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REMOTE MAINTENANCE "LESSONS LEARNED" ON PROTOTYPICAL REPROCESSING EQUIPMENT*

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ABSTRACT

Hardware representative of essentially every major equipment item necessary for reprocessing breeder reactor nuclear fuel has been installed and tested for remote maintainability. This testing took place in a cold mock-up of a remotely maintained hot cell operated by the Consolidated Fuel Reprocessing Program (CFRP) within the Fuel Recycle Division at Oak Ridge National Laboratory (ORNL). The reprocessing equipment tested included a Disassembly System, a Shear System, a Dissolver System, an Automated Sampler System, removable Equipment Racks on which various chemical process equipment items were mounted, and an advanced servomanipulator (ASM). These equipment items were disassembled and reassembled remotely by using the remote handling systems that are available within the cold mock-up area. This paper summarizes the "lessons learned" as a result of the numerous remote maintenance activities associated with each of these equipment items.

INTRODUCTION

A major objective of CFRP at ORNL is to develop and demonstrate the technology required to reprocess spent fuel. Over the past 16 years, the program has undertaken this objective by designing and testing hardware representative of essentially every major process equipment item included in most fuel reprocessing plant conceptual designs. These designs are based on total remote maintenance to increase plant availability and reduce radiation exposure to plant operators. The cell designs include modular equipment to facilitate maintainability and the remote manipulation necessary to accomplish the maintenance tasks. The development during the 1980s of high performance, electronically controlled servomanipulators has permitted the designer of hot-cell equipment to take this approach in the layout of equipment in the cell with the potential for a reduction in cell size and improvements in maintenance efficiency and plant availability. These servomanipulators provide a dexterity approaching that of mechanical master/slave manipulators and, when mounted on a suitable transporter system, can provide essentially full-volume coverage of a cell. The objective of this paper is to summarize the lessons learned as a result of the application of this total remote maintenance concept and the numerous remote maintenance operations accomplished on the prototypical equipment items.

REPROCESSING CELL EQUIPMENT

The major portion of fuel reprocessing functions currently identified in most fuel reprocessing plant conceptual designs take place in a single heavily shielded cell. Figure 1 represents one example of such a cell. The primary equipment items depicted are listed along with a brief explanation of their functions:

Disassembly System -- To initially receive and position the fuel assembly and then remove the nonprocessible hardware from the assembly and deliver the fuel bearing portion to the shear.

Shear System -- To shear the fuel bearing portion of the fuel element into approximately 1-in. lengths and deposit the sheared segments into the dissolver.

Dissolver System -- To dissolve the fuel from the fuel pins by exposing the pins to a nitric acid solution within a rotating drum.

Automated Sampler System -- To traverse the periphery of the process cell on a track system that uses a self-propelled vehicle to collect process liquid from sample stations.

Equipment Rack -- To provide both physical support and accurate positioning for chemical process equipment and allow remote replacement of individual equipment items or replacement of the entire rack.

Servomanipulator -- To perform the maintenance on all other equipment located within the cell, including other maintenance systems, by providing full-volume coverage.

As a result of the full-volume coverage afforded by the servomanipulator, most equipment items can be mounted on the vertical faces of the equipment racks and still remain accessible to the manipulator for remote maintenance or replacement leading to better utilization of cell volume.

