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Revision History

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K. Vaziri	1- updated experimental program 2- updated off site dose, due to air emissions, table	May 2019
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Fermilab
ES&H Section

Fermilab Radionuclide Air Emissions Measurement Procedure Document

K. Vaziri, B. Hartman, M. Quinn and D. Reitzner

(May 2019)

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(Initial Issue: April 2008)

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I. Program Statement and Summary

Fermi National Accelerator Laboratory (Fermilab) is a single purpose federal research laboratory that is owned by the Department of Energy and operated by the Fermi Research Alliance (FRA). FRA is a consortium of 72 universities (URA) and the University of Chicago (U. Chicago) as Fermi Research Alliance (FRA), a limited liability company (LLC). Fermilab is located in Kane and DuPage counties in the greater Chicago area. It covers roughly 10.6 square miles (27.5 square kilometers) in an area, which is rapidly changing from agricultural to residential use. The terrain is generally flat as a result of past glacial action, with elevations ranging from 715 feet (218 meters) to 800 feet (244 meters) above mean sea level (MSL). The climate is continental, with a typical rainfall of about 35 inches (90 centimeters) per year. The facility consists of a series of proton accelerators used to conduct basic research in high-energy physics and related disciplines. Currently, Fermilab's distinguishing feature is a 120 GeV proton synchrotron named the Main Injector (MI). The MI ring is housed in an underground. Its mission is to provide high intensity proton beams to explore the fundamental nature of matter and energy through basic high energy physics research.

The present physics research program is currently operated by running concurrent beams to the Fixed Target experiments at 8 and 120 GeV. Fixed target experiments are conducted in the 8 GeV proton to the Booster Neutrino Beam linebeam line (BNB) nad the Muon Campus G-2 experiment, the Neutrinos at the Main Injector (NuMI) beam line, Neutrino beam line and in the Meson beam lines. As the lab's experimental program changes other Fixed Target beam lines may be prepared and put into operation. For example, E1039 (SpinQuest) experiment is being prepared to run on the Neutrino Center beam line in 2019, the Main Injector Particle Production (MIPP) experiment ran on the Meson-Center beam line from 2004 to 2006. In addition to the Meson Test beam line, Meson-Center beam line has also been and will be utilized for detector tests for various Fermilab and non-Fermilab experiments. The MuCool Test Area (MTA), a branch of the Linac 400 MeV proton beam is being converted to a radiation studies beam

When directed at substantial masses of material such as large targets, beam absorbers or scraped against long lengths of beam pipes, high energy particle beams or their secondaries can induce various nuclear reactions in the surrounding material including ambient air. Some of these reactions can result in the formation of airborne radionuclides. It is the measurement and monitoring of these airborne radionuclides that is the primary focus of the Fermilab Radionuclide Air Emissions Program.

On December 15, 1989, the Unites States Environmental Protection Agency (USEPA) National Emission Standards for Hazardous Air Pollutants (NESHAP), issued as 40 CFR Part 61, became effective (Ref. 1). In particular Fermilab, as a DOE laboratory, is subject to Subpart H of this regulation which specifically exempts Fermilab from the requirements of 40 CFR 61.10. Since Fermilab emissions have always been kept well below 1% of the 10 mrem/yr. maximum allowed by the standard, according to 40 CFR 61.93(b)(4)(i) continuous monitoring is not required. However, as an act of good faith, Fermilab has had a continuous air monitoring program since the mid 1980s. In fact, Fermilab began investigations of its air emissions in the mid 1970s; well before it was explicitly required. (Refs. 2 and 3)

I.(a). PROGRAM:

References (4) and (5) document the general methods for calibrating the monitor systems used to evaluate airborne emissions. Reference (5) primarily documents the methods used to assess the relative isotopic composition of radionuclides emitted from various stacks. Information from this reference is used to break down the total activity emitted from a given stack into relative contributions from various radionuclides. The NuMI and MiniBooNE exhaust stacks continue to be monitored with detectors similar to those described in Ref. 5. The ESH&Q Section instrumentation team is responsible for calibration of these monitors. These monitors are calibrated twice a year according to the ESH&Q Section instrumentation team calibration procedure contained in Appendix A of this manual.

The rest of this note describes the stack monitors data collection and logging network, logging and tally of stack monitor data, calibration of the stack monitors detectors, stack air flow measurements and modeling of the radioactive air releases.

I.(b). RESPONSIBILITIES:

The Chief Safety Officer (CSO) is responsible for the air monitoring program. CSO has delegated various subsidiary responsibilities to other individuals and groups. Calibration of the stack monitors has been delegated to the Instrumentation Team of the ESH&Q Section. Assessment of the areas in the divisions and sections has been delegated to the assigned Radiation Safety Officers (RSOs) for those areas. Direct measurement of the stack emissions, modeling of the data generated by the stack monitors, and instrumentation development has been delegated to the Radiation Physics Science and Engineering Teams of the ESH&Q Section.

The ESH&Q Section Radiation Physics ScienceTeam maintains several spreadsheets documenting the beam intensity data, muon surveys, neutron surveys and weekly results from various stacks. At the end of each calendar year the results from these spreadsheets are compiled and analyzed for inclusion in the site Environmental Report to the Director and various other required reports to DOE and regulatory agencies. Should the total air emission levels exceed or be expected to exceed the limits set forth in the laboratory's IEPA permit (Ref. 6) for any given year, the CSO must notify the Laboratory Director as soon as it is known of the possibility. The Laboratory Director will then decide to stop, or alter operations such that the limits will not be exceeded or to request an exemption from DOE.

I.(c). APPRAISALS:

Appraisals are periodically conducted by DOE and by Fermilab to assess program compliance. Outside regulatory agencies such as US EPA and IEPA also conduct reviews of this program.

I.(d). CORRECTIVE ACTION:

Any deficiencies identified in the air monitoring program during a formal or informal appraisal, a routine inspection, or by an individual will be reported to the CSO and entered into the iTrack. Subsequently, the CSO shall assure the development of an appropriate corrective action plan.

I.(e). SAMPLING:

When it is necessary to take grab samples from the various exhaust stacks, those samples shall be taken as specified in the Fermilab ESH&Q Manual, Section 8080 (Ref. 7) and the references therein.

I.(f). QUALITY ASSURANCE:

Reference (1), Subpart H 61.93(b)(5)(v), requires a quality assurance program which meets the requirements of Part 61, Appendix B, Method 114.4. Currently, the Fermilab air emissions monitoring program cited in this note is to the best of our knowledge and belief in full compliance with the Fermilab Quality Assurance Policy.

This program statement and the various procedures which are part of this note address all of the requirements.

Completed copies of radioactive air emissions spread sheets, stack monitor and flow meter calibrations are saved in the ESH&Q Section's permanent files. Logbooks documenting measurements are also saved by the various ESH&Q Section's groups/teams.

II. Stack Monitor Data Logging

This section describes the method used to track and record the output from various Fermilab stack monitors.

Reference (8) describes the operation of and quality assurance provisions for the ESH&Q Section radiation safety data collection network, MUX system, in sufficient detail. Each stack monitor is assigned a unique data identification number (DIN) in the MUX system before the beginning of operations in the area where the stack monitor is located. This DIN consists of a Quad locator number (0-3) and an address number (000-255). For example, the MUX DIN for the antiproton area stack monitor is 2-070.

