DE-AC21-92MC29112--99

Intelligent Mobile Sensor System (IMSS) For Drum Inspection and Monitoring - Volume III

Final Report
October 1, 1993 - April 22, 1995

Work Performed Under Contract No.: DE-AC21-92MC29112

For
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Disclaimer

Who Should Read This Manual

This manual is intended to be read by people who will use the IMSS system on a regular basis, who will be referred to as *IMSS system operators*. Portions of this manual are intended to be read by operations staff who need to understand certain aspects of the IMSS system since their staff will be working near the IMSS vehicle and docking station.

Sections 1 through 4, which are outlined below, provide general information of interest both to operations staff and IMSS system operators:

- Section 1, "Introduction to the IMSS System": This section gives a brief description of the IMSS system for anybody not familiar with what the IMSS system looks like and what the IMSS system is designed to do.
- Section 2, "Operational Modes of the IMSS Vehicle": If anybody were to follow the IMSS vehicle around and watch what it did, this section describes what that person would see (and hear).
- Section 3, "Safety": This section describes what anybody working near the IMSS vehicle needs to know about safety related to the IMSS system.
- Section 4, "Suggested Procedures for Operations Staff Working Inside the Building": This section describes the modifications that are required of the regular human operations performed inside the building in which the IMSS vehicle is installed.

The remainder of this manual provides information of interest mainly to IMSS system operators:

- Section 5, "Day-to-Day Operations of the IMSS System": This section explains everything that the IMSS system operator will need to do on a daily basis. Detailed instructions on using the IMSS operator interface for day-to-day operations are provided in the next section.
- Section 6, "How to Use the IMSS Control Station for Day-to-Day Operations": This section explains how to use the IMSS control station for day-to-day operations, and provides a tutorial example.
- Section 7, "Setup Operations for a New or Modified Facility": This section provides instructions for setting up the initial facility model used by the IMSS system, modifying an existing facility model to reflect changes made to the facility, and executing the required "baseline run" with the IMSS vehicle.
- Section 8, "IMSS Hardware and Maintenance": This section covers a variety of topics related to the hardware, including maintenance.
- Section 9, "Glossary": This section defines some terms used throughout this manual and that may not be familiar to all readers.

This manual is customized for use of the IMSS system at the DOE Idaho National Engineering Laboratory (INEL), specifically in Buildings 628 through 634 at INEL's Radioactive Waste Management Complex (RWMC). The vast majority of this manual is applicable to any installation site -- only a few minor details are specific to INEL. This manual will be complemented by one-on-one training provided to INEL personnel by the IMSS system development team

Considerable technical detail on the design and previous evaluations of the IMSS system can be found in the final report for Phase 3 of the IMSS project: "Intelligent Mobile Sensor System for Drum Inspection and Monitoring", Contract Number DE-AC21-92MC29112, Topical Report for the period 1995 - 1997.

Table of Contents

1. Introduction to the IMSS System

The Intelligent Mobile Sensing System (IMSS) is the product of a research, development, and demonstration program for automated inspection of waste storage containers in storage facilities at Department of Energy (DOE) sites. The IMSS vehicle is an operational prototype robotic vehicle with enhanced intelligence and maneuverability, capable of conducting routine inspection of stored hazardous, radioactive, and mixed waste drums.

The IMSS system has three main components: a mobile robot; an operator's control station; and a docking station. The mobile robot is capable of autonomously departing from the docking station on an assigned mission, navigating through narrow aisles between rows of drums stacked on pallets, and avoiding obstacles along the way. Equipped with an integrated sensor suite, the robot gathers data to identify and report anomalous drum conditions. These defects include rust spots, rust streaks, areas of corrosion, significant areas of change on the drum face, dents, tilted drums, drums out of place on a pallet, missing barcode identification labels, and barcode labels inconsistent with the site-wide drum database. After completing an inspection mission, the IMSS vehicle returns to its docking station to recharge its batteries and download data across an Ethernet communications link to the operator's control station. At the control station, an operator utilizes a graphical user interface to review the results of an inspection mission. The operator also uses the control station to define and schedule subsequent inspection missions for the robot to perform.

A single control station services multiple waste storage buildings, as illustrated in Figure 1-1. The control station contains a model of each building, a database of all the drums for each building, and a database of defects located in each building. The control station can be linked to a printer for printing inspection reports, and to a storage unit for automatic archiving of inspection results and data. Each waste storage building contains a docking station, which the vehicle uses to automatically recharge its batteries. Each vehicle communicates with the control station via an ethernet link. Specifically each vehicle links with its docking station via a radio ethernet, and each docking station is connected to the central control station via the hardwired site-wide ethernet. In order to better coordinate vehicle operations with human operations inside the warehouse, the docking station also includes a remoter radio control panel from which "pause" and "emergency" stop signals can be sent to the vehicle. An option exists to display a live video feed from a camera on the vehicle to a TV monitor at the docking station, so a visitor can get some feeling for what the robot is doing (the IMSS system does not itself use this video data).

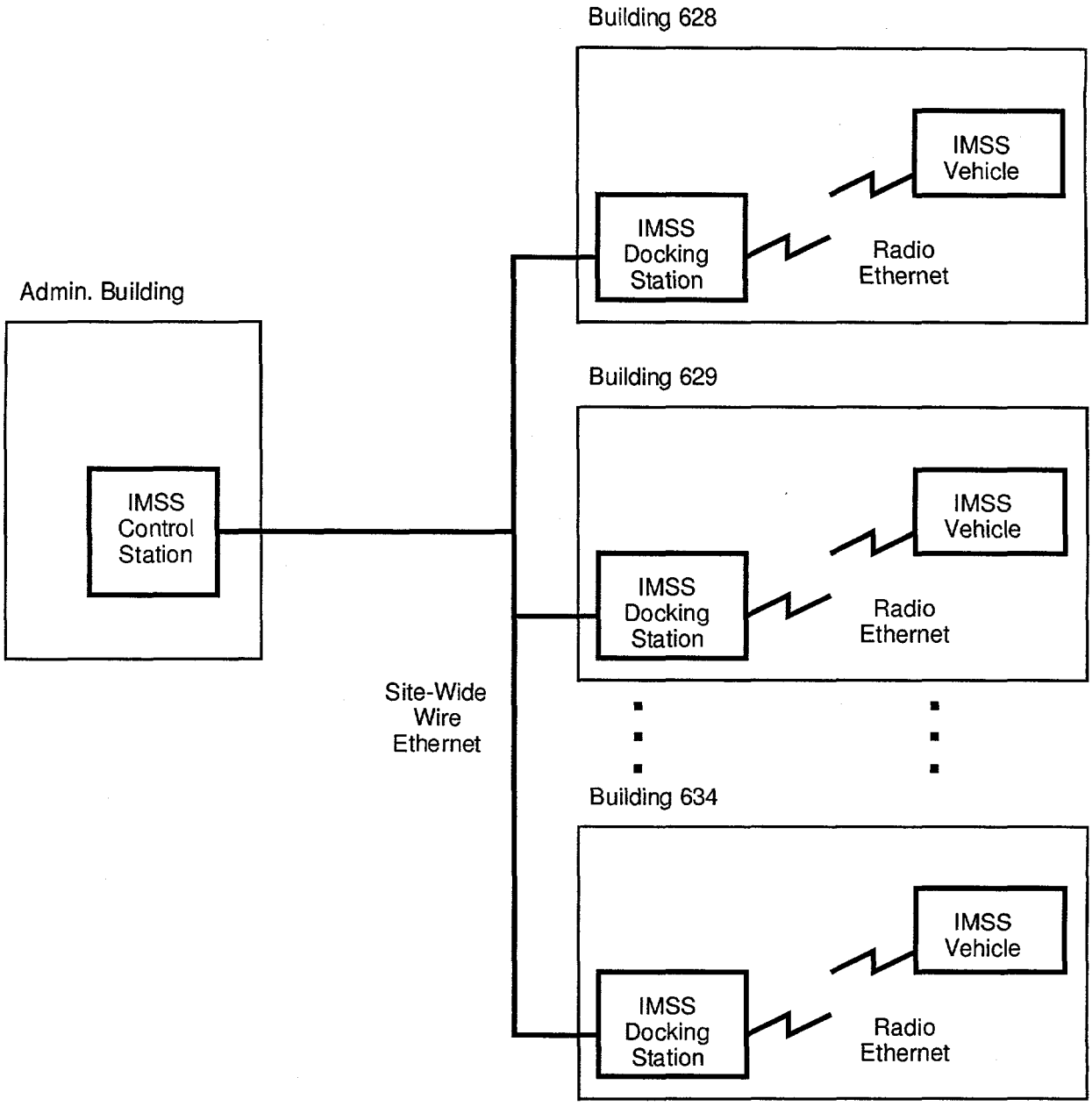

Figure 1-1. A single, central control station controls multiple vehicles in multiple buildings.

1.1 The IMSS Vehicle

The IMSS vehicle is shown in Figure 1-2. Key features of the IMSS system include:

- Mobility platform measuring 21 inches wide by 39 inches long, allowing navigation through aisles down to 27 inches wide. The current operational system is validated down to 30 inch aisles -- operations in narrower aisles requires new mounting fixtures for certain ultrasonic sensors on the vehicle body.
- Articulated sensor mast hosting four sensor suites, allowing simultaneous viewing of a four-high stack of drums and non-simultaneous viewing of the fifth level of five-high stacks. (The figure shows an older variant of the IMSS vehicle before the addition of the fourth sensor suite on a mast extension.)
- Self-contained battery power system providing 4 kW-hours at 48 volts, with 5-6 hours of operation at room temperature on a single charge.
- All planning and scheduling of vehicle operations, and all drum image analysis is done on-board the vehicle in real-time.
- Data storage of defect logs, databases, and images of drums containing detected defects to an on-vehicle hard disk drive.
- Feature-based navigation using only pre-existing building landmarks such as pallets and drums.
- Hardware and software safety systems, including skin-mounted contact sensors, ultrasonic transducers for collision detection and avoidance, battery parameter monitoring, etc.
- Automated recovery from operational anomalies such as obstacles and blocked aisles.

Some of the key components of the IMSS system are summarized on the following pages.

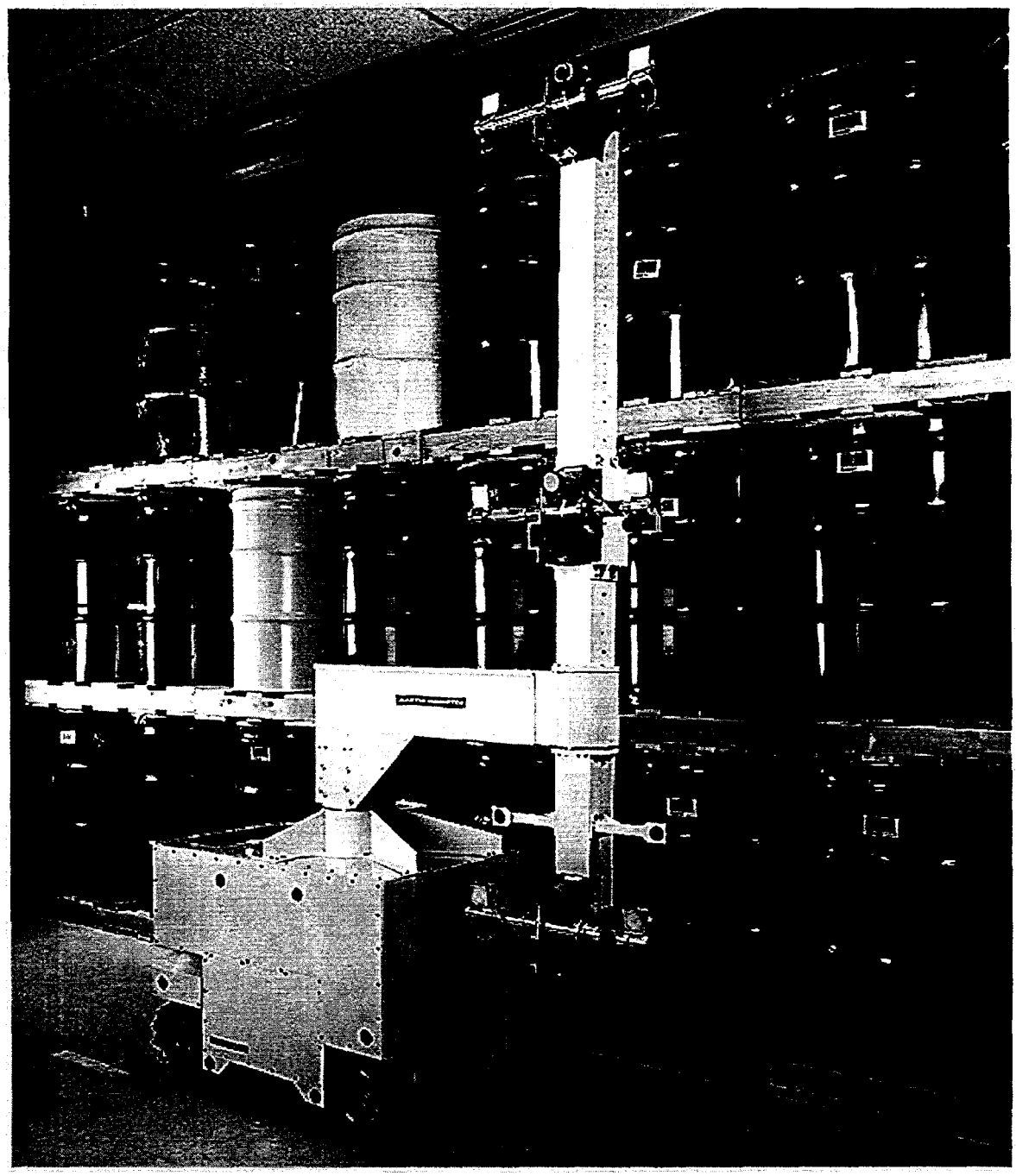

Figure 1-2. The IMSS vehicle.

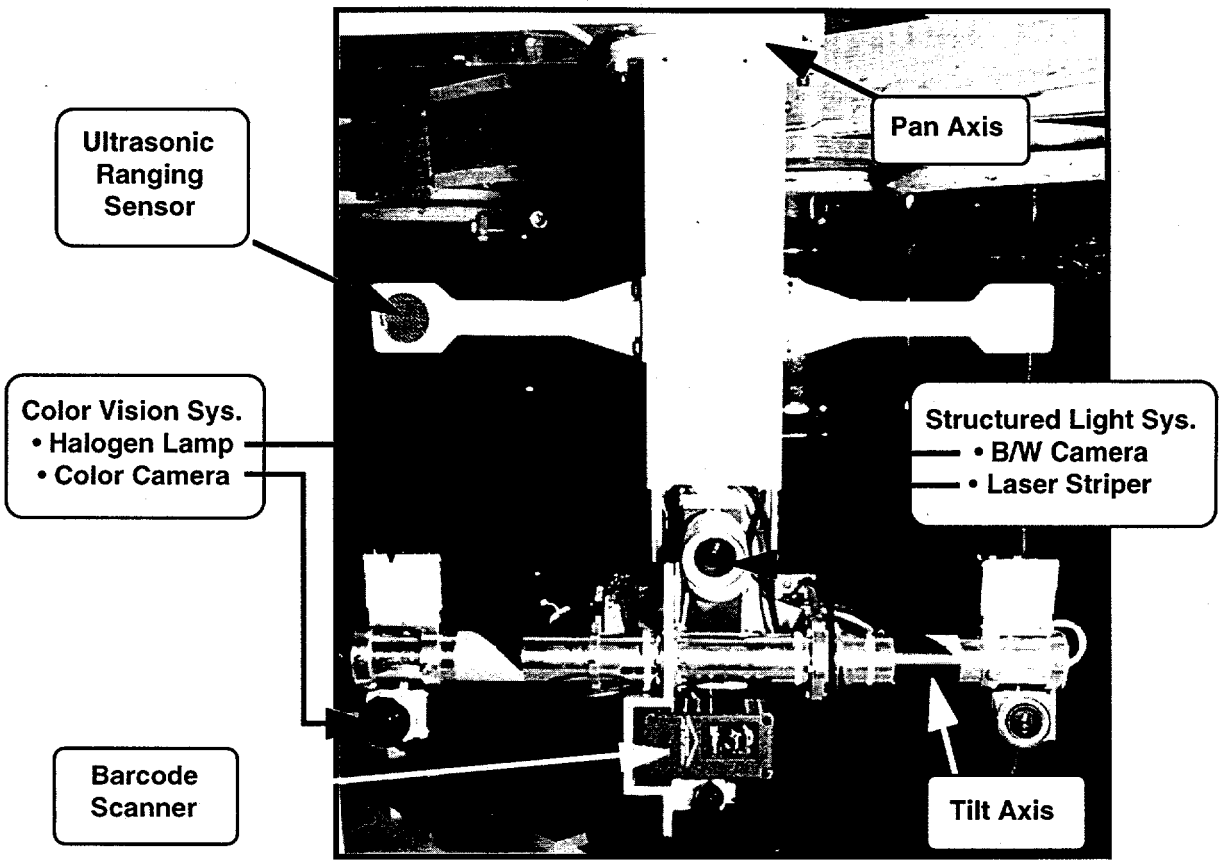

Figure 1-3. Close-up of lower sensor suite on the IMSS vehicle's sensor mast.

Mounted on the vehicle's sensor mast are four identical integrated sensor suites that gather data to identify and report anomalous drum conditions. A photograph of the lower-level sensor suite is shown in Figure 1-3. The IMSS vehicle can detect and report three categories of drum defects: 1) bar code defects, 2) geometric defects, 3) corrosion defects and any other changes on a drum's face. Moreover, the IMSS system is designed to report only *new or changing* defects. For example, each time a drum is inspected, its present condition is compared against a baseline defect list compiled from previous inspections. This trend-based method reduces the amount of data to be stored during an inspection and safeguards against the reporting of false positives.

1.1.1 Bar Code Reading

Bar code labels can be used to identify and track waste storage drums. A drum's bar code label provides positive identification of the drum being inspected and is the unique index to the various databases used for the inspection process. An off-the-shelf bar code scanner/decoder system is used for reading bar coded labels. A scanner head is mounted in each sensor suite, allowing the scanner's laser stripe to be scanned over any portion of a drum face. Decoder units are mounted inside the vehicle's body and interface with the vehicle's mission processor through a serial port. The system can be configured to report a "defect" when a drum's bar code label is not read, either because it is missing or it is unreadable due to improper placement or a defective label. With access to a comprehensive drum database, detailed inventory tracking could also be performed. The IMSS system can also be configured to read and use bar code identifiers when they exist, but otherwise not consider it a "defect" if one is missing or can not be read. The IMSS system can also be configured to never read bar code labels and always use an identifying label automatically generated based on a drum's position in the building. (Note that for a drum with no other defects except a missing/unread barcode label, the IMSS system does not store color images of the drum for later viewing at the operator's control station. Such color images are stored only when a drum has either geometric defects or corrosion defects.)

1.1.2 Geometric Defects

Geometric defects include surface dents and drums tilted due to bulging on the bottom or a broken pallet. These defects are detected using a Class II *structured light system*. It consists of a Class IIIb laser line (i.e., stripe) projector, a video camera and a frame grabber. As a laser stripe is scanned across the surface of a drum, video images are acquired and sent to on-board image processors that extract the location of the stripe in the video images. Based on triangulation of the extracted stripes, a 3-dimensional image of the drum contour is generated and then fitted to a model of a cylinder. A patch of 3-dimensional data that lays underneath the model cylinder indicates the location of a dent. The angle of tilt is determined from the orientation of the modeled cylinder's major axis. When new defects are found, the following parameters of interest are recorded: the location and size of a dent, the drum's angle of tilt, and any abnormal positional displacement on the pallet or spacer rings. Color images of defective drums are stored to a hard disk for later viewing at the operator's control station.

1.1.3 Corrosion Defects

Corrosion defects include patches of rust, rust streaks, and areas of blistering, chipped, peeling, or missing paint. These defects are detected using a color vision system consisting of two pairs of color video cameras and halogen lamps. Four or six images of a drum (depending upon drum size) are collected and sent to on-board image processors for color analysis. When new defects are found, their size and locations are recorded. Color images of defective drums are also stored to a hard disk for later viewing.

The IMSS vehicle's *Automated Baseline Change Detection* (ABCD) system detects any significant changes in the visual appearance of the face of a drum. It complements the original color-based corrosion detection system, increasing the defect detection performance of the IMSS system. The ABCD system operates on 4 or 6 color images (depending on drum size) and reports similar defect results as does the corrosion detection system.

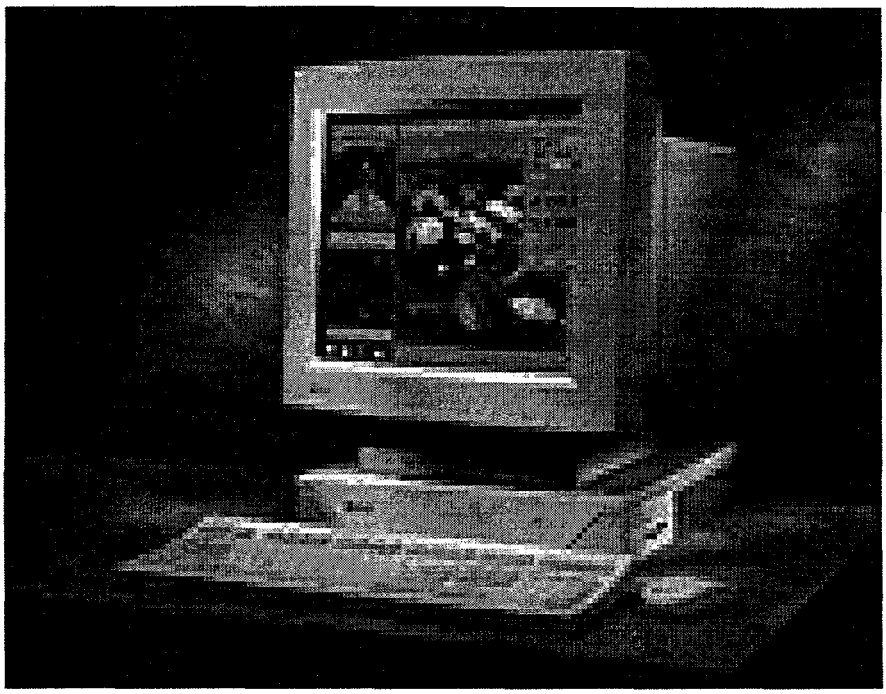

Figure 1-4. The IMSS control station.

1.2 The IMSS Control Station

During an inspection mission, all vehicle activity is coordinated by the vehicle's on-board mission executive software and its real-time planner. However, site personnel are involved to supervise operations before and after a mission. This is done through a graphical user interface from the centralized IMSS control station, shown in Figure 1-4.

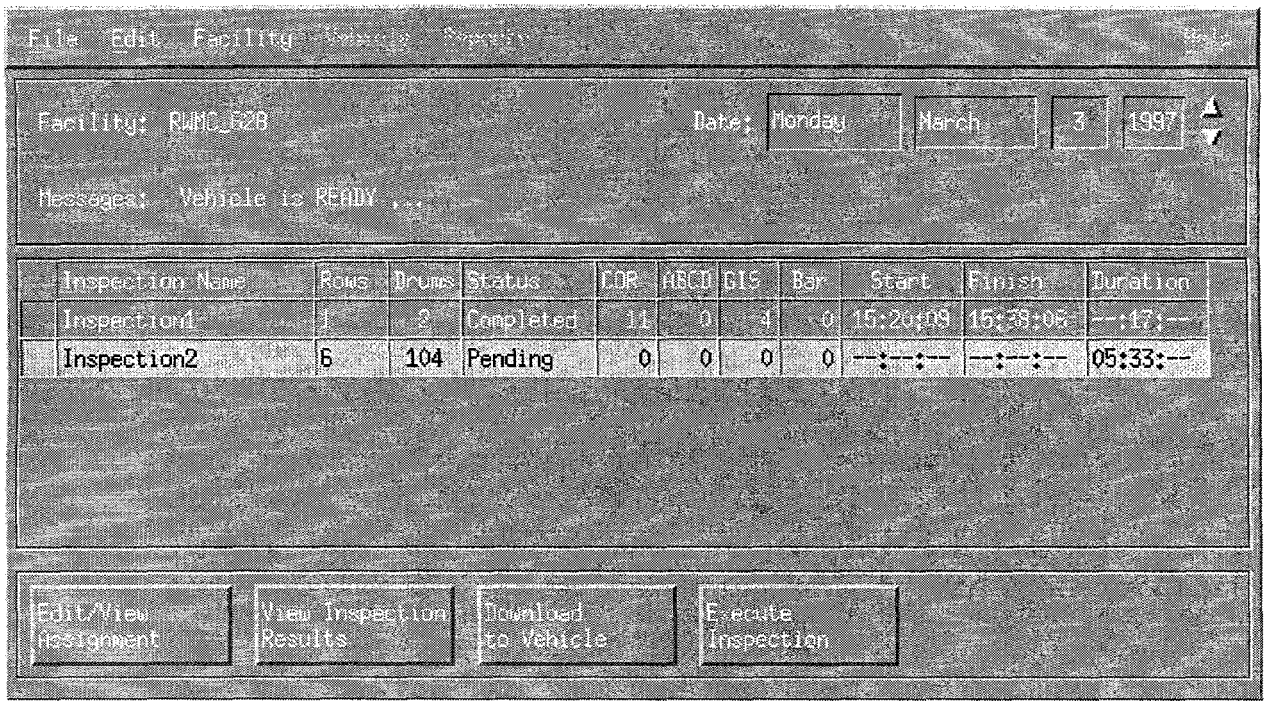

Figure 1-5. Main Screen of the IMSS operator interface.

The graphical user interface that the operator sees initially, called the Main Screen, is shown in Figure 1-5. This screen shows the inspection missions scheduled or already completed for a specified day of the year, and is the starting point for all other functions the operator may perform.