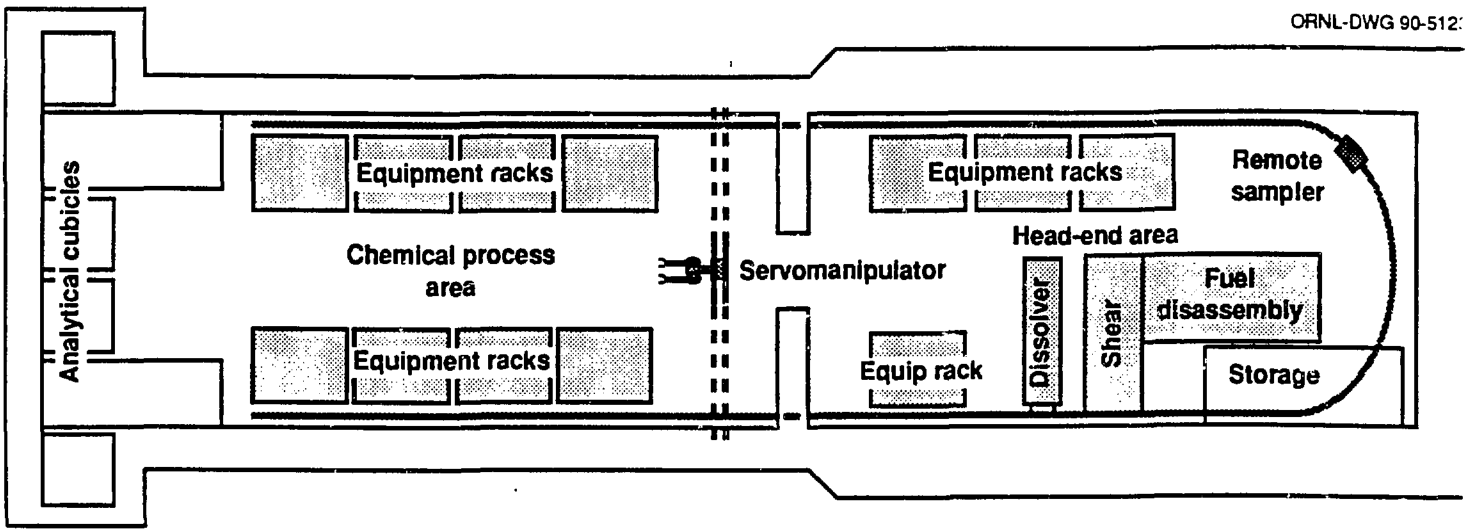

Fig. 1. Typical fuel reprocessing cell equipment layout.

Furthermore, by positioning these racks along the walls of the cell, a center aisle free of obstructions is retained for moving equipment into or out of the cell. Hence, the height of the cell can be reduced since vertical clearances are no longer required for moving equipment over the top of other equipment.

MAINTENANCE SYSTEMS

A remote maintenance facility has been developed by CFRP to demonstrate the remote operability and maintainability of equipment items in a full-scale, cold mock-up of a reprocessing hot cell. It consists of a large high bay area with a 15-m (48 ft) working height and a 586-m^2 (6000 ft^2) floor space. Assembled in this area are two remote maintenance systems that include force-reflecting servomanipulators, auxiliary hoists, closed-circuit television viewing systems, and manipulator transport bridges. An overhead gantry bridge crane with two 10-ton hoists is also available. Approximately half of the mock-up cell is serviced by a first generation servomanipulator system, the Central Research Laboratories' Model M-2. Under a joint development effort, Sargent Industries' Central Research Laboratories and ORNL developed the Model M-2 servomanipulator. It was installed in the facility in mid-FY 1983, has been extensively used in test programs, and has proven to be a very effective remote handling device. The M-2 was basically a proof-of-principle device, since it was not designed to be remotely maintained. Figure 2 shows most of the CFRP remote maintenance test area with the manipulator transport bridge, the M-2 servomanipulator, the Fuel Disassembly System, and the Shear System.

The second generation servomanipulator system, which services the remainder of the CFRP remote maintenance test area, is ORNL's ASM. It was developed with basically the same characteristics as the M-2 and incorporated advanced electronic hardware and an improved operator interface. A unique feature of the ASM slave is its modular construction to facilitate remote maintenance using a companion manipulator for its own repair by modular replacement. This system was put into operation in mid-FY 1986 and it too has proven to be an effective and reliable system. Figure 3 shows the ASM and the Equipment Rack.

Each of the servomanipulator systems is a dual-arm, bilateral, force-reflecting system with three television cameras (one camera mounted over each shoulder and one belly mounted), lighting, and an auxiliary hoist (500 and 1000 lb, respectively, for the M-2 and ASM). Each M-2 slave arm

