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Consolidated Fuel Reprocessing Program

THE REMOTE OPERATION AND MAINTENANCE DEMONSTRATION FACILITY AT THE OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

The Remote Operation and Maintenance Demonstration (ROMD) Facility at the Oak Ridge National Laboratory has been developed by the Consolidated Fuel Reprocessing Program to demonstrate remote handling concepts on advanced nuclear fuel reprocessing equipment and for other programs of national interest. The ROMD facility is a large-volume high-bay area that encloses a complete, technologically advanced remote maintenance system and full-scale development reprocessing equipment. The maintenance system consists of a full complement of teleoperated manipulators, manipulator transport systems, and overhead hoists that provide the capability of performing a large variety of remote handling tasks. This system has been used to demonstrate remote manipulation techniques for the U. S. Department of Energy (DOE), the Power Reactor and Nuclear Fuels Development Corporation of Japan, the U.S. Navy, and the National Aeronautics and Space Administration. Extensive tests of manipulative systems and remote maintainability of process equipment have been performed. This paper describes the ROMD facility and key remote maintenance equipment and presents a summary of major experimental activities.

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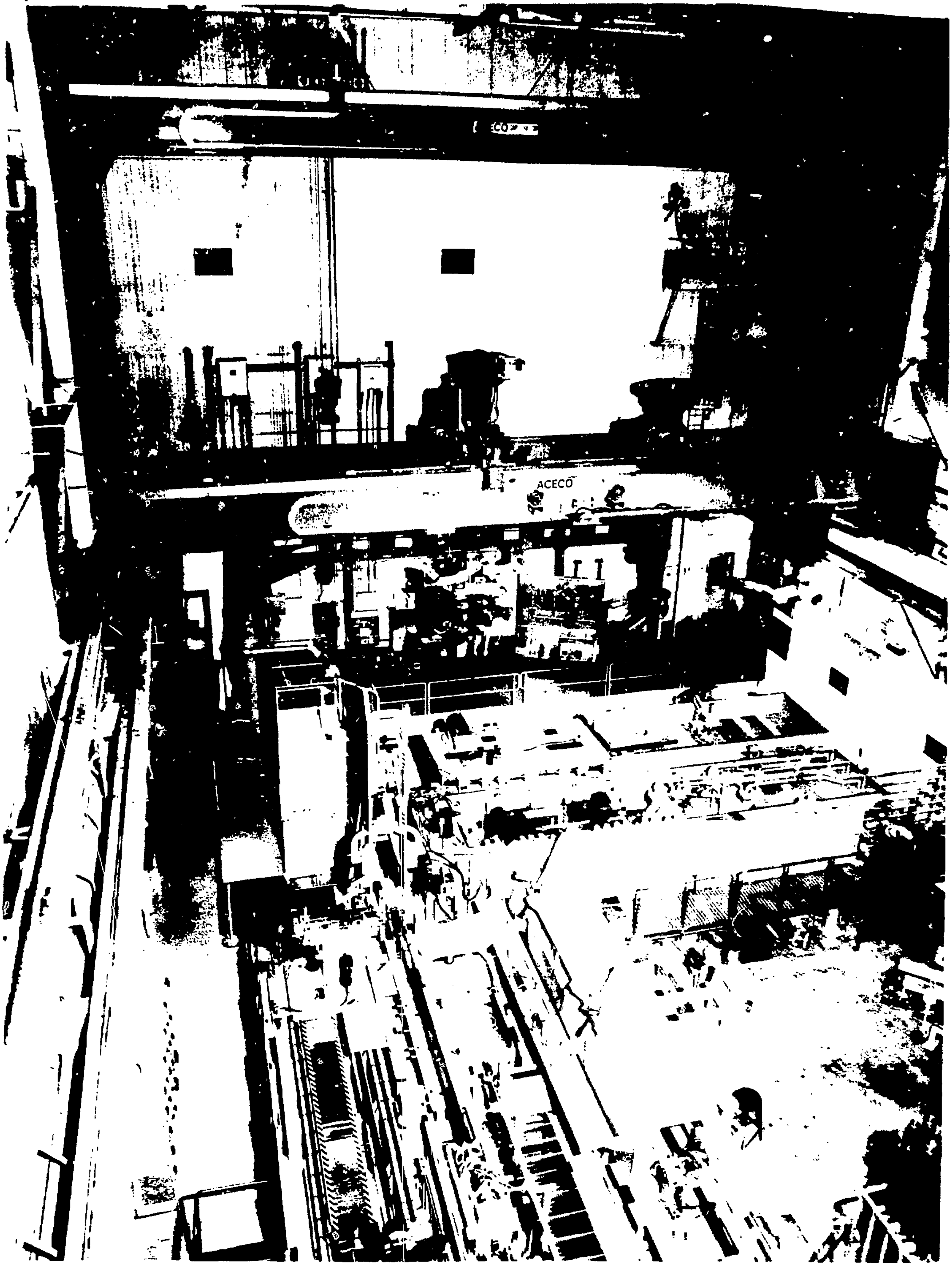
INTRODUCTION