The stack monitors are modularized systems consisting of a standard 1 gallon, 2 inches thick lead or brass container, a thin window pancake GM probe (identical to those used in the Frisker survey instrument) described in chapter five of the Fermilab Radiological Control Manual (Ref. 9), an air pump, an air flow meter, and electronic readout to process the signals from the pancake probe. Gas sampled from near the center of the stack is pumped into the bottom of the sealed container where it diffuses toward the top and then leaves from an exit port in the lid. During the time the gas is in the container, positron and beta emissions from the airborne radionuclides are detected in the GM probe. Electronic pulses from the GM probe are processed and converted to a proportional MUX pulse routed to the appropriate MUX station. There is also a portable version of the stack monitor in which the shielded container is replaced with a 1 gallon Paint can. This version is used by radiation safety personnel to assess the air activity levels inside areas which can be accessed after the beam has been turned off.

Some stack monitors are located outdoors near the stacks. In order to isolate them from the diurnal and seasonal temperature variations, they are placed inside an insulated ice-box inside a small hut, which is equipped with a fan, a heater and a thermostat to keep the temperature inside the hut stable.

The ESH&Q assigned RSO or representative for the Division/Section having jurisdiction over the area in which a particular stack monitor is located, is responsible for requesting a MUX DIN for that stack monitor from the ESH&Q Section Instrumentation Team. This assignment must be made at least two weeks before beam is received in the area where the stack monitor is located. Once the assignment is made it may not be changed without the consent of the CSO.

A designated member of the Radiation Physics ScienceTeam is responsible for monitoring the performance of the stack monitors on the weekly MUX reports and ensuring that the data from the monitors is transcribed to a spread sheet. In this way the total emissions from each stack are updated weekly.

The RADMUX report is inspected to assure proper functioning of the MUX network and the monitored instrument during the entire week. “Proper functioning implies no “dead” period or period with large, spurious readings indicative of system malfunctioning during time periods when beams were not operating.

III. ESH&Q Section Logging Procedures for Off Site Radiological Parameters

The collection of data connecting accelerator and beam line operations with offsite radiological impact of Fermilab operations is accomplished by means of three spreadsheets using the current version of Microsoft Excel™. The spread sheet Radstacks keeps track of the emissions of individual stacks using weekly stack monitor data from the MUX reports and proton intensity reports. The second spreadsheet, Offsite Emissions, uses the weekly proton reports, the stacks annual average activity per proton to calculate, total annual radioactive air emissions. The third spread sheet, NuMI_MI-65_HTO_Evaporator, keeps track of the amount of tritiated water from NuMI beam line chiller and dehumidifiers that is boiled off. This spreadsheet uses the weekly evaporator tank sample tritium concentrations and the amount of water evaporated to calculate the weekly release. The evaporator operation started in November 2007.

The parameters collected document offsite releases of airborne radionuclides. These spreadsheets and copies of proton intensity reports are maintained on a server (\\eshserver1\ "U:\KamranDocs\Off site emissions\Emissions") located on Fermilab’s computing network, which is backed up daily. Additionally, the essential data used in these spreadsheets such as the beam intensity reports, stack monitor data and the calibration factors are backed up. Proton beam intensity data are obtained using the Accelerator Divisions data acquisition and control network (ACNT), and are backed up daily. Stack monitor data are obtained through the MUX data network (see section II), and are saved on electronic media via the ESH&Q server (\\eshserver1\Radmux\ReadAccess\Data\Processed) and paper. The stack monitor detector calibration data is also saved both electronically and as hardcopy as part of the records of the ESH&Q Section Instrumentation Team. Measurements to characterize the stacks emissions are recorded in logbooks that are kept by the ESH&Q Section Radiation Physics Science Team. The results of these characterizations are reported as Radiation Physics Notes.

The procedures in this document are those for maintaining the three spreadsheets. Examples of the 3 spreadsheets are in the Appendices B, C and D.

III. (a). Sources

Data input to these spreadsheets originates from several sources listed as follows:

Source 1**:** The Accelerator Division Operations Group keeps a log of the proton beam intensities at different accelerators and beam lines. This data is collected on an electronic on-line database called Beam Budget Monitor (BBM). A monthly BBM report is regularly obtained by the ESH&Q Radiation Physics Science Team. The proton data arrive in the form of spreadsheets, binned in one week intervals as measured at the various target stations and beam intensity monitors. These beam intensities are calibrated by the Accelerator Division with assistance as needed from the ESH&Q Section.

Source 2**:** The RADMUX system maintained by the ESH&Q Section, logs the stack monitors data that is used to measure the airborne releases from the monitored stacks. The MUX reports are issued via E-mail on a weekly basis, usually Monday mornings. The report “Special.TXT” contains the stack monitor data. In addition to the hourly data, a running tally of the stack monitor data is provided at the end of this report.

Source 3**:** Radioactive air emissions characterization measurements are made at each operational stack using the Mobil Environmental Radiation Laboratory (MERL). These are used to estimate annual emissions and dose to a Maximally Exposed Individual offsite. All measurements are documented in Logbooks. When new methods are developed or employed in order to make the necessary measurements, these methods and procedures are documented in Radiation Physics Notes and Environmental Protection Notes as appropriate.

Source 4**:** The neutralization/evaporator tank tritium concentrations are measured periodically. The evaporator tank samples are taken by the ESH&Q Radiation Physics Engineering group and analyzed by the Radionuclides Analysis Facility (RAF).

Source 5**:** The data on the volume of tritiated water evaporated as a function of time is provided by the Accelerator Division

Source 6**:** The data on the number of the magnets debonded annually is provided by the RSO for the Technical Division.

Source 7**:** Sources that can not be directly characterized, are conservatively modeled form the first principles. The air emissions due to the beam loss on the Main Injector collimators at MI-30 is such an example. As detailed in reference 10, the area geometry and the beam loss scenario is modeled using the Monte Carlo code MARS (ref. 11). The calculated flux of secondary particles in the air around the collimators and the elementary cross sections for the production of radioisotopes from air is used to estimate the amount of activate air per proton incident on the collimators. This result in conjunction with the annual beam loss on the collimators (provided by the Accelerator Division) is used to conservatively estimate the amount of activated air release from the Main Injector.

III.(b). Spreadsheets

Radstacks (Calendar Year)

This spreadsheet consists of one page for each of the monitored stacks which release significant amounts of airborne radionuclides. The format for each stack is similar and thus the procedure is the same for each page. The upper left corner of the page indicates the stack being considered. The spreadsheet consists of 10 columns. In the main body of the spreadsheet each row consists of data for a given week of accelerator/beam line operations or a one week period of no operations to document background conditions and take care of maintenance shutdowns, etc. The columns consist of the following entries:

Column A; Date	Each entry is the date at which the week covered by the RADMUX report ends (Source 2). On occasion, this date may be different than one week later than the previous entry in this column because of holidays, etc. and the fact that the first day of the year may not necessarily be a Sunday.
Column B; Day	This column calculates the day of the year corresponding to the entry on column A. The top entry in this column is calculated for 12/31 of the previous year as the reference number for this calculation.
Column C; Rtally Change	This is the number of counts for the given stack monitor as read off of the MUX printout for the week corresponding to the particular row (Source 2).
Column D; Gross Cts	This entry is normally set equal to that of column C and corresponds to the gross counts measured on the stack monitor. If there was a malfunction of the RADMUX system noted, then an alternate means of estimating the value of "gross counts" is employed (see below).
Column E; BKG Cts	This entry corresponds to background counts for the detector expected during a given week. It is determined by taking the entry made in column H (see below) and multiplying it by the number of hours in the period covered by the RADMUX printout. This period is normally 7 days but may be a few more or a few less dependent upon when the RADMUX report was generated.
Column F; Net Cts	This entry corresponds to the difference between the entries in columns D and E and is the count upon which the measurement of the release during

	the RADMUX recording period (nominally one week, see above) will be made using the calibration factor.
Column G; Beam Int.	This column registers the total beam targeted as measured by the Accelerator Division and reported from Source 1. It is entered, in units of 1E12 protons per week.
Column H; BKG/hr	The entry in this column corresponds to the background counting rate in RADMUX counts per hour. The background counting rate is observed during non-operational periods by inspection of the RADMUX reports. Non-operational periods such as long shutdowns are utilized for this purpose. It is updated during an accelerator running cycle as opportunity arises during maintenance shutdowns. When such measurements are made, an appropriate note is made in Column J. This background rate is used to determine the BKG counts which appear in column E.
Column I; cts/E12 prt	The entry in this column divides the Net Cts from column F by the number of protons in units of 1E12 protons. This column is used to determine short term fluctuations in this quantity.
Column J: Comments	This column is used to note particular operating circumstances, operating difficulties with monitors, RADMUX, or non-operational period in which the background readings were refreshed in column H.

