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ERA	☑	RIP	☐	DOE	☑		☐	1. 050800
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WDA	☐	CRF	☐	SNI	☐			3.
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AUGMENTATION:

SPLIT	DESCRIPTORS	FLAGS	
	Maintenance		
	remote handling		
	Control rooms	T1	Q2
	Consolidated Fuel Reprocessing Program		
	Design		01
	remote handling equipment		
	man-machine systems		
	Fuel reprocessing plants	T2	

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Consolidated Fuel Reprocessing Program

A CONTROL ROOM CONCEPT FOR REMOTE MAINTENANCE IN HIGH RADIATION AREAS*

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ABSTRACT

This paper summarizes the design of a control room concept for an operator interface with remote maintenance equipment consisting of force-reflecting manipulators, tools, hoists, cranes, cameras, and lights. The design development involved two major activities. First, detailed requirements were defined for foreseeable functions that will be performed by the control room operators. Second, concepts were developed, tested, and refined to meet these requirements. Each of these activities is summarized below. 6 ref., 3 fig.

1. Definition of Requirements

A clear statement of the mission to be performed in the control room was generated. The mission description included lists of all areas where operators would interact with remote equipment (e.g., controlling remote cameras or cranes), a detailed task analysis, and consideration of the probable characteristics of the operators themselves (e.g., anthropometry). Next, literature reviews, visits to other facilities engaged in similar work, a survey of experts in the field, and in-house remote handling

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experience were used as the bases for determining that a two-person team would be the most efficient crew size. Consideration of operator work load capabilities and of the sequence in which tasks would be performed led to an allocation of function between persons: one person would handle manipulator functions; the other would be responsible for cameras, lights, remote sound, tools, and all other nonmanipulative needs.

2. Development of a Design Concept

Several different concepts were evaluated from which a single solution was synthesized into an efficient and aesthetically pleasing design. The solution incorporates two persons at separate control areas, close enough to communicate directly. Maximum use was made of advanced display and control techniques — for example, integrated graphics, voice input and output, and touch- and cursor-controlled menus with minimum reliance on discrete controls. A full-scale lightweight mock-up of the most important elements in the concept was then constructed.

A series of walkthrough experiments, using volunteer subjects to perform simulated tasks, verified that the design objectives were attained. Some minor modifications were needed. The height and viewing angles of several monitors were adjusted for better visibility, and the writing/conference area was enlarged for improved operator comfort and efficiency. Detailed plans for the hardware implementation of the concept are now proceeding.

1. INTRODUCTION

Conceptual designs for future nuclear reprocessing facilities require large, canyon-like process cells where high radiation levels preclude any human entry for repair or maintenance. The Remote Control Engineering (RCE) Task at the Oak Ridge National Laboratory (ORNL) is developing advanced remote system technology to totally replace the human presence in these remote process cells. The Advanced Integrated Maintenance System (AIMS) consisting of advanced elbows-down, electronic, force-reflecting servomanipulators with remote viewing, sound, tooling, and transporter capabilities will be capable of performing all necessary remote repair and maintenance tasks. Consequently, the design of the AIMS control room has been an important aspect of the RCE activity since it is here that the human operator will interface with the remote equipment. The specific design goal has been to provide a safe, efficient interaction between the operator and all AIMS equipment. This paper describes the five-stage method used in the development of this design: mission description, design requirements, preliminary design solution, construction, and verification of the mock-up, and refinement of the design solution.

2. MISSION DESCRIPTION

The authors' goal was to generate a clear account of tasks that would be done in the control room, the information and outputs operators would need to do these tasks, the characteristics of the operators themselves, and the characteristics of the environment in which the tasks would be performed.

Typical remote small-volume maintenance tasks (e.g., removing a bolt from a metal plate) and typical large-volume tasks (e.g., unbolting and transporting a large flange) were constructed in a simulated remote environment. Manipulator operators then performed the tasks under a series of experimental conditions, providing the means to generate concise statements about the information and controls the operator would need in a hot facility control room.[1,2]

Details of television displays the operators would need from the remote cell were stated (e.g., views from the three cameras on-board the manipulator; from fixed, wall cameras; and from a small, portable camera held by the slave arm of the remote manipulator). Details of necessary alphanumeric/graphic and hard-copy displays were also stated. For example, operators would need information about the slave's position in space, condition of its motors, and schematics of the equipment on which it would be working. Remote sound information from the process cell, as well as audio alarms and signals, were also considered.

