Chapter 8

Near detector installation

8.1 Overview

This Chapter describes the installation of the MINOS near detector and the infrastructure required in the near hall, in the NuMI facility[1] and in other locations at Fermilab. It includes an overview of the detector, the near hall facilities, and other work and storage areas at Fermilab. Subsequent Sections discuss the technical requirements, the interfaces to other MINOS systems, and give detailed descriptions of the WBS Level 3 tasks, including materials handling and detector checkout and validation. Although the near detector installation procedures described in this Chapter are based on those developed for the MINOS far detector, described in Chapter 7, the installation effort requirements are quite different owing to the different labor environments at the Soudan and Fermilab sites. The near detector installation task must be closely coordinated with the fabrication of detector components: the magnet steel and coils (Chapter 4), the scintillator detector (Chapter 5) and the electronics systems (Chapter 6).

An overview of the design of the near detector has already been given in Chapter 3 and the details of its construction have been described in the Chapters 4, 5 and 6. The main parameters of the detector and laboratory infrastructure are summarized in Table 8.1.

8.1.1 The near detector facility

The MINOS near hall is located at the downstream end of the NuMI facility at Fermilab. Access to the underground hall is through a 98 m deep shaft approximately 70 m upstream of the hall entrance. The base of the shaft and the floor of the hall are at the same elevation, in contrast to the sloping tunnels in other areas of the NuMI facility. The upstream face of the near detector is located 290 m from the end of the decay pipe; 240 m of this distance is the muon shield (unexcavated rock), 10 m is for muon monitor pits within the shield, and 40 m is air drift space between the end of the shield and the near detector. The near hall is approximately 45 m long by 9 m wide and 10 m high. The ventilation, electrical, water control and safety systems are provided as part of the NuMI civil construction task[1]. Figure 8.1 shows plan and elevation views of the near hall facility.

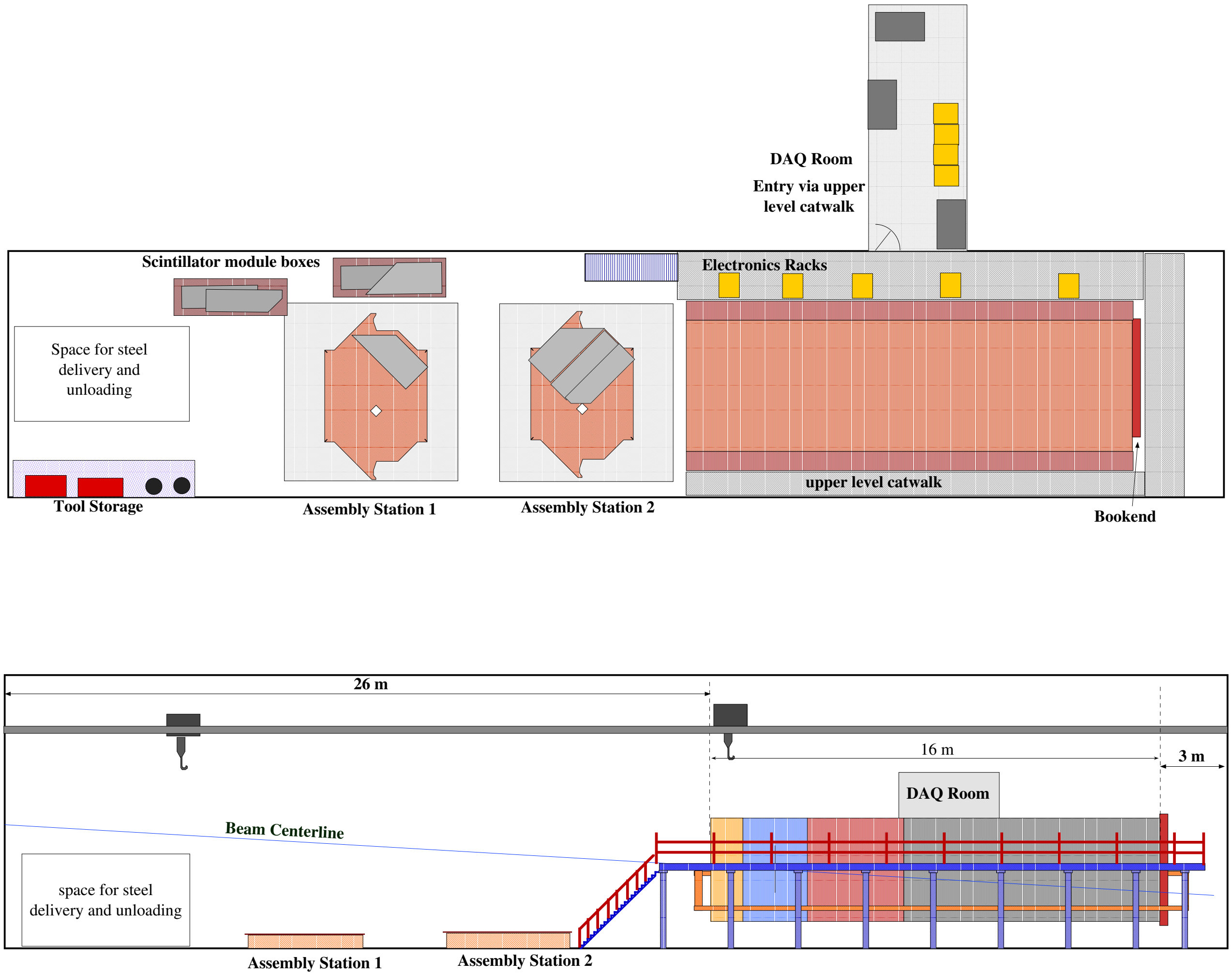

Figure 8.1: Sketches of the layout of MINOS near detector hall, showing the location of the assembly workstations and the size of the completed detector. The upper drawing is a plan view and the lower drawing is a side-elevation view of the facility.

