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MEMORANDUM OF UNDERSTANDING

Between

the MINOS Experiment (E-875) and

Fermi National Accelerator Laboratory

July 2008

INTRODUCTION

Fermilab experiment E875, the Main Injector Neutrino Oscillation Search (MINOS), seeks to measure the parameters of neutrino oscillations. To do this, the MINOS experiment will study the interactions of the NuMI neutrino beam in two locations: the MINOS Near Detector Hall at Fermilab and the MINOS Far Detector Hall at the Soudan Underground Laboratory in Soudan, Minnesota, 735 km away. The NuMI beam is produced by extracting protons from the Main Injector and transporting them down the NuMI beamline, which is aimed precisely at Soudan. The protons are focused on to a production target and a set of magnetic horns focuses the secondary particles, mainly pions and kaons, into a decay pipe 677 m long. The meson decays in this region produce a neutrino beam comprised of mostly muon neutrinos. A hadron absorber and rock barrier upstream of the Near Detector Hall absorb the charged particles, leaving a beam composed only of neutrinos, which passes through both the Near and Far Detector Halls.

The two MINOS detectors are of similar design. The basic design is a series of steel planes aligned along the direction of the beam. Most of the planes bear a layer of scintillator strips. The steel provides a target for neutrino interactions and the scintillator counters provide a means of detecting the charged particles produced in the primary interactions and from showers in the detector bulk. Each detector comprises several hundred planes, which allows for muon identification, energy deposition measurements, and event reconstruction. The steel is toroidally magnetized by a high-current coil running longitudinally through each supermodule of the detectors. This enables the MINOS detectors to distinguish charged-current interactions of neutrinos from those of anti-neutrinos. The far detector has two supermodules; the near detector is a single unit.

The primary goal of the MINOS Experiment is to measure the parameters $\sin^2(\theta_{23})$ and Δm^2_{23}. These parameters define elements of the neutrino mixing matrix that relate the mass eigenstates m_2 and m_3. They can be determined by comparing the rates of muon-neutrino interactions in the two MINOS detectors. The phenomenon of neutrino oscillations is expected to reduce the observed rate at Soudan, due to transitions from the initially-produced neutrino flavor state (muon) to another (electron or tau). The total rate and the energy dependence of this "disappearance" will provide the most precise determination to date of ν_μ to ν_τ oscillations. MINOS data will also allow us to search for sub-dominant $\nu_\mu \rightarrow \nu_e$ oscillations.

This is a Memorandum of Understanding (MOU) between Fermi National Accelerator Laboratory and the MINOS Experiment. This memorandum is intended solely for the purpose of providing a framework in which the roles and responsibilities of various organizations of Fermilab and the participating institutions can be stated. It reflects arrangements that currently are satisfactory to the parties; however, it is recognized and anticipated that changing circumstances of Laboratory budgets and organizations, as well as the evolving research program, will necessitate revisions. The parties agree to negotiate amendments to this memorandum as needed to accommodate such adjustments.

1 PERSONNEL AND INSTITUTIONS

The MINOS collaboration includes approximately 200 researchers from 27 institutions in 5 countries, including Brazil, France, Greece, the United Kingdom and the United States. Institutions may be added or removed in accordance with the MINOS Collaboration Bylaws.[1] The scientific leadership of the MINOS collaboration consists of two co-spokespersons, as described in the bylaws. The co-spokespersons are elected periodically as specified by the collaboration bylaws. Although this MOU is signed by the co-spokespersons holding office at the time of its completion, future co-spokespersons are expected to abide by its stipulations unless otherwise negotiated with the Laboratory.

The co-spokespersons are supported by a deputy spokesperson, whose role is to assist them in the management and representation of the collaboration, by a MINOS financial officer, and by the MINOS Run Coordinator and the MINOS Analysis Coordinator. Additional advice to the Spokespersons is supplied by the MINOS Executive board which consists of representatives selected according to the collaboration bylaws.

The experimental activities of the MINOS experiment are implemented by Physics Analysis Groups (e.g. Charged Current, etc.) and Physics Infrastructure Groups (e.g Offline/Reconstruction, etc.) These groups are created when needed by the Spokespersons. The leadership of these groups is selected by the Spokespersons for approximately 2 year terms, depending on circumstances and availability of personnel.

The Spokespersons appoint the MINOS Analysis Coordinator and Deputy Analysis Coordinator, who are responsible for oversight of the MINOS Physics Analysis Groups, and for assuring maximum cooperation and minimal unnecessary overlaps between different Physics Analysis Groups. The Spokespersons and the Analysis Coordinator and Deputy Analysis Coordinator serve as the MINOS Physics Oversight Group (MIPOG), and meet regularly.

The MINOS Run Coordinator is appointed by the Spokespersons, and is responsible for daily coordination and direction of activities involving the MINOS detectors, as well as daily liaison with Accelerator Division personnel responsible for the NuMI beamline . The term of the Run Coordinator is determined by the pool of collaborators available to serve in this position. The Run Coordinator may appoint a deputy to assist him/her, and to serve as acting Run Coordinator when necessary.

The Spokespersons meet as needed with representatives of the Fermilab Divisions and Sections, usually including the head of the PPD/Neutrino Dept., the head of the Accelerator/External Beam Dept., and the designated Liaison of the Computing division.

The collaborating institutions on the MINOS experiment, are tabulated in Appendix IV.

2 EXPERIMENTAL AREA, BEAMS AND SCHEDULE CONSIDERATIONS

2.1 Locations

The MINOS Near Detector operates in the MINOS Near Detector Hall at the downstream end of the NuMI tunnel, approximately 300 feet underground. MINOS experimenters access the Near Detector Hall by means of the elevator in the MINOS service building. All MINOS experimenters who work in underground areas receive the appropriate training. In general, MINOS experimenters who go underground work in the Near Detector Hall and their activities will be in the areas downstream of the MINOS shaft. Except for occasions when it is necessary to access the muon alcoves, they go no farther up the tunnel than the "elephant" doors to the NuMI Absorber bypass tunnel. These doors separate the regions of the NuMI facility that are the responsibility of the Particle Physics Division (downstream) and the Accelerator Division (upstream).[2]

The MINOS experiment is operated from the MINOS Control Room in Wilson Hall. It is located in the northwest corner of the 12th floor. The MINOS Collaboration has experimenters on shift 24 hours a day while the beam is operating. When the beam is not operating, the shift schedule may be adjusted or suspended.

The MINOS Far Detector Hall is located in the Soudan Underground Laboratory at the Soudan Underground Mine State Park in Soudan, Minnesota. It is at a depth of 2341 feet below the surface (649 feet below sea level). The state park is operated by the Minnesota Department of Natural Resources (MDNR). The University of Minnesota operates the Soudan Underground Laboratory under an agreement with the MDNR. Fermilab's arrangement with the University of Minnesota is described in Section 3.1.

