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Executive Summary of Major NuMI Lessons Learned

A review of relevant meetings of

Fermilab's

DUSEL Beamline Working Group

Working Group Members

Mike Andrews, Jeffrey A. Appel , Dixon Bogert, Sam Childress, Don Cossairt,
William Griffing, Nancy Grossman, David Harding, Jim Hylen, Vic Kuchler,
Chris Laughton, Byron Lundberg, Mike Martens, Elaine McCluskey,
Rob Plunkett, Gina Rameika, George Velez, and Bob Zwaska

Occasional Guests

Phil Adamson, Alan Bross, Mike Gerardi, Patrick Hurh, Gary Leonard,
Peter Lucas, and Mayly Sanchez

Representatives from Other Laboratories

Bob Wagner from ANL
Mary Bishai and Milind Diwan from BNL
John Corlett and Mike Zisman from LBNL

Introduction

We have gained tremendous experience with the NuMI Project on what was a new level of neutrino beams from a high power proton source. We expect to build on that experience for any new long baseline neutrino beam. In particular, we have learned about some things which have worked well and/or where the experience is fairly directly applicable to the next project (e.g., similar civil construction issues including: tunneling, service buildings, outfitting, and potential claims/legal issues). Some things might be done very differently (e.g., decay pipe, windows, target, beam dump, and precision of power supply control/monitoring). The NuMI experience does lead to identification of critical items for any future such project, and what issues it will be important to address. The DUSEL Beamline Working Group established at Fermilab has been meeting weekly to collect and discuss information from that NuMI experience. This document attempts to assemble much of that information in one place.¹

In this Executive Summary, we group relevant discussion of some of the major issues and lessons learned under seven categories:

1. Differences Between the NuMI Project and Any Next Project
2. The Process of Starting Up the Project
3. Decision and Review Processes
4. ES&H: Environment, Safety, and Health
5. Local Community Buy-In
6. Transition from Project Status to Operation
7. Some Lessons on Technical Elements

We concentrate here on internal project management issues, including technical areas that require special attention. We cannot ignore, however, two major external management problems that plagued the NuMI project. The first problem was the top-down imposition of an unrealistic combination of scope, cost, and schedule. This situation was partially corrected by a rebaselining. However, the full, desirable scope was never achievable. The second problem was a crippling shortage of resources. Critical early design work could not be done in a timely fashion, leading to schedule delays, inefficiencies, and corrective actions.

The Working Group discussions emphasized that early planning and up-front appreciation of the problems ahead are very important for minimizing the cost and for the greatest success of any such project. Perhaps part of the project approval process should re-enforce this need. The cost of all this up-front work is now reflected in the DOE cost of any project we do. If we are being held to an upper limit on the project cost, the only thing available for compromise is the eventual project scope.

Differences Between the NuMI Project and Any Next Project

The Working Group discussions were based on the recognition that any next project will be different from the NuMI project in important ways:

It is likely that a new long baseline neutrino program will have flagship-program priority, and risk mitigation (which has already risen in importance) will be more critical than it was for NuMI. The more robust designs and quality assurance procedures will require increased engineering effort and increased other costs. Sufficient staff must also be allocated for EVMS reporting.

Decommissioning planning is coming to be a part of DOE expectations, with unknown future standards. The project construction design and operating plans will have implications for the cost of decommissioning, and should be a consideration in the design of a future project.

Any next project will aim to have up to an order of magnitude more beam power on the target than was in the design for NuMI. This has serious implications regarding reliability that must be considered very carefully. Higher power levels can be expected to increase the radiation damage to component materials. It is a high priority to understand the risks of failure, and to mitigate them to the extent possible. At higher radiation levels, it may be that different strategies should be employed from those that have been used in the past. For example, making the most robust component possible and making it a permanent installation may be less desirable than making a more fragile, but easily replaced component. This would imply a need to build more spares and design in remote handling capability. Higher activation levels may preclude repairs.