Next, a list of all the control functions the operators would need to perform the specified tasks was generated. First, all controls for remote equipment were considered: controls for cameras, lights,[3] tools, transporter, and crane. Second, the controls necessary to present this information to the operators were considered: monitor controls, video switching, mixing, interaction with computer-generated graphic displays, controls for remote sound, and emergency responses.

Since the control room must conform to the people who work there, a list of personnel characteristics that would have to be accommodated was generated. The list included operator reach and viewing envelopes for 5th percentile female to 95th percentile male,[4] normal visual acuity, and normal color vision.

All other accessories and equipment needed in the control room (e.g, electronic racks, printers, storage for nonelectronic documents) were listed. Information was also obtained on the probable size and shape of the room, and the location of doorways and ducts. Finally, experience suggests that the operators be close enough to communicate efficiently by direct speech rather than by telephone or other nondirect means and that each operator be able to see the other easily and without obstruction.

3. DESIGN REQUIREMENTS

The next stage in the design involved developing specific design requirements. The material generated in the mission description played an important part in requirement development; however, other inputs were also used. The authors became familiar, through literature surveys and on site visits, with other facilities engaged in similar work and the kinds of design solutions they have employed.[5] Next, two separate surveys of experts were conducted. Eleven experts in remote handling in nuclear and other hazardous environments (NASA, U.S. Navy, Los Alamos National Laboratory, etc.) were surveyed as to the kind of remote tasks they performed, how many operators made up a typical crew, the function of each member, typical errors, and recovery from errors. Fourteen experts in remote systems at

ORNL were presented with typical task scenarios and were asked what size crew should do the task and which operator should use each control or display. Data were then collected at the Remote Systems Development Facility giving valuable information on the frequency and sequence in which operators used various controls and displays, and on the effect of decreased crew size on task performance time.

Finally, analysis of the mission description, and of the information described above were then used to develop general design requirements which are summarized below.

Operator-Related Requirements

Two-person team: A manipulator operator (MANOP) will control all manipulator functions; a secondary operator or camera operator (CAMOP) will control lights, tooling, transporter, cranes, and all other functions necessary to support the MANOP.

Proximity of operators: Operators must be physically close enough to communicate by direct speech and have a clear view of each other without obstructing each other's views. All MANOP television monitor information must be duplicated on the CAMOP displays.

Anthropometric range: The design must accommodate the anthropometric characteristics of the anticipated wide range of the work force population (5th percentile female through 95th percentile male) with normal viewing and hearing.

Equipment/Architecture-Related Requirements

Aesthetics: The control station must provide a pleasant, nonstressful work environment for long maintenance tasks. A pleasing design also reinforces the operators' perception of the tasks' importance as well as the operators' self-image.

Positioning: All MANOP displays and controls must be out of reach of the maximum extension of the master to prevent interference.

Use of controls/displays: Advanced integrated controls/displays (i.e., touch or voice-actuated units, graphics displays, etc.) should be utilized to the maximum extent. Reliance on discrete dedicated controls should be minimized to avoid clutter and potential confusion and to permit easier configuration in dedicated controls.

Modularity: The use of modular units will allow easy repair or input of new technology.

Flexibility: One operator must be able to perform all functions when tasks are easy or when circumstances mandate this approach (e.g., emergencies).

4. PRELIMINARY DESIGN SOLUTION

Several different concepts were devised and evaluated, and then synthesized into a single efficient aesthetically pleasing design,[6] which incorporates several advanced state-of-the-art features in original ways (Fig. 1). First, MANOP selects major manipulative functions by voice or from menu displays. Because the menu displays are located out of range of any interference from the manipulator master arms they are also out of MANOP's reach and cannot be touch controlled. They are activated instead by a small switch on the master controller handle which moves a light cursor over the menu to select necessary item. Second, CAMOP controls remote equipment (cameras, lights, cranes, etc.) through two small integrated hand controllers, similar to that shown in Fig. 2, to which CAMOP will assign functions by touch screen or voice. The controllers can

