Introduction

The Neutrino experimental area underwent a large functional upgrade this past summer and fall. Anyone driving down Road A between the Neutrino and Meson Areas in the period July - October would have seen the evidence in vast heaps of earth and long deep trenches. The purpose of this article is to describe the projects undertaken and what they will accomplish in the near term (400 GeV) and longer range (Tevatron II) lepton scattering programs at Fermilab.

There were three projects undertaken. All had to be mutually coordinated because each interacted in a fundamental way with the others. The projects were Neutrino Target Hall Extension, Neutrino Muon Absorber Shield Upgrade, and N7/N3 Beam Relocation. The projects are shown schematically below. We will describe them in turn.

Symbolic view of summer 1980 Neutrino construction projects.
Target Hall Extension

Much of the neutrino experimentation in recent years has been concentrated in long runs for precision experiments using the dichromatic neutrino spectrum that comes from the Fermilab narrow band target train. These experiments exploit the weak-decay kinematics associated with a narrow momentum band of hadrons emerging in a very parallel beam into the long vacuum decay pipe. Typically, the momentum of the hadrons is high (several hundred GeV) and the resulting neutrinos have high energies that are correlated with their angles of emission in the decays and hence with the observed event location in the detectors.

The technical realization of a target train that meets the difficult optical conditions implied by the above criteria, that will minimize unwanted low-energy neutrinos from decays within the target train (wide-band background), and that will provide a long-lived and reliable target system was found to be impossible within the physical constraints of the existing target tube. An interim approach to the problem was taken in the past, namely, the last criterion (reliability) was compromised in hopes that the first two could be met. The Target Hall Extension (Front Hall) was designed as a long-term solution to the problem, allowing all three design criteria to be successfully met in a single train design.

In addition to its function in upgrading the reliability of current energy trains, the new extension was carefully designed to be compatible with the needs of narrow-band neutrino beams of energy up to 750 GeV. This criterion was, of course, imposed in anticipation of a Tevatron-era neutrino program. The same principles that led to increased reliability of the current trains also allow a programmatic extension without modification to Tevatron-era energies. We have tried to implement this principle in all our current projects so that no further changes will be necessary when the Tevatron is approved and the energy ranges are doubled.

The target hall extension consists of a 122-meter tunnel reaching south from the upstream end of the existing target hall (Neuhall). The tunnel was formed of precast concrete pieces and has a cross section of rectangular shape 3.0-m wide and 2.4-m high (see figure at the top of the next page). The new tunnel slopes downward toward the accelerator at a 1% grade, corresponding to the slope of the proton beam as it rises from the Main Ring elevation to that of the NO line. The south terminus of the new tunnel replaces Enclosure G3 forming a continuous hall from G3 to the existing target tube.

Under the 60-m section nearest Neuhall, a large gravel-filled pit with an impermeable plastic liner (bathtub) underlies the new tunnel. This arrangement allows a new target station and beam dump to be located at this point while safely protecting the Laboratory water table from radionuclides produced by neutrons in
the bathtub soil. Forward-going hadrons not captured in the beam dump will be stopped by massive shielding doors that come together around the beam pipe in the transition section between the new tunnel and Neuhall.

The ability to target high-intensity proton beams in Front Hall has several favorable consequences: longer decay path for high-energy beams, lower overall bending requirements for dichromatic beams, and increased reliability and serviceability for dichromatic trains.

The new Front Hall is serviced by a set of narrow-gauge railroad tracks incorporated in the existing Neuhall-Target Tube-Target Service Building rail network. Switches allow target and beam-focusing trains to be placed anywhere along the track network. Electric power and cooling water are supplied along the tunnel walls and ceiling from the existing N1 Service Building adjacent to Neuhall. The entire Front Hall tunnel is covered by a large earth berm of minimum thickness 4.0 m to shield outside areas from radiation produced by targeting of the external proton beam.

**Neutrino Muon Absorber**

From its inception, the earthen neutrino muon shield has suffered from a basic problem caused by the location of a hadron beam in the critical volume of the shield. The beam pipe for
this beam and about 125 m of magnet-enclosure tunnels were placed astride or adjacent to the centerline of the muon shield, giving rise to a "Swiss cheese" effect that significantly lowered the stopping power of the shield and frustrated attempts to monitor the muon fluxes in the berm, and hence the neutrino fluxes.

A perfect earthen shield without holes would have stopped muons up to about 500 GeV (less at the Wonder Building). Various attempts to improve the shielding, especially at the Wonder Building, were made. At an early point in the neutrino program about 4,000 tons of steel were placed in the earth berm immediately upstream of the Wonder Building to increase its stopping power and to lower muon fluxes. This worked at accelerator energies up to about 350 GeV but failed at 400. Since neutrino fluxes and event rates climb quickly with energy, it was highly desirable to improve the shield further.

With the decommissioning of the Argonne ZGS, a large quantity of steel became available to help solve this problem. The solution is shown at the right. A large, roughly cylindrical steel stack of minimum diameter 3.6 m and total length 139 m has replaced the Swiss cheese area of the berm. The shield is divided into three sections of length 36, 67, and 36 m, respectively. There remains room to add up to 70 m more steel with a smaller cross section inside existing Enclosure 100 at some future date.

