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Consolidated Fuel Reprocessing Program

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ABSTRACT

The Consolidated Fuel Reprocessing Program (CFRP) at the Oak Ridge National Laboratory is developing advanced teleoperator systems for maintenance of future nuclear reprocessing facilities. Remote maintenance systems developed by the CFRP emphasize man-in-the-loop teleoperation. Consequently, human factors issues which affect teleoperator performance must be addressed. This paper surveys research and development activities carried out by the human factors group within the Remote Control Engineering Task of the CFRP.

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1. INTRODUCTION

The Consolidated Fuel Reprocessing Program (CFRP) at the Oak Ridge National Laboratory (ORNL) is responsible for research and development of all facets of advanced nuclear fuel reprocessing applicable to the commercial nuclear fuel cycle in the United States. The Remote Control Engineering (RCE) task within CFRP is committed to development of advanced teleoperator systems for the maintenance and repair of future nuclear facilities. The RCE development program covers all aspects of advanced, mobile, remote maintenance systems using teleoperation. For the past six years, the RCE task has been developing techniques, equipment, and guidelines to improve the efficiency of remote maintenance operations. This work is based on the use of force-reflecting servomanipulators for dexterous manipulation over large cell volumes, television viewing of the task site, and man-in-the-loop teleoperation. 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. Consequently, the human operator is an important component for teleoperator performance. Human factors work is a major component of RCE task efforts, contributing to the RCE task mission through applied research and design of human-machine interfaces. The basic approach of the human factors group within the RCE task is 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 improve component designs by taking these factors into account. This paper surveys some of the work in human factors conducted within the RCE task.

2. VIEWING SUBSYSTEM

The viewing subsystem is composed of the television cameras in the remote area, the controls for positioning the cameras, and the television monitors available in the teleoperator cockpit. The viewing system is a critical component of the human-machine interface for teleoperated systems since operators obtain the majority of the information they use for performing remote work through it. Since television is so important, attention was given to problems associated with optimizing television for remote work early in the human factors effort. Research has failed to find any advantage for color television in the performance of remote handling tasks which require manual dexterity[1] but color may be useful for visual inspections or for search and location tasks.[2] Other research found that lighting can be used to improve the accuracy of depth judgments[3] by providing coherent shadow patterns. 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. This lighting arrangement provides an easily interpreted pattern of light and shadow which may be used to obtain depth information.

Recently, the RCE task has been cooperating with the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan to perform viewing subsystem research. A suite of three experiments has been conducted to compare the performance of a state-of-the-art, high-definition television (HDTV) system to the performance of monoscopic and stereoscopic standard-resolution television systems. The HDTV transmits a video image with more than twice the number of horizontal scan lines as standard-resolution television (1125 for HDTV to 525 for standard-resolution television). The resulting improvement in picture quality (compared to standard-resolution television) is very impressive. Objects in the HDTV picture have more sharply defined edges, better contrast, and more accurately reproduced shading and color patterns. To the casual observer, the HDTV picture provides greater sensation of depth. Since operators of remote handling equipment depend on television systems for the information necessary to do work, such an improvement in television picture quality could mean an improvement in the speed and accuracy with which they perform their tasks. Analysis of the data from these experiments is currently under way; the results will be available in the near future.

3. FORCE REFLECTION

Other studies by the human factors group have attempted to increase understanding of the effect of force reflection on remote manipulator handling performance. Force reflection is feedback of information about the forces applied to slave portions of manipulators in the remote area, provided by backdriving the master controllers. When a joint of the slave arm is loaded, the weight (or inertia) of the load is recreated at the corresponding master controller joint. A preliminary comparison of task performance with and without force reflection (conducted in cooperation with PNC, Japan) has been completed at the Remote Operations and Maintenance Demonstration facility at CFRP. Experience garnered during testing led to generation of a series of hypotheses concerning the circumstances under which force reflection is beneficial for remote operations. Force reflection seems helpful when operators are inexperienced with tasks or manipulators, when force reflection provides unique information about operations (as when an operator inserts an electrical connector into a socket "by feel" and force reflection provides alignment cues not available via television), and when forces applied in the remote area are important (as when handling fragile objects). An experiment currently being conducted at the ROMD facility is testing these hypotheses.

