Chapter 18. Environment, Safety, and Health Considerations

D. Cossairt, K. Vaziri, and R. Walton

18.1 Introduction

The Proton Driver presents a number of challenges in the general area of environment, safety, and health. This chapter identifies these challenges and makes a preliminary assessment of how they might be addressed and of their potential impact on the project. While many of these issues are very similar to those that have been encountered and solved during the construction and operation of other facilities at Fermilab and elsewhere, others are quite novel. The novel ones will require particular attention as the project proceeds to assure their timely resolution in a cost-effective manner that meets the approval of the Department of Energy and the public. It is concluded here that with adequate planning in the design stages, these problems can be addressed in a manner that merits the support of the Laboratory, the Department of Energy, and the public. Future R&D needs are identified and summarized at the end of the chapter.

18.2 Overall View of Procedural/Regulatory Matters

The actual design, construction, and operation of the Proton Driver will have to meet a number of procedural/regulatory milestones in the area of environment, safety, and health to assure its success. The devotion of early attention to these issues is likely the best way to enhance public support of the project. These requirements are currently provided in Fermilab's Work Smart Standards in Environment, Safety, and Health [1]. The list of Work Smart Standards is reviewed annually.

18.2.1 Safety and Health Procedural/Regulatory Matters

The Laboratory will be required to prepare an assessment of the environment, safety, and health issues associated with this project in the form of a Safety Assessment Document (SAD). Given the size and scope of this project, the preparation of a Preliminary Safety Assessment Document (PSAD) will likely occur first. The purpose of the PSAD is to identify the relevant ES&H issues at an early stage and propose how they might be mitigated. The SAD, then, documents the resolution of the issues. It is quite possible that DOE will review these safety documents by utilizing an external review team. Just prior to facility operation, a readiness review will be conducted in similar fashion. PSAD/SAD activities generally begin after funds are released. Early planning will expedite this task. DOE is presently "self-regulating" in the areas of industrial safety and occupational radiation protection. Developments in these areas are being monitored closely to identify new requirements or procedures that might apply to new projects such as the Proton Driver. Fire safety/Life Safety Code considerations, particularly those concerning egress conditions should be especially carefully thought out prior to Title I design.

18.2.2 Environmental Protection Procedural/Regulatory Matters

All new DOE projects are subject to the National Environmental Policy Act (NEPA). Initially, the project will be analyzed to determine the appropriate level of review. For a project of this scope, DOE will require an Environmental Assessment (EA). The required analysis is broad in scope and includes societal impacts, such as traffic and noise, along with the standard environmental protection topics. Also included would be investigation of archaeological and historic preservation sites located within the footprint. DOE will choose the methods used to involve the public. The conclusion of the environmental assessment process is either a Finding of No Significant Impact (FONSI) or the need to prepare an Environmental Impact Statement (EIS). The possibility of a determination by DOE that an EIS would be necessary should not be dismissed. The requirement to proceed with the preparation of an EIS may well hinge on how the Proton Driver is connected with other actual or anticipated sources such as a neutrino source or a muon collider. If the Proton Driver project becomes formally connected with some larger project that clearly requires an EIS, then the environmental review of the Proton Driver would likely need to be included in that EIS. The environmental impacts associated with the proposed project could also bear importantly on the level of NEPA review. The completion of the EIS results in the issue of a formal notice called a Record of Decision (ROD). To set the time scale, the process of preparing an EA from the beginning to the publication of the FONSI could be anticipated to take from one year to 18 months. Two or three years are likely needed, at a minimum, to complete an EIS. The NEPA process is generally considered to be arduous, but one that can be followed to a successful conclusion. This task must be completed prior to expenditure of project funds or any "detailed design."

