2014 ALARA Activities at DOE

At the Fermi National Accelerator Laboratory (Fermilab), a policy consistent with integrated safety management (ISM) and in accordance with 10 CFR Part 835 requirements is to conduct activities in such a manner that worker and public safety, and protection of the environment are given the highest priority. Fermilab is committed, in all its activities, to maintain any safety, health, or environmental risks associated with ionizing radiation or radioactive materials at levels that are As Low As Reasonably Achievable (ALARA). Likewise, Fermilab management supports related work planning and review activities in support of the ALARA program.

During 2014, the primary activities at Fermilab that resulted in occupational radiation exposures were upgrade and repair activities of the Fermilab accelerator. Nearly all radiation doses to personnel were due to exposures to items activated by the accelerated beams. During the fall of 2014, Fermilab had a 6 week shutdown, with a one-week contingency, for a total of 7 weeks. The shutdown timing was driven by Commonwealth Edison Company's mandatory distribution system work.

Work was performed in Proton Source, Booster, Main Injector, and Recycler to accommodate higher intensities and higher Booster injection energy. Many of the repairs and upgrades made during this shutdown were also intended to improve operational reliability and hence, reduced maintenance needs in the future. Additionally, Proton Improvement Plan-II supports longer term physics research goals which will deliver increased beam power to the Deep Underground Neutrino Experiment (DUNE). DUNE will provide experimenters with the most powerful means to study neutrinos.

The shutdown provided the opportunity for upgrades to Neutrinos at the Main Injector (NuMI) which supports Main Injector Neutrino Oscillation Search (MINOS) and NO*v*A experiments. The MINOS experiment is a long-baseline neutrino experiment designed to observe neutrino oscillations. MINOS uses two detectors, one located at Fermilab and the other at the Soudan Underground Mine State Park in Tower-Soudan, Minnesota. The NO*v*A experiment is designed to search for oscillations of muon neutrinos to electron neutrinos by comparing the electron neutrino event rate measured at the Fermilab site with the electron neutrino event rate measured at a detector near Ash River, Minnesota.

Shutdown work included renovations to infrastructure needed to support the Muon Campus Program which is comprised of the Muon-to-Electron Conversion Experiment (Mu2e) and Muon g-2 Experiment (g-2). These experiments use former antiproton source infrastructure. Mu2e will probe with excellent precision measurements required to characterize the conversion of electrons to muons as part of the Intensity Frontier. Muon g-2 will explore the interactions of muons with a strong magnetic field to determine fundamental properties of nature.

Booster Neutrino Beam supports MicroBooNE, SeaQuest, and the Fermilab Test Beam Facility (FTBF). The MicroBooNE experiment measures low energy neutrino cross sections. The Fermilab SeaQuest experiment is part of a series of fixed target Drell-Yan experiments designed to measure the quark and antiquark structure of the nucleon. FTBF uses secondary beamlines to provide beam for a host of energy ranges and particle types.

1. ALARA Job Planning Prior to Shutdown

As with all maintenance and upgrade shutdowns, it is recognized that many of the repairs to be performed must be conducted in intense radiation fields dominated by gamma rays due to induced radioactivity from years of operation at high intensities. The Fermilab Accelerator Division (AD) established a task review process that requires all work to be performed in the accelerator to be entered into a database for review by all of its support departments. This initiative improves efficiency by preventing scheduling conflicts and also affords the AD Environment, Safety, and Health (ESH) Department the opportunity to identify those radiological tasks that require special attention or might represent other environment, safety, and health issues needing mitigation.

During this shutdown, the majority of tasks were successfully performed with lower collective dose than originally planned by implementing ALARA dose-saving measures such as careful planning, conducting dry runs for hot jobs, and ongoing input from task supervisors and individual workers on how to optimize ALARA as the work proceeded. The shutdown coordinator, radiological control technicians, and workers spent much effort to modify work schedules and procedures to reduce collective dose.

2. Summary of Collective Dose to Personnel

The total collective dose for this shutdown was 3,400 person-mrems. Individual radiation doses for workers who received dose were tracked during the 2014 shutdown. Nearly 70% of shutdown workers received 25 mrem or less. Fifteen percent of the workers received between 26 mrem and 50 mrem. The remainder of the dose was distributed among 22 workers. These workers received between 51 mrem and 150 mrem. *Exhibit 1* illustrates the dose distribution per number of workers for the 2014 shutdown. *Exhibit 2* summarizes the total collective dose received during this shutdown.

