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Waste Systems Data and Development Program

POTENTIAL APPLICATIONS OF ADVANCED REMOTE HANDLING AND MAINTENANCE TECHNOLOGY TO FUTURE WASTE HANDLING FACILITIES

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POTENTIAL APPLICATIONS OF ADVANCED REMOTE HANDLING AND MAINTENANCE TECHNOLOGY* TO FUTURE WASTE HANDLING FACILITIES†

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ABSTRACT

The Consolidated Fuel Reprocessing Program (CFRP) at the Oak Ridge National Laboratory (ORNL) has been advancing the technology in remote handling and remote maintenance of in-cell systems planned for future U.S. nuclear fuel reprocessing plants. Much of the experience and technology developed over the past decade in this endeavor are directly applicable to the in-cell systems being considered for the facilities of the Federal Waste Management System (FWMS). The ORNL developments are based on the application of teleoperated force-reflecting servomanipulators controlled by an operator completely removed from the hazardous environment. These developments address the nonrepetitive nature of remote maintenance in the unstructured environments encountered in a waste handling facility. Employing technological advancements in dexterous manipulators, as well as basic design guidelines that have been developed for remotely maintained equipment and processes, can increase operation and maintenance system capabilities, thereby allowing the attainment of two Federal Waste Management System major objectives: decreasing plant personnel radiation exposure and increasing plant availability by decreasing the mean-time-to-repair in-cell maintenance and process equipment.

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INTRODUCTION

The Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) is responsible for the development of a comprehensive national system for radioactive waste conditioning, transportation, storage, and disposal. The special technical needs of this program are being addressed by the evaluation of the potential application of available and emerging technologies. One such technology is that of remote handling and manipulation techniques which remove humans from potentially hazardous environments.

The CFRP at the ORNL has been advancing the technology in remote handling and remote maintenance of in-cell systems planned for future U.S. nuclear fuel reprocessing plants. Much of the experience and technology developed over the past decade in this endeavor are directly applicable to the proposed in-cell systems being considered for the facilities of the FWMS.[1] The application of teleoperated, force-reflecting servomanipulators with television viewing could be a major step forward in waste-handling-facility design. The primary emphasis in the current program is the operation of a prototype remote handling system, the Advanced Integrated Maintenance System (AIMS), which specifically addresses the requirements of fuel reprocessing and waste handling with emphasis on force reflection, remote maintainability, reliability, radiation tolerance, and corrosion resistance.

Concurrent with the evolution of dexterous manipulators, concepts that provide guidance for standardization of the design of the remotely operated and maintained equipment, the interface between the maintenance tools and the equipment, and the interface between the in-cell components and the facility have also been developed. These concepts described in a remote maintenance design guide are also adaptable to the highly mechanized equipment of the FWMS.

The ORNL philosophy emphasizes the total-system approach, which has led to synergism between the capabilities of the remote handling systems; compatibility of the in-cell equipment with these capabilities; and optimization of the facility from the initial component and facility designs through fabrication, operation, and finally decommissioning.

ADVANCED INTEGRATED MAINTENANCE SYSTEM

The AIMS, which is shown in Fig. 1, is the culmination of CFRP's development program and is a prototype remote handling system. The system includes all the major subsystems necessary to apply dexterous manipulators to large-volume reprocessing and waste handling applications. Included are manipulators, transporters, sensors, tooling, signal and power transmission, and human-machine interfaces. The key feature of the AIMS is the Advanced Servomanipulator (ASM), the first force-reflecting servomanipulator system designed for modular remote maintainability. The major subsystems of the AIMS are described in the following paragraphs.

Advanced Servomanipulator

The ASM was developed specifically for the extremes of a reprocessing environment. The two prototype ASM arms, installed in AIMS (Fig. 2), were