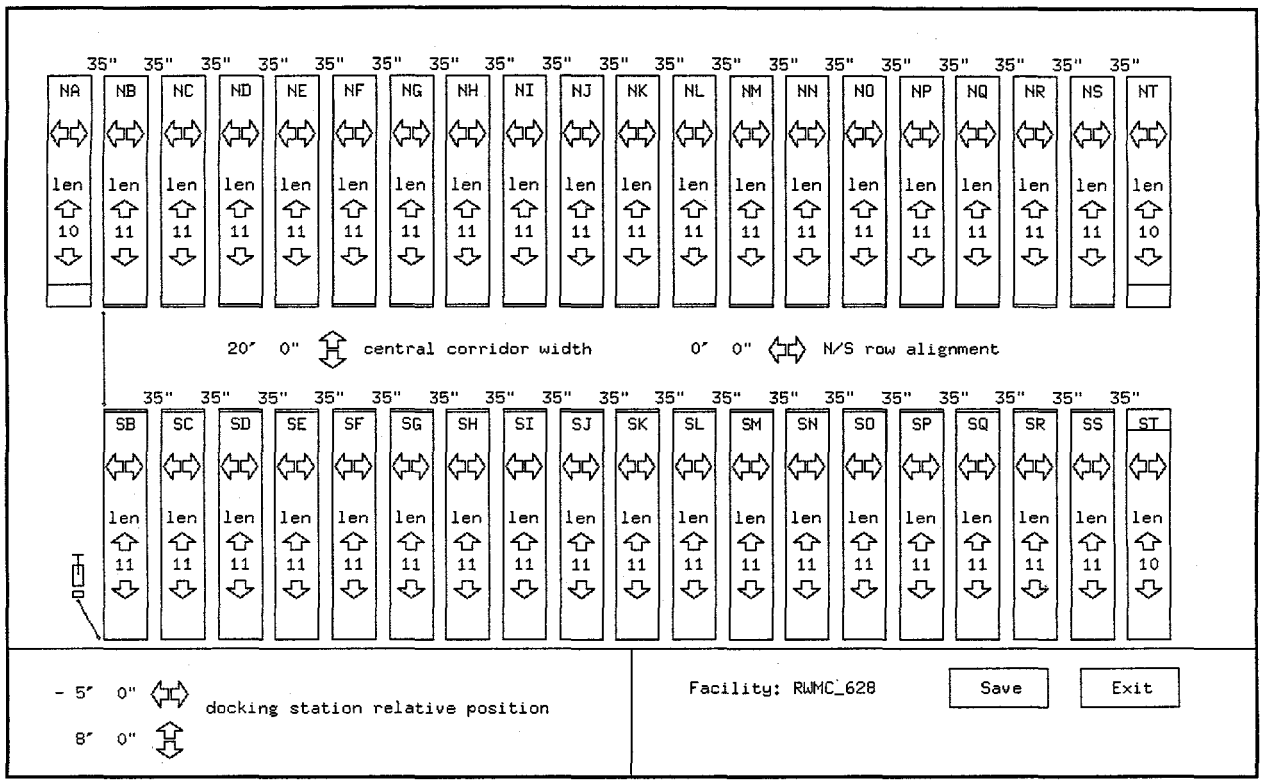

Figure 1-6. IMSS Facility Model Editor.

The *Facility Model Editor* function of the control station is normally only used occasionally. It allows an operator to specify the physical layout of the rows of drums inside the building where the IMSS vehicle is installed, as shown in Figure 1-6. The vehicle uses this information to help drive around inside the building.

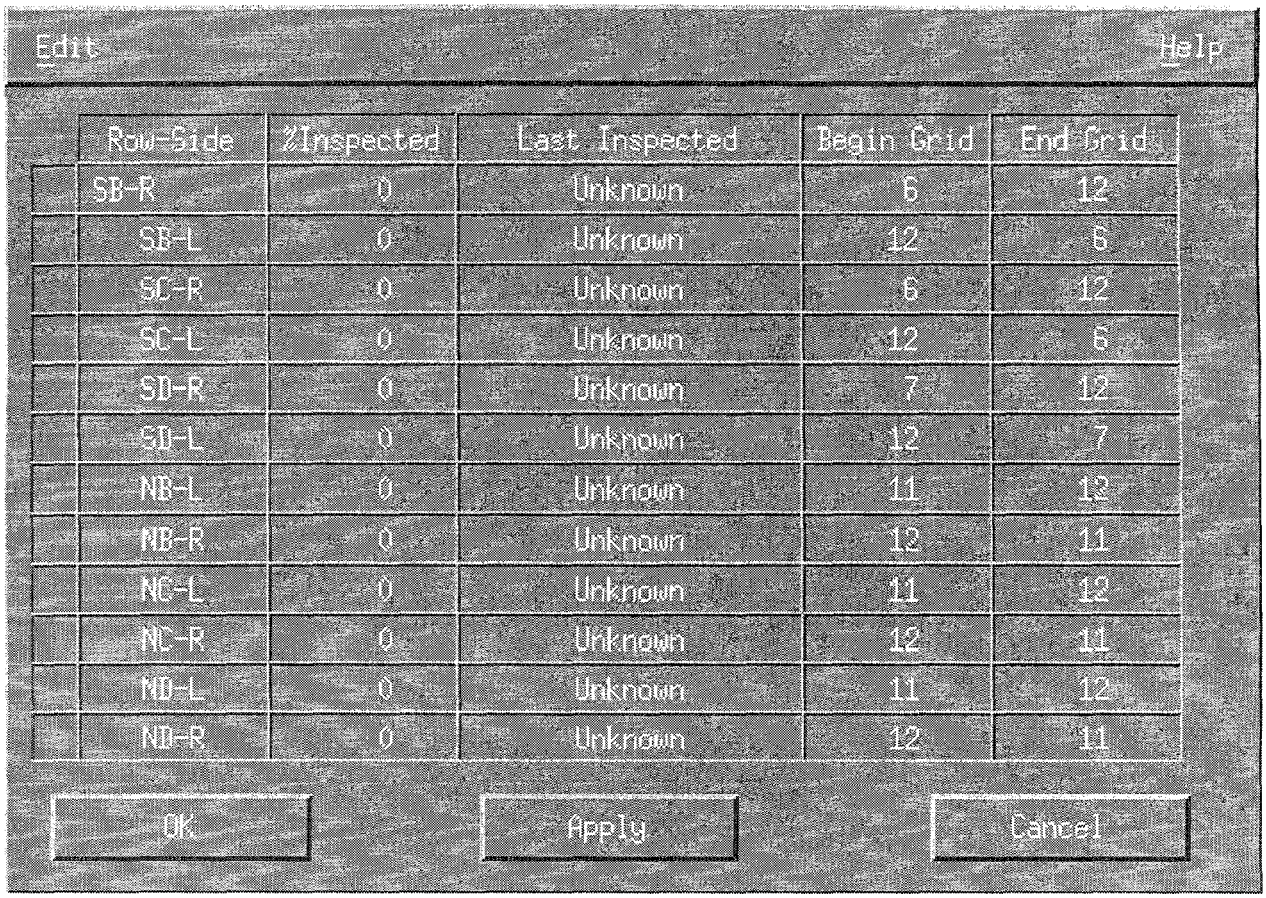

Figure 1-7. IMSS Mission Assignment Screen.

The *Mission Assignment* function of the control station allows an operator to specify an exact sequence of rows to be inspected, or simply to confirm a default assignment based on the building's current state of inspection. Figure 1-7 shows a sample of the Mission Assignment interface.

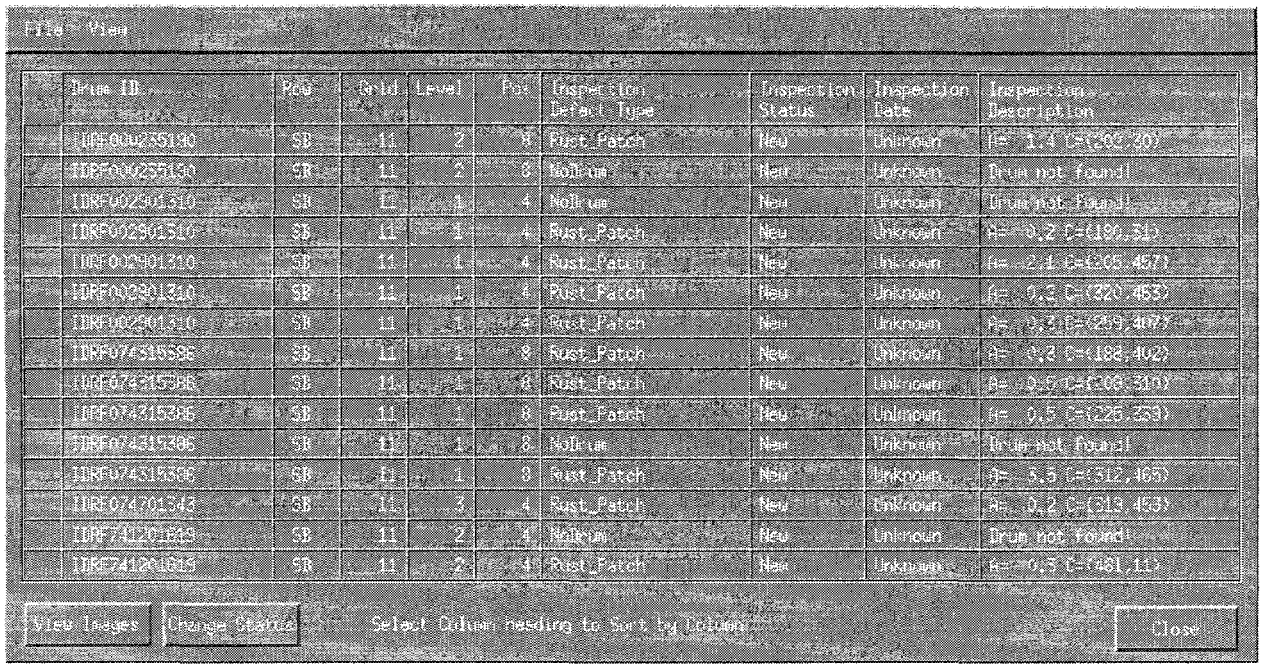

Figure 1-8. IMSS Mission Assessment Screen.

The *Mission Assessment* function of the operator interface allows an operator to review a mission's defect logs, display color images of defective drums, and generate a report summarizing the mission along with a list of reported defects. Figure 1-8 shows a sample of the Mission Assessment interface.

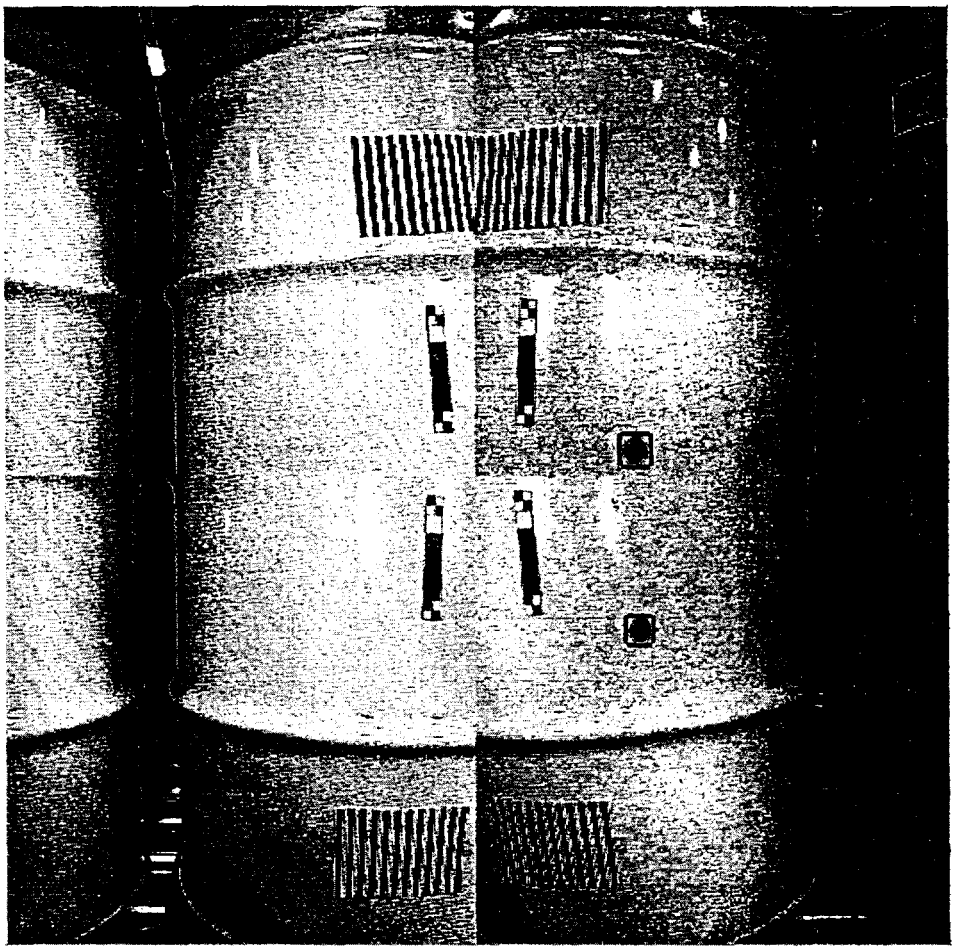

Figure 1-9. Boxes are drawn around detected corrosion defects in the composite image of a drum that the operator can summon for verification purposes.

A color image of every drum with geometric or corrosion defects is stored on the vehicle's hard disk for later viewing at the operator's control station. Figure 1-9 shows a sample of the processed image that is stored. It is the composite of four images. Corrosion defects are outlined by red boxes (defects detected based on color) or green boxes (defects detected based on changes seen in the drum since the last inspection).

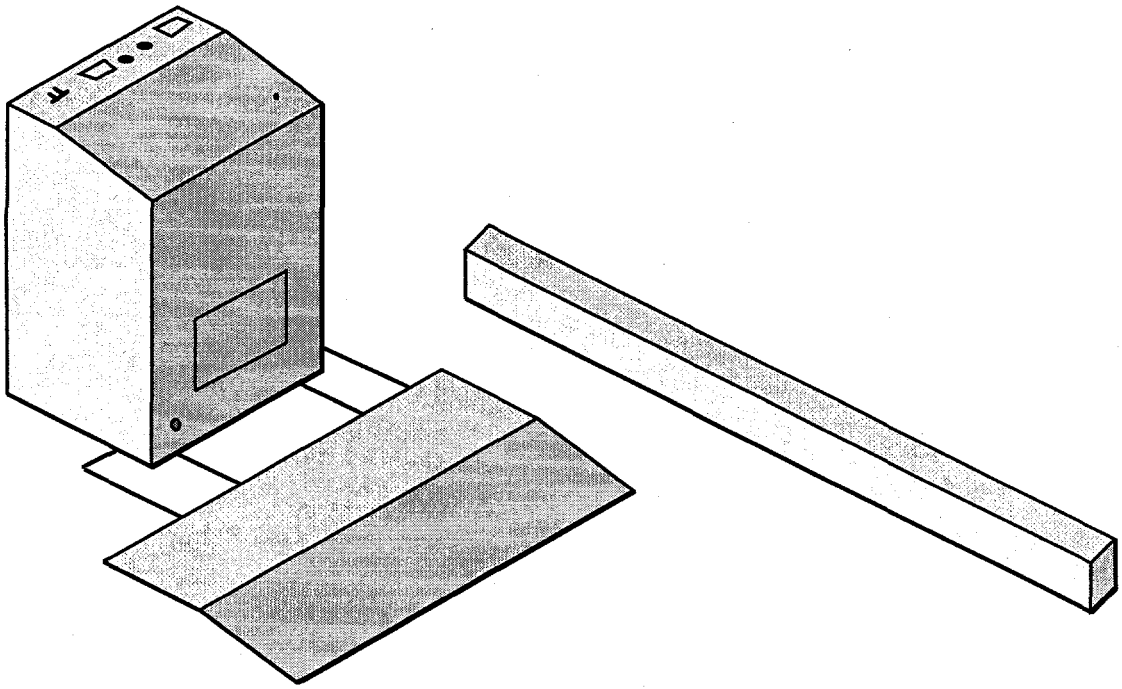

Figure 1-10. The IMSS docking station.

1.3 The IMSS Docking Station

The docking station (Figure 1-10) for the IMSS vehicle supports three functions: battery recharging, radio and wire ethernet communication, and it provides a fixed location for registration of the vehicle with the building coordinate system.

The vehicle batteries are charged at a 60 amp rate using a 5 kW variable voltage DC power supply. The power supply requires 208 VAC, 3-phase building power. At a 60 amp rate the batteries can be charged to their full 95 amp-hr capacity in under 30 minutes. Power is supplied to the vehicle through two spring loaded contacts that mate with charge plates on the rear of the vehicle near floor level. The contacts are energized by a charge relay only after two safety interlocks are overridden. The first safety interlock is defeated only when the weight of the vehicle rear wheels depresses a spring loaded pedal under the wheels. The second safety interlock is defeated only when the vehicle has docked completely and has fully compressed the spring loaded charge contacts. A guard plate is located above the contacts to deter accidental depression.

The vehicle automatically recharges its batteries as needed. The vehicle will automatically delay the start of a mission or return in the middle of a mission to recharge batteries, and then resume the mission.

The docking station includes a small frame that contains three antennas used to communicate with the vehicle. This frame is mounted on the inside wall of the building at a height above the highest level of drums. One antennas is for the radio ethernet. Another antenna supports a remote control panel from which the vehicle can be signaled to "pause" its operations or to initiate an "emergency stop". The third antenna provides a live video feed from a camera on the vehicle monitor at the docking station, so that a casual visitor or somebody using the remote control panel can more easily observe and verify the operations of the vehicle.

2. Operational Modes of the IMSS Vehicle

This section describes how the IMSS vehicle will behave in normal operation. After reading this section, operations staff who work near the IMSS vehicle will be familiar with how the vehicle will behave during normal operation. This should help people feel comfortable working inside the same building as the IMSS vehicle, and may help them recognize anomalous behavior by the vehicle if such should ever occur.

2.1 State Sequence Diagram

The IMSS vehicle moves around inside a waste storage building in a highly structured manner. Internally, the vehicle maintains information on its logical state within the building (e.g., entering aisle between row NA and row NB), its spatial (x,y) position within the building, and its position relative to the drums based on counting drums using ultrasonic sensors (e.g., 14th drum down row NA). Internally the vehicle uses a highly complex set of logical states and transitions between them.

Figure 2-1 shows a simplified state transition diagram that describes all the possibilities for how the vehicle might move around inside a building. Figure 2-2 shows the spatial areas corresponding to each state in the state transition diagram. The remainder of this subsection describes each logical state and explains the general behavior of the vehicle in that state. Following subsections provide more detail on the movement and other visible behavior of the vehicle.

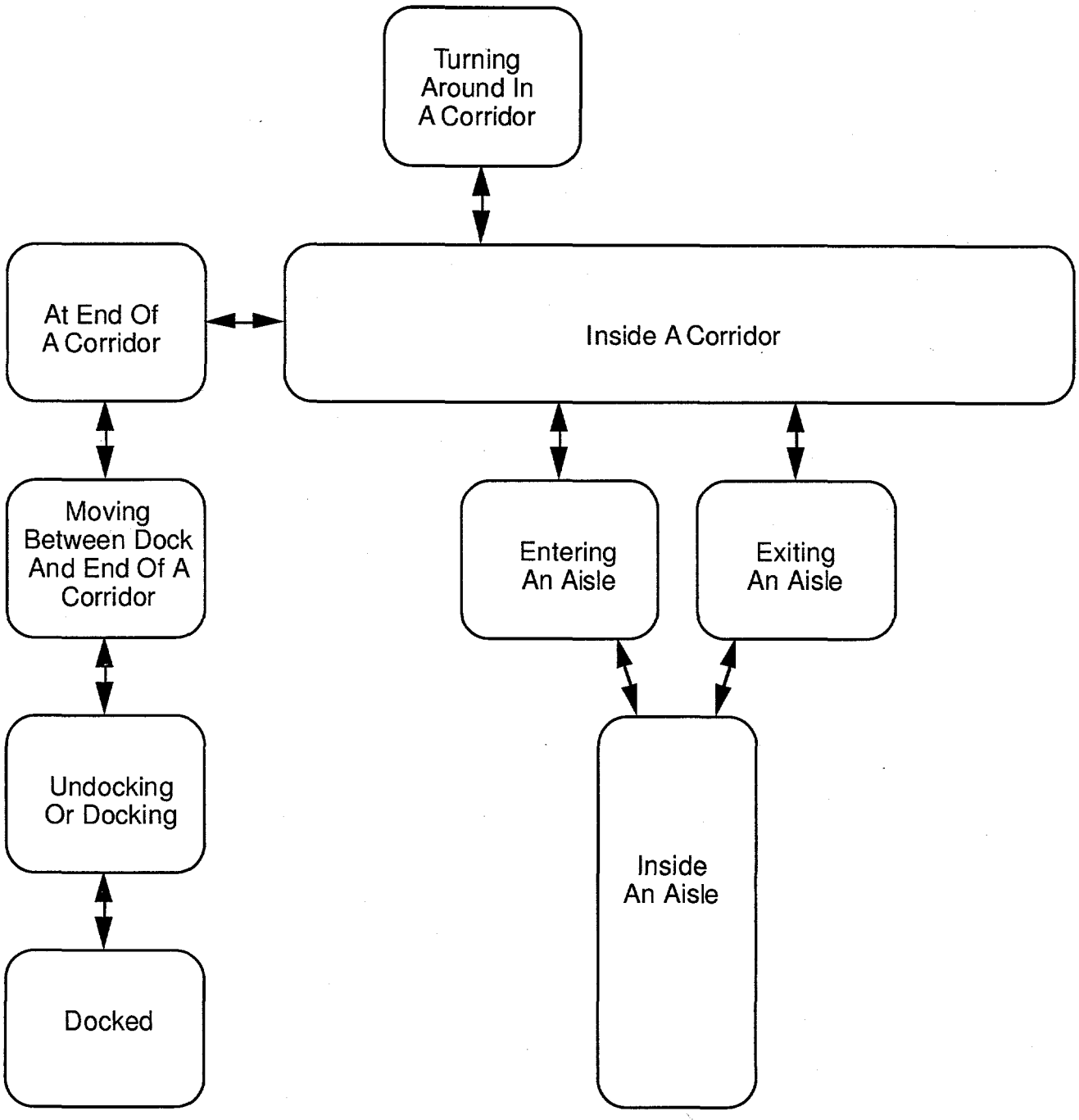

Figure 2-1. State transition diagram showing the logical states and transitions regarding the movement of the IMSS vehicle inside a waste storage building. This diagram shows the states for one side (e.g., south side) of the building. A second copy of this diagram would show the same states for the other side (e.g., north side) of the building. The Docked state is shared between those two diagrams.

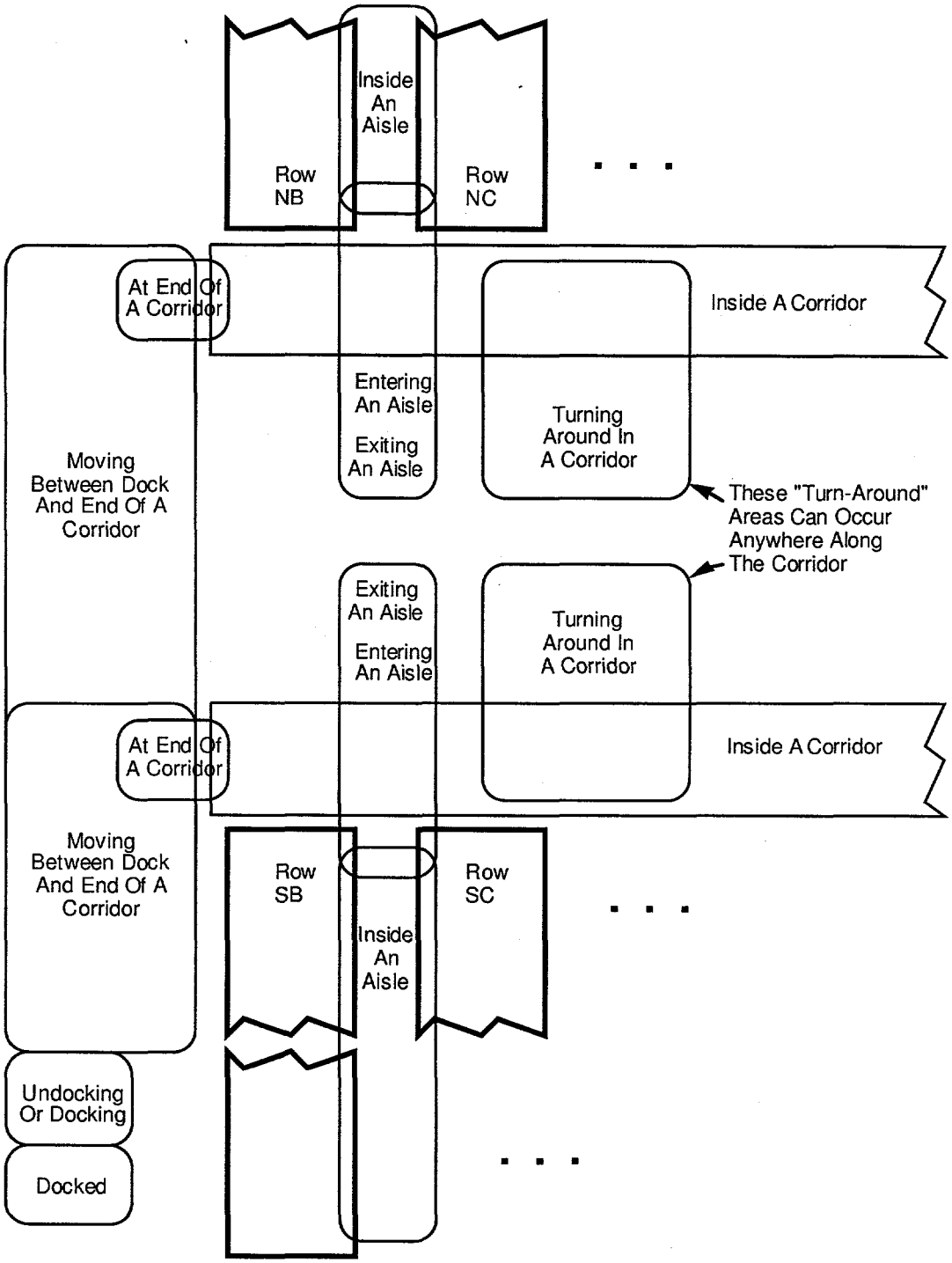

Figure 2-2. Bounds of the spatial areas corresponding to each logical state in the state transition diagram (Figure 2-1).