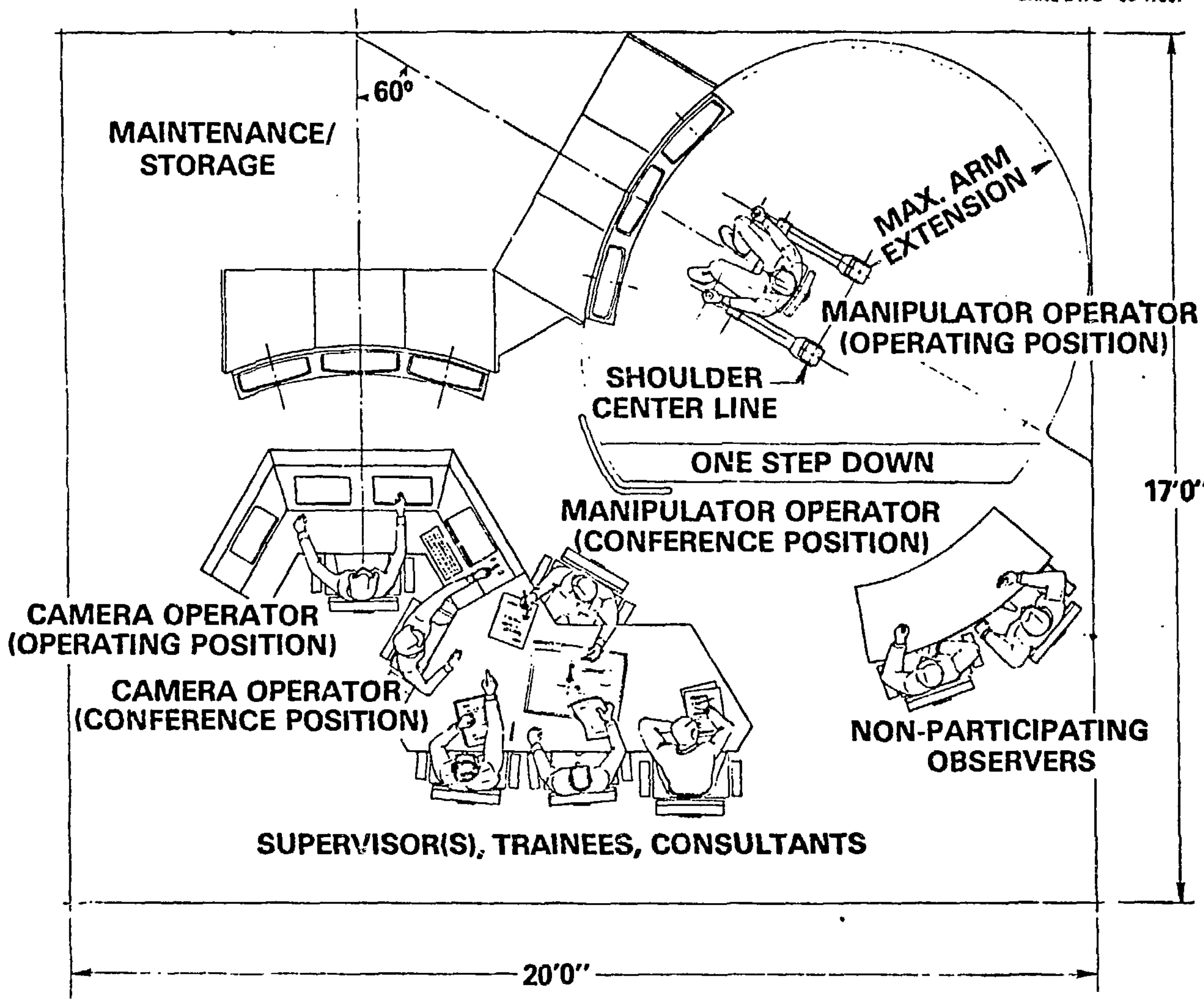

Fig. 1. Control room design

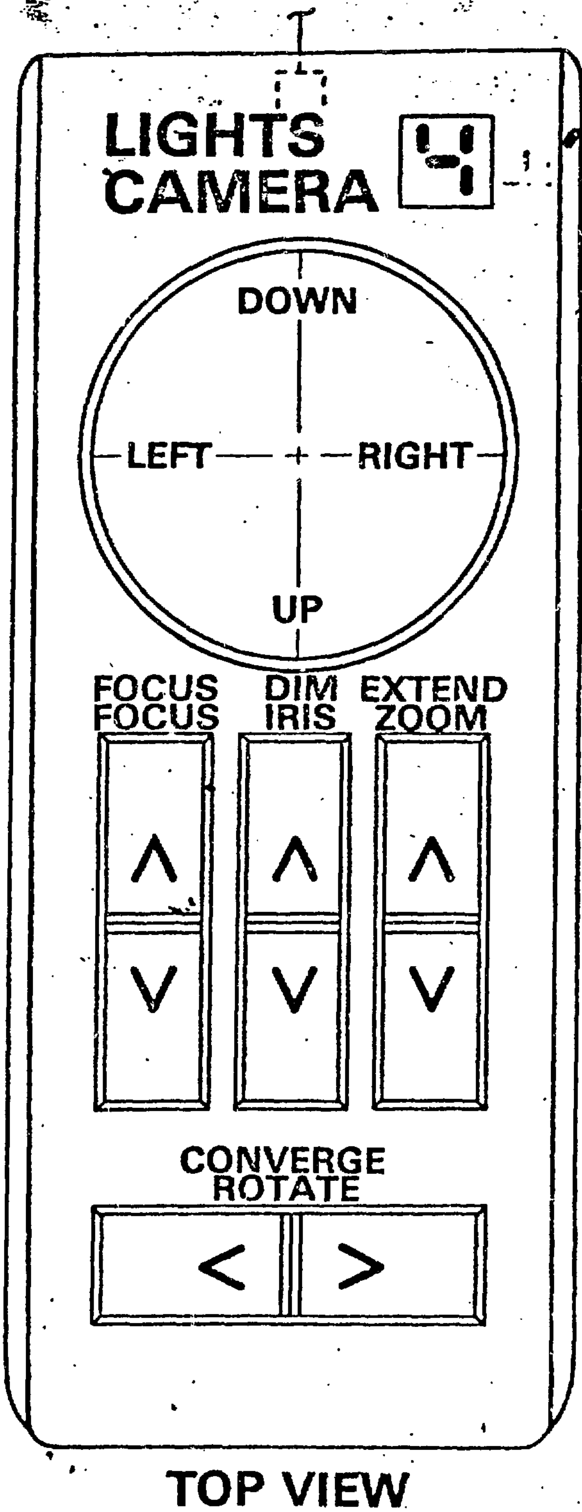

Fig. 2 Hand controller

also be operated from the MANOP station, allowing the whole task to be under one person's control if necessary. Third, the design relies on advanced graphic displays for both control menus and information display. Fourth, all dimensions, viewing angles, and reach envelopes have been selected to accommodate the body size and strength of the expected operator population.

5. CONSTRUCTION AND VERIFICATION OF MOCK-UP

In order to evaluate the spatial relationships between the operators and their controls and displays, the authors built a full-scale soft model of the CAMOP station and MANOP displays. Photographs of the task or of alphanumeric or graphic displays simulated dynamic visual information. Fourteen volunteer subjects (staff at ORNL), ranging in height from 4 ft 11 in. (5th percentile female) to 6 ft 4 in. (99th percentile male), performed simulated tasks using the information on the various "screens" and on the simulated hand controller. Subjects' ease or difficulty in seeing and reaching all required equipment was noted and subjects were also asked to complete a questionnaire about their general impression of the design. The two worst case subjects (4 ft 11 in. and 6 ft 4 in.) were more intensively evaluated as regards any difficulty in using a real facility. Based on the data collected during the evaluation, the height and angulation of several monitors were adjusted for better visibility and the writing/conference area was refined for improved comfort and efficiency. In addition, further analysis of lines of sight from CAMOP to MANOP suggested that the step down to the MANOP work area was unnecessary; it was removed. The initial solution (Fig. 1) was modified to incorporate the improvements suggested by the mock-up. The modified design is shown in Fig. 3. Now that these modifications are in place, detailed plans for hardware fabrication are proceeding.

