CONF-880202--1

Consolidated Fuel Reprocessing Program

DESIGN OF A MULTISYSTEM REMOTE MAINTENANCE CONTROL ROOM

J. V. Draper*
S. J. Handel*
C. T. Kring

CONF-880202--1

DE88 005067

Fuel Recycle Division
Oak Ridge National Laboratory†
Oak Ridge, Tennessee 37831
and
S. Kawatsuma
Power Reactor and Nuclear Fuel Development Corporation
Tokyo, Japan

Paper to be presented
at the

International Atomic Energy Agency
International Conference on
Man-Machine Interface in the Nuclear Industry
Tokyo, Japan

February 15-19, 1988

*Under subcontract with Human Machine Interfaces, Inc., Knoxville, Tennessee.

†Operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy, under contract No. DE-AC05-84OR21400.

IAEA-CN-49/71P

Consolidated Fuel Reprocessing Program

DESIGN OF A MULTISYSTEM REMOTE MAINTENANCE CONTROL ROOM*

J. V. Draper
S. J. Handel
C. T. Kring
Fuel Recycle Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

and

S. Kawatsuma
Power Reactor and Nuclear Fuel Development Corporation
Tokyo, Japan

ABSTRACT

The Remote Systems Development Section of the Consolidated Fuel Reprocessing Program at the Oak Ridge National Laboratory (ORNL) and Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC) recently collaborated in the development of a control room concept for remote operations. This report describes design methods and the resulting control room concept. The design project included five stages. The first was compilation of a complete function list; functions are tasks performed by operators in the control room while operating equipment located in the remote area. The second step was organization of the function list into "function groups;" function groups are sets of functions that operate one piece of equipment. The third stage was determination of crew size and requirements for supervision. The fourth stage was development of conceptual designs of displays and controls. The fifth stage was development of plans for placement of crew stations within the control room.

---

*Research sponsored by the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan under U.S. Department of Energy Project No. ERD-86-600.

INTRODUCTION

The human-machine interface has a profound effect on system performance, especially for remotely controlled systems. Remote manipulation requires information from an array of remote sources and requires skilled responses from operators. For optimal remote system performance, displays and controls must match the capabilities and avoid the limitations of human operators.

The PNC is planning a plant for vitrifying liquid, radioactive waste. It will be necessary to repair and maintain the plant by remote control. PNC and ORNL's Remote Systems Development Section recently collaborated in developing a control room concept for vitrification plant remote maintenance systems.

METHODS

The design process included five stages: (1) function list development; (2) function organization; (3) crew requirements determination and function allocation; (4) conceptual design of control panels; and (5) panel integration into workstations, workstations into teams, and teams into control room layout.

The first stage was identification of the equipment operated from the control room and functions necessary for control of the equipment. The second was organization of functions into function groups. A function group is a set of functions necessary to operate a piece of equipment. Each piece of equipment has at least one function group, but may have more. For example, manipulators have two function groups, one for routine remote handling functions and the other for setting manipulator operating parameters.

The third stage was crew size determination and function allocation. The control room concept features two-person work teams. Information provided by function group organization, probable course of work flow, and operational experience at ORNL indicated that this was the best arrangement. Each team includes an operator responsible for manipulation and transporter movement and a support operator responsible for crane motion and television control. The support operator can also do secondary manipulator functions and control the transporter. The control room will include three two-person teams, one single-person workstation (crane functions only), and a supervisor.

The fourth stage was function group assignment to control panels and panel conceptual design. Panels integrate similar functions and segregate dissimilar functions. For example, cranes and transporters have similar control requirements; a single panel includes controls for both. Television control is different, requiring a separate panel. Each function was given an input device and panel location based on the type of function (continuous or discrete), frequency of use, importance to safety, and ergonomic guidelines.

The fifth stage was integration of workstations into team stations and team stations into a control room layout plan. Workstation integration emphasized communication between team members. Team station integration emphasized communication between the supervisor and support operators.

CONTROL ROOM LAYOUT

The control room layout is the arrangement of workstations within the control room. Several issues were important to developing the layout of workstations, including interoperator communication, movement of personnel within the control room, and access to the control room. Figure 1 is a layout plan for the control room.