The Consolidated Fuel Reprocessing Program (CFRP) is sponsored by the U.S. Department of Energy (DOE) for the research and development of advanced nuclear fuel reprocessing technology. The Remote Operation and Maintenance Demonstration (ROMD) facility, shown in Fig. 1, has been developed by the CFRP for the demonstration of remotely operated and maintained nuclear fuel reprocessing equipment. This facility is a major component of the Integrated Equipment Test (IET) project,[1] a full-scale, cold demonstration reprocessing facility.

The ROMD facility is equipped with a complete state-of-the-art remote handling system that includes a two-armed, force-reflecting servomanipulator system, two power manipulators, two manipulator transport bridges, an overhead gantry bridge crane with two 9-metric-ton (10-ton) hoists, a closed circuit television viewing system, and a remote operator control station. The current fully operational status of the IET and ROMD facilities culminates a 10-year effort by the CFRP. Experimental remote handling operations in ROMD were first initiated in FY 1982 but were limited in scope until completion of facility construction and equipment installation activities in late FY 1984.

The CFRP developmental activities are based on the concept of a centralized reprocessing cell design with complete remote operation and maintenance and no planned human entry.[2] A totally remotely maintained in-cell plant design – to include the maintenance system itself – is a departure from historical methods and has been developed in order to:

1. Increase overall plant availability.
2. Reduce occupational radiation exposure levels to as low as reasonably achievable.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3. Reduce recovery time from forced (unplanned) outages.
4. Facilitate the remote handling aspects of ultimate decontamination and decommissioning of the facility.

FACILITY DESCRIPTION

The IET and ROMD facilities are located at the Fuel Recycle Division of Oak Ridge National Laboratory (ORNL). The ROMD (see Fig. 1) section is a large high-bay area with a 15-m (48-ft) working height and a 400-m^2 (4,312-ft^2) ground-level floor. A 97-m^2 (1,046-ft^2) pit area is also included that extends 9 m (30 ft) below the facility ground level. Large sections of the facility floor are available for remote handling experiments with portable equipment mock-ups and test stands. These areas also provide space for component maintenance stands.

Prototypical reprocessing equipment currently installed in ROMD and remotely serviceable by the maintenance system represents the mechanically intensive "head-end" portion of the demonstration reprocessing plant. This equipment was designed for a nominal reprocessing throughput of 0.5 MTHM/d and includes (1) a fuel disassembly system, (2) a hydraulically actuated fuel-shear system, (3) a rotary dissolver-based fuel-dissolution system, and (4) an automated process fluid sampling system with a robotic sampling vehicle. The design of this equipment incorporates modular construction and special remote handling features to facilitate remote maintenance. Developmental reprocessing equipment requiring installation in non-ROMD areas of IET can be initially installed or mocked-up in ROMD for maintenance demonstration.

REMOTE MAINTENANCE SYSTEM

The ROMD remote maintenance system allows comprehensive development and demonstration of key remote maintenance concepts and techniques. The original system began acceptance test operations in early FY 1982 and was based on electro mechanical manipulators (EMMs), more specifically, Programmed and Remote (PaR) Systems model 6000 manipulators. Currently, the CFRP pursues the use of force-reflecting teleoperated manipulators to enhance remote handling capabilities in the unstructured remote environment typical of reprocessing. Under a joint development effort, Sargent Industries' Central Research Laboratories (CRL) and ORNL developed the model M-2 servomanipulator.[3] The model M-2, described in more detail in the following section, is a state-of-the-art, bilateral, force-reflecting servomanipulator and is the first totally digitally controlled force-reflecting servomanipulator system in existence.[4] This manipulator essentially duplicates the dexterous handling capabilities of through-the-wall mechanical master slave systems but has the added advantage of being able to perform operations over a large facility volume. The model M-2 slave and master control station are shown in Figs. 2 and 3, respectively.