At the bottom of the spreadsheet, summary entries appear. These are:

Tot Cts	This is the total net counts used to determine the release and represents the sum of column F entries.
Tot Bm	This is the total delivered beam in units of protons and represents the sum of column G entries converted to units of protons rather than 1E12 protons.
cts/prt	This is the quotient of Tot Cts to Tot Bm. It is used as an overall normalization. In cases of failures of the RADMUX system, it can be used along with the entry in column G to provide an otherwise

	unavailable entry for column D after the addition of an appropriate entry from column E.
Bq/ct	This is the calibration factor obtained from detailed analysis of the samples from the stack. The calibration factor for each stack is determined separately. Section VI describes the details of this calibration.
Ci/ct	This is the above entry converted to Ci/ct (simple unit conversion).
Bq/prt	This is the product of Bq/ct and Cts/prt.

The bottom four entries correspond to releases during the set of calendar quarters by summing on appropriate ranges of rows in the table (column F) and multiplying them by the value of Ci/ct. The last item at the bottom is the grand total for the calendar year for this particular stack.

Offsite Rad (Calendar Year); "Offsite Radiological Impact Cy-(calendar year) (All Intensities XE12)"

This spreadsheet serves to place all of the offsite radiological impact data due to Fermilab accelerator operations on one page. In the top part of the spreadsheet, the columns consist of the following:

Column A; Date	Each entry is the date at which the week covered by the RADMUX report ends (Source 2). On occasion, this date may be different than one week later than the previous entry in this column because of holidays, etc. and the fact that the first day of the year may not necessarily be a Sunday.
Column B; Day	The day of the year corresponding to the entry on column A is calculated in this column. The top entry in this column is calculated for 12/31 of the previous year as the reference number for this calculation.
Columns C-K	This set of columns give the entered beam intensities provided in Source 1 for each beam line of interest for each week tabulated.

The rest of the spreadsheet is essentially organized by rows which will be described by their label in Column A:

Protons (1E12): This is the total of the protons in any given column (Columns C-K) for the calendar year at a given point in time.

Overall Airborne for CY: This is the heading for what is to follow.

Air, µBq/proton: This is the normalized value of airborne release obtained from the bottom of appropriate pages of the “Radstacks” spreadsheet for each beam line in units of micro-Bq/proton. This value is updated weekly.

Bq released: This is the product of the total delivered intensity, “Protons(x 1E12)” row and the above micro-Bq/proton row. It should agree with that tabulated in the Radstacks spreadsheet at any given point in time.

Ci/released: This is the previous row with a simple unit conversion.

The next four sets of four rows are similar to the above, except it is air releases calculated for each quarter of the calendar year. The box at the bottom of the spreadsheet contains the total air released from all sources.

Tot. Ci released to Air (1^{st} Qtr): This is the sum of the release activity from all the sources during the first calendar quarter.

Tot. Ci released to Air (2^{nd} Qtr): This is the sum of the release activity from all the sources during the second calendar quarter.

Tot. Ci released to Air (3^{rd} Qtr): This is the sum of the release activity from all the sources during the third calendar quarter.

Tot. Ci released to Air (4^{th} Qtr): This is the sum of the release activity from all the sources during the fourth calendar quarter.

Grand Total Ci. Released to Air: This entry is the sum of the previous four entries.

NuMI_MI-65_HTO_Evaporator (Calendar Year)

This spreadsheet is used to calculate the annual amount of tritiated water that is collected from the NuMI target hall dehumidifiers and chillers and evaporated from the evaporator located at MI-65 building. The upper left corner of the page indicates the stack being considered. The spreadsheet consists of nine columns. In the main body of the spreadsheet the data obtained from sources 4 and 5 are used to calculate the amount of tritiated water evaporated annually. The columns consist of the following entries:

Column A; RAF Sample ID	Each entry is the ID of neutralization tank water samples submitted to the Radionuclides Analysis Facility (RAF) for tritium analysis (Source 4). This ID is composed of the date in the form of (yymmdd), initials of the person who took the sample followed by a two digit sample number.
Column B; Date Collected	This column is the date of the day that the water sample was collected.
Column C; Tritium Concentration (pCi/ml)	This is the tritium concentration of the sample in pCi/ml. from the RAF report (Source 4). It is assume that this is the concentration of the daily emissions until the next sampling date.
Column D; Error (pCi/ml)	This entry is the reported error associated with the analysis report from source 4. The error is in the same units as the concentration.
Column E; Evaporated volume (liters/day)	This entry is the average amount of water evaporated (source 5) per day for that date.
Column F; Evaporated Activity (pCi)	This entry corresponds to the product of column D and column E converted to ml.
Column G; Evaporated Activity (Ci)	This is the above entry converted to Curies (simple unit conversion).
Column H; Total annual (Ci)	The entry in this column is a running sum of the daily releases from the first day of calendar year up to and including the day given in column B of this row.
Column I; Comments	This column is used to note particular operating circumstances, operating difficulties with monitors or when interpolation is used to estimate the daily amount of water evaporated.

The box at the bottom of the spreadsheet gives the grand total of emissions for the calendar year for this particular stack. It should be equal to the last entry in column H

IV. Stack Monitor Detector Calibration

The GM detector in the stack monitors and its associated electronics is tested for functionality. The detector response is checked using a radioactive source. This work is done biannually by the instrumentation team of the Radiation Protection Group, located at the Radiation Physics Calibration Facility (RPCF). A sample of the calibration test and procedures is given in appendix A.

V. Stack Air Flow Measurements

The CAP88 computer code used for modeling the air releases from point sources such as exhaust stacks, requires knowledge of the stack dimensions and the exhaust volume flow rate. Knowledge of the air flow patterns and velocities are also necessary in order to evaluate whether the ventilation of a given area meets the requirements of reference (12).

V.(a). EQUIPMENT:

(A) Alnor Series 6000 Velometer (reference 13)
(B) Pitot Probe (Type 6050-PI)
(C) Pitot Probe (Type 6060-P)
(D) Pitot Probe (Type 6070-P)

V.(b). METHOD:

Measurements of the air flow velocity in ventilation stacks are based on the method outlined in reference (14), except that the above alternative types of Pitot tubes were used for the measurements rather that the Type S specified in reference (14). In support of this decision, it should be noted that the measured flow rates of stacks did not significantly deviate from the manufacturers' specification in any case.