A significant part of the NEPA process, regardless of the level of the final review (i.e., EA or EIS), consists of an analysis of alternatives to this proposal, identifying the environmental impacts of all of them and demonstrating that the proposed project either has the least impact or that the impacts are justified by other considerations. Potential "hypothetical" alternatives must include the "no action" alternative, i.e., "making do" with the present Linac and Booster. Other obvious alternatives that should be considered are upgrading the Booster in its current location and placing the Proton Driver in a different location on the Fermilab site or elsewhere. Alternative locations may have a substantial effect on the analysis of impacts. For example, locating the project in non-wetland areas (e.g., south of Giese Road, or west of the NuMI access road) may warrant serious consideration if it results in the alleviation of important environmental problems. Furthermore, any decontamination or decommissioning of portions of the accelerator complex that might be replaced by the Proton Driver (e.g., the 8 GeV Booster) should be included in the environmental analysis.

Other procedural requirements apply in the arena of environmental protection in the form of environmental permits that will be needed. Some of these apply during the construction stages, others apply to operations, and some apply to both stages. Topics covered by such permits include storm water discharges, discharges of cooling water, wetlands mitigation, releases of air pollutants for both non-radioactive pollutants and for radionuclides, and construction in any floodplains. Some of these topics are covered by existing environmental permits issued to DOE and the Laboratory. However, the operating conditions of the Proton Driver will likely result in the need to modify these permits. A prominent example is the need to secure a permit under the National Emissions Standards for Hazards Air Pollutants (NESHAPS) to construct a new source of airborne radionuclide emissions [2]. The lead-time required for submittal of these permits is typically 180 days or longer. The above permits all come with lists of "terms and conditions", all of which are enforceable by the regulating agencies and will need to be properly assured during both construction of the facility and its subsequent operations. Specifically, requirements for periodic monitoring, maintenance, inspection and reporting commonly arise. It is particularly important that these issues be carefully considered and realistically planned for early in the project and included in the preparation of cost estimates for the bidding process. This early attention is needed to avoid major funding and compliance problems later, where they can, under some scenarios, delay the completion of construction.

18.2.3 Wetlands Impact

The wetland impacts would be major for this project as it is currently envisioned. At this early stage, it is estimated that the extent of the construction area is roughly 20 acres, nearly all of which would be in jurisdictional wetlands (i.e., wetlands of a size of regulatory importance). That means that an individual permit from the U.S. Army Corps of Engineers (CoE) must be obtained before the commencement of construction. For a project of this size, the permitting process is likely to take a minimum of one year from the date of submittal. The permit would certainly require the replacement of the wetland acreage lost. The CoE typically wants replacement wetlands to be "in kind", that is, of the same type as that lost. Unfortunately, the wetland in the location presently preferred is forested, which is essentially impossible to replace. Therefore, the CoE is likely to require a higher ratio of replaced to lost acres than the typical 1.5:1. A replacement ratio of 2:1 or even 3:1 should be anticipated, resulting in the necessity to create up to 60 acres of new wetland. The process of choosing a place on site for such a large expanse of wetland should be done carefully, since the new wetland becomes essentially untouchable for development in the future. At the time of this writing, replacement wetland typically costs about $50,000 per acre to build and manage. Created wetland acreage must be monitored as a condition of the permit, typically for a period of five years, and failure to meet performance criteria would necessitate remediation. Obviously efforts that can be made to reduce the size of the impacted wetlands can pay considerable dividends in terms of overall project cost and perhaps even in complexity of construction.

Additional wetland and/or floodplain impacts may result from siting of a new twenty acre cooling pond. Siting such a pond in a wetland or floodplain would constitute “fill” as defined in regulations, and would add to the permit burden.

18.3 Environment, Safety, and Health Considerations During Construction

18.3.1 Occupational Safety During Construction of the Facility

These facilities all would be located within the glacial till strata at a distance below the surface of less than 33 ft (10 meters). At this level construction is likely to proceed by the standard "cut and fill" method. The Occupational Safety and Health Administration's (OSHA) regulations on the construction activities will be followed. Industrial radiography operations and any other work conducted using radioactive sources must be performed in compliance with State of Illinois requirements. Other routine radiological issues that might arise will be handled according to the *Fermilab Radiological Control Manual* (FRCM). There are no new occupational safety issues identified with this work. However, should alternative methods of construction such as underground tunneling be chosen, perhaps in order to minimize the size of impacted wetlands, further review may be necessary.