3. Summary of Fermilab ALARA Activities

The following activities highlight the continued commitment to keeping exposures ALARA at Fermilab.

3.1. Booster

The Booster is the first circular accelerator, or synchrotron, in the chain of accelerators at Fermilab. It consists of a series of magnets arranged around a 75-meter radius circle. Proton beams enter the Booster from the Linac, accelerating to an energy of 8 GeV.

Exhibit 1:
Numerical Distribution of Shutdown Workers in Terms of Dose Received in 2014

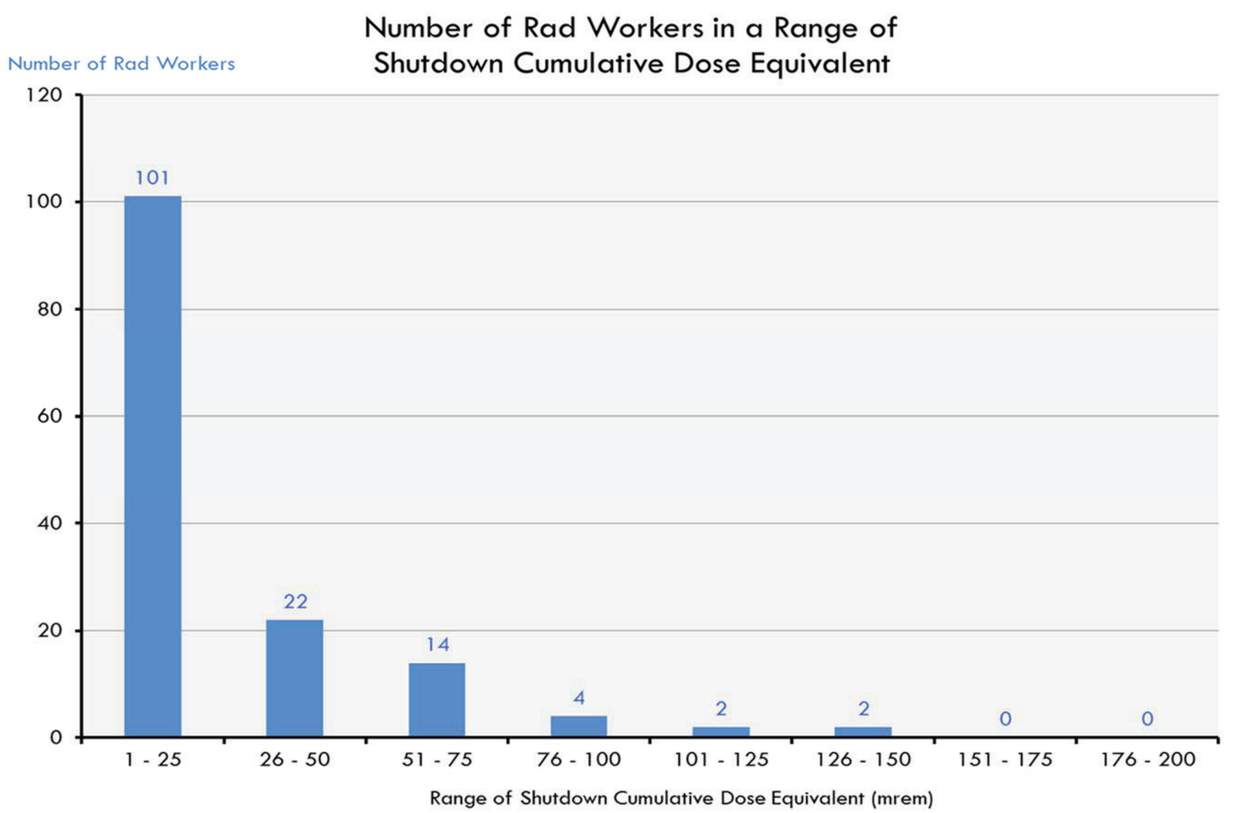
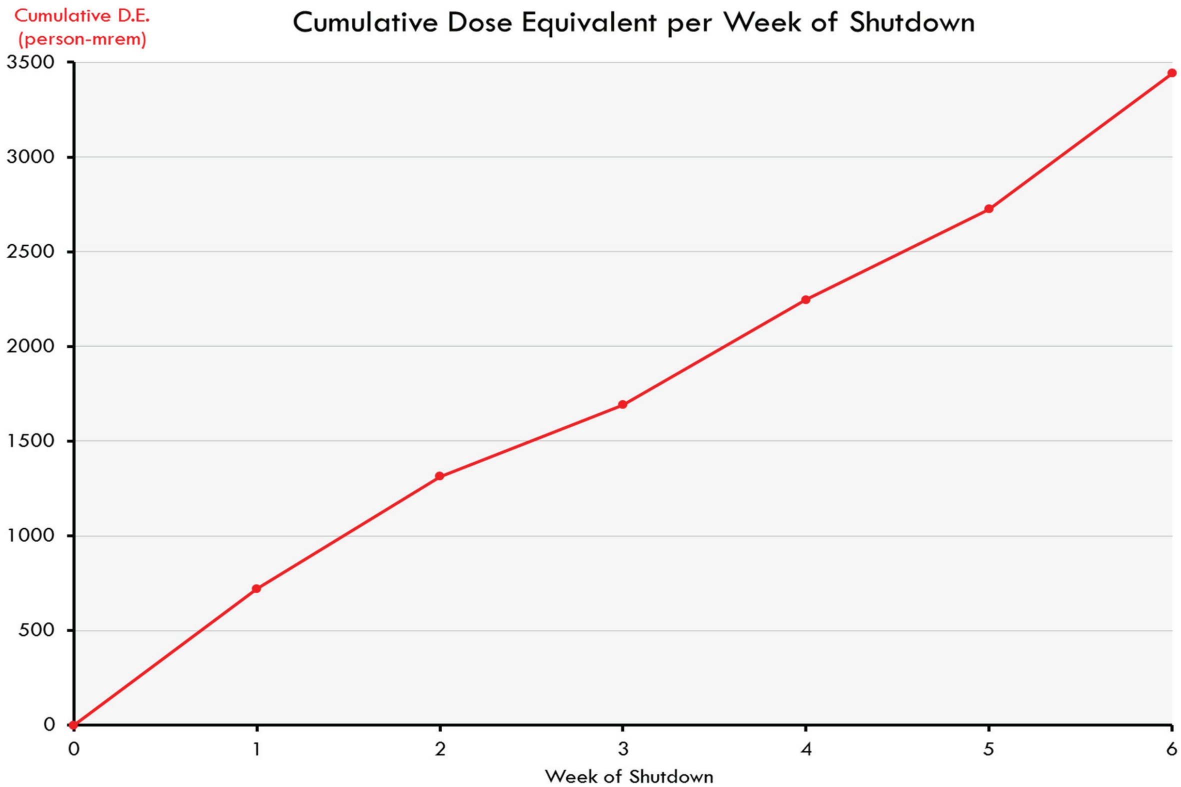