Docked: In this state the vehicle is located at the docking station such that the charge plates on the back of the vehicle are touching the charge plates on the front of the docking station. Whenever the vehicle is not inspecting drums, it will remain in the docked position. Normally, the vehicle is always powered on, and will either be waiting in a ready state or be recharging its batteries.

Undocking Or Docking: When the vehicle is undocking it simply moves forward to an open area just in front of the docking station. When the vehicle is docking, it must precisely align itself with the docking station so that the charging contact plates on the back of the vehicle and the front of the docking station touch each other. This precise alignment requires multiple movements by the vehicle. The vehicle begins at the point where it ends up after it has undocked, but since the vehicle normally would have returned from inspecting drums it will be facing towards the docking station. The vehicle will then turn around by rotating in place, align itself with the 2x4 on the floor that is attached to the docking station, back up to the docking station, and do a final precise backup move to make contact between the charge plates.

At End Of A Corridor: Here, the term *corridor* has a specific meaning. Imagine a long hallway carpet that is about four feet wide. If such a carpet was placed down past the inside ends of all the rows on one side (e.g., north) side of the building, then the area covered by that carpet is what we refer to as a *corridor*. The vehicle normally drives up and down the corridor to get to any aisle on that side of the building. The logical state named "At End Of A Corridor" is a small area at the end of a corridor that is nearest to the docking station.

Moving Between Dock And End Of A Corridor: As this logical state's name implies, when the vehicle is in this logical state: the vehicle is either (a) traveling from the docking station to the "At End Of A Corridor" position for either the rows on the north side of the building or for the rows on the south side of the building, or the vehicle is (b) traveling in the reverse direction, returning to the docking station. Note that if the vehicle is inspecting drums on one side of the building (e.g., north) and needs to travel to drums on the other side (e.g., south) it will first return to the docking station before going to the other side. In other words, the vehicle will never cross from one side of the building to the other at an arbitrary position. The area associated with the "Moving Between Dock And End Of A Corridor" logical state (see Figures 2-1 and 2-2) is the only area through which the vehicle will pass when going to/from an inspection of the drums on one side of the building or the other. The vehicle makes a series of separate moves when moving in this logical state. This series of separate moves helps improve the precision of the vehicle's movement over the long distance that it must travel in this logical state.

Inside A Corridor: The vehicle is in this logical state whenever it is traveling from the end of one row of drums to the end of another row of drums (or to the "At End Of Corridor" state). The vehicle can be facing in either direction down the length of the corridor. In this state the vehicle drives down the corridor while counting drums (four at the end of each row) until it is at the end of the row that is its immediate destination. Note that this state can lead to several other states in which the vehicle will move outside of the corridor area.

Entering An Aisle: In this state the vehicle turns and moves from its position inside the corridor to a new position that is further away from the corridor and that is facing into an aisle. This is in preparation for the vehicle to drive forward to visit drums inside the aisle on either side. The vehicle may perform several smaller-sized movements when in this state.

Inside An Aisle: When in this state, the vehicle in located inside an aisle and is inspecting a set of drums on either side of the aisle. The vehicle always faces forward into the aisle, and will move both forward and backward inside the aisle. The vehicle may move back and forth inside the aisle in an arbitrary fashion, but in most cases it will move all the way down the aisle while inspecting drums on one side the aisle and then move backward in the aisle while inspecting drums on the other side. The vehicle will typically stop in front of every bottom-level drum, and remain there for

perhaps a minute or two. At this time the vehicle is inspecting the bottom-level drum and all the drums stacked directly above it. The sensors on the mast will move during the inspection process. The IMSS vehicle will spend the majority of its time in this state. (The other state where the vehicle spends a great deal of time is the Docked state.)

Exiting An Aisle: In this state the vehicle begins inside an aisle and backs outward from the aisle. Then the vehicle will turn and move so it is inside the corridor and facing one way or the other down the corridor.

Turning Around In A Corridor: In this state the vehicle will slide away from the corridor (in the direction away from the nearby rows of drums), turn around, and slide back into the corridor. As a result, the vehicle will be at the same position it started from, but facing in the other direction down the corridor.

2.2 Motions To Be Expected

The IMSS vehicle uses an unusual type of wheel called a Mecanum wheel, which will be unfamiliar to most people. Mecanum wheels allow the vehicle to drive forward or backward as would be expected. The vehicle can also rotate in place. (In other words it does not require a turning radius like a automobile's steering requires.) The vehicle can also drive directly sideways, left or right. The vehicle can also move using any simultaneous combination of these individual movements. For example, the vehicle can rotate and move forward simultaneously.

Most often, the IMSS vehicle simply drives forward or backward. But occasionally the vehicle must make other types of moves, and occasionally these involve one of the potentially unusual variety of moves listed above (e.g., a move directly sideways).

Operations staff must be aware of the potential for these unusual movements, and know to keep an appropriate distance from the vehicle. A good general rule is to stay at least 6 feet away from the vehicle at all times (see the Safety section for other procedures to follow to help assure safe operations).

The IMSS vehicle should never move faster than a few inches per second. Whenever the vehicle moves, it moves with a constant speed. It should never speed up (or slow down), except for the very brief moments when a movement starts and ends. The IMSS vehicle motors are technically capable of moving the vehicle quite fast, but this should never happen unless a hardware error occurs (see the Safety section for more details).

In most cases, immediately before the start of a movement by the IMSS vehicle, the vehicle will first reposition the sensor mast in preparation for that move. The mast must be moved in some cases in order to make use of sensors contained on the mast. Otherwise, the vehicle generally tries to point the mast so its sensors point in the direction of motion -- specifically, so that the mast's mechanical collision sensor and the mast's ultrasonic range measurement sensors are pointed in the direction of motion.

Once the vehicle has arrived at a position in front of a drum inside an aisle and when the vehicle begins the process of inspecting that drum (and simultaneously those stacked directly above it), the vehicle will make two types of movements. First, the four sensor suites on the sensor mast will tilt up and down. This enables the sensors to view all parts of the drum's faces. And second, the vehicle may make a small forward or backward movement -- as much as 2 inches -- in order to precisely position itself in front of the drums.

2.3 Noises To Be Expected

The vehicle makes a few noises during normal operations. The soft blowing sound of a set of fans will be heard whenever the vehicle is powered on. The vehicle makes a soft grinding-type of sound whenever the vehicle moves -- this sound is caused by elements of the wheel and motor subsystem. A soft, regular clicking sound will also be heard whenever the vehicle is moving -- this sound is from the ultrasonic sensors used to measure distances to drums and to detect obstacles. Different subsets of ultrasonic sensors are used during different movements, so the clicking sound might sound slightly different from one move to another.

The vehicle intermittently makes some other sounds at certain specific times. The vehicle contains several mechanical relays that make a loud clicking sound when they turn on or off. These relays will make noises at the following times: during the automatic startup after the vehicle is first turned on, when the vehicle is turned off, whenever the vehicle starts and finishes charging its batteries, whenever a kill switch is activated (see the Safety section), when restarting the vehicle from a kill switch event, and if the vehicle power is ever automatically turned off by the vehicle's internal safety circuitry.

When the vehicle is performing the inspection of a drum, the sensor suites will move, which sometimes makes a slight swishing sound. Also, when the sensor suites move and the bar code readers successfully read bar codes on the drums being inspected, the bar code readers will beep once for each bar code that was successfully read.

When the vehicle docks and undocks, two safety switch mechanisms built into the docking station will make small noises. One sound occurs when the vehicle climbs the ramp in front of the docking station and the vehicle's weight slightly depresses the hinged ramp. The other sound occurs when the docking station's charging contacts are contracted and pressed in by the vehicle.

The motors located inside each sensor suite on the mast will occasionally make a slight high-pitched whining noise, which should not endure for long periods of time. If these noise do endure for long periods, they should be reported to the IMSS system operator.

2.4 Lights To Be Expected

A panel on the back side of the IMSS vehicle contains several status lights, which should not be of concern during normal operations. The meaning of these lights is described in the section on Vehicle Hardware and Maintenance.

Two "pause" switches are located on top of the arm connecting the vehicle's body with its mast. Whenever one of these switches is set to the "pause" position, a red light adjacent to one of the switches will turn on. These switches are described in the Safety section.

Each of the four sensor suites on the mast contains several types of lights involved in the process of inspecting drums. A laser projection module uses a laser that projects a "stripe" of light that is visible on a drum face as a red line. Never look directly into these laser beams (See the Safety section below). This laser is on only when it is used to scan a drum for geometric defects, and is automatically turned off at all other times.

The bar code reader module also uses a laser that appears as a dim line on a drum face. It may be difficult to see this line. There is no eye safety issue associated with this laser, but one should never look directly into a laser beam in any situation. This laser is on only when it is used to read a barcode, and is automatically turned off at all other times.

Each sensor suite also has a pair of halogen lights which are turned on briefly when the vehicle is collecting pictures of a drum during the inspection process.

The slanted face of the docking station contains a red light that is on when the charging plates on the front of the docking station are electrically powered. This situation can only occur if the weight of the vehicle is pressing down on the docking station's ramp, the vehicle is pressed up against the docking station's charging plates, and the docking station power supply is turned on. See the Safety section below for additional information. The panel for the power supply built into the docking station also has a few red lights indicating that the power is on and indicating the status of the power supply.

The equipment associated with the docking station has a few lights indicating that power is turned on to the various devices (radio devices, site ethernet connections).

3. Safety

We recommend that the installation site for the IMSS system develop their own safety plan and associated operational procedures related to the IMSS vehicle and docking station. In support of developing such a plan, this section recommends operational procedures to help maintain a safe operating environment around the IMSS vehicle and docking station. A safety plan can not be properly developed without an understanding of the issues that effect safety. Therefore, this section provides a detailed explanation of potential hazards related to the IMSS vehicle and docking station.

3.1 How to "Emergency Stop" Any Motion of the IMSS Vehicle

3.1.1 Recommended Safety Procedures

If ever necessary, anybody can immediately stop the motion of the vehicle by using any of the methods described below. The result is sometimes called an *emergency stop*, and as the name implies an emergency stop is intended for emergency situations. However, if you are ever concerned about the motion of the vehicle, and in a hurry for any reason, then you should feel free to emergency stop the vehicle.

(Some effort is required to recover from an emergency stop. For non-emergency situations when the vehicle needs to be temporarily stopped and there is no hurry, a different safety mechanism is provided. This mechanism, called a *pause*, is discussed later in this section.)

A good general procedure to follow is to stay at least 6 feet away from the IMSS vehicle at all times. Never place your head or body in very close proximity to the sensor mast. Never try to squeeze past the IMSS vehicle when it is located inside an aisle between rows of drums.

3.1.2 The Safety System

There are several ways to trigger an *emergency stop*, which will quickly stop the motion of the vehicle and the vehicle's mast. All these methods, called *kill switches*, are based on physical switches. All these methods produce the same result: the power to all the vehicle's motors is immediately disabled. When any kill switch is triggered, the motion of the vehicle body will stop almost immediately. When any kill switch is triggered, the motor moving the vehicle's mast is immediately turned off, but the mast usually has some momentum and it may travel a short distance before its motion stops.

Figure 3-1 shows the location of all the kill switches on the vehicle:

- A red colored "mushroom" button is located on the flat top surface at the back of the vehicle. This button is easily accessible when standing behind the vehicle, and can also be accessed from the sides of the vehicle. To operate this button, push down firmly on it. Once pushed, the button will remain in the down position. (The button must be pulled upward to unset the switch.) This mushroom switch is the best kill switch to use.
- A similar red color mushroom button is located on the flat top surface of the "arm" connecting the mast to the vehicle. This button can be reached from the front of the vehicle, but requires reaching around the mast.
- The sheet metal skins on the left and right sides of the vehicle have numerous built-in kill switches. Any part of these skin surfaces can be pressed to activate a kill switch.
- The mast collision sensor is also a kill switch.

A remote kill switch is available on the radio button panel located at the docking station, as shown in Figure 3-2. The "number 4" button on the button panel sends a radio signal to the IMSS vehicle activating an internal kill switch. Note that the radio requires a line of sight path between the antenna mounted on the wall above the docking station and the antenna mounted on top of the IMSS vehicle's mast. The radio will not work if there is no line of sight path, or if there is any radio interference from outside sources.

When the emergency stop system is triggered one of more status lights on the status panel (on the back left corner of the vehicle) will turn on. Procedures for restarting the IMSS vehicle after a kill switch has been activated are provided in the section on Day-to-Day Operations of the IMSS System.

3.1.3 Explanation of the Hazard

The wheel motors of the IMSS vehicle are capable of causing the vehicle to move quickly. The vehicle weighs in excess of 700 pounds. The IMSS vehicle's software is designed to always drive the vehicle at a slow and very safe speed. However, it is conceivable (though highly unlikely) that some error (e.g., a hardware error) could cause the vehicle to move at the maximum possible speed (at least 3 feet per second).

The motor that causes the IMSS vehicle's sensor mast to swing from side to side is capable of moving the mast quickly. The mast is relatively heavy. The IMSS vehicle's software is designed to move the mast at a slow and very safe speed. However, it is conceivable (though unlikely) that some error (e.g., a hardware error) could cause the mast to swing at a very high speed. Physical blocks on the sensor mast's "arm" limit the motion of the mast so that it can not move through the two planes the define the left and right side surfaces of the vehicle.

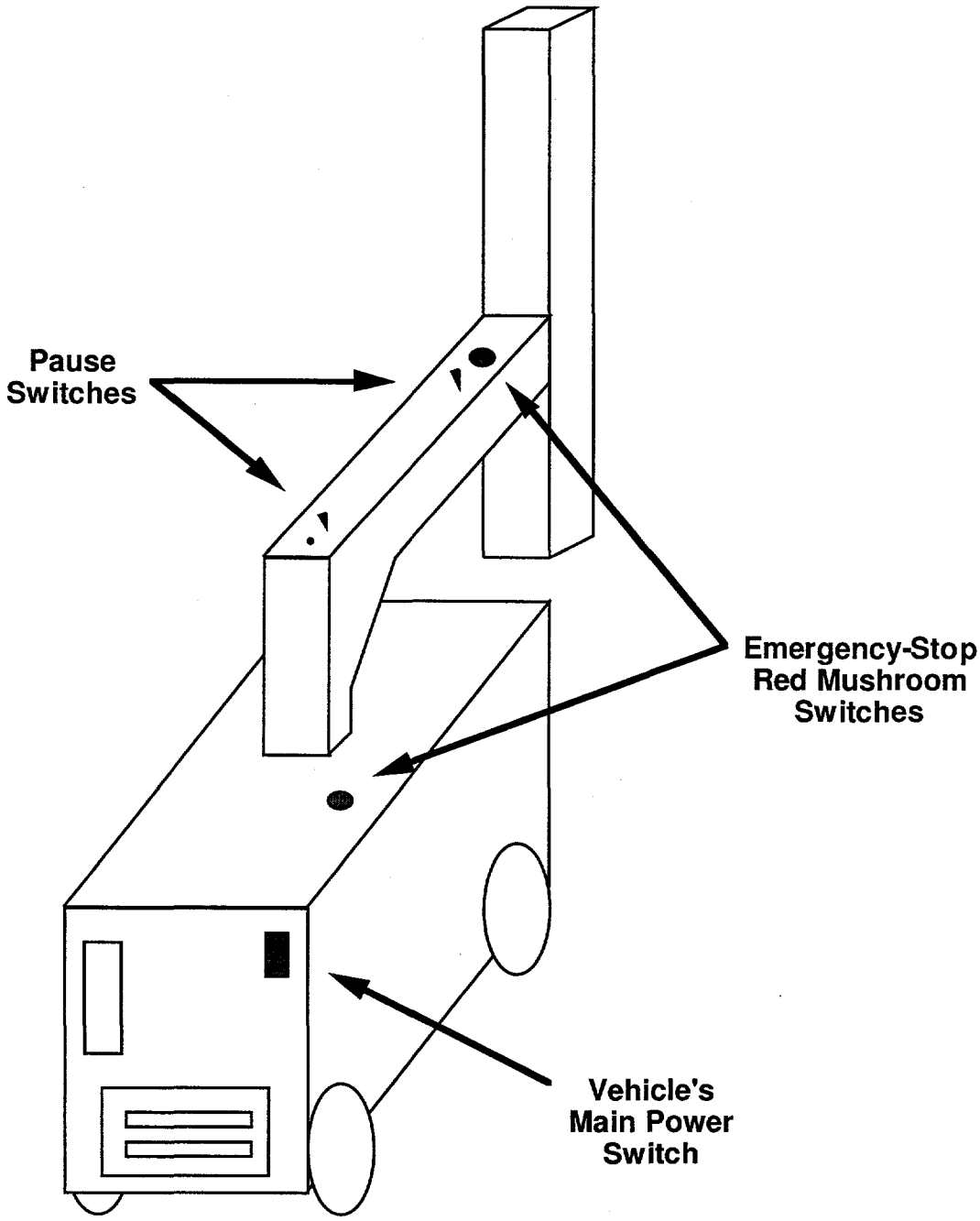

Figure 3-1. Location of the kill switches and pause switches on the IMSS vehicle.

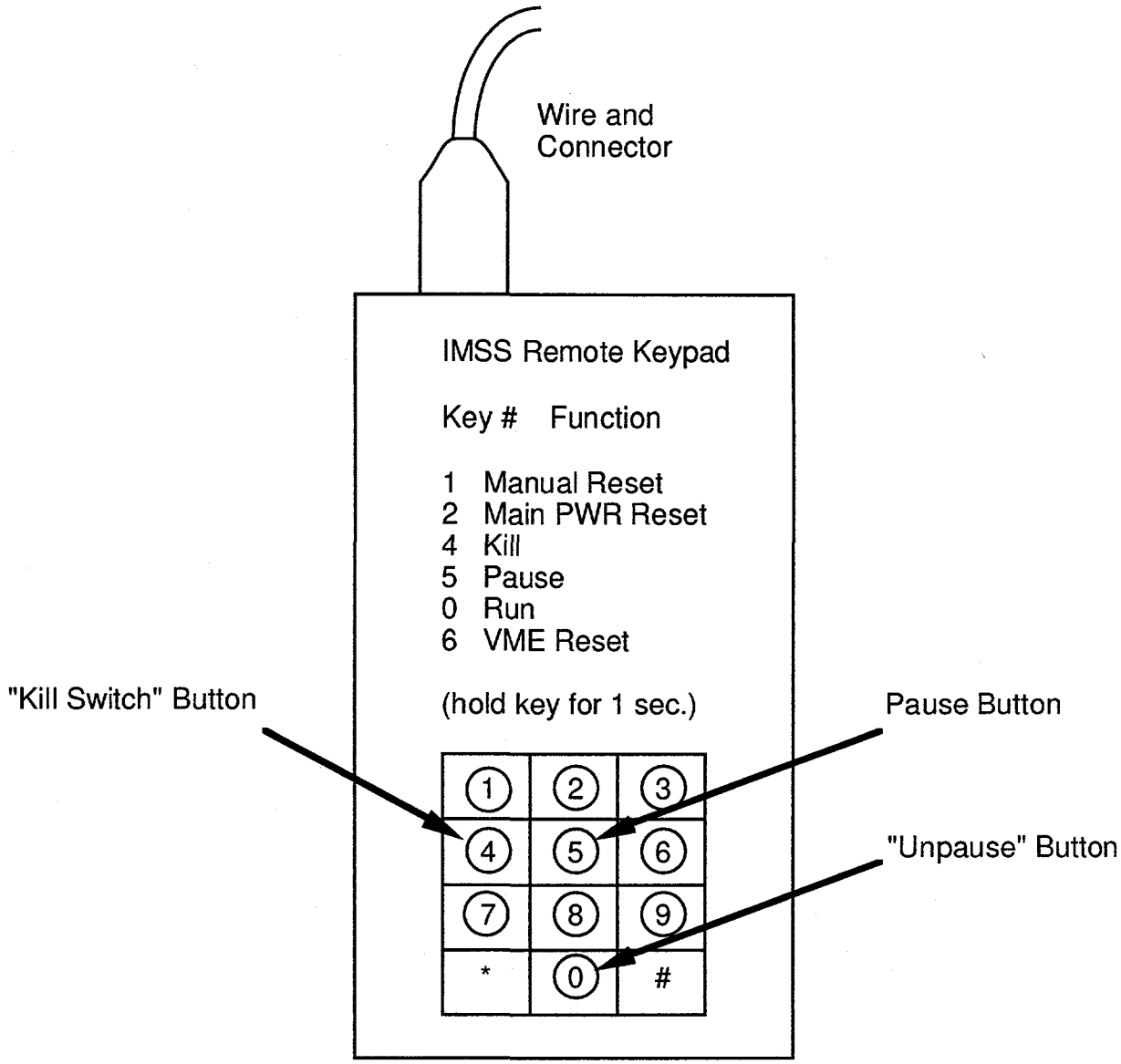

Figure 3-2. Location of the kill switches, pause, and run (unpause) switches on the radio button panel at the IMSS docking station

3.2 How to "Pause" All Motion of the IMSS Vehicle

3.2.1 Recommended Safety Procedures

During normal (non-emergency) situations a person may want to temporarily stop the motion of the vehicle, and later allow it to resume operation. For example, it may be necessary for people to perform a task involving considerable movement of forklifts inside the building, and the people may prefer that the IMSS vehicle not move while they are performing their task.

Anybody can temporarily stop and later resume the motion of the vehicle by using any of the methods described below. This action of temporarily stopping and later resuming the motion of the vehicle is called *pausing* the vehicle (and unpausing the vehicle).

The vehicle should not be paused for long periods of time (certainly not for more than an hour), since if the vehicle batteries drain to the point of needed a recharge during the pause time, the vehicle will not be able to return to the docking station to automatically recharge. If the vehicle can not recharge its batteries, it will eventually execute an automatic emergency power-down.

Even when the vehicle has been placed into its pause state, a good general procedure to follow is to stay at least 6 feet away from the IMSS vehicle at all times. Never place your head or body in very close proximity to the sensor mast. Never try to squeeze past the IMSS vehicle when it is located inside an aisle between rows of drums.

3.2.2 The Safety System

The vehicle can be paused via two switches on the vehicle or via a button on the remote button panel. When a pause switch/button is activated the IMSS vehicle will complete its current motion (if any), which sometimes can take many seconds, and then the vehicle wait motionless until the pause switch is disabled.

Figure 3-1 shows the location of the two pause switches on the vehicle: Two pause switches are located on the flat top surface of the "arm" connecting the mast to the vehicle. A red light next to one of these switches will turn on to indicate that a switch is enabled.

The "number 5" button on the button panel (see Figure 3-2) located at the docking station sends a radio signal to the IMSS vehicle activating an internal pause switch. The "number 0" button (labeled "Run") send a radio signal to the IMSS vehicle to deactivate that internal pause switch, which will unpause the vehicle after it had been paused from this same panel. Note that the radio requires a line of sight path between the antenna mounted on the wall above the docking station and the antenna mounted on top of the IMSS vehicle's mast. The radio will not work if there is no line of sight path, or if there is any radio interference from outside sources.

3.2.3 Explanation of the Hazard

The pause mechanism is intended to help avoid the inconvenience of having the vehicle move when people come to work in the area.

3.3 Hazardous Voltages at the IMSS Vehicle

3.3.1 Recommended Safety Procedures

The IMSS vehicle does not have any hazardous voltages that are exposed on the outside of the vehicle for potential contact by a human, so no safety procedures are necessary in this regard.

There are no user serviceable parts inside the IMSS vehicle. We do not recommend opening the IMSS vehicle body.

(Safety procedures do exist when the vehicle is located at the docking station, as explained later in this section.)

3.3.2 The Safety System

The IMSS vehicle is design so that it does not have any hazardous voltages that are exposed on the outside of the vehicle body or within the vehicle's mast.

The vehicle body should never be opened to expose internal electrical circuits, so there is no resultant hazard. If the vehicle body is opened, physical barriers (Plexiglas panels) located inside the vehicle help block access to the specific areas inside the vehicle that contain potentially dangerous electrical circuits.

3.3.3 Explanation of the Hazard

The batteries inside the IMSS vehicle can produce an extremely dangerous voltage and current, however all electrical wires carrying such currents are located both inside the vehicle body and behind additional physical barriers inside the vehicle body.

The vehicle contains a number of fuses in two major areas inside the vehicle, and several individual components inside the vehicle have their own fuses. However, we do not recommend that local personnel attempt to access or replace these fuses. If a fuse were to blow, it would be because there is some other fundamental hardware problem within the vehicle, which means that IMSS system development team personnel will be required to analyze and fix the problem.

The charge plate located on the back of the vehicle is used for charging the batteries. These plates never have live electricity on them except in the one case when the vehicle is located at the docking station and is actively charging its batteries (more on this below). In all other cases the charge plates on the back of the vehicle are electrically disconnected (via a software-controlled relay) from the batteries. As an additional safety measure, the charge plate includes a diode in its wiring, which permits electricity to enter into the battery but none to exit from the battery through the charge plates (and thus potentially into a human).

3.4 Hazardous Voltages at the IMSS Docking Station

3.4.1 Recommended Safety Procedures

Never place hands or feet into the space between the docking station and the docked vehicle. A good general procedure to follow is to stay at least 3 feet away from the docking station at all times.

3.4.2 The Safety System

The docking station has a partially exposed exterior charging contact plate that forms an electrical circuit with the vehicle when it is docked. This contact plate is partially covered with a guard plate designed to help reduce the possibility of human contact, however the contact plate must remain partially exposed so that the IMSS vehicle can make electrical contact with it in order to recharge its batteries. When the vehicle is not docked at the docking station, two independent safety switches cause the docking station's charging contact plate to be electrically disconnected from the DC power supply. The first of these switches is enabled only when the vehicle is located adjacent to the docking station and is exerting its weight on the ramp leading up to the contact plate. The second of these switches is enabled only when the vehicle is pushing up against the docking station's contact plate sufficiently to depress the contact inward by about 1/2 inch.

A sign clearly warning of this extreme danger is mounted on the docking station. The changing contact plate of the docking station is outlined with a yellow-colored tape to indicate the potentially live electrical area. A "Do Not Enter" zone around the docking station is outlined on the floor with a yellow-colored tape.

3.4.3 Explanation of the Hazard

When the IMSS vehicle is not docked at the docking station, the docking station does not pose a hazard since all the docking station's safety interlocks will be engaged in this situation.