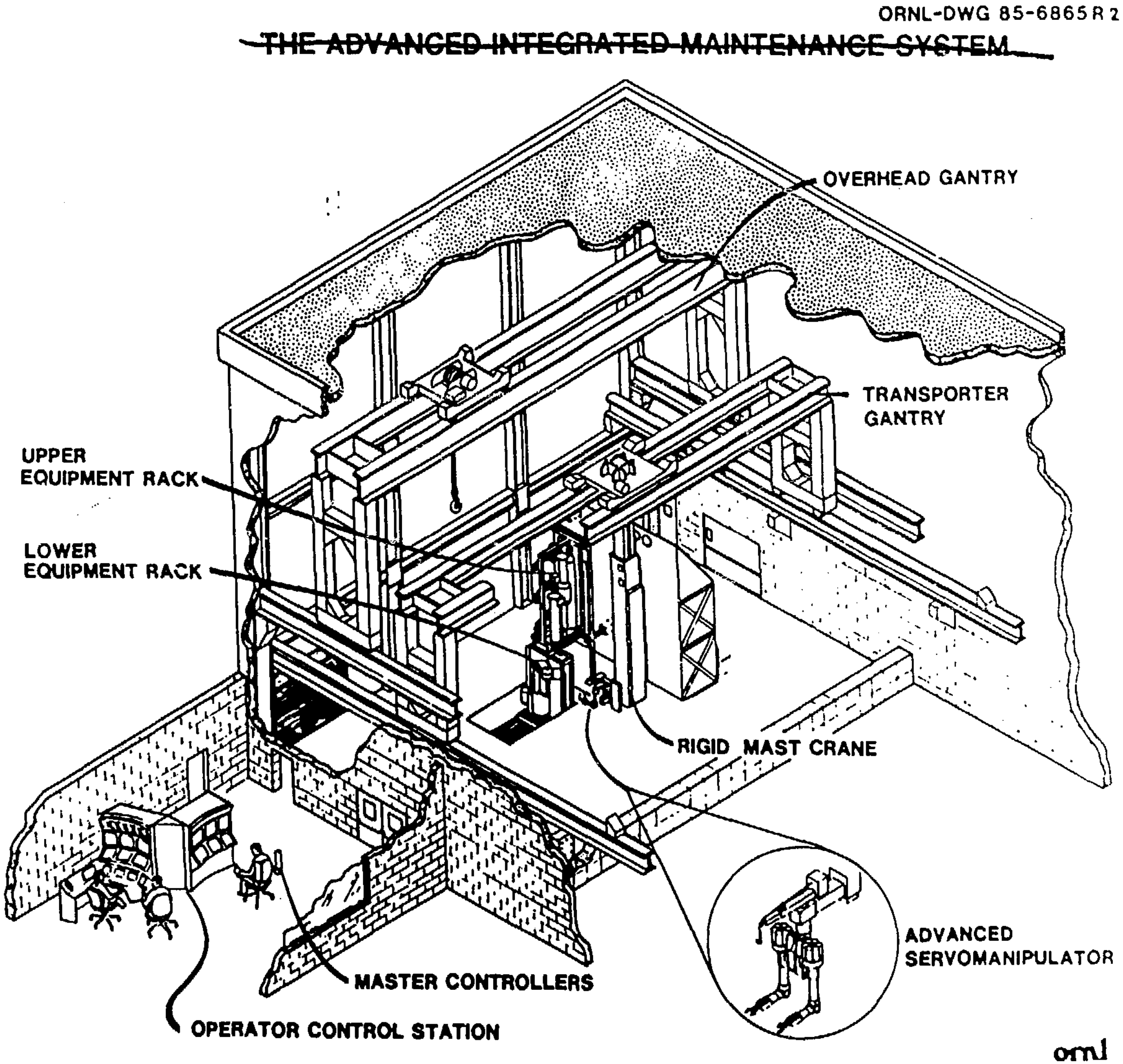

Fig. 1. Advanced Integrated Maintenance System.