Exhibit 2:
Numerical Distribution of Shutdown Workers in Terms of Dose Received in 2014

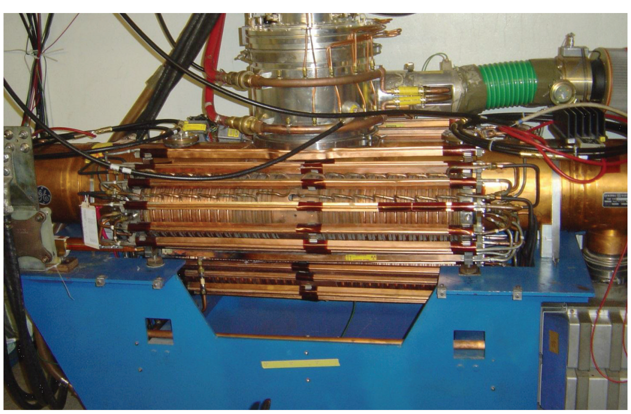


Shutdown upgrades to the Booster include repair of Booster magnets, cabling, turbo pump replacements, and conversion of Booster radio-frequency (RF) stations to solid state.

1. Booster Radio-Frequency Station Upgrades

   During the shutdown, Booster tunnel RF cavity upgrades continued. (*Exhibit 3*) It takes about 8-12 weeks per cavity for refurbishment. Upstream RF cavities are more radioactive than downstream cavities. There was approximately one year of work to complete the refurbishment of all 19 RF cavity stations. The estimated collective dose with cool down of the accelerator was 1,536 person-mrems for the entire year of work. The actual collective dose was 1,403 person-mrems.

Exhibit 3:
Booster RF Cavity



2. Booster Cable Pulls

   Cables were pulled and replaced around the entire Booster tunnel during the 2014 shutdown. The average dose rate was 2 mrem/hr, but there were 2 areas that were posted as radiation areas. For cable pulls in these areas, cables were set up outside the radiation area, then rapidly pulled to minimize time in the area. The estimated collective dose was 128 person-mrem and the actual collective dose received by workers was only 65 person-mrem.

3. Booster Corrector Magnet Replacement

   Corrector magnets in the Booster are also called "bend," "trim," or "dipole" magnets. The function of corrector magnets is to bend the proton beam in either a horizontal or vertical direction. (*Exhibit 4*) Corrector magnet L1 failed and had to be replaced. Corrector magnet S12 had to be replaced with a corrector with a larger aperture. The collective dose estimate for L1 corrector replacement was 22 person-mrem and the actual collective dose received was 20 person-mrem. The collective dose estimate for S12 was 93 person-mrem and the actual dose received was 53 person-mrem. The reason for the difference in the collective dose estimate and the actual dose received for the S12 replacement is that dose rates decreased more than anticipated after the magnet that failed was removed from the area.

4. Booster Turbo Pump Replacements

   A total of 24 new 400 MeV turbo pumps, vacuum controllers, and associated cabling were installed to replace old turbo pumps in the Booster. The collective dose estimate for this work was 98 person-mrem, but because the work went twice as fast as predicted, the workers only received a collective dose of 44 person-mrem.

Exhibit 4:
Booster Corrector Magnet

3.2. Main Injector – Recycler Work

The Recycler is a storage ring for proton beams after they exit the Booster. Proton beams in the Recycler are combined into batches to form a more intense proton beam. The Main Injector (MI) is a synchrotron accelerator with a circumference of 3319 meters and is located directly under the Recycler in the same tunnel. The MI accelerates proton beams from 8 GeV up to 150 GeV. Several upgrades to the MI-Recycler were made during the 2014 shutdown.

1. Main Injector Microwave Detector Removal

   One of the tasks conducted during the shutdown was removal of 2 microwave detectors that were located near quadrupole magnets located at MI regions 201 and 202. These detectors were leaking and subsequently caused dose rates to be higher at these locations in the Main Injector. The dose rate in this area was 170 mrem/hr at 1 foot from the quadrupole magnet. Radioactive contamination was also present. Removal of the microwave detectors required a cutting fixture and a band saw. These items became contaminated, but were placed in radioactive waste bags to prevent cross-contamination. One of the microwave devices measured 80 mrem/hr at 1 foot upon removal and it was also bagged to prevent cross-contamination. The collective dose estimate was 158 person-mrem, but the actual collective dose received to 5 workers and a Radiological Control Technician (RCT) was 49 person-mrem. Efficient work and use of ALARA principles resulted in a lower collective dose to these workers.

2. Installation of Phase 1 Main Injector 52 Extraction Line

   This large upgrade involved installation of a new extraction line in the MI52 region to the P150 line. The highest dose rate was 100 mrem/hr at 1 foot, but many areas measured 20 mrem/hr at 1 foot. Lead blankets were placed at the highest dose rate levels to reduce personnel doses. A lead reticulating wall was placed in front of septa to reduce rates to a few mrem/hr. After all lead shielding was in place, all dose rates were at or below 10 mrem/hr at 1 foot. The collective dose estimate for this upgrade was 799 person-mrem. The actual collective dose received was 845 person-mrem. The actual collective dose was higher to the 34 workers and the RCT because tasks took more time than anticipated due to unforeseen complications, but it was still well within the 25% contingency collective dose of 998 person-mrem.