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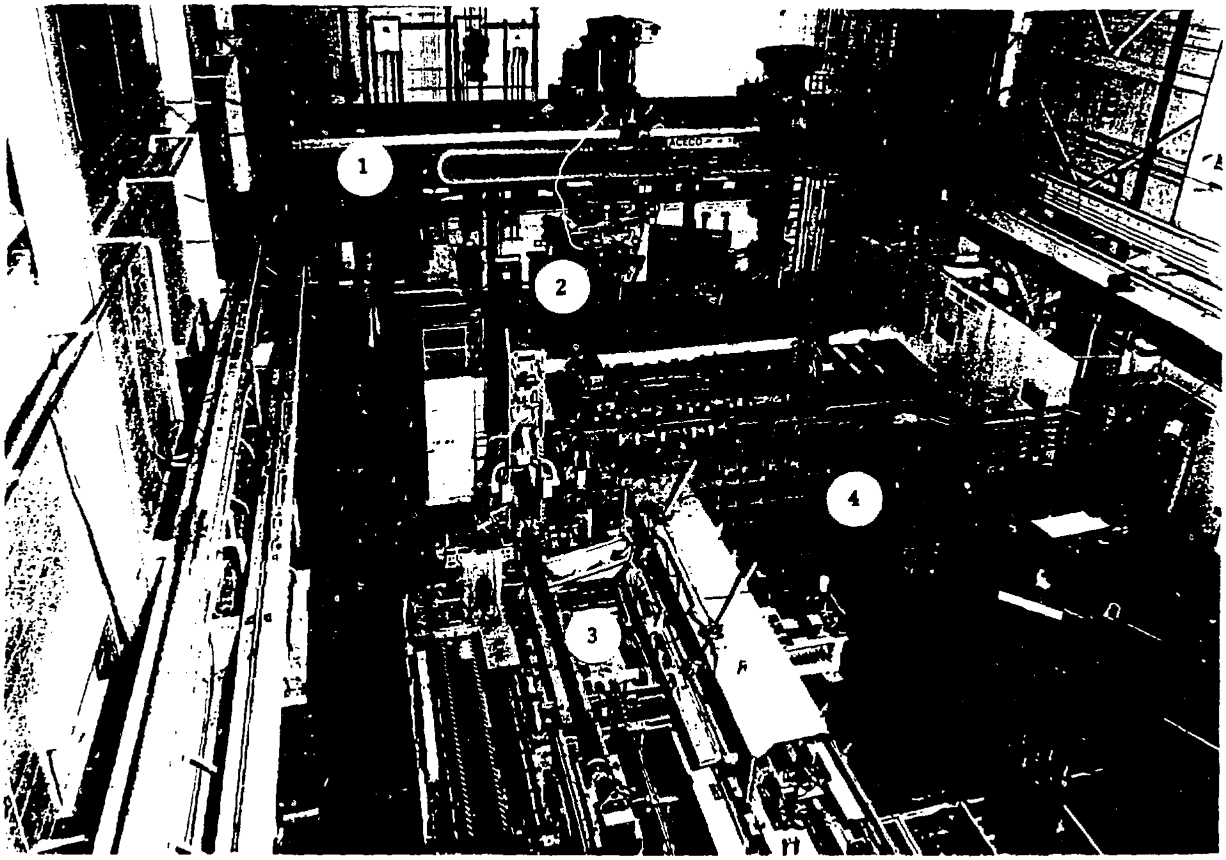

Fig. 2. Remote maintenance test area: (1) manipulator transport bridge, (2) M-2 servomanipulator, (3) Fuel Disassembly System, and (4) fuel shear system.

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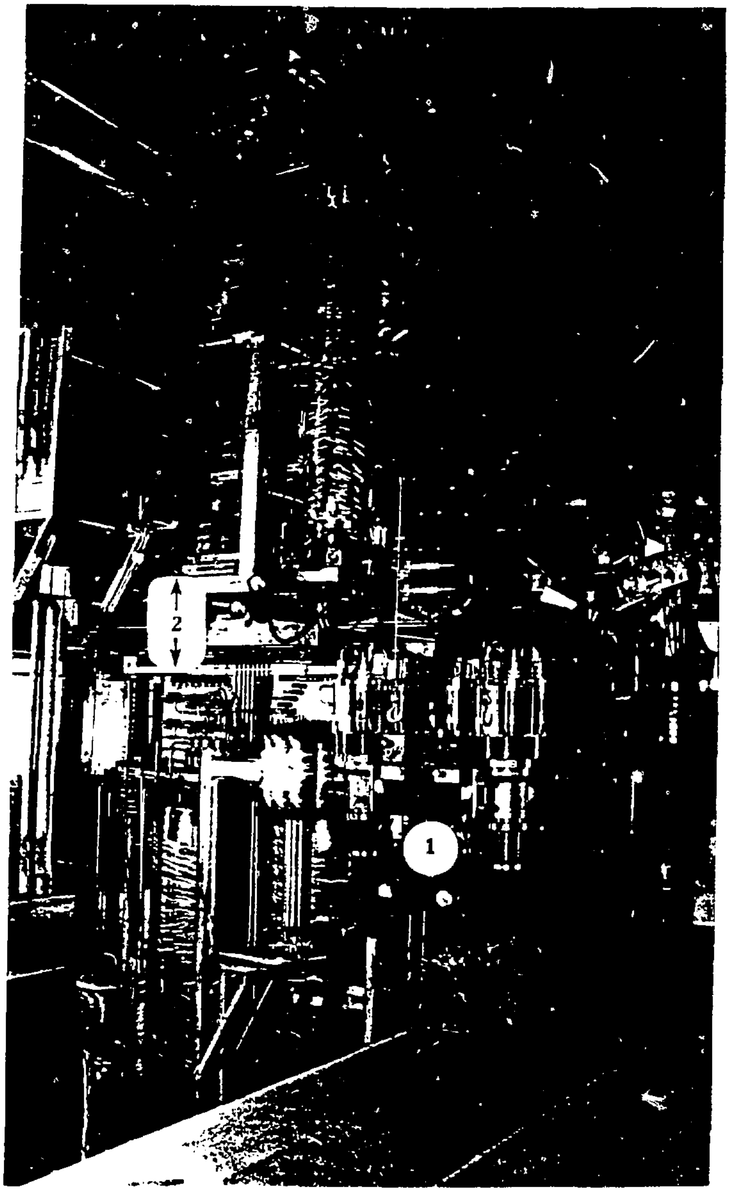

