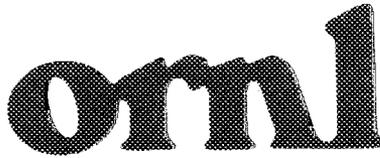




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ORNL/TM-12432

OAK RIDGE
NATIONAL
LABORATORY

MARTIN MARIETTA

Task Analysis for the Single-Shell Tank Waste Retrieval Manipulator System

John V. Draper

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Environmental Restoration and Waste Management Program

**TASK ANALYSIS FOR THE SINGLE-SHELL TANK
WASTE RETRIEVAL MANIPULATOR SYSTEM**

John V. Draper

Date Published—March 1993

NOTICE This document contains information of a preliminary nature.
It is subject to revision or correction and therefore does not represent a
final report.

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for the
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CONTENTS

| | |
|---|-----|
| LIST OF FIGURES | v |
| LIST OF TABLES..... | vii |
| ABSTRACT | ix |
| 1. INTRODUCTION..... | 1 |
| 2. TASK LIST | 3 |
| 2.1 MISSION PHASES | 4 |
| 2.2 FIRST MISSION PHASE: INSERT TWRMS EQUIPMENT | 4 |
| 2.2.1 Activate Aux. CCTV System..... | 4 |
| 2.2.2 Insert Aux. CCTV System into SST | 7 |
| 2.2.3 Inspect Tank Interior..... | 7 |
| 2.2.4 Develop Riser Cutting Strategy..... | 9 |
| 2.2.5 Activate TWRMS | 10 |
| 2.2.6 Insert TWRMS | 10 |
| 2.3 SECOND MISSION PHASE: REMOVE WASTE LAYERS | 13 |
| 2.3.1 Cut Risers/ITH | 13 |
| 2.3.2 Remove Cut-up Risers/ITC..... | 13 |
| 2.3.3 Characterize Waste | 24 |
| 2.3.4 Remove Waste Layer..... | 27 |
| 2.3.5 Remove Residual Waste | 31 |
| 2.4 THIRD MISSION PHASE: REMOVE TWRMS EQUIPMENT | 36 |
| 2.4.1 Remove TWRMS Package | 36 |
| 2.4.2 Remove Aux. CCTV System | 36 |
| 3. TASK ANALYSIS RESULTS | 39 |
| 3.1 METHODS..... | 39 |
| 3.2 RESULTS..... | 39 |
| 3.2.1 User Actions, Displays, and Controls..... | 39 |
| 3.2.2 Crew Size and Function Allocation..... | 39 |
| 3.2.3 Panel Groups | 64 |
| 4. REMAINING STEPS IN THE PROJECT | 74 |
| 4.1 CONTROL PANEL DESIGN..... | 74 |
| 4.2 WORKSTATION DESIGN | 74 |
| 4.3 CONTROL ROOM LAYOUT | 74 |
| 5. SUMMARY | 75 |
| REFERENCES | 77 |
| APPENDIX TASK ANALYSIS FORMS | 79 |

LIST OF FIGURES

| | |
|---|----|
| Fig. 1. Mission phases during a tank remediation campaign..... | 4 |
| Fig. 2. Subfunctions during the first mission phase | 5 |
| Fig. 3. Task elements during the subfunction “Activate Aux. CCTV System”..... | 6 |
| Fig. 4. Task elements during the subfunction “Insert Aux. CCTV System into SST” | 8 |
| Fig. 5. Task elements during the subfunction “Inspect Tank Interior”..... | 9 |
| Fig. 6. Task elements during the subfunction “Develop Riser Cutting Strategy”..... | 9 |
| Fig. 7. Task elements during the subfunction “Activate TWRMS”..... | 11 |
| Fig. 8. Task elements during the subfunction “Insert TWRMS” | 12 |
| Fig. 9. Subfunctions during the second mission phase..... | 14 |
| Fig. 10. Tasks during the subfunction “Cut Risers/ITH” | 15 |
| Fig. 11. Task elements during the task “90. Map Surface” | 16 |
| Fig. 12. Task elements during the task “96. Manual Cut”..... | 16 |
| Fig. 13. Task elements during the task “94. Teach Cut” | 17 |
| Fig. 14. Task elements during the task “95. Robotic Cut” | 18 |
| Fig. 15. Tasks during the subfunction “Remove Cut-up Risers/ITH”..... | 19 |
| Fig. 16. Task elements during the task “130. Exchange EE” | 20 |
| Fig. 17. Task elements during the task “134. Map Surface”..... | 21 |
| Fig. 18. Task elements during the task “140. Teach Removal”..... | 22 |
| Fig. 19. Task elements during the task “160. Robotic Removal”..... | 23 |
| Fig. 20. Task elements during the task “161. Manual Removal”..... | 23 |

| | |
|---|----|
| Fig. 21. Tasks during the subfunction “Characterize Waste” | 24 |
| Fig. 22. Task elements during the task “185. Exchange EE” | 25 |
| Fig. 23. Task elements during the task “194. Map Surface”..... | 26 |
| Fig. 24. Task elements during the task “211. Determine Composition” | 27 |
| Fig. 25. Tasks during the subfunction “Remove Waste Layer”..... | 27 |
| Fig. 26. Task elements during the task “202. Exchange EE” | 28 |
| Fig. 27. Task elements during the task “214. Teach Removal” | 29 |
| Fig. 28. Task elements during the task “228. Robotic Removal” | 30 |
| Fig. 29. Tasks during the subfunction “Remove Residual Waste” | 31 |
| Fig. 30. Task elements during the task “214. Map Surface”..... | 32 |
| Fig. 31. Task elements during the task “245. Exchange EE” | 33 |
| Fig. 32. Task elements during the task “254. Teach Removal” | 34 |
| Fig. 33. Task elements during the task “286. Robotic Removal” | 35 |
| Fig. 34. Subfunctions during the third mission phase | 36 |
| Fig. 35. Task elements during the subfunction “280. Remove TWRMS” | 37 |
| Fig. 36. Task elements during the subfunction “284. Remove CCTV” | 38 |
| Fig. 37. Typical completed task analysis form..... | 40 |

LIST OF TABLES

| | | |
|-----------|---|----|
| Table 1. | User actions, displays, and controls during each subfunction of the first mission phase | 41 |
| Table 2. | User actions, displays, and controls during the second mission phase | 44 |
| Table 3. | User actions, controls, and displays during the third mission phase..... | 50 |
| Table 4. | User functions for each crew member | 51 |
| Table 5. | Panel groups for the TWRMS chief | 64 |
| Table 6. | Revised/control display panel groups for the TWRMS chief | 65 |
| Table 7. | Panel groups for the TWRMS chief during each task in the first mission phase | 66 |
| Table 8. | Panel groups for the TWRMS chief during each task in the second mission phase | 67 |
| Table 9. | Panel groups for the TWRMS chief during each task in the third mission phase | 69 |
| Table 10. | Panel groups for the TWRMS monitor..... | 70 |
| Table 11. | Revised set of control/display panel groups for the TWRMS monitor | 71 |
| Table 12. | Panel groups for the TWRMS monitor during each task in the first mission phase | 72 |
| Table 13. | Panel groups for the TWRMS monitor during each task in the second mission phase | 73 |
| Table 14. | Panel groups for the TWRMS monitor during each task in the second mission phase | 74 |

ABSTRACT

This document describes a task analysis for the Tank Waste Retrieval Manipulator System. A task analysis is a formal method of examining work that must be done by the operators of human-machine systems. The starting point for a task analysis is the mission that a human-machine system must perform, and the ending point is a list of requirements for human actions and the displays and controls that must be provided to support them.

The task analysis approach started with a top-down definition of the steps in a tank retrieval campaign. It started by dividing a waste retrieval campaign for one single-shell tank into the largest logical components (*mission phases*), then subdivided these into secondary components (*subfunctions*), and then further subdivided the secondary components into tertiary units (*tasks*). Finally, the tertiary units were divided into potentially observable operator behaviors (*task elements*). In the next stage of the task analysis, the task elements were evaluated by completing an electronic task analysis form patterned after one developed by the Nuclear Regulatory Commission for task analysis of nuclear power plant control rooms. In the final stage, the task analysis data base was used in a bottom-up approach to develop clusters of controls and displays called *panel groups* and to prioritize these groups for each subfunction. Panel groups are clusters of functionally related controls and displays. Actual control panels will be designed from panel groups, and panel groups will be organized within workstations to promote efficient operations during retrieval campaigns.

1. INTRODUCTION

This document describes a task analysis for the Tank Waste Retrieval Manipulator System (TWRMS). While the information contained in this document is tentative because the systems are still evolving, it provides a foundation for control room design efforts. These efforts will support the design of a test bed control room in the near future and an operational control room later.

The TWRMS will comprise systems capable of teleoperation and autonomous operations. While operating these systems, the crew will shift from continuous manual control (e.g., using master controllers) to symbolic interaction (e.g., selecting actions from a computer menu), depending on the circumstances. In other words, the human operator's contribution will range from controlling every movement of the machine by directly controlling servomotor operation to entering task-level commands. Specifically, operators will carry out some varying mix of five tasks: (1) programming: storing a behavioral repertoire via symbols, including words; (2) teaching: storing a behavioral repertoire by stepping through examples; (3) controlling: exercising continuous manual control; (4) commanding: control via manipulating symbols to trigger behavioral repertoires; and (5) monitoring: observing the machine perform commands and switching to another task as required. A control room for the TWRMS must include workstations that can support all five user tasks during waste tank remediation campaigns. This document provides supporting information for the design of such workstations. However, because the TWRMS is an emerging system, this analysis must be reviewed prior to developing final control room concepts to ensure that the process model and conclusions contained within it remain applicable.

Control room design must proceed systematically if it is to be effective. One approach is to follow three phases: (1) function analysis, (2) task analysis, and (3) design. A task analysis is a formal method of examining work that must be done by human users. The starting point for a task analysis is the mission that a human-machine system must perform, and the ending point is a list of requirements for human actions and the displays and controls that must be provided to support them. Between the start and the end is a process of dividing and subdividing the work into smaller yet significant components. The TWRMS task analysis began by defining the system mission based on information about the TWRMS mission and system concepts.¹ The second step was listing the system components and user functions needed to operate them.² The third step was to develop, based on what was known from the first two steps, a detailed list of tasks that might take place during waste retrieval. Section 2 lists the tasks necessary to complete a waste retrieval campaign for a single storage tank. The final step in the analysis was to use a formal task analysis method to examine the tasks, with the aim of discovering the human actions required to carry out the tasks, and the controls and displays necessary within each task. The task analysis method used was that developed for task analysis of nuclear power plant control rooms,³ with some modifications to account for the special requirements of remote handling systems. Section 3 describes the outcomes of the task analysis.

The task analysis approach started with a top-down definition of the steps in a tank remediation campaign. It started by dividing a waste retrieval campaign for one single-shell tank into the largest logical components, then subdivided these into secondary components, and then further subdivided the secondary components into tertiary units. Finally, the tertiary units were divided into potentially observable operator behaviors. The highest level components are called *mission phases*, the secondary components are called *subfunctions*, the tertiary units are called *tasks*, and the observable operator behaviors are called *task elements*.

In the next stage of the task analysis, the list of mission phases, subfunctions, tasks, and task elements was evaluated by completing an electronic task analysis form patterned after one developed by the Nuclear Regulatory Commission (NRC) for task analysis of nuclear power plant control rooms. The task analysis form allows determination of the controls and displays necessary for each task element, and the entire set of completed forms provides a task analysis data base for tank remediation.

In the final stage of the task analysis, the task analysis data base was used in a bottom-up approach to develop clusters of controls and displays called *panel groups* and to prioritize these groups for each subfunction. Panel groups are clusters of functionally related controls and displays. Actual control panels will be designed from panel groups, and panel groups will be organized within workstations to promote efficient operations during remediation campaigns.

The task analysis assumes that the TWRMS gantry is in place over the subject tank and that the long reach manipulator (LRM) and auxiliary systems are ready for activation. The mission profile is based on the operating scenario for single-shell tank (SST) remediation described in the retrieval manipulator specification.¹

2. TASK LIST

This section lists the tasks that must be performed to complete a waste tank retrieval campaign for one tank and defines the starting point, events, and ending point that comprise each task. Because this is a developing system, the information necessary for this evaluation had to be derived from documentation and could not be directly observed. As a consequence, descriptions of the mission phases and tasks must be somewhat speculative and, therefore, the description of the campaign is hypothetical to some degree. In other words, this document describes how tank remediations **might be** carried out, not how they are carried out. However, it is a reasonable approximation of the activities that will take place; the task descriptions contained in this document are best estimates of what an SST remediation campaign will be like and provide a baseline for human-machine interface development. As better information becomes available, it will be incorporated as required.

The retrieval effort for one tank may be called a mission; within the mission there are key milestones that must be accomplished and these milestones delineate mission phases. Within each mission phase there exist functions that must be done to successfully complete the mission phase. For example, in the first mission phase the auxiliary television system (Aux. TV) must be activated, the Aux. TV must be inserted into the tank, the tank interior must be inspected, and a strategy (sequence) for cutting the risers must be developed. These secondary units are the subfunctions. Each subfunction comprises an *initiator*, the event or condition that requires or allows the subfunction; a *task sequence*, the sequential list of tasks that operators must complete; and a *sequence terminator*, the event or condition that is the goal of the subfunction. The tertiary units are tasks. A task is a set of human behaviors executed to fulfill a goal-directed strategy. The task sequence is a set of tasks carried out to fulfill the goal of the subfunction. Tasks are composed of task elements, which are human behaviors required to complete the task.

The following sections list the mission phases and the subfunctions within mission phases. Within each subfunction, the initiator at the start is listed, followed by a sequential list of tasks required and the terminator for the subfunction. The initiator is the status of the system at the start of the subfunction, and the terminator is the goal status of the system for the subfunction. The emphasis in this list is on user tasks, so certain aspects of system functioning are not present. For example, during waste removal the operation of the waste conveyance system is not mentioned. Even though this is an important part of system functioning, it does not require any user behavior beyond manual control of the TWRMS and monitoring system status. Therefore, it is not explicitly listed although it must be running for the waste retrieval end effector to function properly.

Perhaps a better way to understand the retrieval campaign is through examining a task network model, which provides a flow chart for the campaign. A task network model was developed using the MicroSAINT software package and is presented in all figures. Each mission phase, subfunction, and task element is clearly represented; however, the tasks in some subfunctions are not well defined. In all of the figures, task elements are represented by ovals, subfunctions and mission phases by boxes, multiple path events by diamonds labeled with an

"M," tactical decisions (operator choices) by diamonds labeled with a "T," and the conclusion of a subfunction with a circle. The flow of work through the model is represented by arrows.

2.1 MISSION PHASES

As Fig. 1 illustrates, there are three mission phases during a TWRMS campaign: (1) Insert TWRMS equipment into the tank. (2) Remove waste layers. (3) Remove TWRMS equipment from the tank. The first mission phase starts with the TWRMS in place above a tank and ready for activation and ends when the TWRMS is in place in the tank and ready to begin waste retrieval. The second mission phase starts at the end of the first phase and ends when all retrievable waste has been removed from the tank. The third and final mission phase starts at the end of the second phase and ends when the TWRMS has been removed from the tank.

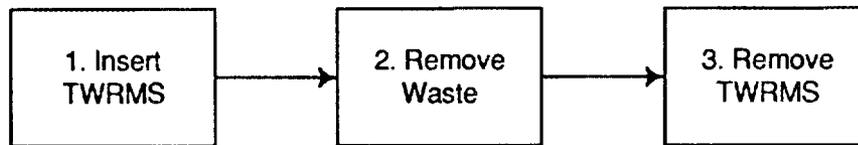


Fig. 1. Mission phases during a tank remediation campaign.

2.2 FIRST MISSION PHASE: INSERT TWRMS EQUIPMENT

During this phase of the mission, the crew takes the auxiliary closed-circuit television (Aux. CCTV) system from an inactive (cold) state to operational readiness within an SST. At the start of the mission phase the TWRMS gantry is in place over the tank and an access port has been prepared. At the end of the mission phase the Aux. CCTV is in the tank, the interior of the tank has been inspected, and a strategy for the first series of cutting operations (if necessary) has been prepared. Figure 2 illustrates the subfunctions within the first mission phase.

2.2.1 Activate Aux. CCTV System

The goal of this subfunction is to safely turn on the power to the Aux. CCTV system and verify that it is operational and ready for insertion. Figure 3 illustrates the task elements in this subfunction.

2.2.1.1 Initiator

TWRMS is in place over SST access port.

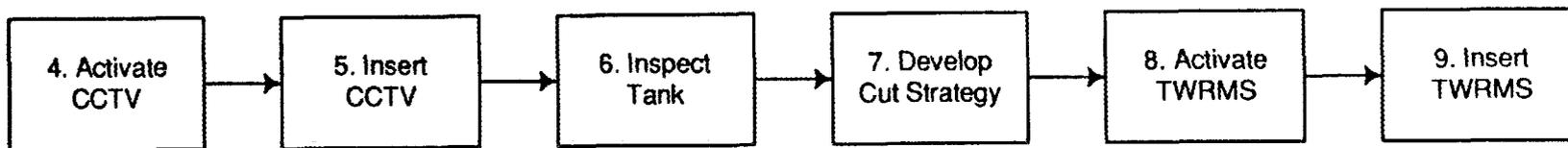


Fig. 2. Subfunctions during the first mission phase.

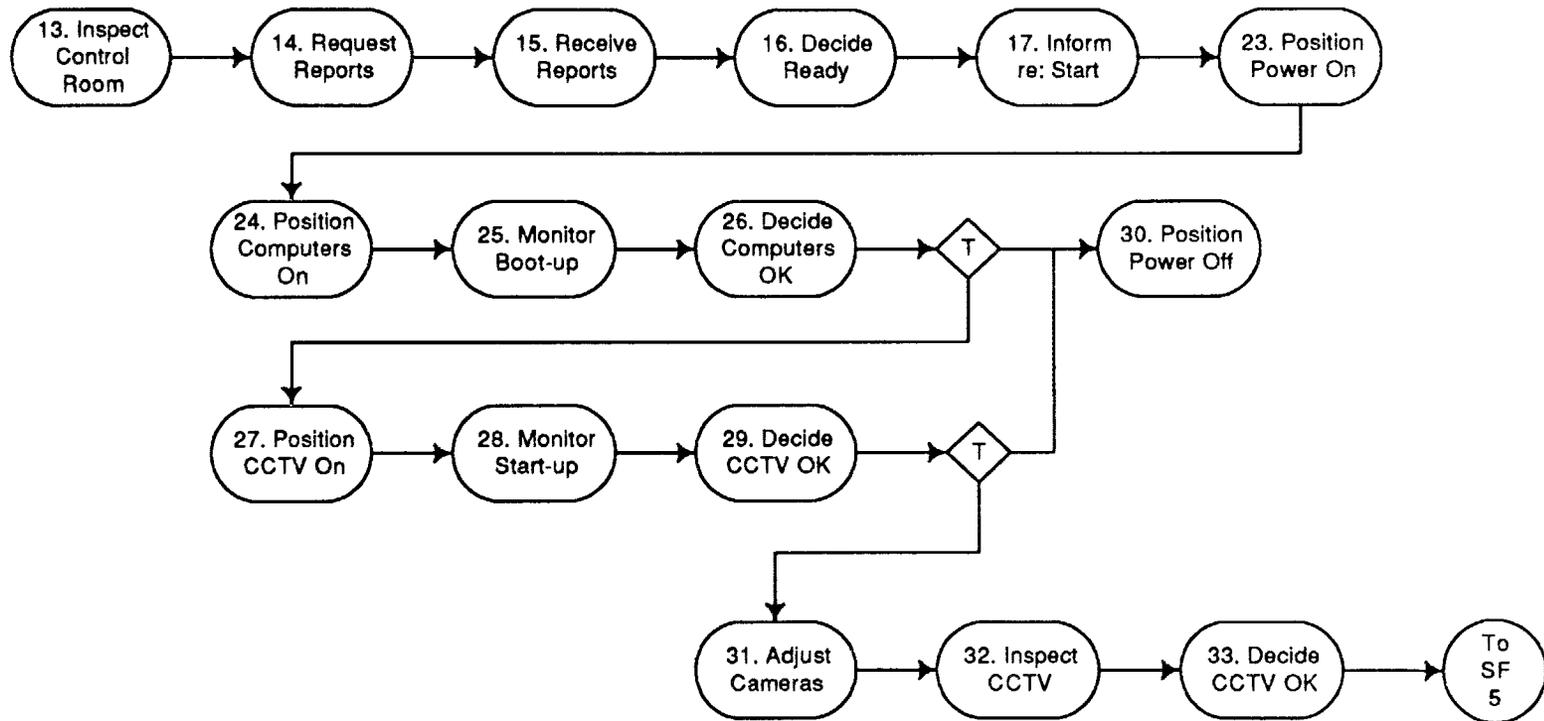


Fig. 3. Task elements during the subfunction "Activate Aux. CCTV System."

2.2.1.2 Task sequence

1. Prepare for Aux. CCTV system activation.
2. Activate Aux. CCTV system.
3. Verify that Aux. CCTV system is functioning properly.

2.2.1.3 Terminator

Aux. TV system is ready for insertion.

2.2.2 Insert Aux. CCTV System into SST

During this subfunction, the crew inserts the Aux. CCTV system into the tank and then verifies that it is in place and functioning properly. The insertion may be teleoperated, using continuous manual control, or it may be automated, in which case the crew would initiate a robotic routine and monitor the progress of the insertion. The best approach to the insertion should be determined on a tank-by-tank basis, depending upon the amount of pre-insertion inspection that has been done and the amount of clutter present around the tank entrance. Figure 4 illustrates the task elements in this subfunction.

2.2.2.1 Initiator

Aux. CCTV system is ready for insertion.

2.2.2.2 Task sequence

1. Choose insertion mode (manual or robotic).
2. Manually insert Aux. CCTV into tank.
3. Initiate robotic Aux. CCTV insertion.
4. Monitor robotic Aux. CCTV insertion.
5. Confirm that Aux. TV system is in place and functioning.

2.2.2.3 Terminator

Aux. TV system is in place and functioning.

2.2.3 Inspect Tank Interior

During this subfunction, the crew inspects the interior of the tank and records the location and description of visible in-tank hardware (ITH) and risers with the ultimate purpose of developing a sequence or strategy for cutting these pieces into removable shapes. Figure 5 illustrates this subfunction.

2.2.3.1 Initiator

Aux. TV system is in place and functioning.

2.2.3.2 Task sequence

1. Inspect tank interior using Aux. TV.
2. Record riser and ITH locations and descriptions.

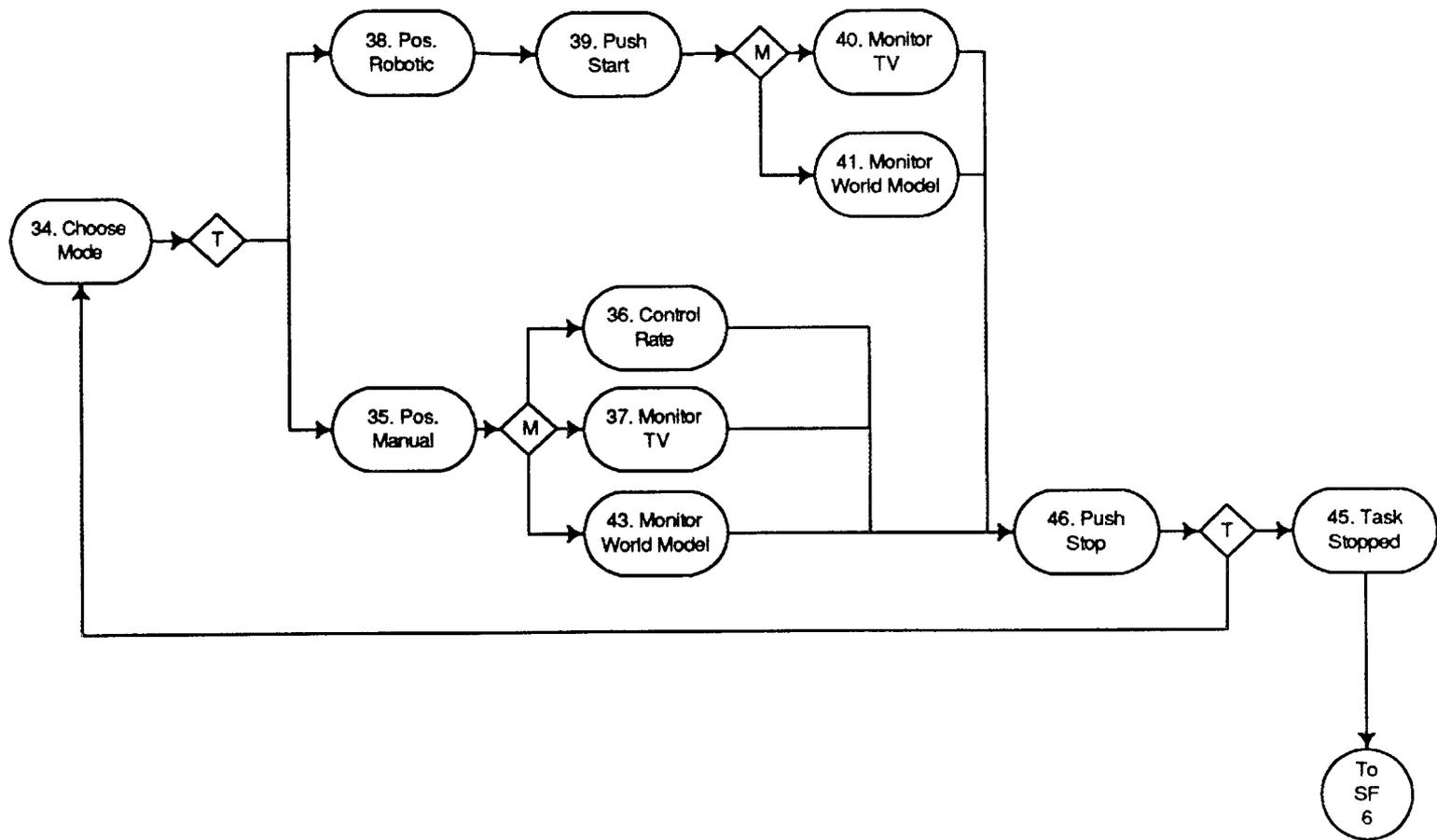


Fig. 4. Task elements during the subfunction "Insert Aux. CCTV System into SST."