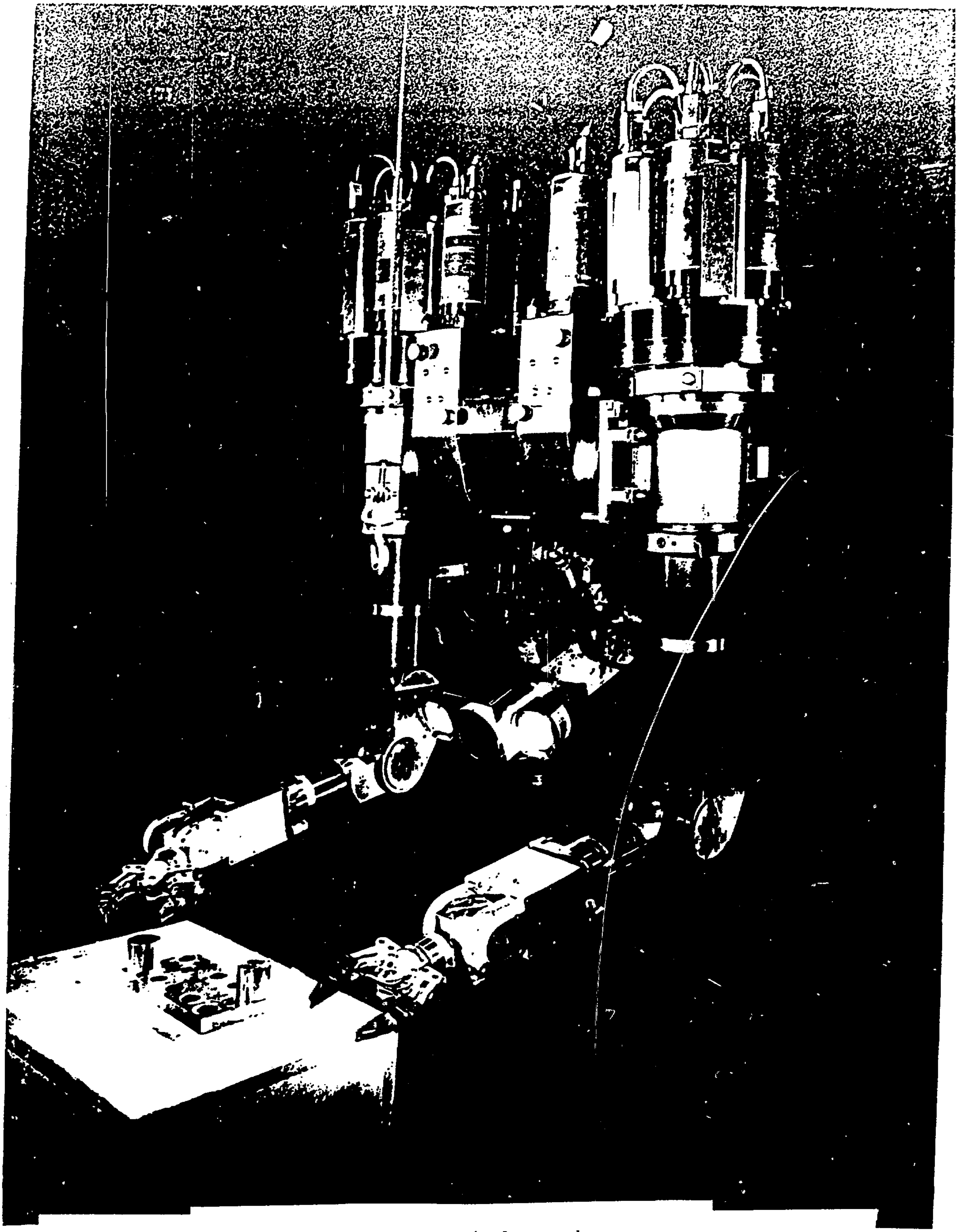

Fig. 2. Advanced servomanipulator slave arms.

designed and fabricated at ORNL. The slave arms were designed for 23-kg capacity in any orientation, end-effectors maximum no-load velocities in excess of 1 m/s for all joints, and low backdriving torque requirements (approximately 2% of capacity) for force-reflecting operation with bilateral, position-position servocontrol. A special brush-type dc servomotor with very low inertia was developed by Inertial Motors Corporation for this application. The arms have 6 D.F. (degrees-of-freedom) for generalized positioning in space with a grip as the seventh D.F. An anthropomorphic (man-like) kinematic arrangement was employed to provide for horizontal reach capabilities into constrained areas. The unique 4-D.F. wrist utilized on the ASM has pitch, yaw, and output roll motions with axes intersecting at a single point and followed by the grip. The arm is composed of 15 individual modules which are each less than 23 kg in weight for handling by another manipulator. These modules are illustrated in Fig. 3. The modularized design is accomplished by precision gear and shaft drives throughout. This is a significant departure from previous designs for bilateral force-reflecting servomanipulators that use tendon drives for reduced friction and inertia. Electronic counterbalancing is used to eliminate balance weights and thus reduce the cross-sectional size of the arm. A detailed description of the ASM slave arms can be found in ref. 2.

Master Controllers

The master controller arms for the ASM were designed for operation in the human-occupied control room and did not require the modularity provided in the slave arms. Stainless-steel cable drives were