3. Recycler Lambertson Beam Box and Flange Replacement

   The Recycler Lambertson magnet located in region 232 needed a beam box and flange replacement. (*Exhibit 5*) Lambertson magnets are used to transport two beams at once, one of which is deflected by the field, while the other beam is not. The old box had to be cut out using a sawzall. Because there were fragments from the sawing operation, a vacuum specifically designated for radioactive materials was used to collect the fragments. The highest dose rate on the upstream end of the Lambertson magnet was 80 mrem/hr at 1 foot. The dose rate on contact measured 1,000 mrem/hr. The pre-job ALARA plan was based upon an estimate of 4 person-hours to conduct the alignment survey. However, due to unanticipated difficulties encountered, the work required almost 40 person-hours. Thus, the collective dose estimate for the alignment portion of the task was 60 person-mrem, but the collective dose received was 109 person-mrem. The estimated collective dose was 486 person-mrem. Even with these and other unforeseen complications, the actual collective dose was 594 person-mrem which was within the 25% contingency collective dose of 607 person-mrem.

4. V904 Magnet Replacement

   A special magnet called the V904 in the extraction beamline near MI region 304 was replaced. Dose rates in the area near this magnet varied between 15 mrem/hr to 20 mrem/hr. This magnet had never been replaced, so this was the first time this task had ever been conducted. Because the magnet was taller than other magnets, it had to be lifted using slings instead of the original plan to use a forklift. Even with the unfamiliar task, the collective dose received by workers was 153 person-mrem compared with the estimated collective dose of 202 person-mrem.

3.3. Main Injector – Recycler Work

The NuMI beamline uses protons from the Main Injector to produce an intense beam of neutrinos which are utilized for experiments. Several NuMI upgrades accomplished during the 2014 shutdown are described below.

1. NuMI Target Station Fan Filter Removal

   During this shutdown, pre-filters in the NuMI target hall air handling unit were changed. (*Exhibit 6*) The filters measured 20 mrem/hr at 1 foot outside of the filter housing. The filters were placed in bags and workers had to handle these bags which measured 70 mrem/hr at 1 foot. The collective dose estimate was 20 person-mrem and the collective dose received was 14 person-mrem.

Exhibit 5:
Region 232 Lambertson Flange and Beam Box Replacement

Exhibit 6:
NuMI Air Handling Unit

2. NuMI Coupon Replacements

   The coupon carrier downstream of Horn 2 in the NuMI target chase was removed and new coupons were inserted. These coupons are comprised of various types of steel and aluminum samples that are used to study corrosion rates under irradiation conditions in high radiation environments. (*Exhibit 7*) The power strip line had to be removed in order for the carrier basket to be accessible. The basket was lifted, coupons were inserted, and the carrier was replaced. The most time consuming portion of this job was removal and replacement of the power strip line. The general area dose rate was 20 mrem/hr. The carrier basket measured 600 mrem/hr at 1 foot and 800 mrem/hr on contact. Because there was potential for contamination, workers wore protective clothing and digital dosimetry to monitor their dose. The estimated collective dose was 51 person-mrem and the collective dose received was 45 person-mrem. This estimate agreed closely with the actual collective dose.

3. NuMI Horn 1 Flapper Valve Replacement

   "Horns" are focusing devices for high energy charged particles emitted from a target struck by a high intensity proton beam. The Horn 1 flapper valve, a device for managing the flow of cooling water to NuMI Horn 1 failed, so it was replaced during the shutdown. (*Exhibit 8*)