System	Parameters
Near hall dimensions	45 m $\times$ 9 m $\times$ 10 m (height)
Detector dimensions	16.6 m long $\times$ 3.8 m high $\times$ 4.8 m wide
Detector mass	955 tons steel + 25 tons scintillator = 980 tons
Steel planes	280 "squashed octagons," 3.4 tons each (5.94 cm pitch)
Steel planes/section	Veto = 20, Target = 40, Shower = 60, Spectrometer = 161
Multiplexing	Forward section - none; muon spectrometer - 4 $\times$
Readout channels	8448 in forward section, 960 in muon spectrometer
Magnetic field	1.5 T at the neutrino beam location
Magnet coil	48-turn water-cooled aluminum, 40 kA turns, 80 kW
Installation time	8 months
Neutrino interactions	10 events/spill/0.5 m of steel
Muons from beam	20/spill entering detector, 130/spill exiting

Table 8.1: Summary of the major parameters of the MINOS near detector facility.

8.1.2 Design of the near detector

The main purpose of the near detector is to provide information about the characteristics of (unoscillated) neutrinos in the NuMI beam. That information is used to predict the numbers and characteristics of neutrino events which would be observed in the far detector in the absence of oscillations. Ideally both the beam and the detectors at the near and far locations should be identical, but in practice we must correct for small differences in beam and detector characteristics using detailed simulations. Predictions of the neutrino beam rate, composition and energy spectrum at the far detector are based on neutrino interactions recorded by the near detector within the central part of neutrino beam ($r <$ 25 cm). This restriction minimizes near-far beam spectrum differences while maintaining an adequate interaction rate. The near detector will also record neutrino interactions at larger radii in order to verify the accuracy of the neutrino beam simulation which is used to predict beam characteristics at the MINOS far detector in the absence of oscillations. The detector size and density of instrumentation has been chosen to contain and measure neutrino interactions with the same energy and spatial resolutions as the far detector.

The near detector is an adaptation of the MINOS far detector design, and is rather similar to a far detector supermodule. Both are constructed of steel planes and use similar scintillator modules and electronics. The support structures and installation procedures are similar for the two detectors. Each will have a magnet coil inserted through its planes after the installation of planes is complete. The detectors differ primarily in size and shape, and in the fractions of the steel plane areas instrumented with scintillator.

The near detector is smaller, both in cross section and in length. The far detector consists of 2.7 kt "supermodules"; the near detector is one module weighing 0.98 kt. The near detector contains 280 1-inch thick steel planes on hanging rail support structure; the 3.4 cm gaps between planes (5.94 cm pitch) give a total length of 16.6 m.

The near detector is longitudinally divided into four logical sections, each with a different number of planes. The first 20 planes are the Veto section, used to reject background events whose tracks could interfere with events of interest. The next 40 planes are the Target section; all interactions used to make comparisons between the near and far locations must occur within these planes. The next 60 planes are the Hadron Shower section, used to contain the showers from interactions occurring anywhere within the Target section. These three sections together comprise the Forward section of the detector and every plane is instrumented with scintillator. The last 160 planes are the Spectrometer section, where the momenta of muons from neutrino interactions are measured. One in every four Spectrometer planes is instrumented with scintillator. This design has been discussed in Section 3.5 and is illustrated there in Figure 3.5.

The near detector planes have an irregular "squashed" octagon shape, shown in Figures 8.2 and 4.5, roughly 3.8 m high and 4.8 m wide, with an area of 16 m^2 (excluding the support "ears"). This squashed octagon requires much less steel than a regular octagon with the same scintillator coverage. The different magnetic field shape in the irregular octagon does not affect the quality of the detector measurements compared to those in the far detector.

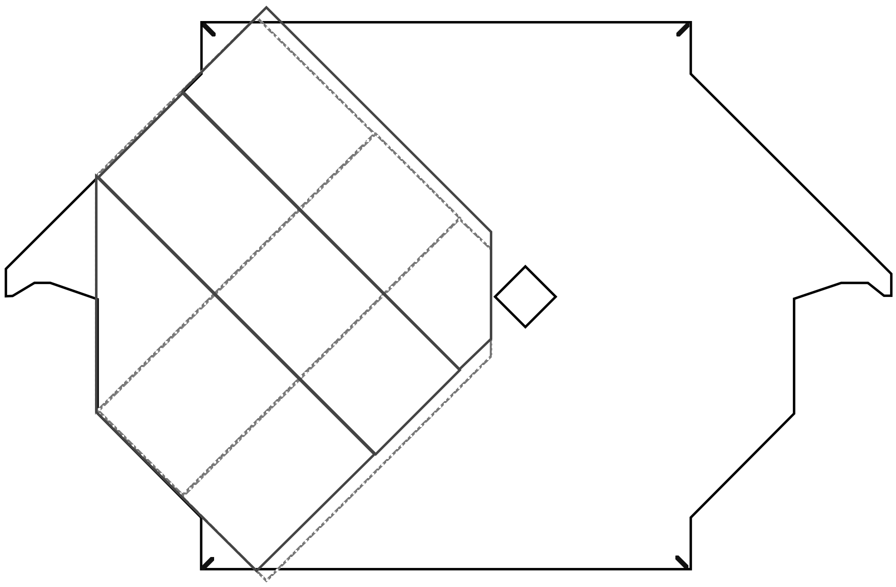

Figure 8.2: Sketch of the layout of scintillator detector modules on the partially instrumented planes of the three "forward" sections (veto, target, and hadron shower) of the near detector. Two 20-strip wide modules are located nearest the coil hole and a single 28-strip wide module is located along the 45° edge of the steel plane. The scintillator strips are read out from their outside ends only, and strip orientations alternate $\pm 90°$ on successive plates. The two orientations are shown by solid and shaded module outlines.