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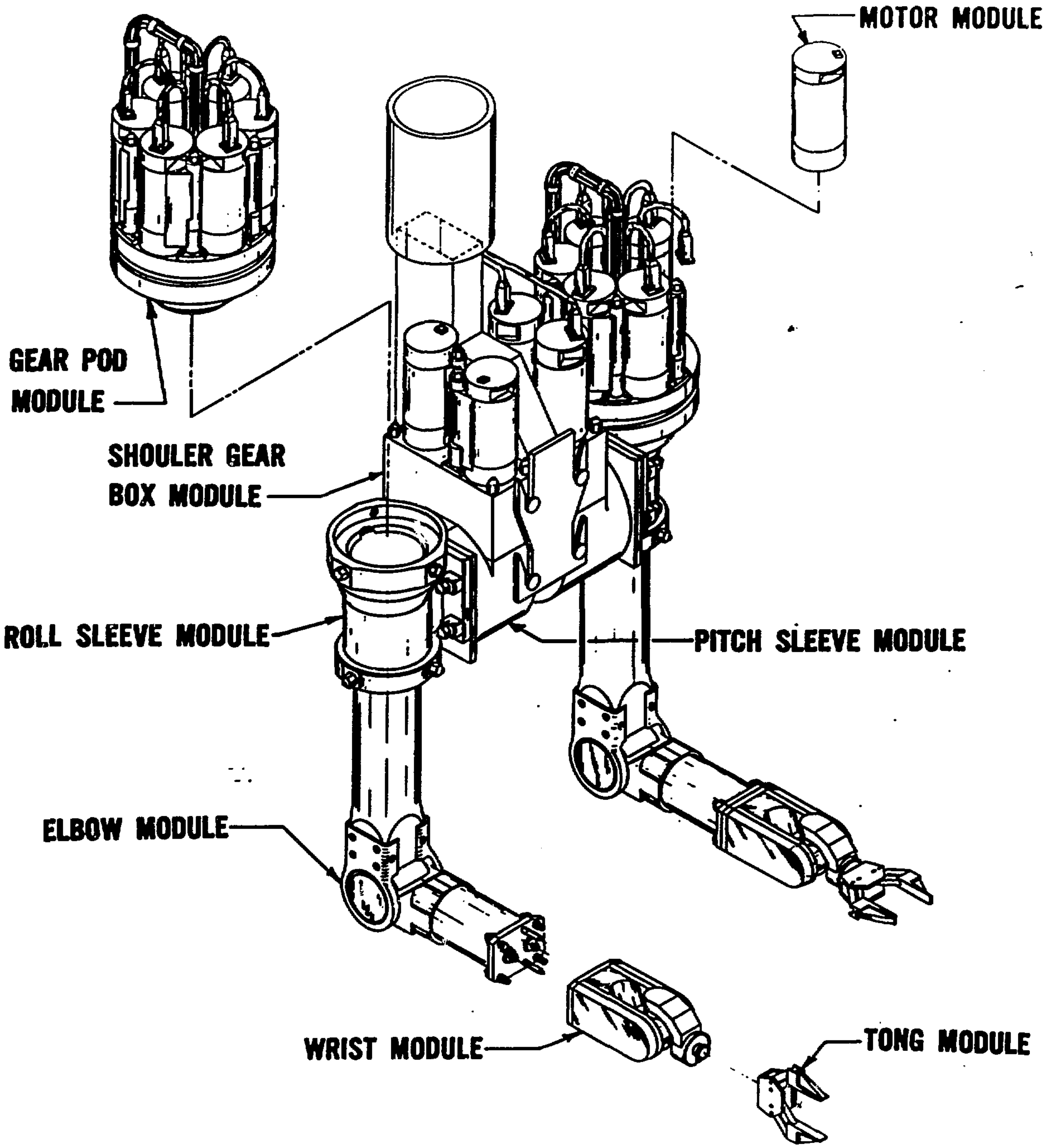


Fig. 3. Advanced servomanipulator slave arm modules.

employed for all joints below the shoulder to minimize friction and inertia. The two prototype arms installed in AIMS (Fig. 4) were designed and fabricated at ORNL. The master controllers were designed for 6-kg capacity in any orientation; end-effector maximum no-load velocities in excess of 1 m/s for all joints; and low no-load backdriving torque (approximately 4% of capacity) for force-reflecting operation with bilateral, position-position servocontrol. The arms are one-to-one kinematic replicas of the slave arms so that real-time transformations are not required. The slave arm torque cross-coupling is mimicked to simplify of control. Mechanical counterbalancing is used on the master for reduced drive friction compared to the electronic counterbalancing of the slave arms. A detailed description of the master controller arms can be found in ref. 3.

Transporter and Interface Package

An adaption of an industrial rigid mast crane has been used for the AIMS transporter system. Based on ORNL concepts and specific requirements, Harnischfeger Corporation performed the detail design and fabrication of a remotely maintainable stacker crane system. The transporter has a three-section, externally telescoping mast with an inner rigid section, a moving secondary mast, and an outer moving carriage. The rigid mast section is mounted on a rotating turntable to provide 370° rotation of the mast. An interface package is remotely detachable from the carriage and provides the balance of the in-cell remote maintenance system. The AIMS interface package, which was designed and fabricated at ORNL,