Special circumstances of low-cost and/or reused elements that were available for NuMI (e.g., access to irradiated steel “blue blocks” for only shipping cost, bend magnets and related power supplies from existing stock for the larger bend angle to DUSEL) may not be available for a next project.

Most of these differences in a next project relative to NuMI render cost projections based on simple use of the NuMI experience to be underestimates.

The Process of Starting Up the Project

Properly managing the start-up process for the project is critical to avoiding unnecessary changes, reworking, and extra costs. It is important to:

Have a more nearly complete design team in place at the beginning of the project than was the case for NuMI. Given the interrelation of so many design elements; e.g., technical and civil-construction components, the team needs to include not just scientists with multiple interests, but also engineers from all the disciplines, designer/drafters, ES&H professionals, a modest project management team, and others. The beamline has many integration issues between the technical systems and the civil construction. These should be identified early so that the technical systems can be designed and installed with minimum cost and schedule risk. For challenging new types of efforts which are very different from our previous experience, it is very

important to both appreciate the differences, and then expand our experience capabilities beyond those already on the staff accordingly.

Have the beam specification early. It should not change during the project. If the possibility of change is significant, the range of changes possible should be part of the initial specification. The specification should include beam tolerances based on their effect on the experiment's systematic errors.

Do risk management project-wide and from the start.

Identify critical technologies early and start R&D early. Front-end loading the R&D (especially on targeting, tunneling, and radiological mitigation) will reduce risks and costs.

Review radiation exposure and environmental release limits, and make them a part of the specification before designs are begun. Similarly, specify maximum down times allowable during scheduled operations and what can be accepted without having a repair and/or replacement capability (e.g., decay pipe and beam dump, if so). More generally, understand (at design time) the operational modes including recovery from failures.

In the early planning, ensure that the project scope as defined can be done for the anticipated allowed cost. Designing to cost is the typical reality, but limits the utility of the facility. Designing longer lifetime for un-exchangeable parts in anticipation of exploitation of facilities beyond original plans is wise. The DOE even recognizes and rewards reusing facilities in its reviews and awards programs. For example, cathodic protection may be required for piping, though an initial specification on longevity of the facility might not require it.

Plan to increase the use of benchmarks and independent validation of key elements of civil construction, of beam design, and of technical components.

The NuMI program has met the anticipated up time over the four years of operation, in spite of well publicized problems. Much of this achievement was the result of "heroic" efforts to repair failed elements while not exceeding radiation-exposure limits or technician endurance. A bit of good fortune was also experienced. This will be harder still, if not impossible, with the increased proton intensity on next generation systems. NuMI was said to be often "one failure away from major down time". Spares and/or a much more elaborate repair facility need to be specified at the start, with remote handling capability engineered into the facilities and components from the start.

A tunnel that is too small, inadequate utilities, limited shielding, un-maintainable equipment, and so forth will all come back to haunt us as we push any additional uses of the facility and the future limits of the intensity frontier.

Decision and Review Processes

All major decisions benefit from internal and/or external reviews. Detailed internal reviews of specific technical issues can be short enough to be efficient, yet detailed enough to be useful. DOE reviews tend to be focused on compliance with DOE procedures, and useful to the DOE to find holes in management or technical processes. However, such reviews are typically only capable of doing sampling, enough to find systemic problems. Technical problems are not the focus of management reviews, and the DOE has begun to ask that technical reviews be held independently from their reviews.

In any case, people with strong technical backgrounds must be in positions to impact decisions. Cost alone should not drive decisions. Reliability, ease of operation, and future operating costs are some other relevant factors which should influence decisions.

ES&H: Environment, Safety, and Health

The current Laboratory Integrated Safety Management System does reduce injury rates and costs. Beyond the formal program, Laboratory management liaison with all levels of the subcontractor team is needed early to ensure our ES&H culture is understood and accepted. This is especially important in the realm of underground work conditions.

There is utility in explaining to everyone the relationships of the physics goals, the technical components, and the civil construction. This explanation should be made to both subcontract workers and supervisors. Among other things, it builds relationships, avoids mistakes, and improves morale on the project.

