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Consolidated Fuel Reprocessing Program

HUMAN-MACHINE INTERFACES FOR TELEOPERATORS: AN OVERVIEW OF RESEARCH AND DEVELOPMENT AT THE OAK RIDGE NATIONAL LABORATORY

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†Operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy.

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The Remote Control Engineering (RCE) task of the Fuel Recycle Division at Oak Ridge National Laboratory (ORNL) is committed to development of advanced teleoperators systems for the maintenance and repair of future nuclear facilities. These teleoperator systems feature man-in-the-loop control to take advantage of human superiority in handling unstructured environments and strategic planning. Consequently, the human operator is a critical component for teleoperator performance. The primary driving force for implementing a teleoperator-based system is the need for use of a human operator to receive sensory data, process this data, and provide output commands. Human operators can be the key contributors to operating inefficiency unless proper attention is given to their needs. Teleoperator systems can also be extraordinarily fatiguing to the human operator. For these reasons, basic human factors

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work has always been a major component of RCE task efforts, contributing to the RCE task effort through applied research and through design of human-machine interfaces. The basic approach of the human factors group at RCE has been to identify human characteristics that are important for performance of remote handling tasks, identify design considerations that may have an impact on the human operator, and then improve component designs by taking these factors into account.

This paper surveys the contributions of human factors to the mission of the RCE task over the last six years. These contributions can be divided into two areas, research efforts and design efforts. Some of the topics covered in human factors research are manipulator comparisons, investigation of viewing system characteristics, research into the effects of force reflection, and studies of crew size and task allocation. In the area of component design the human factors group was primarily responsible for the conceptual design of the Advanced Integrated Maintenance System (AIMS) control room, including all operator work stations and overall control room architecture. The human factors group also contributed to the design of the AIMS master controller handle.

Recent research at the RCE task has centered on comparison of manipulator systems. This research was planned and conducted by the human factors group and other ORNL personnel. The research is aimed at evaluating three important characteristics of manipulator systems: system dynamics, force feedback, and the human-machine interface.

One critically important component of teleoperated systems is the viewing subsystem, operators or remote handling systems obtain the majority of the information they use to perform tasks through vision. Since the mission of the RCE task is to develop mobile teleoperators, in RCE-designed systems operators must depend on television for visual inputs. RCE research found that persons performing simple tasks with direct contact take nearly twice as long to complete the tasks (the ratio of television to direct-viewing tasks time was 1.71:1) when required to use television as they do when viewing directly. Therefore, early in the human factors effort attention was given to problems associated with optimizing television viewing systems for remote work. Research compared monchromatic and color television for remote handling task performance and found no difference for completion of simple tasks; however, operators preferred to use color television. Research on the effect of television system resolution on performance of the same tasks found no difference between high-resolution television and standard-resolution television. An investigation of a high-definition television system is currently under way. Placement of television cameras to provide optimal coverage and control/display relationships has also been investigated, operators seem to prefer television cameras placed 45° to either side of the midline of the manipulator (±30°) or on the midline (±30°), and 30 to 45° above the horizon. A study of lighting for the remote area found that the majority of operators aligned objects in depth less accurately with floodlighting than with two lights offset 45° from the camera line of sight (one on each side), one of which was five times more intense than the other.

Voice control and automation for remote camera aiming have been shown to allow operators to perform some tasks more quickly than use of conventional joysticks and switches. Operators using voice control required 89% of the time usually required to do tasks with manual control, and using automated cameras required 84% of manual control time.

Psychophysical studies dealing with how well people judge weight and inertia with teleoperators have been conducted, and a preliminary comparison of task performance with and without force reflection was included in the manipulator comparative testing program. Further investigations, based on an information-processing theory of how operators use force information, will be conducted in the autumn of 1985. Research into the effects of force reflection of remote task performance has just begun.

Research into crew size for teleoperators and task allocation for teleoperator crew members was conducted as part of the design effort for the AIMS control room. A survey of operational facilities in the United States was conducted to identify the optimal crew size. A modified Delphi technique-type survey was used to gather data about task allocation from subject-matter experts (including manipulator operators, design engineers, and other persons with remote handling experience). The results of these surveys led to the adoption of the two-operator crew for the AIMS.

Research by the human factors group also provided the RCE task with a set of methods for evaluating teleoperator systems. Several important types of dependent variables have been identified, including task-performance measures, manipulator measures, forces applied to remote task components, and operator perceptions.

The human factors group was responsible for the design of the control room for the AIMS, including individual operator work stations and overall control room architecture. The AIMS control room was designed to accommodate 95% of the U.S. adult population, to meet U.S. government standards for nuclear control rooms, to maximize the use of integrated controls and displays (e.g., touch screens), to promote good interoperator communication, and to provide a safe and pleasing work environment.

