitric acid to generate nitrous acid, which, in turn, represses the volatilization of fission product ruthenium.

The HAW evaporator was designed for a maximum feed rate of about 1,200 g mol/h of nitric acid (75.6 kg/h as HNO_3) and a minimum rate of about 824 g mol/h of nitric acid. The steam-heated vertical reboiler creates a natural circulation loop of the process liquid within the evaporator. The concentrated bottoms waste overflows continuously by gravity to an airlift for transfer to the HAWC catch tank (32F09). In an actual plant demonstration, the concentration of nitric acid in 32F09 would be reduced to 12 wt % from about 36 wt % by continuous addition of sugar solution. Under these conditions NO_x would be generated, and the vessel off-gas would be sent to the NO_x scrubber system. However, this operational feature of the IET liquid waste system remains for future demonstration.

The contents of 32F09 are transferred by airlift to the HAWC accountability tank (32F11) on a batch basis for the last point of heavy-metal accountability before the liquid waste leaves the process systems. The contents of the tank are sampled to determine both

the heavy metal and nitric acid concentration. The batch volume is determined by level measurements with the batch temperature maintained at standard measurement conditions.

The overhead vapor product from 32C06 is sent to the acid fractionator (32E15) for the second stage of separation in this system. According to design criteria, the column distills the 8 wt % nitric acid feed, producing water (<250 ppm HNO_3) overhead and a nitric acid bottoms product that is 56 wt % (12 *M*) nitric acid. The acid fractionator is currently operated for production of 11 *M* HNO_3 to reduce system corrosion rates. The bottoms product overflows from the vertical thermosiphon fractionator reboiler through a cooler (32C16) for collection in the recycle acid surge tank (32F17). The overhead water vapor from the fractionator is condensed (32C19) and collected in the recycle water surge tank (32F20).

The basement drains of the building are collected in the pit sump tank (32F31). The floor in the organic treatment area is sloped so that solvent spills will drain rapidly to the pit sump tank. The tank's contents are automatically batch transferred by steam jet to the sump tank (32F33), which normally collects waste from the floor drains on the ground floor. This tank is equipped for separation and removal of organic wastes by decantation.

B.7 IODOX SYSTEM

The Iodox process uses hyperazeotropic nitric acid (about 95% HNO_3) in a gas-liquid contactor to scrub the iodine from the gas phase and oxidize it to hydriodic acid. The IET system was designed to demonstrate all operations of an integrated Iodox process and was sized to process the dissolver off-gas from a 0.5-metric-ton/d nuclear fuel reprocessing plant. However, only 4 iodine scrubbing stages were included in the Iodox scrubber tower in place of 8 to 12 stages that might be used for a "hot" fuel reprocessing installation. The system is designed for a normal iodine feed rate of 15 g/h and a maximum gas rate of 75,000 standard L/h. These rates are about 63% higher in iodine and 50% higher in total gas flow than would normally be present in the gases from a 0.5-metric-ton/d reprocessing plant.

The nitric acid scrubber solution from the Iodox column is sent to a concentrator (28C04) for evaporation and recovery of the nitric acid. The concentrated hydriodic acid solution that remains is drained into the crystallizer (28C05) for evaporation to a solid cake of HI_3O_8. This 6-in.-diam titanium vessel is expended as the primary storage container for iodine discharged from the reprocessing facility. The acid vapor from the iodine concentrator (28C04) is condensed as about 83 wt % nitric acid and is collected in a titanium surge tank (28F11) for recycle as feed to the acid concentration system.

B.8 ACID CONCENTRATION SYSTEM

The high-strength nitric acid (95 wt % HNO_3) required by the Iodox process cannot be produced by simple distillation from dilute acid because of the limiting concentration (68 wt %) of its azeotrope. The acid concentration system uses a commercial method for producing hyperazeotropic nitric acid by extractive distillation from a hot magnesium nitrate solution. The diluted nitric acid stream from the Iodox process and the makeup

recycle acid from the plant system are mixed with hot, concentrated magnesium nitrate solution as feed to a distillation tower. Water is extracted into the magnesium nitrate solution, and the concentrated nitric acid is flashed overhead.