The model M-2 was installed in the ROMD facility in mid-FY 1983 and has been extensively used in many test programs since that time. It has proven to be a very effective and reliable remote handling device. However, the M-2 is primarily a demonstration and developmental manipulator and was not designed to be remotely maintained, a feature required for future reprocessing facilities. A next-generation servomanipulator with modularized component features has been designed and built by ORNL and is currently undergoing operational development in an adjacent facility.[5,6]

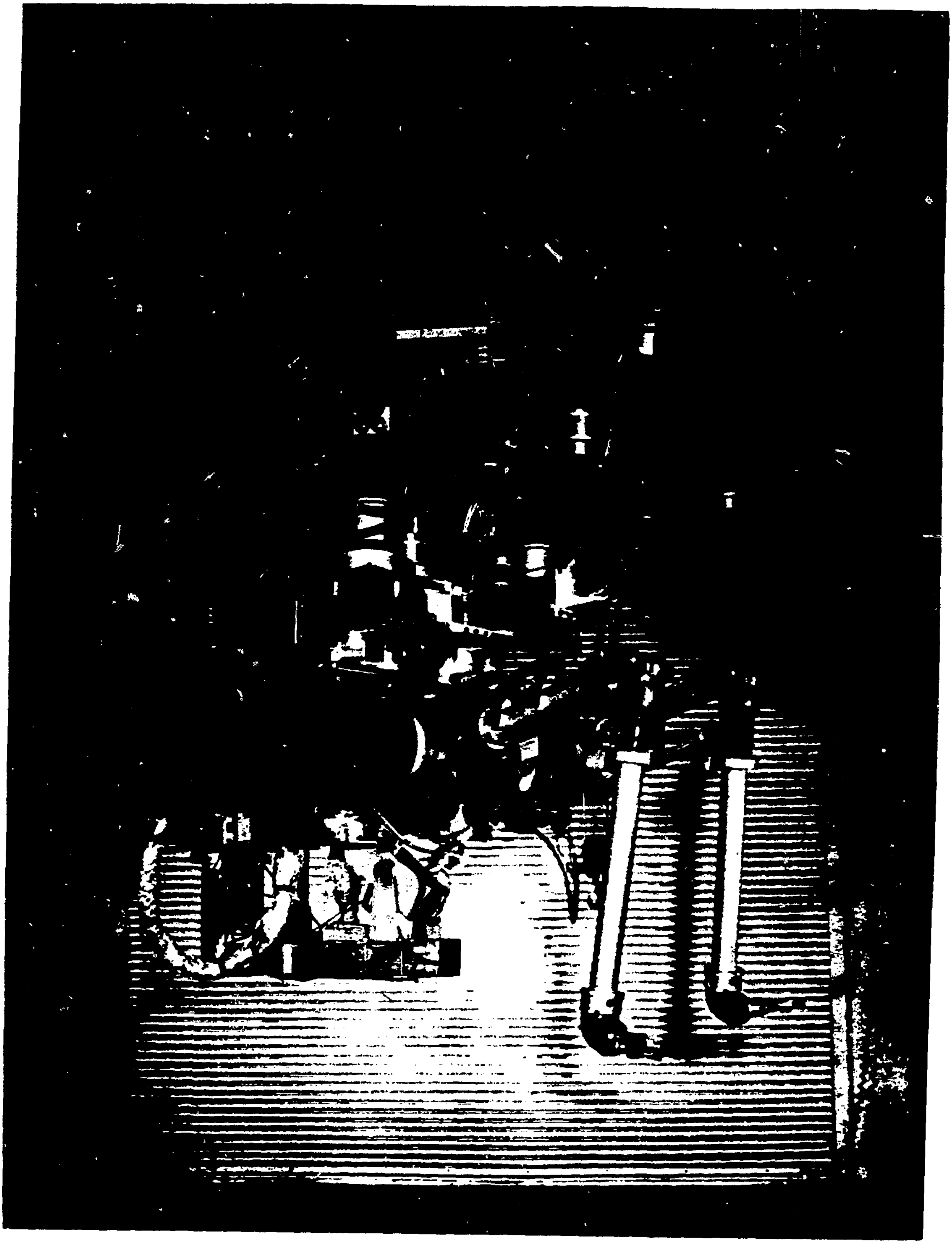

Fig. 2. The model M-2 servomanipulator slave.

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Fig. 3. The model M-2 master control station.

Operator interface with the remote handling equipment of the ROMD facility is based on a centralized control room that is located adjacent to the facility and houses the M-2 control station, a viewing system monitor console, and an operating panel containing the closed-circuit television system controls and control units for the balance of the maintenance system (i.e., hoists, transports, and EMMs). A discussion of each of the major components of the maintenance system follows.

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 seven degrees of freedom. The slave arms each have a continuous handling capacity of 23 kg (50 lb) and a peak handling capacity of 46 kg (100 lb) for all arm positions. The M-2 master and slave joints are each driven by a brushless dc servomotor with integral position and velocity encoding. The output of the upper 3 D.F. (degrees of freedom) of the master and slave are gear and lever driven. The lower 4 D.F. of the slave are cable driven. The master controller lower 4 D.F. are tape driven. A standard position-position bilateral control technique, implemented in digital control hardware, provides force reflection in ratios from 1:1 to 8:1 as well as operations without force reflection. Incorporated in the M-2 system slave design are three on-board cameras and a 227-kg (500-lb) capacity hoist to provide a complete maintenance package. A console of three 19-in. monitors provide viewing at the M-2 control station.