Because the neutrino beam interactions occur within a small region, the upstream detector planes need to be instrumented only in this area. Only part of the area ($\sim$6 m^2) of most Forward section planes is instrumented, as shown in Figure 8.2. The detector is positioned so that the beam is centered on the Forward section instrumented area, which avoids the magnet coil hole. Every fifth plane in the Forward section is covered with a larger area of scintillator in order to have better tracking ability for muons which exit the partially covered Forward planes some distance upstream of the Spectrometer section. The instrumented Spectrometer section planes are similarly covered by 13.2 m^2 of scintillator. Figure 8.3 shows the layout of scintillator modules on a fully instrumented plane. In both sections, every other instrumented plane has its scintillator strips oriented perpendicular to its neighbors. Table 8.2 summarizes the near detector instrumentation.

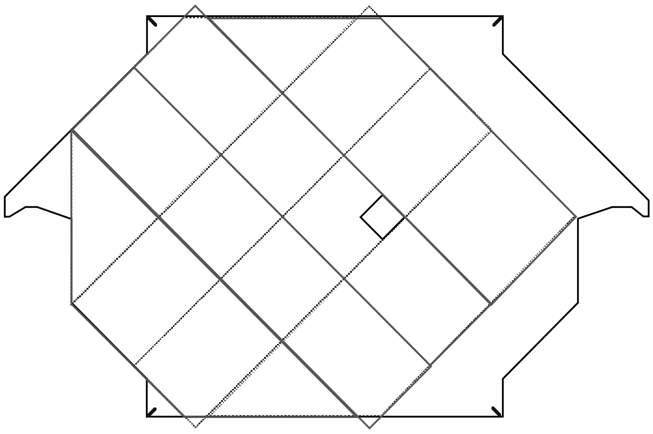

Figure 8.3: Sketch of the layout of scintillator detector modules on the fully instrumented planes (e.g., in the spectrometer section) of the near detector. Two 20-strip wide modules are located nearest the coil hole and 28-strip wide modules are located along the 45° edges of the steel plane. The scintillator strips are read out from their beam-side ends only, and strip orientations alternate $\pm 90°$ on successive plates. The two orientations are shown by solid and shaded module outlines.

8.1.3 Near detector infrastructure

Installation of the near detector begins when the civil construction contractor has completed work and grants beneficial occupancy of the underground laboratory. At that time all environmental and water control systems, fire protection and life safety systems, and basic plumbing and electrical service are operational. These systems are specified in the NuMI Technical Design Report[1]. Operation and maintenance of these systems, including the FIRUS alarm system, is performed by the Fermilab Facilities Engineering Services Section (FESS).

The NuMI downstream access shaft contains a freight elevator and a hoist shaft serviced by a 20-ton crane. The surface building over this area is of sufficient size to contain a loading bay and storage space for staging one week's worth of steel and detector components at the shaft head. The 3.6 m wide access hallway in the tunnel between the drop shaft and the detector hall is of sufficient size to accommodate the movement of detector components and personnel.

System	Parameters
Forward section	
Number of planes	120 steel planes, 120 scintillator planes
Detector units	96 planes $\times$ 64 strips in 3 short modules/plane
	24 planes $\times$ 96 strips in 4 full-length modules
Readout	120 planes: 1-ended, not multiplexed
Channel count	$6144 + 2304 = 8448$
Photodetectors	528 16-channel PMTs
Spectrometer section	
Number of planes	161 steel planes, 40 scintillator planes
Detector units	40 planes $\times$ 96 strips in 4 full-length modules
Readout	40 planes: 1-ended, 4 $\times$ multiplexed
Channel count	$40 \times 96 \div 4 = 960$
Photodetectors	60 16-channel PMTs

Table 8.2: Summary of the major parameters of the near detector. A 4 $\times$ multiplexing level means that fibers from 4 different scintillator strips are viewed by a single PMT pixel. The four strips in each partially instrumented plane (of short modules) which do not overlap the strips of adjacent planes (with orthogonal strip orientation) are not read out. This gives a convenient 64 active strips (4 PMTs) per plane.

The hall is outfitted with two bridge cranes on a single set of rails, covering the two assembly stations and the area occupied by the completed detector. One crane has a 15-ton capacity and the other a minimum 6-ton capacity. A room for the data acquisition hardware is carved into the west wall at a location near the center of the detector.

Other facilities required on the Fermilab site include an area for the initial delivery, inspection, and short-term storage of the steel delivered from the supplier. The scintillator modules delivered from the factories are also inspected and stored in this location until they are moved to the downstream surface building prior to installation.

8.1.4 Near detector installation

The near detector installation task includes the procedures used to move steel and scintillator detector components into the underground hall, to assemble the planes of steel and scintillator at two workstations, and to install these planes on the hanging file detector support structure. This procedure is described in detail in Section 8.4. The near detector construction cost estimate and schedule[2] are based on the detailed cost estimates and schedules developed for the MINOS far detector, described in Chapter 7. The cost of effort for the labor-intensive installation process is the largest component of the near detector installation task[3]. Safety considerations have been included as integral design requirements for all near detector installation tasks. Safety issues for all NuMI-MINOS facilities at Fermilab are described in the NuMI Project Preliminary Safety Assessment Document[4].

Figure 8.1 shows plan and side-elevation views of the near hall, with the locations of the workstations, the completed detector, the DAQ room, and an area to unpack the boxes of scintillator modules. Before the assembly and installation of the steel planes begins, the detector support structure is constructed. Next the strongbacks are assembled; these are the steel frames used to carry the completed planes to the detector support rails. An area on the floor around each strongback defines an assembly workstation. Detector assembly starts with the most downstream section (Spectrometer) and proceeds upstream. The mounting of electronics crates and installation of readout cables proceeds in parallel with the installation of the planes. Once all the planes are installed, the strongbacks are removed and the magnet coil is installed.