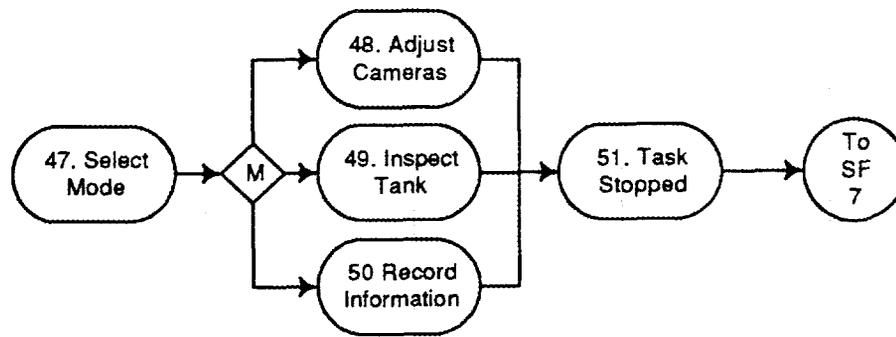


Fig. 5. Task elements during the subfunction "Inspect Tank Interior."

2.2.3.3 Terminator

Risers and ITH are noted, located on tank map, and described in operations log.

2.2.4 Develop Riser Cutting Strategy

During this subfunction, the crew decides upon a riser/ITH cutting sequence and records it in the operations log. (The operations log should be an electronic diary of operations and events and should have the capability of translating a cutting sequence into world map coordinates.) Figure 6 illustrates this subfunction.

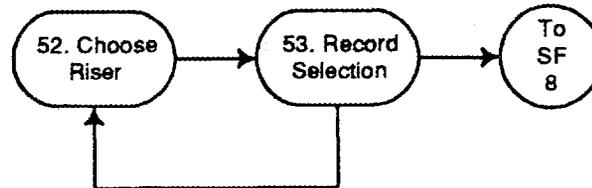


Fig. 6. Task elements during the subfunction "Develop Riser Cutting Strategy."

2.2.4.1 Initiator

Risers and ITH are noted, located on tank map, and described in operations log.

2.2.4.2 Task sequence

1. Develop riser cutting sequence.
2. Record riser cutting sequence in operations log.

2.2.4.3 Terminator

Riser cutting sequence is recorded.

2.2.5 Activate TWRMS

During this subfunction, the crew turns on the power to the TWRMS and prepares it for insertion into the tank. Figure 7 illustrates this subfunction.

2.2.5.1 Initiator

Aux. CCTV is in the tank, and TWRMS is in place over the access port.

2.2.5.2 Task sequence

1. Prepare to activate TWRMS.
2. Activate TWRMS.
3. Verify that TWRMS is functioning properly.

2.2.5.3 Terminator

TWRMS is functioning properly.

2.2.6 Insert TWRMS

During this subfunction, the crew inserts the TWRMS into the tank and then verifies that it is in place and functioning properly. The insertion may be teleoperated, using continuous manual control, or it may be automated, in which case the crew would initiate a robotic routine and monitor the progress of the insertion. The best approach to the insertion should be determined on a tank-by-tank basis, depending upon the amount of pre-insertion inspection and the amount of clutter present around the tank entrance. Figure 8 illustrates the task elements in this subfunction.

2.2.6.1 Initiator

TWRMS is functioning properly.

2.2.6.2 Task sequence

1. Choose TWRMS insertion mode (manual or robotic).
2. Manually insert TWRMS into tank.
3. Initiate robotic TWRMS insertion.
4. Monitor robotic TWRMS insertion.
5. Confirm that TWRMS is in place and functioning.

2.2.6.3 Terminator

TWRMS is in place in tank.

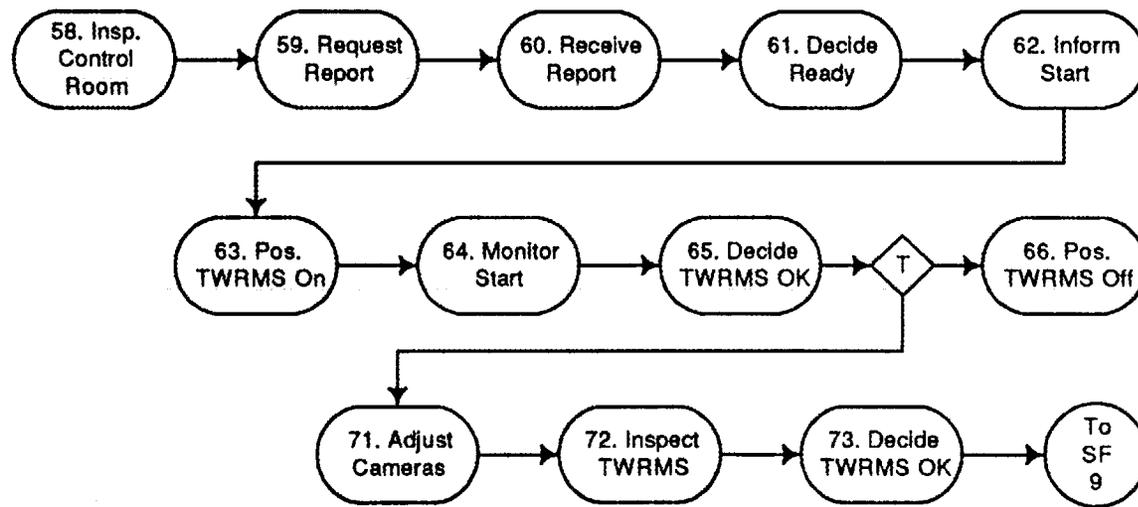


Fig. 7. Task elements during the subfunction "Activate TWRMS."

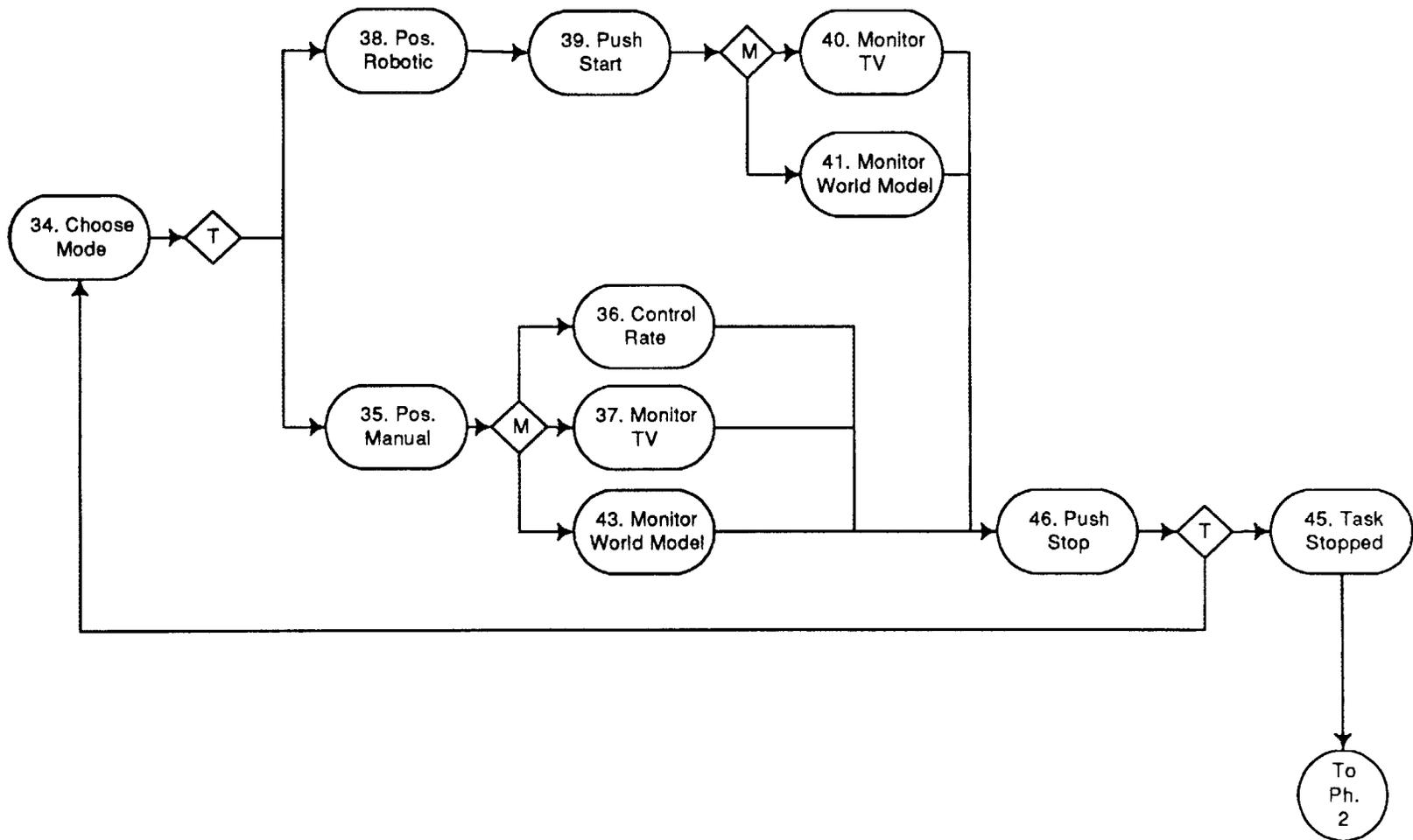


Fig. 8. Task elements during the subfunction "Insert TWRMS."

2.3 SECOND MISSION PHASE: REMOVE WASTE LAYERS

During the second mission phase, risers, ITH, and waste are removed in an iterative process. The mission phase starts with the complete TWRMS operational inside the tank, and it ends with all the risers, ITH, and waste removed from the tank. Figure 9 illustrates the subfunctions in this mission phase; the loop from the end of the fourth subfunction (Remove Waste Layer) to the first subfunction (Cut Risers/ITH) indicates the iterative nature of the process. The iterations could represent the number of layers that must be removed or the number of mines, or pits, dug into the waste by end effectors; the labels used in the current document refer to layers but could just as easily refer to mines or pits.

2.3.1 Cut Risers/ITH

This subfunction is executed repetitively until all risers and ITH are cut into manageable segments, down to the level of the existing waste layer. Figure 10 illustrates the tasks within the subfunction, and Figs. 11–14 illustrate the task elements within each task. Riser/ITH cutting may be teleoperated or automated, depending on the capabilities of the TWRMS. The most efficient scenario may be a combined teleoperated/robotic approach in which the TWRMS moves from workspace to workspace (i.e., from one riser location to the next), approaches to within 3 to 6 in. of the riser, and then requests that the crew intervene to do the actual cutting.

2.3.1.1 Initiator

TWRMS is operational in tank.

2.3.1.2 Task sequence

1. Map waste surface (see Fig. 11).
2. Teach riser cutting sequence (see Fig. 12).
3. Robotically cut risers (see Fig. 13).
4. Manually cut risers (see Fig. 14).

2.3.1.3 Terminator

Risers/ITH cut into manageable sections.

2.3.2 Remove Cut-up Risers/ITH

During this subfunction the sectioned risers and ITH that have fallen onto the waste surface are picked up, placed in the conveyance system, and removed from the tank (these may be removed as they are cut instead). Figure 15 illustrates the tasks in this subfunction, and Figs. 16–20 illustrate the task elements within each task. This operation may be done by teleoperation or robotically, but it is unlikely that robotic operations will be efficient given the high variability likely to occur in the waste surface and section locations; it may be best to do the entire retrieval by teleoperation.

2.3.2.1 Initiator

Risers/ITH are cut into manageable sections.

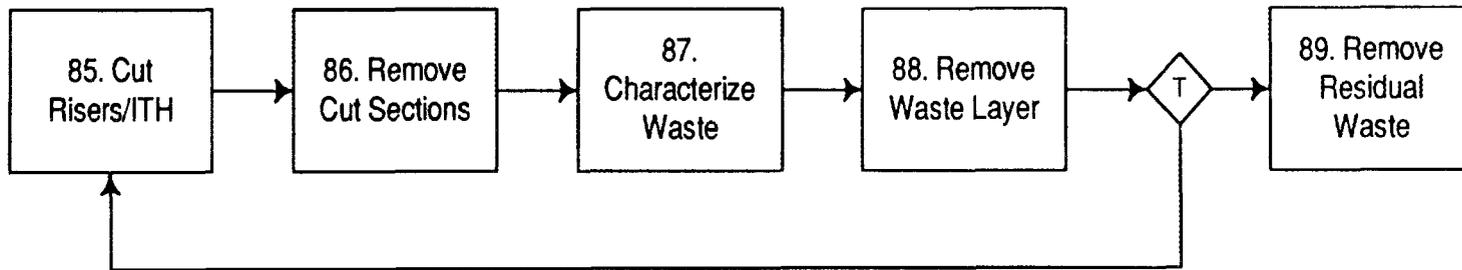


Fig. 9. Subfunctions during the second mission phase.

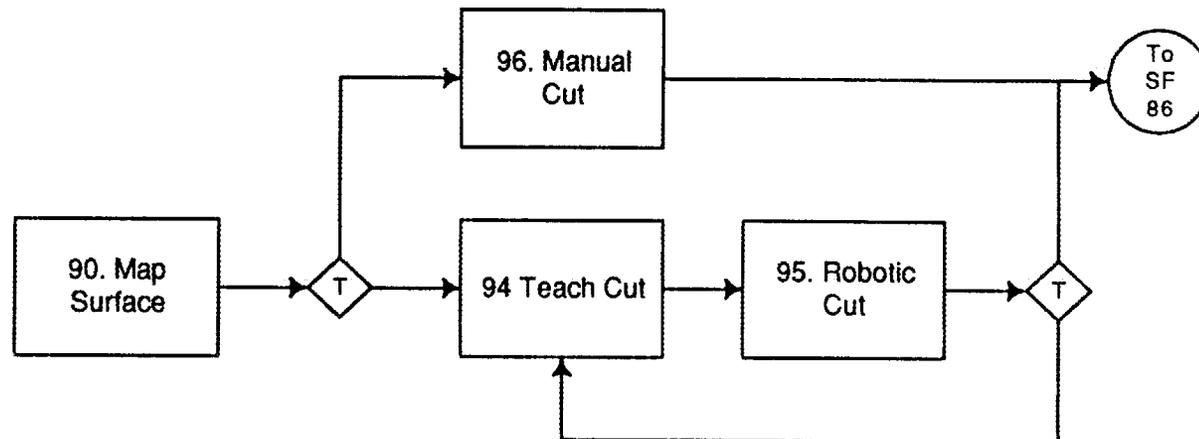


Fig. 10. Tasks during the subfunction "Cut Risers/ITH."

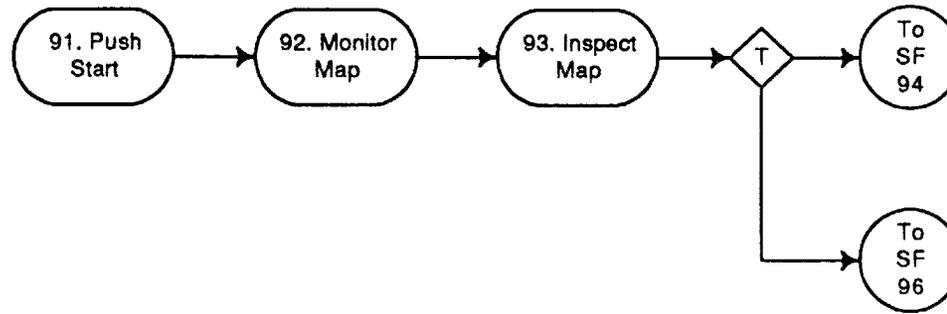


Fig. 11. Task elements during the task "90. Map Surface."

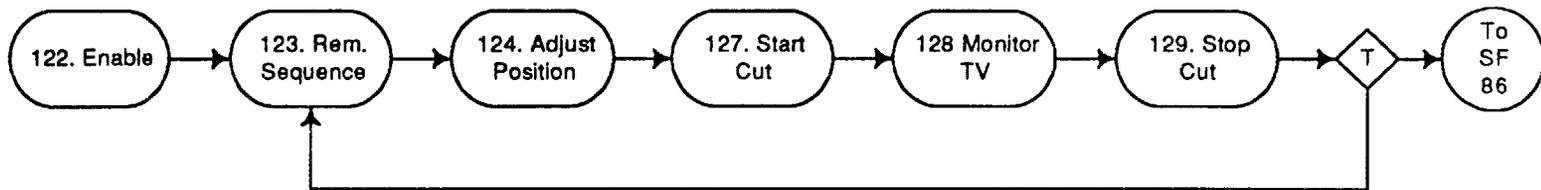


Fig. 12. Task elements during the task "96. Manual Cut."

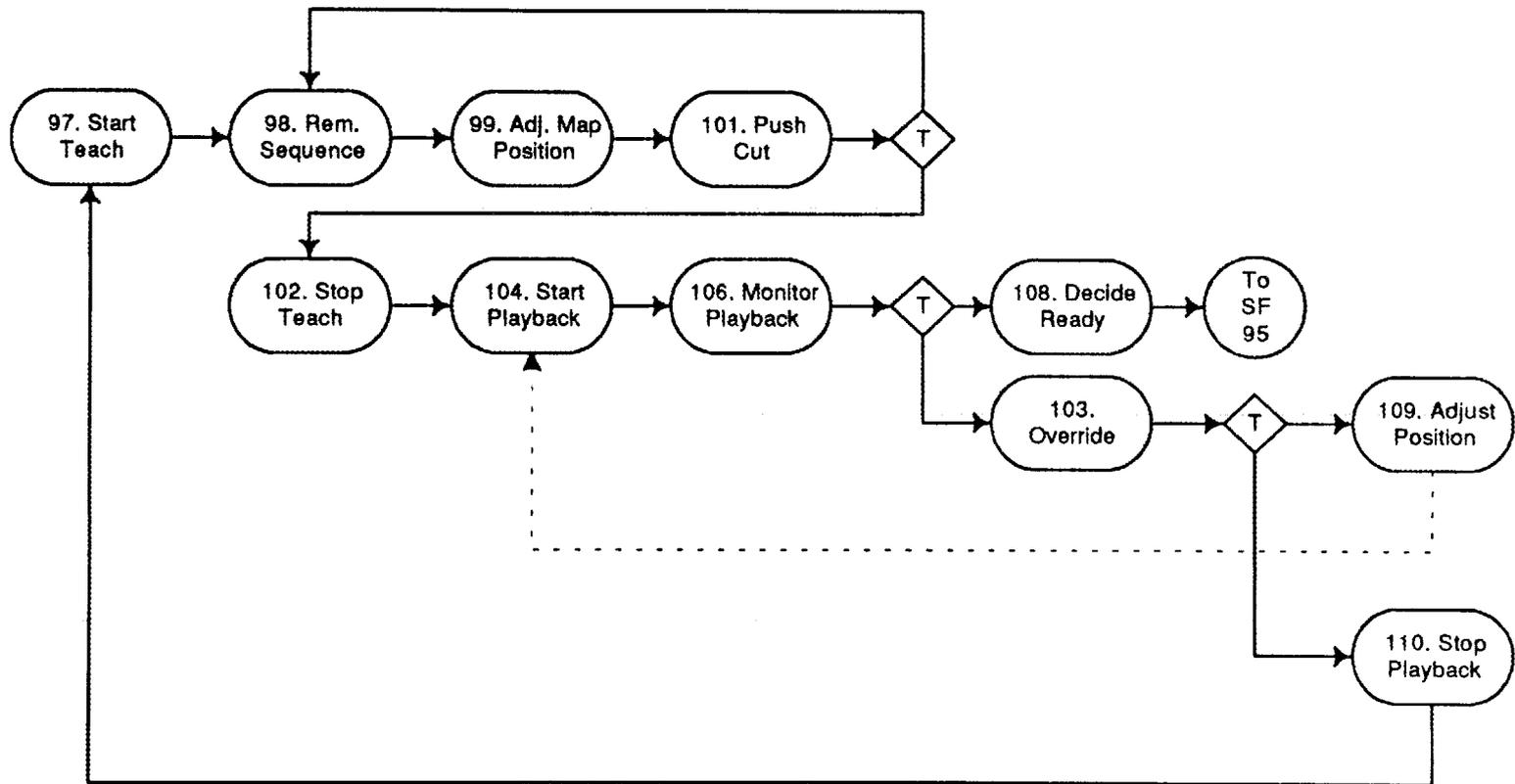


Fig. 13. Task elements during the task "94. Teach Cut."

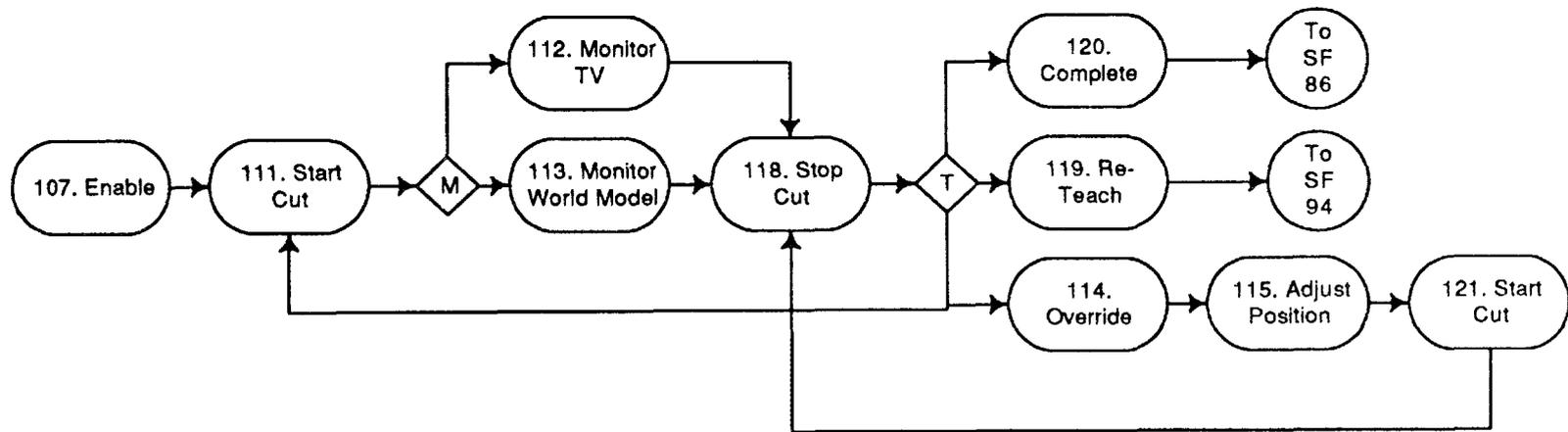


Fig. 14. Task elements during the task "95. Robotic Cut."