The acid concentration system operates as a continuous process at pressures less than 30 psig and temperatures up to 160°C. The maximum design production rate of 95 wt % (22.5 *M*) nitric acid was estimated at 28 L/h and was based on a nominal consumption rate of about 11.8 L/h of 95% acid in the Iodox system.

B.9 NO_x SCRUBBER SYSTEM

The IET facility's NO_x emissions control strategy provides local NO_x scrubbers for the small-volume, high-NO_x content streams before they are combined with other gas streams and given a final treatment prior to their release. However, most of the design information for NO_x scrubbers covers high-pressure commercial scrubbers rather than atmospheric-pressure NO_x scrubbers recommended for fuel reprocessing applications. Although the IET NO_x scrubber system was built to provide experimental data on NO_x scrubbing at atmospheric pressure, it also serves two other functions in IPD operations. It will remove most of the NO_x from a small flow of high-NO_x content off-gases from the liquid waste and the acid concentration systems before they are mixed with a large volume of miscellaneous off-gas from the rest of the plant. The scrubber system also provides continuous neutralization of solvent washing wastes by mixing them with the liquid effluent from the NO_x scrubber and with the high nitrous acid content condensate from the scrubber feed gas.

The maximum design off-gas rate to the NO_x scrubber (27E03) was 509 L/min (1 atm; 35°C) of gas that contained about 10% NO_x by volume. The term, NO_x, was defined as the reactive nitrogen oxides, NO and NO_2. The scrubber effluent should contain less than 1% NO_x. The scrub liquid feed is 1.2 to 1.4 *M* HNO_3 at the nominal ambient operating temperature (35°C) of a process cell. The scrubber uses bubble cap plates and has provisions for extensive gas and liquid sampling and temperature measurements. The scrubber system also provides the necessary off-gas vacuum for the liquid waste system and for the acid concentration system.

B.10 CHEMICAL MAKEUP SYSTEM

The chemical makeup system is comprised of several separate units that are used for the preparation, storage, and supply of the various chemicals required by the IPD process systems. The primary units maintain the supply and distribution of recycle acid, recycle water, and compressed gases. The preparation and storage of the organic solvent are also major functions. Other units furnish solutions of process chemicals such as magnesium nitrate, gadolinium nitrate, and sugar. Nonradioactive substitutes for fission products can also be provided for investigations of process chemistry and equipment performance tests.

The recycle acid system stores and supplies 56 wt % (12 *M*) nitric acid to a pressurized header system for use throughout the IPD area. Diluted nitric acid is also automatically prepared and supplied to a separate header system. Although most of the recycle

nitric acid is recovered from the acid fractionator (32E15), fresh acid from commercial sources is added to replace process losses. Diluted nitric acid is automatically prepared by feeding recycle acid and water to an on-line mixer (90L20) that is regulated by the conductivity of the diluted acid stream.

The recycle water system stores and supplies process water to a pressurized header system for use throughout the IPD area. Recycle water is recovered as the slightly acidic distillate from the acid fractionator (32E15) and is supplemented with demineralized water from the building supply system.

Appendix C

DISTRIBUTED DATA ACQUISITION AND CONTROL SYSTEM

A major activity of the IPD area of the IET facility addresses the complex process and equipment control procedures that are required for the integrated operation of a chemical process facility. The DDACS provides for process control by both operator interface and automated methods and for all data acquisition and handling functions that are required for the integrated operation of a chemical process facility. The DDACS also provides monitoring and interlocking functions required for controlling the sequential operations of the various mechanical devices in the IPD area. These combined features represent the level of process control that will be required for the integrated operation of a "hot" nuclear fuel reprocessing plant.

The distributed control concept is a method for physically spreading the responsibility for process control among several discrete controllers within a plant rather than concentrating it in a single piece of equipment. An obvious advantage of this control system is that the failure of a discrete controller will affect only the specific area to which it is associated. A backup controller can be implemented for those areas where failure is particularly critical to the overall process operation.