Our experience is that facilities run longer than initially envisioned. This further increases the already critical importance of mitigation of radiation problems, and planning for this mitigation should be done starting up front. This includes consideration of not only tritium, but also more generally air flow, etc. The migration of radiation-induced activation must be followed through the full lifetime of the facility operation.

Design proper air handling systems early, including enough room (and perhaps contingency space) for such systems. Consider use of inert gas in high air ionization areas. Make a radiological monitoring plan for the tunnels and components that will work for the duration of the operation period.

Compliance with the National Environmental Policy Act (NEPA) is now a bigger concern than it was for NuMI. More recent experience with NOvA points to the need for NEPA planning from the start of the project. The required Environmental Assessment has to be done in a way that accomplishes its milestones in harmony with regulatory requirements beyond the control of the project, Fermilab, or even DOE.

The radiological and environmental implications of operation beyond the initial scope of the project are significant, and should be recognized and considered in the development phase.

Local Community Buy-In

Given that the beam line and near detector hall will extend to the site boundary, there will be proximity to the Woodland Hills subdivision. So, it is important to work with that community and others affected by the anticipated construction. The Laboratory's community outreach activities have developed since the NuMI project, and the main point is to start outreach communications well before the project is approved.

Transition from Project Status to Operation

It has been typical to define project completion at a low level of technical achievement, culminating in readiness for installation or simple installation and powering in order to minimize on-project costs. Since staff and funding tied to the project tend to evaporate even before the formal completion of a project, it is critical to plan for the transition from project to operations. This includes having the right people available for debugging and commissioning, having the necessary training and documentation in place, and having the funding of all this effort in place before the transition begins. It is also important to recognize that even first real operation does not resolve all the issues that will arise with time during operations.

In the case of NuMI, the NuMI Department was dissolved before operations were fully established. "Project people evaporated at the end of the project."

The transition to operations needs to be a part of the project planning process: including documentation and training in the Work Breakdown Structure and cost estimates, doing risk analysis for operations from the start of the project, involving operations personnel in the design effort (and, not just in reviews).

Spares which take extended time to build need to be available at the start of operations, not just planned for as a part of operating costs following expected lifetimes. Early failures at NuMI included the target system and horns. Later, anticipated lifetimes were met or exceeded, but "infant mortality" requires spares availability early.

Some Lessons on Technical Elements

The following items were called out as especially important lessons learned from the NuMI experience:

- Improve drain access in tunnels and halls for inspection and maintenance.

- Shotcrete, if not concrete, should be applied to all exposed rock surfaces.

- R&D is needed to understand radiation-induced damage to a new target system. This could involve testing in beams at reactors or the Spallation Neutron Source or in test beams (for instance expanding Nick Simos' studies at the Brookhaven Linac Isotope

Producer, BLIP). Autopsies of the NuMI targets which have seen substantial beam could supply the most relevant information if we continue with graphite targets. The baseline design should only use parameters of which we are certain.

Avoid use of high-strength steel components susceptible to stress corrosion (cracking in radioactive, humid environments) unless all load and environmental factors (such as products of air ionization) have been taken into consideration.

More generally, understand radiation-accelerated corrosion; doing early R&D including serious environmental monitoring at NuMI and studies of effects on coating, plating, and new materials. Consider possible deterioration of horn systems, the decay pipe, and windows. Consider the pros and cons of replacing air with inert gas in the high radiation areas of target pile, decay pipe, and beam dump.

The possible use of Main Ring B2's, now 40 years old, needs to be reviewed and a cost-benefit analysis done of reuse, with possible need to de-bond and re-pot the coils, versus building new pulsed magnets (possibly Main Injector type dipoles with less costly operation).

With ten times the protons on target, a next design will need to understand the tails on the beam ten times better. There is a need now to refine the knowledge of uncertainties in what is known, and how these might affect the design of a new facility.

Plan fully and early for operational activities involving radioactive component handling, including providing enough room in underground storage/repair areas to support operational needs.