The human factors group also assisted in the design of the master controller handle for the AIMS. Many manipulator handles are too large for comfortable use, are equipped with switches or buttons that are poorly located or too small, or require use of a precision grasp as opposed to a power grasp. (Pencils and pens are held with a precision grasp and hammers are held with a power grasp.) Precision grasp is not appropriate for control of teleoperators performing maintenance tasks since it uses weak and easily fatigued muscles in the arm. Some designs are also prone to carpal tunnel restrictions (the carpal tunnel is a structure in the wrist through which passes nerves and blood vessels), which can lead to fatigue or even to damage of the hand. The human factors group continues to work closely with the RCE task engineers to develop a master controller handle that provides an interface between operator and manipulator which is easy and comfortable to use. Toward that end, a set of design guidelines for master controller handles was developed for use in evaluations of handle design alternatives.

The human factors group at the RCE task has made significant contributions to the task through the development of experimental and statistical methods, the design of human-machine interfaces, performance of comparative tests of teleoperators and other equipment, and addition to the operational experience of the RCE task through the execution of teleoperator research.

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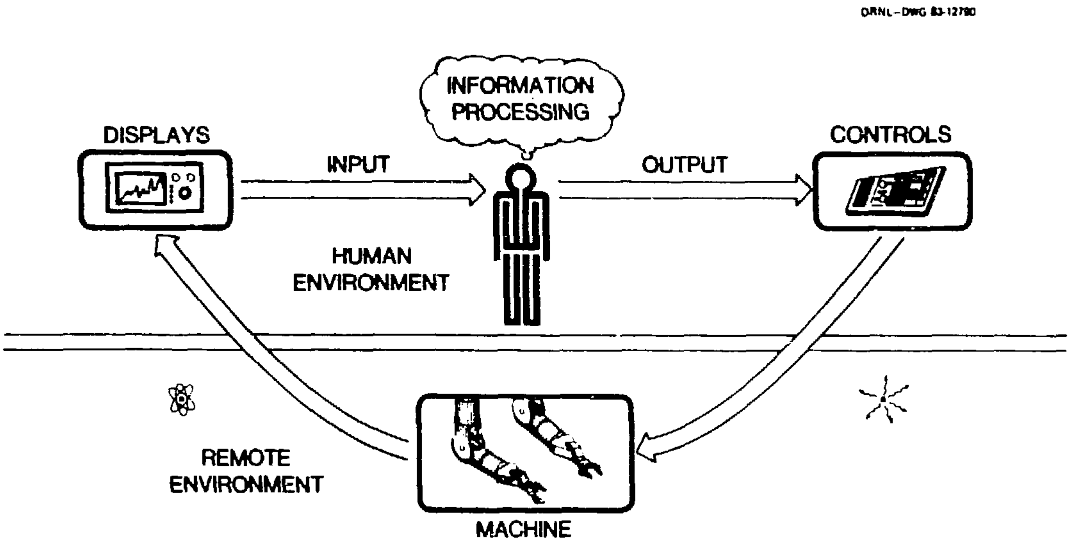
THE HUMAN OPERATOR IS AN IMPORTANT ELEMENT IN TELEOPERATIONS



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THE HUMAN OPERATOR IS IMPORTANT FOR SEVERAL REASONS, INCLUDING . . .

- VARIABLE ENVIRONMENT
- NONREPETITIVE TASKS
- REQUIREMENTS FOR MULTIPLE TOOLS
- REQUIREMENTS FOR STRATEGIC DECISIONS

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HUMAN FACTORS ENGINEERING IMPROVES SYSTEM PERFORMANCE BY IMPROVING HUMAN PERFORMANCE

- IDENTIFIES IMPORTANT HUMAN CHARACTERISTICS
- IDENTIFIES RELEVANT DESIGN CONSIDERATIONS
- IMPROVES COMPONENT DESIGNS
  - —PROVIDES NECESSARY CONTROLS AND DISPLAYS
  - —OPTIMIZES HUMAN-MACHINE INTERFACE

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HUMAN FACTORS ENGINEERING IS AN INTEGRAL PART OF ORNL TELEOPERATOR DEVELOPMENT

- RESEARCH
  - —MANIPULATOR COMPARISONS
  - —VIEWING SYSTEM CHARACTERISTICS
  - —FORCE REFLECTION
  - —CREW SIZE
  - —TASK ALLOCATION
- DESIGN
  - —ADVANCED INTEGRATED MAINTENANCE SYSTEM (AIMS) WORK STATIONS
  - —AIMS CONTROL ROOM
  - —AIMS MASTER CONTROLLER HANDLE

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RESEARCH: MANIPULATOR COMPARISONS