PaR Model 6000 Manipulator

The PaR model 6000 is a standard rate-controlled power manipulator. The manipulator arm has seven joints, an overall length of 2 m (7 ft), and a 181-kg (400-lb) capacity for any arm positions. Permanent magnet dc motors with continuously variable speed control drive each joint. A switchbox-type controller with spring-returned potentiometers provides individual rate control of each arm joint. A magnetically-coupled clutch in the end-effector drive allows adjustment of gripping forces from the control panel. This type of manipulator provides no feedback regarding forces exerted by 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.

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 (132 ft)] of the high-bay facility and full east-west access along its 18-m (60-ft) span with the two trolley assemblies. Special design features of the bridge system include remotely maintainable trolley hoist assemblies, motorized hook rotation, and load-block electrical power outlets (dc voltage) for remote tool operation and control. Various remote tools and fixtures are supported and operated from the load blocks in the course of remote maintenance.

A second gantry bridge system, which is at a lower elevation than the primary bridge, is nested between the end-truck and girder supports of the primary bridge system and operates over approximately 27 m of the north-south length of the facility. This secondary bridge system is equipped with three telescoping-tube trolley assemblies and provides three-axis positioning of the two manipulator systems and a closed-circuit television camera boom over the facility volume. Currently, the bridge system supports and provides mobility for the model M-2 servomanipulator, a PaR model 6000 manipulator, and two boom-mounted, closed-circuit television cameras. The telescoping feature of the tubes provides a 10-m positioning range from the fully extended to fully retracted positions. The telescoping-tube trolley assemblies were designed for remote maintainability, and the two supported manipulator systems can each be removed at the 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 rotary dissolver system. This vertical bridge system travels along three walls of the pit on a double, U-shaped, guide-and-support track. A PaR model 6000 manipulator is supported and positioned by a trolley and boom assembly that is raised and lowered along the 8-m (26-ft) vertical axis of the bridge by means of an integral hoist. This system was designed for remote maintainability, but it is not prototypical of transport and manipulator systems currently considered for fuel reprocessing applications.

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. Cameras are mounted on the secondary bridge, the primary bridge, and the facility walls. Two of the secondary bridge cameras are mounted on the center telescoping-tube boom 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 base. Camera controls and eight 17-in. monitors are located at the remote maintenance console in the ROMD control room. Full camera view selection capabilities to these monitors, the M-2 control station monitors, and two video cassette recorders are provided by this system.

OPERATING EXPERIENCE

Remote handling test operations in the ROMD facility were first initiated in FY 1982. Since this time, a number of experimental test programs that vary in scope and experimental design have been completed. These test programs are based on formalized test plans and procedures prepared and approved by multidiscipline CFRP staff members. The ROMD test programs can be generally categorized as one of the following types:

- Process Equipment Maintenance Demonstrations

  The demonstration and verification of developed maintenance procedures and techniques on existing prototypical reprocessing equipment (proof-of-principle).

- Maintainable Equipment Design Experiments

  Experimentation directed toward evaluation of fundamental maintenance design concepts for potential application to in-cell equipment design.

- Maintenance System Evaluation Experiments

  Experiments designed to evaluate and analyze maintenance system performance and effectiveness to aid in the development of improved maintenance systems.

- General Hazardous Environment Remote Handling Demonstrations

  Remote handling demonstrations for non-CFRP organizations with specific interests in hazardous environment teleoperations.

Process equipment maintenance demonstrations thus far have been completed on a process module equipment rack mock-up, the dissolution system rotary dissolver, an eight-stage bank of solvent extraction system centrifugal contactors, a robotic sampling vehicle, and portions of the fuel disassembly system. These demonstrations entailed a large variety of remote handling tasks, ranging from dexterous handling of relatively small and precisely aligned components, such as electrical connectors, to the removal and replacement of heavy, complete systems from their mounting bases. Figure 4 shows the remote removal of a 164-kg (360-lb) fuel bundle handling adaptor of the fuel disassembly system. In-cell equipment is modularized in design to a degree dependent on the expected frequency of