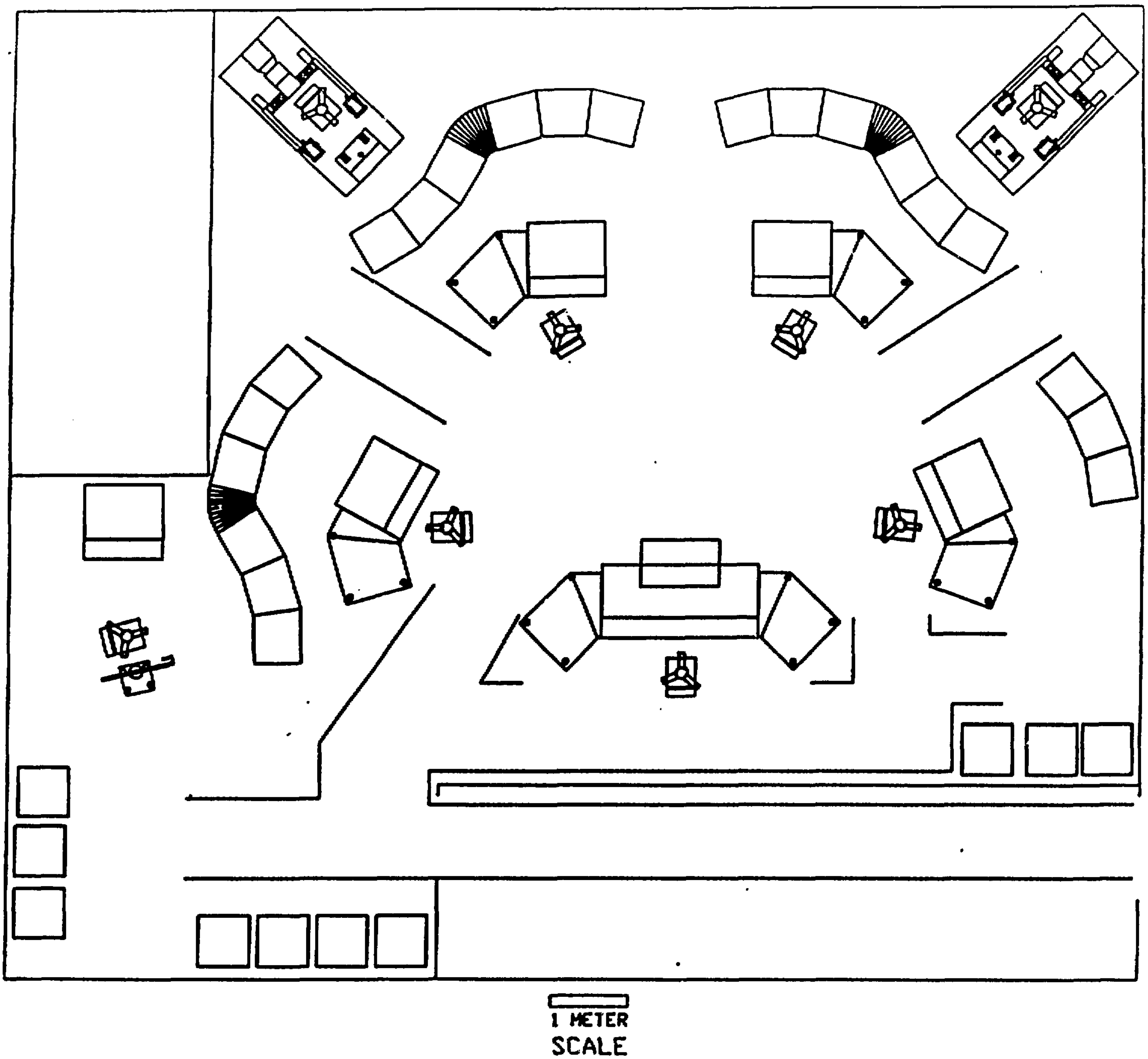

Fig. 1. Plan view of control room concept.

Maintenance team placement allows communication between supervisor and support operators, communication between support operators of teams that might work together, and supervisor observation of teams.