2.2 Beam Requirements

The MINOS experiment uses a wide-band neutrino beam. It is produced by extraction of protons from the Main Injector at 120 GeV/c into the NuMI beamline. The extraction is made with a set of fast kicker magnets. The protons are then directed into the NuMI Target Hall, 125 feet underground. The energy spectrum of the neutrino beam can be adjusted by moving the NuMI target. The NuMI horns can also be re-positioned to modify the neutrino beam energy, but movement of the target is the method that normally will be employed. The MINOS Collaboration anticipates running primarily with the target and focusing horns configured for a low-energy beam (neutrino spectrum peak ~ 2 – 4 GeV), although periods of medium-energy or high-energy beam may be scheduled.

2.2.1 Data Taking

In order to make precise measurements of neutrino oscillation parameters, the MINOS experiment requires high-statistics data sets of neutrino interactions in its detectors. Hence, the experimental goal for this phase is to maximize the integrated neutrino flux. The flux is provided by the horn-focused neutrino beam.

NuMI will co-exist with the Run II collider experiments, which require antiproton production from the Main Injector in the same acceleration cycle. In this cycle, six proton batches are accelerated to 120 GeV in the Main Injector. One batch is extracted to the Antiproton Source target and the remaining five batches are delivered to NuMI. The Main Injector may run dedicated NuMI cycles, with six batches delivered to the NuMI target, as the accelerator schedule allows.

Radiation protection may impose an additional constraint on the protons delivered to MINOS. The Main Injector shielding assessment indicates that the shielding is adequate to accelerate to 120 GeV an intensity of 9.6×10^{16} protons/hour, based on the overburden. This would correspond to a rate of 5×10^{13} protons/pulse with 1.87 s cycle time, although the limit presently designated for the MI is 4×10^{13} protons/pulse. Any future upgrades to the NuMI primary beam intensity may require that shielding issues be addressed. The intensity of protons delivered to the NuMI target will initially be 2.5×10^{13} protons/pulse. Further details of realized and expected delivered proton intensity are found in tables 2.1 and 2.2.

The Accelerator Division will be responsible for setting adequate measures to provide groundwater protection in the transport of 120 GeV protons from the Main Injector to the NuMI target.

2.2.2 Schedule and Run Plan

Construction of the MINOS Far Detector was completed in July, 2003. The Near Detector was completed in October, 2004. Both detectors have been collecting cosmic ray data since their completion. The MINOS experiment now has a substantial set of cosmic ray data in hand and the detectors are well-understood.

Commissioning of the NuMI beamline began in December, 2004 and the first beam neutrinos were observed in the MINOS Near Detector in January, 2005. The first beam-induced neutrinos were seen in the Far Detector in March, 2005. NuMI beam commissioning was completed by the end of March 2005, and physics data taking has been on-going since then.

The five-year run plan is shown in Tables 2.1 (status as of 1/1/07) and 2.2. The expectations in Table 2.2 are based on the model utilized to generate the Fermilab Proton Plan. Most of the MINOS runs will be taken with the NuMI horns and target in the low-energy configuration, however some data will be taken in the medium-energy and high-energy configurations for special studies. All table entries refer to protons on the NuMI target at 120 GeV.

Calendar Year	End-of-year Protons per Week $\times 10^{18}$	Annual Protons on Target $\times 10^{20}$	Integrated Protons $\times 10^{20}$
2005	**4.8**	**1.1**	**1.1**
2006	**5.5**	**1.2**	**2.3**

Table 2.1 Protons delivered to MINOS in 2005-2006

Calendar Year	End-of-year Protons per Week $\times 10^{18}$	Annual Protons on Target $\times 10^{20}$	Integrated Protons $\times 10^{20}$
2007	4.8-6.9	2.0 - 2.4	4.3-4.7
2008	5.0-7.3	2.0 - 2.9	6.3-7.6
2009	5.0-7.3	2.1 - 3.1	8.4-10.7

Table 2.2 Expected number of protons for MINOS, based on Fermilab Proton Plan. Note that the weekly totals shown in column one include effects of an anticipated up-time efficiency of 70-80%

3 RESPONSIBILITIES BY INSTITUTION – NON-FERMILAB

3.1 The Soudan Underground Laboratory

Operation of the Soudan Underground Laboratory is critical to the MINOS experiment. The University of Minnesota operates and maintains the Soudan Underground Laboratory under an agreement with the MDNR and supports the MINOS experiment as described in a separate MOU[3].

3.2 MINOS Collaborating Institutions

All of the collaborating institutions are responsible for contributing manpower for shifts and the general support of the experiment. This support includes financial contribution to a common fund for the maintenance and operation (M&O) of the experiment. Details of the common fund are described below.

In addition, some institutions have key hardware and online or offline software maintenance and support responsibilities, which are further described in Appendix IV.

3.2.1 MINOS Common Fund

The MINOS Collaboration has institutional members from four countries other than the US: Brazil, France, Greece, and the United Kingdom. The percentage contribution of each nation to the MINOS Common Fund is determined by the percentage of active authors from each country. These percentages are shown in Table 3.1. The active author

list is updated annually in June and these statistics are used for the common fund distribution of costs. The annual operating expenses for the MINOS Experiment (exclusive of accelerator operations) are almost $1 million. The actual amount for each year is predicted based on the prior year actual expenses, subsequently adjusted for inflation. The expected contribution from each country is transmitted to the institutional representatives by the MINOS financial officer, followed up by a letter from the MINOS spokesperson. Institutions whose national funding agencies are unable to contribute to the common fund may have this assessment waived by requesting a waiver from the spokesperson and the MINOS financial officer. To the extent possible, waived contributions will be covered by the Fermilab operating budget for the MINOS experiment.

At the first collaboration meeting following the start of each US fiscal year (October) the MINOS financial officer will report on operating expenditures for the previous year to the IB. The projection for the next year will be presented and subsequently approved by the IB. Contributions to the fund will be made during the coming fiscal year at a time appropriate for each country.

3.2.2 Shift Responsibilities

Member institutions of the MINOS collaboration are responsible for providing shift personnel in accordance with the rules established by the MINOS Institutional Board[4]. Shift responsibilities generally are fulfilled by shifts in the MINOS Control Room at Fermilab, but other duties, such as shifts at Soudan and shifts in the Main Control Room may satisfy shift obligations with the concurrence of the co-spokespersons and the Institutional Board.