- MANIPULATOR COMPARATIVE TESTING
  - CENTRAL RESEARCH LABORATORIES MODEL M-2
  - MEIDENSHA BILARM 83A
  - PAR MODEL 6000 MANIPULATOR
- IMPORTANT MANIPULATOR CHARACTERISTICS
  - DYNAMICS
  - FORCE REFLECTION
  - HUMAN-MACHINE INTERFACE

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RESEARCH: VIEWING SYSTEM CHARACTERISTICS

- EFFECTS OF TELEVISION VIEWING
  - INEFFECTIVE GRASPING DUE TO MISLOCATION
  - MISALIGNMENT
  - FREQUENT OBSTRUCTION OF VIEWS
  - DEGRADED DEPTH CUES
  - HIGH LEVELS OF OPERATOR ADAPTATION AND INTERPRETATION NECESSARY
- TELEVISION : DIRECT VIEWING RATIO 1.7:1 FOR SIMPLE DIRECT CONTACT TASKS

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RESEARCH: VIEWING SYSTEM CHARACTERISTICS (CONTINUED)

- COLOR VERSUS BLACK AND WHITE
  - NO PERFORMANCE DIFFERENCES ON GENERIC SUBTASKS
  - OPERATOR PREFERENCE FOR COLOR
- RESOLUTION
  - LITERATURE SUGGESTS HIGH RESOLUTION IS DESIRABLE FOR SEARCH AND INSPECTION
  - EXPERIMENTS WITH HIGH DEFINITION TELEVISION UNDERWAY

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RESEARCH: VIEWING SYSTEM CHARACTERISTICS (CONTINUED)

- OBSERVATIONS: CAMERA LOCATION/VIEWING ANGLE
  - —OPERATORS VERY ADAPTABLE
  - —OPERATORS PREFERRED VIEWS FROM MIDLINE OR 45 DEGREE OFFSET
  - —OPERATORS PREFERRED VIEWS 30–45 DEGREES ABOVE HORIZON
  - —CAMERAS NOT MOVED FROM PREFERRED POSITIONS DURING PERFORMANCE OF SMALL VOLUME TASKS

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RESEARCH: FORCE REFLECTION

- MANIPULATOR COMPARATIVE TESTING PROGRAM
  - FORCE VERSUS NONFORCE CONDITIONS INCLUDED
- FORCE REFLECTION TESTING PROGRAM
  - OPTIMAL FORCE LEVEL
  - EFFECT ON SKILL LEARNING
  - EFFECT UNDER DEGRADED VISUAL CONDITIONS

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RESEARCH: CREW SIZE AND TASK ALLOCATION

- SURVEY OF OPERATIONAL FACILITIES
  - MULTI-OPERATOR CREWS RECOMMENDED
- MODIFIED DELPHI TECHNIQUE
  - EXPERTS RECOMMENDED TASK ALLOCATION
- TASK ALLOCATION RESULTS
  - PRIMARY OPERATOR: MANIPULATORS
  - SECONDARY OPERATOR: TRANSPORTER, CAMERAS, HOIST, TOOLS

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ORNL RESEARCH LED TO DEVELOPMENT OF METHODS FOR EVALUATING TELEOPERATORS

- TASK PERFORMANCE MEASURES
  - —ELAPSED TIME TO COMPLETE TASKS
  - —NUMBER OF ERRORS COMMITTED
  - —TYPE OF ERROR COMMITTED
- MANIPULATOR MEASURES
  - —MOTOR CURRENTS
  - —END-EFFECTOR VELOCITY

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METHODS FOR EVALUATING TELEOPERATORS (CONTINUED)

- FORCES APPLIED TO TASK COMPONENTS
- OPERATOR PERCEPTIONS
  - —OPINIONS
  - —SUBJECTIVE WORKLOAD
  - —PSYCHOPHYSICAL MEASUREMENTS

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DESIGN: ADVANCED INTEGRATED MAINTENANCE SYSTEM CONTROL ROOM

- WORK STATIONS
  - FIT 5TH TO 95TH PERCENTILE POPULATION
  - MEET APPLICABLE STANDARDS (NUREG CR-1580)
  - MAXIMIZE INTEGRATED CONTROLS/DISPLAYS
  - SAFE
- CONTROL ROOM ARCHITECTURE
  - ALLOW GOOD INTEROPERATOR COMMUNICATION
  - PROVIDE OPTIMAL WORK ENVIRONMENT (NOISE, LIGHTING, VENTILATION, ETC.)
  - AESTHETICALLY PLEASING

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HUMAN FACTORS ENGINEERING HAS MADE SIGNIFICANT CONTRIBUTIONS TO ORNL TELEOPERATOR DEVELOPMENT

- EXPERIMENTAL AND STATISTICAL METHODS
- HUMAN-MACHINE INTERFACE DESIGN
- TELEOPERATOR EVALUATION
- OPERATING EXPERIENCE

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