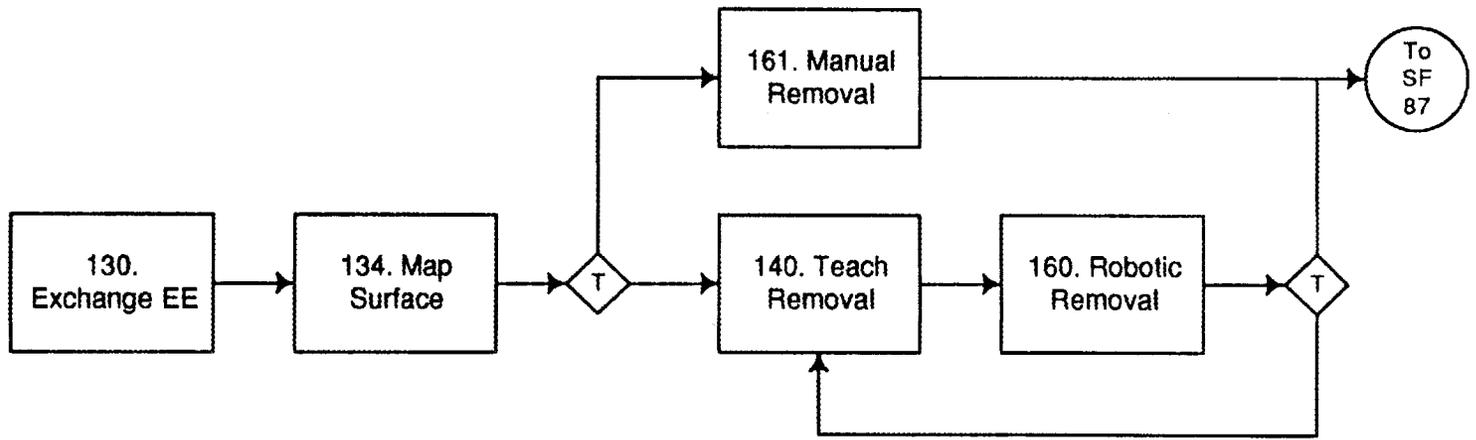


Fig. 15. Tasks during the subfunction "Remove Cut-up Risers/ITH."

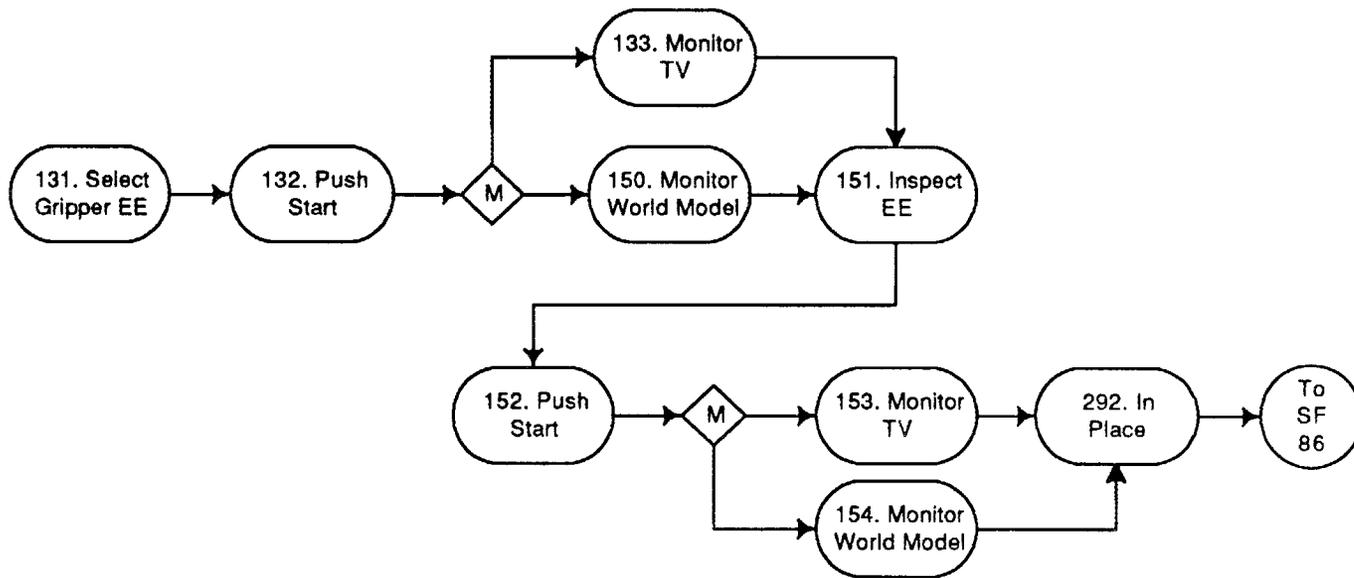


Fig. 16. Task elements during the task "130. Exchange EE."

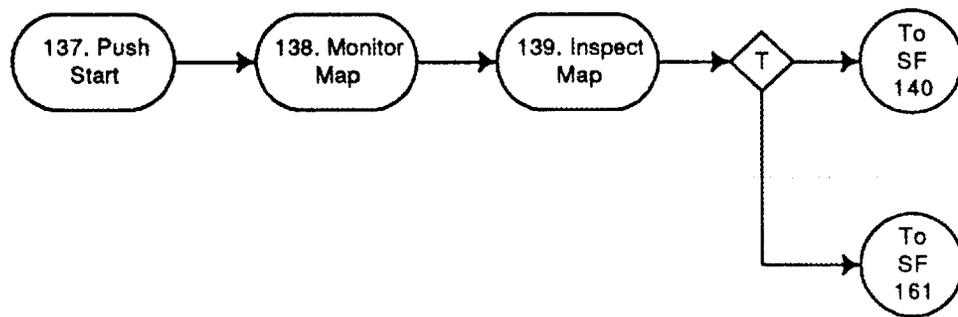


Fig. 17. Task elements during the task "134. Map Surface."

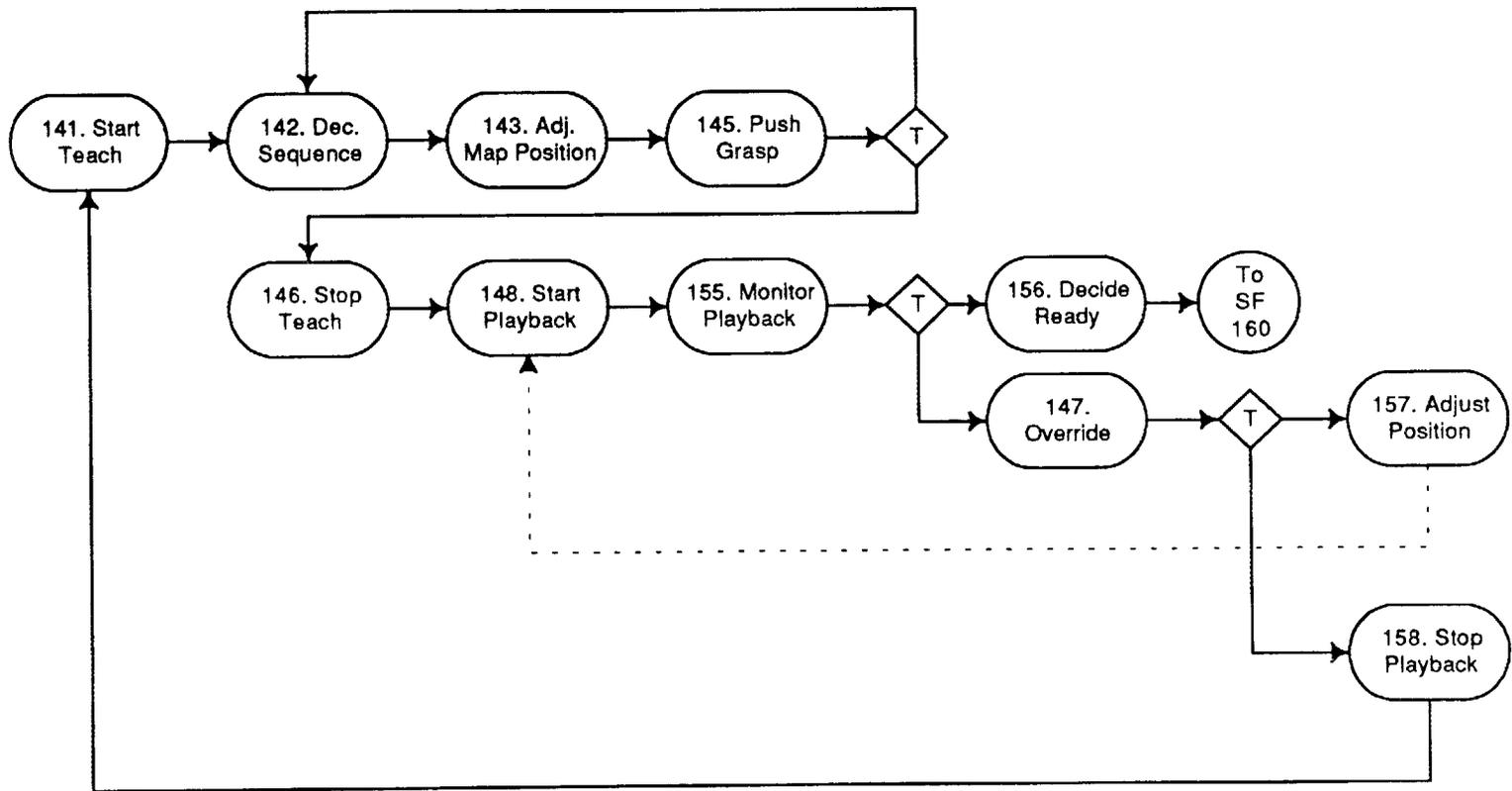


Fig. 18. Task elements during the task "140. Teach Removal."

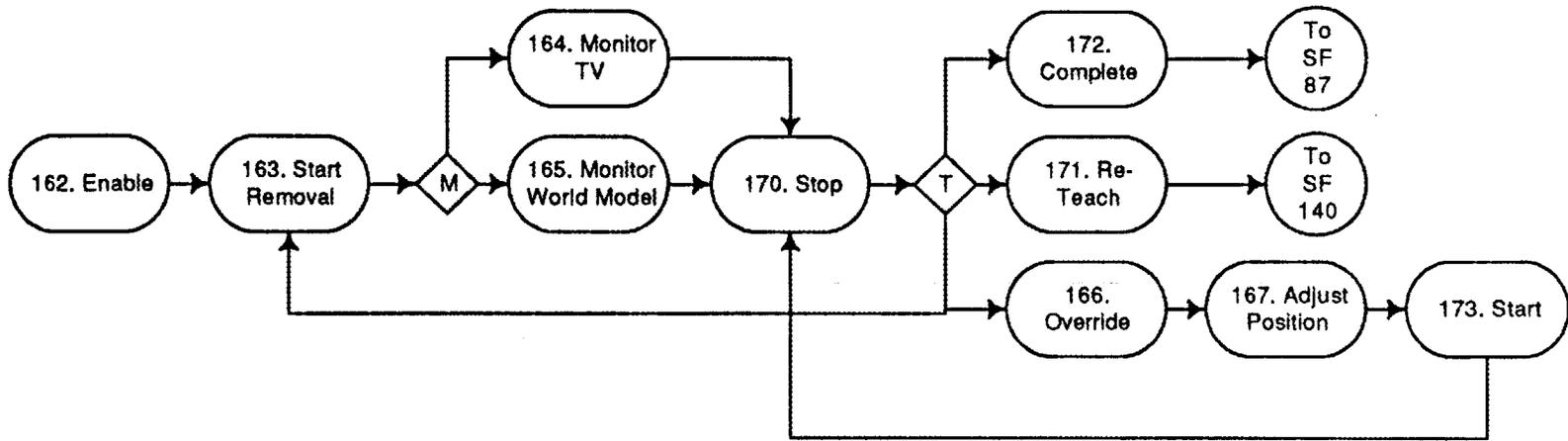


Fig. 19. Task elements during the task "160. Robotic Removal."

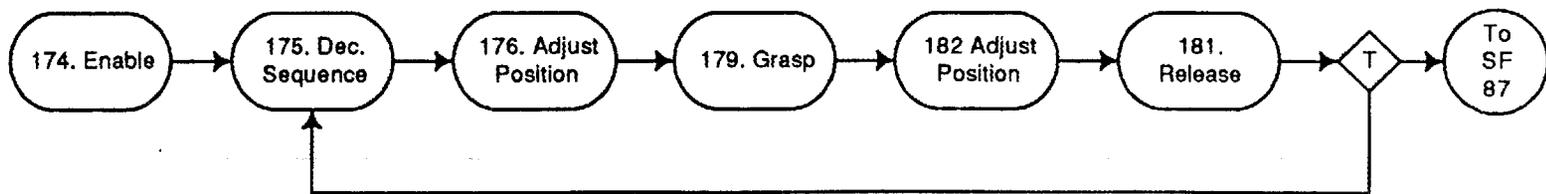


Fig. 20. Task elements during the task "161. Manual Removal."

2.3.2.2 Task sequence

1. Exchange cutting end effector for gripper end effector (Fig. 16).
2. Map waste surface (Fig. 17).
3. Teach riser/ITH removal sequence (Fig. 18).
4. Robotically remove riser/ITH sections (Fig. 19).
5. Manually remove riser/ITH sections (Fig. 20).

2.3.2.3 Terminator

Risers/ITH are removed from the tank.

2.3.3 Characterize Waste

During this subfunction the waste surface and subsurface are mapped and characterized. Figure 21 illustrates the tasks in this subfunction, and Figs. 22–24 illustrate the elements within each task.

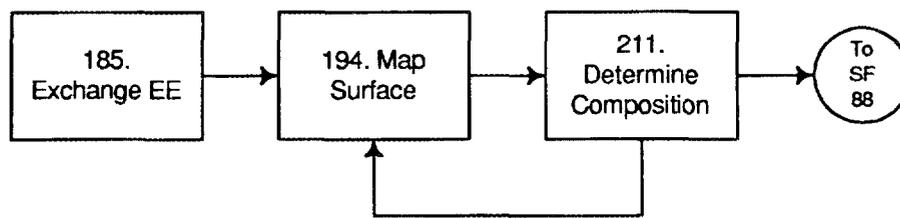


Fig. 21. Tasks during the subfunction "Characterize Waste."

2.3.3.1 Initiator

Risers/ITH are out of the tank.

2.3.3.2 Task sequence

1. Exchange gripper for mapping end effector (Fig. 22).
2. Map waste surface (Fig. 23).
3. Determine waste composition (Fig. 24).

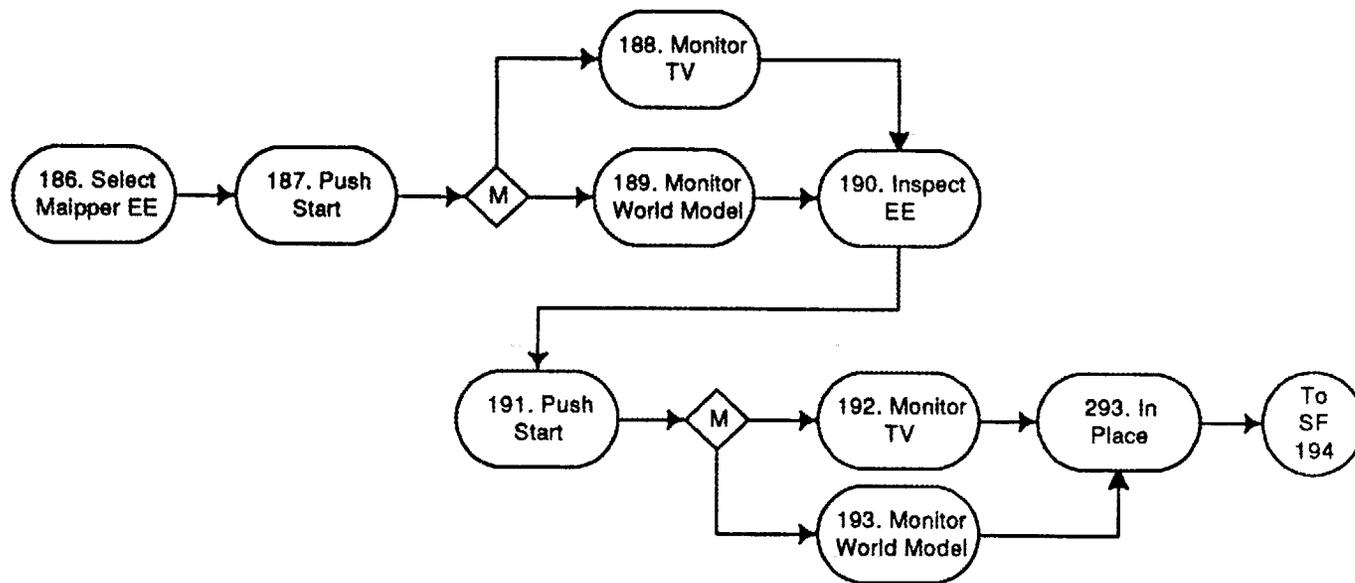


Fig. 22. Task elements during the task "185. Exchange EE."

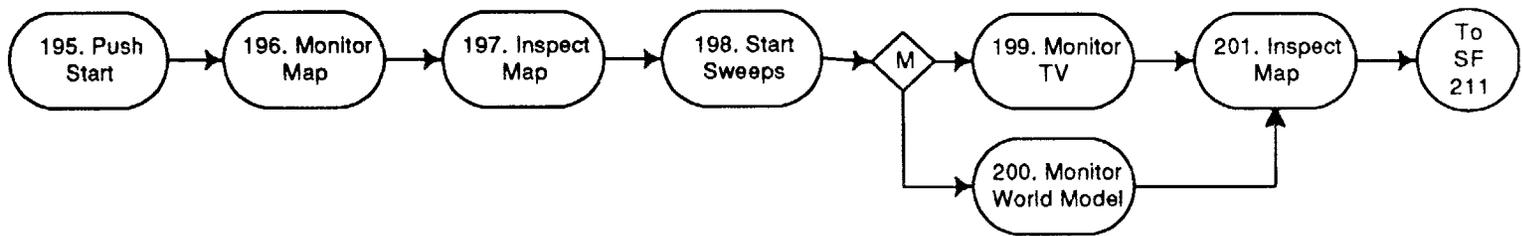


Fig. 23. Task elements during the task "194. Map Surface."

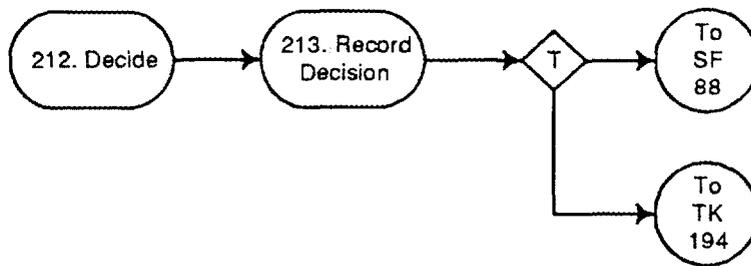


Fig. 24. Task elements during the task "211. Determine Composition."

2.3.3.3 Terminator

Waste is mapped and characterized.

2.3.4 Remove Waste Layer

During this subfunction a layer of waste is removed using the appropriate waste dislodging and capture tools. At the end of a repetition, the process is restarted with riser cutting or continues to tank cleaning. Figure 25 illustrates the tasks within this subfunction, and Figs. 26–28 illustrate the task elements within each task. The subfunction may be completed using teleoperation or robotically, but given the low rates (3 in./s) and the positioning tolerances (within 1 in. of the surface for some) required by the end effectors, it will be difficult for the crew to maintain the appropriate pace and position. Therefore, automation is the preferred option; operator aiding through end-effector path restrictions could also be used for these end-effector performance regimes.

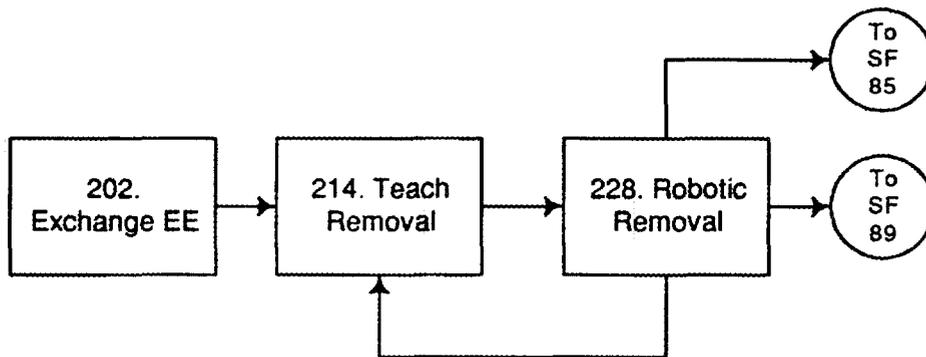


Fig. 25. Tasks during the subfunction "Remove Waste Layer."

2.3.4.1 Initiator

Waste is mapped and characterized.

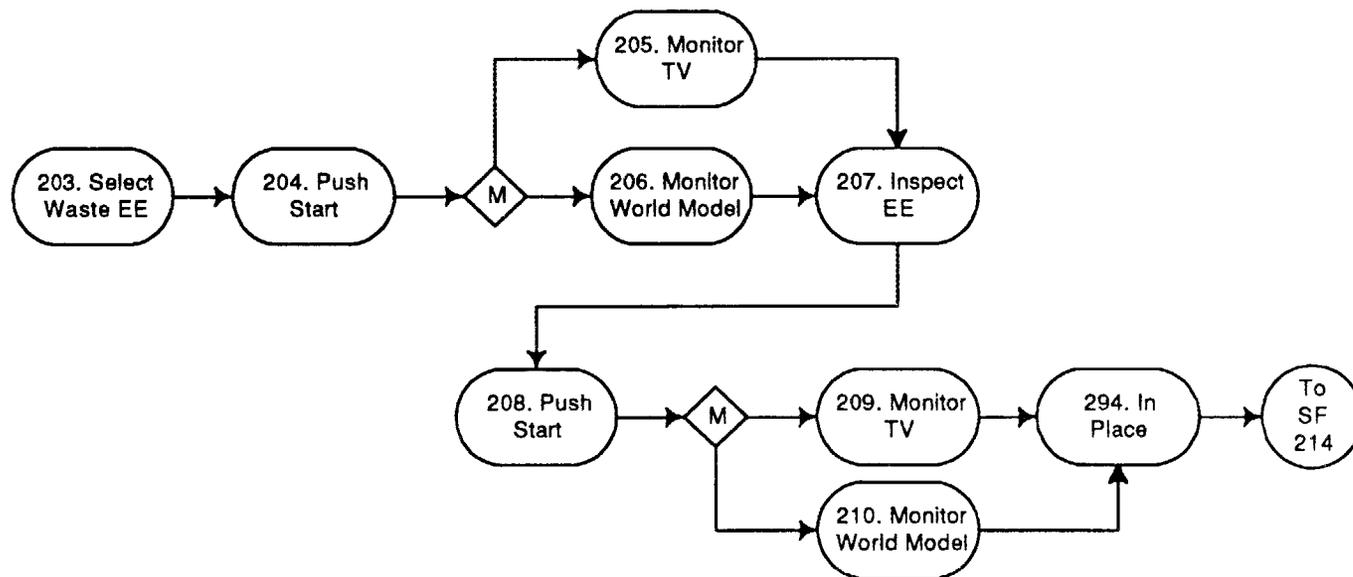


Fig. 26. Task elements during the task "202. Exchange EE."