18.3.2 Environmental Protection During the Construction of the Facility

Erosion control measures similar to those employed elsewhere must be employed in accordance with good engineering practice and Federal and State regulations. Dust and runoff from any spoil piles must be kept under control. A National Pollutant Discharge Elimination System (NPDES) storm water permit for construction will be needed. This will include specific erosion and sedimentation controls that must be followed during the construction period. The usual precautions to prevent pollution from spills of regulated chemicals from the construction equipment will need to be taken. Noise from construction activities is not expected to be significantly more intense than that associated with normal civil construction activities in the vicinity of Fermilab. It is important to demonstrate adequate care for floodplains due to significant local public concerns about flood prevention. Also, due to the fact that Indian Creek runs through the proposed site, it is very likely that the construction would qualify as a "Class III" dam, a condition that would require a permit from the State of Illinois.

18.4. Environment, Safety and Health Considerations During Operation

18.4.1. Occupational Safety Hazards During Operations

The occupational safety hazards encountered at all other large particle accelerator facilities, including the present complex at Fermilab, will be found in this facility:

- The project will use high current electrical circuits in the magnets on a large scale.
- Radio frequency (RF) generation and distribution equipment will be used extensively.

- Large amounts of cables in cable trays, with associated fire protection implications, will be installed.
- Long tunnels will be present with corresponding egress and fire protection issues that need to be addressed.
- There will be movements and alignment of large, heavy components.
- There will be significant amounts of cooling water present.

These have been successfully addressed in the past by the application of well-known technologies and safety practices that should be applied to this facility.

The incorporation of unusual materials in accelerator components or as target materials could pose industrial hygiene issues that will need proper evaluation and mitigation.

18.4.2. Ionizing Radiation Safety During Operation of the Proton Driver

The major issues related to ionizing radiation have been discussed in detail in Chapters 9 and 10 of this report. The discussion here is based upon the latest (at the time of this writing) statement of the parameters of the Proton Driver [3] and on extensive Monte Carlo calculations that have already been carried out [4,5]. The latter calculations were specifically performed to establish and control allowable beam losses and to understand their consequences. The discussions of this chapter are based on the machine parameters for Phase II Proton Driver as they appear in Table 1 of Ref. [3]. This choice was made in consideration of the finality of the civil construction. It is crucial to recognize that radiological issues pertaining to future target stations are not within the scope of this report. Preliminary discussions of the significant impacts of an example of such a target station have been provided in the Neutrino Factory Feasibility Study [6].

18.4.2.1 Prompt Radiation Shielding

The Proton Driver will require massive amounts of hadron shielding similar in scale and type to that of other proton accelerators in this energy and intensity regime. It is clear that suitable combinations of steel, concrete, and earth shielding can meet the standard criteria for above ground shielding at Fermilab. Figure 6 of Ref. 4 provides useful results of calculations of the dose equivalent due to a quasi-local loss of protons on a magnet centered in a 2 m radius tunnel comprised of 0.3-m concrete walls as a function of the radial thickness of earth of standard density typically found at Fermilab ($\rho = 2.24$ g cm^{-3}). These were done for the various energy stages. Likewise, presently available civil construction conceptual drawings show the lateral shielding thicknesses selected in a preliminary manner.

From the standpoint of machine reliability, it is inconceivable for a catastrophic loss of the full beam to continue for more than about one second during a given one hour period of operations. Likewise, as stated in Ref. 4, the maximum credible uncontrolled loss of beam on a steady state basis would most certainly be less than 0.1%. Results for the presently-envisioned lateral shields are given in Table 18.1. The maximum dose equivalent rate external to the shield due to the quasi-local loss of the beam of duration one second is given along with the dose equivalent rate outside of the shield expected at a quasi-local 0.1 % steady-state loss of beam.