8.1.5 Testing of scintillator modules

Detector components which are delivered to the near hall have already passed quality control inspections and performance tests before being shipped from commercial vendors (e.g., steel plates) or from the MINOS fabrication facilities (e.g., scintillator modules and electronics). Nevertheless, some damage may occur to the scintillator modules due to mechanical shock or temperature extremes experienced while being transported from the fabrication facility to the near hall. It is important to repeat some of the performance tests after arrival and before mounting the detectors on steel planes. Malfunctioning modules will delay the installation schedule if they have to be replaced after they are mounted on the steel planes. The performance tests are conducted after the scintillator modules are moved underground. Modules are tested before they are placed onto a steel plane, and again before the plane, with modules attached, is mounted onto the detector support structure.

8.1.6 Detector operational requirements

Electronics is installed on completed sections of the detector as soon as possible so that the performance of the scintillator, photodetectors and electronics can be evaluated and monitored continuously. There is a buffer zone of approximately 10 planes between the activated sections and the upstream end where installation of planes is still occurring. Electrical noise from the crane and heavy equipment is not expected to be a problem for the electronics. In part this is because the electrical systems for utilities and for electronics are isolated from each other; in addition the electronics components are packaged within shielded boxes, and long cable runs consist of optical fiber rather than copper signal cable. Dust and dirt from the ongoing installation process is isolated by simple protective covers for the electronics and multiplexing boxes.

8.2 Technical requirements

The goal of the near detector installation task is to assemble and install the MINOS near detector and data acquisition system, to verify that its performance meets physics requirements, and to provide the infrastructure needed to install, maintain and operate the detector and associated systems to record neutrino interactions and cosmic ray muons. The following sub-tasks are included in the near detector installation WBS element:

- **Infrastructure tasks:**

  1. **Design liaison.** Participate in the design specification and review processes for items in other WBS elements which affect the near detector infrastructure tasks. These include the footprint and layout of the hall, the power and environmental requirements, and the detector support structure. The liaison task involved with the layout of the hall also establishes the necessary training for personnel to access the underground areas and identifies hazards in accordance with FESH rules.
  2. **Detector support.** Install the detector support structure.
  3. **Electronics power installation.** Install outlets at all locations along the length of the detector where electronics will be located. The circuits for these outlets originate from the isolated power panels installed by the NuMI Civil Construction task.
  4. **DAQ room.** Install the racks, work benches, terminals and associated hardware for testing and operation of the detector DAQ. This includes the central data system, trigger farm, and networks. Install the outlets to supply all these systems; these circuits also originate from the isolated power panels.
  5. **Magnet power.** Install the power supply and connect cables for the detector magnet coil.

- **Materials handling and installation tasks:**

  6. **Design liaison.** Participate in the design specification and review processes for items in other WBS elements which affect the near detector materials handing and installation tasks. These include the access shaft lifting equipment, the underground transport carts, the near hall cranes, the magnet coil and cooling design, the scintillator mounting, and the electronics mounting and cabling.
  7. **Assembly workstations.** Install the strongbacks at the two assembly workstations. Establish an appropriate inventory of tools and supplies for general use during detector installation. Schedule and operate the detector plane assembly workstations and associated equipment. Coordinate tasks involving the supply of components to the workstations and scheduling of workers.
  8. **Transport systems.** Establish procedures for receiving detector components (steel, scintillator modules, electronics, photodetectors and fiber optics connections) at the staging area within the downstream surface building, and for moving them underground as needed. This includes handling materials around the access shaft and the use of the underground vehicles and carts to deliver materials to the hall.
  9. **Work and storage areas.** Set up the staging areas in the downstream access building for steel and scintillator. Set up a scintillator crate unpacking area in the near hall, and work bench space for the scintillator detector testing equipment.
  10. **Plane assembly.** Schedule and perform the tasks to attach scintillator modules to steel planes. Coordinate tasks involving the supply of components to the workstations and scheduling of workers.

11. **Plane mounting.** Schedule procedures for installation of steel and scintillator planes on the body of the detector. This includes the installation of fiber optics connections to the scintillator modules. Perform tests on the completed planes to ensure that detector performance meets established criteria.
12. **Electronics installation.** Schedule and coordinate the installation and checkout of photodetectors, front-end electronics, and other electronics hardware and power supplies.
13. **Magnet installation.** Install and check out the magnet coil.
14. **Alignment and survey tasks.** Install the survey monuments required to position the detector support structure, and install the equipment used to survey the detector planes as they are assembled and mounted. Design procedures for measuring and recording the locations of all components within the assembled detector. Operate the software required to manage this information.
15. **Transition to physics operation.** Establish operating procedures and performance criteria for installed sections of the detector and begin routine data acquisition of cosmic ray and neutrino events. Begin operation of the data recording and distribution system, and of the software systems for identifying and characterizing events of interest.

8.3 Interfaces to other MINOS systems

8.3.1 NuMI near detector hall

The NuMI Facility TDR[1] describes the excavation and outfitting of the near hall and gives the specifications for the access shaft, tunnel and near hall.

8.3.2 Near detector steel structures

The magnet steel and coils task (Chapter 4) includes the design and fabrication of the following structures and fixtures:

- **Detector support structure.** This steel-beam structure supports the rails on which the near detector planes rest and also supports elevated catwalks for access along both sides of the detector planes. The structure includes the "bookend" support to which the first steel detector plane is attached. Platforms used to hold electronics crates at the four 45° sides of the octagonal detector are also attached to the support structure. Electronics platforms are installed only after the planes which they serve are in place.

- **Steel plane design.** The steel plane design includes the details of the locations of axial bolts, the size of the support "ears" which rest on the hanging file rails of the support structure, and the placement of the central hole for the magnet coil.

- **Strongbacks.** A strongback is used as a rigid support upon which each steel plate is laid before the placement of scintillator modules. After the scintillator modules are attached to a steel plane, the strongback and detector plane assembly is raised into the vertical orientation by the 15-ton bridge crane and set on the detector support rails where it is supported by the steel plane "ears."