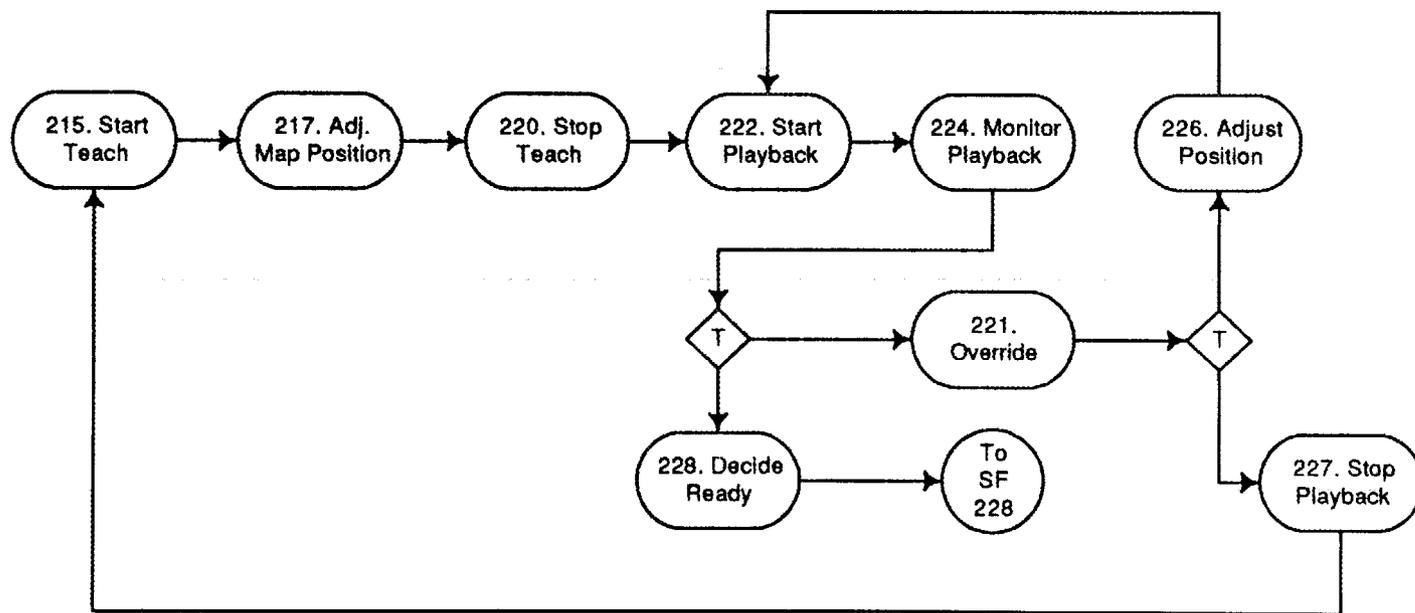


Fig. 27. Task elements during the task "214. Teach Removal."

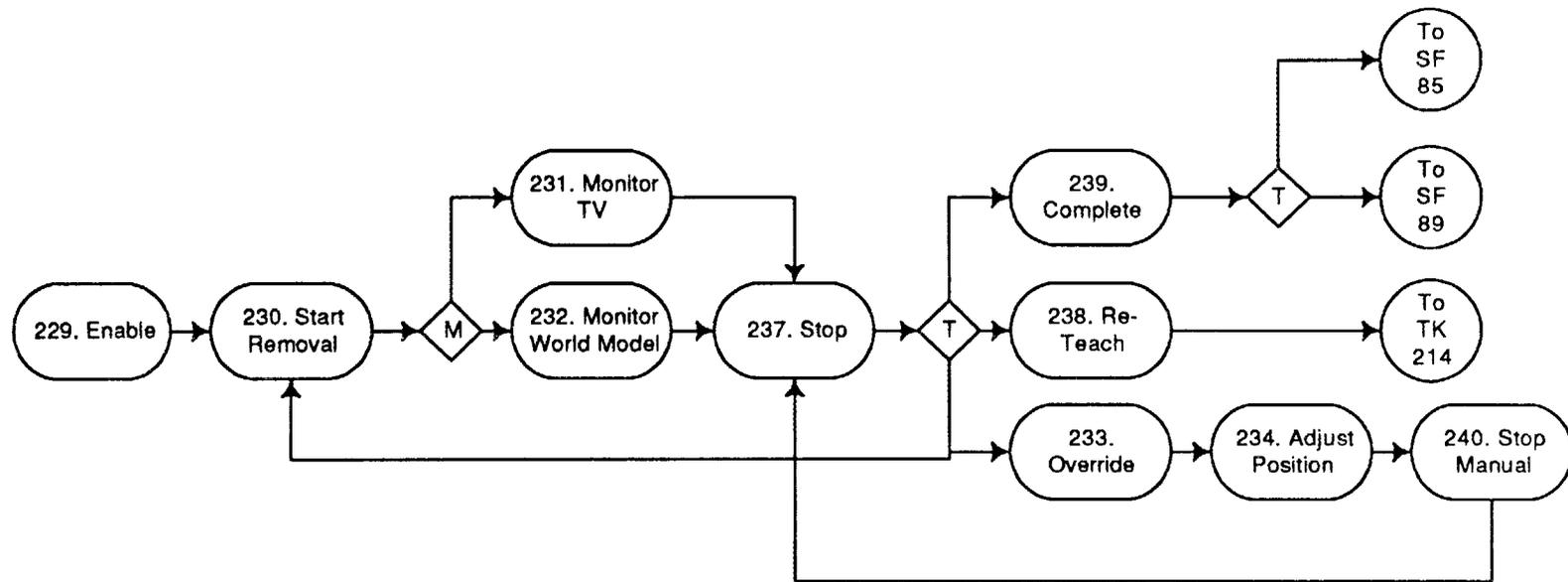


Fig. 28. Task elements during the task "228. Robotic Removal."

2.3.4.2 Task sequence

1. Exchange mapping end effector for waste removal end effector (see Fig. 26).
2. Teach robotic removal sequence (see Fig. 27).
3. Execute robotic removal (see Fig. 28).

2.3.4.3 Terminator

Waste layer is removed.

2.3.5 Remove Residual Waste

During this subfunction, the waste remaining after the last layer has been removed is cleaned from the walls and bottom of the tank. Figure 29 illustrates the tasks in this subfunction, and Figs. 30–33 illustrate the task elements within each task. Once again, automated robotic removal is the preferred option because of the anticipated slow work rate of the end effector.

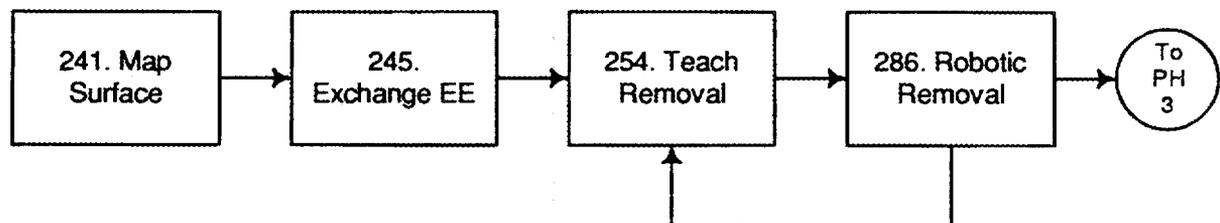


Fig. 29. Tasks during the subfunction "Remove Residual Waste."

2.3.5.1 Initiator

Last layer of waste is removed.

2.3.5.2 Task sequence

1. Map tank surface (see Fig. 30).
2. Exchange waste removal end effector for cleaning end effector (see Fig. 31).
3. Teach robotic removal (see Fig. 32).
4. Execute robotic removal (see Fig 33).

2.3.5.3 Terminator

Residual waste is removed.

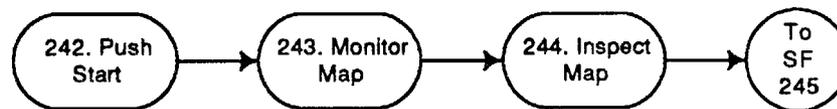


Fig. 30. Task elements during the task "214. Map Surface."

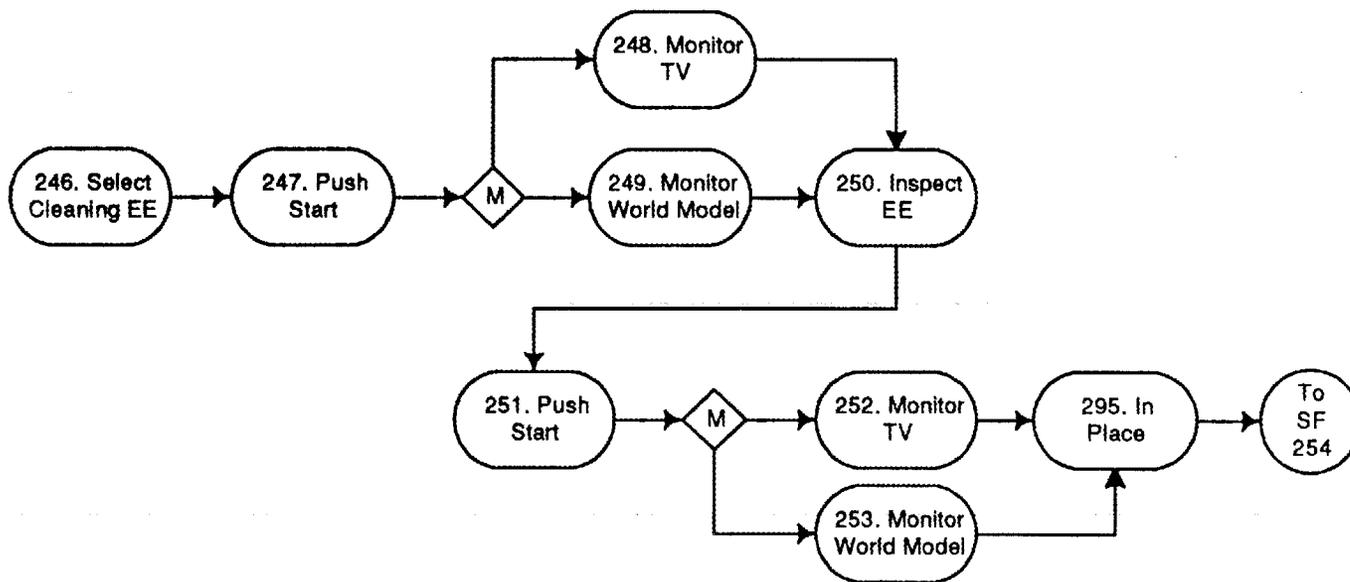


Fig. 31. Task elements during the task "245. Exchange EE."

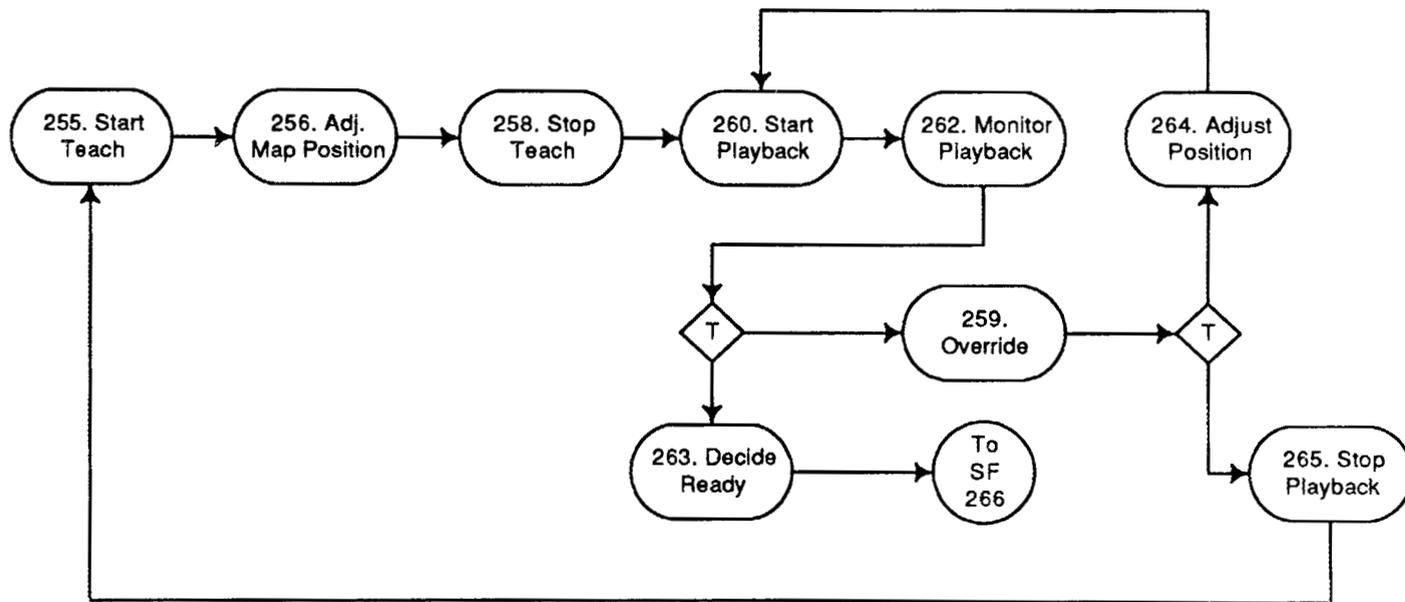


Fig. 32. Task elements during the task "254. Teach Removal."

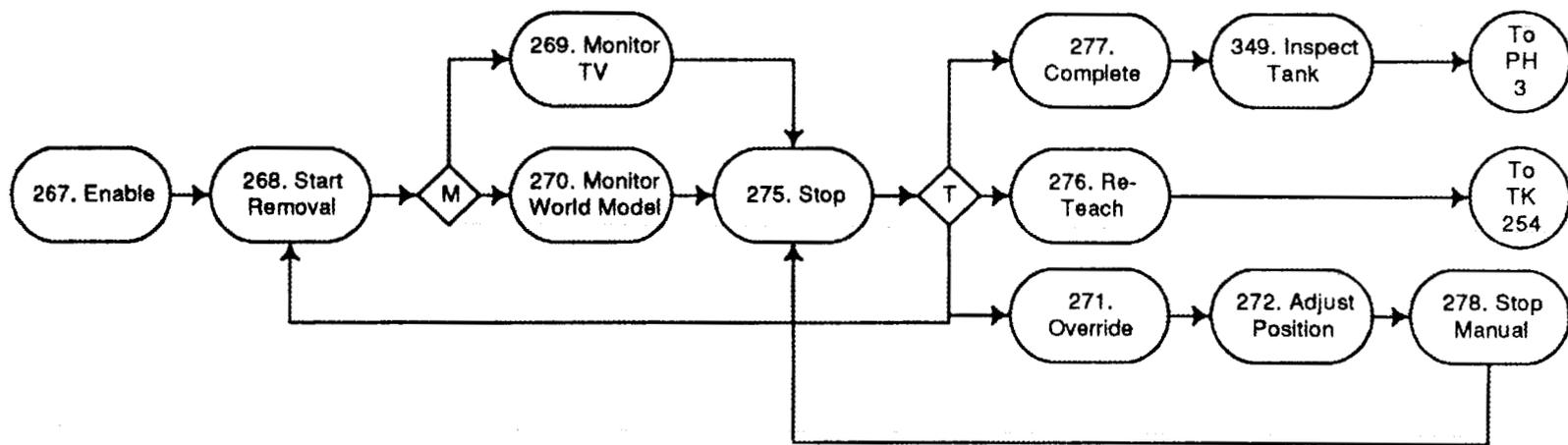


Fig. 33. Task elements during the task "286. Robotic Removal."

2.4 THIRD MISSION PHASE: REMOVE TWRMS EQUIPMENT

During the third mission phase, the TWRMS equipment is removed from the inside of the storage tank. Figure 34 illustrates the subfunctions in this mission phase, and Figs. 35 and 36 illustrate the task elements in each subfunction.

2.4.1 Remove TWRMS Package

The first step in this phase is to remove the TWRMS from the tank.

2.4.1.1 Initiator

Residual waste is removed.

2.4.1.2 Task sequence

1. Prepare for TWRMS removal.
2. Remove TWRMS from tank.

2.4.1.3 Terminator

TWRMS is out of the tank.

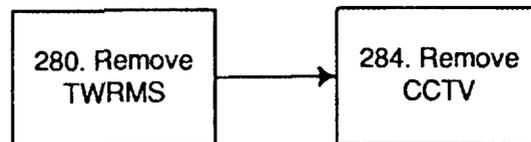


Fig. 34. Subfunctions during the third mission phase.

2.4.2 Remove Aux. CCTV System

During the final subfunction of the campaign, the crew removes the Aux. CCTV system from the tank.

2.4.2.1 Initiator

TWRMS is out of the tank.

2.4.2.2 Task sequence

1. Prepare for Aux. CCTV removal.
2. Remove Aux. CCTV from the tank.

2.4.2.3 Terminator

Aux. CCTV system is out of the tank.

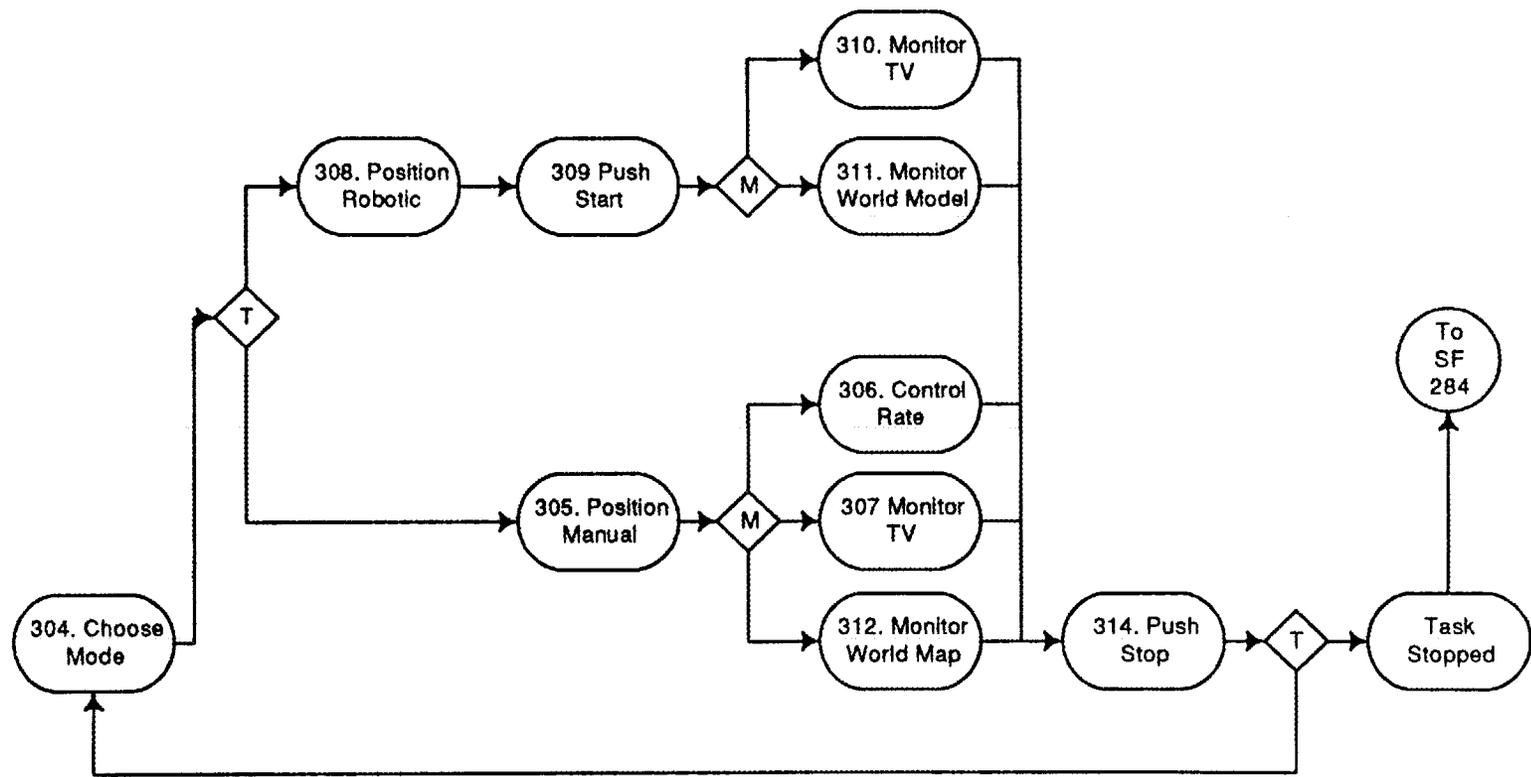


Fig. 35. Task elements during the subfunction "280. Remove TWRMS."

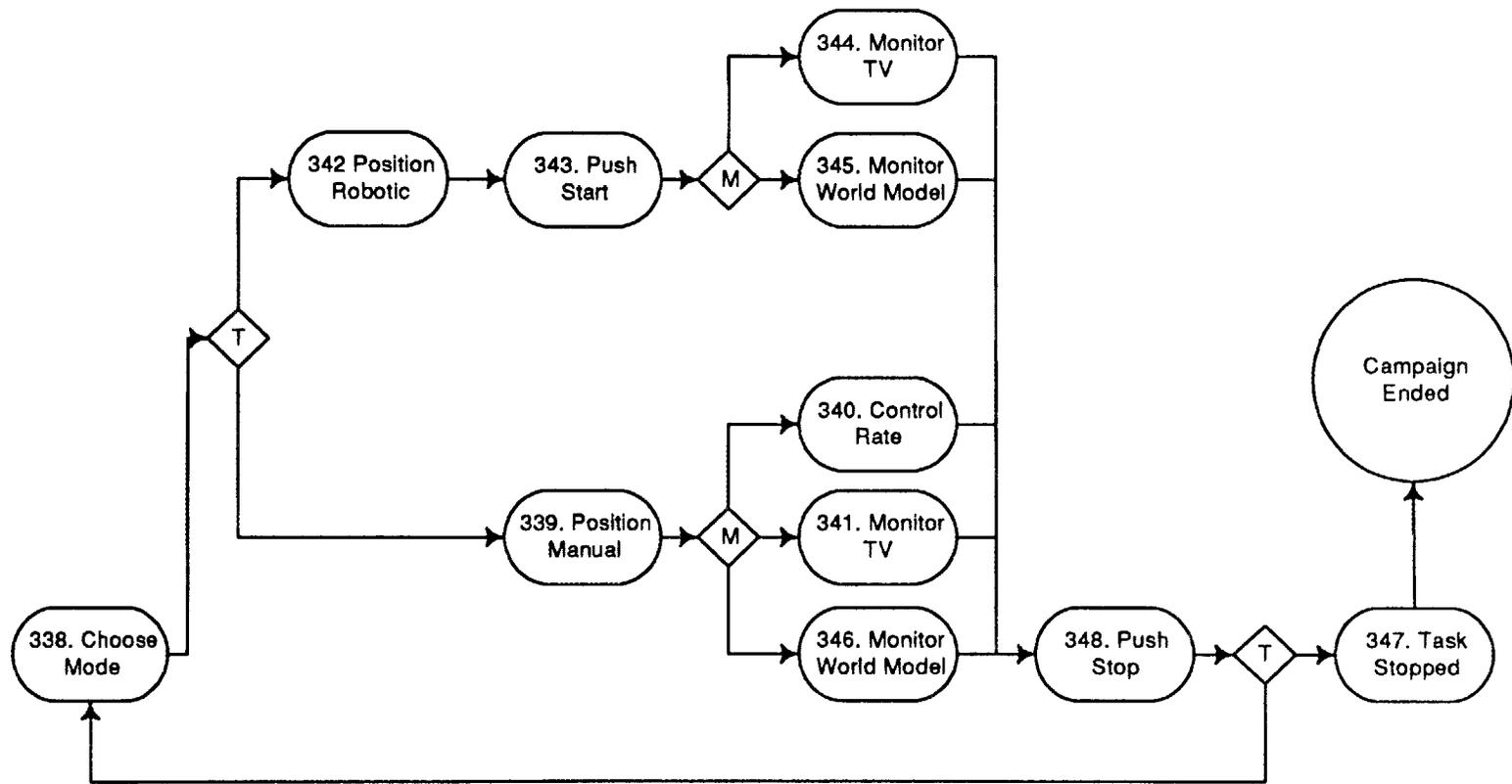


Fig. 36. Task elements during the subfunction "284. Remove CCTV."

3. TASK ANALYSIS RESULTS

3.1 METHODS

The steps in the task analysis thus far have defined a likely sequence for tasks and task elements during a waste retrieval campaign. The next step was to formally examine the task elements and (1) categorize the operator behavior according to a standard behavioral taxonomy,³ (2) determine what system or system component is being controlled or observed, and (3) determine what means (i.e., controls, displays, log books, etc.) are necessary. This was done by filling out an electronic task analysis form for each task. Figure 37 shows a typical, completed task analysis form. The full set of task analysis forms is provided in the Appendix. The task analysis form was designed and completed using the Microsoft Access data base management program, so the completed task analysis forms are a task analysis data base for waste retrieval system operations. This method follows that developed by the NRC for nuclear power plant control rooms³ with some modifications to the task analysis vocabulary necessary to fit the unique needs of the waste retrieval application.

3.2 RESULTS

3.2.1 User Actions, Displays, and Controls

The information provided by the task analysis is a list of the user functions, displays, and controls necessary to operate the system. The task analysis data base makes it possible to identify the user actions, displays, and controls necessary during each subfunction by sorting and reorganizing the information in the data base. Tables 1–3 provide such a list.