Reference (1) requires that the stack flow to be mapped in two perpendicular transverse directions to assure that the flow is not cyclonic and sampling is representative of the stack effluents. Reference (14) provides recommendations for the number of transverse measurements and their locations for different stacks of different diameters (e.g. Table 1.2 ref. 14). An Alnor velometer is used for mapping the transverse flow profile of the stacks. An average velocity for the stack gases is then estimated by averaging the velocities in the central uniform part of the flow profile in both directions. Volume flow rates are calculated by multiplying the average velocity by the cross sectional area of the stack. This volume flow rate and gas velocity is used in the computer models to model the off site doses from Fermilab air emissions.

V.(c). CALIBRATION:

Calibration of the Alnor velometer is performed annually by the manufacturer. The velometer is calibrated using standards whose accuracies are traceable to the

National Institute of Standards and Technology (NIST). The Industrial Hygienist of the Safety and Environmental Protection Group of the ESH&Q Section is responsible for this instrument. Appendix E is an example of Alnor velometer Calibration Certificate

V.(d). RESULTS:

The results of the measurements of dimensions and flow rates made on each of the operating exhaust stacks are summarized in Table 1.

Table 1. Operating stacks dimensions and flow rates as of April 2013

Point Source	**Inside Diameter** (meters)	**Nominal Volume Flow Rate** (ft^3/min)	**Height** (m)
AP1 stack	0.26	560	4.28
M02 Stack (Meson Test)	0.38	2500	1.54
M05 stack (Meson Center)	0.38	2500	1.54
MI-40 stack[a]	0.30	0	1.80
MiniBooNE MI-12 Stack	0.40	100	1.50
NuMI EAV1 stack	0.30	1890	2.80
NuMI EAV2 stack	0.48	1336	3.20
NuMI EAV3 stack	0.39	571	2.80
NuMI EAV4 stack	0.43	4500	1.20
NuMI MI-65 stack	0.30	400	1.80
Magnet Debonding Oven	0.69	1149	2.80

[a] The vent to this stack is closed; radioactive air is trapped and decays in the absorber room.

VI. Characterization of Stack Emissions

Description of sources

Wherever the proton beam and secondary particles produced by the interaction of the beam with matter pass through the air, radioactivation of air occurs. The beam is generally delivered to the targeting areas via evacuated beam pipes. This is done to, minimize the interaction of the primary proton beam with intervening material such as air and hence prevent beam losses. At the target stations or absorbers, where these beams of protons produce secondary beams, there are areas where the protons and secondary particles must travel through air. This is the reason the radioactivation of the air is concentrated at these locations. Relatively short-lived radionuclides are produced in these interactions and released through the operational ventilation stacks. Interaction of high-energy particles with nitrogen and oxygen in the air produces a mixture of primarily ^{11}C (20 minute half-life), ^{13}N (10 minute half-life), ^{15}O (2.1 minute half-life) with smaller amounts of ^{41}Ar (1.8 hour half-life), and much smaller amounts of ^{38}Cl (37 minute half-life) and ^{39}Cl (56 minute half-life). Monitoring is conducted at stacks where air emissions are considered to be significant contributors to the overall transport of radioactive effluents offsite. The details of the methods used to characterize the stack emissions are given in references (4) and (5).

In addition to gaseous isotopes mentioned above, the air released from the NuMI stacks also contains longer lived tritiated emissions. The gaseous radioisotopes ^{11}C, ^{13}N, ^{15}O, and ^{41}Ar along with a small amount of tritiated moisture are released from the Exhaust Air Vents EAV1, 2 and 3. In 2012, the operation of the survey Sight Riser #3 (SR3), at the end of the NuMI target hall, which was used for the release of tritiated moisture, extracted from the target hall air (Ref. 15) was discontinued. This use of dehumidifiers and collection of their condensate made the operation of this stack unnecessary. A closed loop air cooling circuit is used to cool the NuMI target chase. During the 2007 shutdown, to further reduce NuMI target chase air humidity an isolated desiccant&Chiller loop was added to the target chase. The water collected from this loop and the condensate from the chase air chiller coil is pumped up to a tank in the MI-65 Service Building, which is then gravity fed to a 24 kW electric evaporator (Ref. 16). The exhaust is through a 6 ft. stack located on the roof. A fan on top of this stack operates at a nominal 400 cfm, to ensure negative pressure relative to the building.

Another possible source of radioactive air emission is the debonding of the radioactivated magnets. Some magnets used in the accelerators at Fermilab are impregnated with epoxy resin to prevent coil movement during normal operation. When the magnets need repair or the coils must be replaced, the epoxy resin must be removed. It has been determined that the most efficient way to remove this epoxy from the magnets was by heating the whole magnet in an oven at 800°F for eight hours. Thus in October 1978 a Construction Permit Application was submitted by Fermilab to the State of Illinois for construction of a magnet debonding oven. The resulting permit required the characterization of emissions to the atmosphere resulting from the operation of the magnet debonding oven. This was accomplished by a series of tests conducted by Fermilab personnel and an outside vendor, the Almega Corporation (Ref. 17), during the summer of 1979. Tritium is the only radionuclide found in the emissions. Based on the number and dose rates from the magnets debonded (source 6) an annual tritium release from this source is estimated (Ref. 18).

VII. Modeling of Releases

The offsite radiation doses potentially received by the public are calculated from data gathered through environmental surveillance of these onsite sources. An EPA approved computer code CAP88-PC (Version 4.1 Reference 19) is used for the calculations. Maximum calculated concentrations offsite have historically been below the level that can be directly measured by monitoring. Different mitigation strategies have intentionally been built into the design of the facilities at Fermilab to keep the annual dose to the maximally exposed individual offsite to less than 0.1 mrem in a year.

Description of Dose Model

The Environmental Protection Agency (EPA) rules for radionuclide emissions to air are under 40 CFR 61, National Emission Standards for Hazardous Air Pollutants (NESHAPS). Emission monitoring and compliance procedures for Department of Energy (DOE) facilities (40 CFR 61.93 (a)) require the use of CAP88-PC model, or other approved procedures, to calculate effective dose equivalents to members of the public.

The CAP88-PC (Clean Air Act Assessment Package - 1988) computer model is a set of computer programs, databases and associated utility programs for estimation of dose and risk from radionuclide emissions to air. CAP88-PC is composed of modified versions of AIRDOS-EPA (Ref. 20) and DARTAB (Ref. 21).

CAP88-PC uses a modified three dimensional Gaussian plume equation to model the average dispersion of radionuclides released from up to six emitting sources. The sources may be either elevated stacks, such as a smokestack, or uniform area sources, such as a pile of uranium mill tailings or a cooling pond. Plume rise can be calculated assuming either a momentum or buoyant-driven plume. Assessments are done for a circular grid of distances and directions for a radius of up to 80 kilometers (50 miles) around the facility.

Sample population files are supplied with CAP88-PC, which the user modifies to reflect their own population distributions. When performing population dose assessments, CAP88-PC uses the distances in the population array to determine the sector midpoint distances where the code calculates concentrations. Linear interpolation is used to determine the equilibrium fractions for distances that do not match the set distances given.

Agricultural arrays of milk cattle, beef cattle and agricultural crop area are generated automatically, requiring the user to supply only the State name or agricultural productivity values. When a population assessment is performed, the arrays are generated to match the distances used in the population arrays supplied to the code, and use state-specific or user-supplied agricultural productivity values. User has the option to override the default agricultural productivity values by entering the data directly on the Agricultural Data tab form.

EPA has made comparisons between the predictions of annual-average ground-level concentration to actual environmental measurements, and found very good agreement. Environmental monitoring data at five Department of Energy (DOE) sites was compared to AIRDOS-EPA predictions in 1987. A report titled, Comparison of AIRDOS-EPA Prediction of Ground-Level Airborne Radionuclide Concentrations to Measured Values (Ref. 22) summarizes the results. EPA concluded that as often as not, AIRDOS-EPA predictions were within a factor of 2 of actual concentrations.