Fig. 3. The (1) advanced servomanipulator and (2) equipment rack.

has a peak capacity of 46 kg (100 lb) and each ASM slave arm has a peak capacity of 23 kg (50 lb). Each of these systems has been thoroughly described in previous papers;[1,2] therefore, further description will be omitted here.

PROCESS EQUIPMENT MODULARITY AND MAINTENANCE TIME SUMMARY

Prototypical examples of each of the equipment items identified in the typical process cell were fabricated, installed, and tested in the CFRP cold mock-up remote maintenance test area. Inherent in the total remote maintenance concept, all in-cell equipment designs were based on modular construction with capability for remote replacement of failed components. The equipment was specifically designed to interface with the manipulators and remote maintenance tools.

The M-2 servomanipulator was utilized for the Shear, the Disassembly, and the ASM maintenance demonstrations. ASM was used for the Equipment Rack, the Dissolver, and the Sampler maintenance demonstrations. Table 1 provides a top-level summary of the average times associated with the remote maintenance activities of each equipment item. It indicates the number of modules incorporated into the design of each system, as well as a breakdown of the modules' sizes by weight. Five weight categories were identified, with the largest being greater than 1000 lb and the smallest being less than 50 lb. Average disassembly and reassembly times are listed for each module weight category for each system. This table provides a rough-order-of-magnitude estimate of the total number of modules to be maintained in a typical process cell.

The systems tested had between 7 and 44 modules each. When considering that 10 to 15 equipment racks would be present in a typical cell (the rack tested was intended to represent a generic rack with examples of many types of modules), it becomes obvious that the vast majority of maintenance activities, strictly derived from the number of modules, will be associated with the racks. It is estimated that between 500 and 800 modules would be mounted on the racks. It might also be noted that the majority of the modules are less than 50 lb and very few are greater than 1000 lb. The average time for disassembly and reassembly for modules less than 50 lb was approximately 30 min, while times for the remainder of the modules ranged approximately from 1 to 3 h.

Table 1. Prototype equipment modularity and maintenance time summary

Heading	No. modules >1000 lb	Times[a] (h/min)	No. modules 1000-500 lb	Times (h/min)	No. modules 500-100 lb	Times (h/min)	No. modules 100-50 lb	Times (h/min)	No. modules <50 lb	Times (h/min)	Total modules
Disassembly system	4	0:32 / 0:48	4	0:36 / 0:42	8	0:19 / 0:24	7	0:28 / 0:30	12	0:05 / 0:09	35
Shear system	7	1:05 / 1:40	3	0:59 / 1:12	7	0:51 / 1:04	1	0:51 / 0:41	7	0:15 / 0:24	25
Dissolver system	3	0:30 / 0:46	0	—	2	0:16 / 0:36	0	—	2	0:05 / 0:08	7
Automated sampler system	1	0:34 / 0:37	0	—	2	0:31 / 0:37	4	0:24 / 0:34	7	0:16 / 0:17	14
Equipment rack[b]	2	0:46 / 0:42	1	1:00 / 2:14	5	0:52 / 1:11	2	0:29 / 1:17	34	0:14 / 0:32	44[c]
Advanced servomanipulator	0	—	0	—	0	—	0	—	28	0:16 / 0:14	28
Total	17		8		24		14		90		153

[a]Times are for disassembly/reassembly, rounded to nearest minute.