Team stations include two workstations with the operators facing one another. This orientation facilitates teamwork and provides a direct line of sight between the two operators while in the primary working positions. The centerlines of the workstations are offset at a 45° angle, which allow the support operator to make eye contact with the manipulator operator across the manipulator operator's television console. Figure 2 shows the positions of the primary and support operators.

The supervisor's console is in the middle of the control room, which allows visibility of all support operator consoles.

WORKSTATION CONCEPTUAL DESIGNS

DESIGN CONSIDERATIONS

Viewing angles and anthropometry are the key issues in workstation design. Viewing angle is the displacement in line of sight (LOS) of an operator looking at an object, measured from his normal LOS. The normal LOS is straight ahead and 15° below horizontal. Viewing angle is important for control room design because it affects display/control ease of use. Objects away from an operator's normal LOS are more difficult to see and use than objects on the normal LOS.

The three Display Areas around an operator are the Preferred, Acceptable, and Unacceptable Display Areas. The Preferred Display Area is the 30° cone centered on the normal LOS. Within this area, the operator can scan displays by moving only his eyes, not his head. The Acceptable Display Area is the area outside of the

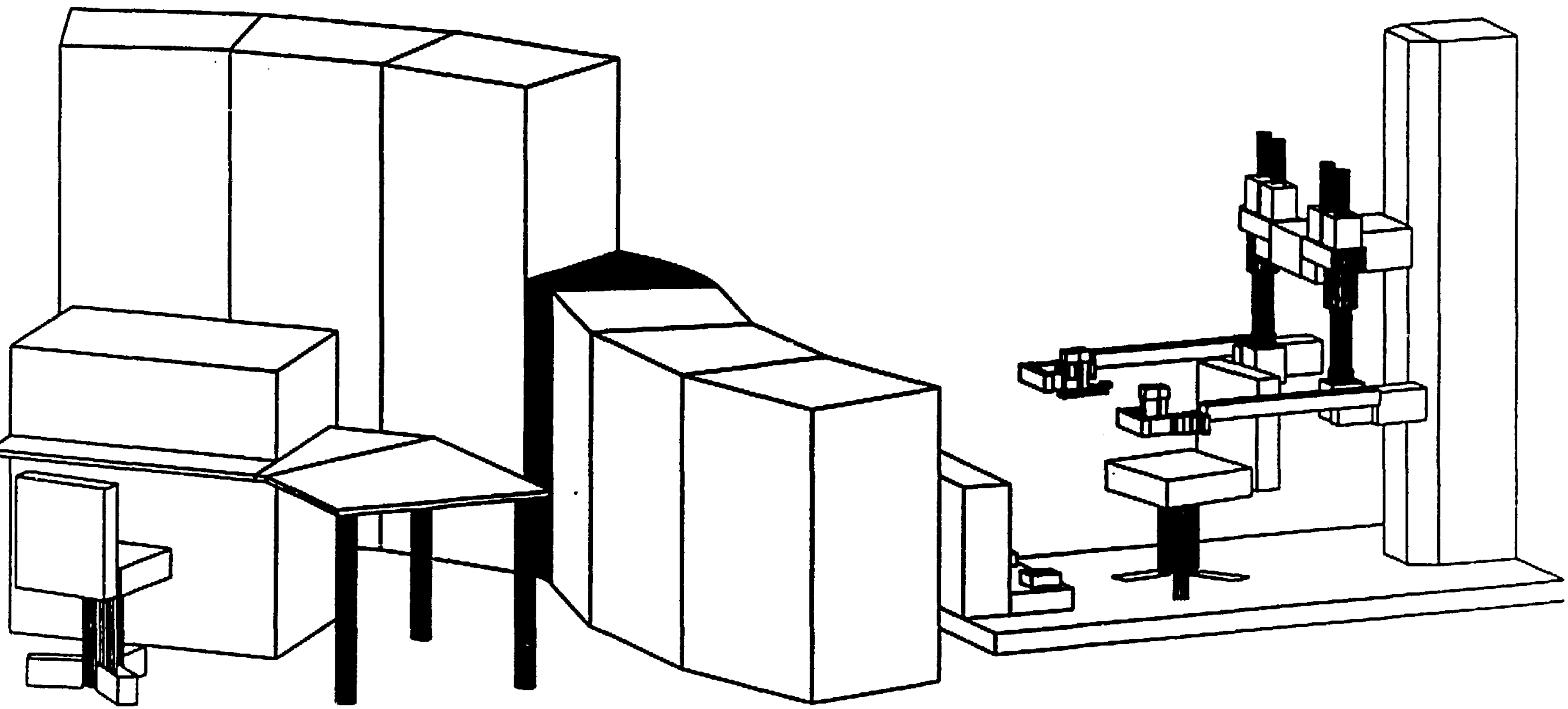

Fig. 2. Manipulator and support operator stations.

preferred zone but within 30° of the normal LOS horizontally, 65° above the normal LOS, and 35° below the normal LOS. The operator can scan displays in this area with head movement. Displays should not occupy places outside the Acceptable Display Area, if possible.

Control placement within Preferred and Acceptable Display Areas should depend on frequency of use and importance. Critical and frequently used controls and displays should be directly on the operator's normal LOS; less important controls/displays may occupy areas not directly on the normal LOS but within the Preferred Display Area; the least important controls may be farther from the LOS.

Anthropometry deals with human physical dimensions. A control room must match the size of the persons who will operate it. Control rooms should fit a range of people. Many designers use the range from the size of the 5th percentile female to the size of the 95th percentile male. It is important to design for a range rather than for one size (for example, the 50th percentile or average) so that the control room provides the best fit for the most people.