Summary of input parameters to CAP88-PC:

1. Meteorological input for the calendar year is taken from an onsite monitoring station.

2. The population grid from the latest U.S. Census is used for calculating collective effective dose equivalent.
3. Stacks Dimensions
4. Distance of the source to the site boundary (Table 2.)

Table 2. Stack distances to the nearest site boundary.

Point Source	*Distance to Nearest Receptor (meters)*	*Direction to Nearest Site Boundary*
AP1 stack	1346	W
M02 Stack (Meson Test)	1638	NNW
NM2 Stack	2210	NNE
MI-40 stack[a]	304	W
MiniBooNE MI-12 Stack	992	W
NuMI EAV1 stack	1388	W
NuMI EAV2 stack	1054	W
NuMI EAV3 stack	1054	W
NuMI EAV4 stack	1234	W
NuMI MI-65 stack	1143	W
Magnet Debonding Oven	2043	NW

[a] MI-40 Stack vent is closed, activated air is not released.

VIII. History of Offsite Equivalent Doses due to Radioactive Air Emissions

Over the years as the intensity of the proton beams in the accelerators has increased, by necessity the optics of the beam lines and the operations have improved to reduce the losses. Air emissions mitigations have also been built into the design of the new facilities to reduce air emissions. The methodologies for measuring and characterizing the emissions have also improved. The effects of these changes are clearly visible in the resulting annual equivalent doses. Table 3. gives the equivalent dose offsite at the maximally exposed individual location, from 1987 to present.

Table 3. Annual equivalent dose to the maximally exposed individual off- site.

CY	Equivalent Dose (mrem)	CY	Equivalent Dose (mrem)	CY	Equivalent Dose (mrem)	CY	Equivalent Dose (mrem)
1987	0.0200	**1997**	0.0150	**2007**	0.0158	**2017**	0.0419
1988	0.0300	**1998**	9E-09	**2008**	0.0364	**2018**	0.0725
1989	0.0200	**1999**	0.0027	**2009**	0.0326	**2019**	
1990	0.0300	**2000**	0.0046	**2010**	0.0411	**2020**	
1991	0.0300	**2001**	0.0061	**2011**	0.0326	**2021**	
1992	0.0090	**2002**	0.0080	**2012**	0.0104	**2022**	
1993	0.0070	**2003**	0.0069	**2013**	0.0053	**2023**	

1994	0.0090	**2004**	0.0077	**2014**	0.0187	**2024**	
1995	0.0020	**2005**	0.0216	**2015**	0.0278	**2025**	
1996	0.0100	**2006**	0.0245	**2016**	0.0411	**2026**	

IX. References

(1) United States Code of Federal Regulations, Title 40, Part61, Subpart H, "National emissions standard for hazardous air pollutants (NESHAP) for the emission of radionuclides other than radon from Department of Energy Facilities", 1989.
Fermilab ESH&Q Section Environmental Reports starting 1972 to present. (last accessed 2/9/2017)
http://www-esh.fnal.gov/pls/default/esh_home_page.page?this_page=12831

(2) Butala and S. Baker, Calibration of the N01 Stack Monitor, Fermilab Radiation Physics Note 68, March 1988.
S. W. Butala, S. I. Baker, P. M. Yurista, Measurements of Radioactive Gaseous Releases to Air from Target Halls at a High-Energy Proton Accelerator, Health Physics, Vol. 57, No. 6, pp. 909-916, 1989.

(3) Vaziri, K., GM Tube Beta-Particle Detection Efficiency Calculations, Radiation Physics Note 105, Fermilab ESH&Q Section (1993).

(4) K. Vaziri, V. Cupps, D. Boehnlein, D. Cossairt, A. Elwyn, T. Leveling, AP0 Stack Monitor Calibration, RP Note 106, Fermilab ESH&Q Section (1993).

(5) Illinois Environmental Protection Agency, Fermilab Lifettime Operating Permit – NESHAP – Revised, January 24, 2001.

(6) The Fermilab ESH&Q Manual, current version.
http://www-esh.fnal.gov/pls/default/esh_home_page.page?this_page=800

(7) The Multiplexed Radiation Data Collection System (MUX System), John Larson, Rev. 2. 1994.
Fermilab Radiological Control Manual, current version. (last accessed 2/9/2017)
http://www-esh.fnal.gov/pls/default/esh_home_page.page?this_page=900.

(8) Vaziri, K., Estimation of the Main Injector air emissions, Radiation Physics Note 153, Fermilab ES&H Section (2008).

(9) N.V. Mokhov, "The MARS Code System User's Guide", Fermilab-FN-628 (1995);N.V. Mokhov, O.E. Krivosheev, "MARS Code Status", Proc. Monte Carlo 2000 Conf., p. 943, Lisbon, October 23-26, 2000; Fermilab-Conf-00/181 (2000).

(10) ANSI 43.1-2004, Radiological Safety in the Design and Operation of Particle Accelerators, Section 2.6.1.

(11) Operating Instructions for the Alnor Series 6000-P Velometer, Alnor Instrument Company, Niles, IL, 11/73.

(12) 40 CFR, Part 61, Appendix A, Method 2.

(13) K. Vaziri "Radiological issues associated with venting tritiated air from NuMI SR3 "Projects-doc-100-v2, March 2007.

(14) K. Vaziri, "Tritium Release from NuMI MI-65 Stack ", Projects-doc-176-v2, May 2007.

(15) The Almega Corporation, "Stack Particulate Emission Testing Magnet Debonding Oven", June 8. 1979, Project I-5206.

(16) V. Cupps, J. D. Cossairt, "Estimation of the Annual Tritium Release Due to Operation of the Magnet Debonding Oven", EP Note 3, Fermilab ESH&Q Section (1990).

"CAP88-PC Version 4.0 User Guide", (last accessed 2/9/2017) https://www.epa.gov/radiation/cap-88-pc-version-4-training

(17) R. E. Moore, C. F.III, Baes, L. M. McDowell-Boyer, A.P., Watson, F.O., Hoffman, J.C., Pleasant, C.W. Miller "*AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides"*, (Reprint of ORNL-5532).,), EPA 520/1-79-009.

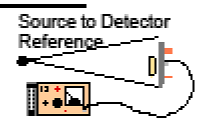
(18) ORNL5692, *DARTAB: A Program to Combine Airborne Radionuclide Environmental Exposure Data With Dosimetric Health Effect Data to Generate Tabulations of Predicted Health Impact*, ORNL-5692/DE81030434, Oak Ridge National Laboratory, Oak Ridge, Tennessee, November 1981.

(19) S.K. Beal and S.C. Cohen, S. Cohen and Associates, H.J. Chmelynski, Jack Faucett Associates, B.S. Parks and J. Hardin, U.S. Environmental Protection Agency, "Comparison of AIRDOS-EPA Predictions of Ground-Level Airborne Radionuclide Concentrations to Measured Values", 1986.

Appendix A.
Stack Monitor Calibration Procedures/Worksheet

Stack Monitor Calibration Worksheet

Serial# ______________ Name ______________ Date ______________
Temperature ______°F Humidity ______% TPS# ________ DVM# ________ FlowMeter# ________
Last Known Location ______________________________



1. ***As Found Performance Check:***
Using the forms below record the as-found response for each range and exposure rate. The final *detector check* readings and adjustments are to be recorded later. All calibration adjustments are located on the back side of the instrument behind a panel labeled calibration.
   a. In calibration cave 3, plug in the instrument power cord and turn power switch on. The power lamp must light. ☐
   b. Connect a cable from the TPS input to the stack monitor MUX output. Set the TPS timer to 100 seconds. Remove detector from chamber can and expose to the following dose rates. Record the meter and MUX readings. Calculate net count by subtracting background from each reading.