[b]The equipment rack tested contained a mix of representative equipment items. Actual racks in a facility will contain more or less modules than the numbers shown.

[c]For multiple equipment racks in a typical processing cell it is estimated that 500 to 800 modules will be required, bringing the total modules in the cell to 600 to 900.

The information provided is a top-level general summary of process equipment modularity and maintenance times, which might be useful in time/motion studies or reliability investigations. The following section is intended to provide an overview from the operators' perspective of the primary considerations that make up a good remote design.

REMOTE MAINTENANCE "LESSONS LEARNED"

In conducting the extensive remote maintenance demonstrations previously described, several factors have been identified from an operational standpoint that, if given the proper attention by equipment designers, will almost invariably lead to a successful operation. These factors can be grouped generally into three basic areas: (1) viewability, (2) accessibility, and (3) replaceability. Each of these areas are briefly discussed as follows:

Viewability -- Modules should be designed to ensure adequate viewing. Probably the most common complaint expressed by operators during the remote maintenance demonstrations was the inability to see the specific view desired. The cell designers should first attempt to design modules so that the operation to be preformed can be readily seen with the camera systems available; then, they should consider the use of small portable cameras which can be positioned independent of the maintenance system. Although viewing is seldom optimal, a more flexible choice of camera viewing positions could significantly improve the maintenance system's capabilities and efficiency.

Accessibility -- Modules should be designed to be reached, disconnected, and handled by available maintenance equipment. The second most common complaint expressed by operators was having an obstruction in the required operating envelope of the manipulator system. A clear path of sufficient size to bring the manipulator into the work space from a direction accessible to the system is a necessity. A good example of this not providing a clear path for the manipulator was seen in the Dissolver maintenance demonstration. Two guides were installed to provide for precise positioning of a large drive motor and the guides worked very well for positioning of the motor, but became obstructions for another remote operation to be performed. There is a significant difference in the accessibility requirements for equipment to be repaired by a servomanipulator and by humans. Considerably more space must be provided for the servomanipulator/camera envelope. If the overhead crane or auxiliary hoist is required for lifting, the area above the module must be clear as well. Several of the modules on the Equipment Rack had sufficient room for the ASM slave arms to perform the disconnect operation but adequate vertical clearance was not provided to use the hoist for a lift.

Replaceability -- Equipment to be maintained should be designed in replaceable modules. Most of the attention from the remote designer is typically given to this area and, in general, is well done. Much experience exists in this area and it is well documented. Standard design solutions, therefore, should be used whenever possible. Modules should be designed to be remotely maintained and the designer should consider the capabilities of the maintenance equipment available. Special tools, jigs, and fixtures should be avoided, if at all possible. A common mistake made by experienced equipment designers is in not considering the number of tools required by the remote operator to perform a particular operation. Most of the equipment items tested, for example, had twice as many bolt head sizes than required. Much of the time spent in actual hot-cell applications is for setup and tool changeout. Having to return one tool and retrieve another for a small change in bolt head size is a common but time-consuming problem.

Even though a designer considers each of these factors, a perfect design is not ensured. All of the equipment tested were designed by personnel knowledgeable of remote maintenance operations. Excellent designs resulted and essentially all of the operations were successfully completed; however, it should be noted that almost invariably something unexpected occurred during some phase of the testing with each equipment item which justified the time and effort associated with the mock-up testing.

CONCLUSIONS

CFRP has pioneered and developed the concept of totally remote operation and maintenance of process equipment in spent fuel reprocessing, utilizing the dexterity of force-reflecting servomanipulators coupled with television viewing and an overhead gantry crane system to enhance mobility. As a result of the remote maintenance demonstrations completed with hardware representative of essentially every major equipment item included in most fuel reprocessing plant conceptual designs, the practicality and viability of the concept has been demonstrated. The experience gained as a result of these demonstrations has been summarized and organized into a design guideline entitled, "Design Guidelines for Remotely Maintained

Equipment,"[4] that suggests a general approach to the design of effective, reliable, and safe remotely operated and maintained facilities. If utilized by future equipment designers, the benefit of many years of remote maintenance experience and lessons learned will be gained and their chances for success will be greatly improved.

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