4. TELEOPERATOR CONTROLS

Another major effort has been in the area of the design and evaluation of teleoperator controls. The RCE human factors group played a major role in the design of the master controller handle for the Advanced Servomanipulator (ASM). The ASM is a dexterous, remotely maintainable master/slave servomanipulator developed by the RCE task at ORNL. It features modular construction for ease of maintenance and a digital electronic control system for high fidelity force reflection and dexterity. The human factors group developed a set of design guidelines for force-reflecting servomanipulator master controller handles[4] and continues to work closely with RCE task engineers to develop a master controller handle for the ASM which is easy and comfortable to use. Many manipulator handles currently in use are too large for comfortable operation, are equipped with switches which are poorly located or too small, or require use of an excessively fatiguing grasp.

Camera controls have also been the subject of RCE task research. Three camera control alternatives have been evaluated: control by manual inputs via switches and joysticks, control by computer word recognition, and automated tracking of manipulator end-effectors. For two moderately complex remote maintenance tasks, operators were able to work more quickly with voice input (11% improvement over manual controls on average) and automated tracking (17% improvement), with no concomitant increase in the amount of errors committed. There was a difference in the way operators used cameras with the various control systems: with voice input, they tended to make fewer camera movements than with manual control, but the movements were of longer duration.[5] Figure 1 illustrates the mean time required to complete tasks with each control system, and Fig. 2 illustrates the relationship of camera control type to movement duration.

5. AIMS CONTROL ROOM

The Advanced Integrated Maintenance System (AIMS) is an integrated, remotely controlled maintenance system for nuclear fuel reprocessing facilities, including the ASM, a 3 degree-of-freedom overhead transporter, television viewing system, and control room. The conceptual design of the AIMS control room was also a project of the human factors group. This included all phases of conceptual design, from preliminary task identification through crew size determination, task allocation, control room architecture, and design of individual work stations.[6,7] Research into crew size for teleoperators and task allocation for teleoperator crew members was conducted as part of the design effort. 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 a