3.2.3 Support & Maintenance of Detector Systems

Member institutions of the MINOS collaboration may have responsibilities for detector subsystems, NuMI beamline components, or other support roles for the experiment. Such responsibilities may include but are not limited to maintenance, repair, configuration, or upgrades of hardware components or supporting software. In all cases, the development, upkeep, and distribution of documentation for a subsystem are an essential part of the support and maintenance responsibility for it.

3.2.4 Experiment Decommissioning

At the completion of the MINOS experiment, procedures for removal or transfer of equipment procured and constructed by non-DOE funds (i.e. UK/STFC funds) will be implemented based on a separate MOU. All other decommissioning work will be the responsibility of Fermilab. At the Soudan site decommissioning of the MINOS detector will be done in accordance with a decommissioning plan developed by Fermilab, the University of Minnesota and the Minnesota Department of Natural Resources (DNR).

Country	Institution	% of Authors	Current Authors
Brazil	UNICAMP		1
Brazil	USP		1
	Brazil	**1.2%**	**2**
France	College de France		1
	France	**0.6%**	**1**
Greece	Athens		4
	Greece	**2.5%**	**4**
UK	Cambridge		6
UK	UCL		8
UK	U of Oxford		12
UK	Rutherford		5
UK	U of Sussex		3
	UK	**21.0%**	**34**
USA	Argonne		5
USA	Benedictine		2
USA	Brookhaven		6
USA	Caltech		7
USA	Fermilab		29
USA	Harvard		4
USA	IIT		3
USA	Indiana		8
USA	U of Minnesota, TC		18
USA	U of Minnesota, Duluth		5
USA	U of Pittsburgh		5
USA	U of South Carolina		5
USA	Texas A&M		3
USA	U of Texas - Austin		6
USA	Tufts		7
USA	William & Mary		2
USA	U of Wisconsin		1
USA	Stanford		5
	USA	**74.7%**	**121**
	Totals		**162**

Table 3.1 Calculation of author percentages for purposes of Common Fund contributions.

Statements of Work (SOW), negotiated between the Fermilab PPD and collaborating institutions,are created if Fermilab funds are to be dispersed to facilitate work at the institutions. An SOW is created for a defined period (specified in the SOW) and can be renewed or modified at the end of that period.

If, for any reason, a collaborating institution is unable to fulfill its support or maintenance responsibilities as specified in a SOW, that institution shall so inform the MINOS co-spokespersons and the MINOS financial officer, so that the responsibility may be re-assigned.

3.2.5 Support Software

Software responsibilities assumed by specific institutions are listed in Appendix IV. Note that general physics analysis tasks are not listed as these are assumed to be distributed throughout the collaboration, independent of institution.

4 RESPONSIBILITIES BY INSTITUTION - FERMILAB

4.1 The Accelerator Division (AD)

The Accelerator Division will be responsible for commissioning, operation and maintenance of the primary proton beam line, the target station and the hadron absorber. The line of demarcation between Accelerator Division and Particle Physics Division responsibilities is, unless otherwise noted, the large doors just upstream of the MINOS shaft.

AD will also be responsible for monitoring intensity and beam quality of the primary proton beam. Overall monitoring of the primary proton beam intensity within 3% is required by the experiment.

The Accelerator Division will develop a plan to upgrade the integrated proton intensity to NuMI to 3.3×10^{20} protons/year, by considering increasing the proton intensity/pulse and/or decreasing the Main Injector cycle time. Fermilab welcomes and encourages collaboration between MINOS non-Fermilab institutions and Accelerator Division in the planning and execution of proton intensity upgrade projects.

The MINOS Experiment depends on support from a number of departments within AD. The AD provides a liaison to the MINOS experiment and that person is a member of the MOB. The deliverables and services expected from each of these groups are described below.

4.1.1 External Beams Department

The External Beams Department is the proprietor of the NuMI beamline from the Main Injector to the hadron absorber and controls access to the muon alcoves. The department provides a Machine Coordinator who is in charge of beamline operations and serves as the point of contact for MINOS questions involving the beam. The Machine Coordinator's responsibilities concern both operational status and requests from MINOS for changes in the beamline, target station or hadron absorber. The department also

provides a Beamline Physicist who aids in day-to-day operational issues and assists the Machine Coordinator as required.

The External Beams Department contains personnel expert in various elements of the design, operation and troubleshooting of any beamline, and are called upon by the Machine Coordinator as needed. In addition, budgeting and purchasing of spare equipment and changes to equipment in the NuMI target hall is coordinated by this department.

4.1.2 Controls Department

The Controls Department is responsible for the front-end computers, links, crates and control cards for the operation of all equipment from the Main Injector to the hadron absorber. These responsibilities include the hardware and software of the Beam Permit System. The Department maintains several pieces of application software for controlling beamlines, specific instances of which are used by NuMI/MINOS. It is responsible for the maintenance of the accelerator consoles in the MINOS Control Room and NuMI service buildings. It installed and maintains several Programmable Logic Controllers dealing with target chase cooling and various water systems including beamline LCW, target hall and absorber RAW and near detector cooling. The computer networking in the NuMI underground and above ground installations is also the responsibility of Controls. This department is responsible for the hardware and software of FIRUS.

4.1.3 EE Support Department

The Electrical Department is responsible for all of the power supplies needed to run the magnets of the primary beamline. It is responsible for the NuMI extraction kicker and its power supply, the large pulsed power supply of the NuMI focusing horns and the electronic control of beamline vacuum.

4.1.4 ES&H Department

The AD ES&H Department shall have ES&H oversight responsibility for the AD areas of the NuMI facility as defined in [2]. In addition, the ES&H Department coordinates underground safety training for all NuMI/MINOS areas.

The department oversees access control to the pre-target beamline enclosure, target hall, decay pipe region, absorber hall and muon alcoves. Oversight is also provided for radiation and electrical safety in the region of the primary proton beam through various access control keys, enclosure interlocks, electrical permits to power supplies, interlocked radiation detectors, and beam inhibit critical devices.

After discussions between AD/ES&H and PPD/ES&H the following responsibilities have been assigned to the AD ESH Department:

a) Radiological shielding assessment of experimental areas;
b) Radiological surveys;

c) Oversight for handling of LCW/RAW systems;
d) Radiation and electrical interlock system related matters;
e) Participation in exposure investigations as necessary;
f) Monitoring and control of underground access at MI-65 (by controlling keys for the elevator and/or radiation areas for MI-65).
g) Monitoring and control of underground access at MINOS interlocked areas (by controlling keys for the elevator and/or hadron absorber area and muon alcoves). Access to the MINOS detector area is controlled by PPD.