- **Steel plate delivery cart.** This 6-ton capacity, 6 m long cart is used to move a single steel plate from the access shaft into the hall.
- **Scintillator module carts.** These 1-ton capacity, 6 m long carts are used to move crates of scintillator modules from the access shaft to the hall.

8.3.3 Magnet coil

The near detector is toroidally magnetized by a conventional water-cooled coil[5]. The coil is fabricated on site and moved into the near hall and installed in the detector after the detector plane installation is complete. Each coil has 48 turns and consists of approx. 18-m long central and return sections. The coil conductors are 1.5 inch by 1.1 inch aluminum (chosen to reduce the weight of the assembly), with a central cooling channel for low-conductivity water. The 40,000 Amp-turn coil has been designed to provide a toroidal magnetic field for muon momentum measurement similar to that in the far detector with minimum temperature rise at the center of the near detector (which could affect detector performance). The coil requires about 80 kVA of electrical power and operates at a temperature of 25° C. The coil cooling-water chiller uses heat exchangers to transfer the heat generated by the coils to the surface.

8.3.4 Scintillator planes

As described in Chapter 5, the MINOS active detector elements for the near detector consist of 4.1-cm wide strips of plastic scintillator which are packaged into modules of 20 or 28 strips each. The fully instrumented planes of the MINOS near detector hold four modules and the partly instrumented planes hold three modules, as shown in Figure 8.2 and Table 8.2. The modules come in several shapes which are designed for particular regions of the steel planes; each type has a unique geometry to fit around the support structures (ears, coil collars). The end pieces on the scintillator modules extend beyond the steel planes edges and contain the fiber optics connections, the WLS fiber light-injection hardware, and the radioactive source tube access points. These end pieces are constrained to fit within the following maximum distances from the edges of the steel planes so as to fit within the detector support structure: 20 cm on the sides, 40 cm on the top, and 25 cm on the bottom. The bottom allowance corresponds to a distance from the bottom edge of the steel plane to the floor of 90 cm, and allows sufficient access space for work on the bottom ends of detector elements.

Scintillator modules are packaged in shipping crates at the fabrication facilities for transportation to Fermilab. Each crate holds modules which are placed on a single steel plate; more than one such crate may be needed for each detector plane. The crates are inspected and stored at a receiving facility until the time nears for their installation. The underground crate unpacking area holds two to three crates. Empty crates are returned to the surface as soon as modules have been tested and installed. Scintillator modules which fail performance tests are returned to the fabrication facilities for repair. Scintillator module test equipment and protocols are provided by the scintillator fabrication task.

The near detector installation task also includes the installation of fiber optics connections between scintillator modules and multiplexing boxes, the multiplexing boxes themselves, the photodetectors and front-end electronics. This is described in the following Section.

8.3.5 Electronics and data acquisition

Electronics and data acquisition hardware is installed on each plane after it is mounted vertically on the detector. Front-end electronics is located in crates along the two 45° faces on the left side of detector (the side away from the coil hole). The crates along the upper face are supported on special cantilevered platforms attached to the side support structures, and can be accessed from the walkways. The crates along the lower face are located on similar platforms supported from the floor. The arrangement is shown schematically in Figure 8.4.

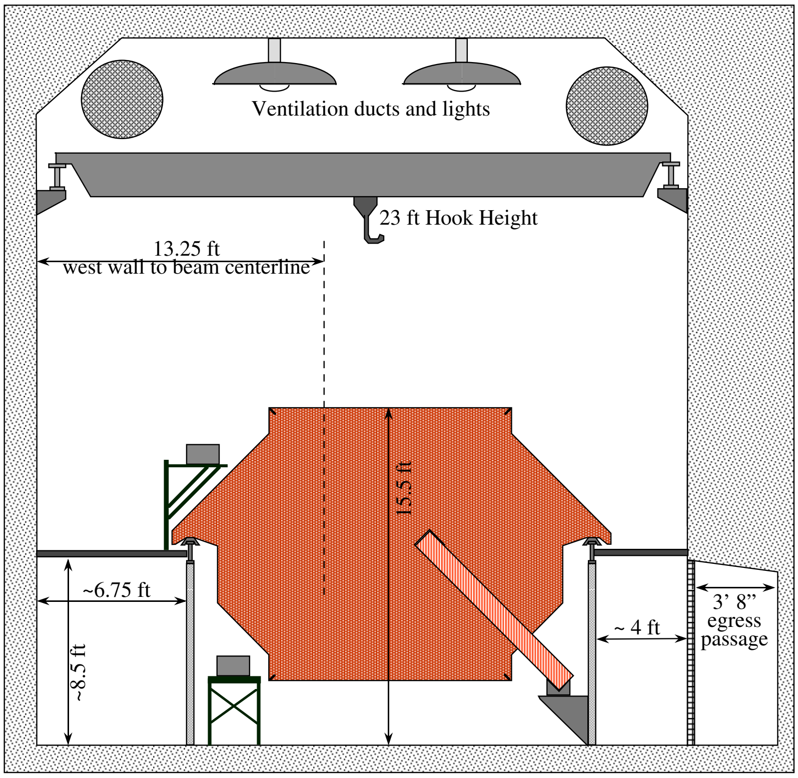

Figure 8.4: Elevation view sketch of the MINOS near detector hall at the location of the detector, showing the multiplexing boxes and front-end electronics crates. The crates are represented by the small shaded boxes near the upper and lower 45° octagon faces on the beam side of the detector (left side of the figure).

The installation task includes the complete installation and commissioning of all electronics components, including the photodetectors, multiplexing boxes, and fiber optics harnesses which connect them to the scintillator modules. As soon as a set of planes has been successfully read out through the electronics and data acquisition system, it becomes part of the operating detector, and records calibration data from cosmic ray events while the remainder of the detector is being assembled.