Distances updated for: 7/1/2007				*As Found/Detector Check*				Tolerances are DT corrected		
				CPM Meter Reading					MUX (100 seconds)	
Range	Source	Distance	Exposure Rate	As-Found		Final		Tolerance	Counts	Tolerance
X1	N/A	N/A	Background		Net		Net	N/A		0 - 1
X1	137-2.4-2	110.6	0.1 mR/Hr					268 - 402		4 - 7
X10	137-3.4-3	121.0	1.0 mR/Hr					2675 - 4012		44 - 67
X100	137-4.5.1	113.4	10 mR/Hr					29.6K - 36.2K		493 - 603
X1000	***Do Not Use This Range***		*The GM tube is incapable of operating properly at the exposure rate needed for this range.*							

If any of the above As-Found readings are out of tolerance the PCN system must be invoked. The detector probe check tolerance was determined by the tube manufacture. They state the tube as 3350 CPM/mR/Hr ±20% using 137Cs.

2. ***Overload Test:*** Expose instrument to a 30 mR/hr field using the 137-5.6-3 source at a distance of 241.8 cm. Meter must not drop below full scale. ☐ Remove the instrument from 30 mR/hr field. Meter must return to background in <2 minutes. ☐
3. ***Change Filter:*** ☐ Move instrument to a technician bench. Open filter assembly, remove old filter, and replace with new one. Verify that old filter is not contaminated. If contaminated dispose of using step 6 of Procedures for Receiving NFG Instruments.
4. ***Physical Inspection:*** ☐ Physically inspect the outside and inside of the entire Stack Monitor System for damage, loose or broken connections, hoses, etc. and repair any problems found.
5. ***Clean Instrument:*** ☐ Clean the entire outside of the instrument using a mild cleaner and paper towels "KayDry". Remove all extraneous tape, calibration labels, etc., from the instrument.
6. ***Electronic Checks:*** Using the forms on following page, record the information as required following the procedures in a - f.
   a. With the power switch in the off position, mechanically zero the meter by adjusting the zero adjustment screw on the meter if needed. Record results.
   b. Remove detector from cable. Turn power switch to the on position. Using a DVM and high voltage probe measure and record the high voltage at the end of the detector cable.
   c. Press the HV button located on the back of the instrument. Observe and record the meter reading.

		As-Found	Final	Adjust	Observe	Tolerance
a.	Meter Zero			meter	meter	0
b.	High Voltage			R5	DVM	*850 - 950
c.	HV Meter			R95	meter	0.85 - 0.95

*when measuring the HV use a 1000 megohm high voltage probe and a DVM with an input impedance of 10^7 ohms.

   d. Connect detector cable to the GM output of the TPS. Turn on TPS and set it in the GM mode. Connect another cable from the TPS input to the stack monitor mux output. Set the TPS timer to 1 second, frequency to 100K, divide by to 1, and push the reset button. After 1 second record the digital display of the TPS on the table under mux reading. This checks the proper operation of the mux divide by 100.

Range	Input Frequency (CPM)	TPS Setting		Mux Reading		Adjust	Tolerance
		Freq.	Divide by	As-Found	Final		
X1K	6000K	100K	1			N/A	999 - 1001

e. Using the table below set TPS as required and record Stack Monitor meter readings. Make adjustments if needed.

As Found/Calibration							
Range	Input Frequency (CPM)	TPS Setting Freq.	TPS Setting Divide by	CPM Meter Reading As-Found	CPM Meter Reading Final	Adjust	Tolerance
X1	250	100	24		*	X1	225 - 275
X1	100	10	6				90 - 110
X1	400	100	15				360 - 440
X10	2.5K	1K	24		*	X10	2.25K - 2.75K
X10	1K	100	6				0.9K - 1.1K
X10	4K	1K	15				3.6K - 4.4K
X100	25K	10K	24		*	X100	22.5K -27.5K
X100	10K	1K	6				9K - 11K
X100	40K	10K	15				36K - 44K

f. Disconnect the TPS and reconnect the detector

7. ***Calibration:***

a. Were all tolerances to this point for both radiation and electronic checks within the specifications stated? Select one.
☐ Yes. Go to step 7.b. ☐ No. Go to step 7.d.

b. Were any adjustments made? Select one. ☐ Yes. Go to step 7.d. ☐ No. Go to step 7.c.

c. To indicate no adjustments were made, write the word *same* under the final column in each table. ☐ Go to step 8.

d. Using the form in step 1, complete the information needed under the column final. Make adjustments as needed.

8. ***Air Pump And Flow Rate Meter:*** This step is to be done "In the Field" for instruments containing bronze chamber.

a. Verify that stack monitor is assembled as diagram below.

b. Connect air flow calibrator (BUCK) from the top hose connection to the air inlet on the filter.

c. Turn pump on. Using the chart to the right set, measure and record the flow rates.

d. Attach a chart indicating the air flow meter readings and the actual flow rates to the instrument. ☐

Liters/Minute	
Flow Gauge	Actual Flow
3	
6	
9	

9. ***Label Change:*** ☐

Place a new calibration label on the instrument. Record the information needed in the spaces provided. This instrument is due for calibration every 12 months.

10. ***Comments:*** Attach any comments to this page.

Procedures Approved By: *[signature]* Date: 6/26/2007

Sources and instruments used for this calibration are traceable to National Institute of Standards and Technology Rev. 11 1/3/2007