4.1.5 Instrumentation Department

The Instrumentation Department is responsible for the maintenance and calibration of primary beamline monitoring devices – loss monitors, total loss monitors, BPMs and toroids. The Department will similarly be responsible for operation of the Optical Transition Radiation (OTR) detector which is to be installed. The University of Texas (Austin) was responsible for the development of segmented-foil emission monitors (SEMs), the hadron monitor, and the muon monitors. UT-Austin is proceeding with a separate MOU with the Accelerator Division to cover the responsibilities for these detectors. The Instrumentation Department will be a signatory to that MOU.

4.1.6 Main Injector Department

The Main Injector Department is responsible for providing beam with appropriate parameters on NuMI timeline cycles. Such parameters include, but are not limited to, intensity, emittance and orbit stability. Often insufficient intensity results from conditions in the Booster, and the Booster Department must also become involved in supplying proper beam to the Main Injector.

4.1.7 Mechanical Support Department

The Mechanical Support Department is responsible for operational support and maintenance, including magnet changes, of all the mechanical equipment in the Accelerator Division controlled areas. This includes vacuum and water systems throughout the beamline as well as the decay pipe region and the hadron absorber. The department has responsibility for technical support of equipment in the target hall and associated areas, including horns, targets, RAW systems, target pile cooling and dehumidification.

4.1.8 Operations Department

The AD, via the Operations Department, is responsible for accelerating and extracting 120 GeV primary protons into the NuMI Primary Proton beamline and for maintaining the beam parameters throughout the line and onto the NuMI target. The primary beamline is controlled from the AD Main Control Room.

The Operations Department is responsible for the administration of accesses to MI65 areas, the Muon Alcoves and the Absorber, and for resecuring these areas after a Supervised Access. AD provides first response to alarms in these areas.

Institution	System	Description of Work
Fermilab	Controls hardware	All of the links, crates, etc for operation of the beamline. The computer network in the NuMI areas and appropriate interconnect hardware
	Primary beam magnets	Spares for all types of magnets have been readied. The ones difficult to transport have been staged in the beamline area.
	Power supplies	Some spare supplies exist, and spare parts for all supplies are available.
	Vacuum equipment	Ion pump failures are addressed either by repairing or by replacing faulty devices.
	Target pile components	There is a spare target and target carrier. There are no spare horns, but work is underway to produce them. There is a work cell that an irradiated target or horn module can be placed in for observation and possible repair.
	Instrumentation	Spares are available for most types of beamline instrumentation. For a few types, repair is the only alternative.

Table 4.1 Fermilab AD Hardware Responsibilities for MINOS

Institution	System Responsibility	Description of Work
Fermilab	ACNET console software	Copies of standard beamline programs: parameter page, BPM/BLM, profile monitors, vacuum, beam permit
	Microprocessor software	BPMs, profile monitors

Table 4.2 Fermilab AD Software Responsibilties for MINOS

4.2 The Particle Physics Division (PPD)

The Particle Physics Division is responsible for the operation of the MINOS experiment and experiment-related activities at Fermilab. The PPD carries out these responsibilities

through the work of several departments, including the Neutrino Department, the Mechanical Department, the Electrical Engineering Department, ES&H/Building Management Department, the Technical Centers, and the Site Department. The deliverables and services expected from each of these groups are described below.

4.2.1 Neutrino Department

The PPD and the MINOS Experiment interact primarily through the Neutrino Department. This department provides an administrative organization for the Fermilab staff working on MINOS, as well as a center for experimental operations, data analysis and future planning. The PPD provides the Neutrino Department an annual operating budget. In addition to providing the funds for the operation of the Department itself, this budget also provides the funds for the operation and maintenance needs of the MINOS Detectors and those parts of the NuMI/MINOS facility for which the PPD is the landlord.

The Neutrino Department provides office space for both resident and visiting MINOS collaborators. Office space provided is commensurate with the amount of time spent at Fermilab.

The PPD provides a liaison to the MINOS experiment, generally from the Neutrino Department..

4.2.2 Mechanical Department

The PPD Mechanical Department provides repair services for mechanical systems in the PPD-controlled areas of the NuMI facility, as directed by PPD management.

The systems include the PPD LCW water system. The Mechanical Department will change de-ionization bottles and conduct preventive maintenance as necessary, as well as performing repair work as needed.

Materials and costs for mechanical repair work are back-charged to the MINOS operations budget. The Neutrino Department will request such support as needed.

4.2.3 Electrical Engineering

The PPD Electrical Engineering Department played a key role in developing the MINOS electronics and continues to provide support for them, including:

a) Ongoing maintenance work for the Near Detector MENU modules;
b) Participation in the production of additional MENUs, if more are needed;
c) Assist in maintaining the MINOS clock system.

4.2.4 ES&H/Building Management

The PPD ES&H Department shall have ES&H oversight responsibility for the PPD areas of the NuMI facility as defined in [2].

The PPD ES&H/Building Management Department has drafted an MOU with the AD for the coordination of ES&H issues. That MOU specifies responsibilities for PPD that include:

a) Communication of pertinent ES&H issues to MINOS Spokespersons;
b) Maintenance of radiological postings in MINOS areas. Residual Activation Surveys are performed by AD under the terms of [2].
c) Wallflowers and friskers;
d) Identifying training requirements for experimenters;
e) Working together with AD if exposure investigations for MINOS experimenters are needed;
f) Coordinating use of radioactive sources in MINOS areas with the collaboration and the ES&H Section;
g) Shipping/receiving of radioactive items between MINOS areas and other areas on-site; the ES&H Section is responsible for handling off-site shipping/receiving of such items;
h) Monitoring and control of underground access at the MINOS building;
i) Providing two (2) keys to the MCR for emergency and operational access to the MINOS area
j) Conduct of an appropriate safety review for any proposed upgrade to the MINOS detectors.

4.2.5 Technical Centers

The PPD Technical Centers Department comprises groups having special technical expertise, including alignment & metrology, detector support, machine development, and others. The Scintillator Group was instrumental in development and production of the MINOS scintillator and may play a role in any repair work that the scintillator or optical fibers may need. The MINOS experiment may solicit support from these groups as needed.

4.2.6 Site Department

The PPD Site Department provides maintenance and support for the MINOS near detector coil power supply. This department also supports the Mechanical Department in maintaining the LCW water system for the near detector. The MINOS experiment may request additional services from the Site Department, including distribution of electrical power and rigging of items down the MINOS shaft or in the near detector hall. Such requests are subject to the approval of the Site Department Head.

4.2.7 Underground Access Coordination

The MINOS experiment shares PPD underground space with various tests and other experiments. Access to the underground areas is controlled via training, access keys, limited occupancy and badging in and out when entering or exiting the areas, respectively. Designation of rules and procedures for access to the underground areas and coordination of permits for work to be performed in the underground areas of the PPD are the responsibility of the PPD MINOS Areas Coordinator.