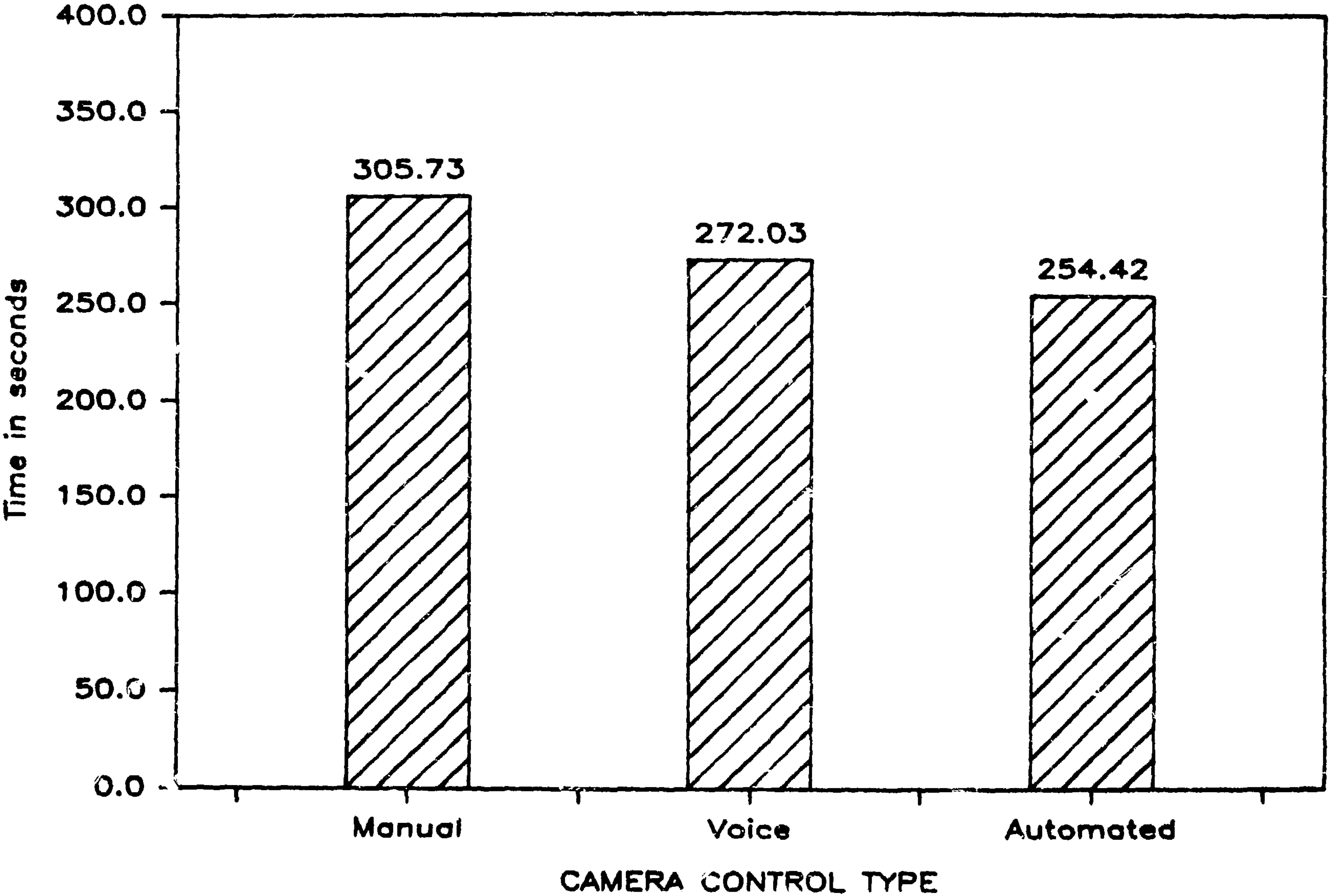

Fig. 1. Mean time to complete tasks with each of the three camera control systems.