The most important measurements define the location of an operator's eyes, reach envelope, and the space required for legs when seated. PNC provided detailed measurements of the likely population of Japanese operators. Table 1 lists the important measurements for 5th and 95th percentile Japanese.

Table 1. Operator dimensions

Item	Length (cm) 5%	Length (cm) 95%
Eye height (from seat)	73.9	84.7
Seat height	36.9	43.0
Total eye height	110.8	127.7
Body depth	19.5	24.7
Thigh length (from dorsal surface)	51.4	60.2
Thigh length (from ventral surface)	31.9	35.5
Maximum reach (arm only)	75.8	87.7

Operator dimensions helped define a console profile, the configuration and dimensions of a section through the consoles at the support operator, and supervisor stations. There were three principal profile design considerations: the console must provide an ergonomically acceptable control/display mounting surface, allow comfortable use, and allow vision over its top.

WORKSTATIONS

The manipulator operator's most important displays are remote television views, and the most important controls are the manipulator master controllers. Graphic displays are secondary. The manipulator operator receives remote views from seven television monitors mounted in the monitor console. The console contains two rows of monitors. The top row has three large televisions for remote camera views. These will display views from the left-hand camera on the manipulator package, the chest-mounted camera, and the right-hand camera. The bottom row of monitors includes four small television monitors, two under the right and left large televisions. A large monitor in the middle of the row is for graphics menu screens. The manipulator master controller handle will provide cursor control. Transporter controls at this station are foot switches on a panel in front of the operator. These provide motion control (X, Y, and Z, and manipulator rotation around the transporter mast).

The Support Operator Station includes three panels: a crane, transporter control panel, a camera control panel, and a data entry panel. Figure 3 shows a layout concept for the support operator consoles. The most important is crane/transporter control. Camera control is secondary, and data entry/retrieval is tertiary. The Primary Panel features a single set of controls which allow switching among crane control, transporter control, and hoist control. The central element of the Primary Panel is a cathode ray tube (CRT) touch-screen display/control. This unit is for display of an