4.3 The Computing Division (CD)

The Fermilab Computing Division provides support to the MINOS experiment in the form of offline computing resources, data storage, networking services, and the provision and maintenance of electronics.

The CD provides a liaison to the MINOS experiment and that person is a member of the MOB.

4.3.1 Offline Computing, Networking & Data Storage

The Fermilab CD has prepared a separate MOU for support of MINOS[5]. This MOU addresses computing support for the experiment and an estimate of the computing resources and CD manpower required.

4.3.2 Electronics Support

The Physics Research Equipment Pool (PREP) is responsible for repair and maintenance of certain electronics components, including

4.3.2.1 MINOS Far Detector

- HV 1440 High Voltage Supplies; on loan from PREP
- VA Front End Boards (VFBs); developed at Oxford
- VA Readout Cards (VARCs); developed at Harvard
- VME Crates
- Weiner Power Supplies
- Low voltage power supplies; developed at Harvard

4.3.2.2 MINOS Near Detector

- HV 1440 High Voltage Supplies; on loan from PREP

The MINOS co-spokespersons will undertake to ensure that no PREP equipment is transferred from the experiment to another use except with the approval of and through the procedure provided by CD management.

Any items for which the experiment requests that Fermilab performs maintenance and repair should appear explicitly in this agreement. A list of PREP equipment presently on loan to the experiment is in Appendix III.

At the completion of the experiment, the MINOS co-spokespersons are responsible for the return of all PREP and Computing Division equipment. If the return is not completed after a period of one year after the end of running, the co-spokespersons will be required to furnish, in writing, an explanation for any items not returned.

4.4 The Facilities Engineering Services Section (FESS)

FESS shall provide support to the MINOS experiment at Fermilab primarily through the FESS Operations Group and the FESS Services Group.

4.4.1 FESS Operations Group

The FESS/Operations Group is responsible for the support described in 4.4.1.1 - 4.4.1.2. FESS will administer the support work described in 4.4.1.3 on a case-by-case basis as requested by the customer, however, it is not within the FESS operational budget and this work may be back-charged to the experiment or to other supporting divisions as appropriate. This work may be performed by FESS staff or by subcontractors as appropriate and within the FESS core services.

4.4.1.1 First response to FIRUS and Metasys alarms

Response is on non-experimental equipment and systems, via the duty electrician and duty mechanic.

4.4.1.2 Preventive and corrective maintenance on included systems and equipment:

a) Electrical distribution (conventional power)
b) Sanitary and drinking water systems
c) Fire protection detection and suppression systems
d) Building Automation and Control Systems for Comfort Systems
e) Water Level Management for the MINOS Pond
f) Natural gas distribution
g) Industrial cooling water (ICW) system
h) Stationary emergency generators
i) Heating, Ventilating and Air Conditioning (HVAC)
j) Area Dehumidification equipment (on surface)
k) Exterior and interior lighting
l) Crane Inspections scheduling, notification and documentation
m) Sump Pumps
n) Emergency diesel pump at MINOS (Maintenance and operation)

4.4.1.3 Items not included in the FESS Operations budget

Although the FESS operational budget does not explicitly cover the cost of these items, FESS will work with the landlord to help schedule inspections and maintenance as necessary and assist in administering the pertinent subcontracts as requested.

a) Davis-Bacon Work
b) Construction / renovation Work
c) Initial spare parts (FESS will maintain stock levels of landlord supplied parts.)
d) Structure Maintenance
e) Costs and work beyond P.M./Minor Repair on stationary emergency generators, HVAC equipment and dehumidification equipment, and other major equipment.
f) The cost of crane inspections and repairs.

4.4.2 FESS Services Group

The FESS Services Group shall provide support at the MINOS service building. These services shall include standard janitorial services for the MINOS building itself as well as the roads and grounds in its environs. Specific services include:

a) Maintenance of the MINOS building parking lot (excluding resurfacing of the parking lot), including snow removal;
b) Assist in arrangement of asphalt repair contracts for the MINOS parking lot as needed;
c) Standard landscaping in the vicinity of the MINOS building;
d) Standard custodial services for the MINOS service building;
e) Maintenance and repair of the roof, overhead door, and glass in the MINOS service building is the responsibility of the landlord organization. Contracted services for these areas may be accessed through the T&M office managed by FESS, or by contracting directly with other contractors, or having the work completed by competent landlord employees.
f) Administration of elevator inspections with repairs at the landlord's expense.

4.5 The Environment, Safety and Health Section (ES&H)

During the construction of the MINOS experiment, the ES&H Section had a separate MOU with the NuMI Project[6], of which the MINOS construction was a part. Upon receiving Critical Decision 4 from the Department of Energy, the NuMI Project was officially completed and ceased to exist. This MOU supersedes the previous MOU between the ES&H Section and the NuMI Project for matters pertaining to the MINOS experiment.

The ES&H Section assumes the responsibilities specified here for the Fermilab site. As described in [3], the University of Minnesota assumes the responsibility for ES&H at the Soudan Underground Laboratory, although the Fermilab ES&H Section may play an advisory role there. The ES&H Section may also provide consultation services upon request from the experiment. While not specifically enumerated here, the requirements and recommendations of the *Fermilab Environment, Safety, and Health Manual* (including the *Fermilab Radiological Control Manual*) and the *Fermilab Emergency Response Plan* apply to MINOS operations.

4.5.1 Radiological Protection

The ES&H Section conducts and supports radiological monitoring in the NuMI facility and the environment as follows (the number of radiation monitors and detectors is approximate):

- Provide and maintain radiation monitors 4 "chipmunk" radiation monitors for NuMI beamline operations;
- Provide and maintain 3 portable survey meters as needed for access to certain NuMI/MINOS enclosures.
- Provide and maintain 3 friskers and 3 wallflowers (or equivalent) at points of egress from radiological areas in the NuMI facility.

- Although preliminary measurements have shown no safety or health concerns due to radon, the Radiation Protection Group may conduct periodic radon monitoring in the MINOS Near Detector Hall.
- In support of future intensity upgrades, the Radiation Protection Group will support shielding studies as needed to increase the Main Injector shielding assessment limits.
- Shipments of radioactive materials, including detector components containing radioactive sources that enter or leave the Fermilab site must go through the ES&H Section.