Table 18.1. Dose Equivalent Rates External to Lateral Shielding

Maximum Energy/Machine	**Preliminary Design Lateral Shield (feet)**	**Normalized Dose Equivalent Rate Outside Shield[a,b] (mSv proton^{-1})**	**Maximum Dose Equivalent Rate Outside Shield[c] (mrem s^{-1})**	**Dose Equivalent Rate Outside Shield at 0.1 % Steady Loss (mrem hr^{-1})**
400 MeV Linac	13.0	2.7 x 10^{-18}	0.14	0.50
1000 MeV Linac	15.5	8.3 x 10^{-18}	1.25	4.5
3 GeV Pre-Booster	24.5	2.9 x 10^{-20}	0.0044	0.016
16 GeV Booster	24.5	7.3 x 10^{-20}	0.011	0.040

[a]This result is read directly from Fig. 6 of Ref. 4 or determined from extrapolations from those results. The extrapolation is reliable since the plotted results are nearly perfectly fit by the exponential function.

[b]The 1000 MeV value was determined, conservatively, by scaling the 3 GeV value as $E^{0.8}$.

[c]The values in this column were determined using the values of beam delivery provided in Table 1 of Ref. 3. For the 400 MeV 15 Hz Linac, this was 3.4×10^{13} protons/pulse for Phase I and 1×10^{14} protons/pulse in Phase II.

Regulatory [7] and DOE [8] requirements pertain to radiation fields present on a DOE site. While Ref. [7] primarily concerns exposures to occupational workers and Ref. [8] pertains primarily to members of the public, these two standards, both incorporated into Ref. 1, are consistent in that the annual radiation dose equivalent must be kept below 100 mrem in locations where members of the public or employees who have not been specifically trained as "radiation workers" could be present. Fermilab has adopted policies that are intended to achieve this condition [9]. If the dose equivalent in an hour resulting from the maximum credible accidental beam loss can be constrained to be less than 1 mrem and if the dose equivalent due to normal operating conditions can be shown to result in a dose equivalent of less than 0.05 mrem hr^{-1}, the affected area needs no further controls, the desired condition for an accelerator such as the Proton Driver. Examining the above results, it is clear that even for the 0.1% beam loss, a level that may be larger than typical operating conditions, the planned lateral shield dimensions for the 3 and 16 GeV synchrotrons are adequate to meet the conditions on dose equivalent. However, for the 400 MeV (Phase I) and the 1000 MeV (Phase II) Linacs these conditions are not met at this fractional rate of beam loss. Since the 400 MeV Linac is constrained by its being housed in the present Linac enclosure, the loss of beam in it must be limited to less than 0.01% since it would be difficult to add the equivalent of 3.1 ft of lateral earth shielding needed to allow for a 0.1 % loss. In particular, the limits on dose equivalent rate must be met in the Linac Gallery due to its high occupancy, an occupancy that presumably would continue during Phase I operations. For the 1000 MeV Linac, based upon the extrapolations of the results of Fig. 6 of Ref. 4, it is recommended that its lateral shielding be increased to 21.6 ft to achieve a consistent level of protection. An alternative would be to provide assurance that *localized* steady-state beam losses under normal operational conditions can be kept below 0.001 %. The control of beam loss in the Linacs as it trades off with lateral shielding requirements clearly needs to be better understood.

Radiation fields due to muons must be considered. At 16 GeV, the range of the muons of maximum energy is less than 100 ft of earth. Due to their forward-peaking, any muons produced by stray beam loss should be ranged-out in the soil shield and hence are of no consequence.