6. SUMMARY

The control room represents a significant departure, technologically and architecturally, from others and is based on sound human engineering and industrial design principles. Essential to the development were task analyses and realtime studies, solicitation of expert operators to participate at various points in the design process and verification of the mock-up to ensure that the design fits the expected operator population. The end result is a design which is not only technically advanced, but also a safe, productive, nonfatiguing, and aesthetically pleasing work environment.

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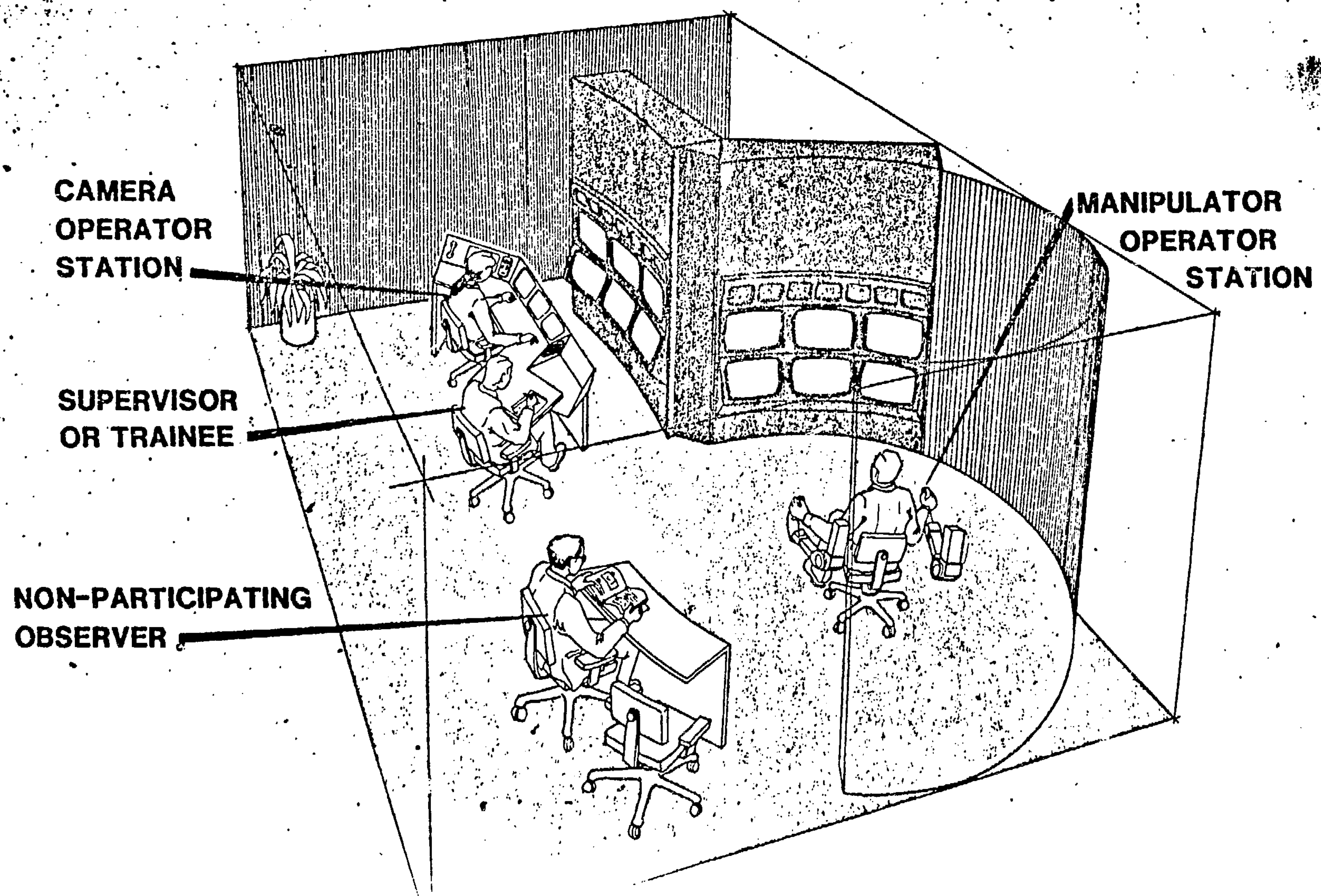
Fig. 3

CONTROL STATION FOR ADVANCED INTEGRATED MAINTENANCE SYSTEM: FINAL CONCEPT



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