4.5.2 Environmental Protection

- Provide and operate 2 stack monitors to monitor airborne radioactivity in emissions from NuMI ventilation stacks.
- Conduct air release measurements for radio nuclides and perform calculations to ensure compliance with applicable regulations.
- Monitor surface water discharges for compliance with respect to the NPDES permit and other pollutants of interest;
- Monitor piezometers and sample groundwater monitoring wells for radio chemicals in accordance with NuMI Groundwater Monitoring Strategy[7];

4.6 The Business Services Section

4.6.1 Emergency Response

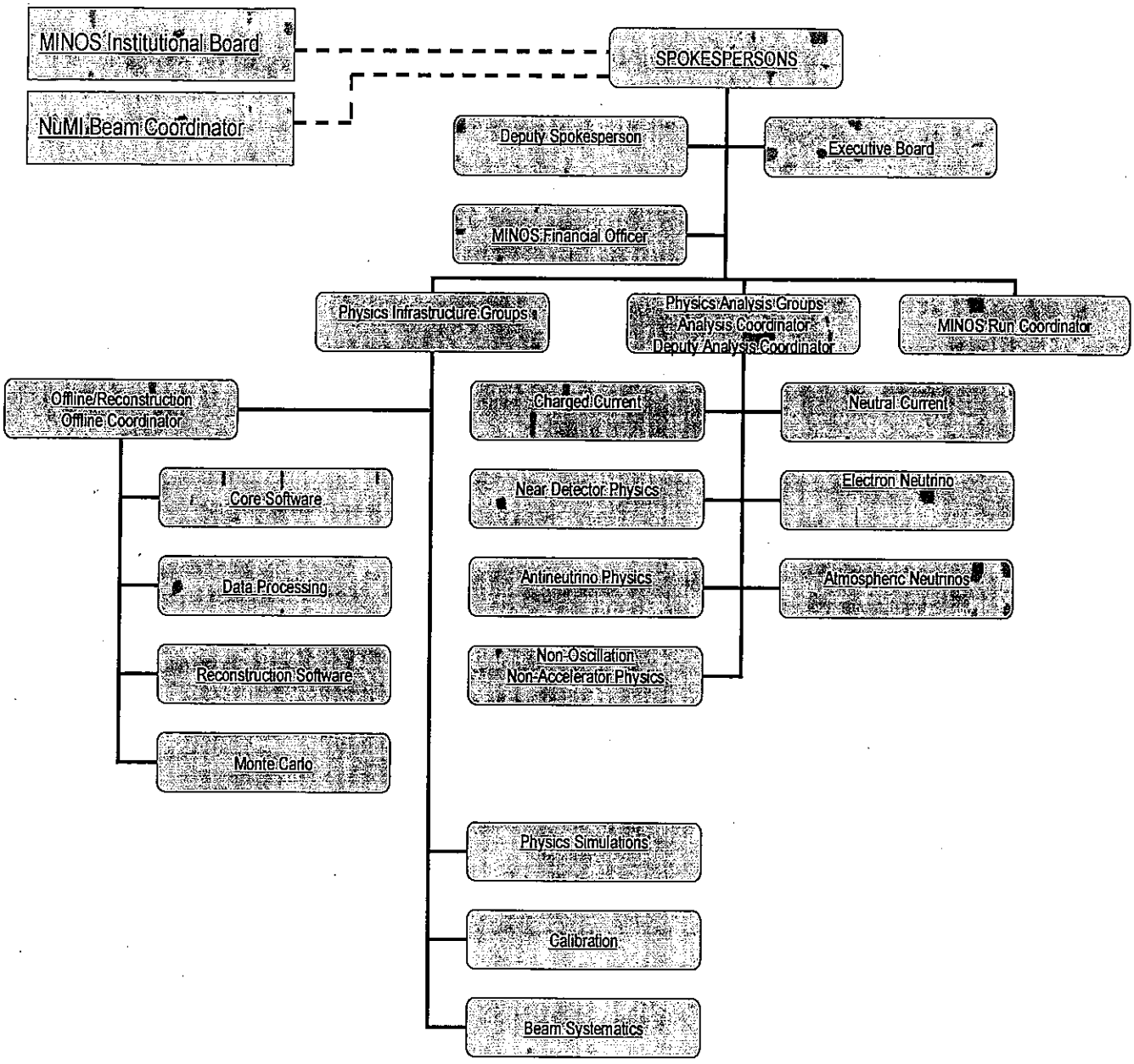
The Fermilab Fire Department is responsible for undertaking any underground rescue operations that may be necessary. To that end, the Fire Department will

- Maintain, test and replace as necessary the equipment necessary for underground rescue operations.
- Undergo recurrent training in underground rescue as necessary.

APPENDIX I: ABBREVIATIONS

AD:	Accelerator Division
CD:	Computing Division
CD-4:	Critical Decision 4 (Commencement of Operations)
DAQ:	Data Acquisition
DCS:	Detector Control Systems
ES&H:	Environment, Safety, and Health
FESS:	Facilities Engineering Services Section
FIRUS:	Facility Incident Reporting and Utility Services
HV:	High Voltage
HVAC:	Heating, Ventilation, and Air Conditioning
ICW:	Industrial Chilled Water
LCW:	Low Conductivity Water
MDNR:	Minnesota Department of Natural Resources
MI:	Main Injector
MINOS:	Main Injector Neutrino Oscillation Search
MOU:	Memorandum of Understanding
OM:	Online Monitoring
NPDES:	National Pollutant Discharge Elimination System
NuMI:	Neutrinos at the Main Injector
PMT:	Photomultiplier Tube
POT:	Protons on Target
PPD:	Particle Physics Division
PREP:	Physics Research Equipment Pool
RA:	Research Associate
RAW:	Radioactive Water

APPENDIX II: COLLABORATION ORGANIZATIONAL CHART



APPENDIX III: PREP REQUEST

The following equipment will be in use until the completion of the experiment.

a) LeCroy 1440 HV system for Near and Far detectors
b) test equipment needed at Near and Far detector halls

Location		**Detector Hall at Fermilab**	
LRS 1440 system	Quantity	CLASS_NAME	TC
	1	LRS: 1441(POWER SUPPLY,LV,1440 SYS	FA
	2	LRS: 1442(POWER SUPPLY,LV,1440 SYS	FA
	16	LRS: 1443NF/12(CARD,HV,16CH,NEG,1440 SYS	FB
	1	LRS: 1449M(MAINFRAME,HV,1440 SYS	FB
	1	LRS: 1445(CONTROLLER,HV,1440 SYS	FI
	1	LRS: 222(GENERATOR,GATE,2CH,NIM	AN
	1	LRS: 2132(INTERFACE,HV,CAMAC	FB
Test equipment	2	Oscilloscope (plus cart, probes)	
	1	Digitizing scope (plus cart, probes)	
	3	Digital voltmeter	
	2	Pulse generator	
	2	pocket pulser	
CAMAC crates	2	CAMAC Crate	
	2	GPIB CAMAC Crate Controller	
Location	**Far**	**Detector Hall at Soudan**	
LRS 1440 system	Quantity	CLASS_NAME	TC
	9	LRS: 1441(POWER SUPPLY,LV,1440 SYS	FA
	18	LRS: 1442(POWER SUPPLY,LV,1440 SYS	FA
	108	LRS: 1443NF/12(CARD,HV,16CH,NEG,1440 SYS	FB
	9	LRS: 1449M(MAINFRAME,HV,1440 SYS	FB
	9	LRS: 1445(CONTROLLER,HV,1440 SYS	FI
	5	LRS: 222(GENERATOR,GATE,2CH,NIM	AN
	1	LRS: 2132(INTERFACE,HV,CAMAC	FB
Test equipment	2	Oscilloscope (plus cart, probes)	
	1	Digitizing scope (plus cart, probes)	
	3	Digital voltmeter	
	2	Pulse generator	
	2	pocket pulser	
CAMAC crates	2	CAMAC Crate	
	2	GPIB CAMAC Crate Controller	