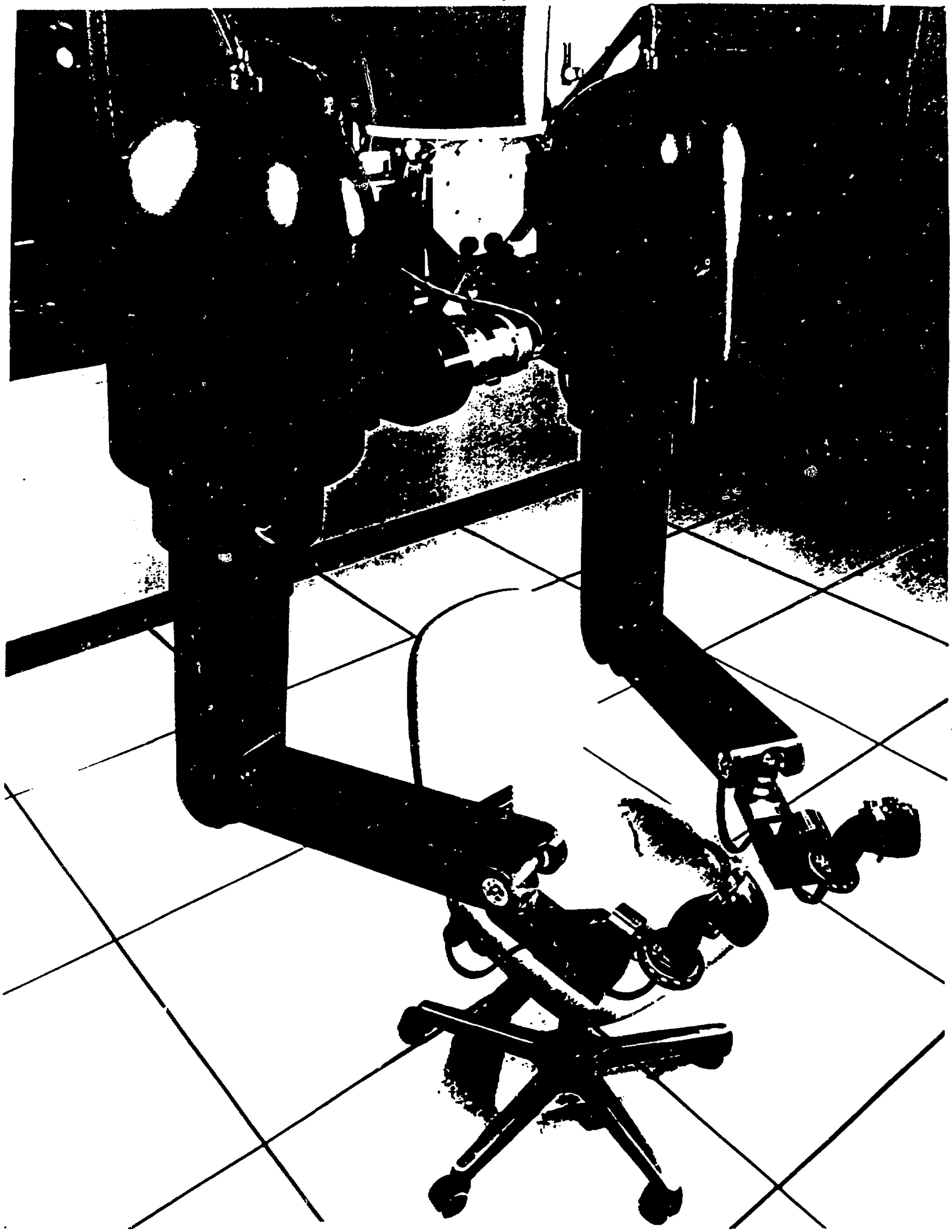


Fig. 4. Master controller arm

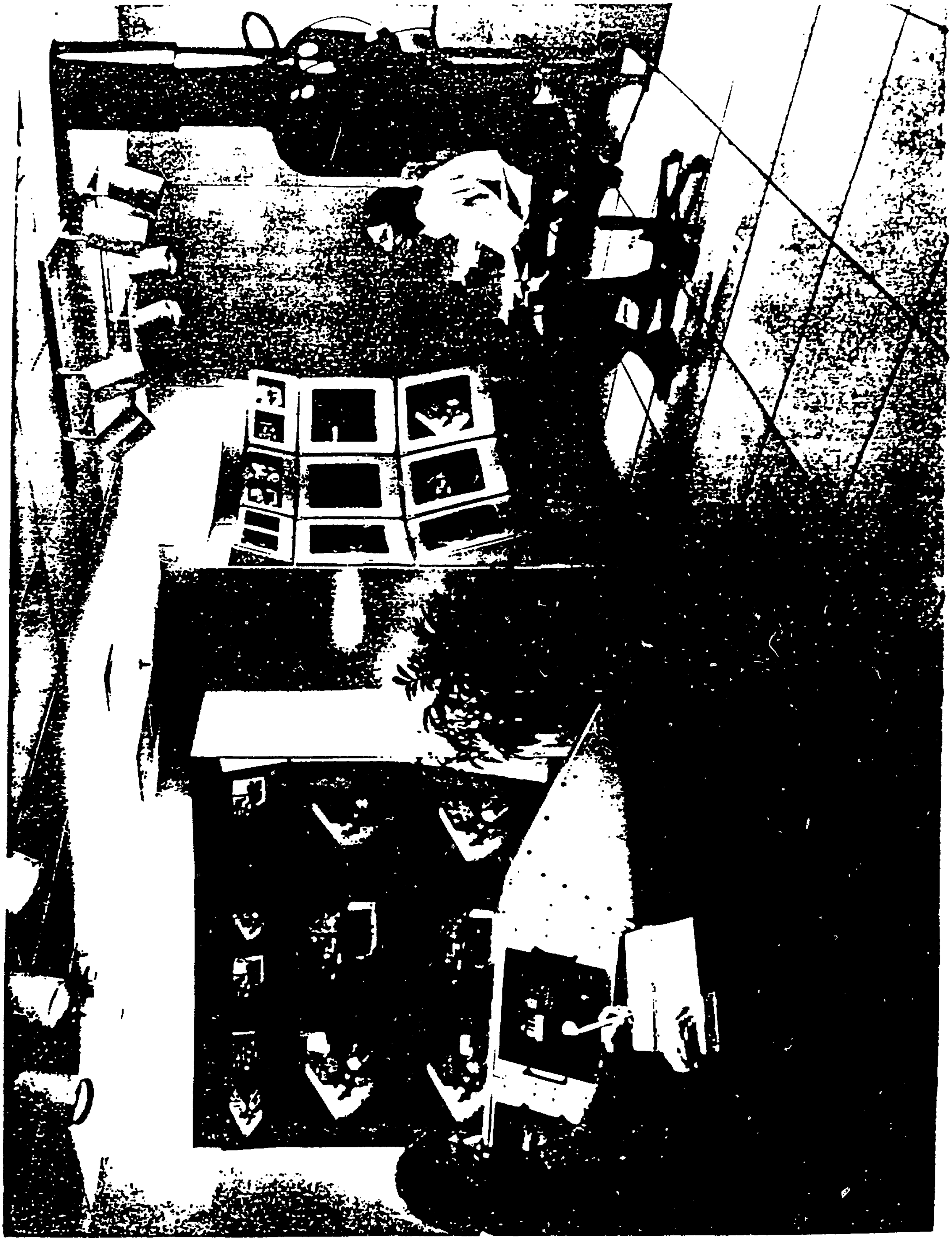
supports two overhead television cameras with lights on 4-D.F. positioners, a center camera with lights on a 2-D.F. positioner, mounts for the ASM slave arms, and a 460-kg-capacity auxiliary hoist with extend/retract motion.

Advanced Integrated Maintenance System Operator Control Station

The AIMS operator station,[4] which is shown in Fig. 5, is based on a two-operator team approach to control maintenance operations with the master controller arms and flexible graphic-display-based controls. Good visual and verbal interoperator communication is provided. The manipulator operator, who is shown on the right of Fig. 5, is responsible for performing dexterous maintenance operations using the master controllers with television viewing. The secondary operator, who is shown on the left, is responsible for control of the transporter, a large overhead 20-ton crane, television camera positioning, control station displays, and overall maintenance supervision.