The docking station is used to charge the IMSS vehicle's batteries, an operation that requires very high current and voltage. An electrical hazard exists when the vehicle is located at the docking station (and presuming the DC power supply inside the docking station is powered on, as it would be during normal operational use of the vehicle). In this situation, the charge plates are a source for a very high electrical current.

3.5 Structured-Light Sensor's Laser Element

3.5.1 Recommended Safety Procedures

Stay at least 3 feet away from the vehicle's mast at all times. Never place your head near the vehicle's sensor mast. A good general procedure to follow is to never look into any laser beam emanating from the vehicle.

3.5.2 The Safety System

The structured-light sensor contains a Class IIIb laser product, which must be operated with special precautions. The laser element is permanently attached to a beam spreader that reduces the energy density to a Class II level within eight inches, so that safety is virtually ensured as long as you are eight inches away when the vehicle is powered. To mitigate the risk of exposure to these lasers, power to the lasers is controlled through a safety panel key-lock and software-controlled power supplies which ensure the lasers are turned on only when scanning to collect data during drum inspection.

3.5.3 Explanation of the Hazard

Looking directly into a high-powered laser presents a potential eye hazard. Laser light from the structured-light sensor that is reflected off a drum does not represent a hazard. The IMSS vehicle's lasers do not pose any skin hazard.

3.6 Automatic Emergency Power-Down

3.6.1 Recommended Safety Procedures

This safety system is built into the vehicle and is fully automatic. No pro-active safety procedures exist in this area.

3.6.2 The Safety System

One of the highest priority programs running on the IMSS vehicle's on-board computer during vehicle operation is the System Monitor task. Its primary purpose is to monitor critical parameters associated with the battery sensor system including: 1) battery voltage, 2) battery current, 3) battery temperature, and 4) the batteries' current state of charge. When one or more safety thresholds is exceeded, the System Monitor alerts the other programs running internally on the vehicle's on-board computer, allowing them time to gracefully exit, and then removes all power to the vehicle system by closing the main battery power relay. Table 3-1 summarizes the triggers for an emergency power-down.

Table 3-1. Emergency Power-Down Triggers.

Cause	Threshold
High Battery Voltage	100 V
Low Battery Voltage	42 V
High Battery Current	±75 A
High Battery Temperature	42 °C
Low Battery Temperature	-17 °C
High Battery Temperature Change	+8 °C
Low Battery State of Charge	2 %

That an emergency power-down was triggered will be obvious when physically visiting the vehicle, since all vehicle power will be off. Procedures for restarting the IMSS vehicle after an emergency power-down is triggered are provided in the section on Day-to-Day Operations of the IMSS System.

3.6.3 Explanation of the Hazard

This safety system is designed to protect the vehicle from potential internal anomalies related to it's battery system.

3.7 Automatic Emergency Stop

3.7.1 Recommended Safety Procedures

This safety system is built into the vehicle and is fully automatic. No pro-active safety procedures exist in this area.

3.7.2 The Safety System

The kill switches discussed earlier in this section cause power to be disconnected from all the motors on the vehicle (for vehicle movement and for mast movement).

Limit switches are mounted on the mast's pan axes and sensor suites' tilt axes. These switches are triggered whenever an axis exceeds its normal range of motion, and cause power to be disconnected from all the motors on the vehicle.

Servo-control of each motion axis is accomplished through commercial analog motion control boards which are integrated with a number of safety features. Primary among these is the detection of excess servo errors, caused, for example, by the failure of a position encoder. If an excess servo error is detected, the motion control board disables commands to the actuator amplifier, effectively inhibiting its operation. Other servo error parameters and thresholds are also implemented on each axis.

When the emergency stop system is triggered one of more status lights on the status panel (on the back left corner of the vehicle) will turn on. Procedures for restarting the IMSS vehicle after an emergency stop is triggered are provided in the section on Day-to-Day Operations of the IMSS System.

3.7.3 Explanation of the Hazard

This safety system is designed to protect the vehicle from physical harm.

4. Suggested Procedures for Operations Staff Working Inside the Building

The installation site for the IMSS system will need to develop procedures for their operations staff working inside a building where the IMSS vehicle and docking station are installed and operating. In support of that effort, this section suggests some operational procedures.

4.1 Stay Clear of the Vehicle

The single best procedure to follow is to stay clear of the IMSS vehicle and docking station at all times.

We recommend staying at least 3 feet away from the vehicle, and 5-6 feet is better -- as discussed in the Safety section of this manual.

The area around the IMSS vehicle's docking station is normally marked off with yellow color tape on the floor. Stay outside of that area. Never places hands or feet in the area between the vehicle and the docking station, where the charging plates are located.

4.2 Unexpected Objects (Obstacles)

Stray objects left in the building (e.g., a forklift, a box, an empty pallet) will generally interfere with the operation of the IMSS vehicle. The IMSS vehicle knows about the rows of drums stacked on pallets inside the building, but it does not know about any other objects located inside the building. The vehicle is able to detect unexpected objects located on the floor, and the result is usually that the vehicle will abort part of its inspection mission. In other words, the vehicle will skip the inspection of some drums in the area where the obstacle was detected, and move on to inspect the remaining drums in its specified inspection mission. However, the vehicle's ability to detect unexpected objects is not perfect, and so for safety reasons all operations staff working inside the building should avoid leaving such stray objects on the floor.

Stray objects are only a problem if they are located in areas of the building where the IMSS vehicle will drive around. There are certain areas where the vehicle will never go, so objects can be placed in those areas. These areas include the following:

- The area at the wall-side end of every row is a safe storage area. The IMSS vehicle never goes into those areas. Note however that the area covered by extending an aisle (i.e., the space between two rows) to the building's wall is an area that the mast part of the vehicle may protrude into.
- The IMSS vehicle currently will not visit the furthest-most rows at the ends of the buildings (because of a highly conservative decision to avoid driving the robot over parts of the ramps at the ends of the building). In INEL Building 628 these are rows NA, NT, and ST. The area between these rows and the side of the building is a safe storage area.
- If the IMSS vehicle is designated to operate in only a portion of the building, then the other areas can have stray objects. The local IMSS system operator can indicate these areas.
- Parking areas for forklifts will be marked on the floor. When forklifts are not in use, do not park them anywhere except in these designated areas.
- Safe areas can be designated for radiation monitoring units and other instrument boxes.

The end of each row of drums in the INEL buildings often have a metal sign (indicating the row label) hung at eye level via a chain. The vehicle will drive past the ends of rows quite regularly. If these signs and chains protrude away from the drums more than a few inches, then they can potentially make contact with the vehicle as it drives past. These signs should not protrude more than about 2 inches out from the drums. These signs and chains can not be allowed onto the floor.

The IMSS vehicle's required mast clearance should be considered before hanging anything down from the ceiling.

4.3 Moving Drums, Rows or Berms

The IMSS system operator needs to be informed if any drums in the area where the IMSS vehicle has been assigned to inspect drums have been moved or removed. The IMSS vehicle maintains a map of the building and how the rows of drums are arranged inside the building, and uses that information to navigate around inside the building. Moving or removing drums without having the IMSS system operator update the IMSS vehicle's map can cause navigation failures.

Replacing a set of drums with other drums is less of an issue if the new drums are exactly the same size and are arranged in exactly the same positions as the original drums. Replacing drums in this manner will not cause navigation failures, but it can cause all the new drums to be reported as "defective", since the vehicle assumes that they are the original drums and sees that they look very different, which the vehicle assumes is the result of new defects appearing on the drums.

The IMSS vehicle currently requires all rows of drums to extend to the edge of the tape nearest the central corridor. Rows can be "short" (i.e., missing pallets) on the side closest to the wall.

Rubber berms render a row un-inspectable by the IMSS vehicle. Also, the IMSS vehicle can not inspect any aisle that can only be reached by driving past an aisle with rubber berms.

4.4 Lights and Doors

The two large rolling doors at the ends of the building should be kept closed when the IMSS vehicle will be inspecting drums. The sun and clouds cause lighting variations that can effect the inspection performance of the IMSS vehicle. Variations in lighting that can affect the inspection process may not be noticeable by the human eye. For similar reasons, the interior lights inside the building should be left on whenever the robot is operating.

4.5 Water or Ice on the Floor

The IMSS vehicle may have difficulty driving over ice -- its wheels might spin and slip.

The IMSS vehicle is able to drive through and work in areas where small puddles exist. Puddles deeper than one inch or wider than 5 feet are considered too large for the IMSS vehicle to drive through.

5. Day-to-Day Operations of the IMSS System

This section describes the common day-to-day operations that the IMSS system operator will need to perform, and provides detailed instructions on how to perform those operations. Detailed instructions for using the IMSS operator interface are organized into a separate section, which follows this section.

5.1 Setup in Preparation for Doing Regular Inspections With the IMSS System

When the IMSS vehicle is first installed in a waste storage building, the IMSS system operator must create an IMSS Facility Map using the IMSS Facility Map Editor, as discussed in the section of this manual named Setup Operations for a New or Modified Facility. Next, the IMSS system operator must have the IMSS system perform a "baseline" inspection mission of the facility. This procedure is also discussed in that section. Once these setup operations have been completed, the IMSS system can begin doing regular inspections of the building.

5.2 Doing Regular Inspections With the IMSS System

Once the IMSS system operator begins to be comfortable using the IMSS system on a regular basis, a regular pattern of row inspections should be devised. The simplest approach is to divide the rows in the building into subsets and assign one subset for inspection on each day of the week.

In practice, the IMSS system operator will used the IMSS operator interface as follows on any given day of the week. The operator would run the regular inspection mission for that day, and carefully review (probably on the next day) the information provided in the list of defects, and perhaps overall patterns observed in the reported defects. The operator can display images to verify whether a defect is an acceptable one or is a true problem defect. Defects that are acceptable are marked as such by the operator, by changing the Inspection Status fields for those defects. When a defect is marked as acceptable, the IMSS system will automatically ignore (and not report) that defect during future inspections unless the defect's area has grown or its shape has changed.

5.3 Regular Computer System Maintenance Activities

Tape backups of the files located on the IMSS control station computer should be made on a regular basis. Weekly backups are recommended. Once a regular tempo of IMSS operations has been achieved, regular backups will be required to maintain enough free disk space from week to week, since stored images can consume the disk space quickly.

The IMSS system is delivered without a password for the "ows" login. We recommend adding a password. Also, it is good practice to change passwords on a regular basis, such as twice a year. The Unix passwd command is used to change a password.

5.4 Interfacing IMSS Drum/Defect Databases with INEL Drum/Defect Databases

In order to function within a building, the IMSS system needs only the IMSS Facility Map. It does not require information from any external database.

The IMSS system can provide the results from its inspection missions for input into the INEL Oracle database system. The Mission Assessment Screen of the IMSS operator interface includes a command to save the displayed list of defects into a file formatted specifically so that the INEL Oracle database system can ingest that file. This save command is covered in the next section on How to Use the IMSS Control Station for Day-to-Day Operations.

5.5 Turning Power On

Once installed at a site, the three main components of the IMSS system (control station, docking station, IMSS vehicle) are designed to be left powered on at all times, from one day and week to the next.

5.5.1 The IMSS Control Station

Locate the power switch for the workstation monitor and turn it on. Turn on any external disk drives, printers, tape drives, or other peripherals. Then turn on the power switch for the main box of the workstation.

Once turned on, the workstation will perform a hardware diagnostic during which time the screen will remain blank, and then the workstation computer will "boot". Once the "login" prompt appears, log in using the name "ows", which stands for Operator WorkStation. Initially, no password is required. After logging in, the IMSS operator interface will automatically be started and appear on the computer's screen.

5.5.2 The IMSS Docking Station

The main power switch for the docking station is located on the top of the unit, and is the main power switch for the power supply that is built into the docking station. Leave the knobs labeled "Voltage" and "Current" in their preset positions. (The proper preset positions are as follows: Turn the "Current" knob to the fully counter-clockwise position. Then, turn the "Voltage" knob until the "DC Volts" meter reads approximately 65 volts.)

If the optional TV monitor is located near the docking station, then it should be turned on.

Any boxes associated with the connection to the site-wide wire ethernet should be turned on. These types of boxes are normally left on at all times.

The radio ethernet system has a box that is normally mounted on the wall at a height above the top level of a 5-high stack of drums. This box is normally left on at all times (the on/off switch is located on the box mounted up on the wall). Verify that all the electrical plugs for this equipment are plugged into the wall.

5.5.3 The IMSS Vehicle

Since the IMSS vehicle uses batteries, you may want to turn it on and off at the start and end of every business day. But this is not necessary. The IMSS vehicle is designed to be left on at all times. The IMSS vehicle will automatically charge its batteries as needed. If the vehicle will not be used for several days, the vehicle and docking station should be turned off -- this will maximize the number of useful recharge cycles available in the life of the batteries.

The IMSS vehicle has a single main power switch, located at the upper back right corner of the vehicle. This switch requires significant force to turn on or off. When the IMSS vehicle is first

turned on it will perform an automatic startup procedure. As part of this procedure you will hear a relay click (to enable power to the motors) and you will see the mast go through a series of small motions (to calibrate its position).

The IMSS vehicle has a status panel, located at the upper back left corner of the vehicle. (The Vehicle Hardware and Maintenance section of this manual shows a picture of this panel.) This panel contains a key switch, which enables power for the lasers used by the dent detection system. In addition to the vehicle's main power switch, this key switch must be turned on in order for the lasers to have power. In practice, since the vehicle is normally left on, this key switch is usually left in the on position (called "enable" and labeled "EN" next to the switch). Be sure that this key is in the on position.

The docking station must always be turned on whenever the IMSS vehicle is on. The vehicle may need to recharge its batteries using the docking station at any time.

The IMSS vehicle must be in the proper "docked position" at the docking station when it is turned on. The proper docked position is illustrated in Figure 5-1. The charge plates on the back of the vehicle must be contacting against the charge plates on the front of the docking station. The vehicle should be centered over the ramp of the docking station. This will also assure that the vehicle and docking station charge plates are lined up so that they overlap in a side-to-side sense. Centering the vehicle over the ramp can be done by eye -- it should be within ±2 inches of the true center. Finally the vehicle should be pushed backwards so that the charge plates of the docking station are fully pushed in by the abutting charge plates of the vehicle.

If the vehicle needs to be moved, follow this procedure: If the vehicle is already turned off, then simply push the vehicle into the proper position. If the vehicle is turned on, press one of the kill switches (e.g., red mushroom switch), turn the vehicle power off, restore the kill switch to its original position, and then push the vehicle into the proper position. Once the vehicle is in the proper position, turn on its main power switch.

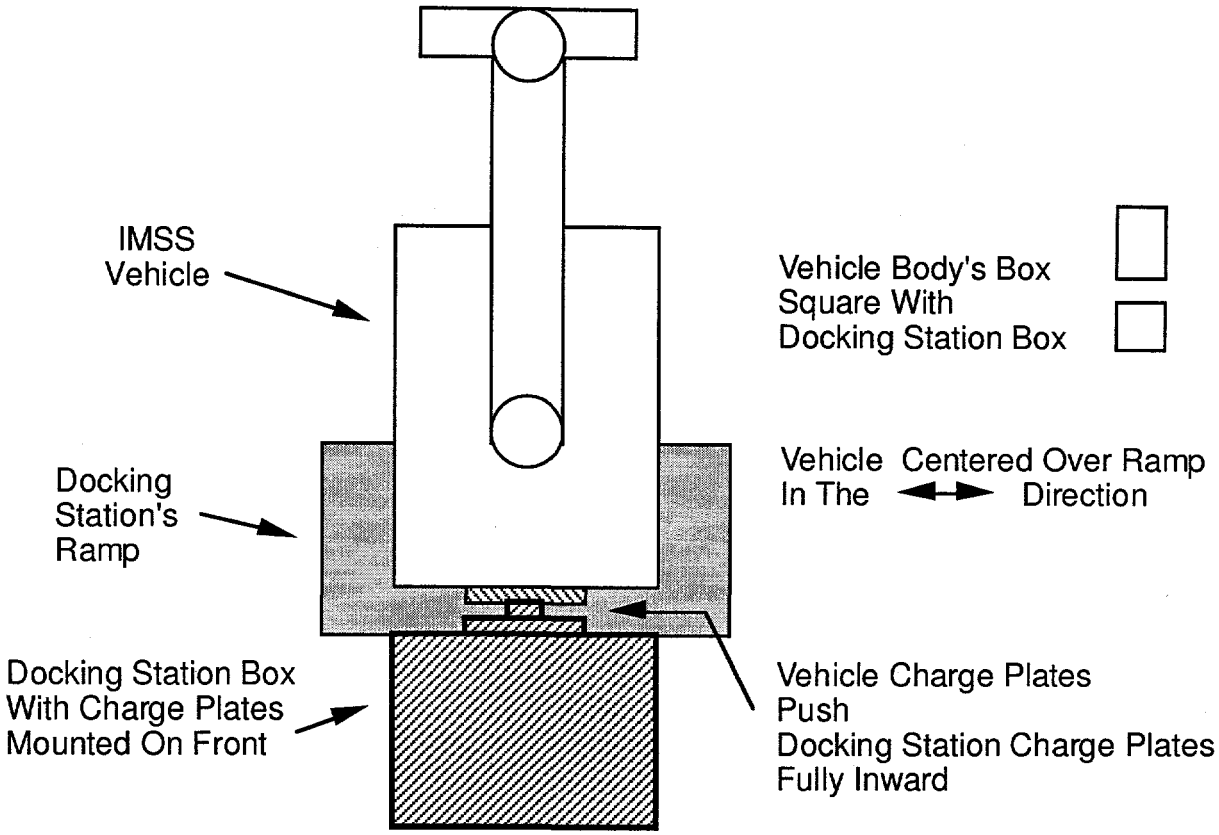

Figure 5-1. The proper docked position for the IMSS vehicle at the docking station.

5.6 Turning Power Off

The IMSS control station computer is shutdown like any other Unix workstation. The operator must login via the root account and execute a shutdown command.

To turn the IMSS vehicle off, first activate a kill switch, then turn power off, and then restore the kill switch.

The docking station and associated equipment can be powered off at any time by using the main power switches on the respective pieces of equipment. The radio transmitters mounted on the inside wall of the building are normally left on, but can be unpowered by unplugging the power cord from the wall socket. Support equipment for the site-wide ethernet wire connection is normally left on.

5.7 How to Recover From An Emergency Stop or An Emergency Power-Down

When a new operator is learning to use the IMSS system, it is more likely that some of the safety mechanisms built into the vehicle may be triggered. This section described how to recover from the most common conditions. One-on-one class instruction during the installation period will provide additional details and practice with restart or recovery operations. That instruction will also cover how to properly manually push the vehicle.

5.7.1 Recovering From An Emergency Stop

An emergency stop disconnects power from all the motors inside the vehicle. The best course of action is as follows:

- Power down the vehicle.
- Determine the cause of the emergency stop. Restore any triggered kill switches to their normal positions.
- Manually return the vehicle to the docked position at the docking station.
- Restart the IMSS operator interface by selecting Quit from the File menu of the Main Screen and then selecting "IMSS OWS" from the workstation's main menu.
- Re-run the mission.

5.7.2 Recovering From An Emergency Power-Down

An emergency power-down will occur when the IMSS vehicle is blocked or otherwise unable to return to its docking station. Any other situation may indicate a problem with the vehicle's battery system and should be further investigated. The best course of action to recover from an emergency power-down is as follows:

- Determine the cause of the emergency power-down.
- Turn the main power switch of the IMSS vehicle OFF.
- Manually return the vehicle to the docked position at the docking station.
- Restart the IMSS operator interface by selecting Quit from the File menu of the Main Screen and then selecting "IMSS OWS" from the workstation's main menu.
- Press the MAIN PWR RESET switch on the status panel at the rear left corner of the IMSS vehicle. Turn the main power switch of the IMSS vehicle on.
- Allow the IMSS vehicle to automatically re-charge its batteries at the docking station. Monitor the vehicle to see that the recharge is completed.
- Resume normal operations with the vehicle.

6. How to Use the IMSS Control Station for Day-to-Day Operations

This section describes how to use the IMSS control station, with an emphasis on doing all the common day-to-day operations that an operator will need to perform. The first part of this section is organized in a reference manual format and provides a comprehensive explanation of how to use all parts of the operator interface. The second part of this section provides a tutorial example. We suggest that the first-time reader skim the first part, then walk through the example, and finally return to review the first half of this section as needed.

During an inspection mission, all vehicle activity is coordinated by the IMSS vehicle by itself. However, the IMSS system operator must supervise operations before and after a mission. This is done through a graphical user interface from the control station. The IMSS operator interface provides three primary interfaces for use in day-to-day operations:

- The *Main Screen* is used to set or select a date, and then view a list of missions completed on that date or scheduled for that date.
- The *Mission Assignment Screen* is used to assign new missions.
- The *Mission Assessment Screen* is used to review the results of a completed mission.

Complete descriptions of each of the above three interfaces and how to use them are provided in the following subsections. The IMSS operator interface also includes the *Facility Model Editor*, which is not used on a daily basis and will be addressed in the later section on Setup Operations for a New or Modified Facility.

6.1 The Main Screen

The work performed by the IMSS vehicle consists of inspection missions. An *inspection mission* is defined by specifying a set of drums that the IMSS vehicle will visit and inspect for defects. Typically, an inspection mission is specified by specifying a set of rows in a building, and all drums inside those rows would be inspected. In typical operations, a standard set of rows would be inspected on each day of the week, such that all the drums contained in the building would be inspected once over the course of one week.

The IMSS operator interface is organized according to inspection missions. The Main Screen for the IMSS operator interface presents a list of inspection missions for one day. Using the Main Screen the operator can select a day, add missions to that day's list, execute missions, and review results from any inspection on any day's list.

The Main Screen is organized into four areas, which are outlined in the snapshot of the Main Screen shown in Figure 6-1:

- The *Menu Bar* is located at the very top of the screen.
- At the top of the screen and directly below the Menu Bar, is the *Selection and Status Panel.*
- The center of the screen contains the *Day's Mission List.*
- *Command Buttons* are located at the bottom of the screen.

The elements of the Main Screen and all the possible commands that can be executed from the Main Screen are summarized below.

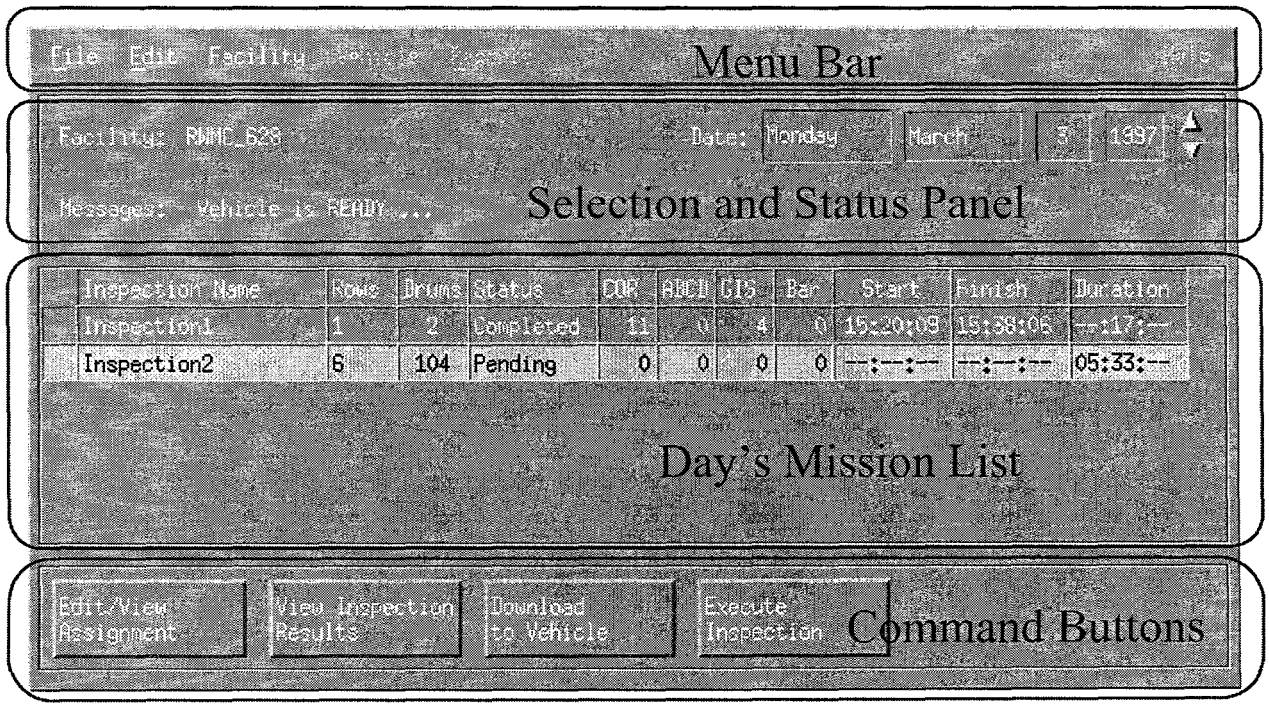

Figure 6-1. The Main Screen of the IMSS operator interface is organized into four different "panels".

6.1.1 Menu Bar

The menus and menu commands accessible inside the Menu Bar are summarized below.

The **File menu** contains the following menu items.

- New Inspection: This menu item will add a new inspection mission to the current day's list, initialize the mission to inspect every drum in the current building, and start the Mission Assignment Screen (described later in this section) so the mission can be edited. New inspections are automatically given names such as Inspection1, Inspection2, etc. These names can be edited later.
- Quit: This menu item will exit the IMSS operator interface program.

The **Edit menu** contains the following menu items.

- Cut: This menu item will "cut" the currently selected mission in the Day's Mission List. Cut means that the mission is deleted from the Day's Mission List, and saved in a "cut/copy buffer" from which it can later be "pasted" back into a Day's Mission List.
- Copy: This menu item will "copy" the currently selected mission in the Day's Mission List. Copy means that a copy of the mission is made from the Day's Mission List, and saved in a "cut/copy buffer" from which it can later be "pasted" back into any Day's Mission List.
- Paste: This menu item will "paste" a copy of the mission contained in the "cut/copy buffer" into any Day's Mission List. The mission will be pasted below the currently selected mission in the Day's Mission List, or if no mission is selected then it will be pasted at the end of the list.

Cut and Copy operate on the currently selected mission. A mission can be selected by clicking the mouse inside the empty square-shaped cell at the far left of a line of the Day's Mission List. When a mission is selected in this manner, the entire line will become hilighted.