Table III.1 EQUIPMENT on loan to MINOS from PREP.

APPENDIX IV: COLLABORATION INSTITUTIONAL RESPONSIBILITIES

All collaborating institutions on MINOS share responsibilities to the experiment as discussed in Section 3.2 of the MOU, in particular in regards to shift responsibility and hence are not listed in this Appendix. The tables in this appendix list the member institutions with key responsibilities on the experiment as of the date of this MOU. Since membership and responsibilities evolve over time, this table will be periodically revised to reflect the current status. In the event that a system expert transfers from one MINOS collaborating institution to another, the question of whether the responsibility for that system remains with the original institution or with the expert will be decided on a case-by-case basis by the MINOS Institutional Board. Table IV.1 lists specific hardware responsibilities; Table IV.2 lists specific software support responsibilities.

In the context of the system responsibilities listed below, "maintenance" is construed to include support and preventive maintenance, documentation, upgrades as necessary, and repair or replacement due to normal wear and tear. It does not include replacement of a system due to catastrophic loss. Any disagreement concerning the scope of a specific responsibility shall be referred to the MINOS Institutional Board.

Institution	System	Description of Work
Argonne National Laboratory	Near Detector Electronics	Performance of routine repairs and maintenance of MINOS near detector electronics, following the initial installation and commissioning of this system; maintain an adequate supply of spare modules at Fermilab.
Fermilab	Near Detector Electronics	FNAL RAs provide monitoring of the Near Detector electronics; they replace defective modules with spares that are stored at Fermilab, and arrange for defective modules to be returned to ANL for repair
	Near Detector High Voltage	If system or component failure occurs FNAL staff will coordinate replacement with new modules from PREP
	Far Detector Electronics	PREP is responsible for repair of the front end electronics boards including the VFB and VA chips
	Far Detector High Voltage	If system or component failure occurs Soudan staff or shifters will coordinate replacement with new modules from PREP

	Far Detector Coil Power Supply	PPD EED Department is responsible for this system
	Near Detector Coil Power Supply	PPD EED Department is responsible for this system
	Near Detector Electronics Racks Cooling System	PPD Mechanical Support Department is responsible for this system
	Control Room hardware	Maintenance and improvements. CD staff are performing this function
University of Minnesota (Duluth)	DCS Hardware Systems : Near and Far	Support of the DCS system, both hardware and software, at both Near and Far detectors.
	Far Detector Operations	A UMD faculty member serves as the Far Detector Operations Manager.
Oxford University	Far Detector front end electronics	Technical expertise on the VFB and VA chip.
	Far Detector timing system	Technical expertise and documentation
	GPS : Near and Far	Technical expertise and hardware maintenance and support
	M64 PMTs (Near Detector) and tube bases.	Maintenance for the M64 bases; M64s can't really be maintained, but Oxford will provide high level expertise.
University of Pittsburgh	Near Detector Electronics Rack Fans	High level expertise available.
Harvard University	Far Detector electronics	High level expertise for VARC boards and low voltage power supplies.
University of Sussex	Light Injection Calibration (near and far systems)	Responsibility for the maintenance and operation of the light-injection calibration system. Currently supplying one of the calibration co-coordinators, and a continuing responsibility for broader calibration issues is anticipated.
Rutherford Appleton Laboratory	Data Acquisition System	Support, maintenance and repair of data acquisition hardware and infrastructure for both near and far detectors using UK funds. Co-ordinate expert on-call support for operations.
Illinois Institute of Technology	Near Detector Rack Infrastructure	Maintenance and repair rack cooling fans. Serve as interface to PPD Electrical Engineering Department for maintenance of VME timing system, VME crates, and power supplies.

University of Texas (Austin)	M16 PMTs (Far Detector) and bases	Maintenance of a test stand and expertise for maintenance and repair of bases
	Hadron Monitor	Maintenance of operations
	Muon Monitors	Maintenance of operations
Tufts University	Far Detector MUX Boxes	Maintenance of a facility for the repair or reconstruction of far detector MUX boxes
College of William & Mary	Magnetic Field Calibration – Bdot system	Maintenance of the B-dot system for near and far detectors, perform magnetic calibration and generation and modeling of magnetic fields.
Stanford University	Light Injection	System maintenance
University of Minnesota	Wide Area Networking	Maintenance and repair network connectivity of the Soudan Laboratory.

Table IV.1 Institutions with key hardware responsibilities for MINOS

Institution	**System Responsibility**	**Description of Work**
Brookhaven National Laboratory	MINOS Database	Support for core software, including the Database Table Czar.
	Beamline Data	Support for the acquisition and monitoring of beamline data.
University of Cambridge	Monte Carlo Generation	Generation of Monte Carlo data files for cosmic rays and atmospheric neutrinos.
	Run Control	Support of run control software.
	Reconstruction code	Support of De-muxer, track-fitter
Fermilab	Near Detector Front End electronics	Maintenance of offline diagnostic software for monitoring Near Detector electronics.