Advanced Integrated Maintenance System Control System

Control of the AIMS system is a challenge because of the breadth of the requirements. The control system must provide for 26 bilateral, force-reflecting joints that require updating at 100 Hz; 58 non-force-reflecting drives; over 100 discrete outputs; 6 graphics displays; 21 television displays; and 2 separate operator control stations. This problem has been solved by a hierarchical, building-block approach (see Fig. 6) utilizing an industry-standard Multibus backplan (IEEE 796) for expandability and flexibility. Single-board Motorola 68000-based computers for control calculations and Megalink communications devices



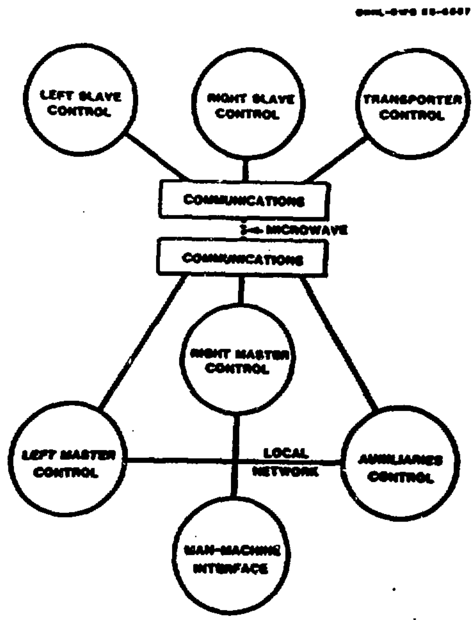


Fig. 6. Control system block diagram.

are used throughout the system with input/output and special devices chosen to meet individual subsystem requirements. All software modules in the system are being programmed in the computer language FORTH for speed of execution in a high-level software environment.