3.2.2 Crew Size and Function Allocation

An earlier study² made a preliminary crew size decision and listed the functions that users must perform. From the task analysis, the preliminary decision to specify a two-person crew appears to be correct. Integrating the function analysis with the task analysis by determining which functions operators perform during each task verifies the crew size decision made in ref. 2 and provides a detailed function allocation for each crew member. Table 4 is a list of tasks and the functions users perform within each task and subfunction.

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sut-Function: 1.2.2 Insert Aux. CCTV System into SST

Task: Robotically insert aux. CCTV into tank

Sequence: 2

Purpose: Carry out robotic insertion

Duration: 0

Cue: Insertion mode selected

Description: After selecting robotic insertion mode, initiate and monitor the insertion process

Comments: Branch 2

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|-------------------|-----------------|-----------|------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | robotic | | aux. CCTV | | discrete control | | |
| 2 | 0 | Pushes | Motor | mode | start | robotic routine | aux. CCTV | | discrete control | | |
| 3 | 0 | Monitors | Perceptual | position | in-band | CCTV platform | aux. CCTV | | TV | | |
| 4 | 0 | Monitors | Perceptual | position | in-band | CCTV platform | aux. CCTV | | world map | | |
| 5 | 0 | Detects | Perceptual | position | out-of-band | CCTV platform | aux. CCTV | | | | |
| 6 | 0 | Pushes | Motor | mode | stop | CCTV platform | aux. CCTV | | discrete control | | |
| 7 | 0 | Chooses | Cognitive | mode | robotic or manual | CCTV platform | aux. CCTV | | | | |

Fig. 37. Typical completed task analysis form.

Table 1. User actions, displays, and controls during each subfunction of the first mission phase

| Subfunction | System/verb | Component/ parameter | State | Means of action |
|---|-------------------------|--------------------------|--------------------|----------------------|
| 1.1 Activate Aux. CCTV System | Inspects | | Readiness | Visual |
| | Requests | | Readiness | Verbal communication |
| | Decides | Readiness | Full | |
| | Inspects | Computer | | |
| | Decides | Mode | Operable | Computer |
| | Informs | Mode | Start | Verbal communication |
| | Receives | Readiness | | Verbal communication |
| | Aux. CCTV | Aux. CCTV remotes | | |
| | Monitors | Output signal | In-band | CRT |
| | Positions | Power | On | Discrete control |
| | Aux. CCTV | Cameras | | |
| | Adjusts | Position | Continuous control | |
| | Aux. CCTV | Control computers | | |
| | Decides | Mode | Operable | |
| | Decides | Mode | Operable | |
| | Monitors | Output signal | In-band | CRT |
| | Positions | Power | On | Discrete control |
| Aux. CCTV | Electrical power | | | |
| Positions | Power | On | Discrete control | |
| 1.2 Insert Aux. CCTV System into SST | | | | |
| | Aux. CCTV | | | |
| | Chooses | Mode | Robotic or manual | |
| 1.2.1 Insert Aux. CCTV System into SST | | | | |
| | Aux. CCTV | | | |
| | Positions | Mode | Manual | Discrete control |
| | Monitors | Position | | TV |
| | Adjusts | Rate | | Continuous control |
| 1.2.2 Insert Aux. CCTV System into SST | | | | |
| | Aux. CCTV | | | |
| | Pushes | Mode | Robotic | Discrete control |
| | Aux. CCTV | CCTV platform | | |

Table 1. (continued)

| Subfunction | System/verb | Component/ parameter | State | Means of action |
|---|-------------------|--------------------------|----------------------|----------------------|
| | Chooses | Mode | Robotic or manual | |
| | Pushes | Mode | Stop | Discrete control |
| | Monitors | Position in-band | | TV |
| | Monitors | Position in-band | | World map |
| | Detects | Position out-of-band | | |
| | Aux. CCTV | Robotic routine | | |
| | Pushes | Mode | Start | Discrete control |
| 1.3 Inspect Tank Interior | | | | |
| | Aux. CCTV | | | |
| | Pushes | Mode | Robotic or manual | Discrete control |
| | Tank | Risers/ITH | | |
| | Inspects | TV | | |
| | Records | Position and status | | Operations Log |
| | Aux. CCTV | TV camera | | |
| | Adjusts | Position | | Continuous control |
| 1.4 Develop Riser Cutting Strategy | | | | |
| | | Risers/ITH | | |
| | Chooses cut order | | | Operations Log |
| | Records | Cut order | | Operations Log |
| 1.5 Activate TWRMS | | | | |
| | Inspects | Readiness | | Visual |
| | Inspects | | | TV |
| | Informs | Mode | Activation | Verbal communication |
| | Decides | Mode | Operable | Computer |
| | Receives | Readiness | Verbal communication | |
| | Requests | Readiness | Verbal communication | |
| | Decides | | Readiness full | |
| | TWRMS | Control computers | | |
| | Decides | | Mode | Operable |
| | Monitors | Output signal | In-band | CRT |
| | Positions | Power | On | Discrete control |
| | TWRMS | Electrical power | | |

Table 1. (continued)

| Subfunction | System/verb | Component/ parameter | State | Means of action |
|------------------------------------|--------------|-------------------------|------------------------|--------------------|
| | Positions | Power | On | Discrete control |
| | TWRMS | TWRMS remotes | | |
| | Monitors | Output signal | In-band | CRT |
| | Positions | Power | On | Discrete control |
| | TWRMS | Manipulator | | |
| | Adjusts | Position | | Continuous control |
| 1.6 Insert TWRMS into SST | | | | |
| | TWRMS | | | |
| | Chooses | Mode | | |
| 1.6.1 Insert TWRMS into SST | | | | |
| | TWRMS | | | |
| | Positions | Mode | Manual | Discrete control |
| | Monitors | Position | | TV |
| | Adjusts | Rate | | Continuous control |
| 1.6.2 Insert TWRMS into SST | | | | |
| | TWRMS | | | |
| | Decides | Mode | Operable or inoperable | |
| | Chooses | Mode | Playback | Discrete control |
| | Pushes | Mode | Playback | Discrete control |
| | Pushes | Mode | Robotic | Discrete control |
| | Chooses | Mode | Robotic or manual | |
| | TWRMS | TWRMS platform | | |
| | Pushes | Mode | Stop | Discrete control |
| | Monitors | Position in-band | World map | |
| | Monitors | Position in-band | TV | |
| | Monitors | Position in-band | World map | |
| | Decides | Position out-of-band | | |
| | TWRMS | Robotic routine | | |
| | Decides | | Mode | Operable |
| | Pushes | Mode | Start | Discrete control |

Table 2. User actions, displays, and controls during the second mission phase

| Subfunction | System/verb | Component/ parameter | State | Means of action |
|---------------------------|---------------------|-------------------------|----------|--------------------|
| 2.1 Cut Risers/ITH | | | | |
| | Computer map | | | |
| | Remembers | Sequence | | Operations Log |
| | Remembers | Sequence | | Operations Log |
| | Inspects | | | CRT |
| | Pushes | Mode | Enable | Discrete control |
| | Pushes | Mode | Enable | Discrete control |
| | World map | Cutting EE | | |
| | Monitors | Cutting | In-band | TV |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Stop | Discrete control |
| | Monitors | Position | | TV |
| | Adjusts | Position | | Continuous control |
| | Monitors | Position | | World map |
| | Monitors | Position | | CRT |
| | Adjusts | Position | | Continuous control |
| | Pushes | Mode | Start | Discrete control |
| | Computer map | Data collection | | |
| | Monitors | Mode | Operable | CRT |
| | Pushes | Mode | Start | Discrete control |
| | World map | TWRMS | | |
| | Monitors | Position | | CRT |
| | Monitors | Position | | CRT |
| | Adjusts | Position | | Continuous control |
| | Adjusts | Position | | Continuous control |
| | World map | Playback | | |
| | Decides | Mode | Operable | |
| | Pushes | Mode | Enable | Discrete control |
| | Monitors | Mode | Operable | TV |
| | Pushes | Mode | Override | Discrete control |
| | Decides | Mode | Override | |
| | Pushes | Mode | Start | Discrete control |
| | Monitors | Mode | Operable | CRT |

Table 2. (continued)

| Subfunction | System/verb | Component/ parameter | State | Means of action |
|---|---------------------|-------------------------|------------------|--------------------|
| | Monitors | Mode | Operable | CRT |
| | Pushes | Mode | Override | Discrete control |
| | Decides | Mode | Override | |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Start | Discrete control |
| | World map | Teach | | |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Stop | Discrete control |
| 2.2 Remove Cut-up Riser/ITH Sections | | | | |
| | TWRMS | | | |
| | Remembers | Sequence | | Operations Log |
| | Remembers | Sequence | | Operations Log |
| | Inspects | | | CRT |
| | Pushes | Mode | Enable | Discrete control |
| | Pushes | Mode | Enable | Discrete control |
| | Monitors | Position | In-band | TV |
| | Computer map | Data collection | | |
| | Monitors | Mode | Operable | CRT |
| | Pushes | Mode | Start | Discrete control |
| | TWRMS | End effector | | |
| | Inspects | TV | | |
| | Pushes | Gripper | Discrete control | |
| | Pushes | Mode | Start | Discrete control |
| | World map | Gripper EE | | |
| | Monitors | Gripper EE | In-band | TV |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Stop | Discrete control |
| | Monitors | Position | | TV |
| | Monitors | Position | | World map |
| | Adjusts | Position | | Continuous control |
| | Adjusts | Position | | Continuous control |
| | Monitors | Position | | CRT |
| | Pushes | Mode | Start | Discrete control |

Table 2. (continued)

| Subfunction | System/verb | Component/ parameter | State | Means of action |
|-------------------------------|------------------|-------------------------|----------|--------------------|
| | World map | TWRMS | | |
| | Adjusts | Position | | Continuous control |
| | Adjusts | Position | | Continuous control |
| | Monitors | Position | | CRT |
| | Monitors | Position | | CRT |
| | Monitors | Position in-band | | CRT |
| | World map | Playback | Playback | Playback |
| | Decides | | Mode | Operable |
| | Pushes | Mode | Enable | Discrete control |
| | Monitors | Mode | Operable | TV |
| | Pushes | Mode | Override | Discrete control |
| | Decides | | Mode | Override |
| | Pushes | Mode | Start | Discrete control |
| | Monitors | Mode | Operable | CRT |
| | Monitors | Mode | Operable | CRT |
| | Pushes | Mode | Override | Discrete control |
| | Decides | | Mode | Override |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Start | Discrete control |
| | World map | Teach | Teach | Teach |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Stop | Discrete control |
| 2.3 Characterize Waste | | | | |
| | TWRMS | | | |
| | Inspects | CRT | | |
| | Monitors | Position in-band | TV | |
| | Computer map | Data collection | | |
| | Monitors | Mode | Operable | CRT |
| | Pushes | Mode | Start | Discrete control |
| | TWRMS | End effector | | |
| | Inspects | TV | | |
| | Pushes | Subsurface mapping | | Discrete control |
| | Pushes | Mode | Start | Discrete control |

Table 2. (continued)

| Subfunction | System/verb | Component/ parameter | State | Means of action |
|-------------------------------|------------------|-------------------------|---------------------|--------------------|
| 2.4 Remove Waste Layer | World map | TWRMS | | |
| | Monitors | Position | In-band | CRT |
| | Decides | Composition etc. | | |
| | Records | Composition etc. | | Operations Log |
| | | TWRMS | | |
| | Remembers | Sequence | | Operations Log |
| | Remembers | Sequence | | Operations Log |
| | Pushes | Mode | Enable | Discrete control |
| | Pushes | Mode | Enable | Discrete control |
| | Monitors | Position | In-band | TV |
| | | TWRMS | End-effector | |
| | Decides | | | |
| | Inspects | | | TV |
| | Pushes | Subsurface mapping | Discrete control | |
| | Pushes | Mode | Start | Discrete control |
| | | World map | TWRMS | |
| | Adjusts | Position | | Continuous control |
| | Adjusts | Position | | Continuous control |
| | Monitors | Position | | CRT |
| | Monitors | Position | | CRT |
| Monitors | Position in-band | | CRT | |
| World map | Playback | Playback | Playback | |
| Decides | | Mode | Operable | |
| Pushes | Mode | Enable | Discrete control | |
| Monitors | Mode | Operable | TV | |
| Pushes | Mode | Override | Discrete control | |
| Decides | | Mode | Override | |
| Pushes | Mode | Start | Discrete control | |
| Monitors | Mode | Operable | CRT | |
| Monitors | Mode | Operable | CRT | |
| Pushes | Mode | Override | Discrete control | |
| Decides | | Mode | Override | |

Table 2. (continued)

| Subfunction | System/verb | Component/ parameter | State | Means of action |
|----------------------------------|------------------|-------------------------|------------------|--------------------|
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Start | Discrete control |
| | World map | Teach | Teach | Teach |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Stop | Discrete control |
| | World map | Waste removal EE | | |
| | Monitors | Gripper EE in-band | TV | |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Stop | Discrete control |
| | Adjusts | Position | | Continuous control |
| | Monitors | Position | | CRT |
| | Monitors | Position | | TV |
| | Adjusts | Position | | Continuous control |
| | Monitors | Position | | World map |
| | Pushes | Mode | Start | Discrete control |
| 2.5 Remove Residual Waste | | | | |
| | TWRMS | | | |
| | Records | Operations Log | | |
| | Inspects | TV | | |
| | Remembers | Sequence | | Operations Log |
| | Remembers | Sequence | | Operations Log |
| | Pushes | Mode | Enable | Discrete control |
| | Pushes | Mode | Enable | Discrete control |
| | Monitors | Position in-band | TV | |
| | TWRMS | End effector | | |
| | Inspects | TV | | |
| | Pushes | Subsurface mapping | Discrete control | |
| | Pushes | Mode | Start | Discrete control |
| | World map | TWRMS | | |
| | Adjusts | Position | | Continuous control |
| | Monitors | Position | | CRT |
| | Adjusts | Position | | Continuous control |
| | Monitors | Position | | CRT |

Table 2. (continued)

| Subfunction | System/verb | Component/ parameter | State | Means of action |
|-------------|------------------|-------------------------|----------|--------------------|
| | Monitors | Position | In-band | CRT |
| | World map | Playback | Playback | Playback |
| | Decides | | Mode | Operable |
| | Pushes | Mode | Enable | Discrete control |
| | Monitors | Mode | Operable | TV |
| | Decides | | Mode | Override |
| | Pushes | Mode | Override | Discrete control |
| | Pushes | Mode | Start | Discrete control |
| | Monitors | Mode | Operable | CRT |
| | Monitors | Mode | Operable | CRT |
| | Decides | | Mode | Override |
| | Pushes | Mode | Override | Discrete control |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Start | Discrete control |
| | World map | Tank cleaning EE | | |
| | Monitors | Cleaning EE | In-band | TV |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Stop | Discrete control |
| | Adjusts | Position | | Continuous control |
| | Monitors | Position | | TV |
| | Monitors | Position | | World map |
| | Adjusts | Position | | Continuous control |
| | Monitors | Position | | CRT |
| | Pushes | Mode | Start | Discrete control |
| | World map | Teach | Teach | Teach |
| | Pushes | Mode | Start | Discrete control |
| | Pushes | Mode | Stop | Discrete control |

Table 3. User actions, controls, and displays during the third mission phase

| Subfunction | System/verb | Component/ parameter | State | Means of action |
|---|---|---|---|---|
| 3.1 Remove TWRMS from SST | TWRMS Chooses | Mode | | |
| 3.1.1 Remove TWRMS from SST | TWRMS Positions Monitors Adjusts | Mode Position Rate | Manual | Discrete control TV Continuous control |
| 3.1.2 Remove TWRMS from SST | TWRMS Pushes Chooses TWRMS Pushes Monitors Monitors Decides TWRMS Pushes | Mode Mode TWRMS platform Mode Position in-band Position in-band Position out-of-band Robotic routine Mode | Robotic Robotic or manual Stop | Discrete control Discrete control World map TV Discrete control |
| 3.2 Remove Aux. CCTV System from SST | Aux. CCTV Chooses Positions Pushes Chooses Monitors Adjusts Aux. CCTV Pushes Monitors Monitors Decides Aux. CCTV Pushes | Mode Mode Mode Mode Position Rate CCTV platform Mode Position in-band Position in-band Position out-of-band Robotic routine Mode | Manual Robotic Robotic or manual Stop Start | Discrete control Discrete control TV Continuous control Discrete control World map TV Discrete control |

Table 4. User functions for each crew member

| 1. Insert WaRMS Equipment into SST | |
|---|--|
| 1.1 Activate Aux. CCTV system | |
| Prepare for Aux. CCTV activation | |
| Chief | Monitor system status Restart system |
| Monitor | Monitor system status Communicate with outside |
| Activate Aux. CCTV system | |
| Chief | Monitor system status Restart system |
| Monitor | Monitor system status |
| Verify Aux. CCTV functioning | |
| Chief | Visually monitor end-effector operations Converge stereo cameras Iris camera Pan camera Roll camera Select camera Tilt camera Zoom camera |
| Monitor | Visually monitor end-effector operations |
| 1.2.1 Insert Aux. CCTV System into SST | |
| Manually insert Aux. CCTV into tank | |
| Chief | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status Manually maneuver aux. |
| Monitor | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status |
| Robotically insert Aux. CCTV into tank | |
| Chief | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Initiate robotic deployment sequence |
| Monitor | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status |
| 1.3. Inspect Tank Interior | |
| Inspect tank interior using Aux. CCTV | |
| Chief | Visually monitor end-effector operations Converge stereo cameras Iris camera Pan camera Roll camera Select camera Tilt camera |

Table 4. (continued)

| | |
|--|--|
| Monitor | Zoom camera Visually monitor end-effector operations Monitor system status Maintain operations log |
| 1.4. Develop Riser Cutting Strategy | |
| Develop and record riser cutting sequence | |
| Monitor | Maintain operations log |
| 1.5. Activate TWRMS | |
| Prepare for TWRMS activation | |
| Monitor | Monitor system status |
| Activate TWRMS | |
| Chief | Monitor system status Restart system |
| Monitor | Maintain operations log |
| Verify TWRMS functioning | |
| Chief | Aurally monitor remote sounds Monitor manipulator forces Monitor manipulator sensor data Visually monitor end-effector trajectories Manually control end effector using position control Manually control end effector using rate control |
| Monitor | Aurally monitor remote sounds Monitor manipulator forces Monitor manipulator sensor data Visually monitor end-effector trajectories Monitor system status Maintain operations log |
| 1.6.1 Insert TWRMS into SST | |
| Manually insert TWRMS into tank | |
| Chief | Monitor functions Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status Manually maneuver aux. |
| Monitor | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status |
| 1.6.2 Insert TWRMS into SST | |
| Robotically insert TWRMS into tank | |
| Chief | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Initiate robotic deployment sequence |
| Monitor | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status |

Table 4. (continued)

| | |
|-------------------------------------|---|
| 2. Remove Waste Layers | |
| 2.1. Cut Risers/ITH | |
| Map waste surface | |
| Chief | Monitor system status Engage acoustic proximity sensor-based surface mapping Engage laser range finder-based surface mapping Engage optical proximity sensor-based surface mapping Engage structured light-based surface mapping |
| Monitor | Monitor system status Maintain operations log |
| Teach riser cutting sequence | |
| Chief | Visually monitor manipulator position Visually monitor playback on world model Engage automatic playback Engage semiautomatic playback Engage step-through playback Engage teaching Manually control end effector using position control Manually control end effector using rate control Manually make teaching inputs Maintain operations log |
| Monitor | |
| Robotically cut risers/ITH | |
| Chief | Aurally monitor remote sounds Monitor end-effector sensor data Monitor manipulator forces Monitor manipulator sensor data Visually monitor end-effector operations on video Visually monitor end-effector trajectories on video Visually monitor manipulator position on world model Detect watchdog action Monitor system status Engage automatic playback Engage semiautomatic playback Engage sensor-based obstacle avoidance Engage step-through playback Engage end effector Converge stereo cameras Disengage end-effector tracking Engage end-effector tracking Iris camera Pan camera Roll camera Select camera Tilt camera Zoom camera |
| Monitor | Aurally monitor remote sounds Monitor collision avoidance system Monitor manipulator forces Monitor end-effector sensor data Monitor manipulator sensor data |

Table 4. (continued)

| | |
|--|--|
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |
| | Maintain operations log |
| Manually cut risers | |
| Chief | <p>Aurally monitor remote sounds</p> <p>Monitor collision avoidance system</p> <p>Monitor end-effector sensor data</p> <p>Monitor manipulator forces</p> <p>Monitor manipulator sensor data</p> <p>Visually monitor end-effector operations on video</p> <p>Visually monitor end-effector trajectories on video</p> <p>Visually monitor manipulator position on world model</p> <p>Detect watchdog action</p> <p>Monitor system status</p> <p>Engage sensor-based obstacle avoidance</p> <p>Engage end effector</p> <p>Converge stereo cameras</p> <p>Disengage end-effector tracking</p> <p>Engage end-effector tracking</p> <p>Iris camera</p> <p>Pan camera</p> <p>Roll camera</p> <p>Select camera</p> <p>Tilt camera</p> <p>Zoom camera</p> |
| Monitor | <p>Aurally monitor remote sounds</p> <p>Monitor collision avoidance system</p> <p>Monitor manipulator forces</p> <p>Monitor end-effector sensor data</p> <p>Monitor manipulator sensor data</p> <p>Visually monitor end-effector operations on video</p> <p>Visually monitor end-effector trajectories on video</p> <p>Visually monitor manipulator position on world model</p> <p>Maintain operations log</p> |
| 2.2 Remove Cut-up Riser/ITH Sections | |
| Exchange cutting end effector for gripper | |
| Chief | <p>Aurally monitor remote sounds</p> <p>Monitor collision avoidance system</p> <p>Monitor end-effector sensor data</p> <p>Monitor manipulator forces</p> <p>Monitor manipulator sensor data</p> <p>Visually monitor automated end effector</p> <p>Detect watchdog action</p> <p>Monitor system status</p> <p>Initiate automated end-effector changeout</p> <p>Manually control end effector using position control</p> <p>Manually control end effector using rate control</p> <p>Converge stereo cameras</p> <p>Disengage end-effector tracking</p> |

Table 4. (continued)

| | |
|--------------------------------------|--|
| | Engage end-effector tracking |
| | Iris camera |
| | Pan camera |
| | Roll camera |
| | Select camera |
| | Tilt camera |
| | Zoom camera |
| Monitor | Aurally monitor remote sounds |
| | Monitor collision avoidance system |
| | Monitor manipulator forces |
| | Monitor end-effector sensor data |
| | Monitor manipulator sensor data |
| | Visually monitor automated end effector |
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |
| | Maintain operations log |
| Map waste surface | |
| Chief | Monitor system status |
| | Engage acoustic proximity sensor-based surface mapping |
| | Engage laser range finder-based surface mapping |
| | Engage optical proximity sensor-based surface mapping |
| | Engage structured light-based surface mapping |
| Monitor | Monitor system status |
| | Maintain operations log |
| Teach riser removal sequence | |
| Chief | Visually monitor manipulator position on world model |
| | Visually monitor playback on world model |
| | Engage automatic playback |
| | Engage semiautomatic playback |
| | Engage step-through playback |
| | Engage teaching |
| | Manually control end effector using position control |
| | Manually control end effector using rate control |
| | Manually make teaching inputs |
| | Maintain operations log |
| Monitor | |
| Robotically remove risers/ITH | |
| Chief | Aurally monitor remote sounds |
| | Monitor collision avoidance system |
| | Monitor end-effector sensor data |
| | Monitor manipulator forces |
| | Monitor manipulator sensor data |
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |
| | Detect watchdog action |
| | Monitor system status |
| | Engage automatic playback |
| | Engage semiautomatic playback |
| | Engage sensor-based obstacle avoidance |

Table 4. (continued)

| | |
|-------------------------------|--|
| | Engage step-through playback |
| | Engage end effector |
| | Converge stereo cameras |
| | Disengage end-effector tracking |
| | Engage end-effector tracking |
| | Iris camera |
| | Pan camera |
| | Roll camera |
| | Select camera |
| | Tilt camera |
| | Zoom camera |
| Monitor | Aurally monitor remote sounds |
| | Monitor collision avoidance system |
| | Monitor manipulator forces |
| | Monitor end-effector sensor data |
| | Monitor manipulator sensor data |
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |
| | Maintain operations log |
| Manually remove risers | |
| Chief | Aurally monitor remote sounds |
| | Monitor collision avoidance system |
| | Monitor end-effector sensor data |
| | Monitor manipulator forces |
| | Monitor manipulator sensor data |
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |
| | Detect watchdog action |
| | Monitor system status |
| | Engage sensor-based obstacle avoidance |
| | Engage end effector |
| | Converge stereo cameras |
| | Disengage end-effector tracking |
| | Engage end-effector tracking |
| | Iris camera |
| | Pan camera |
| | Roll camera |
| | Select camera |
| | Tilt camera |
| | Zoom camera |
| Monitor | Aurally monitor remote sounds |
| | Monitor collision avoidance system |
| | Monitor manipulator forces |
| | Monitor end-effector sensor data |
| | Monitor manipulator sensor data |
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |

Table 4. (continued)

| | |
|--|---|
| | Maintain operations log |
| 2.3 Characterize Waste | |
| Exchange gripper for mapping end effector | |
| Chief | <ul style="list-style-type: none"> Monitor collision avoidance system Monitor end-effector sensor data Monitor manipulator forces Monitor manipulator sensor data Visually monitor automated end effector Detect watchdog action Monitor system status Initiate automated end-effector changeout Manually control end effector using position control Manually control end effector using rate control Converge stereo cameras Disengage end-effector tracking Engage end-effector tracking Iris camera Pan camera Roll camera Select camera Tilt camera Zoom camera |
| Monitor | <ul style="list-style-type: none"> Aurally monitor remote sounds Monitor collision avoidance system Monitor manipulator forces Monitor end-effector sensor data Monitor manipulator sensor data Visually monitor automated end effector Visually monitor end-effector operations on video Visually monitor end-effector trajectories on video Visually monitor manipulator position on world model Maintain operations log |
| Map waste surface | |
| Chief | <ul style="list-style-type: none"> Monitor system status Engage acoustic proximity sensor-based surface mapping Engage laser range finder-based surface mapping Engage optical proximity sensor-based surface mapping Engage structured light-based surface mapping |
| Monitor | <ul style="list-style-type: none"> Monitor system status Maintain operations log |
| 2.4. Remove Waste Layer | |
| Exchange mapping EE for waste removal EE | |
| Chief | <ul style="list-style-type: none"> Monitor collision avoidance system Monitor end-effector sensor data Monitor manipulator forces Monitor manipulator sensor data Visually monitor automated end effector Detect watchdog action Monitor system status Initiate automated end-effector changeout |

Table 4. (continued)

| | |
|-------------------------------------|--|
| | Manually control end effector using position control |
| | Manually control end effector using rate control |
| | Converge stereo cameras |
| | Disengage end-effector tracking |
| | Engage end-effector tracking |
| | Iris camera |
| | Pan camera |
| | Roll camera |
| | Select camera |
| | Tilt camera |
| | Zoom camera |
| Monitor | Aurally monitor remote sounds |
| | Monitor collision avoidance system |
| | Monitor manipulator forces |
| | Monitor end-effector sensor data |
| | Monitor manipulator sensor data |
| | Visually monitor automated end effector |
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |
| | Maintain operations log |
| Teach waste removal sequence | |
| Chief | Visually monitor manipulator position on world model |
| | Visually monitor playback on world model |
| | Engage automatic playback |
| | Engage semiautomatic playback |
| | Engage step-through playback |
| | Engage teaching |
| | Manually control end effector using position control |
| | Manually control end effector using rate control |
| | Manually make teaching inputs |
| | Maintain operations log |
| Monitor | |
| Robotically remove waste | |
| Chief | Aurally monitor remote sounds |
| | Monitor collision avoidance system |
| | Monitor end-effector sensor data |
| | Monitor manipulator forces |
| | Monitor manipulator sensor data |
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |
| | Detect watchdog action |
| | Monitor system status |
| | Engage automatic playback |
| | Engage semiautomatic playback |
| | Engage sensor-based obstacle avoidance |
| | Engage step-through playback |
| | Engage end effector |
| | Converge stereo cameras |
| | Disengage end-effector tracking |

Table 4. (continued)

| | |
|--------------------------------------|--|
| | Engage end-effector tracking |
| | Iris camera |
| | Pan camera |
| | Roll camera |
| | Select camera |
| | Tilt camera |
| | Zoom camera |
| Monitor | Aurally monitor remote sounds |
| | Monitor collision avoidance system |
| | Monitor manipulator forces |
| | Monitor end-effector sensor data |
| | Monitor manipulator sensor data |
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |
| | Maintain operations log |
| Manually remove waste | |
| Chief | Aurally monitor remote sounds |
| | Monitor collision avoidance system |
| | Monitor end-effector sensor data |
| | Monitor manipulator forces |
| | Monitor manipulator sensor data |
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |
| | Detect watchdog action |
| | Monitor system status |
| | Engage sensor-based obstacle avoidance |
| | Engage end effector |
| | Converge stereo cameras |
| | Disengage end-effector tracking |
| | Engage end-effector tracking |
| | Iris camera |
| | Pan camera |
| | Roll camera |
| | Select camera |
| | Tilt camera |
| | Zoom camera |
| Monitor | Aurally monitor remote sounds |
| | Monitor collision avoidance system |
| | Monitor manipulator forces |
| | Monitor end-effector sensor data |
| | Monitor manipulator sensor data |
| | Visually monitor end-effector operations on video |
| | Visually monitor end-effector trajectories on video |
| | Visually monitor manipulator position on world model |
| | Maintain operations log |
| 2.5. Remove Residual Waste | |
| Exchange waste removal EE for | |
| cleaning EE | |

Table 4. (continued)

| | |
|--|---|
| Chief | Monitor collision avoidance system Monitor end-effector sensor data Monitor manipulator forces Monitor manipulator sensor data Visually monitor automated end effector Detect watchdog action Monitor system status Initiate automated end-effector changeout Manually control end-effector using position control Manually control end-effector using rate control Converge stereo cameras Disengage end-effector tracking Engage end-effector tracking Iris camera Pan camera Roll camera Select camera Tilt camera Zoom camera |
| Monitor | Aurally monitor remote sounds Monitor collision avoidance system Monitor manipulator forces Monitor end-effector sensor data Monitor manipulator sensor data Visually monitor automated end effector Visually monitor end-effector operations on video Visually monitor end-effector trajectories on video Visually monitor manipulator position on world model Maintain operations log |
| Teach tank cleaning sequence | |
| Chief | Visually monitor manipulator position on world model Visually monitor playback on world model Engage automatic playback Engage semiautomatic playback Engage step-through playback Engage teaching Manually control end effector using position control Manually control end effector using rate control Manually make teaching inputs Maintain operations log |
| Monitor | |
| Robotically remove residual waste | |
| Chief | Aurally monitor remote sounds Monitor collision avoidance system Monitor end-effector sensor data Monitor manipulator forces Monitor manipulator sensor data Visually monitor end-effector operations on video Visually monitor end-effector trajectories on video Visually monitor manipulator position on world model Detect watchdog action |

Table 4. (continued)

| | |
|---|--|
| | <p>Monitor system status</p> <p>Engage automatic playback</p> <p>Engage semiautomatic playback</p> <p>Engage sensor-based obstacle avoidance</p> <p>Engage step-through playback</p> <p>Engage end effector</p> <p>Converge stereo cameras</p> <p>Disengage end-effector tracking</p> <p>Engage end-effector tracking</p> <p>Iris camera</p> <p>Pan camera</p> <p>Roll camera</p> <p>Select camera</p> <p>Tilt camera</p> <p>Zoom camera</p> |
| Monitor | <p>Aurally monitor remote sounds</p> <p>Monitor collision avoidance system</p> <p>Monitor manipulator forces</p> <p>Monitor end-effector sensor data</p> <p>Monitor manipulator sensor data</p> <p>Visually monitor end-effector operations on video</p> <p>Visually monitor end-effector trajectories on video</p> <p>Visually monitor manipulator position on world model</p> <p>Maintain operations log</p> |
| Manually remove residual waste Chief | <p>Aurally monitor remote sounds</p> <p>Monitor collision avoidance system</p> <p>Monitor end-effector sensor data</p> <p>Monitor manipulator forces</p> <p>Monitor manipulator sensor data</p> <p>Visually monitor end-effector operations on video</p> <p>Visually monitor end-effector trajectories on video</p> <p>Visually monitor manipulator position on world model</p> <p>Detect watchdog action</p> <p>Monitor system status</p> <p>Engage sensor-based obstacle avoidance</p> <p>Engage end effector</p> <p>Converge stereo cameras</p> <p>Disengage end-effector tracking</p> <p>Engage end-effector tracking</p> <p>Iris camera</p> <p>Pan camera</p> <p>Roll camera</p> <p>Select camera</p> <p>Tilt camera</p> <p>Zoom camera</p> |
| Monitor | <p>Aurally monitor remote sounds</p> <p>Monitor collision avoidance system</p> <p>Monitor manipulator forces</p> <p>Monitor end-effector sensor data</p> |

Table 4. (continued)

| | |
|--|--|
| | Monitor manipulator sensor data Visually monitor end-effector operations on video Visually monitor end-effector trajectories on video Visually monitor manipulator position on world model Maintain operations log |
| Inspect tank interior | |
| Chief | Visually monitor end-effector operations Converge stereo cameras Iris camera Pan camera Roll camera Select camera Tilt camera Zoom camera |
| Monitor | Visually monitor end-effector operations Monitor system status Maintain operations log |
| 3. Remove WaRMS Equipment from SST | |
| 3.1.1. Remove TWRMS from SST | |
| Manually remove TWRMS from tank | |
| Chief | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status Manually maneuver aux. |
| Monitor | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status |
| 3.1.2. Remove TWRMS from SST | |
| Robotically remove TWRMS from tank | |
| Chief | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Initiate robotic deployment sequence |
| Monitor | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status |
| 3.2. Remove Aux. CCTV System from SST | |
| Manually remove Aux. CCTV from tank | |
| Chief | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status Manually maneuver aux. |
| Monitor | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status |

Table 4. (continued)

| 3.2. Remove Aux. CCTV System from SST | |
|---|---|
| Robotically remove Aux. CCTV from tank | |
| Chief | Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment |
| Monitor | Initiate robotic deployment sequence Aurally monitor remote sounds Monitor collision avoidance system Visually monitor deployment Monitor system status |

3.2.3 Panel Groups

A panel group, the fundamental building block of a control room concept, is a set of displays or controls that must be simultaneously available for an operator to successfully complete a task. Panel groups should not be confused with control/display panels; the panel group is an organizational concept that specifies what must be available within the control/display panel that is its physical manifestation. In a systematic design approach, panel groups define what control/display panels must include; control/display panels are then designed to meet these requirements efficiently and integrated into workstations that meet the operator's needs during the campaign.

Panel groups for the TWRMS were identified by examining the task analysis forms for each subfunction and the user functions table (i.e., by combining, for each operator, Tables 1–3 and Table 4). This allows identification of controls and displays that must be available at the same time.

3.2.3.1 TWRMS chief

Table 5 lists 16 panel groups that may be identified from the task and function analyses for the TWRMS chief.

Table 5. Panel groups for the TWRMS chief

| Panel type | Panel description |
|----------------|--|
| Display groups | <ol style="list-style-type: none"> 1. System status monitors 2. Remote viewing 3. Remote sound 4. Collision avoidance 5. Manipulator outputs 6. World map 7. End-effector outputs |
| Control groups | <ol style="list-style-type: none"> 1. Power (startup) 2. Camera controls 3. Auxiliary CCTV system maneuvering 4. Manipulator inputs 5. TWRMS platform maneuvering 6. Remote mapping 7. Virtual maneuvering 8. End-effector inputs 9. Robotic operations |

Some of these panel groups are similar functions or may include a small number of functions. For example, auxiliary CCTV system maneuvering and LRM platform maneuvering will likely require some identical controls and may be combined into one panel, which may be called the platform maneuvering panel. For another example, end-effector inputs will likely be limited to turning the end effector on or off. This control may be integrated into another panel, perhaps manipulator inputs. There are also natural couplings between some displays and controls: (1) The remote viewing display panel will be manipulated by the camera control panel. (2) The power control panel will have an impact on system status monitors. (3) The remote mapping control panel will have an impact on the world map display panel. These natural similarities and relationships allow a smaller set of panel groups to be specified for the TWRMS chief. Table 6 lists a revised set of panel groups for the TWRMS chief.

Table 6. Revised/control display panel groups for the TWRMS chief

| Panel type | Panel description |
|----------------|---|
| Display groups | <ol style="list-style-type: none"> 1. System status 2. Remote viewing 3. Remote sound 4. Collision avoidance 5. Manipulator outputs 6. World map 7. End-effector outputs |
| Control groups | <ol style="list-style-type: none"> 1. Power (startup) 2. Camera controls 3. Platform maneuvering 4. Manipulator and end-effector inputs 5. Remote mapping 6. Virtual maneuvering 7. Robotic operations |

Returning to the task analysis, we can identify for each task the display and control panels that are required and, furthermore, rank the criticality of each panel for that task. By understanding the work flow (via the task analysis) and integrating the criticality rankings for each panel during each task, it will be possible to configure the workstation to optimize efficiency throughout the process. Tables 7-9 show a prioritized list of TWRMS chief panels required during each task.

3.2.3.2 TWRMS monitor

A similar process can be used to identify panels for the TWRMS monitor. From the task and function analyses, 16 panel groups may be identified for the TWRMS monitor (see Table 10).

Table 7. Panel groups for the TWRMS chief during each task in the first mission phase

| Mission Phase 1 | Subfunction | Task | Primary display panel | Primary control panel | Secondary display panel | Secondary control panel | Tertiary display panel | Tertiary control panel |
|------------------------------------|--|---|-----------------------|---|---------------------------|----------------------------|------------------------|----------------------------|
| 1. Insert WaRMS equipment into SST | 1.1 Activate Aux. CCTV system | Prepare for Aux. CCTV activation | None | None | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.1 Activate Aux. CCTV system | Activate Aux. CCTV system | System status panel | Power panel | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.1 Activate Aux. CCTV system | Verify Aux. CCTV functioning | Remote viewing panel | Camera control panel | System status panel | Power panel | None | None |
| 1. Insert WaRMS equipment into SST | 1.2 Insert Aux. CCTV system into SST | Choose insertion mode (manual or robotic) | None | None | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.2.1 Insert Aux. CCTV system into SST | Manually insert Aux. CCTV into tank | Remote viewing panel | Platform maneuvering panel | System status panel | Power panel | Remote sound panel | None |
| 1. Insert WaRMS equipment into SST | 1.2.2 Insert Aux. CCTV system into SST | Robotically insert Aux. CCTV into tank | Remote viewing panel | Robotic operations panel | System status panel | Power panel | Remote sound panel | Platform maneuvering panel |
| 1. Insert WaRMS equipment into SST | 1.3 Inspect tank interior | Inspect tank interior using Aux. CCTV | Remote viewing panel | Camera control panel | System status panel | Platform maneuvering panel | Remote sound panel | Robotic operations panel |
| 1. Insert WaRMS equipment into SST | 1.4 Develop riser cutting strategy | Develop and record riser cutting sequence | None | None | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.5 Activate LRM system | Prepare for LRM activation | None | None | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.5 Activate LRM system | Activate LRM system | System status panel | Power panel | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.5 Activate LRM system | Verify LRM functioning | Remote viewing panel | Manipulator and end-effector inputs panel | Manipulator outputs panel | Platform maneuvering panel | System status panel | Power panel |
| 1. Insert WaRMS equipment into SST | 1.6 Insert LRM system into SST | Choose insertion mode (manual or robotic) | None | None | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.6.1 Insert LRM system into SST | Manually insert LRM into tank | Remote viewing panel | Platform maneuvering panel | System status panel | Power panel | Remote sound panel | None |
| 1. Insert WaRMS equipment into SST | 1.6.2 Insert LRM system into SST | Robotically insert LRM into tank | Remote viewing panel | Robotic operations panel | System status panel | Power panel | Remote sound panel | Platform maneuvering panel |

Table 8. Panel groups for the TWRMS chief during each task in the second mission phase

| Mission Phase 2 | Subfunction | Task | Primary display panel | Primary control panel | Secondary display panel | Secondary control panel | Tertiary display panel | Tertiary control panel |
|------------------------|--------------------------------------|---|----------------------------|---|---------------------------|---|----------------------------|---|
| 2. Remove waste layers | 2.1 Cut risers/ITH | Map waste surface | World map panel | Remote mapping panel | System status panel | Camera control panel | Remote viewing panel | None |
| 2. Remove waste layers | 2.1 Cut risers/ITH | Teach riser cutting sequence | World map panel | Virtual maneuvering panel | Remote viewing panel | Camera control panel | None | Manipulator and end-effector inputs panel |
| 2. Remove waste layers | 2.1 Cut risers/ITH | Robotically cut risers/ITH | Remote viewing | Robotic operations panel | World map panel | Manipulator and end-effector inputs panel | Remote sound panel | Manipulator outputs panel |
| 2. Remove waste layers | 2.1 Cut risers/ITH | Manually cut risers | Remote viewing panel | Manipulator and end-effector inputs panel | Manipulator outputs panel | Camera controls panel | Remote sound panel | None |
| 2. Remove waste layers | 2.2 Remove cut-up riser/ITH sections | Exchange cutting end-effector for gripper | Remote viewing panel | Robotic operations panel | World map panel | Manipulator and end-effector inputs panel | End-effector outputs panel | None |
| 2. Remove waste layers | 2.2 Remove cut-up riser/ITH sections | Map waste surface | World map panel | Remote mapping panel | System status panel | Camera control panel | Remote viewing panel | None |
| 2. Remove waste layers | 2.2 Remove cut-up riser/ITH sections | Teach riser removal sequence | World map panel | Virtual maneuvering panel | Remote viewing panel | Camera control panel | None | Manipulator and end-effector inputs panel |
| 2. Remove waste layers | 2.2 Remove cut-up riser/ITH sections | Robotically remove risers/ITH | Remote viewing | Robotic operations panel | World map panel | Manipulator and end-effector inputs panel | Remote sound panel | Manipulator outputs panel |
| 2. Remove waste layers | 2.2 Remove cut-up riser/ITH sections | Manually remove risers | Remote viewing panel | Manipulator and end-effector inputs panel | Manipulator outputs panel | Camera controls panel | Remote sound panel | None |
| 2. Remove waste layers | 2.3 Characterize waste | Exchange gripper for mapping end effector | Remote viewing panel | Robotic operations panel | World map panel | Manipulator and end-effector inputs panel | End-effector outputs panel | None |
| 2. Remove waste layers | 2.3 Characterize waste | Map waste surface | World map panel | Remote mapping panel | System status panel | Camera control panel | Remote viewing panel | None |
| 2. Remove waste layers | 2.3 Characterize waste | Determine waste composition | End-effector outputs panel | Remote mapping panel | Remote viewing panel | Camera control panel | System status panel | None |
| 2. Remove waste layers | 2.4 Remove waste layer | Exchange mapping EE for waste removal EE | Remote viewing panel | Robotic operations panel | World map panel | Manipulator and end-effector inputs panel | End-effector outputs panel | None |
| 2. Remove waste layers | 2.4 Remove waste layer | Teach waste removal sequence | World map panel | Virtual maneuvering panel | Remote viewing panel | Camera control panel | None | Manipulator and end-effector inputs panel |
| 2. Remove waste layers | 2.4 Remove waste layer | Robotically remove waste | Remote viewing | Robotic operations panel | World map panel | Manipulator and end-effector inputs panel | Remote sound panel | Manipulator outputs panel |
| 2. Remove waste layers | 2.4 Remove waste layer | Manually remove waste | Remote viewing panel | Manipulator and end-effector inputs panel | Manipulator outputs panel | Camera controls panel | Remote sound panel | None |
| 2. Remove waste layers | 2.5 Remove residual waste | Exchange waste removal EE for cleaning EE | Remote viewing panel | Robotic operations panel | World map panel | Manipulator and end-effector inputs panel | End-effector outputs panel | None |
| 2. Remove waste layers | 2.5 Remove residual waste | Teach tank cleaning sequence | World map panel | Virtual maneuvering panel | Remote viewing panel | Camera control panel | None | Manipulator and end-effector inputs panel |

Table 8. (continued)

| Mission Phase 2 | Subfunction | Task | Primary display panel | Primary control panel | Secondary display panel | Secondary control panel | Tertiary display panel | Tertiary control panel |
|------------------------|---------------------------|-----------------------------------|-----------------------|---|---------------------------|---|------------------------|---------------------------|
| 2. Remove waste layers | 2.5 Remove residual waste | Robotically remove residual waste | Remote viewing | Robotic operations panel | World map panel | Manipulator and end-effector inputs panel | Remote sound panel | Manipulator outputs panel |
| 2. Remove waste layers | 2.5 Remove residual waste | Manually remove residual waste | Remote viewing panel | Manipulator and end-effector inputs panel | Manipulator outputs panel | Camera controls panel | Remote sound panel | None |
| 2. Remove waste layers | 2.5 Remove residual waste | Inspect tank interior | Remote viewing panel | Camera control panel | System status panel | Platform maneuvering panel | Remote sound panel | Robotic operations panel |

Table 9. Panel groups for the TWRMS chief during each task in the third mission phase

| Mission Phase 3 | Subfunction | Task | Primary display panel | Primary control panel | Secondary display panel | Secondary control panel | Tertiary display panel | Tertiary control panel |
|------------------------------------|--------------------------------------|---|-----------------------|----------------------------|-------------------------|-------------------------|------------------------|----------------------------|
| 3. Remove WaRMS equipment from SST | 3.1 Remove LRM system from SST | Choose removal mode (manual or robotic) | None | None | None | None | None | None |
| 3. Remove WaRMS equipment from SST | 3.1.1 Remove LRM system from SST | Manually remove LRM from tank | Remote viewing panel | Platform maneuvering panel | System status panel | Power panel | Remote sound panel | None |
| 3. Remove WaRMS equipment from SST | 3.1.2 Remove LRM system from SST | Robotically remove LRM from tank | Remote viewing panel | Robotic operations panel | System status panel | Power panel | Remote sound panel | Platform maneuvering panel |
| 3. Remove WaRMS equipment from SST | 3.2 Remove Aux. CCTV system from SST | Choose removal mode (manual or robotic) | None | None | None | None | None | None |
| 3. Remove WaRMS equipment from SST | 3.2 Remove Aux. CCTV system from SST | Manually remove Aux. CCTV from tank | Remote viewing panel | Platform maneuvering panel | System status panel | Power panel | Remote sound panel | None |
| 3. Remove WaRMS equipment from SST | 3.2 Remove Aux. CCTV system from SST | Robotically remove Aux. CCTV from tank | Remote viewing panel | Robotic operations panel | System status panel | Power panel | Remote sound panel | Platform maneuvering panel |

Table 10. Panel groups for the TWRMS monitor

| Panel type | Panel description |
|----------------|--|
| Display groups | <ol style="list-style-type: none"> 1. System status monitors 2. Remote viewing 3. Remote sound 4. Collision avoidance 5. Manipulator outputs 6. World map 7. End-effector outputs |
| Control groups | <ol style="list-style-type: none"> 1. Power (startup) 2. Communications 3. Operations log |

In addition to these functions required by the assignment of responsibilities in the task analysis, other control functions could be added so that the TWRMS monitor can assist the TWRMS chief during periods of high workload. These functions are camera controls, remote mapping, virtual maneuvering, and robotic operations. Table 11 lists the complete set of panel groups for the TWRMS monitor. Tables 12–14 provide a prioritized list of the panel groups for the TWRMS monitor during each mission phase, subfunction, and task.