	Offline Software	CD personnel provide support for MINOS offline computing.
Harvard University	Offline Software	Production and documentation of scripts to process the different types of data.
	Data Processing	Administration of the software and the database used on processing farms; validation protocols.
Illinois Institute of Technology	Data Processing Farms	Support and administration for the MINOS data processing farms, and contributions to the calibration and operation of the MINOS detectors.
Indiana University	Offline and Reconstruction Software	Coordination of development and optimization of the MINOS offline framework and reconstruction software.
University College London	Calibration Support	Coordination of calibration group efforts.
University of Minnesota	Core Software support	I/O and data storage routines; particle transport code.
	Monte Carlo Production	Coordination, planning and management of use of resources at various sites.
Oxford University	Database Distribution	Coordination of the distribution of the MINOS database.
Oxford University	Timing System	Support, maintenance and development of near and far detector timing system software.
Argonne National Laboratory	Near Detector Electronics	Support, maintenance and development of near detector electronics calibration and DAQ interface software for VME based processors.
Rutherford Appleton Laboratory	Data Acquisition Systems (DAQ)	Support, maintenance and development of DAQ software and associated infra-structure for both near and far detectors. Provision of framework and co-ordination of quasi-online software. Co-ordination of

		expert on-call support for operations
	Monte Carlo Generation	Implementation and maintenance of RAL processor MC farm resources.
Sussex University	Light Injection Calibration Support	Support and maintenance of software for the light injection calibration system. Coordination of calibration group efforts.
Caltech University	Monte Carlo Generation	Implementation and maintenance of the Caltech processor MC farm resources
Tufts University	Monte Carlo Generation	Implemention and maintenance of the Tufts processor MC farm resources
College of William and Mary	Monte Carlo Generation	Implemention and maintenance of W&M processor MC farm resources
Stanford University	Offline software	Framework development

Table IV.2 Institutions with key software responsibilities for MINOS

APPENDIX V: SPARE COMPONENTS

This appendix lists responsibilities for MINOS spare components. These responsibilities may include maintenance, repair, testing, or storage. Replacement or provision of new components is not assumed to be an institutional responsibility unless explicitly stated. The actual number of available spares of any given component is a quantity that can change at any time, therefore no attempt is made to track the spares on hand here. The following tables are a snapshot, not a running inventory. Their purpose is to specify the status of and responsibilities for important spare components for the MINOS experiment.

Component	Designed by	Maintained by	Location	Notes
LI Pulser Box	Sussex	Sussex	Sussex	
M64 PMT	Hamamatsu	Oxford	Fermilab	Experts available at Oxford for consultation
M64 Base	Oxford	Oxford	Fermilab	Maintenance performed by Oxford
M16 PMT	Hamamatsu	Texas	Soudan/Texas	
M16 Base	Texas	Texas	Soudan/Texas	
PMT Far Detector MUX Boxes	Indiana	Indiana	Soudan	
PMT Near Detector Alner Boxes	RAL	RAL	Fermilab	
VME Master Crates	Wiener	Fermilab	Soudan	Experts at Fermilab
Near Detector Front-end Crates	Wiener	ANL	Fermilab/ANL	Experts at ANL
Near	FNAL/IIT	FNAL/IIT	Fermilab	

Detector Clock Boards				
ND Trigger KEEPER boards	ANL	ANL	ANL/Fermilab	
ND Minder Readout Cards	ANL	ANL	Fermilab/ANL	Experts at ANL
ND MENU Frontend Cards	FNAL	ANL/FNAL	ANL/Fermilab	Experts at ANL
Rack Protection Boxes	BIRA	Duluth	Duluth/FNAL/Soudan	Experts at Duluth
TCU	Oxford	Oxford	Fermilab	Maintenance performed by Oxford
GPS Receiver	Commercial	Oxford	Fermilab	Maintenance performed by Oxford
TRC	Oxford	Oxford	Soudan	Maintenance performed by Oxford
PVIC PCI cards	Commercial	Rutherford	Soudan mine	Maintained by RAL; Commercial repair
PVIC PCI cards	Commercial	Rutherford	Fermilab	Maintained by RAL; Commercial repair
PVIC VME cards	Commercial	Rutherford	Soudan mine	Maintained by RAL; Repairs by CES
PVIC VME cards	Commercial	Rutherford	Fermilab	Maintained by RAL; Commercial repair
PVIC Cable Connectors	Commercial	Rutherford	Soudan mine	Maintained by RAL
PVIC Cable Connectors	Commercial	Rutherford	Fermilab	Maintained by RAL
VME	Commercial	Rutherford	Soudan mine	Maintained

processors (RIO)				by RAL; Commercial repair
VME processors (RIO)	Commercial	Rutherford	Fermilab	Maintained by RAL; Commercial repair
Universal Device Server (UDS)	Commercial	Rutherford	Soudan mine	Maintained by RAL
Universal Device Server (UDS)	Commercial	Rutherford	Fermilab	Maintained by RAL
DAQ PC	Commercial	Rutherford	Soudan mine	Maintained by RAL
DAQ PC	Commercial	Rutherford	Fermilab	Maintained by RAL
DAQ Power Distribution Unit (PDU)	Commercial	Rutherford	Soudan mine	Maintained by RAL
DAQ Power Distribution Unit (PDU)	Commercial	Rutherford	Fermilab	Maintained by RAL

Component	**Designed by**	**Maintained by**	**Location**	**Notes**
VA Front-End Board (VFB)	Oxford	Fermilab PREP		Experts available at Oxford for consultation
VA Readout Card (VARC)	Harvard	Fermilab PREP		Experts available at Harvard for consultation

Table V.1 MINOS Spare Parts

SIGNATURES

S. Wojcicki – MINOS Co-spokesperson — Date: 8/4/08

R. Plunkett – MINOS Co-spokesperson — Date: 7/10/08

R. Rameika – MINOS Financial Officer — Date: 7/30/08

R. Dixon – Accelerator Division Head — Date: 7/29/08

G. Bock – Acting Particle Physics Division Head — Date: 7/29/08

V. White – Computing Division Head — Date: 7/29/08

R. Ortgiesen – FESS Head — Date: 7-22-08

W. Griffing – ES&H Director — Date: 7-23-08

D. Carlson – BSS Head — Date: 7-23-08

S. Holmes – Associate Director for Accelerators — Date: 7/31/08

Y-K. Kim – Deputy Director — Date: 8/1/08

P. Oddone – Fermilab Director — Date: 8/1/08

REFERENCES

[1] MINOS Collaboration Bylaws, current revision, http://www-numi.fnal.gov/collab/ib.
[2] Letter from Roger Dixon and James Strait to Michael Witherell, subject: NuMI Facility, September 24, 2004.
[3] *Memorandum of Understanding between the University of Minnesota and Fermi National Accelerator Laboratory for Construction of an Experimental Area for and Installation and Operation of the MINOS Detector at the Soudan Underground Laboratory*, November 6, 1998.
[4] *Minutes of the MINOS Institutional Board Meeting at Fermilab*, September 28, 2004, NuMI-MIN-GEN-1055.
[5] *Memorandum of Understanding between the MINOS Experiment and the Computing Division*, October, 2006.
[6] *Memorandum of Understanding between the Fermilab ES&H Section and the NuMI Project for the Support of NuMI at Fermilab*, January 4, 2000.
[7] Memo from G. Bock to W. Griffing, December 24, 2003. MINOS-967 and Appendix "M", NuMI SAD.