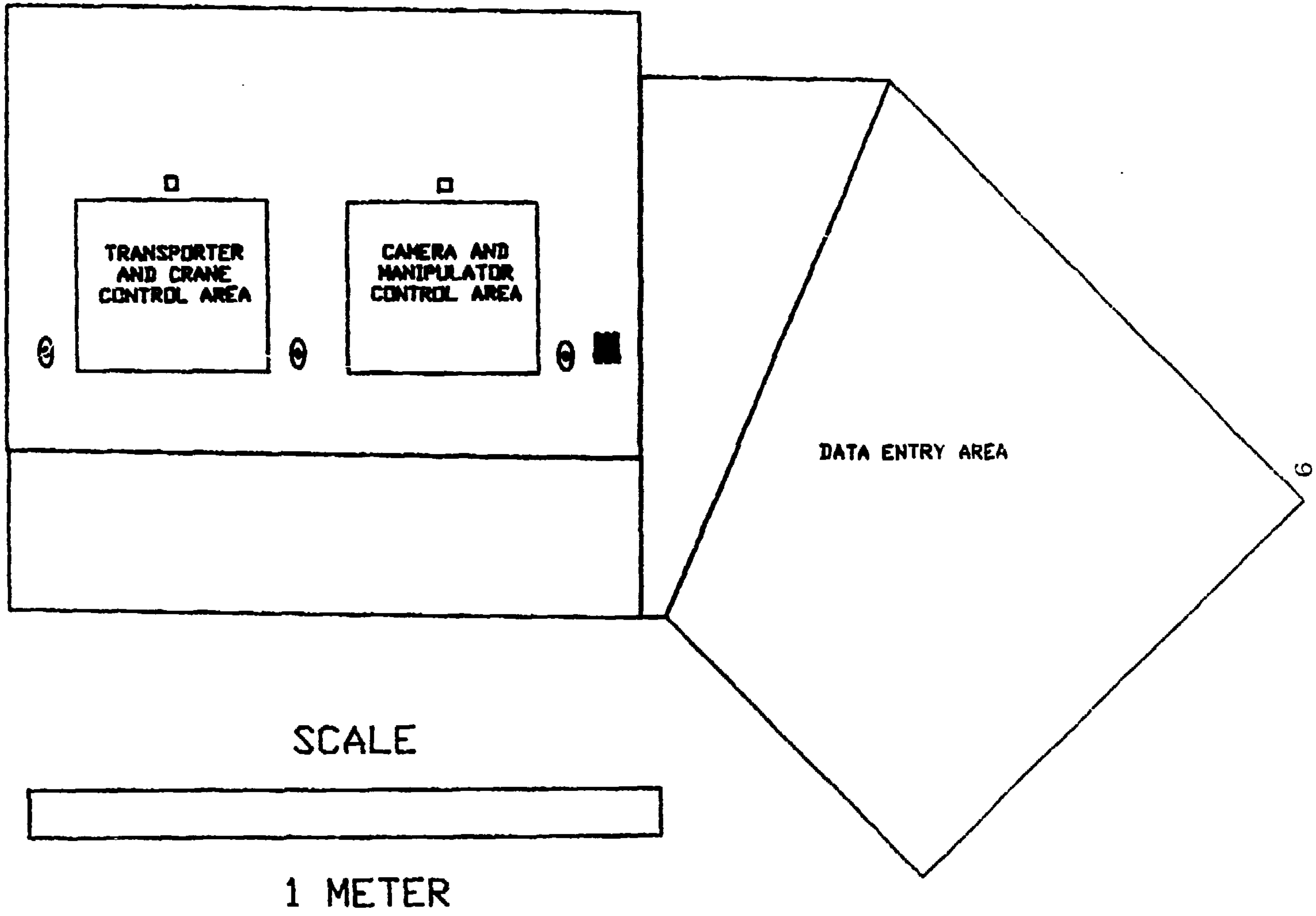

Fig. 3. Support operator's console.

animated, real-time cell map. It will also allow menu selections and message display. Aircraft-style joysticks provide control over X, Y, Z, and crane, transporter, and hoist rotation. A joystick located to the left of the display controls elevation and triggers control speed.

The secondary panel provides manipulator and television control. Its central feature is a CRT touch-screen. A menu system will provide control of secondary manipulator functions and some television control functions. A control cluster to the right of the CRT provides television camera pan, tilt, iris, zoom, and focus. Camera assignment to controls is done through the touch-screen menu. The joystick provides control of pan and tilt. A trio of slide switches to the right of the joystick control iris, zoom, and focus. A two-position switch above the slide switches turns off and on lights associated with the controlled camera.