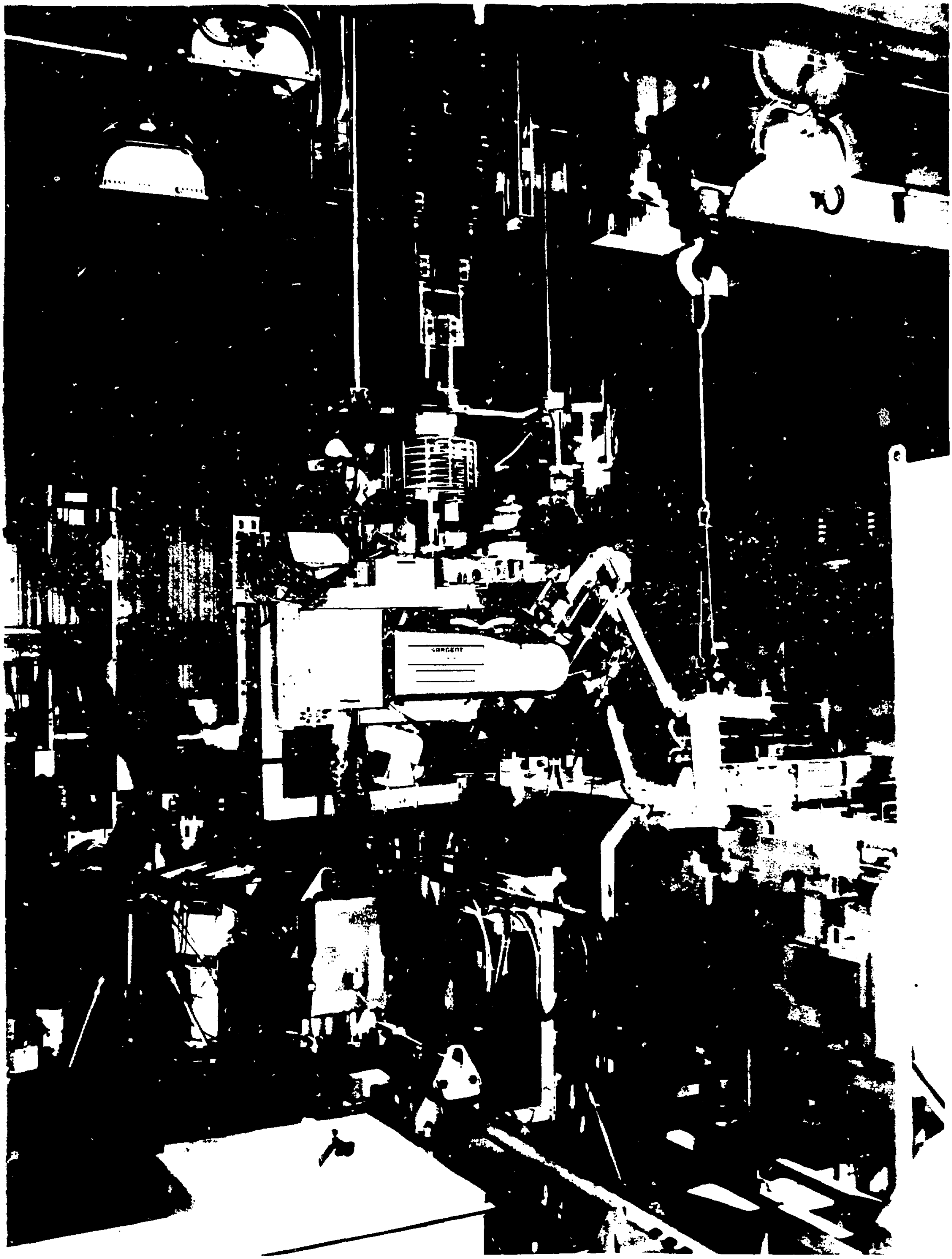

Fig. 4. Remote removal of a fuel disassembly system fuel bundle handling adapter

component changeout. For example, electric motors in high-radiation fields will unavoidably require replacement during the life of the plant and are therefore designed for individual replacement. In a maintenance demonstration, each of the modularized components of the equipment or system in question is evaluated for remote maintainability through actual demonstration. The end result of these efforts includes deployable maintenance designs, proven maintenance techniques documented through video recordings and written procedures, and the establishment of a maintenance data base in support of plant availability studies. Commonly employed maintenance tools include electric impact wrenches positioned and supported using manipulator tongs or a hoist, electric "nut-runner"-type wrenches, manually operated ratchet and torque wrenches, general rigging equipment (slings, chains, hooks, etc.), and specialized lifting and alignment fixtures. Where practical, commercially available tools are used that have been modified to enhance remote handling. Process equipment and systems incorporate standardized maintenance designs to minimize requirements for specially designed tools.