Thus, the shielding against the prompt radiation hazards is well understood and can be addressed by conventional means. An especially welcome result is the elimination of the quite troublesome shielding problem associated with the present 8 GeV Booster and certain work places of high occupancy. However, the present conceptual drawings show various support structures, presumably occupied during operations, as being located nearly directly above the planned beam enclosures and protected by the minimum value of lateral earth shielding. While initial shielding estimates may determine that these locations are adequately shielded, they should not be placed directly over the beam enclosures. Experience at nearly all accelerators, including the present Fermilab Booster, is that future upgrades nearly always are compromised or made more costly by such "occupied structures" being located above or beside the accelerator enclosure. Instead, they should be kept at the same elevation but relocated horizontally away from being directly over the accelerator enclosures. It is suggested that this be done in a way that results in at least 3 ft of additional shielding in order to provide approximately an order of magnitude of additional attenuation in radiation levels at relatively low cost. Otherwise, operational difficulties are likely to arise due to the need to control radiation exposures in work places much more stringently than those required to control those in "uncontrolled" areas, where one has options such as fencing available as fallback positions.

18.4.3.2 Residual Radioactivity of Components

References [4] and [5] have documented initial studies of the residual activation problem. The result of this work has been the identification of a scheme for using collimation to limit the beam loss to a well-shielded collimation system while achieving an average loss of about 0.3 W m^{-1} elsewhere. The resulting radiation levels at contact with the beam pipe in unshielded portions of the 16 GeV lattice should be less than approximately 130 mrem h^{-1} while those at contact with magnets should be less than about 10 mrem h^{-1}. It turns out that at 16 GeV, a beam loss of 0.3 W m^{-1} averaged over the circumference of 711.32 m corresponds to a total fractional loss of beam of only 5.5 x 10^{-3} per cent, a challenging level to achieve. For the 16 GeV Booster, these levels are acceptable from the standpoint of the control of occupational radiation exposure during routine maintenance activities. However, the prompt radiation levels are sufficient to require continuous attention to beam loss during operations and careful planning of maintenance activities in order to keep occupational radiation exposures as low as reasonably achievable, in compliance with the requirements of Ref. 7. Engineered-in design features which provide for easier access and replacement of equipment will help in easing the radiological operational issues. Proper selection of materials for the buildings and equipment will also help to reduce the residual activation.

18.4.3.3 Airborne Radioactivity

Airborne radioactivity levels will largely be encountered either in areas where collimators are employed to limit beam loss (see Sect. 18.4.3.2) or at the target stations that are not within the scope of this report. The design of the collimation system will include a calculation of the airborne radioactivity released, to support the permitting requirements outlined in Section 18.2.2 and to assure compliance with regulations governing airborne radionuclide releases set forth in Ref. [2]. An early assessment of this issue will allow the inclusion of mitigation into the design of the facility.

18.4.3.4 Radioactivity in Soil and Groundwater

The results of Refs. [4] and [5] considered soil activation due to losses of beam in the various acceleration stages. For all stages considered, it was demonstrated that the control of residual activity to the levels described in Section 18.4.3.2 will achieve acceptable levels of soil activation. As the design proceeds, this issue will warrant continued attention. In particular, a hydrogeological survey in the vicinity of the planned facility should be conducted to better refine the parameters relevant to groundwater activation prior to the finalization of the design.

18.4.4 Non-Radiological Environmental Protection Issues During Operations

Efforts should be made to prevent the creation of regulatory mixed wastes and to control spills. Surface water discharges must be managed in accordance with Laboratory policies and any State and Federal environmental permits that are in place. Depending on previous analyses of radioactivation of soil/groundwater, monitoring wells may be in place, requiring a sampling and maintenance schedule. These considerations are quite similar to those encountered at other Fermilab facilities located in the glacial till.

The cooling water requirements for the Proton Driver are significant. These requirements should be examined to determine if the impact on Fermilab's industrial cooling water (ICW) system requires modifications to the Laboratory's current National Pollutant Discharge Elimination System (NPDES) permit under which these systems are operated. Any chemical additives to these systems must be approved within the framework of existing permits.