The Support Operator's Television Display Console is similar to the manipulator operator's. The console includes a row of three large monitors at the top of a 1.75-m rack and six small monitors in a row beneath the first row. The Support Operator's Television Display Console attaches to the Manipulator Operator's Television Display Console at a 45° angle. The Support Operator is able to look over the Manipulator Operator's television console.

The supervisor's station is in the center of the control room. Figure 4 shows a conceptual design for the supervisor's console. The most important function of the supervisor is collision avoidance. Therefore, the primary panel at the supervisor station provides collision avoidance displays and controls. Secondary functions include the ability to control cranes, transporters, and cameras. The primary control-display panel at the supervisor's workstation consists of a full-cell map (a real-time animation showing the location of mobile equipment) and switches for cutting power to systems. The cell map display is a CRT screen located on

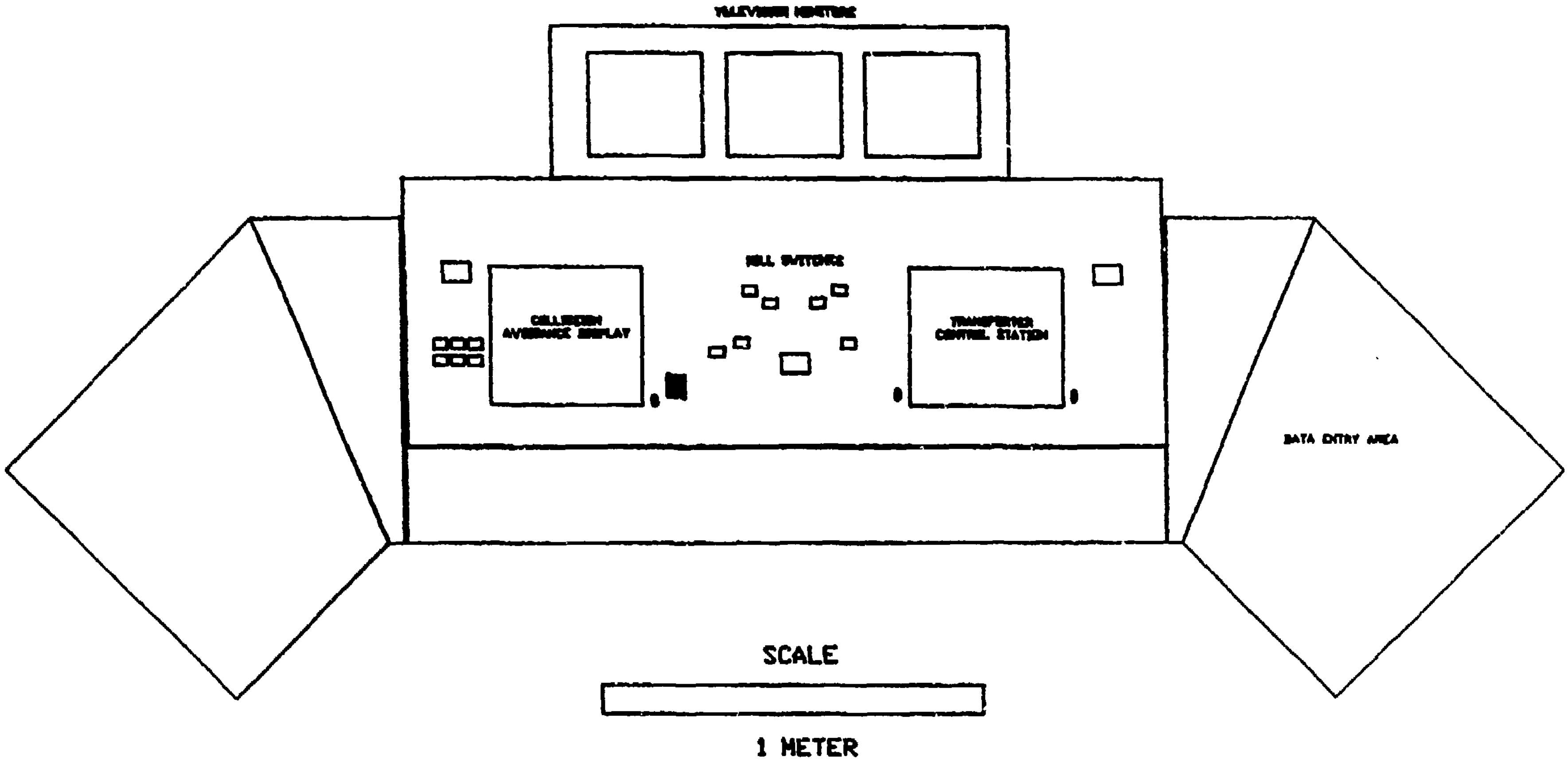

Fig. 4. Supervisor's console.