Appendix B.
Example of Stack Monitor Data Log Worksheet – Radstack

	A	B	C	D	E	F	G	H	I	J
1	**AP0 Stack Monitor:**									
2	**End Date**	**Day**	**Rtally**	**Gross Cts**	**BKG Cts**	**Net Cts**	**Beam Int.**	**BKG/hr**	**cts/E12 prt**	**Comments**
3			**Change**				**(XE12)**	**(observed)**		
4	1/1/2007	37621								
5	1/8/2007	7	739436	739436	3696	735740	1.66E+06	22	0.44	
6	1/15/2007	14	664968	664968	3696	661272	1.45E+06	22	0.46	
7	1/22/2007	21	581717	581717	3696	578021	1.41E+06	22	0.41	
8	1/29/2007	28	501502	501502	3696	497806	1.05E+06	22	0.47	
9	2/5/2007	35	285494	285494	3696	281798	6.68E+05	22	0.42	
10	2/12/2007	42	563179	563179	3696	559483	1.17E+06	22	0.48	
11	2/19/2007	49	685960	685960	3696	682264	1.40E+06	22	0.49	
12	2/26/2007	56	690032	690032	3696	686336	1.45E+06	22	0.47	
13	3/5/2007	63	774489	774489	3696	770793	1.63E+06	22	0.47	
14	3/12/2007	70	720604	720604	3696	716908	1.42E+06	22	0.50	
15	3/19/2007	77	631796	631796	3696	628100	1.31E+06	22	0.48	
16	3/26/2007	84	685512	685512	3360	682152	1.47E+06	20	0.46	
17	4/2/2007	91	581613	581613	3360	578253	1.31E+06	20	0.44	
18	4/9/2007	98	635912	635912	3360	632552	1.46E+06	20	0.43	
19	4/16/2007	105	643720	643720	3360	640360	1.37E+06	20	0.47	
20	4/23/2007	112	683928	683928	3360	680568	1.45E+06	20	0.47	
21	4/30/2007	119	696080	696080	3360	692720	1.50E+06	20	0.46	
22	5/7/2007	126	612801	612801	3360	609441	1.37E+06	20	0.44	
23	5/14/2007	133	615398	615398	3360	612038	1.34E+06	20	0.46	
24	5/21/2007	140	613903	613903	3360	610543	1.34E+06	20	0.46	
25	5/28/2007	147	677458	677458	3360	674098	1.39E+06	20	0.48	
26	6/4/2007	154	786038	786038	3360	782678	1.64E+06	20	0.48	
34	7/30/2007	210	934845	934845	3360	931485	1.68E+06	20	0.55	
35	8/6/2007	217	495662	495662	3360	492302	9.98E+05	20	0.49	
36	8/13/2007	224	4276	4276	3360	916	0.00E+00	20		Shutdown
37	8/20/2007	231	5240	5240	3360	1880	0.00E+00	20		Shutdown
38	8/27/2007	238	4854	4854	3360	1494	0.00E+00	20		Shutdown
39	9/3/2007	245	4871	4871	3360	1511	0.00E+00	20		Shutdown
40	9/10/2007	252	3789	3789	3360	429	0.00E+00	20		Shutdown
41	9/17/2007	259	3417	3417	3360	57	0.00E+00	20		Shutdown
42	9/24/2007	266	3462	3462	3360	102	0.00E+00	20		Shutdown
43	10/1/2007	273	3364	3364	3360	4	0.00E+00	20		Shutdown
44	10/8/2007	280	3290	3290	3360		0.00E+00	20		Shutdown
45	10/15/2007	287	3199	3199	3360		0.00E+00	20		Shutdown
46	10/22/2007	294	141569	141569	3360	138209	2.80E+05	20	0.49	
47	10/29/2007	301	136745	136745	3360	133385	3.00E+05	20	0.44	
48	11/5/2007	308	506173	506173	3360	502813	1.06E+06	20	0.47	
49	11/12/2007	315	236699	236699	3360	233339	5.55E+05	20	0.42	
50	11/19/2007	322	420784	420784	3360	417424	8.56E+05	20	0.49	
51	11/26/2007	329	613547	613547	3360	610187	1.30E+06	20	0.47	
52	12/3/2007	336	532812	532812	3360	529452	1.13E+06	20	0.47	
53	12/10/2007	343	418694	418694	3360	415334	8.45E+05	20	0.49	
54	12/17/2007	350	580156	580156	3360	576796	1.13E+06	20	0.51	
55	12/24/2007	357	394421	394421	3360	391061	7.91E+05	20	0.49	
56	12/31/2007	364	118189	118189	3360	114829	2.40E+05	20	0.48	
57										
58					**Tot cts:**	2.504E+07				
59					**Tot bm:**	5.195E+19				
60					**cts/prt:**	4.820E-13				
61					**Bq/ct:**	5.023E+04				
62					**Ci/ct:**	1.358E-06				
63					**Bq/prt:**	2.421E-08				
64				**1st qtr**	**Ci rel.**	1.094E+01				
65				**2nd qtr**	**Ci rel.**	1.227E+01				
66				**3rd qtr**	**Ci rel.**	5.264E+00				
67				**4th qtr**	**Ci rel.**	5.516E+00				
68				**Total**	**Ci rel:**	3.399E+01				

Appendix C.
Example of Offsite Emissions Worksheet

A	B	C	D	E	F	G	H	I	J	K
End Date	Day	TeV Abort A0 (XE12)	MI Abort (XE12)	Booster Absorb (XE12)	Switchyard (XE12)	AP0 (XE12)	MiniBooNE (XE12)	NuMI (XE12)	MT (XE12)	MC (XE12)
1/3/2005	36893									
1/10/2005	7	6.96E+01	9.91E+03	1.47E+04	0.00E+00	5.05E+05	5.99E+06	0.00E+00	1.37E+03	5.50E+01
1/17/2005	14	6.02E+01	1.85E+04	2.07E+04	0.00E+00	6.14E+05	1.03E+07	0.00E+00	1.62E+03	1.35E+02
12/19/2005	350	8.08E+01	2.83E+04	1.49E+04	0.00E+00	9.60E+05	7.55E+06	0.00E+00	5.15E+01	9.86E+01
12/26/2005	357	7.40E+01	7.82E+03	2.84E+04	0.00E+00	1.08E+06	4.69E+06	3.36E+06	4.00E+00	3.46E+01
1/2/2006	364	8.35E+01	2.37E+03	2.88E+04	0.00E+00	1.01E+06	2.96E+06	4.12E+06	2.84E+00	4.22E+01
Protons (XE12)		4.85E+03	9.94E+05	9.65E+05	4.97E+01	3.99E+07	2.88E+08	1.12E+08	21169.0344	7295.8495
Overall Airborne for CY										
Air,uBq/proton			0	0	0.00E+00	2.58E-02	1.01E-04	6.94E-03	0	0
Bq released			0.00E+00	0.00E+00	0.00E+00	1.03E+12	2.90E+10	7.78E+11	0.00E+00	0.00E+00
Ci released			0.00	0.00	0.00E+00	2.79E+01	7.82E-01	2.10E+01	0.00	0.00
1st Qtr						2.58E-08	1.01E-10	6.94E-09		
Air,uBq/proton			0	0	0.00E+00	2.58E-02	1.01E-04	6.94E-03	0	0
Bq released			0.00E+00	0.00E+00	0.00E+00	2.52E+11	1.03E+10	5.98E+09	0.00E+00	0.00E+00
Ci released			0	0	0.00E+00	6.81E+00	2.79E-01	1.62E-01	0	0
2nd Qtr						2.58E-08	1.01E-10	6.94E-09		
Air,uBq/proton			0	0	0.00E+00	2.58E-02	1.01E-04	6.94E-03	0	0
Bq released			0.00E+00	0.00E+00	0.00E+00	2.56E+11	7.79E+09	1.27E+11	0.00E+00	0.00E+00
Ci released			0.00	0.00	0.00E+00	6.91E+00	2.11E-01	3.43E+00	0.00	0.00
3rd Qtr						2.58E-08	1.01E-10	6.94E-09		
Air,uBq/proton			0	0	0.00E+00	2.58E-02	1.01E-04	6.94E-03	0	0
Bq released			0.00E+00	0.00E+00	0.00E+00	2.71E+11	5.16E+09	3.39E+11	0.00E+00	0.00E+00
Ci released			0.00	0.00	0.00E+00	7.31E+00	1.39E-01	9.15E+00	0.00	0.00
4th Qtr						2.58E-08	1.01E-10	6.94E-09		
Air,uBq/proton			0	0	0.00E+00	2.58E-02	1.01E-04	6.94E-03	0	0
Bq released			0.00E+00	0.00E+00	0.00E+00	2.52E+11	5.66E+09	3.06E+11	0.00E+00	0.00E+00
Ci released			0.00	0.00	0.00E+00	6.82E+00	1.53E-01	8.27E+00	0.00	0.00

Tot. Ci released to Air (1st Qtr):	7.25
Tot. Ci released to Air (2nd Qtr):	10.55
Tot. Ci released to Air (3rd Qtr):	16.60
Tot. Ci released to Air (4th Qtr):	15.24
Grand Total Ci. Released to Air:	49.65