ORNL leads the world in the development of digital-based control systems for bilateral force-reflecting servomanipulators. The controls for the ASM,[5] which are based on the hardware described above, are the most advanced of any existing force-reflecting servomanipulators. Through special software compensation methods, the adverse effects of much higher levels of friction, inertia, and cross-coupling of torques on the ASM slaves have been minimized. In addition, electronic counter-balancing of the slave arms has been achieved without significant adverse effects on the force-reflection sensitivity.

GENERAL CONCEPTS FOR THE DESIGN OF REMOTELY MAINTAINED EQUIPMENT

In any facility incorporating remote operation and remote maintenance, the design of the facility and cell equipment is strongly influenced by the repair philosophy and the remote maintenance equipment capabilities. The facility and all in-cell equipment must be arranged to facilitate repair. All in-cell equipment, from very large equipment modules and shielding plugs to the smallest tubing jumper or gasket, must incorporate features necessary to allow the maintenance system to accomplish its task. Lack of consideration of these issues during facility design and construction can result in exceedingly long outage time when failures in process equipment occur. Consideration must also be given to the entire life cycle of the facilities, not only startup and operation, but decommissioning as well. Facility decommissioning is an extremely time-consuming and costly process, which, if properly planned for during the initial design phase, can be significantly simplified with corresponding cost benefits.

Therefore, concurrent with the development of the tools for maintenance, the CFRP at ORNL has developed concepts for the design of in-cell equipment. The critical features of these concepts are available, in the form of a remote maintenance design guide, and this guide can be used to ensure compatibility of equipment designed by the various participants. Many of these reprocessing plant critical features are directly adaptable to the highly mechanized equipment of the FWMS. The use of a remote maintenance design guide provides guidance for standardization of the design of the in-cell equipment and establishes the interface between the maintenance tools and the process equipment. A few of the significant points that should be included in this design guide will be addressed.

Determine Repair Methodology

In an entirely remotely operated and maintained facility, a determination must be made at the design stage of the process equipment concerning the possibility and the method for repair of the equipment. An example of this methodology is provided by the remote maintenance schematic (Fig. 7), which outlines the various steps normally followed in a remotely maintained facility. The most frequent occurrence is the replacement of a module, which is shown on the right side of Fig. 7. Examination of the various steps will determine whether the item in question is to be discarded or repaired. If the former is required, only the extent of decontamination and the means for disposal must be

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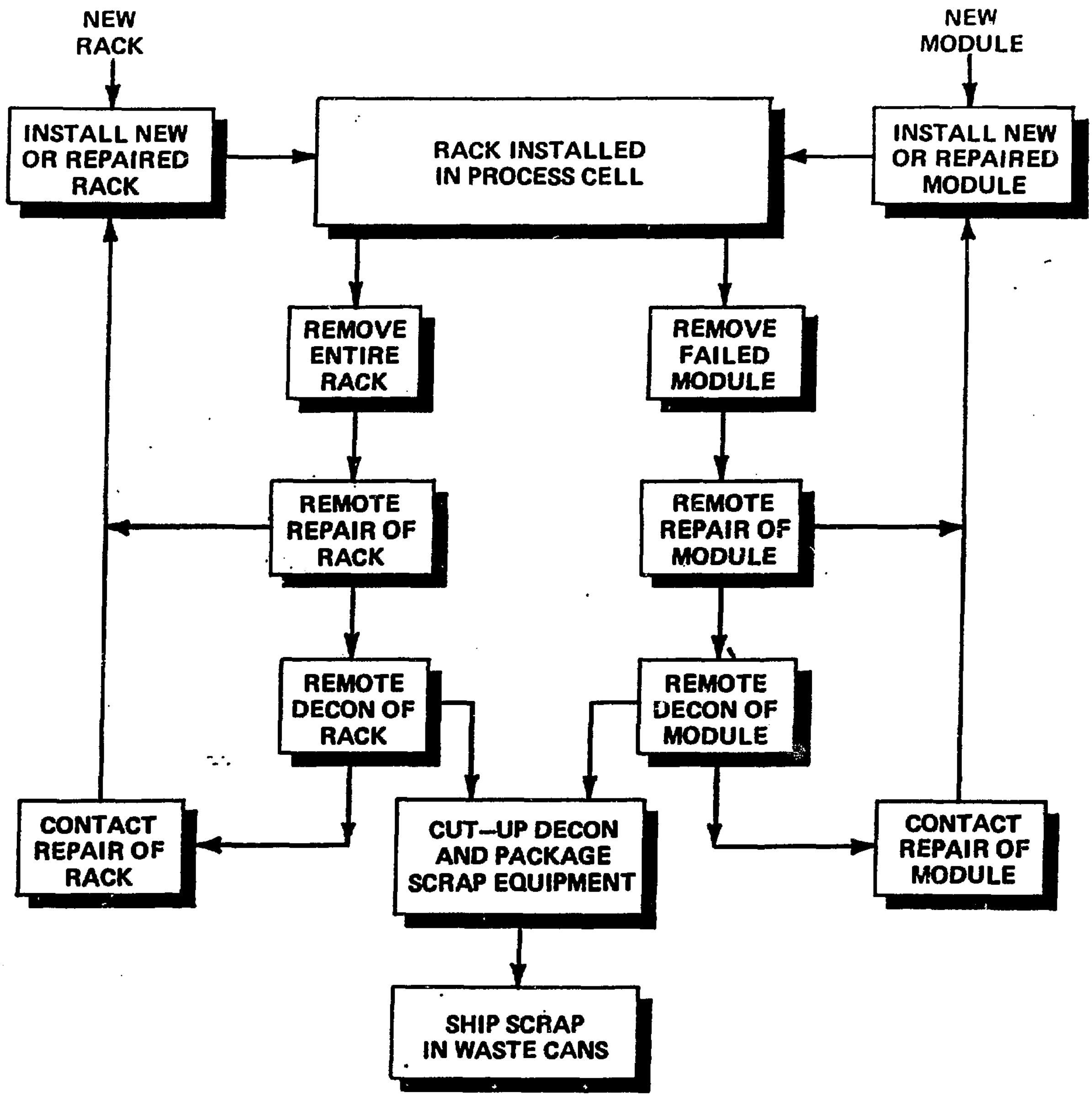