the right side of the supervisor's console. An array of emergency switches, one for each overhead bridge/trolley, occupies the center of the console. The switches occupy locations that reflect the location of the operator controlling them. Each kill switch is color coded accordingly. A large switch in the center of the array cuts power to all systems. The primary panel has joystick controls for the operation of cranes, transporters, and hoists. These are identical in operation to the support operator's crane controls.

The secondary panel at the supervisors console is a cell map used primarily for camera control. The secondary panel is similar to that at the crane operator's workstation with one exception. Under the graphics screen there are two rows of three touchpads. The top row is to request control to adjust the view of the camera displayed on one of the three TV monitors. The bottom row is to display a camera view on one of the three monitors. A joystick and slide switch bank identical to that found at the Support Operators' console is to the left of the CRT. The CRT will also serve as menu display. Three small television monitors for the supervisor/traffic controller occupy the top row of the console.

GRAPHICS INTERFACE

The graphics interfaces are high-resolution graphics monitors that use touch-screens for display and control. Each workstation has one or two graphics screens. Figure 5 shows the standard screen layout. The screen has one control graphics area, two status areas (warning and status), two control areas (interlock and cancel), and one menu area. The primary screen for the control area is an animated display.

The animated process cell display shows crane, manipulator, and transporter position. Icons represent the cranes, transporters, and all cameras mounted on the cranes and transporters. Additional icons represent fixed cameras mounted on cell walls. The display