Table 11. Revised set of control/display panel groups for the TWRMS monitor

| Panel type | Panel description |
|----------------|--|
| Display groups | <ol style="list-style-type: none"> 1. System status 2. Remote viewing 3. Remote sound 4. Collision avoidance 5. Manipulator outputs 6. World map 7. End-effector outputs |
| Control groups | <ol style="list-style-type: none"> 1. Power (startup) 2. Camera controls 3. Remote mapping 4. Virtual maneuvering 5. Robotic operations 6. Communications 7. Operations log |

Table 12. Panel groups for the TWRMS monitor during each task in the first mission phase

| Mission phase | Subfunction | Task | Primary display panel | Primary control panel | Secondary display panel | Secondary control panel | Tertiary display panel | Tertiary control panel |
|------------------------------------|--|---|-----------------------|-----------------------|-------------------------|-------------------------|------------------------|------------------------|
| 1. Insert WaRMS equipment into SST | 1.1 Activate Aux. CCTV system | Prepare for Aux. CCTV activation | None | None | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.1 Activate Aux. CCTV system | Activate Aux. CCTV system | System status panel | Communication panel | None | Operations log | None | None |
| 1. Insert WaRMS equipment into SST | 1.1 Activate Aux. CCTV system | Verify Aux. CCTV functioning | Remote viewing panel | Power panel | System status panel | Operations log | None | None |
| 1. Insert WaRMS equipment into SST | 1.2 Insert Aux. CCTV system into SST | Choose insertion mode (manual or robotic) | None | Operations log | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.2.1 Insert Aux. CCTV system into SST | Manually insert Aux. CCTV into tank | Remote viewing panel | Camera control panel | System status panel | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.2.2 Insert Aux. CCTV system into SST | Robotically insert Aux. CCTV into tank | Remote viewing panel | Camera control panel | System status panel | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.3 Inspect tank interior | Inspect tank interior using Aux. CCTV | Remote viewing panel | Camera control panel | System status panel | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.4 Develop riser cutting strategy | Develop and record riser cutting sequence | Remote viewing panel | Operations log | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.5 Activate LRM system | Prepare for LRM activation | None | None | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.5 Activate LRM system | Activate LRM system | System status panel | Communication panel | None | Operations log | None | None |
| 1. Insert WaRMS equipment into SST | 1.5 Activate LRM system | Verify LRM functioning | Remote viewing panel | Power panel | System status panel | Operations log | None | None |
| 1. Insert WaRMS equipment into SST | 1.6 Insert LRM system into SST | Choose insertion mode (manual or robotic) | None | Operations log | None | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.6.1 Insert LRM system into SST | Manually insert LRM into tank | Remote viewing panel | Camera control panel | System status panel | None | None | None |
| 1. Insert WaRMS equipment into SST | 1.6.2 Insert LRM system into SST | Robotically insert LRM into tank | Remote viewing panel | Camera control panel | System status panel | None | None | None |

Table 13. Panel groups for the TWRMS monitor during each task in the second mission phase

| Mission phase | Subfunction | Task | Primary display panel | Primary control panel | Secondary display panel | Secondary control panel | Tertiary display panel | Tertiary control panel |
|------------------------|--------------------------------------|---|-----------------------|--------------------------|-------------------------|---------------------------|------------------------|------------------------|
| 2. Remove waste layers | 2.1 Cut risers/TTH | Map waste surface | World map | Remote mapping panel | System status panel | Operations log | None | None |
| 2. Remove waste layers | 2.1 Cut risers/TTH | Teach riser cutting sequence | World map | Remote mapping panel | None | Operations log | None | None |
| 2. Remove waste layers | 2.1 Cut risers/TTH | Robotically cut risers/TTH | Remote viewing panel | Robotic operations panel | World model | Virtual maneuvering panel | System status panel | Operations log |
| 2. Remove waste layers | 2.1 Cut risers/TTH | Manually cut risers | Remote viewing panel | Camera control panel | System status panel | Operations log | None | None |
| 2. Remove waste layers | 2.2 Remove cut-up riser/TTH sections | Exchange cutting end effector for gripper | Remote viewing panel | Camera control panel | World model | Virtual maneuvering panel | System status panel | Operations log |
| 2. Remove waste layers | 2.2 Remove cut-up riser/TTH sections | Map waste surface | World map | Remote mapping panel | System status panel | Operations log | None | None |
| 2. Remove waste layers | 2.2 Remove cut-up riser/TTH sections | Teach riser removal sequence | World map | Remote mapping panel | None | Operations log | None | None |
| 2. Remove waste layers | 2.2 Remove cut-up riser/TTH sections | Robotically remove risers/TTH | Remote viewing panel | Robotic operations panel | World model | Virtual maneuvering panel | System status panel | Operations log |
| 2. Remove waste layers | 2.2 Remove cut-up riser/TTH sections | Manually remove risers | Remote viewing panel | Camera control panel | System status panel | Operations log | None | None |
| 2. Remove waste layers | 2.3 Characterize waste | Exchange gripper for mapping end effector | Remote viewing panel | Camera control panel | World model | Virtual maneuvering panel | System status panel | Operations log |
| 2. Remove waste layers | 2.3 Characterize waste | Map waste surface | World map | Remote mapping panel | System status panel | Operations log | None | None |
| 2. Remove waste layers | 2.3 Characterize waste | Determine waste composition | World map | Remote mapping panel | System status panel | Operations log | None | None |
| 2. Remove waste layers | 2.4 Remove waste layer | Exchange mapping EE for waste removal EE | Remote viewing panel | Camera control panel | World model | Virtual maneuvering panel | System status panel | Operations log |
| 2. Remove waste layers | 2.4 Remove waste layer | Teach waste removal sequence | World map | Remote mapping panel | None | Operations log | None | None |
| 2. Remove waste layers | 2.4 Remove waste layer | Robotically remove waste | Remote viewing panel | Robotic operations panel | World model | Virtual maneuvering panel | System status panel | Operations log |
| 2. Remove waste layers | 2.4 Remove waste layer | Manually remove waste | Remote viewing panel | Camera control panel | System status panel | Operations log | None | None |
| 2. Remove waste layers | 2.5 Remove residual waste | Exchange waste removal EE for cleaning EE | Remote viewing panel | Camera control panel | World model | Virtual maneuvering panel | System status panel | Operations log |
| 2. Remove waste layers | 2.5 Remove residual waste | Teach tank cleaning sequence | World map | Remote mapping panel | None | Operations log | None | None |
| 2. Remove waste layers | 2.5 Remove residual waste | Robotically remove residual waste | Remote viewing panel | Robotic operations panel | World model | Virtual maneuvering panel | System status panel | Operations log |
| 2. Remove waste layers | 2.5 Remove residual waste | Manually remove residual waste | Remote viewing panel | Camera control panel | System status panel | Operations log | None | None |
| 2. Remove waste layers | 2.5 Remove residual waste | Inspect tank interior | Remote viewing panel | Camera control panel | System status panel | Operations log | None | None |

Table 14. Panel groups for the TWRMS monitor during each task in the second mission phase

| Mission phase | Subfunction | Task | Primary display panel | Primary control panel | Secondary display panel | Secondary control panel | Tertiary display panel | Tertiary control panel |
|------------------------------------|--------------------------------------|---|-----------------------|-----------------------|-------------------------|---------------------------|------------------------|------------------------|
| 3. Remove WaRMS equipment from SST | 3.1 Remove LRM system from SST | Choose removal mode (manual or robotic) | None | None | None | None | None | None |
| 3. Remove WaRMS equipment from SST | 3.1.1 Remove LRM system from SST | Manually remove LRM from tank | Remote viewing panel | Camera control panel | World map | Virtual maneuvering panel | System status panel | Operations log |
| 3. Remove WaRMS equipment from SST | 3.1.2 Remove LRM system from SST | Robotically remove LRM from tank | Remote viewing panel | Camera control panel | World map | Virtual maneuvering panel | System status panel | Operations log |
| 3. Remove WaRMS equipment from SST | 3.2 Remove Aux. CCTV system from SST | Choose removal mode (manual or robotic) | None | None | None | None | None | None |
| 3. Remove WaRMS equipment from SST | 3.2 Remove Aux. CCTV system from SST | Manually remove Aux. CCTV from tank | Remote viewing panel | Camera control panel | World map | Virtual maneuvering panel | System status panel | Operations log |
| 3. Remove WaRMS equipment from SST | 3.2 Remove Aux. CCTV system from SST | Robotically remove Aux. CCTV from tank | Remote viewing panel | Camera control panel | World map | Virtual maneuvering panel | System status panel | Operations log |

4. REMAINING STEPS IN THE PROJECT

The third phase of the task (after function analysis and task analysis) will be to develop conceptual designs of control panels, workstations, and the control room layout. In this phase the panel group organization developed in the first phase will be translated into recommendations for arranging physical components in the control room. The outcome of this phase will be a set of conceptual design drawings describing workstation and control room layout concepts.

4.1 CONTROL PANEL DESIGN

Control panels are the building blocks of workstation design and include all displays and controls necessary for one operator to perform an activity for which he is responsible. The outcome of this part of the task will be conceptual designs for all of the control panels required by each member of the crew. This step will use the panel groups identified in the task analysis and the flow charts (at the task element level) to optimize the arrangement of displays and controls within panels.

4.2 WORKSTATION DESIGN

Workstations include control panels and supporting equipment. Some crew members may require multiple panels (e.g., a control panel to turn on and initialize the equipment and a control panel to conduct manipulator operations); workstations will be designed to integrate or separate multiple control panels as necessary to optimize user efficiency. Workstations will also support the users by providing room for manuals, storage, etc. The outcome of this part of the task will be conceptual design drawings for workstations, including recommendations for displays, controls, cabinets, and seating. This step will use the panel groups and task analysis flowcharts (at the task and subfunction levels) to optimize the arrangement of control/display panels within workstations.

4.3 CONTROL ROOM LAYOUT

The final stage of the design phase will be to integrate workstations into a control room. The control room layout will optimize cooperation and communication among users of separate workstations. The outcome of this part of the task will be a conceptual design drawing for a recommended layout of workstations within the control room. This stage will use task analysis flowcharts at the mission phase and subfunction level to optimize the arrangement of workstations within the control room.

5. SUMMARY

A task analysis was conducted to support control room conceptual design work for the TWRMS. Initially, the control room will be deployed for an integrated demonstration of retrieval technology, but it will also serve as a prototype for a deployable control room for waste retrieval operations.

The study used existing TWRMS concepts to generate a campaign scenario; a formal task analysis, using methods developed for nuclear power plant control rooms, was conducted in this scenario. The task analysis (1) verified preliminary crew size decisions, (2) allowed detailed allocation of functions between members of a two-person crew, (3) allowed organization of control/display requirements for each crew member into related groups, and (4) allowed prioritization of panel groups based on mission stages. The resulting panel groups and prioritization will guide future control/display panel conceptual design work. A task network model developed alongside the task analysis will also guide future control/display panel, workstation, and control room layout conceptual design work.

REFERENCES

1. S. M. Babcock et al., *Single-Shell Tank Waste Retrieval Manipulator System*, ORNL/TM-12210, Oak Ridge Natl. Lab., Martin Marietta Energy Systems, Inc., September 1992.
2. J. V. Draper, *Function Analysis for the Tank Waste Retrieval Manipulator System*, ORNL/TM-12417, Oak Ridge Natl. Lab., Martin Marietta Energy Systems, Inc., August 1993.
3. D. Burgy, et al., *Task Analysis of Nuclear Power Plant Control Room Crews: Project Approach and Methodology* (NUREC/CR-3371, Vol. 1-4). Washington, D.C.: U.S. Nuclear Regulatory Commission 1983.

**APPENDIX
TASK ANALYSIS FORMS**

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.1. Activate Aux. CCTV System

Task: Prepare for aux. CCTV activation **Sequence:** 1

Purpose: Get crew and equipment ready for start-up. **Duration:** 0

Cue: Receive instructions to proceed

Description: After receiving instructions to proceed, prepare the crew and equipment for aux. CCTV system activation.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|---------------|-----------|-------|-----------|-----------|--------------|----------------------|---------------|------------------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Inspects | Perceptual | readiness | | | | control room | visual | | |
| 2 | 0 | Requests | Communication | readiness | | | | | verbal communication | crew | readiness report |
| 3 | | Receives | Communication | readiness | | | aux. CCTV | | verbal communication | | |
| 4 | 0 | Decides | Cognitive | readiness | full | | | | | | |
| 5 | 0 | Informs | Communication | mode | start | | aux. CCTV | | verbal communication | crew | warning |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.1. Activate Aux. CCTV System

Task: Activate aux. CCTV system **Sequence:** 2

Purpose: Turn on the aux. CCTV system **Duration:** 0

Cue: Crew and equipment prepared to activate system

Description: After preparing the crew and equipment for activation, turn on the aux. CCTV system

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|---------------|----------|-------------------|-----------|------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Positions | Motor | power | on | electrical power | aux. CCTV | | discrete control | | |
| 2 | 0 | Positions | Motor | power | on | control computers | aux. CCTV | | discrete control | | |
| 3 | 0 | Monitors | Perceptual | output signal | in-band | control computers | aux. CCTV | | CRT | | |
| 4 | 0 | Decides | Cognitive | mode | operable | control computers | aux. CCTV | | | | |
| 5 | 0 | Positions | Motor | power | on | aux. CCTV remotes | aux. CCTV | | discrete control | | |
| 6 | 0 | Monitors | Perceptual | output signal | in-band | aux. CCTV remotes | aux. CCTV | | CRT | | |
| 7 | 0 | Decides | Cognitive | mode | operable | control computers | aux. CCTV | | | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.1. Activate Aux. CCTV System

Task: Verify aux. CCTV functioning **Sequence:** 3

Purpose: Make sure that the CCTV systems are functioning properly and are **Duration:** 0

Cue: Aux. CCTV activated

Description: After turning on the aux. CCTV, make sure that it is functioning properly.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|---------|-----------|-----------|----------|-----------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Adjusts | Motor | position | | cameras | aux. CCTV | | continuous control | | |
| 2 | 0 | Inspect | | | | | aux. CCTV | | computer | | |
| 3 | 0 | Decides | Cognitive | mode | operable | | aux. CCTV | | computer | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.2. Insert Aux. CCTV System into SST

Task: Choose insertion mode (manual or robotic) **Sequence:** 1

Purpose: Select an insertion mode **Duration:** 0

Cue: Aux. CCTV is ready for insertion

Description: After deciding that the aux. CCTV is ready for insertion, decide whether to use manual or robotic insertion mode.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|---------|-----------|-----------|----------------------|-----------|-----------|------------|-----------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Chooses | Cognitive | mode | robotic or manual | | aux. CCTV | | | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.2.1 Insert Aux. CCTV System into SST

Task: Manually insert aux. CCTV into tank **Sequence:** 2

Purpose: Carry out manual insertion **Duration:** 0

Cue: Insertion mode selected

Description: After selecting manual insertion mode, manually control the insertion process

Comments: Branch 1

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|--------|-----------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Positions | Motor | mode | manual | | aux. CCTV | | discrete control | | |
| 2 | 0 | Adjusts | Motor | rate | | | aux. CCTV | | continuous control | | |
| 3 | 0 | Monitors | Perceptual | position | | | aux. CCTV | | TV | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.2.2 Insert Aux. CCTV System into SST

Task: Robotically insert aux. CCTV into tank **Sequence:** 2
Purpose: Carry out robotic insertion **Duration:** 0
Cue: Insertion mode selected

Description: After selecting robotic insertion mode, initiate and monitor the insertion process

Comments: Branch 2

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|-------------------|-----------------|-----------|------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | robotic | | aux. CCTV | | discrete control | | |
| 2 | 0 | Pushes | Motor | mode | start | robotic routine | aux. CCTV | | discrete control | | |
| 3 | 0 | Monitors | Perceptual | position | in-band | CCTV platform | aux. CCTV | | TV | | |
| 4 | 0 | Monitors | Perceptual | position | in-band | CCTV platform | aux. CCTV | | world map | | |
| 5 | 0 | Detects | Perceptual | position | out-of-band | CCTV platform | aux. CCTV | | | | |
| 6 | 0 | Pushes | Motor | mode | stop | CCTV platform | aux. CCTV | | discrete control | | |
| 7 | 0 | Chooses | Cognitive | mode | robotic or manual | CCTV platform | aux. CCTV | | | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.3. Inspect Tank Interior

Task: Inspect tank interior using aux. CCTV

Sequence: 1

Purpose: Use the aux. CCTV to examine the tank interior

Duration: 0

Cue: Aux. CCTV system in place and functioning

Description: After inserting the aux. CCTV, use it to inspect the tank interior.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|---------------|---------------------|-------------------|------------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | robotic or manual | | aux. CCTV | | discrete control | | |
| 2 | 0 | Adjusts | Motor | position | | TV camera | aux. CCTV | | continuous control | | |
| 3 | 0 | Inspects | Perceptual | | | risers/ITH | tank | | TV | | |
| 4 | 0 | Records | Communication | position and status | | risers/ITH | tank | | Operations Log | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.4. Develop Riser Cutting Strategy

Task: Develop and record riser cutting sequence **Sequence:** 1

Purpose: Determine the order for cutting risers and ITH and record the seq **Duration:** 0

Cue: Risers/ITH noted and described

Description: After inspect the tank and recording the position and status of risers/ITH, develop a cutting strategy and record it in the Operations Log

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Communication | |
|---------|------|---------|----------------|-----------|-------|------------|--------|------------|-----------------|--------------------|
| | | | | | | | | | Means of Action | Respondent Content |
| 1 | 0 | Chooses | Cognitive | cut order | | risers/ITH | | | Operations Log | |
| 2 | 0 | Records | Communicati on | cut order | | risers/ITH | | | Operations Log | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.5. Activate LRM System

Task: Prepare for LRM activation **Sequence:** 1

Purpose: Get crew and equipment ready for start-up. **Duration:** 0

Cue: Aux. CCTV in tank

Description: After receiving instructions to proceed, prepare the crew and equipment for LRM system activation.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Communication | | |
|---------|------|----------|---------------|-----------|------------|-----------|--------|--------------|----------------------|------------|------------------|
| | | | | | | | | | Means of Action | Respondent | Content |
| 1 | 0 | Inspects | Perceptual | readiness | | | | control room | visual | | |
| 2 | 0 | Requests | Communication | readiness | | | LRM | | verbal communication | crew | readiness report |
| 3 | 0 | Receives | Communication | readiness | | | LRM | | verbal communication | | |
| 4 | 0 | Decides | Cognitive | readiness | full | | LRM | | | | |
| 5 | 0 | Informs | Communication | mode | activation | | LRM | | verbal communication | crew | warning |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.5. Activate LRM System

Task: Activate LRM system **Sequence:** 2

Purpose: Turn on the LRM system **Duration:** 0

Cue: Crew and equipment prepared to activate system

Description: After preparing the crew and equipment for activation, turn on the LRM system

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|---------------|----------|-------------------|--------|------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Positions | Motor | power | on | electrical power | LRM | | discrete control | | |
| 2 | 0 | Positions | Motor | power | on | control computers | LRM | | discrete control | | |
| 3 | 0 | Monitors | Perceptual | output signal | in-band | control computers | LRM | | CRT | | |
| 4 | 0 | Decides | Cognitive | mode | operable | control computers | LRM | | | | |
| 5 | 0 | Positions | Motor | power | on | LRM remotes | LRM | | discrete control | | |
| 6 | 0 | Monitors | Perceptual | output signal | in-band | LRM remotes | LRM | | CRT | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.5. Activate LRM System

Task: Verify LRM functioning **Sequence:** 3

Purpose: Make sure that the LRM systems are functioning properly and are r **Duration:** 0

Cue: LRM activated

Description: After turning on the LRM, make sure that it is functioning properly.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|----------|-------------|--------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Inspects | Perceptual | | | | LRM | | TV | | |
| 2 | 0 | adjusts | Motor | position | | manipulator | LRM | | continuous control | | |
| 3 | 0 | Decides | Cognitive | mode | operable | | LRM | | computer | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.6. Insert LRM System into SST

Task: Choose insertion mode (manual or robotic)

Sequence: 1

Purpose: Select an insertion mode

Duration: 0

Cue: LRM is ready for insertion

Description: After deciding that the LRM is ready for insertion, decide whether to use manual or robotic insertion mode.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Communication | |
|---------|------|---------|-----------|-----------|-------|-----------|--------|------------|-----------------|------------|
| | | | | | | | | | Means of Action | Respondent |
| 1 | 0 | Chooses | Cognitive | mode | | | LRM | | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.6.1. Insert LRM System into SST

Task: Manually insert LRM into tank **Sequence:** 2

Purpose: Carry out manual insertion **Duration:** 0

Cue: Insertion mode selected

Description: After selecting manual insertion mode, manually control the insertion process

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|--------|-----------|--------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Positions | Motor | mode | manual | | LRM | | discrete control | | |
| 2 | 0 | Adjusts | Motor | rate | | | LRM | | continuous control | | |
| 3 | 0 | Monitors | Perceptual | position | | | LRM | | TV | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 1. Insert TWRMS Equipment into SST

Sub-Function: 1.6.2. Insert LRM System into SST

Task: Robotically insert LRM into tank

Sequence: 2

Purpose: Carry out robotic insertion

Duration: 0

Cue: Insertion mode selected

Description: After selecting robotic insertion mode, initiate and monitor the insertion process

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|-------------|-----------------|--------|------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | robotic | | LRM | | discrete control | | |
| 2 | 0 | Chooses | Cognitive | mode | playback | | LRM | | discrete control | | |
| 3 | 0 | Pushes | Motor | mode | playback | | LRM | | discrete control | | |
| 4 | 0 | Monitors | Perceptual | position | in-band | LRM platform | LRM | | world map | | |
| 5 | 0 | Decides | Cognitive | mode | operable | robotic routine | LRM | | | | |
| 6 | 0 | Pushes | Motor | mode | start | robotic routine | LRM | | discrete control | | |
| 7 | 0 | Monitors | Perceptual | position | in-band | LRM platform | LRM | | TV | | |
| 8 | 0 | Monitors | Perceptual | position | in-band | LRM platform | LRM | | world map | | |
| 9 | 0 | Decides | Cognitive | position | out-of-band | LRM platform | LRM | | | | |
| 10 | 0 | Pushes | Motor | mode | stop | LRM platform | LRM | | discrete control | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

| | | | | | |
|----|-----------|-----------|------|---|-----|
| 11 | 0 Decides | Cognitive | mode | operable or inoperable | LRM |
| 12 | 0 Chooses | Cognitive | mode | robotic or manual | LRM |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.1. Cut Risers/ITH

Task: Map waste surface

Sequence: 1

Purpose: Create a computerized map of the waste surface and the risers/ITH

Duration: 0

Cue: LRM operational in tank

Description: After the LRM is operational inside the tank, create a computerized map of the waste surface including the positions of any risers or ITH present.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|----------|-----------------|--------------|------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | start | data collection | computer map | | discrete control | | |
| 2 | 0 | Monitors | Perceptual | mode | operable | data collection | computer map | | CRT | | |
| 3 | 0 | Inspects | Perceptual | | | | computer map | | CRT | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.1. Cut Risers/ITH

Task: Teach riser cutting sequence **Sequence:** 2

Purpose: Teach the system to do riser/ITH cutting **Duration:** 0

Cue: Map completed

Description: After mapping the waste surface, teach the system to cut the risers/ITH into pieces manageable by the removal system.

Comments: This is a teaching, not programming task. Elements 2-6 and 7-13 could occur repetitively.

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|----------|------------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | | Pushes | Motor | mode | start | teach | world map | | discrete control | | |
| 2 | | Remembers | Cognitive | sequence | | | | risers/ITH | Operations Log | | |
| 3 | 0 | Adjusts | Motor | position | | LRM | world map | | continuous control | | |
| 4 | 0 | Monitors | Perceptual | position | | LRM | world map | | CRT | | |
| 5 | 0 | Pushes | Motor | mode | start | cutting EE | world map | | discrete control | | |
| 6 | 0 | Pushes | Motor | mode | stop | teach | world map | | discrete control | | |
| 7 | 0 | Pushes | Motor | mode | start | playback | world map | | discrete control | | |
| 8 | 0 | Monitors | Perceptual | mode | operable | playback | world map | | CRT | | |
| 9 | 0 | Decides | Cognitive | mode | override | playback | world map | | | | |
| 10 | 0 | Pushes | Motor | mode | override | playback | world map | | discrete control | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

| | | | | | | | |
|----|------------|------------|----------|-------|----------|-----------|--------------------|
| 11 | 0 Adjusts | Motor | position | | LRM | world map | continuous control |
| 12 | 0 Monitors | Perceptual | position | | LRM | world map | CRT |
| 13 | 0 Pushes | Motor | mode | start | playback | world map | discrete control |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.1. Cut Risers/ITH

Task: Robotically cut risers/ITH

Sequence: 3

Purpose: Cut risers/ITH robotically

Duration: 0

Cue: Cutting program taught

Description: After the cutting program is taught, execute and monitor the program, intervening manually as necessary.