18.5 Summary

The Proton Driver provides a number of challenges in the area of environment, safety, and health. Many of these have been encountered, and effectively addressed, at Fermilab and other accelerators. Some of the problems are common to technological advancements in other accelerators worldwide. For these, collaborative efforts should continue to develop and improve the solutions that are needed. This project raises a few new issues that must be addressed. Continued attention to these issues is anticipated as the project proceeds.

18.6 Need for Work on Environmental and Safety Issues

A. The Fire Safety/ Life Safety Code considerations need to be carefully addressed prior to Title I design (Section 18.2.1).

B. The needed environmental permit applications should be developed and submitted at the earliest possible stage (Sections 18.2, and 18.3.2). Specific time requirements for each permit application process are available from the ES&H section, but all permits must be assumed to take at least 180 days.

C. The alternatives to be studied as part of the NEPA process must be identified (Section 18.2.2).

D. Archaeological/historic sites within the footprint project will need to be surveyed (Section 18.2.2).

E. The potential size/type of impacted wetlands and floodplains should be further investigated before the "footprint" of the project becomes completely defined by other constraints (Section 18.2.3). Modifications to the footprint should be considered that would minimize the impacted areas.

F. The cost of environmental compliance, maintenance, monitoring and oversight must be included explicitly in early planning/budgeting processes. This is especially true for projects of this magnitude, where such costs could be several million dollars, and the efforts needed extend for years beyond actual construction. Significant funds may also be necessary to complete studies for preliminary environmental work (e.g., wetland delineations, wildlife surveys, groundwater investigations) prior to project funding *per se* (Sections 18.2.2, 18.2.3, and 18.3.2).

G. The trade-off between control of beam loss in the Linac with additional lateral shielding needs to be better understood (Section 18.4.3.1).

H. The support structures should be located so that they are not above any part of the accelerator enclosures and are shielded by more than "the minimum" amounts of lateral shielding to allow for uncertainties in shielding calculations and to accommodate future upgrades (Section 18.4.3.1).

I. Calculations of airborne radionuclide releases are needed concerning the beam collimation system to establish permitting requirements and demonstrate that operations will be within established regulatory requirements (Section 18.4.3.3).

J. A hydrogeological survey in the vicinity of the planned facility should be conducted to better refine the parameters relevant to groundwater activation prior to the finalization of the design (Section 18.4.3.4).

References

[1] "Fermilab Work Smart Standards Set," Fermi National Accelerator Laboratory, http://www-lib.fnal.gov/library/protect/worksmart.html, November 15, 1999.

[2] United States Code of Federal Regulations, Title 40, Part 61, Subpart H, "National Emissions Standard for Hazardous Air Pollutants (NESHAP) for the Emission of Radionuclides other than Radon from Department of Energy Facilities," 1989.

[3] W. Chou, "Proton Driver", FERMILAB-Conf-00/180, August 2000.

[4] O. E. Krivosheev and N. V. Mokhov, "Tolerable Beam Loss at High-Intensity Proton Machines," FERMILAB-Conf-00/192, August 2000.

[5] A. I. Drozhdin, C. J. Johnstone, and N. V. Mokhov, "Beam Collimation System for a 16 GeV Proton Driver," FERMILAB-Conf-00/194, August 2000.

[6] N. Holtkamp and D. Finley, editors, "FNAL Feasibility Study on a Neutrino Source Based on a Muon Storage Ring," FERMILAB-Pub-00/108-E, June 2000, (http://www.fnal.gov/projects/muon_collider/nu/study/report/machine_report/). The ES&H material has been expanded by J. D. Cossairt in "Environment, Safety, and Health Considerations for a Neutrino Source Based on a Muon Storage Ring," FERMILAB-TM-2112, May 2000.

[7] Code of Federal Regulations, 10 CFR 835, "Occupational Radiation Protection," current version.

[8] DOE Order 5400.5, "Radiation Protection of the Public and the Environment," January 1993.

[9] *Fermilab Radiological Control Manual*, Article 236.