The Edit menu commands can be used to cut or copy a mission from the Day's Mission List of one day into the Day's Mission List of a different day. It can be quicker for the operator to copy a previously defined mission instead of creating and editing a new one using the New Inspection menu command. It may also be quicker for the operator to copy and then edit a previously defined mission that is similar to a new mission that the operator wants to create, than to create that new mission from scratch using the New Inspection menu command.

The **Facility menu** contains the following menu items.

- Create New Facility: This menu item will start the Facility Model Editor (which will appear in a new, separate window), and causes the Facility Model Editor to begin with a new, generic facility model. If this new facility model is edited and saved it will then replace the current facility model.
- Edit / View Current Facility: This menu item will start the Facility Model Editor and allow the user to view and edit the current facility model.

The **Vehicle menu** contains the following menu items.

- This menu is included for future expansion. It currently is disabled.

The **Reports menu** contains the following menu items.

- This menu is included for future expansion. It currently is disabled. The command for printing reports are currently located in the File menu.

The **Help menu** contains the following menu items.

- This menu is included for future expansion. It currently is disabled.

6.1.2 Selection and Status Panel

The Selection and Status Panel has three parts:

- The name of the facility is displayed in the upper left corner of the panel.
- The currently selected date is displayed in the upper right corner of the panel. The elements of the date can be selected and modified using the increment/decrement buttons at the far right.
- Messages indicating the status of the vehicle are displayed in the bottom half of this panel, in the area labeled "Messages:". The majority of the status messages indicate the progress of the vehicle when an inspection mission is being executed, whether the vehicle is recharging its batteries, or whether the vehicle is waiting in a ready state at the docking station.

6.1.3 Day's Mission List

The Day's Mission List is displayed as a table. Each line of the table summarizes one mission. The table contains the following columns:

- **Inspection Name:** Inspection missions are automatically named Inspection1, Inspection2, Inspection3, etc.
- **Rows:** This is the number of rows contained in the mission.
- **Drums:** This is the number of drums located at level 1 (floor level) that are contained in the mission. Since drums are stacked five high at INEL, the actual number of drums that will be inspected during the mission is five times the number shown here.
- **Status:** The status of a mission is either New, Pending (i.e., executing) or Completed.
- **COR, ABCD, GIS, BAR:** These columns list the total number of new defects of each type (corrosion, change, geometric, barcodes) that were detected in the mission. These numbers are only updated after a mission is completed. These values will be zero before and during the execution of a mission.
- **Start, Finish:** These values are the actual start and finish time of the mission (displayed as hours:minutes:seconds).
- **Duration:** This value is the estimated duration of the mission (also displayed as hours:minutes:seconds). Note that the estimated duration is not replaced with the actual duration after the mission is completed.

A mission in the table can be selected by clicking the mouse on the empty square-shaped cell at the far left of the line in the table. This will cause the entire line to be highlighted. The highlighted line is referred to as the currently selected mission.

Clicking on any column label will cause the list of missions to be sorted according to the increasing order of the cell values contained in that column.

6.1.4 Command Buttons

The Command Button area of the screen contains the following command buttons:

- **Edit / View Assignment:** This button shows the Mission Assignment Screen using the currently selected mission. Details of the mission can then be edited from that screen.
- **View Inspection Results:** This button displays the Mission Assessment Screen using the results from the currently selected mission. The mission's results can then be reviewed in more detail from that screen.
- **Download to Vehicle:** This button downloads the currently selected mission to the IMSS vehicle, in preparation for executing that mission. A status message will indicate when the download has completed.
- **Execute Inspection:** This button signals the IMSS vehicle to execute the downloaded mission as soon as the vehicle is ready to depart. The vehicle will delay its departure if it is in the process of recharging its batteries. Status messages will indicate the progress of the vehicle during the mission.

6.2 The Mission Assignment Screen

The Mission Assignment Screen allows an operator to review or change the details of an inspection mission. It is possible to use the Mission Assignment Screen to specify in great detail the exact drums to visit during an inspection mission.

6.2.1 How a Mission Is Defined

A person individually inspects the drums in a row by walking down the aisle on the left side of a row and then down the aisle on the right side of that row. The IMSS vehicle inspects drums in the same way.

For the IMSS system, an inspection mission is specified as an ordered list of rows and grids. The IMSS vehicle will visit the rows and grids in exactly the order that they are listed. Since the IMSS system distinguishes between the left and right sides of a row, each row requires two lines in the inspection mission. One line in the inspection mission specifies the left side of a row, and the other line specifies the right side of that row. Typically, each line in a mission will specify that all the grids in a row should be inspected, but it is possible to specify that only a contiguous range of grids in that row should be inspected.

When a new inspection mission is created (using the "New Inspection" menu item on the Main Screen), the initial inspection mission that is automatically created will have the IMSS vehicle inspect every row in the building. Figure 6-2 shows the initial inspection mission generated for INEL Building 628. Note that the mission is quite long and that the scroll bar must be used to scroll through and view the entire list. The mission will first inspect all the rows on the south side of the building, and then inspect all the rows on the north side of the building. The rows on one side are inspected in increasing order. For example, on the north side of the building the rows are inspected in the order: row NB, row NC, row ND, ..., row NS.

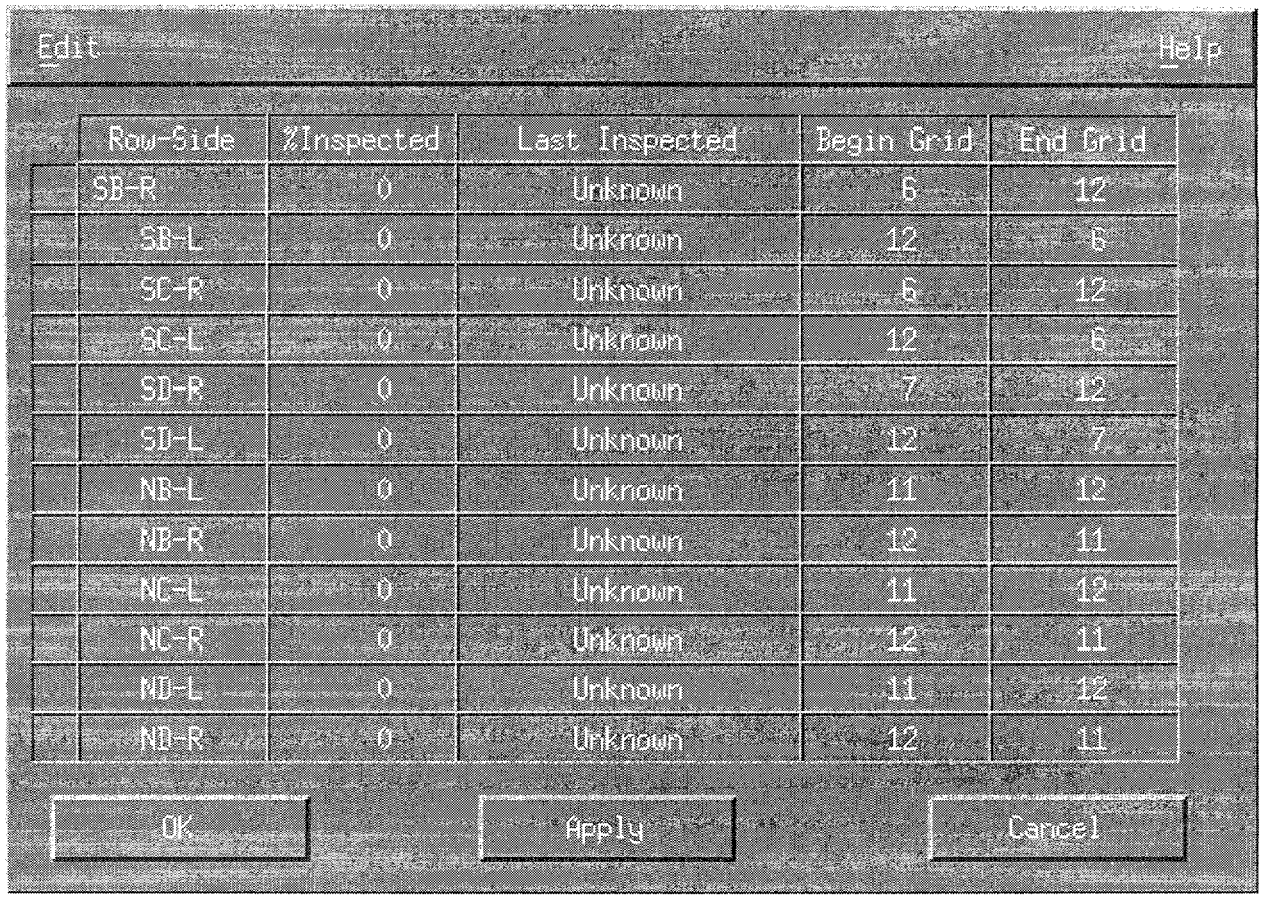

Figure 6-2. Mission Assignment Screen of the IMSS operator interface.

6.2.2 How a Mission is Displayed on the Screen

The inspection mission is defined as a list and is displayed on the screen as a table, and the user can interact with that table. Recall that the Main Screen also used a table for the Day's Mission List. We will see later that the Mission Assessment Screen is also organized as a table.

Each line in the inspection mission (a line in the table) specifies a set of drums in a row. The "Row-Side" column specifies the row (e.g., row NA) and the side of that row (-L for left, and -R for right). The range of grids in that row are specified by the "Begin Grid" and "End Grid" columns.

The remaining two columns in the table provide information of when the IMSS vehicle last inspected that side of that row. "%Inspected" shows the percentage of that row that was successfully inspected the last time the IMSS vehicle visited that row, and "Last Inspected" shows when that last visit occurred.

6.2.3 Editing the Fields in a Line in an Mission

The only fields that can be edited in the table are the "Begin Grid" and the "End Grid" values. These values are edited by selecting a specific cell in the table, and using the keyboard and/or mouse to edit the text inside the cell. You **must** press the ENTER key when you are done editing the cell, or press the TAB key to advance to the next cell. If you do not, your edit will not take effect.

6.2.4 Cutting and Pasting Groups of Lines in a Mission

A line in the table can be selected by clicking the mouse inside the empty square-shaped cell at the far left side of a row. This will cause the entire row to be highlighted. A set of rows can be selected by dragging the mouse down that column at the far left side. Do not attempt to select a set of rows by dragging the mouse upward -- this will not work properly (this is an unfortunate feature of the commercial software tool used to create the IMSS operator interface).

Once one or several rows are selected the "Copy", "Cut" and "Paste" commands in the "Edit" menu can be used to perform the respective editing operations.

6.2.5 Menus at the Top of the Mission Assignment Screen

The menus and menu commands at the top of the Mission Assignment Screen are summarized below.

The **Edit menu** contains the following menu items.

- Cut: This menu item will "cut" the currently selected row or set of rows in the mission. Cut means that the rows are deleted from the mission, and saved in a "cut/copy buffer" from which they can later be "pasted" back into the same mission but in a different place, or they can be pasted into a different mission later on.
- Copy: This menu item will "copy" the currently selected row or set of rows in the mission. Copy means that a copy of the rows is made from the mission, and saved in a "cut/copy buffer" from which they can later be "pasted" back into a mission.
- Paste: This menu item will "paste" a copy of the rows contained in the "cut/copy buffer" into the mission currently displayed.
- Filter & Sort...: This menu item is included for future expansion. It currently is disabled.

The **Help menu** contains the following menu items.

- Help: This menu item is included for future expansion. It currently is disabled.

6.2.6 Buttons at the Bottom of the Mission Assignment Screen

The Mission Assignment Screen contains the following buttons at the bottom of the screen:

- **OK:** Pressing this button will cause the edits made to this mission to be accepted and stored away, and then the Mission Assignment Screen will close (i.e., disappear). The user can resume using the Main Screen of the IMSS operator interface.
- **Apply:** Pressing this button will cause the edits made to this mission to be accepted and stored away. The Mission Assignment Screen will remain open (i.e., visible for use).
- **Cancel:** Pressing this button will cause the edits made to this mission to be thrown away. The mission will remain the same as it was before the Mission Assignment Screen was entered. Then, the Mission Assignment Screen will close (i.e., disappear). The user can resume using the Main Screen of the IMSS operator interface.

6.3 The Mission Assessment Screen

The Mission Assessment Screen allows an operator to review the inspection results of a mission. The inspection results consist of a list of the (new) defects that the IMSS vehicle detected on the drums it was assigned to inspect during the specified mission. An example of a typical Mission Assessment Screen is shown in Figure 6-3.

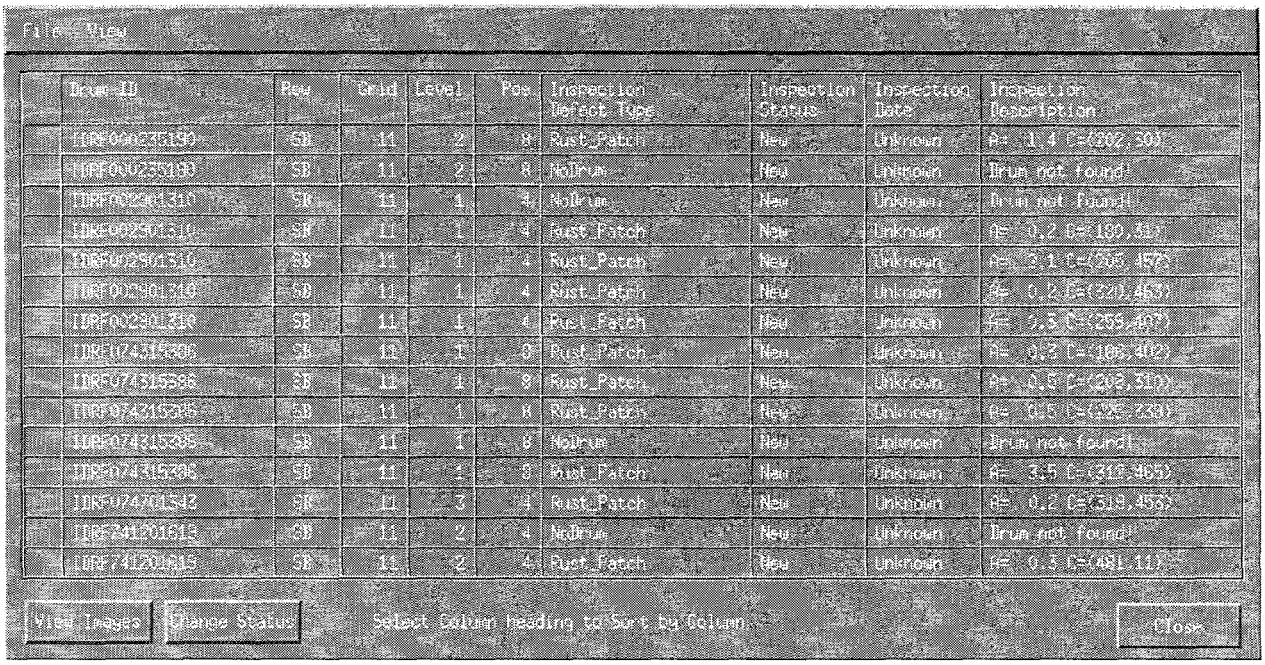

Figure 6-3. Mission Assessment Screen of the IMSS operator interface.

6.3.1 How Inspection Results are Displayed on the Screen

Inspection results are presented as a simple list, which is displayed as a table that the user can interact with. Each individual defect found on a drum is listed as a separate row in the table. Note that one drum can be represented by several rows if it has multiple defects.

The table contains the following columns, most of which should be self explanatory:

- **Drum ID:** This is the drum identification that was read from the drum's bar code label, if the IMSS vehicle was able to read a bar code. (The vehicle can not read bar codes that are not visible to it -- beyond about ±45 degrees of the drum center.) When a bar code does not exist or could not be read, then the IMSS system generates a substitute drum identification name that is uniquely determined by the position of the drum inside the building.
- **Row:** This is the row number inside the building. INEL rows are "numbered" using the letters A through Z, and are prefixed by the letter N or S indicating the north or south side of a building.
- **Grid:** This is the grid number within the row. Grids correspond with the pallet positions on the floor. Grid 1 is at the end of the row closest to the building's wall.

- **Level:** This is the level within the row where the drum is located. The drums on the pallet on the floor are at level 1, and level 2 rests on top of level 1, and so forth.
- **Pos:** This is the position of the drum on the specified grid in the specified row. Positions 1 through 4 are located across the long side of the pallet nearest the building's wall and are ordered from left to right. Positions 5 through 8 are numbered across the other side of the pallet, also from left to right.
- **Inspection Defect Type:** This field identifies the type of defect that the IMSS vehicle detected. The types of defects that are currently distinguished are explained further below.
- **Inspection Status:** All newly detected defects are given the Inspection Status of "New". After reviewing the inspection results, an operator can change the Inspection Status of any defect to "Ignore" -- indicating that this is an acceptable defect that the IMSS system should ignore in the future.
- **Inspection Date:** This field is provided for future expansion purposes. The values in this field are currently always displayed as "Unknown".
- **Inspection Description:** This field provides additional descriptive detail about the specific defect.

The various types of defects current detected by the IMSS vehicle and reported in the Inspection Defect Type column in the table are described below:

- The following defects are detected by the IMSS vehicle's "corrosion detection" (COR) subsystem:
  -- Rust_Patch: Any new rust that was detected.
- The following defects are detected by the IMSS vehicle's "automated baseline change detection" (ABCD) subsystem:
  -- Changing_Patch or Changing_Patch2: A patch on the drum that has changed significantly since the last inspection.
- The following defects are detected by the IMSS vehicle's "geometric inspection subsystem" (GIS):
  -- Dent: Drum has a significant dent.
  -- Tipped: Drum is significantly tipped to one side.
  -- Drum_Displacement: Drum is significantly displaced from its expected position on the pallet or spacer ring.
  -- NoDrum: No drum was present at the grid location.
- The following defects are detected by the IMSS vehicle's "barcode reading" subsystem:
  -- Barcode_Not_Found: No barcode was present or could be read by the vehicle.
  -- Barcode_Mismatch: The barcode that was read does not match the barcode seen on the previous inspection by the vehicle.

6.3.2 Sorting the List of Defects

The list of defects displayed in the table can be sorted in increasing order based on any column by clicking the mouse on the label at the top of a column. For example, clicking the mouse on the label for the "Level" column will reorder the defects in the list so they are listed in the order of increasing level number.

6.3.3 Menus at the Top of the Mission Assessment Screen

The menus and menu commands at the top of the Mission Assessment Screen are summarized below.

The **File menu** contains the following menu items.

- Save: This menu item will write the list of defects to two different text files. One file is formatted so that in can be ingested into the INEL drum database system. The other file is formatted as a plain text file, and can be printed as a report or viewed using a text editor program. Printing requires that a printer be accessible by the workstation. The two files are written into the directory containing all internal IMSS files related to a mission, which will have the following form: /work/working/Facility/RWMC_628/Date/InspectionName.

The **View menu** contains the following menu items.

- All Database Records: This menu item toggles a mode that determines whether "Ignore" type defects are displayed in the table. Initially they are not, selecting this menu item will cause "Ignore" defects to be included, and selecting this menu item again will cause them to be omitted from the display again.
- Defect Description: This menu item is included for future expansion. It currently performs no function.

6.3.4 Buttons at the Bottom of the Mission Assessment Screen

The Mission Assessment Screen contains the following buttons at the bottom of the screen:

- **View Images:** Pressing this button will display a composite image showing the drum for a selected defect. Such images are stored if the drum has any geometric defect or any corrosion defect. Images are not stored if the drum has no defect other than a missing or unread barcode label. A defect is selected by clicking the mouse on the empty square-shaped cell at the far left of a line in the table. When a defect is selected in this way the line in the table will become highlighted.
- **Change Status:** Pressing this button will change the Inspection Status field for a selected defect. The value in the field is changed from "New" to "Ignore", or back to "New" again. The Ignore value informs the IMSS system that this defect is an acceptable defect and that the IMSS system should not report this same defect in the future. Note that if you change the status of any defects to Ignore, close the screen, and return to review the inspection results again, those defects will normally no longer be listed when you return.
- **Close:** Pressing this button will close the Mission Assessment Screen, leaving the operator back at the Main Screen.

An example of a drum image is shown in Figure 6-4. The IMSS vehicle collects 4 images for a 55-gallon drum and combines them into the composite image shown. Defects detected by the vehicle's color-based corrosion detection subsystem are surrounded by red boxes. Defects detected by the vehicle's change-based defect detection (ABCD) subsystem are surrounded by green boxes.

The Inspection Status field can be changed for an entire range of defect report lines in the table. A set of rows can be selected by dragging the mouse down the far left-side column of the table. Do not attempt to select a set of rows by dragging the mouse upward -- this will not work properly (this is an unfortunate feature of the commercial software tool used to create the IMSS operator interface).

Figure 6-4. Image of a defective drum displayed from within the Mission Assessment screen of the IMSS operator interface.

6.4 A Tutorial Example

This section presents a simple but complete example on how to use the IMSS system to inspect a few drums. This example assumes that you have just started the IMSS operator interface for the first time. You will create a mission to inspect the drums on one grid in the building, you will make the IMSS vehicle execute that mission, and you will review the results of the mission.

The sequence of operations that you will perform in this example are typical of regular usage of the IMSS system. Generally the following sequence of events will occur:

- The operator creates a new mission from the Main Screen.
- The operator edits the new mission so that only the desired rows are inspected.
- The operator presses the "Download to Vehicle" command button. This command downloads the currently selected mission (which is actually stored as a plain text file) to the IMSS vehicle, which would normally be docked at the docking station waiting for its next mission.
- The operator presses the "Execute Inspection" command button. This command signals to the vehicle that it should begin the inspection mission as soon as the vehicle is ready. If the vehicle is currently charging its batteries, it will wait until the charging is completed.
- The vehicle then proceeds to execute the inspection mission. The Main Screen displays how much time the mission is expected to take, and it displays a variety of status information as the vehicle proceeds through the inspection mission. The vehicle will automatically return to recharge its batteries if needed and automatically resume its inspection mission.
- When the vehicle has completed its inspection mission, it automatically returns to the docking station and uploads the mission results to the control station. The operator interface indicates when the upload is complete.
- The operator can then review the list of inspection results, display images of defective drums located by the vehicle, and print reports of the mission results.
- The operator can then repeat the above process, to assign subsequent missions, execute them, and review their results.

6.4.1 Setup for the Tutorial

In this tutorial you will first execute a "baseline" mission, as if the IMSS vehicle had freshly been installed in a waste storage building, and then you will execute a regular inspection mission.

One setup operation is required in preparation for the baseline mission. You must open a shell window on the workstation and type the following in that window:

```
Unix-Prompt$      rsh mortisha
VxWorks-Prompt>   <setup-for-baseline
VxWorks-Prompt>   ~.
Unix-Prompt$
```

This setup operation will clear (delete) any existing IMSS defect databases, IMSS drum databases, and ABCD baseline images.

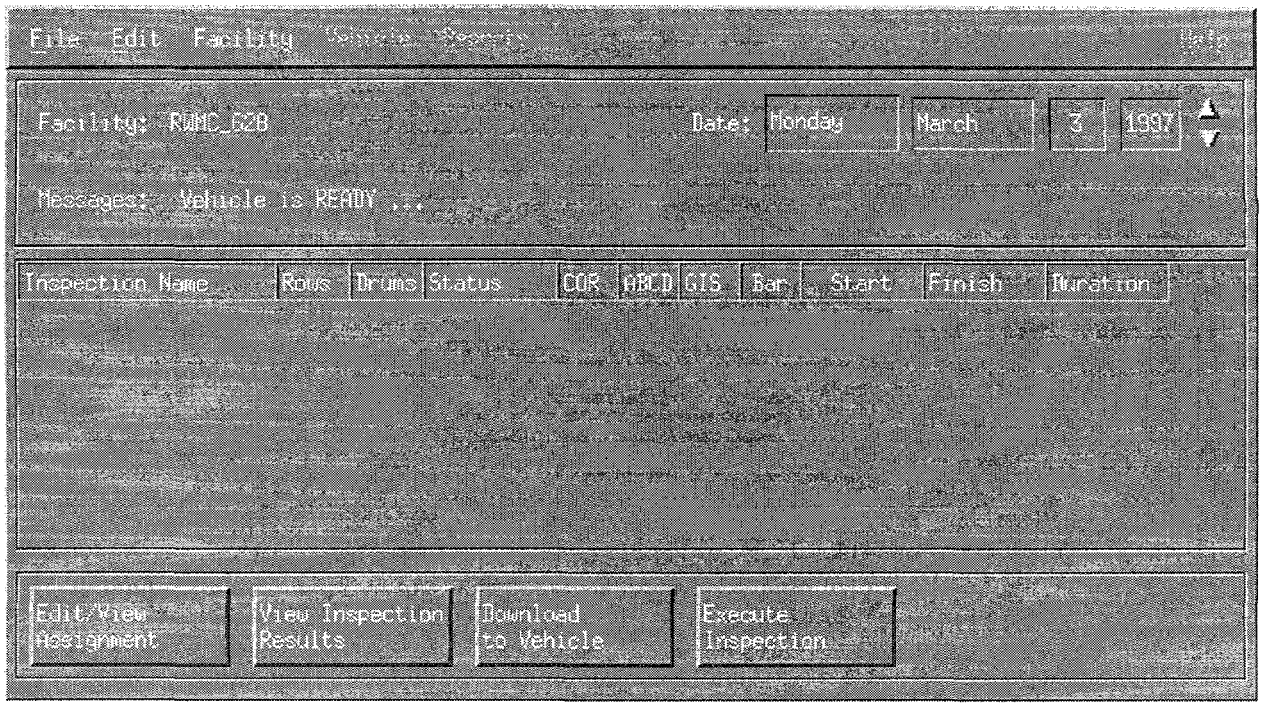

Figure 6-5. When starting on a new day, the Day's Mission List is empty.

6.4.2 Changing the Selected Date

When you first start the IMSS operator interface, you will normally see the screen shown in Figure 6-5. Today's date will be displayed in the upper right portion of the Selection and Status Panel. The list in the Day's Mission List should be empty, since this is the first time you have used the IMSS operator interface today. (If somebody has already used the IMSS operator interface today, and created missions for today, then you will see those missions listed. You can ignore them, since we will be adding a new mission to the list.)