Testing of more fundamental equipment design concepts was the focal point of the Remote Connector Test Program. Remote handling characteristics of selected commercially available fluid and electrical connectors were evaluated for potential service in remotely maintained equipment. Reprocessing facilities utilize a large number of these connections that in the past have been custom designed to assure remote operability. With the improved remote handling capabilities of the new generation servomanipulators such as the model M-2, it may be feasible to use more cost-effective, off-the-shelf equipment designs. Comparable flareless tube fittings from three manufacturers (28 total) and electrical connectors from five manufacturers (24 total) were examined. Tubing connectors in 0.25-, 0.5-, and 1-in. sizes were tested. Electrical connectors ranged in size from 1-pin coaxial to 60-pin in both straight and 90° configurations. These connectors were mounted in varying jumper arrangements on a portable test panel which is shown in Fig. 5. The different mounting orientations allowed evaluation of accessability and viewing limitations for operation. The experimental data characterized each connector according to its type, size, panel location, test configuration, tool requirements, and operator identification. The times required to disconnect and to connect the test jumper for each of 25 repetitions were recorded along with results of systematic checks of connector integrity and video recordings of test operations. With the exception of a small BNC-type coax connector (too small for the M-2's tongs), all connectors were remotely operable using the model M-2 servomanipulator. The majority of the connectors withstood 25 cyclings with no evidence of damage. Preferred mounting orientations and connector makes were identified.

Two major manipulator system performance evaluation test programs have been completed: The Manipulator Comparative Test Program and the Force Reflection Evaluation Test Program. The Manipulator Comparative Test Program was jointly sponsored by the DOE and the Power Reactor and Nuclear Fuels Development Corporation of Japan and evaluated the relative performance of three manipulative systems: the Model M-2 servomanipulator, a PaR model 6000 manipulator, and a Meidensha model 83A Bilarm manipulator. The Meidensha manipulator was temporarily installed in RCMD for the test