Exhibit 7:
NuMI Coupons in Carrier Basket

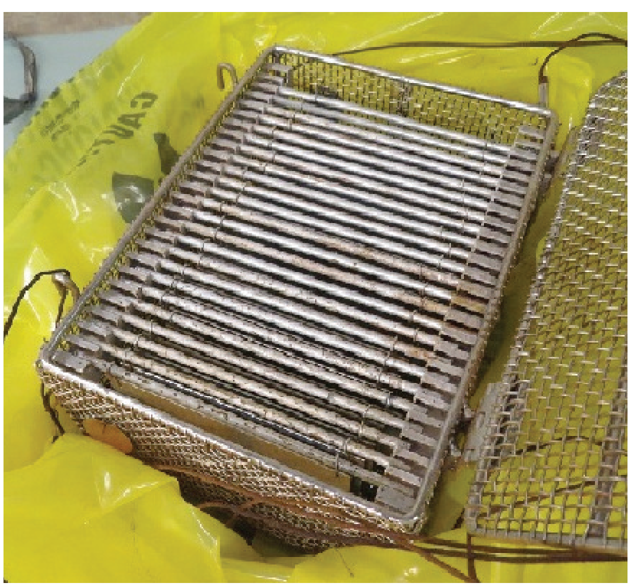
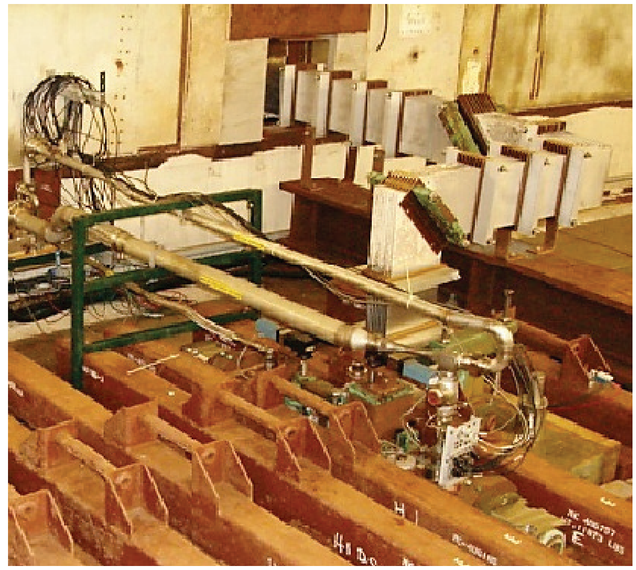


Exhibit 8:
NuMI Horn 1 in Chase



   The area was considered to have loose contamination, so workers wore full protective clothing for the duration of this work. The general area dose rate was 80 mrem/hr. Dose rates were lower than estimated after the chase was uncovered, so the ALARA plan was modified. The original collective dose estimate was 164 person-mrem, but it was revised and lowered to 37 person-mrem. The total time for the work was also less than anticipated. The collective dose received was 35 person-mrem.

4. NuMI Beryllium Window Vacuum Pipe Replacement

   Because a vacuum pipe with a beryllium window was leaking, it was removed from the target chase wall in the NuMI pre-target area. Because there was a potential for radioactive contamination, workers wore protective clothing, booties, and gloves. The dose rate directly in line with the beryllium window measured 80 mrem/hr at 1 foot. Measurements taken on the vacuum pipe downstream from the window were between 15 mrem/hr and 20 mrem/hr. Once the pipe was removed, it was encased in plastic to prevent contamination of other surfaces. (*Exhibit 9*) The estimated collective dose was 5 person-mrem and the actual collective dose was 4 person-mrem.

Exhibit 9:
NuMI Beam Tube with Beryllium Window

5. NuMI Target Transfer to Target Service Building (TSB)

   NuMI Target NT-07 was transferred from the MI-65 target hall morgue to the TSB for storage. The target was activated and contaminated, so transport of this item was controlled to prevent radioactive contamination and exposure to personnel during transport. The target was placed into a transport coffin and then placed into a wooden box for storage at TSB. (*Exhibit 10*) The estimated collective dose was 33 person-mrem and the actual collective dose received was 25 person-mrem.

Exhibit 10:
NuMI Target NT-07 in Coffin at TSB

6. NuMI Horn 1-02 Transfer to CZero Storage Building

   During the shutdown, NuMI Horn 1-02 was transported from storage in the target hall “morgue” to a building located at CZero for storage. The horn was activated and contaminated, so transport was controlled to prevent exposure and release of contamination. The horn was loaded into a transport coffin and placed into a storage bay at CZero. (*Exhibit 11*) The estimated collective dose was 27 person-mrem and the collective dose received was 25 person-mrem.

Exhibit 11:
NuMI Horn 1-02 in Coffin Being Loaded for Transport to CZero

3.4. Technical Division Vertical Test Stands

In 2014, two state-of-the-art test stands became operational in the Technical Division Test and Instrumentation Department. Vertical test stands (VTS) are used to make measurements of isolated superconducting RF cavities under carefully controlled conditions. The large orange concrete and steel radiation shield moves to cover the VTS while it is operational. (*Exhibit 12*).

Exhibit 12:
Vertical Test Stand at Technical Division

3.5. Acknowledgements

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