Fig. 7. Remote maintenance schematic.

considered. If repair is required, then the means and tools for remote repair or the decontamination and methods of contact repair to be used necessitate attention. This latter pathway requires a decision as to whether the assembly and its intricate parts can be handled in the restrictions imposed by gloveboxes or whether it can be handled in the open. In certain instances, a component is either low in cost or is considered expendable because of its inherent characteristics of non-repairability. Such items bypass all the steps illustrated directly to disposal. The pertinent issue here is that the application of this methodology be made during the initial design.

Establish Dimensional Baseline

To ensure the successful remote replacement of all the equipment in the shielded cells initially and throughout the operating life of the facility, an accurate dimensional baseline or grid system should be established. The design of all equipment is referenced to this dimensional baseline. A mock-up of the grid system is maintained during initial fabrication and throughout the operating lifetime of the facility, usually in an on-site shop. Following fabrication, all equipment is verified operationally and dimensionally in this mock-up before committing it to the hostile environment. This ensures that no adjustments are required following emplacement of the equipment in the remote cell. Maintaining this procedure through the life of the facility ensures confident remote replacement of any component in the cell.

Establish Logical Subdivision of Equipment

Consistent with the philosophy of establishing a dimensional baseline, a machine or unit operation should be subdivided into logical assemblies or parts mounted on a main base frame or equipment rack. The subdivision is determined initially by its operating functions followed by the expected failure frequency, handling ability with the available tools, inherent repair possibilities, and the proposed repair method. Generally, the greater the failure potential, the easier must be the replacement. To keep overall plant availability high, small equipment items, such as mechanical activators, electrical switches, in-line instruments, and electrical connectors, are designed to be replaceable in situ. The larger and heavier support racks or other massive machine parts requiring little-to-no maintenance are removable, but removal most likely will not be required, except for replacement with advanced technology or until final decommissioning.

Utilize Computer-aided Design

The adaptation of computers to aid in the design of equipment provides the ability to generate computer models that mimic the movements of a manipulator. These models permit checking the interface between the components and the tools that maintain the components during the design phase and provides the ability to check manipulator/process equipment clearances, thereby confirming the design prior to fabrication. The retention of the data will then provide an operating tool to demonstrate to the maintenance personnel, sometime in the future, how a component is assembled and the means for its replacement.

SUMMARY

Because of the similarity between equipment and operations in reprocessing facilities and the FWMS waste conditioning facilities, most of the remote handling technology and many of the guidelines and concepts developed at ORNL for the design of in-cell process equipment have direct application. Incorporation of this technology and these concepts and guidelines into FWMS waste processing facilities design will decrease plant personnel radiation exposure and increase plant availability by decreasing the mean-time-to-repair in-cell maintenance and process equipment.

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