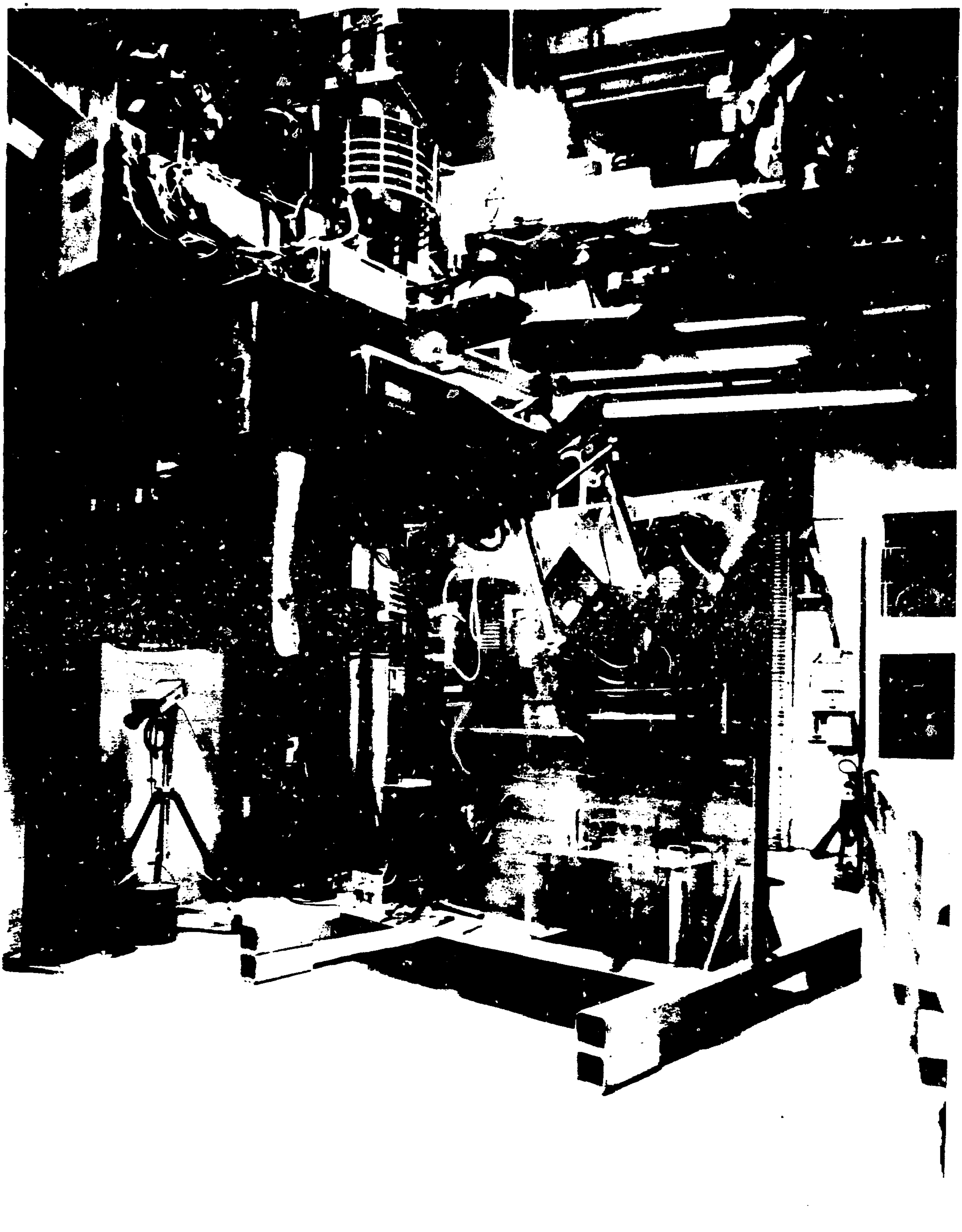

Fig. 5. Evaluation of fluid and electrical connector remote handling using the model M-2.

program and is shown in Fig. 6. The Bilarm is an eight-jointed system designed for individual joint control like the PaR manipulator and also equipped with a master control arm with three force-reflecting joints. The test program experimental design included six realistic remote handling tasks, four experienced manipulator operators, and common test conditions and viewing for each of the manipulative systems. The order of presentation to operators of manipulation systems and test tasks was organized to accommodate statistical analytical methods and to compensate for learning effects that would bias performance comparisons. Experimental data collected for test evaluation included: (1) time-to-task completion, (2) number of errors (collisions, dropped items, or other critical incidents), (3) operator opinions on manipulator performance; and (4) simultaneous video recordings of operations at the remote site and master control station. Results of this experiment are to be published later this year.[7]

The Force Reflection Evaluation Test Program provided data for the analysis of the utility of servomanipulator force feedback in operator performance of remote handling tasks. In many respects, this program was similar to the manipulator comparative test program with highly controlled test conditions common to each of six experienced test operators and experimental procedures organized for accommodation of statistical analysis. Four remote handling tasks similar to those used in the manipulator comparative test were repeatedly performed using the model M-2 servomanipulator under three force-feedback ratio conditions (1:1, 4:1, and no force feedback). Forces exerted by the M-2 slave during task execution were recorded