8.4 Description of WBS elements

This Section describes the near detector installation activities included in each WBS-2.5 Level 3 task. Tasks under Level 4 EDIA consist mainly of items which are contained in other Level 2 WBS elements, but are entered under WBS 2.5 as a special class of liaison tasks. Input from the near installation project managers is a necessary part of the overall design and review process; the liaison tasks cover this effort. Installation oversight EDIA is included under various tasks at WBS Level 6.

8.4.1 Infrastructure (WBS 2.5.1)

This Section describes the near detector installation tasks associated with the facility and supporting components required by the detector.

8.4.1.1 Near hall footprint and layout

This is a liaison task to those items in WBS 1.2 (NuMI civil construction) which cover the physical layout of the near hall and the tunnel, the access shaft, and the downstream surface building. The liaison ensures that all the criteria and designs meet the needs of the near detector installation and operation. This includes defining the size and location of the DAQ room, and defining a "stay clear" zone for the beam which no walls or structures can intersect. WBS 1.2 covers the implementation of fire protection and life safety recommendations; the liaison task ensures that the detector installation does not interfere with any of these systems and coordinates the installation of rack fire protection and the inputs into the FIRUS alarm system from detector subsystems.

8.4.1.2 Power and cooling requirements

This is a liaison task to those items in WBS 1.2 which cover the underground environment (temperature, humidity, ventilation) and the types of AC power to be supplied to the near hall. Power circuit design includes requirements imposed by the detector electronics, such as quiet AC power and an isolated ground network.

8.4.1.3 Detector support design

This is a liaison task to WBS 2.1.3, the near detector support structure. The liaison ensures that the support structure meets the requirements for the elevation and transverse location of the detector with respect to the beam centerline. This task also ensures that sufficient space exists on and below the support structure catwalks for the detector electronics equipment.

8.4.1.4 Work and storage areas setup

The steel plates delivered from the fabricator are unloaded and checked at some appropriate location on-site. The downstream service building contains a steel staging area which holds 6 to 10 plates. The staging area is kept supplied during detector assembly. Plates are moved underground one at a time, as needed. There are no steel storage areas underground.

Crates of scintillator modules are also received at the staging area. The crates are likewise moved underground only as needed and empty crates are returned to the surface.

An assembly work area surrounds each strongback. Work benches and shelves to hold the tools and materials needed for the plane assembly procedures are set up in this location. Once modules are attached to planes, but before the planes are mounted on the detector, the scintillator is tested (see below). A work bench area is also set up for test equipment.

8.4.1.5 Detector support

This task covers the installation of the near detector support structure. The structure is prefabricated in pieces which can easily be transported down the access shaft and tunnel. A survey is first done to establish the locations of the support columns. After the columns are installed, the hanging file rails are placed and checked for flatness. The "bookend" is then installed at the downstream end. Finally, the upper catwalk, stairs, and guard rails are installed. After the detector planes are installed, brackets to hold the return coil are attached to the detector support columns in preparation for the coil installation.

8.4.1.6 DAQ room

A room for the DAQ equipment is carved into the rock on the west side of the hall, midway along the length of the detector, and is entered from the upper level catwalks. This task is concerned with setting up the supporting equipment required by the DAQ. HVAC, power, racks and tables are installed as required by the DAQ equipment. A controls end-rack placed here provides access to the ACNET, the Fermilab closed circuit TV system, and the hardware for distributing the accelerator clock signals. Connections to the site networks are also included, as are the lines needed to transmit GPS clock data to the DAQ system, as described in Section 7.4.1.5.

8.4.1.7 Magnet power supply

The power supply for the magnet coil is located at the upstream end of the near hall. The supply requires connections to the AC power and cooling water, similar to magnet power supplies used elsewhere on the Fermilab site. Power and water lines are supplied to this area as part of WBS 1.2 and as specified by the liaison task WBS 2.5.1.1.2. Bus lines from the supply to the coil are connected after the coil is installed.

8.4.1.8 Assembly crew training

The near detector installation uses two types of work crews, one to move materials into the hall and place completed planes onto the detector, and one to assemble planes. Before starting the assembly process, the crews will spend approximately one week in training. This includes all safety training recommended by FESH.

8.4.2 Materials handling (WBS 2.5.2)

This Section describes the near detector installation tasks associated with supplying materials to the detector hall. Reference [3] describes the work flow for this task in detail, as well as its coordination with the effort requirements of the detector assembly task (WBS 2.5.3).

8.4.2.1 Shaft lifting equipment

This is a liaison task to those items in WBS 1.2 which concern the hoist in the downstream access shaft and the areas around the upper and lower ends of the shaft. The crane is rated for the weight of the items to be moved in, and the shaft dimensions are based on their size. The shaft must accommodate the near detector steel plates, the magnet coils, and smaller items. The areas at each end of the shaft must accommodate the rigging of these items into the shaft at the top and into the tunnel at the base.

8.4.2.2 Underground transport carts

This is a liaison task to the design of the underground transport carts. The carts are of two types, one to deliver single steel plates, and the other to deliver boxes of scintillator modules. Each has its own weight ratings and is sized to pass through the tunnel between the base of the access shaft and the hall. The steel carts are designed for efficient handling of the plates, which are held vertically on the carts.

8.4.2.3 Assembly fixtures

This is a liaison task to the design of the fixtures used to attach scintillator modules to the steel plates.

8.4.2.4 Install assembly fixtures

The installation fixtures consist of the strongbacks and a surrounding assembly area. The strongbacks are prefabricated on site in sections which are easily transported down the access shaft and tunnel, and assembled in the hall. A strongback is a simple welded and bolted steel frame structure the size and shape of a near detector steel plane. It is used as a work surface for mounting scintillator modules on a steel plane. The strongback supports the plane and keeps it flat while it is installed onto the detector support structure.