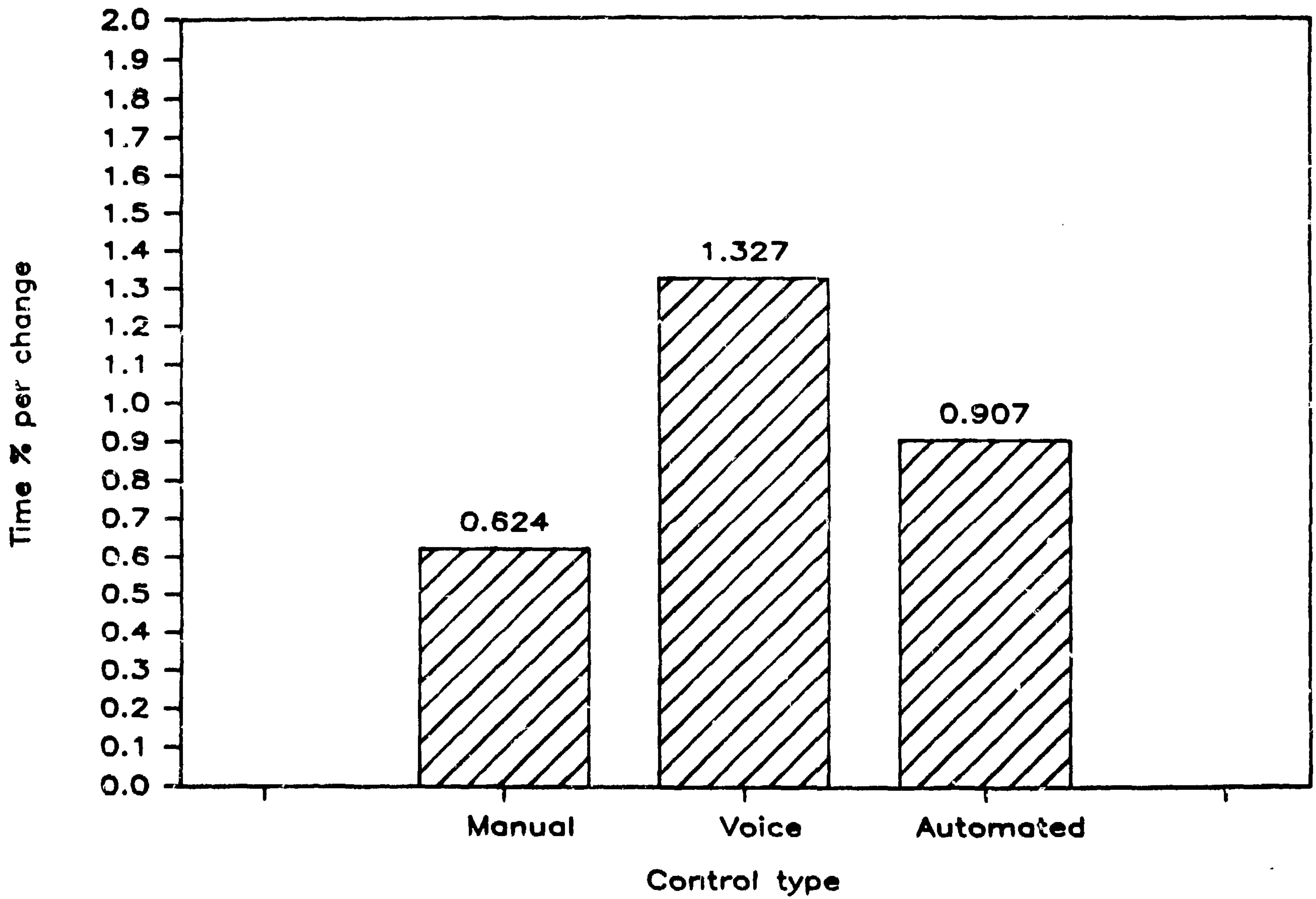

Fig. 2. Camera movement duration with each of three camera control systems.

two-operator crew for the AIMS control room. Figure 3 is a photograph of the AIMS control room. The control room is designed around the two-operator team, with one operator responsible for remote handling and the other for control of transporter motion, television camera aiming, television monitor switching, lighting, and remote tools. The individual work stations make intensive use of integrated, programmable controls/displays in the form of touch-screen graphics displays. Voice control of some functions is also included in the AIMS cockpit. The AIMS control room was designed to accommodate 95% of the U.S. adult population (5th percentile female to 95th percentile male), to meet guidelines for human factors design of nuclear facility control rooms,[8] to promote good interoperator communication, and to provide a safe and pleasing work environment.

6. TELEOPERATOR PERFORMANCE CRITERIA

Another area where the human factors group has made a significant contribution to the RCE task mission is in the development of criteria of teleoperator performance. Teleoperators are complex systems, and quantification of the performance of these systems and of their impact on the remote environment and human operators requires a multimeasure approach. Several important variables have been identified in RCE task human factors research, including task completion time, critical incidents, operator opinions, joint motions, and forces applied in the remote area.

Task completion time measures the ease with which an operation may be completed with a manipulator. Given a common task, operation is easiest with the teleoperator which requires the least amount of time to complete the task. Task completion time measures the quantity of work that may be done with a teleoperator system.

Fig. 3. Photograph of the AIMS control room.

Critical incidents measure the quality of work. The RCE task critical incidents checklist, which is still being refined and validated, includes 18 events that subject matter experts identified as important indicators of the quality of teleoperator performance. These events include errors as well as events that are important but that are not necessarily examples of poor performance. The list includes dropping grasped objects, collisions of the manipulator with objects in the remote area, two-handed use of the manipulator master controller handle, and misalignment of task components during assembly. Scores on the individual critical incidents and on the total of the critical incidents provide a measure of performance quality and allow isolation of specific problem areas within an experimental condition.