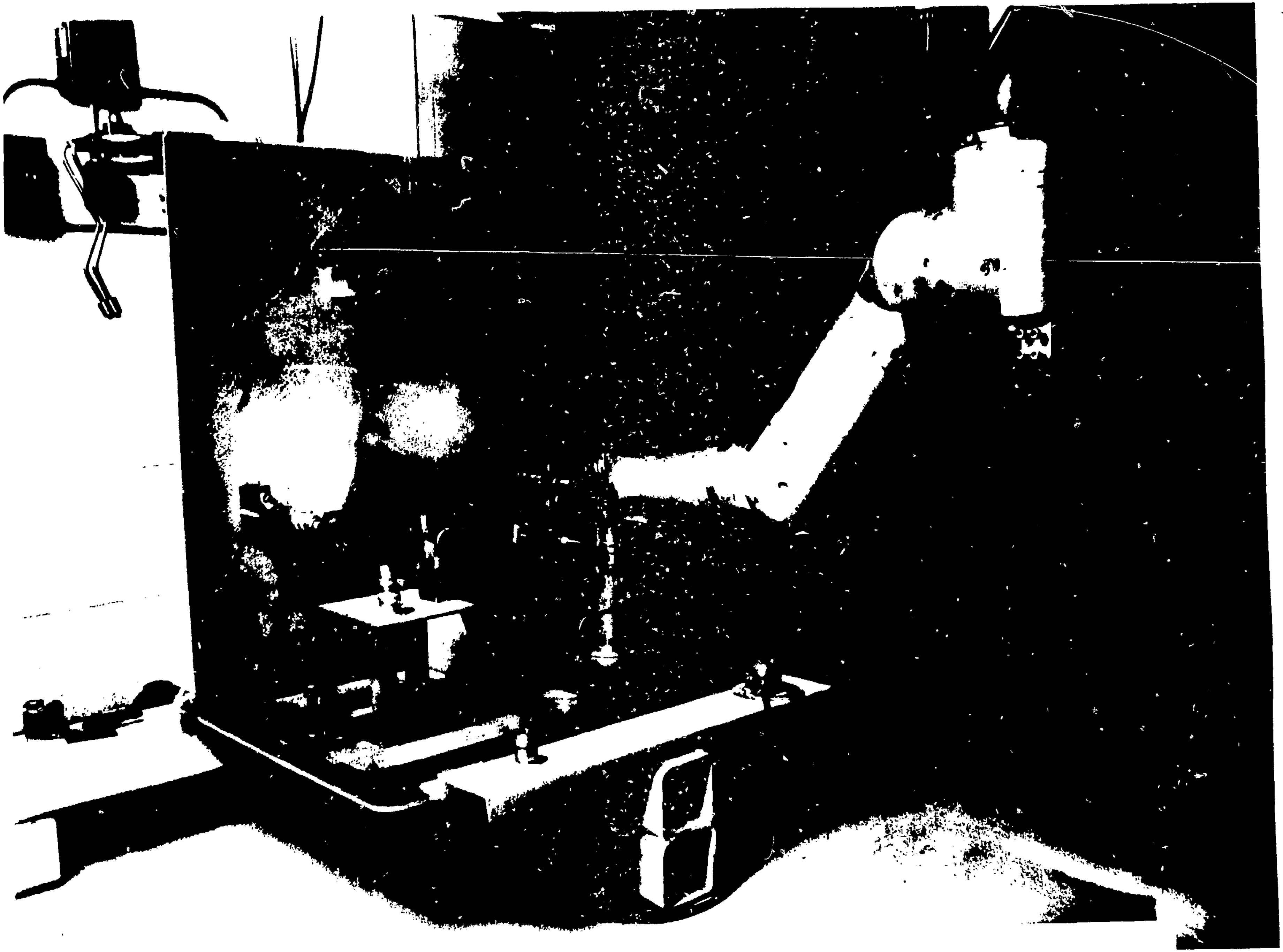

Fig. 6 The Meidensha Bilarm manipulator performing manipulator comparative test tasks.

using a six-axis force-sensing table and a computerized data acquisition system. Additional slave arm performance data were recorded along with task completion times, number of committed errors, and video recordings of test operations. These data are currently being analyzed.

Remote handling demonstrations have been conducted for the U.S. Navy and National Aeronautics and Space Administration (NASA). An examination of heliarc type welding tasks and weld inspection using the Model M-2 was performed for the U.S. Navy. Remote handling and operation of standard welding tools and the performance of die-penetrant checks on weld specimens were successfully demonstrated. The test supported general conclusions that servomanipulators were capable of performing such tasks remotely; however, development of remote tooling is required to improve the efficiency of these operations. Developmental organizations at ORNL are currently engaged in conceptualizing a servomanipulator system for space applications. As a demonstration to NASA of the capabilities of existing technology, a satellite-refueling coupling was remotely operated using the model M-2. This coupling is being developed by NASA for refueling of orbiting satellites by astronauts and has been identified as a potential remote operation. Without any modification for remote handling, complete operation of the coupling was demonstrated.

CONCLUSIONS

The RCMD facility provides an engineering-scale laboratory for the demonstration and development of remote handling techniques on advanced fuel reprocessing equipment. This facility also provides a unique opportunity for the demonstration and development of remote handling concepts for other hazardous environments where direct human contact is not possible. Advanced remote handling equipment and techniques are being demonstrated that have direct application to hot-cell facilities under development by other organizations and DOE programs.

Representing a substantial monetary investment, DOE has developed a national resource for remote technology development that can be utilized and exploited for the benefit of other programs in both the government and commercial sectors.

REFERENCES

1. "Title I Design Report for Integrated Prototype Equipment Test Facility," X-OE-58, Oak Ridge National Laboratory, February 1978.
2. F. L. Peishel, R. W. Mouring, and S. L. Schrock, "Evolution of Design Concepts for Remotely Maintained Equipment Racks," Proceedings of the ANS Topical Meeting on Waste Management and Decontamination and Decommissioning, September 1986.
3. J. N. Herndon et al., "The State-of-the-Art Model M-2 Maintenance System," pp. 147-154, Proceedings of the ANS Topical Meeting on Robotics and Remote Handling in Hostile Environments, April 1984.
4. P. E. Satterlee, Jr., et al., "Control Software Architecture and Operating Modes of the Model M-2 Maintenance System," pp. 355-365, Proceedings of the ANS Topical Meeting on Robotics and Remote Handling in Hostile Environments, April 1984.
5. J. N. Herndon et al., "Advanced Remote Handling Developments for High Radiation Applications," pp. 5-53-65, Proceedings of the 10th International Conference on Robotics, Robotics International of SME, April 1986.
6. N. R. Grant et al., "Remote Maintenance for Waste Handling: Application of Servomanipulators to a New Generation of Hot Cells," Proceedings of the ANS Topical Meeting on Waste Management and Decontamination and Decommissioning, September 1986.
7. J. V. Draper et al., "Manipulator Comparative Testing Program," paper to be presented at the 34th Conference on Remote Technology, American Nuclear Society, November 1986.