Recall that the IMSS operator interface is organized around the missions performed or scheduled for a specific date. As an exercise, let's change the date displayed in the Selection and Status Panel. This is not necessary for this example, but change the date and then restore it back to today's date so that you are familiar with how this works.

The date display is divided into separate fields: the day of the week, the month, the day of the month, and the year. Any one of these fields can be selected by clicking on it with the mouse, which will cause the field to be highlighted. Initially, the day of the week field is highlighted. The up and down arrows (located at the far right) can be used to increase or decrease the value in the selected field. Whenever the date is changed, the Day's Mission List will show the missions for that date.

Try changing the date now. The Day's Mission List shown will be empty for every day you select. (If anybody has previously been using the IMSS operator, you will see missions they had already defined for other dates.)

Now change the date back to today's date, and we will resume with the example.

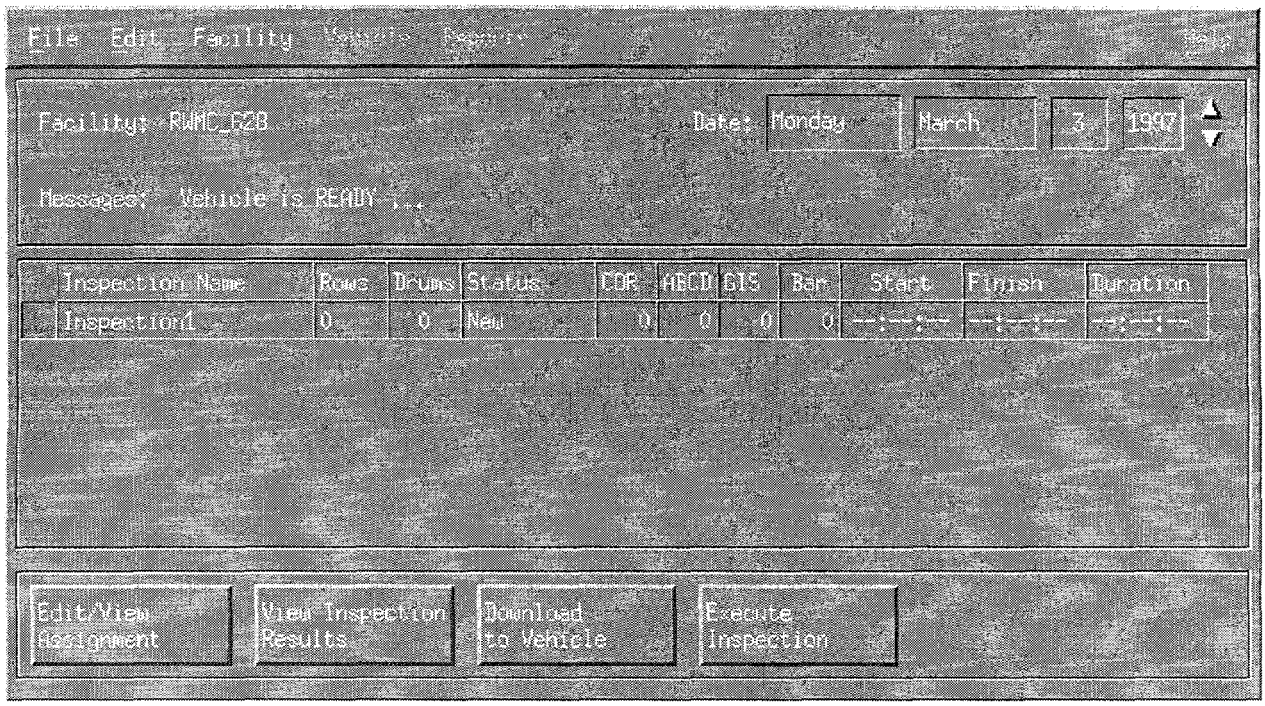

Figure 6-6. After adding a new mission, the Day's Mission List now contains a line summarizing the new mission.

6.4.3 Adding a New Mission

A new mission is added to the Day's Mission List by selecting the "New Inspection" menu item from the "File" menu in the menu bar. Selecting this menu item will have two effects. First, a new mission will be added to the Day's Mission List. And second, a new window that contains the Mission Assignment Screen will appear.

Use the menu to add a new mission now. Figure 6-6 shows what the Day's Mission List will look like after you do this --- a new mission is listed. And Figure 6-7 shows the Mission Assignment Screen that will automatically appear.

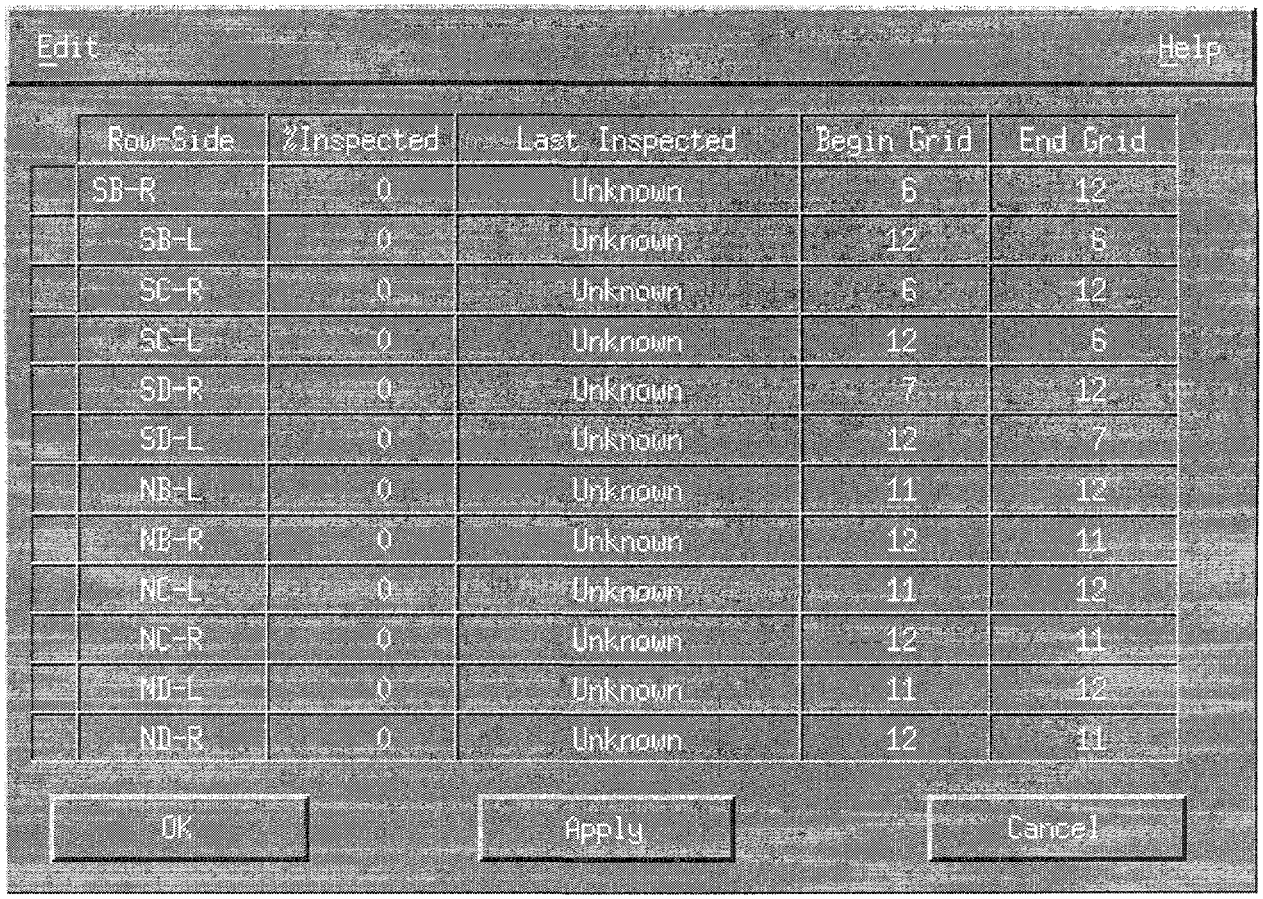

Figure 6-7. After adding a new mission, the Mission Assessment Screen shows the details of the new mission.

6.4.4 Editing a Mission

The initial inspection mission that is automatically created will have the IMSS vehicle inspect every (full-length) row in the building. For our simple example, we want the vehicle to inspect only one side of one grid in one row.

Begin by deleting all the lines in the mission except for the very first line (which is for Row-Side SB-R). Click the mouse on the empty square-shaped cell at the far left side of the second line in the table, and while holding the mouse button down, drag the mouse down that column. By doing this you have "selected" these lines in the mission, and those lines in the table should be highlighted. Now select the "Cut" menu item in the "Edit" menu at the top of the screen. This will cause the selected lines to be cut (i.e., deleted) from the table. Repeat this process as many times as needed to cut out all the lines in the table, except for that first line (Row-Side SB-R).

Now that there is only one side of one row listed in the mission, you must further edit that one line so that only one grid near the inside end of the row will be inspected. Select the "Begin Grid" cell and change its value to 11. Then change the value in the "End Grid" to be 11 also. You **must** press the ENTER key when you are done editing each cell, or press the TAB key to advance to the next cell. If you do not, the edit will not take effect. At this point, your Mission Assignment Screen should look like Figure 6-8.

The result, in this example, is that the two positions (grid positions 4 and 8) that constitute the right side of grid 11 in row SB will be inspected. The IMSS vehicle always inspects all five levels of drums that are stacked over one position in a grid, so in this example a total of ten drums will be inspected. These two grid positions were selected for this example because in INEL Building 628 the IMSS vehicle can drive to them quickly.

Finally, to accept and store the new mission, press the "OK" button at the bottom of the screen. This will close the Mission Assignment Screen and return you to the Main Screen. Note that the one-line mission summary in the Day's Mission List reflects the new mission you have created.

Figure 6-8: The mission used in the tutorial example.

6.4.5 Downloading and Executing a Mission

You are now ready to execute the mission you just created.

The IMSS vehicle and docking station equipment must have been turned on previously. If they have not yet been turned on, do so now, and wait until the vehicle has completed its automatic startup procedures. Wait until the status messages in the "Messages:" area on the Main Screen indicates that the vehicle is ready for operation.

Select the mission by clicking the mouse on the empty square-shaped cell at the far left side of the appropriate line in the Day's Mission List. (In the tutorial there is only one mission to choose from.) Then press the "Download to Vehicle" button (see Figure 6-9) to download the selected mission to the IMSS vehicle. Wait until the status messages in the "Messages:" area indicates that the mission has been downloaded to the vehicle.

Now press the "Execute Inspection" button to have the IMSS vehicle begin executing the mission. Status messages in the "Messages:" area will indicate the vehicle's progress during the mission.

Watch the status messages and wait until they indicate that the vehicle has both completed its mission and uploaded the results from the mission.

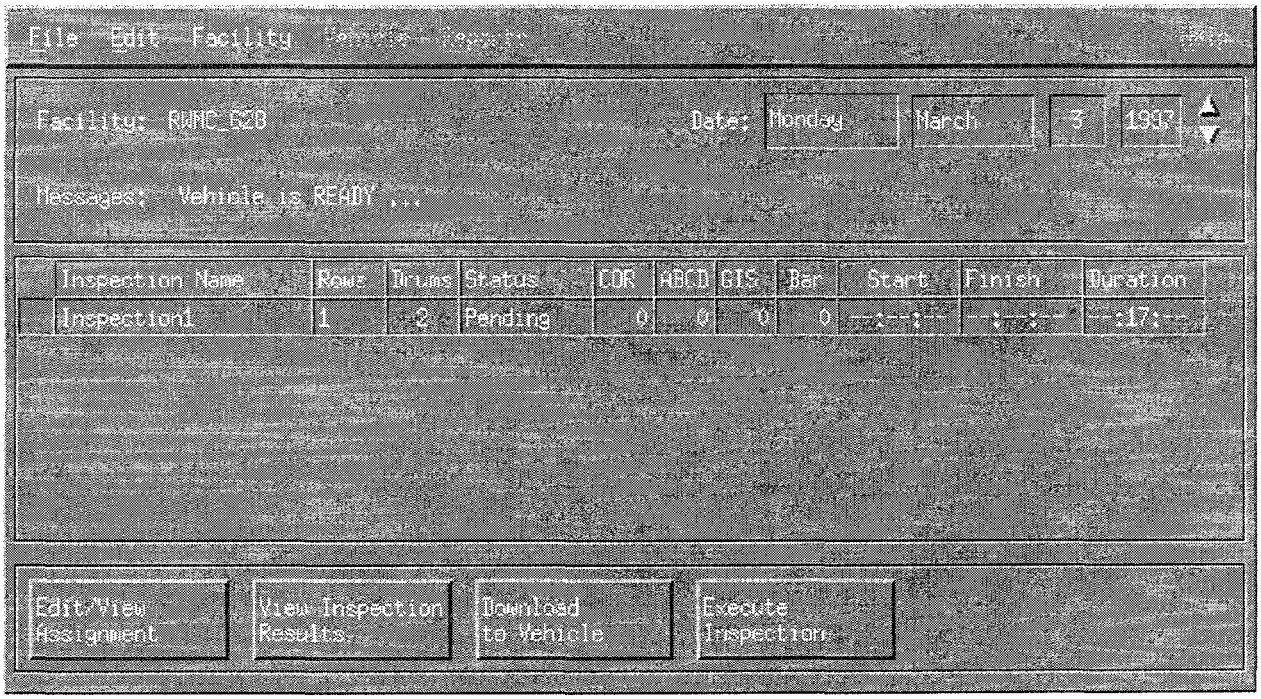

Figure 6-9. The buttons to download and execute the currently selected mission are located at the bottom of the Main Screen.

6.4.6 Reviewing the Results from a Mission

Once a mission is completed, the mission summary line in the Day's Mission List will be updated to reflect that status. Figure 6-10 shows what the screen will typically look like after executing the example mission.

The value in the Status column will have changed from New to Completed, reflecting the fact that the mission was successfully executed and thus has been completed. The Finish column shows the time of the day when the mission was finished. Note that the Duration column shows the originally estimated amount of time needed to execute the mission (and it is not changed to show the actual amount of time taken to execute the mission).

The column labeled COR lists the number of defects located by the vehicle's color-based corrosion detection subsystem (called COR for short). Similarly, the ABCD column shows the number of defects located by the vehicle's change-based defect detection subsystem. The GIS column shows the number of geometric defects detected, and the Bar column shows the number of missing or inconsistent barcode labels.

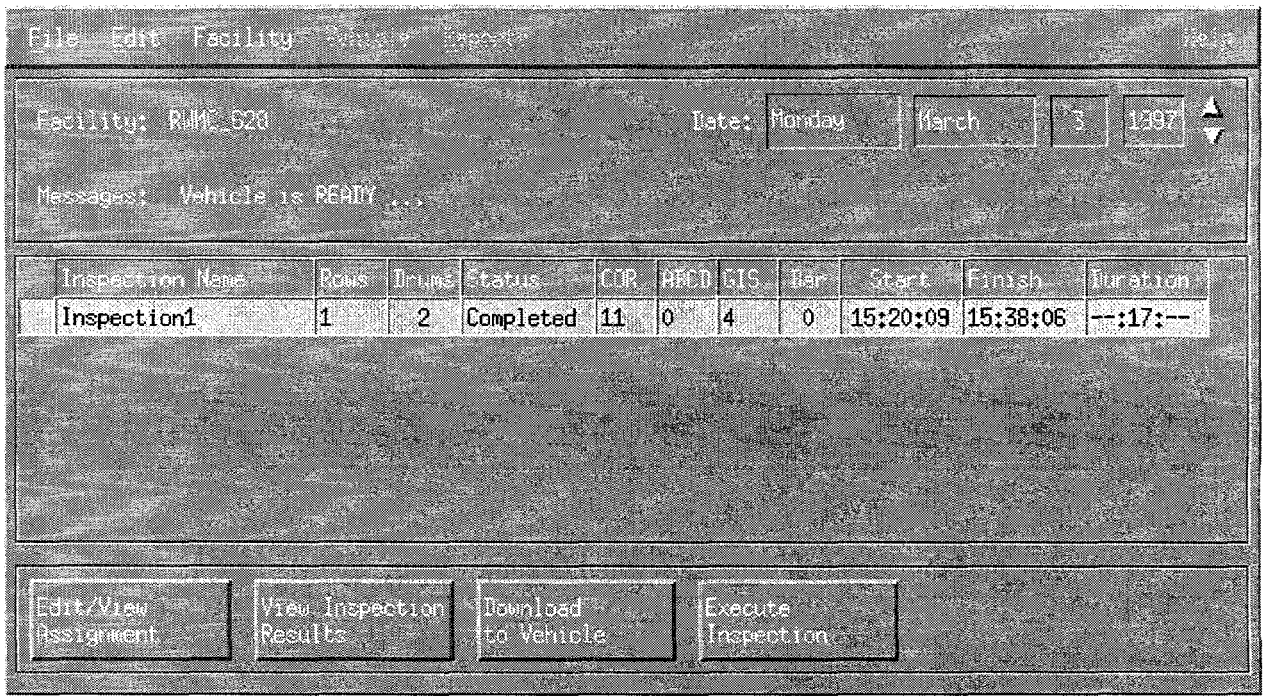

Figure 6-10. A Day's Mission List on the Main Screen is updated to reflect a summary of the results after completing a mission.

The detailed results from any mission can be reviewed by first selecting the mission in the Day's Mission List, and then pressing the "View Inspection Results" button. (In the tutorial there is only one mission to choose from.) Pressing the button will cause the Mission Assessment Screen to appear, which shows the complete inspection results for the selected mission. Figure 6-11 shows an example of the Mission Assessment Screen.

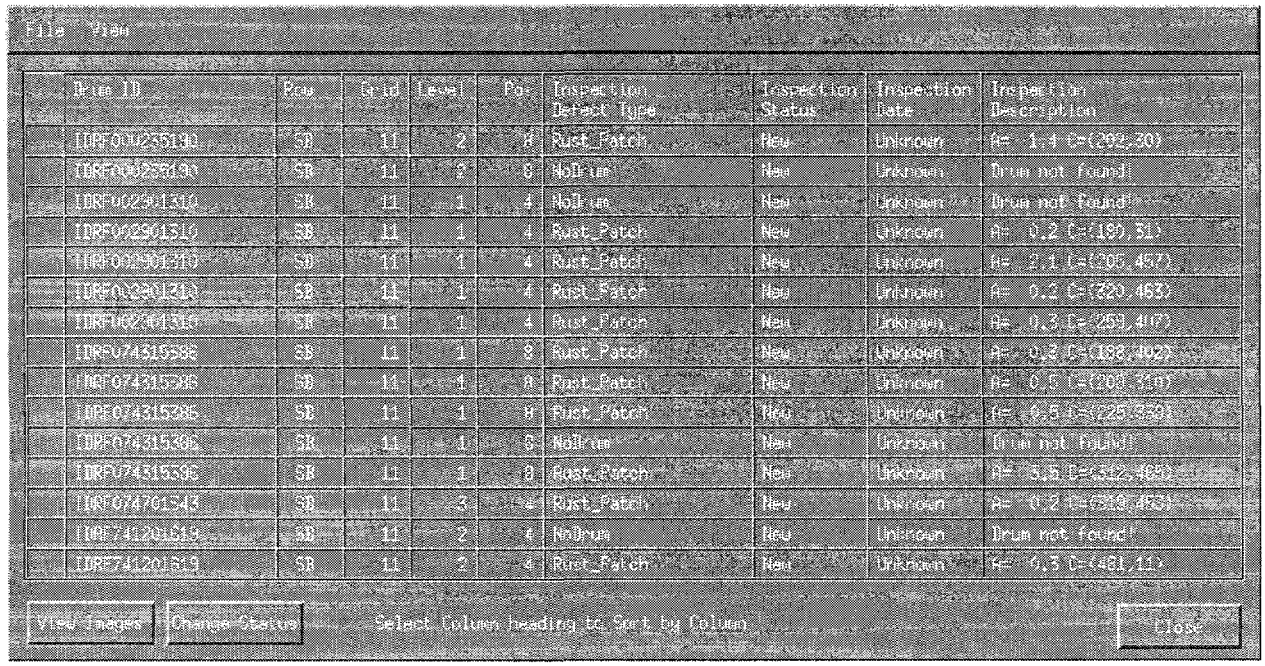

Figure 6-11. An example of typical defects reported on the Mission Assessment Screen after executing the example mission.

6.4.7 Executing the (Real) Inspection Mission

A baseline mission and regular inspection missions are assigned and executed in the same way. The only difference is that a baseline mission must be preceded by the baseline setup operation, as you did at the beginning of this tutorial example, and the inspection results are reviewed differently by the operator. Ideally, for the baseline run the operator will know that there are no true defects among all the inspected drums. In this case, the operator can simply select all the defects reported by the IMSS system and change their status to Ignore. If there are indeed some drums with true defects, then the operator will have to selectively change the status of all but those defects to Ignore.

The mission that you have just executed is the baseline mission, so you should now change the status of all the reported defects to ignore.

The last task in this tutorial is for you to assign and execute another mission. This mission will be a regular inspection mission. (Be sure not to repeat the baseline setup operation step.) When reviewing the results for the regular inspection mission, you will now see that ABCD defects (based on detected changes) in the drums are reported. You may want to temporarily attach a small pieces of paper to one drum to cause such a defect to be reported.

7. Setup Operations for a New or Modified Facility

Certain one-time setup operations are required when the IMSS system is first installed in a building. Similar operations must also be performed if the drum stacking layout changes inside a building where the IMSS system has been installed and is currently operating.

First, this section provides some description of activities related to installation, initial setup and verification of the IMSS system in a new or modified facility -- these activities will be performed by the IMSS system development team from Lockheed Martin Astronautics in Denver when the system is first installed. Second, this section describes how to use the IMSS Facility Model Editor, a part of the IMSS operator interface.

7.1 Setup Operations

7.1.1 Creating the Facility Model for a New Facility

The first step when creating a facility model for a new facility is to visit the building in-person and measure all the required relative distances using a tape measure. These are all the distance values that are displayed on the facility model editor's screen. If the docking station has not yet been installed, the measured docking station origin point should be marked on the building floor with tape or chalk. Note that expansion seams in the concrete floor slabs of the RWMC buildings cause some aisles to have unusual widths.

Note that the IMSS system should not be allowed to inspect the rows inside an RWMC building that are near the building entrance ramps. These are rows NA, NT, and ST in Building 628. We do not recommend having the IMSS vehicle visit these rows because of a (highly conservative) safety concern about having the vehicle drive over parts of these ramps. Currently, the Facility Model Editor displays those particular rows, but will essentially ignore them. (Specifically, the editor will not allow the user to define those specific rows as being full-length rows, and the IMSS system will not visit or inspect non-full-length rows.)

Once all measurements are in hand, start the facility model editor, enter all the values, save the facility model, and exit the facility model editor.

Note that the advanced keyboard commands can be very useful when entering an initial facility model, particularly when a contiguous block of rows must be moved an amount in the same direction. (Otherwise, each row must be moved individually, one inch at a time.)

7.1.2 Modifying an Existing Facility Model

Modifying an existing facility model is usually very simple. Typically one or a few measurements inside the building have changed. Simply measure the new distances and update the original facility model using the editor. To begin modifying an existing facility model, select the menu item named "View Current Facility" from the "Facility" menu in the Main Screen.

Whenever a facility model is modified using the facility model editor it will be necessary to execute a new baseline run. (Modifying a facility model causes the drum database maintained internally by the IMSS system to be cleared out.)

7.1.3 Executing the Baseline Run

When the IMSS vehicle had freshly been installed in a waste storage building, the IMSS system operator must have the vehicle execute a "baseline" mission. A new baseline mission should be execute if a large part of the facility is ever changed.

One setup operation is required in preparation for the baseline mission. You must open a shell window on the workstation and type the following in that window:

```
Unix-Prompt$      rsh mortisha
VxWorks-Prompt>   <setup-for-baseline
VxWorks-Prompt>   ~.
Unix-Prompt$
```

This setup operation will clear (delete) any existing IMSS defect databases, IMSS drum databases, and ABCD baseline images.

Next, you must assign and execute a mission that has the vehicle inspect every drum in the facility.

Ideally, for the baseline run the operator will know that there are no true defects among all the inspected drums. In this case, the operator can simply select all the defects reported by the IMSS system and change their status to Ignore. If there are indeed some drums with true defects, then the operator will have to selectively change the status of all but those defects to Ignore.

Once this operation is completed, the IMSS system is ready to begin regular inspection missions.

7.2 How to Use the IMSS Facility Model Editor

The operator uses the IMSS Facility Model Editor to create an overhead map view of each building. The user can move and re-size primitive facility objects anywhere in the map view of the building. The IMSS Facility Model Editor has been specially designed to handle the types of waste storage buildings in the INEL RWMC. (The IMSS system includes another facility model editor for general-purpose building layouts, but it is more complex and was intended for use only by the IMSS system development team.)

7.2.1 Introduction to Facility Models

A model of each waste storage building (also called a facility) must exist before an operator can assign the IMSS vehicle to perform inspection missions inside the building. The IMSS facility model consists of two parts: the facility map and the drum database.

The IMSS facility map is a description of the physical layout of the building, meaning such things as the number, size and location of aisles, pallets, ramps, known obstacles (e.g., support columns), *etc.* This information is entered using the IMSS Facility Model Editor, which is the main topic of this section.

The IMSS drum database contains an entry for each drum in the building, and contains information such as drum barcode, size, color, and location. Some of this information is provided from the physical layout of the building, as contained in the IMSS facility map. The remaining information is obtained during the initial or "baseline" run that the vehicle makes through the building.

7.2.2 Introduction to the Facility Model Editor's Screen

To run the IMSS Facility Model Editor, select the menu item named "Create New Facility" from the "Facility" menu in the Main Screen of the IMSS operator interface. This menu item is used to create a new facility model, and the editor will be initialized to begin with a generic INEL RWMC building layout. When started, the facility model editor appears as a new window on the screen, as shown in Figure 7-1.