Beam commissioning and tuning elements for DUSEL intensities

- need redundancy for primary beam instrumentation (both of elements and technologies; e.g.: BPMs, profile monitors, toroids, wall monitors, and more if possible)
- need redundancy for secondary beam instrumentation (both of elements and technologies; e.g.: hadron monitor, in-chase ionization chamber, baffle temperature, Budal monitor, muon monitors, etc.)
- develop devices early, and test them in the NuMI line in the NOvA era.
- software needs to be ready before beam commissioning, and should be tested in advance
- software should be convenient to use on line, and detector responses need quick calibration for this to work
- software should be developed to examine correlations among the various monitors
- if the near detector is to be used as a monitor, dependence on calibration and alignment should be minimized and/or rapid calibration and alignment possible

Finally ...

A great deal of detail beyond what is in this executive summary is available from the presentations and discussion summaries of the 28 DUSEL Beamline Working Group meetings. These are available on the web from

<https://beamdocs.fnal.gov/SNuMI-public/DocDB/ListTopics>

The individual meetings, topics, and presenters are listed here by topic, starting with more general topics and then going in the order of things as one proceeds down the beamline, to facilitate looking at particular topics:

Management

- 6/2 Overview: What we want; What we did.
Gina Rameika
- 12/8 Management
Dixon Bogert (with comments from Greg Bock)
- 10/13 Public Liaison
Judy Jackson
- 11/17 Legal/Contract Management
Gary Leonard
- 11/17 DOE view
Steve Webster
- 2/9 Davis Bacon and Union Issues in Construction Projects
Dave Carlson and Gary Leonard
- 3/9 Oversight and Reviews and Preparing for Them
Dean Hoffer
- 6/23 Personnel Needs to Get to CDR for DUSEL Beamline
Gina Rameika

ES&H: Environment, Safety, and Health

- 9/22 ES&H Experience
Don Cossairt and Mike Andrews
- 1/12 Underground Access and Safety
Mike Andrews and/or Chris Laughton
- 10/20 Radiology
Byron Lundberg
- 10/27 Tritium Mitigation
Rob Plunkett

Civil Construction

- 6/9 Siting Considerations for DUSEL Beamline
Dixon Bogert

- 9/15 Issues Working Underground
Chris Laughton and Tom Lackowski
- 1/12 Underground Access and Safety
Mike Andrews and/or Chris Laughton

Primary Proton Beam

- 6/23 Beam Power from the Main Injector and at 8 GeV vs MI Energy
Bob Zwaska
- 9/29 Systems Integration and Extraction/Primary Beam
Sam Childress
- 11/3 Magnets
Dave Harding
- 11/10 Geodesy and Alignment
Virgil Bocean

Neutrino Beam

- 3/16 Constraints on Hadron Production from the MINOS Near Detector
Zarko Pavlovic
- 8/25 Target, Horns, and Their Enclosure
Jim Hylen
- 9/08 Decay Pipe/Window and Cooling
Dave Pushka
- 1/26 Decay Pipe, Absorber, and Bypass
Cat James
- 2/23 DUSEL Beamline Design: A Tale of Tails
Mary Bishai

Beam Monitoring

- 12/15 Beam Monitoring
Sacha Kopp
- 11/10 Geodesy and Alignment
Virgil Bocean

Near Detector and Physics

- 1/5 Physics Flexibility
Mary Bishai
- 3/2 Use of Near Detector in MINOS ν_e Appearance Measurement
Mayly Sanchez
- 3/16 Constraints on Hadron Production from the MINOS Near Detector
Zarko Pavlovic

Visit to Neutrino Beam Facility at J-PARC

3/23 J-PARC Visit Report

Jim Hylan and Sam Childress

4/6 Continuation of J-PARC Visit Report

Jim Hylan

Footnotes

1. The individual presentations, meeting summaries, and related documents from the DUSEL Beamline Working Group are available on the web under the DUSELBWG heading from
<https://beamdocs.fnal.gov/SNuMI-public/DocDB/ListTopics>