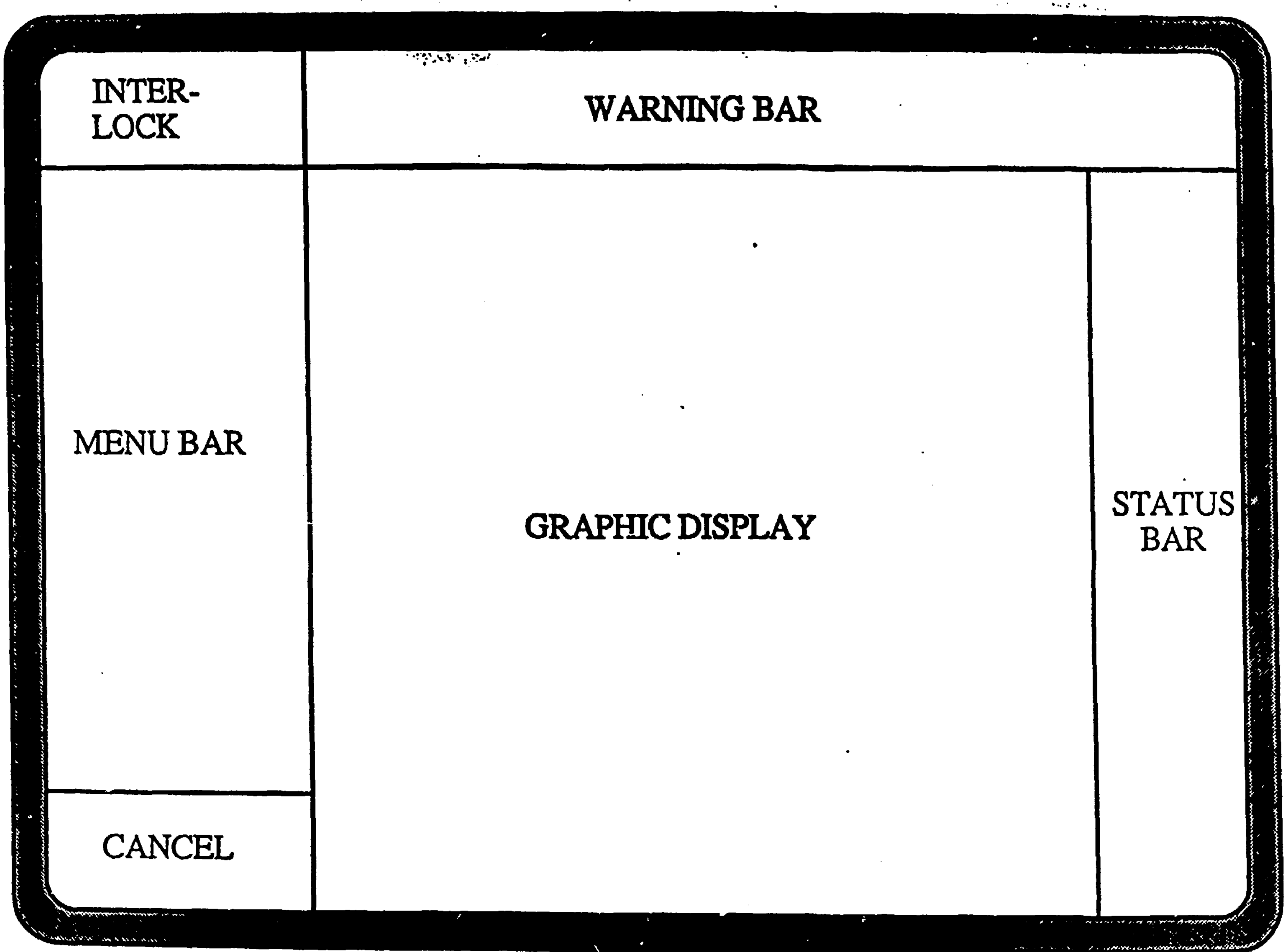

Fig. 5. Graphic screen arrangement.

must be real time with remote equipment position and movement accurately shown. There should be two levels of display. The first level shows the entire cell and all equipment. The second level shows only the area immediately around one piece of equipment. This is a "Local Cell Map" or a "Zone Map." The actual local cell map shown on the display would depend on the equipment's in-cell position.

The cell map serves two functions: first, to detect impending collisions between moving pieces of equipment (e.g., between a transporter and crane) or between a moving piece of equipment and a fixed obstacle. For this reason, as a transporter or crane approaches a fixed obstacle, that obstacle should appear as a cross on the screen. If there is danger of collision, there should be a visual and auditory alarm. Second, the cell map is for video switching. Each camera icon is a touchpad. Any operator can control a camera by touching the appropriate camera icon touchpad.

The graphics screens identify teams with color codes. Each team has a unique color. A crosshatch pattern identifies the supervisor. Crane, transporter, and camera animations display equipment in the controlling team's color. If equipment control switches teams, the animation color switches.

The warning bar alerts operators to danger. It displays potential dangers as muted (low contrast or faded) until activated. Then they brighten and blink, with a concurrent audio signal. PNC will select actual items in the warning bar. They may differ among the primary operator's, support operator's, and supervisor's screens. Warnings might include: (a) smoke in an area of the cell; (b) high temperature; (c) impending collision of a system in motion; (d) over-load of a crane, transporter, or manipulator; (e) end-of-travel in the crane, transporter, or manipulator motion ranges. If a warning occurs, the appropriate areas of the local or full-cell map in the central display should brighten and blink to specify the nature and location of the alert.

The function of the status bar is to signal the failure of a system component. The status bar displays each component in muted shades until a problem occurs, then it switches to bright and blinking.

The other areas on the screen are the interlock display/control, the cancel touchpad, and the menu area. The interlock display/control allows equipment control switching among workstations and prevents control conflicts. The cancel touchpad occupies the standard screen's lower left corner. It returns the menu bar to the previous menu. The Menu Area contains system menus and allows item selection by touch.

SUMMARY

The human-machine interface is an important component of remote handling systems. This paper described steps taken to design human-machine interfaces for a multisystem remote handling control room and describes a control room concept developed by PNC and ORNL. Key parts of the concept include the organization of functions into control panels, control and display concepts, the layout of workstations within the control room, and the software interfaces design.

DISCLAIMER