Comments: Elements 4-11 would occur repetitively

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|----------|-----------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Decides | Cognitive | mode | operable | playback | | | | | |
| 2 | 0 | Pushes | Motor | mode | enable | | LRM | | discrete control | | |
| 3 | 0 | Pushes | Motor | mode | start | playback | LRM | | discrete control | | |
| 4 | 0 | Monitors | Perceptual | mode | operable | playback | LRM | | TV | | |
| 5 | 0 | Monitors | Perceptual | mode | operable | playback | world map | | CRT | | |
| 6 | 0 | Decides | Cognitive | mode | override | playback | LRM | | | | |
| 7 | 0 | Pushes | Motor | mode | override | playback | LRM | | discrete control | | |
| 8 | 0 | Adjusts | Motor | position | | cutting | EE LRM | | continuous control | | |
| 9 | 0 | Monitors | Perceptual | position | | cutting | EE LRM | | TV | | |
| 10 | 0 | Monitors | Perceptual | position | | cutting | EE LRM | | world map | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

| | | | | | | | |
|----|----------|-------|------|--------|----------|-----|---------------------|
| 11 | 0 Pushes | Motor | mode | enable | playback | LRM | discrete control |
|----|----------|-------|------|--------|----------|-----|---------------------|

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.1. Cut Risers/ITH

Task: Manually cut risers

Sequence: 4

Purpose: Cut risers under manual control

Duration: 0

Cue: Map completed

Description: After the map is completed, cut the risers/ITH into manageable sections using manual control.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|---------|-----------|--------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | enable | | LRM | | discrete control | | |
| 2 | 0 | Remembers | Cognitive | sequence | | | | risers/ITH | Operations Log | | |
| 3 | 0 | Adjusts | Motor | position | | cutting | EE LRM | | continuous control | | |
| 4 | 0 | Monitors | Perceptual | position | | cutting | EE LRM | | CRT | | |
| 5 | 0 | Pushes | Motor | mode | start | cutting | EE LRM | | discrete control | | |
| 6 | 0 | Monitors | Perceptual | cutting | in-band | cutting | EE LRM | | TV | | |
| 7 | 0 | Pushes | Motor | mode | stop | cutting | EE LRM | | discrete control | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.2. Remove Cut-up Riser/ITH Sections

Task: Exchange cutting end-effector for gripper **Sequence:** 1

Purpose: Discard the cutting end-effector and attach the gripper so that s **Duration:** 0

Cue: Risers/ITH cut into sections

Description: After completing cutting, exchange the cutting end-effector for the gripper end-effector.

Comments: This should be done automatically.

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|---------|--------------|-----------|----------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | | Pushes | Motor | | gripper | end-effector | LRM | | discrete control | | |
| 2 | 0 | Pushes | Motor | mode | start | end-effector | LRM | change program | discrete control | | |
| 3 | 0 | Monitors | Perceptual | position | in-band | | LRM | | TV | | |
| 4 | 0 | Monitors | Perceptual | position | in-band | LRM | world map | | CRT | | |
| 5 | 0 | Inspects | Perceptual | | | end-effector | LRM | | TV | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.2. Remove Cut-up Riser/ITH Sections

Task: Map waste surface

Sequence: 2

Purpose: Create a computerized map of the waste surface and the risers/ITH

Duration: 0

Cue: Gripper end-effector installed

Description: After the gripper end-effector is installed, create a computerized map of the waste surface including the positions of any risers or ITH present.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|----------|-----------------|--------------|------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | start | data collection | computer map | | discrete control | | |
| 2 | 0 | Monitors | Perceptual | mode | operable | data collection | computer map | | CRT | | |
| 3 | 0 | Inspects | Perceptual | | | | computer map | | CRT | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.2. Remove Cut-up Riser/ITH Sections

Task: Teach riser removal sequence

Sequence: 3

Purpose: Teach the system to do riser/ITH cutting

Duration: 0

Cue: Map completed

Description: After mapping the waste surface, teach the system to pick up riser/ITH sections.

Comments: This is a teaching, not programming task. Elements 2-6 and 7-13 could occur repetitively.

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|----------|------------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | | Pushes | Motor | mode | start | teach | world map | | discrete control | | |
| 2 | | Remembers | Cognitive | sequence | | | | risers/ITH | Operations Log | | |
| 3 | 0 | Adjusts | Motor | position | | LRM | world map | | continuous control | | |
| 4 | 0 | Monitors | Perceptual | position | | LRM | world map | | CRT | | |
| 5 | 0 | Pushes | Motor | mode | start | gripper EE | world map | | discrete control | | |
| 6 | 0 | Pushes | Motor | mode | stop | teach | world map | | discrete control | | |
| 7 | 0 | Pushes | Motor | mode | start | playback | world map | | discrete control | | |
| 8 | 0 | Monitors | Perceptual | mode | operable | playback | world map | | CRT | | |
| 9 | 0 | Decides | Cognitive | mode | override | playback | world map | | | | |
| 10 | 0 | Pushes | Motor | mode | override | playback | world map | | discrete control | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

| | | | | | | | |
|----|------------|------------|----------|-------|-----------|--------------------|------------------|
| 11 | 0 Adjusts | Motor | position | LRM | world map | continuous control | |
| 12 | 0 Monitors | Perceptual | position | LRM | world map | CRT | |
| 13 | 0 Pushes | Motor | mode | start | playback | world map | discrete control |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.2. Remove Cut-up Riser/ITH Sections

Task: Robotically remove risers/ITH

Sequence: 4

Purpose: Remove riser/ITH sections robotically.

Duration: 0

Cue: removing program taught

Description: After the removing program is taught, execute and monitor the program, intervening manually as necessary.

Comments: Elements 4-11 would occur repetitively

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|----------|-----------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Decides | Cognitive | mode | operable | playback | | | | | |
| 2 | 0 | Pushes | Motor | mode | enable | | LRM | | discrete control | | |
| 3 | 0 | Pushes | Motor | mode | start | playback | LRM | | discrete control | | |
| 4 | 0 | Monitors | Perceptual | mode | operable | playback | LRM | | TV | | |
| 5 | 0 | Monitors | Perceptual | mode | operable | playback | world map | | CRT | | |
| 6 | 0 | Decides | Cognitive | mode | override | playback | LRM | | | | |
| 7 | 0 | Pushes | Motor | mode | override | playback | LRM | | discrete control | | |
| 8 | 0 | Adjusts | Motor | position | | gripper | EE LRM | | continuous control | | |
| 9 | 0 | Monitors | Perceptual | position | | gripper | EE LRM | | TV | | |
| 10 | 0 | Monitors | Perceptual | position | | gripper | EE LRM | | world map | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

| | | | | | | | |
|----|----------|-------|------|--------|----------|-----|---------------------|
| 11 | 0 Pushes | Motor | mode | enable | playback | LRM | discrete control |
|----|----------|-------|------|--------|----------|-----|---------------------|

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.2. Remove Cut-up Riser/ITH Sections

Task: Manually remove risers **Sequence:** 5

Purpose: Remove riser/ITH sections manually. **Duration:** 0

Cue: Map completed

Description: After the map is completed, remove the risers/ITH into manageable sections using manual control.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|------------|-----------|--------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | enable | | LRM | | discrete control | | |
| 2 | 0 | Remembers | Cognitive | sequence | | | | risers/ITH | Operations Log | | |
| 3 | 0 | Adjusts | Motor | position | | gripper | EE LRM | | continuous control | | |
| 4 | 0 | Monitors | Perceptual | position | | gripper | EE LRM | | CRT | | |
| 5 | 0 | Pushes | Motor | mode | start | gripper | EE LRM | | discrete control | | |
| 6 | 0 | Monitors | Perceptual | gripper | EE in-band | gripper | EE LRM | | TV | | |
| 7 | 0 | Pushes | Motor | mode | stop | gripper | EE LRM | | discrete control | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.3 Characterize Waste

Task: Exchange gripper for mapping end-effector **Sequence:** 1

Purpose: Discard the gripper and attach the sub-surface mapping end-effect **Duration:** 0

Cue: Risers/ITH sections removed

Description: After completing riser/ITH removal, exchange the gripper for the sub-surface mapping end-effector.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|---------------------|--------------|-----------|----------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | | Pushes | Motor | | sub-surface mapping | end-effector | LRM | | discrete control | | |
| 2 | 0 | Pushes | Motor | mode | start | end-effector | LRM | change program | discrete control | | |
| 3 | 0 | Monitors | Perceptual | position | in-band | | LRM | | TV | | |
| 4 | 0 | Monitors | Perceptual | position | in-band | LRM | world map | | CRT | | |
| 5 | 0 | Inspects | Perceptual | | | end-effector | LRM | | TV | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.3 Characterize Waste

Task: Map waste surface

Sequence: 2

Purpose: Create a computerized map of the waste surface and the risers/ITH

Duration: 0

Cue: Sub-surface mapping end-effector in place

Description: After the sub-surface mapping end-effector is installed, create a computerized map of the waste surface including the positions of any risers or ITH present.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|----------|-----------------|--------------|------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | start | data collection | computer map | | discrete control | | |
| 2 | 0 | Monitors | Perceptual | mode | operable | data collection | computer map | | CRT | | |
| 3 | 0 | Inspects | Perceptual | | | | computer map | | CRT | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.3. Characterize Waste

Task: Determine waste composition **Sequence:** 3

Purpose: Decide what the waste is like, that is, its consistency, composition **Duration:** 0

Cue: Map completed

Description: After completing the surface map, determine and record the characteristics of the waste layer.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Communication | |
|---------|------|---------|---------------|------------------|-------|-----------|--------|-------------|-----------------|--------------------|
| | | | | | | | | | Means of Action | Respondent Content |
| 1 | 0 | Decides | Cognitive | composition etc. | | | | waste layer | | |
| 2 | 0 | Records | Communication | composition etc. | | | | waste layer | Operations Log | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.4. Remove Waste Layer

Task: Exchange mapping EE for waste removal EE **Sequence:** 1

Purpose: Discard the sub-surface mapping EE and attach the waste removal e **Duration:** 0

Cue: Waste layer mapped and characterized

Description: After the waste has been described and the description recorded, change the mapping end-effector for the appropriate waste removal end-effector

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Communication | |
|---------|------|----------|------------|-----------|---------------------|--------------|-----------|----------------|------------------|--------------------|
| | | | | | | | | | Means of Action | Respondent Content |
| 1 | 0 | Decides | Cognitive | | | end-effector | LRM | | | |
| 2 | 0 | Pushes | Motor | | sub-surface mapping | end-effector | LRM | | discrete control | |
| 3 | 0 | Pushes | Motor | mode | start | end-effector | LRM | change program | discrete control | |
| 4 | 0 | Monitors | Perceptual | position | in-band | | LRM | | TV | |
| 5 | 0 | Monitors | Perceptual | position | in-band | LRM | world map | | CRT | |
| 6 | 0 | Inspects | Perceptual | | | end-effector | LRM | | TV | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.4. Remove Waste Layer

Task: Teach waste removal sequence **Sequence:** 2

Purpose: Teach the system to do waste removal **Duration:** 0

Cue: Waste removal end-effector in place

Description: After change end-effectors, teach the system to remove the waste layer.

Comments: This is a teaching, not programming task. Elements 2-6 and 7-13 could occur repetitively.

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|----------|------------------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | | Pushes | Motor | mode | start | teach | world map | | discrete control | | |
| 2 | | Remembers | Cognitive | sequence | | | | waste | Operations Log | | |
| 3 | 0 | Adjusts | Motor | position | | LRM | world map | | continuous control | | |
| 4 | 0 | Monitors | Perceptual | position | | LRM | world map | | CRT | | |
| 5 | 0 | Pushes | Motor | mode | start | waste removal EE | world map | | discrete control | | |
| 6 | 0 | Pushes | Motor | mode | stop | teach | world map | | discrete control | | |
| 7 | 0 | Pushes | Motor | mode | start | playback | world map | | discrete control | | |
| 8 | 0 | Monitors | Perceptual | mode | operable | playback | world map | | CRT | | |
| 9 | 0 | Decides | Cognitive | mode | override | playback | world map | | | | |
| 10 | 0 | Pushes | Motor | mode | override | playback | world map | | discrete control | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

| | | | | | | | |
|----|------------|------------|----------|-------|----------|-----------|--------------------|
| 11 | 0 Adjusts | Motor | position | | LRM | world map | continuous control |
| 12 | 0 Monitors | Perceptual | position | | LRM | world map | CRT |
| 13 | 0 Pushes | Motor | mode | start | playback | world map | discrete control |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.4. Remove Waste Layer

Task: Robotically remove waste

Sequence: 3

Purpose: Remove waste layer robotically.

Duration: 0

Cue: Waste removal program taught

Description: After the waste removal program is taught, execute and monitor the program, intervening manually as necessary.

Comments: Elements 4-11 would occur repetitively

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|----------|---------------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Decides | Cognitive | mode | operable | playback | | | | | |
| 2 | 0 | Pushes | Motor | mode | enable | | LRM | | discrete control | | |
| 3 | 0 | Pushes | Motor | mode | start | playback | LRM | | discrete control | | |
| 4 | 0 | Monitors | Perceptual | mode | operable | playback | LRM | | TV | | |
| 5 | 0 | Monitors | Perceptual | mode | operable | playback | world map | | CRT | | |
| 6 | 0 | Decides | Cognitive | mode | override | playback | LRM | | | | |
| 7 | 0 | Pushes | Motor | mode | override | playback | LRM | | discrete control | | |
| 8 | 0 | Adjusts | Motor | position | | waste removal | LRM EE | | continuous control | | |
| 9 | 0 | Monitors | Perceptual | position | | waste removal | LRM EE | | TV | | |
| 10 | 0 | Monitors | Perceptual | position | | waste removal | LRM EE | | world map | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

| | | | | | | | |
|----|----------|-------|------|--------|----------|-----|---------------------|
| 11 | 0 Pushes | Motor | mode | enable | playback | LRM | discrete control |
|----|----------|-------|------|--------|----------|-----|---------------------|

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.4. Remove Waste Layer

Task: Manually remove waste **Sequence:** 4

Purpose: Remove waste layer manually. **Duration:** 0

Cue: Waste layer mapped and characterized

Description: After the map is completed, remove the waste using manual control.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|------------|---------------|--------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | enable | | LRM | | discrete control | | |
| 2 | 0 | Remembers | Cognitive | sequence | | | | waste | Operations Log | | |
| 3 | 0 | Adjusts | Motor | position | | waste removal | LRM EE | | continuous control | | |
| 4 | 0 | Monitors | Perceptual | position | | waste removal | LRM EE | | CRT | | |
| 5 | 0 | Pushes | Motor | mode | start | waste removal | LRM EE | | discrete control | | |
| 6 | 0 | Monitors | Perceptual | gripper | EE in-band | waste removal | LRM EE | | TV | | |
| 7 | 0 | Pushes | Motor | mode | stop | waste removal | LRM EE | | discrete control | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.5. Remove Residual Waste

Task: Exchange waste removal EE for cleaning EE **Sequence:** 1

Purpose: Discard the waste removal end-effector and attach the cleaning EE **Duration:** 0

Cue: Last waste layer removed

Description: After the last layer of waste is removed, exchange the waste removal EE for the cleaning EE.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|---------------------|--------------|-----------|----------------|------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | | sub-surface mapping | end-effector | LRM | | discrete control | | |
| 2 | 0 | Pushes | Motor | mode | start | end-effector | LRM | change program | discrete control | | |
| 3 | 0 | Monitors | Perceptual | position | in-band | | LRM | | TV | | |
| 4 | 0 | Monitors | Perceptual | position | in-band | LRM | world map | | CRT | | |
| 5 | 0 | Inspects | Perceptual | | | end-effector | LRM | | TV | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.5. Remove Residual Waste

Task: Teach tank cleaning sequence **Sequence:** 2

Purpose: Teach the system to do tank cleaning **Duration:** 0

Cue: Tank cleaning end-effector in place

Description: After changing end-effectors, teach the system to remove the residual waste.

Comments: This is a teaching, not programming task. Elements 2-6 and 7-13 could occur repetitively.

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|----------|------------------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | | Pushes | Motor | mode | start | teach | world map | | discrete control | | |
| 2 | | Remembers | Cognitive | sequence | | | | waste | Operations Log | | |
| 3 | 0 | Adjusts | Motor | position | | LRM | world map | | continuous control | | |
| 4 | 0 | Monitors | Perceptual | position | | LRM | world map | | CRT | | |
| 5 | 0 | Pushes | Motor | mode | start | tank cleaning EE | world map | | discrete control | | |
| 6 | 0 | Pushes | Motor | mode | stop | teach | world map | | discrete control | | |
| 7 | 0 | Pushes | Motor | mode | start | playback | world map | | discrete control | | |
| 8 | 0 | Monitors | Perceptual | mode | operable | playback | world map | | CRT | | |
| 9 | 0 | Decides | Cognitive | mode | override | playback | world map | | | | |
| 10 | 0 | Pushes | Motor | mode | override | playback | world map | | discrete control | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

| | | | | | | | |
|----|------------|------------|----------|-------|----------|-----------|--------------------|
| 11 | 0 Adjusts | Motor | position | | LRM | world map | continuous control |
| 12 | 0 Monitors | Perceptual | position | | LRM | world map | CRT |
| 13 | 0 Pushes | Motor | mode | start | playback | world map | discrete control |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.5. Remove Residual Waste

Task: Robotically remove residual waste

Sequence: 3

Purpose: Remove waste layer robotically.

Duration: 0

Cue: Tank cleaning program taught

Description: After the tank cleaning program is taught, execute and monitor the program, intervening manually as necessary.

Comments: Elements 4-11 would occur repetitively

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|----------|------------|-----------|----------|---------------------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Decides | Cognitive | mode | operable | playback | | | | | |
| 2 | 0 | Pushes | Motor | mode | enable | | LRM | | discrete control | | |
| 3 | 0 | Pushes | Motor | mode | start | playback | LRM | | discrete control | | |
| 4 | 0 | Monitors | Perceptual | mode | operable | playback | LRM | | TV | | |
| 5 | 0 | Monitors | Perceptual | mode | operable | playback | world map | | CRT | | |
| 6 | 0 | Decides | Cognitive | mode | override | playback | LRM | | | | |
| 7 | 0 | Pushes | Motor | mode | override | playback | LRM | | discrete control | | |
| 8 | 0 | Adjusts | Motor | position | | tank cleaning EE | LRM | | continuous control | | |
| 9 | 0 | Monitors | Perceptual | position | | tank cleaning EE | LRM | | TV | | |
| 10 | 0 | Monitors | Perceptual | position | | tank cleaning EE | LRM | | world map | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

| | | | | | | | |
|----|----------|-------|------|--------|----------|-----|---------------------|
| 11 | 0 Pushes | Motor | mode | enable | playback | LRM | discrete control |
|----|----------|-------|------|--------|----------|-----|---------------------|

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.5. Remove Residual Waste

Task: Manually remove residual waste **Sequence:** 4

Purpose: Remove waste layer manually. **Duration:** 0

Cue: Waste layer mapped and characterized

Description: After the map is completed, remove the residual waste using manual control.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-------------|---------|------------------|--------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Pushes | Motor | mode | enable | | LRM | | discrete control | | |
| 2 | 0 | Remembers | Cognitive | sequence | | | | waste | Operations Log | | |
| 3 | 0 | Adjusts | Motor | position | | tank cleaning EE | LRM | | continuous control | | |
| 4 | 0 | Monitors | Perceptual | position | | tank cleaning EE | LRM | | CRT | | |
| 5 | 0 | Pushes | Motor | mode | start | tank cleaning EE | LRM | | discrete control | | |
| 6 | 0 | Monitors | Perceptual | cleaning EE | in-band | tank cleaning EE | LRM | | TV | | |
| 7 | 0 | Pushes | Motor | mode | stop | tank cleaning EE | LRM | | discrete control | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 2. Remove Waste Layers

Sub-Function: 2.5. Remove Residual Waste

Task: Inspect tank interior **Sequence:** 5

Purpose: Inspect the interior of the tank after cleaning and record the st **Duration:** 0

Cue: Waste cleaning completed

Description: After cleaning the tank, inspect the tank and make a record of its status.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|---------|-------|-----------|-------|-----------|--------|---------------|-----------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Inspect | | | | | | tank interior | TV | | |
| 2 | 0 | Record | | | | | | tank interior | Operations Log | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 3. Remove TWRMS Equipment from SST

Sub-Function: 3.1. Remove LRM System from SST

Task: Choose removal mode (manual or robotic) **Sequence:** 1

Purpose: Select a removal mode **Duration:** 0

Cue: Tank inspection completed

Description: After deciding that the LRM is ready for removal, decide whether to use manual or robotic removal mode.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|---------|-----------|-----------|-------|-----------|--------|------------|-----------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Chooses | Cognitive | mode | | | LRM | | | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 3. Remove TWRMS Equipment from SST

Sub-Function: 3.1.1. Remove LRM System from SST

Task: Manually remove LRM from tank

Sequence: 2

Purpose: Carry out manual removal

Duration: 0

Cue: Removal mode selected

Description: After selecting manual removal mode, manually control the removal process

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|--------|-----------|--------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Positions | Motor | mode | manual | | LRM | | discrete control | | |
| 2 | 0 | Adjusts | Motor | rate | | | LRM | | continuous control | | |
| 3 | 0 | Monitors | Perceptual | position | | | LRM | | TV | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 3. Remove TWRMS Equipment from SST

Sub-Function: 3.1.2. Remove LRM System from SST

Task: Robotically remove LRM from tank **Sequence:** 2

Purpose: Carry out robotic removal **Duration:** 0

Cue: Removal mode selected

Description: After selecting robotic removal mode, initiate and monitor the removal process

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Communication | |
|---------|------|----------|------------|-----------|-------------------|-----------------|--------|------------|------------------|------------|
| | | | | | | | | | Means of Action | Respondent |
| 1 | 0 | Pushes | Motor | mode | robotic | | LRM | | discrete control | |
| 2 | 0 | Pushes | Motor | mode | start | robotic routine | LRM | | discrete control | |
| 3 | 0 | Monitors | Perceptual | position | in-band | LRM platform | LRM | | TV | |
| 4 | 0 | Monitors | Perceptual | position | in-band | LRM platform | LRM | | world map | |
| 5 | 0 | Decides | Cognitive | position | out-of-band | LRM platform | LRM | | | |
| 6 | 0 | Pushes | Motor | mode | stop | LRM platform | LRM | | discrete control | |
| 7 | 0 | Chooses | Cognitive | mode | robotic or manual | | LRM | | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 3. Remove TWRMS Equipment from SST

Sub-Function: 3.2. Remove Aux. CCTV System from SST

Task: Choose removal mode (manual or robotic)

Sequence: 1

Purpose: Select a removal mode

Duration: 0

Cue: LRM removed

Description: After deciding that the aux. CCTV is ready for removal, decide whether to use manual or robotic removal mode.

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|---------|-----------|-----------|-------|-----------|-----------|------------|-----------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Chooses | Cognitive | mode | | | aux. CCTV | | | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 3. Remove TWRMS Equipment from SST

Sub-Function: 3.2. Remove Aux. CCTV System from SST

Task: Manually remove aux. CCTV from tank **Sequence:** 2

Purpose: Carry out manual removal **Duration:** 0

Cue: Removal mode selected

Description: After selecting manual removal mode, manually control the removal process

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Means of Action | Communication | |
|---------|------|-----------|------------|-----------|--------|-----------|-----------|------------|--------------------|---------------|---------|
| | | | | | | | | | | Respondent | Content |
| 1 | 0 | Positions | Motor | mode | manual | | aux. CCTV | | discrete control | | |
| 2 | 0 | Adjusts | Motor | rate | | | aux. CCTV | | continuous control | | |
| 3 | 0 | Monitors | Perceptual | position | | | aux. CCTV | | TV | | |

Modified Task Analysis Form for Waste Retrieval Manipulator System

Mission Phase: 3. Remove TWRMS Equipment from SST

Sub-Function: 3.2. Remove Aux. CCTV System from SST

Task: Robotically remove aux. CCTV from tank

Sequence: 3

Purpose: Carry out robotic removal

Duration: 0

Cue: Removal mode selected

Description: After selecting robotic removal mode, initiate and monitor the removal process

Comments:

| El. No. | Time | Verb | Group | Parameter | State | Component | System | Other Obj. | Communication | |
|---------|------|----------|------------|-----------|-------------------|-----------------|-----------|------------|------------------|------------|
| | | | | | | | | | Means of Action | Respondent |
| 1 | 0 | Pushes | Motor | mode | robotic | | aux. CCTV | | discrete control | |
| 2 | 0 | Pushes | Motor | mode | start | robotic routine | aux. CCTV | | discrete control | |
| 3 | 0 | Monitors | Perceptual | position | in-band | CCTV platform | aux. CCTV | | TV | |
| 4 | 0 | Monitors | Perceptual | position | in-band | CCTV platform | aux. CCTV | | world map | |
| 5 | 0 | Decides | Cognitive | position | out-of-band | CCTV platform | aux. CCTV | | | |
| 6 | 0 | Pushes | Motor | mode | stop | CCTV platform | aux. CCTV | | discrete control | |
| 7 | 0 | Chooses | Cognitive | mode | robotic or manual | | aux. CCTV | | | |

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