Operator opinions have been collected with questionnaires, interviews, and group discussions. In each case, the persons who actually use the teleoperators have provided unique insights into operation of these systems.

Joint motion recordings have been used to identify patterns in the utilization of joints by operators. For example, in the experiment involving camera controls, principal components factor analysis of the percent of time each joint of a seven degrees-of-freedom, force-reflecting master/slave manipulator was in motion isolated two important factors. The four joints closest to the end-effector (tong closure, tong roll, tong pitch, and tong yaw) formed the first factor. The first three joints of the manipulator (shoulder pitch, shoulder roll, and elbow pitch) formed the second factor. Since movement of the joints included in the first factor involves translation/rotation of small (less than 8 in.) arm links, this factor represents fine-adjusting motion. The second factor represents slewing motion. In testing at the RSDF, operators used joints in the first cluster almost twice as frequently as those in the second cluster. This two-factor pattern was consistent for three of the four operators involved in the study.

Forces applied to the remote area may be indicative of the quality of teleoperator performance. Measurement of forces allows analysis of the likelihood of damage to the teleoperator or objects in the remote area.

7. FUTURE DIRECTIONS

Currently, the RCE task is embarking on a new phase of its mission: having designed the ASM and its associated control station, the emphasis will be on evaluation of the design. As a consequence, the role of the human factors group will also change. In the past, effort was concentrated on design; in the future, the emphasis will be on evaluation and testing of prototypical interfaces and equipment. The Manipulator Comparative Testing Program, which the CFRP conducted in cooperation with the PNC is an example. In this series of experiments, three manipulator systems were compared in terms of how well operators using them were able to perform typical remote handling tasks. The impact of the manipulator systems on operators in terms of subjective workload, fatigue, and potential for injuries was also assessed.

8. CONCLUSION

Human factors work within the RCE task has contributed to the mission of the task by designing human-machine interfaces which promote good performance and avoid excessive fatigue, and by identifying important human-machine issues. In addition, although the primary emphasis has been on application of human factors principles to teleoperator designs, research conducted here has added to our knowledge of how humans interact with complex teleoperated systems. 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.

REFERENCES

1. M. M. Clarke, S. J. Handel, and J. Garin, "A Comparison of Color and Black and White Television for Remote Viewing in Nuclear Facilities," p. 239 in Transactions of the American Nuclear Society, Washington, November 1982.

2. M. M. Clarke and A. Preston-Anderson, Color Coding of Televised Task Elements in Remote Work: A Literature Review with Practical Recommendations for a Fuel Recycle Facility, ORAU-190, Oak Ridge Associated Universities, November 1981.

3. J. V. Draper, "Lighting for Remote Viewing Systems," p. 69 in Proceedings of the 1984 Topical Meeting on Robotics and Remote Handling in Hostile Environments, American Nuclear Society, Oak Ridge, Tenn., April 1984.

4. J. V. Draper, Human Factors Guidelines for Force- Reflecting Master/ Slave Manipulator Handles, ORNL/TM, Oak Ridge National Laboratory, Oak Ridge, Tenn., in preparation.

5. J. V. Draper, A Comparison of Manual, Voice, and Automated Control of a Teleoperator Viewing System, unpublished doctoral dissertation, University of Tennessee, Knoxville, Tenn., 1985.

6. M. M. Clarke and J. G. Kreifeldt, "Elements of an Advanced Integrated Operator Control Station," p. 425 in Proceedings of the 1984 Topical Meeting on Robotics and Remote Handling in Hostile Environments, American Nuclear Society, Oak Ridge, Tenn., April 1984.

7. M. M. Clarke and J. G. Kreifeldt, "A Control Room Concept for Remote Maintenance in High Radiation Areas," pp. 230-234 in Proceedings of the Human Factors Society 28th Annual Meeting, Human Factors Society, San Antonio, October 22-26, 1984.

8. K. Mallory et al., Control Room Evaluation, NUREG/CR-1580, July 1980.