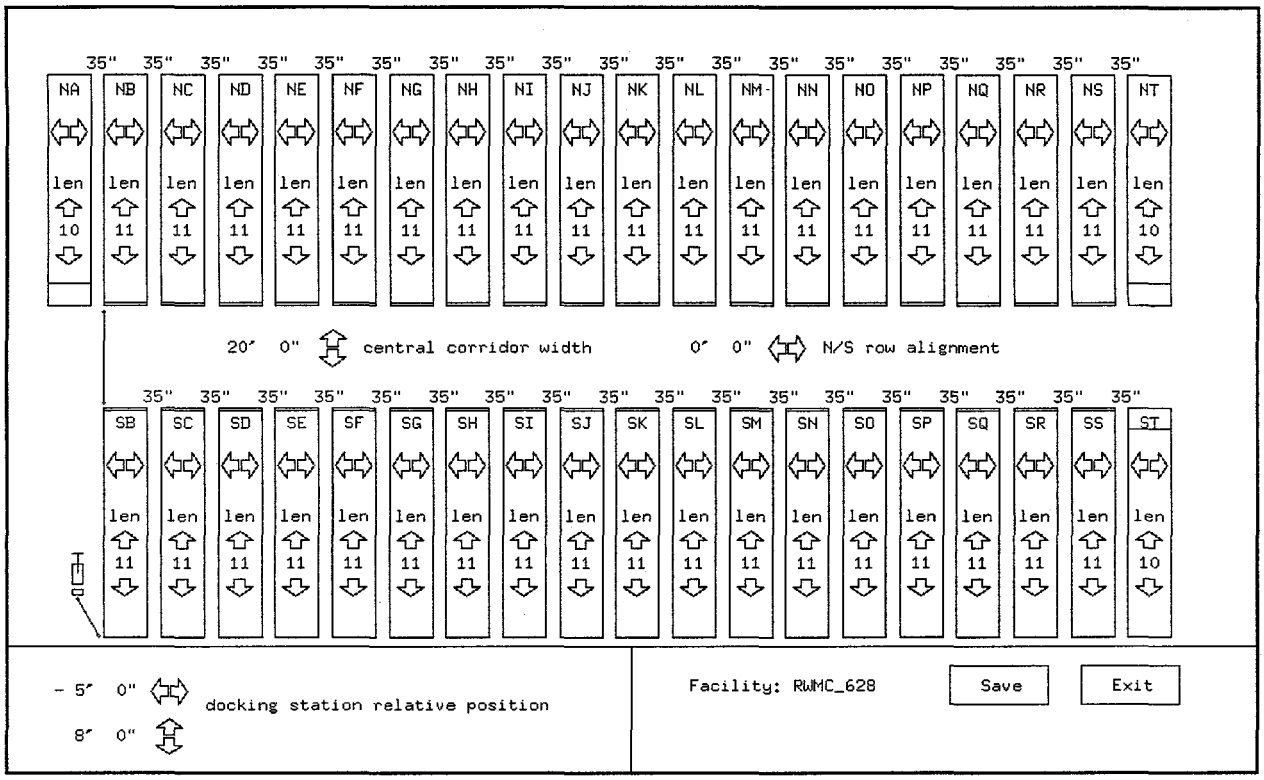

Figure 7-1. The IMSS Facility Model Editor.

The operator interacts with the facility model editor in a simple and intuitive way: by clicking the mouse on any of the several graphical buttons shown on the screen. All of the buttons are displayed on the screen at all times, as seen in Figure 7-1. There are no menus in the facility model editor.

The screen for the facility model editor contains a scale map of the building showing the outline of the building and the outline for every row of drums inside the building. The layout of the screen has four different areas, summarized below:

- **Drum Area:** Most of the screen is filled with the map that shows the location of every row of drums. Each row of drums contains several arrow-shaped buttons that change the characteristics of that one row. The facility model editor always shows the same number of rows, as shown in the figure. Rows can be "removed" by setting them to have zero length.
- **Center Corridor:** Waste storage containers inside the INEL RWMC buildings are normally arranged into a set of rows on the north side (the rows labeled NA through NT in the figure) and a set of rows on the south side (SB through ST in the figure). A central corridor runs down the length of the building between the north and south sides.

On the screen of the facility model editor, a set of arrow-shaped buttons are located in the central corridor area. These buttons are used to set the width of the central corridor and the relative east-west position of the rows on either side of the central corridor.

- **Docking Area:** The preferred location for the IMSS docking station inside the INEL RWMC buildings is in the large open area at the south-west corner of the building, which corresponds with the lower-left corner of the facility model editor's screen. An outline of the docking station (with an IMSS vehicle docked at it) is shown graphically inside that area. The lower-left corner of the screen also contains a set of arrow-shaped buttons used to set the exact position of the docking station inside the building.
- **Save/Exit Area:** The lower-right corner of the screen contains buttons used when the operator is finished using the facility model editor. These buttons allow the operator to save the edited facility model and/or to exit the facility model editor and return to the Main Screen of the IMSS operator interface.

Next, the buttons located in the above four areas of the screen will be explained in detail. Later, the typical sequence of operations used to create a new facility model will be summarized.

7.2.3 Changing The Position or Length of Rows

In the INEL RWMC buildings, a full-length row of drums nominally consists of 11 grids containing 55-gallon drums. A grid is a 4' by 8' pallet containing eight 55-gallon drums arranged in a 2 by 4 pattern. The outline of each full-length row in the INEL RWMC buildings are permanently painted onto the floor as an aid for arranging the pallets on the floor. The rows are labeled with a letter (N for north, S for south) and a row number (A through T). The IMSS system can also operate with 85-gallon drums. The IMSS system can readily be enhanced to operate with waste storage boxes.

The facility model editor's screen shows an outline for every potential full-length row of drums in the building. This outline corresponds with the painted outlines on the floor inside a building. Every row on the screen (as highlighted in Figure 7-2) contains a set of buttons that can be used to change the position and length of that row. The values for the relative position and length of the row are also displayed. The INEL RWMC row number is also displayed for each row.

As an illustration, row NB is highlighted in Figure 7-2. This row is currently 11 grids in length, as denoted by the "len" (length) value of "11" displayed inside the row. The length of the row is also depicted by a line denoting the pallet edge closest to the central corridor. Since this row is a full length row, this line is barely visible at the bottom edge of the full-length row outline. For comparison, note how rows NA and NT -- both with lengths of 10 grids -- are displayed.

Clicking the mouse on the arrow-shaped button that points down will decrease the length of the row by one grid (down to a minimum of zero). Similarly, the upward arrow will increase the length of the row by one grid (up to a maximum of 11 grids).

The IMSS system only needs to know about the position of rows relative to one another. (It also needs to know the location of the docking station relative to one row -- more on that later). The IMSS system assumes that all the rows on each side the building are parallel to each other, and that the row ends facing the central corridor are all lined up. Any small deviations (up to about 1.5 inches) in these alignments do not need to be entered into the facility map -- the IMSS system can readily adapt to such small deviations as the vehicle encounters them. Thus the only information that the IMSS system needs to know is how far apart the rows are, or in other words, how wide the aisles between the rows are.

Each mouse-click on the left or right arrow inside a row moves that row by one inch in the indicated direction. The width of the aisles on either side of the row are displayed at the top end of the row outline, and these are updated as a row is moved. Aisles are currently restricted to be at least 30 inches wide, so the IMSS vehicle can fit inside them. (The IMSS vehicle platform is designed for aisles down to 27 inches, but the system is currently validated only to 30 inches.)

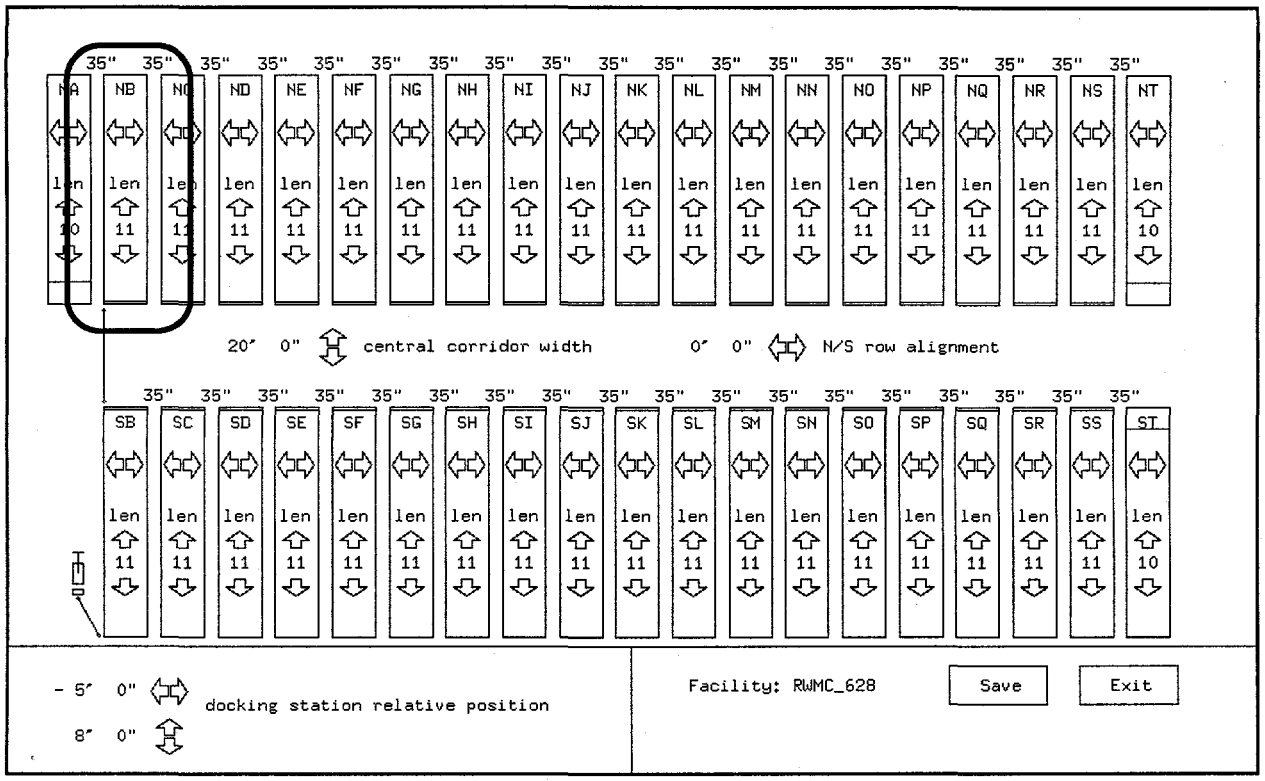

Figure 7-2. Control buttons and displayed feature values for one row of drums.

7.2.4 Changing The Width of the Central Corridor or the Relative Position of the Rows On Either Side of It

The IMSS system needs to know about the position of the rows on the north side of the building relative to the rows on the south side of the building. It is sufficient to know only the relative position of row SB with row NB, and thus it is this relative position that must be entered into the facility model editor. The relative position of row SB with row NB is depicted graphically by a line segment on the facility model editor's screen. This line segment is highlighted on the left in Figure 7-3. The numeric values for the relative offsets are displayed inside the area highlighted on the right.

The values for the relative position of row SB with row NB are set using arrow buttons located inside the central corridor area on the screen. These buttons are highlighted on the right in Figure 7-3. The up and down buttons change the width of the central corridor, defined as the distance between the ends of row SB and row NB. The relative east-west position of rows SB and NB are controlled by the left and right buttons. Each click on an arrow button changes the specified distance by one inch. Note that using the buttons inside rows SB or NB to move those individual rows will also cause the east-west position values discussed here to change.

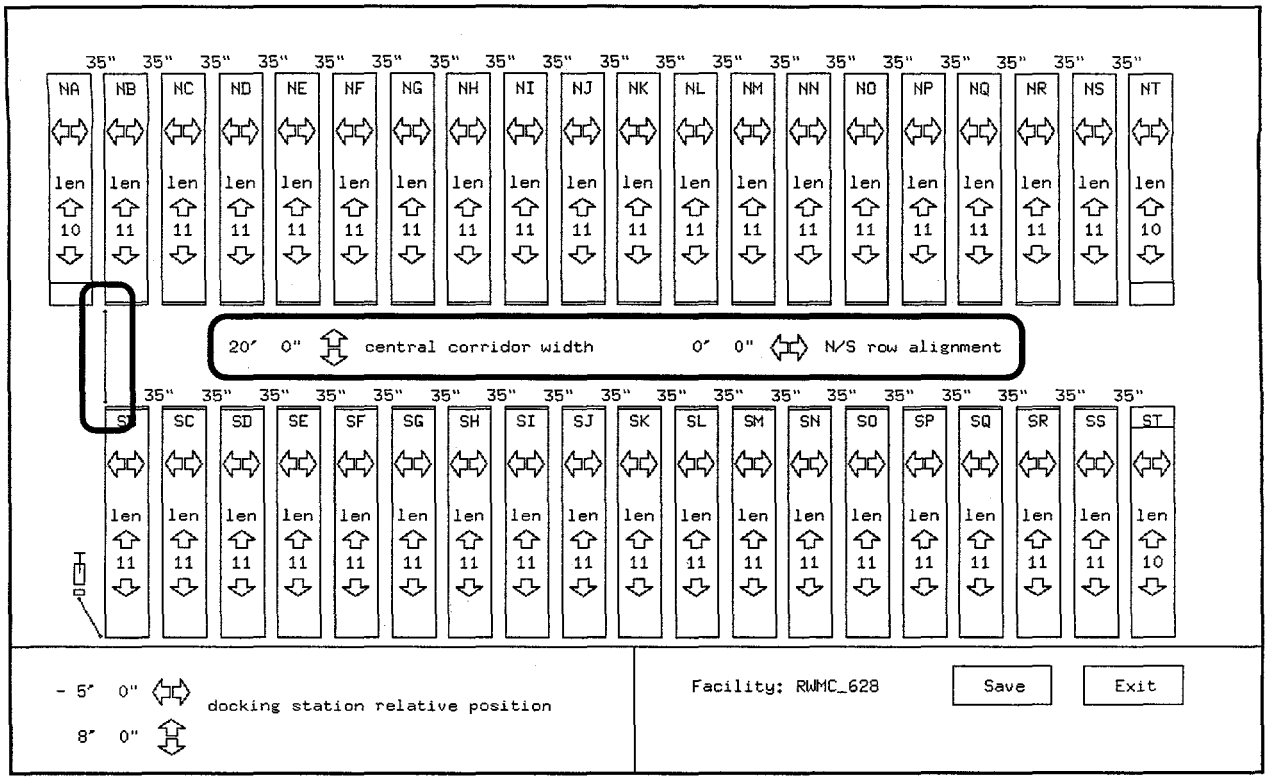

Figure 7-3. Buttons for changing characteristics of the central corridor width and relative alignment of the north/south rows of drums.

7.2.5 Changing the Position of the Docking Station

The IMSS system needs to know the position of the docking station relative to the adjacent row. Specifically this relative distance is measured between the south-west corner of row SB and the docking station's origin point. The outline of a docking station with an IMSS vehicle docked at it is displayed on the facility model editor's screen, as highlighted in Figure 7-4. The screen also displays a line segment illustrating the relative position of the docking station and row SB. Figure 7-5 illustrates the location of the docking station's origin point.

The lower-left corner of the screen (the lower-most highlighting in the figure) displays numeric values for the relative position of the docking station, and contains a set of buttons for changing those values. Each click on a button changes the relative position by one inch. Note that using the buttons inside row SB to move that individual row will also change the values of the relative distance to the docking station.

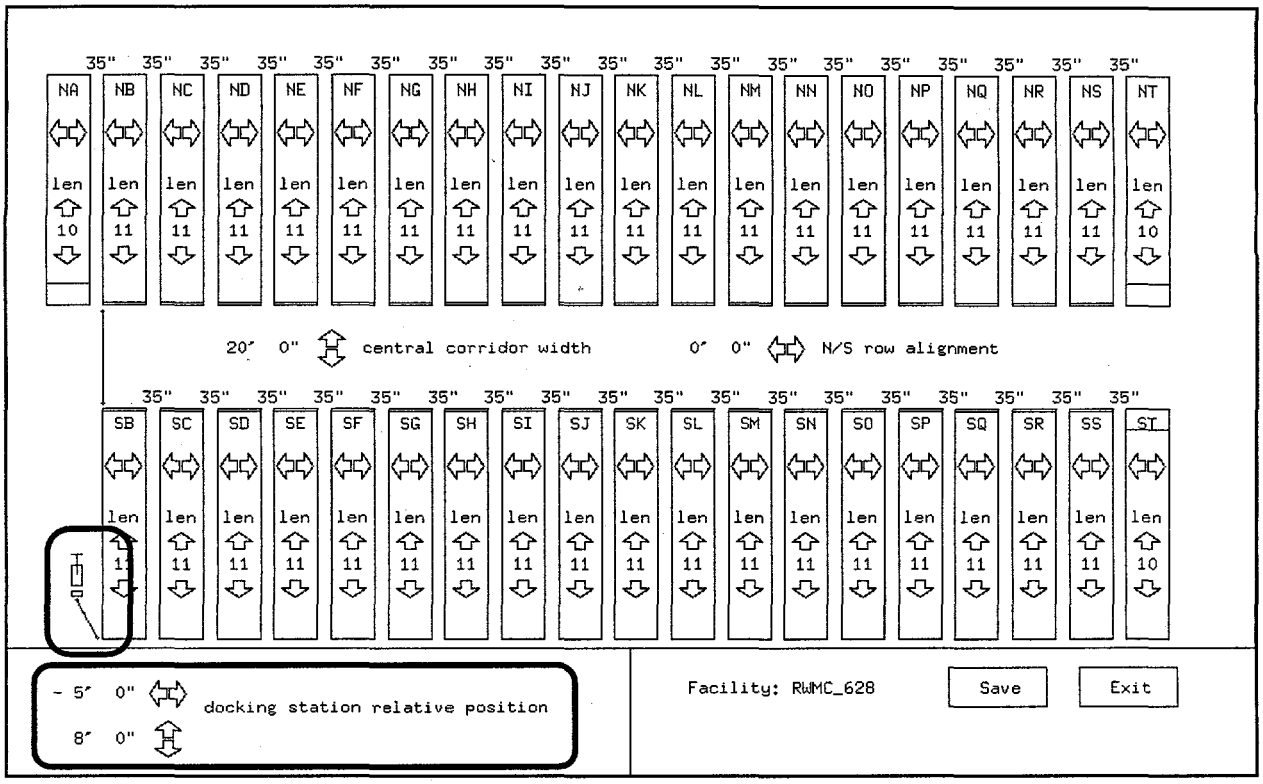

Figure 7-4. Buttons for changing the location of the docking station.

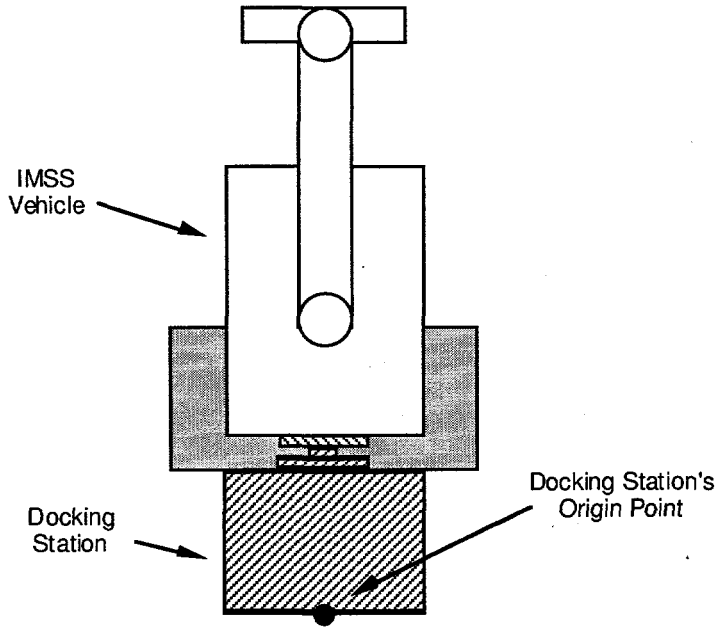

Figure 7-5. The docking station's "origin point" is located in the middle of the backside of the docking station. This point is not marked on the docking station, and should be measured as halfway across the back of the docking station.

7.2.6 Advanced Keyboard Commands

The facility model editor uses keyboard buttons to provide some advanced features, described below. The keyboard commands are summarized in Table 7-1, and explained in more detail below. The commands fall into two categories: commands to speed-up large movements, and commands to use different types of pallets and drum sizes.

Table 7-1. Summary of keyboard commands.

"f" or "Control"	Hold down for movement of 4 inches instead of 1 inch
"l" or "Left Shift"	Hold down to operate on a row and all the rows to the left
"r" or "Right Shift"	Hold down to operate on a row and all the rows to the right
"5"	Change row to contain all 55-gallon drums
"8"	Change row to contain all 85-gallon drums
"4"	Change row to contain all pallets that have 4 drums across
"3"	Change row to contain all pallets that have 3 drums across
"2"	Change row to contain all pallets that have 2 drums across
"?"	Print summary of keyboard commands to text window (if available)

"Control" or "f" (for fast): Holding down either of these keys when moving a row causes movements in increments of 4 inches instead of 1 inch. Holding down either of these keys when increasing or decreasing a row's length sets the row length to the maximum (11) or minimum (0) length.

"Left Shift" or "l" (for left): Holding down either of these keys during a mouse click on a button or when using another keyboard command inside a row causes the operation to occur on that row and all the rows to the left.

"Right Shift" or "r" (for right): Holding down either of these keys during a mouse click on a button or when using another keyboard command inside a row causes the operation to occur on that row and all the rows to the right.

"5": Pressing this key when the mouse pointer is inside a row changes that row to contain all 55-gallon drums. The pallet size will automatically be changed if required, and the dimensions of the row outline will change to reflect the new pallet size.

"8": Pressing this key when the mouse pointer is inside a row changes that row to contain all 85-gallon drums. The pallet size will automatically be changed if required, and the dimensions of the row outline will change to reflect the new pallet size.

"4": Pressing this key when the mouse pointer is inside a row changes that row to contain pallets that have 4 drums across the long dimension of the pallet. The dimensions of the row outline will change to reflect the new pallet size.

"3": Pressing this key when the mouse pointer is inside a row changes that row to contain pallets that have 3 85-gallon drums across the long dimension of the pallet. The dimensions of the row outline will change to reflect the new pallet size. The row is automatically changed to contain all 85-gallon drums.

"2": Pressing this key when the mouse pointer is inside a row changes that row to contain pallets that have 2 drums across the pallet. The dimensions of the row outline will change to reflect the new pallet size.

"?": If a text window is available, this key will cause a brief summary of the keyboard commands to be printed inside that window.

7.2.7 Saving Your Changes and Exiting the Facility Model Editor

The buttons at the lower-right of the screen (see Figure 7-6) are used when the operator is done with the Facility Model Editor.

When you have finished creating or editing the facility model, simply click on the "Save" button to save the new facility model.

When you have finished using the facility model editor, click on the "Exit" button to exit and return back to the Main Screen of the IMSS operator interface.

If you chose to exit without having saved any changes made to the facility model, the editor will ask if you are sure that you want to exit without saving those changes. This prompt appears below the "Exit" button, as shown in Figure 7-7. Select "Yes" to continue exiting without saving the changes. Select "No" to cancel the "Exit" command and continue using the editor -- you can then choose to save the facility and exit the editor again.

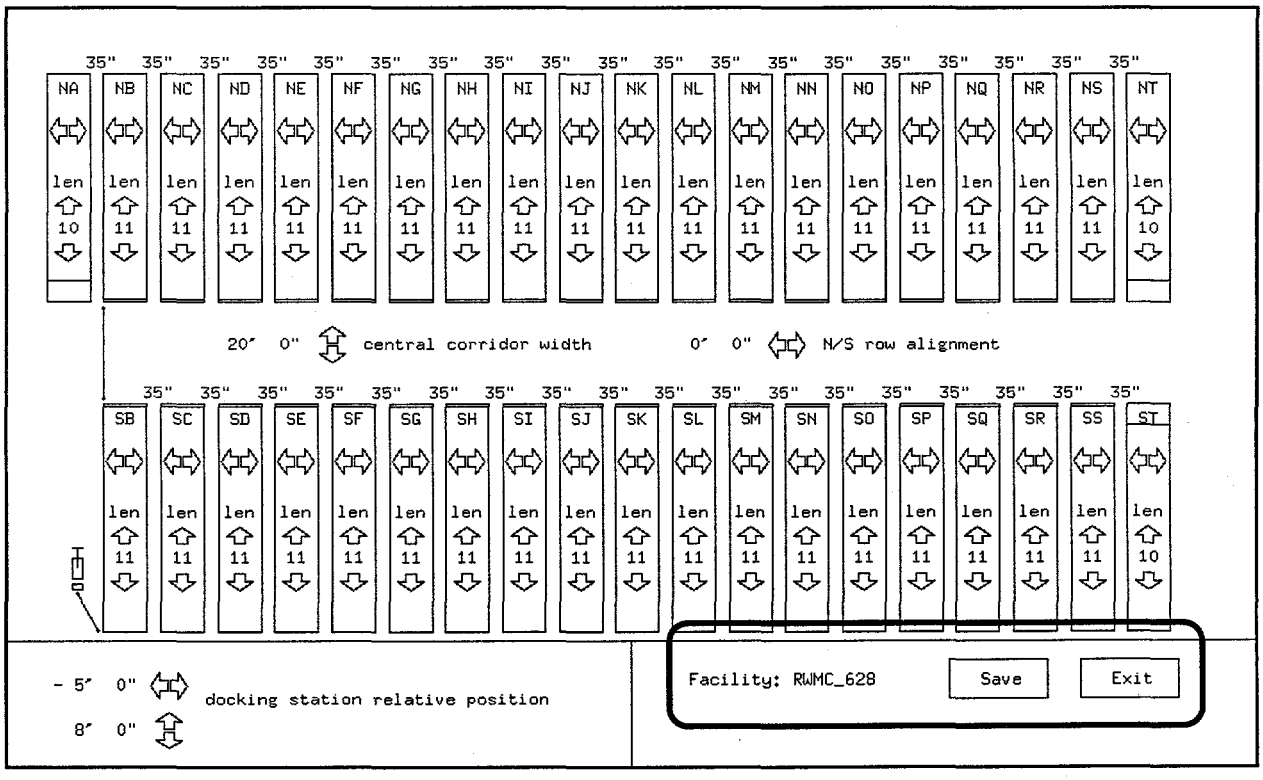

Figure 7-6. Buttons for saving the facility map and exiting the editor.