8.4.2.5 Transport systems

The transport systems consist of the carts and the vehicles to push or pull them. They are fabricated on the surface as part of WBS 2.1 and delivered soon after beneficial occupancy of the hall. Items such as steel plates or crates of scintillator are lowered down the access shaft and placed directly onto the appropriate carts. A single plate is placed directly on a cart, oriented vertically, and bolted to the cart's supporting structures before the hoist is disengaged. The cart is then moved into the hall. Either of the hall cranes can be used to pick up the steel plate from the cart and place it directly onto a strongback. Crates of scintillator are lowered in an orientation which keeps the modules flat, and are placed directly onto a cart, and then delivered to the hall. The modules are removed directly from the crate and mounted onto a plane. Empty crates are returned to the base of the access shaft and the downstream surface building.

The transport system will be tested and used to train the work crews soon after beneficial occupancy of the hall.

8.4.2.6 Materials delivery

The downstream surface building holds a staging area for both steel plates and crates of scintillator modules. There are two assembly workstations in the hall. During part of the time while a plane is being assembled on one workstation, the other workstation's strongback is free for assembling the next plane. When a strongback is free, a single steel plate is lowered on the shaft hoist, delivered to the hall, and immediately unloaded from the cart and placed onto the free strongback. The crew doing this task then delivers the crates of scintillator modules to be assembled on the steel plate. At about the time all the materials for assembling a new plane are delivered, the assembly of the plane on the other workstation is finished. The crew which delivered materials then goes to work on the task of mounting the finished plane onto the detector.

For either steel or scintillator modules, one cycle of delivery is estimated to take a total of 2 hours: 15 minutes for hoist attachment and handling at the top of the shaft, 30 minutes for hoist drop time, 15 minutes for hoist detachment and handling at the base of the shaft, 45 minutes for transit time to the hall and parking the load, 15 minutes for forklift truck return time to the base of the shaft. The hoist is raised back to the top of the shaft while the load is being driven to the hall. Two 5-man delivery crews work one of two shifts each day, five days per week.

Forward section planes each require two delivery cycles, one for the steel plate and the other for the scintillator. Three out of every four Spectrometer planes are steel only, so fewer overall delivery cycles are required for the Spectrometer section than for the Forward section.

8.4.3 Detector assembly (WBS 2.5.3)

This Section describes the near detector installation tasks associated with assembling the detector planes and mounting them on the detector. Reference [3] describes the work flow for this task in detail, as well as its coordination with the effort requirements of the materials handling task (WBS 2.5.2).

8.4.3.1 Magnet coil

This is a liaison tasks to the design of the near detector magnet coil.

8.4.3.2 Scintillator mounting

This is a liaison task to the design of the scintillator module mounting system. The goal of the design is to make a mounting system which is robust but which is also simple to install and requires a minimum of parts. The liaison ensures that the procedures for mounting the modules are transferred to the crews who perform that task.

8.4.3.3 Near hall cranes

This is a liaison task to those items in WBS 1.2 which concern the bridge cranes in the near hall, ensuring that they meet the specifications of the plane assembly procedures.

8.4.3.4 Detector electronics mount and cable

This is a liaison task to the design of the mechanical aspects of the electronics design. The liaison ensures that the framework attached to the detector support structure can accommodate the electronics hardware. The design task also lays out the locations of racks and cable runs, and the liaison ensures that spaces in the near hall are reserved for these items.

8.4.3.5 Mechanical assembly procedures

This is a liaison task to assist in the safety review of the procedures used to install the detector.

8.4.3.6 Detector assembly

The plane assembly in the near detector is modeled on the procedure used for the far detector. As described in Section 4.1.2, the near detector planes are single plates of 1-inch thick steel cut by the manufacturer to the designed shape. The near detector workstations, defined by the area where a strongback is laid on the floor of the hall, are used as work spaces for mounting scintillator modules to steel planes. The strongback provides a flat surface and reference points for assembly, and then also serves as a lifting fixture when a plane is installed on the detector.

There is space in the near detector hall for two assembly workstations. A four-man crew is needed to assemble a plane. The assembly process begins when all the materials are in the hall: a steel plate is placed on the strongback and scintillator modules are delivered to the hall. The detector plane assembly procedure involves the attachment of an array of scintillator modules to the face of a steel plane. The far detector plane assembly has been discussed extensively in Section 7.4.3.2. The procedures used for the near detector are very similar. These techniques involve steel packing straps fastened to tack-welded switchplates, shelf bars, and edge bracket connections on one end.

The scintillator modules for the near detector are of the same widths as those used for the far detector planes (see Figure 8.2). However, the modules are shorter than those used for the far detector, and most of them do not extend across the entire width of the steel, even those termed "full length." Also, some of the shorter modules terminate near the central coil hole. Supporting the ends of these and other near detector modules requires special fixturing and procedures.

Two types of near detector planes must be assembled, those with short modules and those with full length modules; the numbers of each are summarized in Table 8.2. For 96 of the Forward section planes, short modules cover approximately one third of the steel area. There are 96 planes of full length modules in the Spectrometer section, plus 24 more interspersed in the Forward section.

After the scintillator modules are mounted, they are given a final performance test using the WLS fiber light injection system and the portable photodetector system. Calibration tests and performance criteria are described in more detail in Chapter 5 and in Section 8.4.5 below. Any detector modules which fail performance tests are replaced before the plane is mounted. The locations of detector elements are recorded using a close-range photogrammetry camera system (see Section 7.4.4).