The new shield contains about 20,000 tons of steel from Argonne plus 4,000 tons that were mined from the earlier position upstream of the Wonder Building. As can be seen in the figure, there are two transverse gaps in the shield which will be used for muon flux monitoring. Now that the shield is homogeneous and regular in shape, it will be possible to use muons to measure and monitor the neutrino flux spectrum for the first time at Fermilab.

The new shield has already been tested at 400 GeV. It is a complete success. Formerly, there were muon fluxes of 300/m² per pulse per 10¹³ protons on target in the Wonder Building. Now there are about 7.5 muons/m² at the same proton intensity. The earlier number was measured at 350 GeV. At 400 GeV, it would have been an order of magnitude higher!

The improved shield is already paying dividends with the current experiment (E-531) in the Wonder Building. It will continue to pay dividends in the future as the Energy Saver and
Tevatron eras arrive. The muon shield should now be good for muons up to 700 GeV at the location of the Fermilab 15-ft bubble chamber. With the added steel in Enclosure 100, this will be raised to about 800 GeV. Such a shield will be adequate for neutrino experiments with primary proton energies up to 1 TeV.

**N7/N3 Beam Relocation**

Completion of the shield upgrade mandated a change in the N7 proton beam line in order to continue use of the N3 and N5 secondary hadron beam lines. The third major project accomplished the relocation of the N7/N3 line out of the shield region of the berm and established a new target station for hadron beams in an extended and newly shielded Enclosure 103.

When the accelerator is upgraded to 1 TeV, the new N7 line will transport accelerator-energy protons most of the way to a prompt-neutrino facility planned for the area just south of Lab E. The remainder of this new beam is planned for construction in summer 1982 in a second upgrade project.

The present project consists of a new section of vacuum pipe 770-m long extending from Neuhall to Enclosure 103 plus upgrade of this enclosure and others in the N3 beam line. The 103 enclosure has been converted from an above-ground beam-handling enclosure of length 32 m to an underground shielded target area of length 77 m with focusing capabilities for the incoming proton beam and focusing and collimation elements for the secondary beams N3 or N5 (they have a common front end). Most of the N3 beam-handling enclosures downstream of 103 had to be extended or relocated to accommodate the new beam optics. All of these changes were grouped under the N7/N3 relocation project.

The new Enclosure 103 was created by adding reinforced concrete walls to the existing part of the enclosure plus the addition of 35 m of 2.4 m by 3.0 m rectangular precast concrete tunnel sections. The entire enclosure was covered with 3.0 m of earth. A rail system similar to that used in Front Hall and Neuhall is combined with a small railroad turntable to provide accommodation and handling of the beam magnets, collimators, and dump.

The Enclosures downstream of 103 that had to be extended or otherwise changed were constructed of stacked shielding blocks (again a gift from the decommissioned Argonne ZGS), which had the dual advantages of low cost plus transverse beam shielding capability. Impermeable plastic membranes were added to the shield block roofs to make them weathertight and the enclosure ends were closed with fabricated metal ends as needed. New beam-pipe sections and cable trays were added as required. A schematic sketch of the new N3 beam line is shown at the top of the next page.
The newly reconstructed N3 beam line will have all the capabilities of the old one for meeting the planned 30-in. bubble chamber program and will be easier to operate and maintain due to several simplifications introduced in the new design. The completion of the N3 transport is expected in mid-January 1981 in time for testing targeting, optics, and yields prior to the planned March shutdown. When the accelerator resumes operation in late March, the N3 line will be operated for experiments 565, 570, and 597 in the 30-in. bubble chamber.

The new beam via its N5 branch will also have the capability for making calibration beams of hadrons for the neutrino area spectrometers and the 15-ft bubble chamber at any time these beams are required. As noted above, in the summer of 1982, the N7 primary proton transport will be extended to a prompt-neutrino beam-dump target and prompt-neutrino facility. The prompt-neutrino facility would be ready to accept 1-TeV protons in 1983.

Summary

The three projects just described represent an enormous amount of careful planning and hard work, not only on the part of the Neutrino Department staff, but also from the people in Architectural Services, Safety Section, Alignment Services, T & M
Services, Business Services, and others. Our grateful thanks go to them for their expert help. We were also fortunate in having two very good general contractors, Martam and Reliable, who carried out the earthmoving and structural work with excellent speed and capability. The steel stacking was done by rigging crews from Rodseth, the Fermilab rigging contractor. This work also went forward with speed and excellent cooperation.

All told, the project was completed exactly on time, within budget, and with no serious mishaps or personnel injuries. The present physics capabilities of the Neutrino Area have been improved significantly by the work and the way has been prepared for Tevatron-era operation in a few years. We are proud and happy with the result and hope that this project portends a smooth way that future projects will go.

A Sunday break from the furious pace of construction that transformed large parts of the Switchyard and Neutrino Target Area during the July-November accelerator shutdown.

(Photograph by T. Kirk)
Leon Lederman awarding diplomas to the first Saturday Morning Physics class.

(Photograph by Fermilab Photo Unit)