As illustrated in Fig. C.1, the DDACS control system is distributed in the sense that it is segmented at the process level into 11 unit controllers corresponding to the 11-unit operations identified for the IPD process. To maximize reliability, DDACS incorporates a hierarchical structure consisting of the unit process control modules (PCMs), which perform dedicated measurement, control, and data acquisition functions with a communications control module (CCM), which coordinates all system communications and a host minicomputer at the plant supervisory level. To ensure flexibility, the various DDACS components are microprocessor based and may be easily reconfigured when needed with appropriate software changes.

At the top of the DDACS structure is the host computer, a PDP 11/70, which is used for software development, microprocessor data-base storage and loading, system monitoring, and alarm-message generation. The host also supports an operator control console incorporating six color monitors and keyboards. Another important function of the DDACS host computer is to collect real-time plant process variables and transmit them to the safeguards/archival host computer.

At the bottom of the hierarchical structure are the PCMs. The primary function of the PCMs is to monitor process variables, to provide continuous control of process loops, and to control sequential operation of mechanical devices. Hardware in the PCMs provides four types of input/output: analog input, analog output, digital input, and digital output. Because a typical PCM has the capability for interfacing with 250 external sensors and actuators, the total system has a capacity for controlling or monitoring about 2,700 points.

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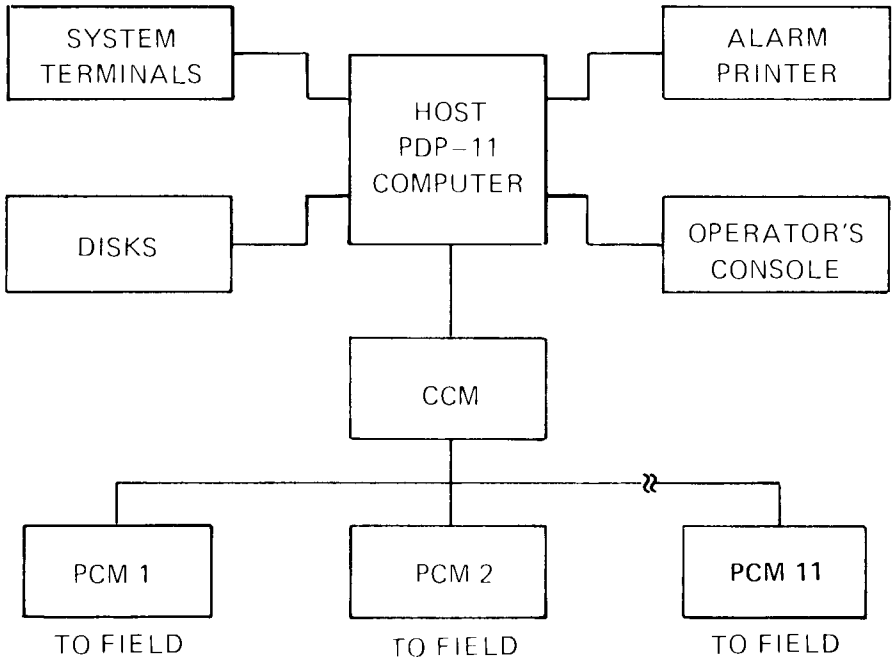

Fig. C.1. Basic DDACS system.

The PCMs are interconnected with each other and with the host computer through a high-speed data highway communications system that is supervised and operated by the CCM. Communication between the host computer and the CCM uses a full-duplex, multidrop, synchronous, serial communications link that operates at a speed of 50 kbaud. Communication between the host computer and the CCM uses a parallel, 16-bit bidirectional interface capable of maintaining message transactions at a rate of 250/s.

An operator's console provides a "window" to the process through six CRT displays. These displays allow the operator to view the process through various levels from a plant "overview" to a "single-loop" display. In addition to the standard displays, dynamic schematics of specific process units may also be displayed on the monitors. These graphic displays consist of symbols, text, and data values that may be statically or dynamically modified as process conditions vary.

Associated with each display on the console is a "function keyboard," which allows the operator to select different displays and to interact generally with the process. For example, via the keyboard, the operator is able to change set points, turn devices on or off, and alter control parameters.

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