Once a plane is assembled and tested, it is mounted onto the detector. The plane mounting operation is very similar to the far detector mounting operation (see Section 7.4.3.3). The strongback serves as a lifting fixture, and maintains rigidity and alignment of the steel and scintillator plane assembly during the lifting and mounting operation. The plane-strongback assembly is lifted to a vertical orientation and moved to the detector by the 15-ton bridge crane. While the plane is vertical, its weight is supported by the strongback support shelves along the bottom edge of the steel plane. The support shelves are configured to latch into the steel plane so that it cannot slip off the strongback during mounting. The plane is transported, mounted and secured to the support structure as described in detail in Section 7.4.3.3. Assembly of the near detector proceeds from downstream to upstream because access to the near hall is from the upstream end.

The same crew which delivers materials to the hall also mounts completed planes onto the detector. The two tasks overlap the time required by the assembly crew to install modules on a plane.

8.4.3.7 Electronics installation

After each plane has been mounted on the body of the detector, the clear fiber optics harnesses are installed on the plane and used to check for proper operation. A special portable photodetector system, which can be temporarily attached to the fiber optics harnesses from the detector access walkways, is used for this purpose. After all of the planes served by a single multiplexing box are in place, the electronics mounting platforms are installed and the final fiber optics connections made between the planes and the multiplexing boxes. Installed detector planes and associated front end electronics are turned on and tested with calibration systems (light injection and radioactive source tubes) and cosmic rays at the earliest possible time. Cosmic ray calibration data are recorded continuously from all installed detector planes as soon as soon as they have passed all calibration performance tests.

8.4.3.8 Magnet coil installation

The near detector magnet coil is quite different from the far detector coil. As described above, the near detector coil is fabricated from 48 aluminum conductor elements in two

L-shaped sections[5], arranged in an 8 by 6 array. Each conductor contains a central cooling water channel, as described in Chapter 4.

The completed magnet coil sections are installed after the 280 planes of the near detector have been mounted. The near return coil is routed along the lower 45° face of the detector. Before the installation can proceed, brackets are mounted on the steel support structure to support the return coil.

The coil is mounted as described in Section 4.4.4.4. After the coil is delivered (in two long pieces, or "L's"), the first coil half is inserted into the central hole using special lifting fixtures. Rollers on the lifting fixture enable the coil half to slide smoothly into the bore hole of the near detector, where it rests on the central collar tube. The lower, return coil is inserted underneath the detector. When it is fully inserted, it is lifted, rotated 45°, and supported from the previously installed brackets. After the installation procedure is complete, the coil sections are self-supporting.

Installing the magnet coil requires splicing the sections of the coil to each other, and making connections to the power supply and to the cooling water system. The conductors are welded after insertion of a stainless steel plug at the join. Conductors must be bent to meet, and properly positioned. Each pair of joins forms a complete turn, which will be checked for electrical and water integrity. The splicing, insulating, leak checking and electrical checkout of the completed circuit are the dominant time components of the assembly procedure.

The average magnetic properties of each plane are measured by its flux integration coil, as described in Section 7.4.3.6, soon after the magnet coil is installed. Each plane is measured as part of the initial magnet certification procedure.

8.4.4 Alignment and survey (WBS 2.5.4)

The near detector is surveyed using many of the same techniques developed for the far detector. The positions of the plane assemblies along the detector axis, and the relative positions of scintillator modules within each plane assembly, are connected to the absolute locations of the near hall survey monuments.

The principal tool used to obtain relative positions of plates and scintillator within the detector is photogrammetry. The system is identical to that used for the far detector, as described in Section 7.4.4.

The higher rate of cosmic ray muons at the near detector location makes it possible to determine quickly any small corrections to surveyed strip locations, and to detect errors in the survey numbers. Once beam is available, neutrino interaction muons will also provide alignment information.

8.4.5 Final checkout and validation

The performance validation of the near detector is intentionally kept as similar to the far detector as possible. These tests are described in detail in Section 7.4.5 . The source, light injection, and charge injection tests described there are reproduced at the near detector. Magnetic field measurements are also the same for both detectors.

Quality control and basic measurement procedures (such as plane thickness) are implemented in the same way as at the far detector. The goal in all cases is to allow direct comparisons which do not rely on complicated simulations.

8.5 Future optimization and engineering

Because of the similarity of the near and far detectors, many of the integration and large-scale prototyping activities described in Section 7.5 are directly relevant to the near detector installation task. An example is the construction of the 4-plane prototypes in the New Muon Lab to study the assembly and plane-hanging procedures; a 4-plane prototype of the near detector assembly will follow the far detector prototype studies. Since the crews performing assembly at the near and far detectors will be different, there is a need to ensure adequate documentation of the information gained by the testing, and to design adequate training programs and supervisory structures for the assembly activities.

There are, in addition, aspects of the near detector construction which are necessarily different from the far detector, and require special attention to ensure optimal design:

- The mounting procedure for short detector modules. This procedure needs to be well characterized, since mechanical stresses and alignment procedures will be different. The near detector 4-plane prototype study will validate the design and also be used to train near detector assembly crews.
- The layout of electronics and MUX boxes. This differs due to the different readout scheme for the partially instrumented planes. This has implications for space layout and service access.
- Hoisting, unloading, and underground transport of detector and coil materials. This should continue to be studied to optimize the procedures and minimize startup time after occupancy of the hall.
- Any differences in the near and far support structures. These are expected to be small (Section 4.1.2).

Chapter 8 References

[1] The Fermilab NuMI Group, "NuMI Facility Technical Design Report," October 1998, Fermilab report NuMI-346.

[2] The Fermilab NuMI Project Staff, "NuMI Project Cost and Schedule Plan," October 1998, Fermilab report NuMI-362.

[3] R. Plunkett, "Work flow of near detector installation," September 1998, Fermilab report NuMI-L-400.

[4] The Fermilab NuMI Project Staff, "NuMI Project at Fermilab: Preliminary Safety Assessment Document," October 1998, Fermilab report NuMI-361.

[5] J. Kilmer, R.W. Fast, R. Currier, and R. Stanek, "Specifications for Aluminum Conductor," September 1998, Fermilab report NuMI-L-411.