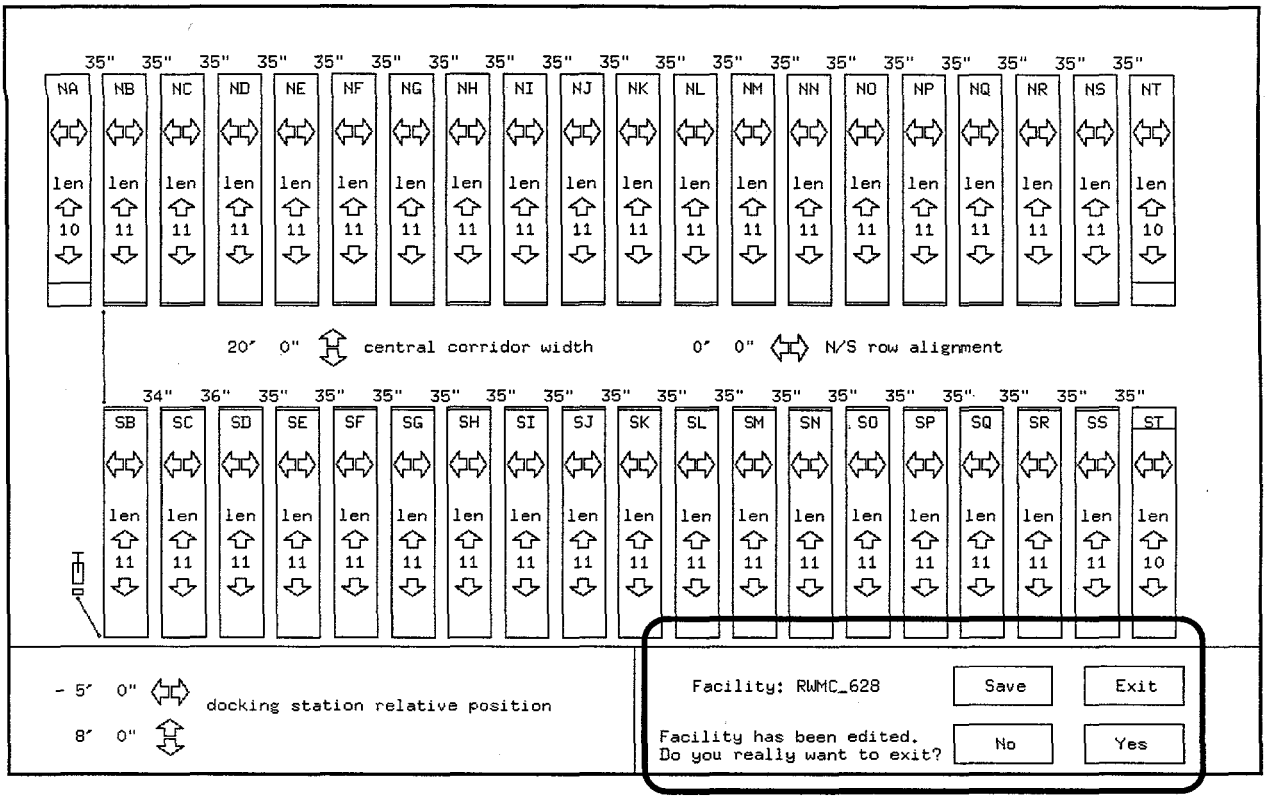

Figure 7-7. Exiting the editor without saving changes requires a verification using the buttons shown here.

8. IMSS Hardware and Maintenance

This section covers a variety of topics related to the IMSS hardware.

8.1 Packing and Unpacking

The topics of how to unpack the hardware components of the IMSS system from their shipping boxes, how to assemble and setup the hardware components, how to re-pack the hardware into their shipping boxes, and how to move the IMSS system hardware from one waste storage building to another will be covered in the one-on-one training provided when the IMSS system is delivered. Most of these operations are complicated and best conveyed by interactive example. Below is a brief summary of how the IMSS system hardware is packed.

8.1.1 The IMSS Control Station

The IMSS control station is a commercial off-the-shelf Unix computer workstation (called a Sun Sparc 20) running the IMSS operator interface software. The control station is packed in the original boxes for the computer workstation. There are three boxes: one holds the computer's monitor; one holds the computer's box, keyboard and mouse; and the last box holds an external disk drive.

The IMSS control station should be assembled and setup according to the instructions enclosed with the Unix computer workstation. This assembly and setup operation should be familiar to many computer users and the enclosed instructions may not be necessary. The workstation must be configured to work on the INEL site ethernet. No additional setup is required for the IMSS operator interface software -- It is pre-installed on the workstation.

8.1.2 The IMSS Vehicle

The IMSS vehicle is packed in a wooden crate specially designed to hold the vehicle for shipping purposes. Moving this crate requires a forklift.

The shipping crate contains a complex set of internal cross members and clamps to hold the vehicle and partially dis-assembled mast in place, which makes unpacking and packing this crate very complicated. At least four people are required to physically hold elements of the crate and vehicle during the unpacking operation. At least three people are physically required to dis-assemble or assemble the mast.

8.1.3 The IMSS Docking Station

The IMSS docking station does not have and dedicated packing crate or box. The docking station will require some dis-assembly or assembly.

8.2 Temporary Local Storage

If the IMSS vehicle and docking station will be left turned off for a long time and will not be stored in packing creates, we recommend putting all the protective covers (lens caps) onto the sensors in each sensor suite: lens caps for the two color cameras, a lens cap for the block and white camera, and a cap for the laser stripe projector. We also recommend placing a waterproof plastic cover over

the body of the vehicle and over the docking station. These covers will prevent dust buildup on the hardware and will help protect the hardware from any blown snow or dripping water.

8.3 Optional Peripherals Attached to the IMSS Control Station

The IMSS control station is designed to be used with a printer (for printing reports) and a tape drive (for file archiving and for managing disk space consumed by drum images accumulated over time). These two peripherals should be available within INEL's networked computer environment, so they are not included in the delivered IMSS system.

8.4 Optional TV Monitor Located at the IMSS Docking Station

The IMSS system includes a video transmitter/receiver system that transmits a live video signal from a camera mounted on the IMSS vehicle's mast to the docking station. An optional TV monitor can be placed at the docking station to display this live video signal. This video monitoring capability is not used by the IMSS system. It is provided as an aid to anybody working inside the building. The video monitor allows a person to see what the robot is doing, without physically entering the rows of drums to watch the vehicle. It is also provides a convenient way to monitor the activity of the robot when using the remote keyboard panel.

8.5 Hardware Maintenance

There are no user serviceable parts inside the body of the IMSS vehicle or inside the IMSS docking station.

The IMSS vehicle requires no regular maintenance other than a few simple tasks that may need to be performed on a very infrequent basis. Procedures for these tasks will be explained during the one-on-one training course when the IMSS system is installed. These tasks include the following:

- Oil the multiple small rollers around the outside of each wheel.
- Use a lens cloth to remove any accumulated dust from the lenses and other optics on all sensor suites.
- Clean any accumulated dust or grime from the outer surfaces of the vehicle.
- Make sure the filters on each GIS camera in each sensor suite fit snugly on its lens.
- Make sure none of the screws holding the outer sheet metal skins onto the vehicle's body have become loose from vibration.
- Remove any copper oxide buildup from the charge plates on the vehicle and on the docking station. First, be sure to turn off and unplug the docking station power supply.
- Replace any burnt-out halogen lamps on any sensor suite.

The IMSS vehicle's batteries should be given a conditioning charge approximately every 100 cycles, in order to improve their life and charge holding capacity. This procedure requires fully discharging the batteries and then performing a special procedure to charge the batteries to a high capacity. This procedure requires access to the potentially dangerous batteries inside the vehicle and should only be performed by personnel from the IMSS system development team.

8.6 Hardware Reference Drawings

8.6.1 IMSS Vehicle Status Panel Lights, Switches and Connectors

Figure 8-1 depicts the status panel located at the rear left corner of the IMSS vehicle.

Pushing the push-button labeled MAIN PWR RESET will restore power to the vehicle after an emergency power-down has occurred. Once the power to restored in this manner, the vehicle would normally be turned off (by turning the main power switch off) and manually pushed back to the docking station. The IMSS system operator should determine why the emergency power-down occurred before doing anything else with the vehicle.

Note: When an emergency power-down has occurred the vehicle's main power switch will still be in the on position. The emergency power-down opens a relay that is wired in series with the main power switch. Turning the main power switch off and on will have no effect until the main power reset push-button is pushed to close that relay.

The section of the status panel labeled BATTERY displays some status information of the battery. The four square lights shows the rough amount of charge contained in the vehicle's batteries. The lights labeled TEMP (for temperature), CURRENT and VOLTAGE come on when high values of these quantities occur. But these lights will be of little interest since the vehicle's automated safety system will trigger an emergency power-down and the light will go off when the vehicle power is cut off.

The section of the status panel labeled EMERGENCY SHUTDOWN displays information related to the emergency stop system. As described in the Safety section of this manual, a number of mechanical switches and events will trigger the emergency stop system, which causes the power for all motors to be disabled immediately. The light labeled ESD indicates whether an emergency stop has been triggered -- if yes, then the light will be on. The event that caused the trigger is indicated by the remaining lights:

- LIMIT indicated that a limit switch was triggered for one of the motors in the mast or in a sensor suite.
- CPU FAIL indicates that the "heartbeat" from the vehicle's main computer has stopped, indicating a hardware fault with the vehicle's computer systems.
- MANUAL indicates that one of the red mushroom switches was pressed. (This light also indicates if the "manual kill switch" was triggered. The manual kill switch is a switch at the end of a long cable that is plugged into the connector labeled KILL, and which was used during development of the IMSS system.)
- S/W ESD indicates that one of the vehicle's software systems that monitors vehicle safety detected an anomaly and triggered an emergency stop via software.
- CONTACT indicates that either the mast collision sensor is triggered or that one of the kill switches built into the outer skins of the vehicle was triggered. This light remains on only as long as the triggering switch is enabled.

If an emergency stop occurs, the IMSS system operator should try to determine the cause of the trigger by examining the status lights and considering the physical position of the vehicle when the trigger occurred. Normally, the operator should turn off the vehicle power at this time and return the vehicle to the docking station. (If the triggering event no longer exists, pushing the push-button switch labeled MANUAL RESET will clear the triggered emergency stop system, and immediately restore power to all motors inside the vehicle. This switch should not be used. It was included for

use during development of the IMSS system. Pressing this switch may cause unexpected motions by the vehicle.)

The key switch labeled LASER PWR is the main power switch for the lasers contained in the structured light systems in each sensor suite. This switch should be left in the EN (enabled, meaning on) position at all times. If the IMSS vehicle is configured to not use the structured light system (called GIS) and to not report geometric defects, then this switch should be left on the OFF position. Adjacent to the switch is a light labeled ON -- the light will turn on when the key switch is in the EN position.

Several connectors are located at the bottom of the status panel. The connector labeled KILL accepts the manual kill switch mentioned above. When the manual kill switch is not connected (which is the normal case), the KILL connector must have a termination plug connected to it. The unlabeled ribbon cable connector below the KILL connector is for manual joystick control box, which was used during development of the IMSS system. The BNC connector labeled ENET is for a wire ethernet. If a wire ethernet is connected here, it will override the radio ethernet link. When the wire ethernet is not used, the ENET connector must have a termination "plug" connected to it. When a wire ethernet is connected, the termination plug should be stored on the BNC connector to the immediate right of the ENET BNC connector.

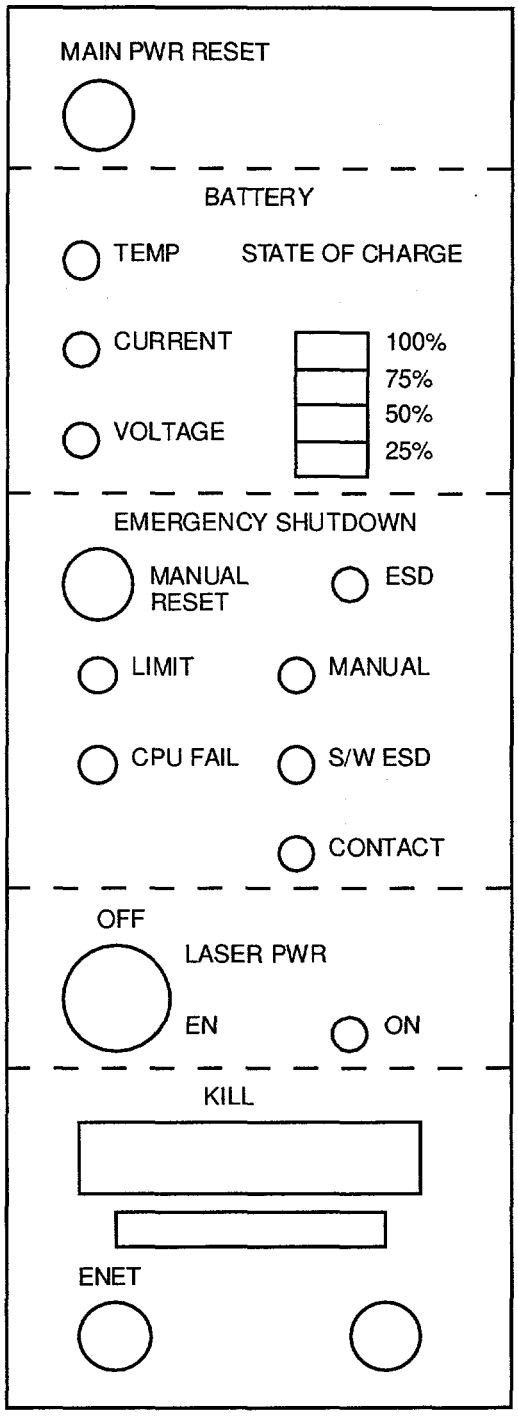

Figure 8-1. Status panel located at the rear left corner of the IMSS vehicle.

8.6.2 IMSS Remote Keypad

Figure 8-2 depicts the remote keypad that can be used to sent certain command signals via an analog radio to the IMSS vehicle. The remote keypad is normally located at the docking station.

Only three of the buttons on this keypad are intended for use during regular operations. These buttons were discussed in the Safety section of this manual. In brief:

- The "4" button (Kill) is a kill switch and will trigger the emergency stop system.
- The "5" button (Pause) will pause the vehicle.
- The "0" button (Run) will "unpause" the vehicle after the "5" button has been pressed.

If the vehicle is paused using the remote keypad, it must be unpaused from the remote keypad. And if the vehicle is paused using one of the pause switches on the vehicle, it must be unpaused by flipping that same switch back in the other direction.

The analog radio that transmits signals when a button on the remote keypad is pressed requires a line of sight path between the antenna mounted on the wall above the docking station and the antenna mounted on top of the IMSS vehicle's mast. The radio will not work if there is no line of sight path, or if there is any radio interference from outside sources.

The remaining buttons on the keypad are intended only for use during development activities. In brief:

- The "1" button (Manual Reset) is equivalent to the EMERGENCY SHUTDOWN -- MANUAL RESET push-button on the status panel at the back left corner of the vehicle.
- The "2" button (Main PWR Reset) is equivalent to the MAIN PWR RESET push-button on the status panel at the back left corner of the vehicle.
- The "6" button (VME Reset) is equivalent to pressing the "reset" button on the host processor board inside the vehicle. This will cause the vehicle's main computer to reboot.

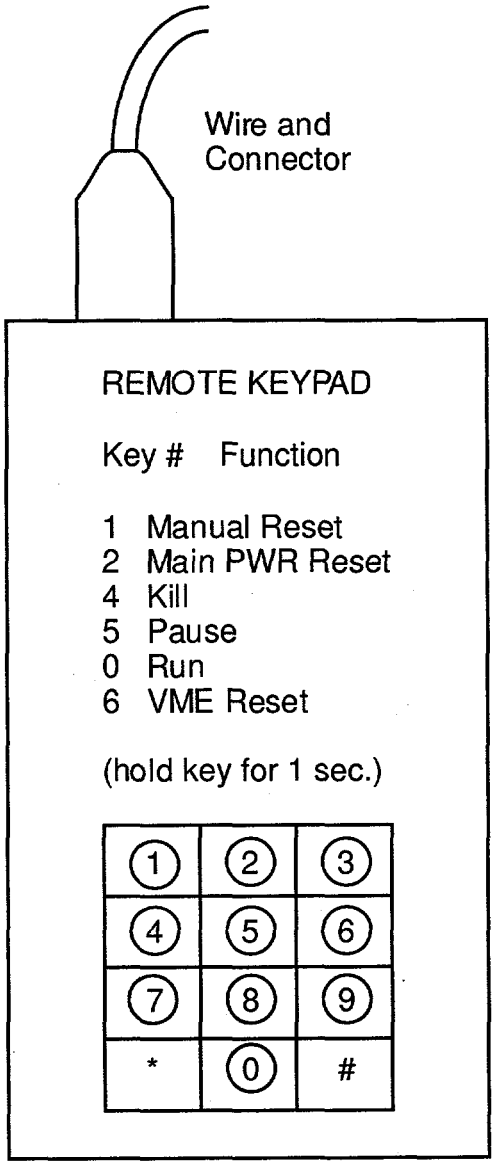

Figure 8-2. Keypad located next to the docking station.

9. Glossary

ABCD: Abbreviation for Automated Baseline Change Detection. Defects that are detected based on analysis of changes observed on a drum's surface since the last time the IMSS vehicle inspected that drum.

Aisle: An aisle is the space between two rows, down which a person would walk.

Arm: The vehicle's arm is the part of the mast assembly that connects the shoulder axis to the core vertical part of the mast. The two pause switches and one red mushroom switch are located on the top surface of the arm.

Baseline Run, or Baseline Mission: A baseline run is normally performed only once, and is the first mission that the vehicle executes in a building. Before a baseline run is started, all the IMSS systems databases are cleared. During the baseline run the vehicle will typically detect a large number of potential defects. The purpose of the baseline run is for the IMSS system operator to verify that all those potential defects are in fact acceptable defects (presumably all or nearly all of them will be). Those defects will never again be reported in all future inspection missions, unless they change significantly in size or shape.

Central Corridor: See Figure 9-1. The large open space down the center of the building.

COR: Abbreviation for CORrosion Detection System. Defects such as potential rust or corrosion that are detected based on analysis of the color of areas on a drum's surface.

Corrosion Defects: A type of potential defect detected by the COR or ABCD subsystem of the IMSS vehicle.

(IMSS) Defect Database: The IMSS system's internal database describing all the defects detected on drums by the vehicle.

(IMSS) Drum Database: The IMSS system's internal description of all the drums (not including defects) in the facility. This is part of the IMSS Facility Model. This is independent of any drum database maintained by INEL operations.

Emergency Stop, or E-Stop: The emergency stop safety system will immediately remove power from all the motors in the vehicle if it is triggered by one of several triggering mechanisms. The triggers include several kill switches, including the red-color mushroom switches that are called emergency stop buttons, and a number of automated software and hardware triggers.

Emergency Power-Down: The emergency power-down system will immediately turn off the vehicle's main power if it is triggered by one of several triggering mechanisms.

(IMSS) Facility Map: The IMSS system's internal description of the physical layout of elements in a building, as described on an overhead map drawing of the building. This is part of the IMSS Facility Model.

(IMSS) Facility Model: The information that the IMSS system uses to describe the physical layout of a facility is called a facility model. It consists of an IMSS Facility Map and an IMSS Drum Database.

Geometric Defects: A type of potential defect detected by the GIS subsystem of the IMSS vehicle.

GIS: Abbreviation for Geometric Inspection System. Defects such as dents, tilted drums, or displaced drums that are detected by measuring and analyzing three-dimensional data of a drum's surface.

Grid: See Figure 9-1. The pallets on the floor, which are arranged single file down the length of a row, correspond with the positions of grids. Grids, in combination with the position number of a drum on a grid (see Figure 9-1), are a method for determining the location of a drum along the length of a row. The grid closest to the outer wall of the building is numbered 1, and the next grid away from the wall is number 2, etc.

IMSS: Abbreviation for Intelligent Mobile Sensor System.

IMSS System Operator: A person fully trained to use the IMSS system.

INEL: Abbreviation for Idaho National Engineering Laboratory.

Kill Switch: A kill switch is a physical switch that will trigger an Emergency Stop.

L and R (or Left and Right): See Figure 9-1. The IMSS system makes a distinction between drums facing into the aisle on one side of a row and the drums facing into the aisle on the other side of the row. When standing in the Central Corridor of the building and looking down the length of a row, the Left (L) side of the row is on the left and the Right (R) side of the row is on the right.

Levels: See Figure 9-1. Drums on the floor are at level 1. Drums stacked immediately above level 1, are at level 2. And so on.

Mission, or Inspection Mission: The entire sequence of operations that the IMSS vehicle performs between the time that it departs from the IMSS docking station and when it returns to the docking station is called an inspection mission. The specific drums that the vehicle inspects during a mission are specified using the Mission Assignment Screen of the IMSS operator interface.

Mission Assessment: Mission assessment is the task of reviewing the results after an inspection mission has been completed.

Mission Assignment: Mission assignment is the task of assigning a specific set of drums in a building that the IMSS vehicle is to inspect.

Pan Axis: The vehicle's mast has a single pan axis. The pan axis allows the core vertical part of the mast to rotate about its center (i.e., in the left-right direction) under control of the vehicle's software. See Shoulder Axis.

Pause, Unpause: The IMSS vehicle can be placed into a paused state, in which the vehicle will not make any further motions. Clearing the paused state is sometimes called unpausing or resuming.

Row (also called a Stack by INEL): See Figure 9-1. In the INEL RWMC buildings, a row is a rectangular area outline on the floor. Pallets of drums are arranged in single file down the length of a row. Each row is labeled by a two letter code. The first letter is N or S, denoting that the row is on the North or South side of the building. The second letter is one of A-T, denoting the sequential order/position of the row on that side of the building.

Row-Side: Since the IMSS system distinguishes between the left and right side of a row (see entry for "L and R"), the system sometimes uses the term "Row-Side" to refer to one specific side or a row. For example, a Row-Side value of NB-R refers to the right side of row NB.

RWMC: Abbreviation for Radioactive Waste Management Complex, a complex within INEL.

Shoulder Axis: The vehicle's mast has a single shoulder axis. The shoulder axis is located where the mast attaches to the body of the vehicle. It allows the entire mast assembly (including the Arm) to swing from side to side under control of the vehicle's software. See Pan Axis.

Structured-Light Sensor System: The sensor system inside each sensor suite that is used by GIS is called a structured-light sensor system. This sensor system includes a laser stripe projector assembly and a black&white camera.

Tilt Axis: Each sensor suite on the vehicle's mast has a tilt axis. The tilt axis allows the sensor suite to tilt up and down under control of the vehicle's software.

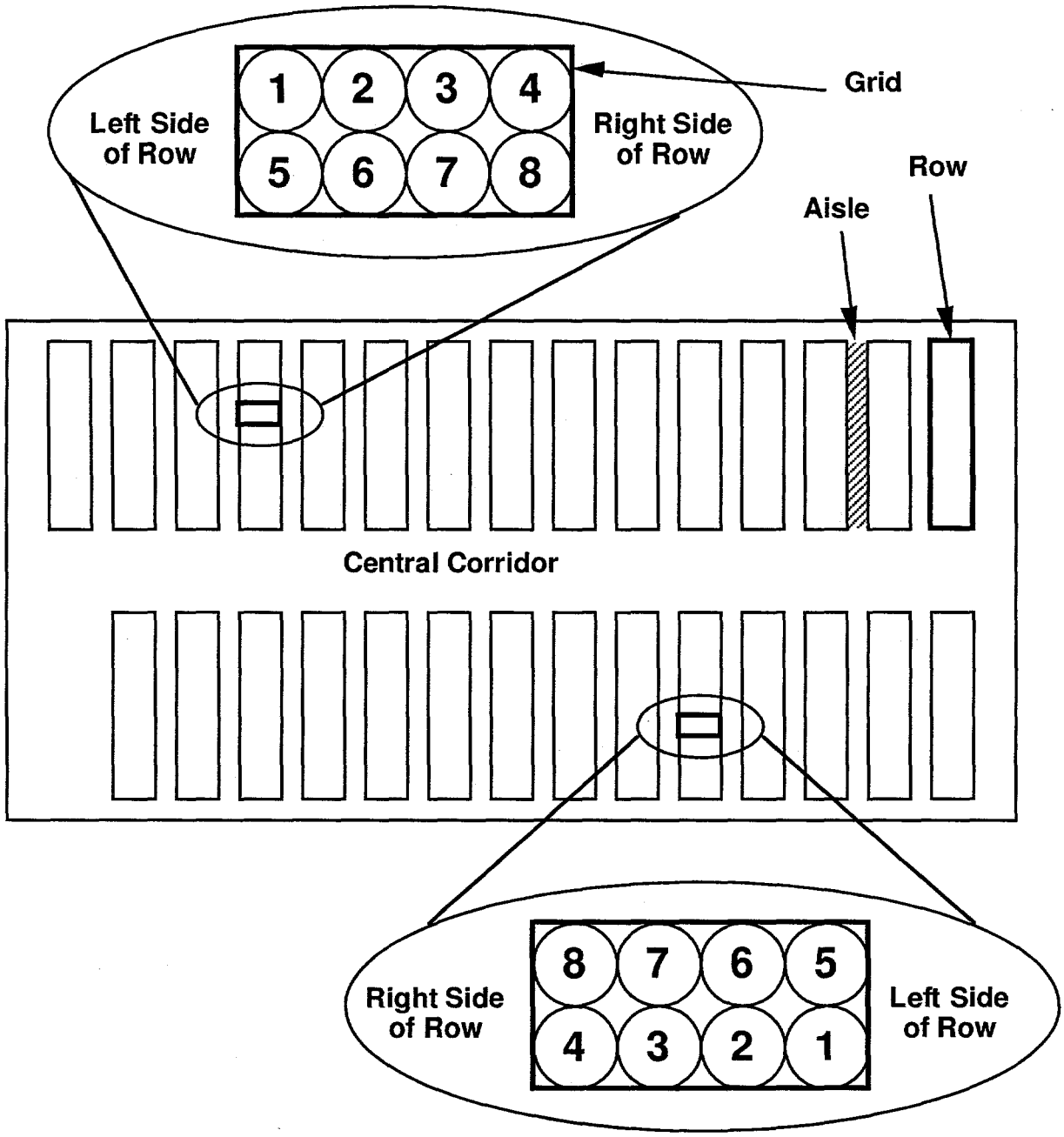

Figure 9-1. Names of some things inside a waste storage building.