Appendix D.
Example of MI-65 Tritium Evaporation Tank Worksheet

NuMI_MI-65_HTO_Boiler2008

A: Sample ID	B: Date Collected	C: Tritium Concentration (pCi/ml)	D: Error (pCi/ml)	E: Evaporated volume (Liters/day)	F: Evaporated Activity (pCi)	G: Evaporated Activity (Ci)	H: Total annual (Ci)	I: Comments
	1/1/2008	50600.0	300	507.5	25679541353	2.6E-02	2.6E-02	
	1/2/2008	50600.0	300	498.4	25217850901	2.5E-02	5.1E-02	
	1/3/2008	50600.0	300	418.5	21174079355	2.1E-02	7.2E-02	
	1/22/2008	50600.0	300	608.1	30769516896	3.1E-02	6.1E-01	
	1/23/2008	50600.0	300	667.0	33749920306	3.4E-02	6.5E-01	
	1/24/2008	50600.0	300	624.1	31581082144	3.2E-02	6.8E-01	
080125TB01	1/25/2008	43600.0	600	623.3	27175987390	2.7E-02	7.0E-01	
	1/26/2008	43600.0	600	623.0	27163930608	2.7E-02	7.3E-01	
	1/27/2008	43600.0	600	642.1	27995848589	2.8E-02	7.6E-01	
080128TB01	1/28/2008	40800.0	500	670.6	27360046893	2.7E-02	7.9E-01	
	1/29/2008	40800.0	500	459.3	18740221810	1.9E-02	8.1E-01	
	1/30/2008	40800.0	500	427.2	17431452556	1.7E-02	8.2E-01	
	1/31/2008	40800.0	500	572.7	23366044171	2.3E-02	8.5E-01	
	2/1/2008	40800.0	500	603.4	24618400957	2.5E-02	8.7E-01	
	2/2/2008	40800.0	500	603.7	24629683450	2.5E-02	9.0E-01	
	2/3/2008	40800.0	500	590.4	24088123759	2.4E-02	9.2E-01	
	2/4/2008	40800.0	500	574.4	23433739132	2.3E-02	9.4E-01	
	2/5/2008	40800.0	500	460.7	18796634278	1.9E-02	9.6E-01	
	2/6/2008	40800.0	500	561.9	22926026922	2.3E-02	9.9E-01	
080207TB01	2/7/2008	45600.0	200	537.6	24513540134	2.5E-02	1.0E+00	
	2/8/2008	45600.0	200	524.3	23908267538	2.4E-02	1.0E+00	
	2/9/2008	45600.0	200	490.8	22382476203	2.2E-02	1.1E+00	
	2/10/2008	45600.0	200	512.4	23366044171	2.3E-02	1.1E+00	
	2/11/2008	45600.0	200	526.5	24009146304	2.4E-02	1.1E+00	
080212TB01	2/12/2008	47400.0	200	492.5	23344640617	2.3E-02	1.1E+00	
	2/13/2008	47400.0	200	540.9	25638471110	2.6E-02	1.2E+00	
	2/14/2008	47400.0	200	524.9	24878230147	2.5E-02	1.2E+00	
	2/15/2008	47400.0	200	530.4	25140382203	2.5E-02	1.2E+00	
	2/16/2008	47400.0	200	524.9	24878230147	2.5E-02	1.2E+00	
	2/17/2008	47400.0	200	523.2	24799584530	2.5E-02	1.3E+00	
	2/18/2008	47400.0	200	476.7	22597507257	2.3E-02	1.3E+00	
080219TB01	2/19/2008	40700.0	200	557.5	22689758233	2.3E-02	1.3E+00	
	2/20/2008	40700.0	200	511.0	20798945047	2.1E-02	1.3E+00	
	2/21/2008	40700.0	200	412.6	16792221867	1.7E-02	1.3E+00	
	2/22/2008	40700.0	200	345.4	14057295651	1.4E-02	1.3E+00	
	2/23/2008	40700.0	200	314.4	12796753527	1.3E-02	1.4E+00	
	2/24/2008	40700.0	200	253.6	10320688641	1.0E-02	1.4E+00	
	2/25/2008	40700.0	200	251.9	10253159598	1.0E-02	1.4E+00	
	2/26/2008	40700.0	200	222.1	9037636836	9.0E-03	1.4E+00	
	2/27/2008	40700.0	200	222.9	9071401357	9.1E-03	1.4E+00	
080228TB01	2/28/2008	34200.0	200	189.1	6468850869	6.5E-03	1.4E+00	
	2/29/2008	34200.0	200	228.1	7802342057	7.8E-03	1.4E+00	
	3/1/2008	34200.0	200	258.0	8823739562	8.8E-03	1.4E+00	
	3/2/2008	34200.0	200	189.7	6487765637	6.5E-03	1.4E+00	
	3/3/2008	34200.0	200	174.5	5967609500	6.0E-03	1.4E+00	
	3/4/2008	34200.0	200	262.2	8965600327	9.0E-03	1.4E+00	
	3/5/2008	34200.0	200	222.3	7603736986	7.6E-03	1.5E+00	
	3/6/2008	34200.0	200	212.9	7282185919	7.3E-03	1.5E+00	
	3/7/2008	34200.0	200	264.9	9060174170	9.1E-03	1.5E+00	
	3/8/2008	34200.0	200	332.1	11358318558	1.1E-02	1.5E+00	
	3/9/2008	34200.0	200	127.1	4347202289	4.3E-03	1.5E+00	
	3/10/2008	34200.0	200	222.1	7596843604	7.6E-03	1.5E+00	
	3/11/2008	34200.0	200	302.0	10329985637	1.0E-02	1.5E+00	
	3/12/2008	34200.0	200	338.2	11567431833	1.2E-02	1.5E+00	
080313TB02	3/13/2008	47600.0	300	310.2	14766795013	1.5E-02	1.5E+00	
	12/31/2008				0	0.0E+00	1.5E+00	

Total 2008 Ci released = 1.5

Appendix E.
Example of Alnor Velometer Calibration Certificate

ALNOR®
TSI Incorporated

CALIBRATION DATA SHEET

Temperature	71.3	☒ °F ☐ °C
Relative Humidity	39 %	
Barometric Pressure	28.62	☒ in Hg ☐ mm Hg
Standards Used	Std. Cal. Due Date	
E002109	10-17-2007	

MODEL NUMBER	VELOMETER® 6000	
SERIAL NUMBER	53232	
☐ NEW	SERVICED	☒ As Found ☐ As Shipped ☐ In Tolerance ☒ Out of Tolerance

AIR VELOCITY in FEET PER MINUTE				
RANGE	STD.	ALLOWED LIMITS	6070P DIFFUSER PROBE	6060P PITOT PROBE
0/10000	9000	8800-9200	8800	8900
	*6000	5800-6200	—	—
	2000	1800-2200	1900	1900
0/5000	4500	4400-4600	4500	4500
	*3000	2900-3100	—	—
	1000	900-1100	900	900
0/2500	2250	2200-2300	2200	2225
	*1500	1450-1550	—	—
	500	450-550	425	425
0/1250	1200	1175-1225	1175	1200
	*800	775-825	—	—
	400	375-425	370	360
			6050PI LOW FLOW PROBE	
0/300	300	294-306	296	
	*150	144-156	—	
	50	44-56	50	

STATIC PRESSURE in INCHES OF WATER			
RANGE	STD.	ALLOW'D LIMITS	6080P PROBE
0/10	8.0	7.5 - 8.5	8.0
	*4.0	3.5 - 4.5	—
	1.0	0.5 - 1.5	1.0
0/1.0	.80	.75 - .85	.80
	*.40	.35 - .45	—
	.10	.05 - .15	.09
0/3.0	2.5	2.35-2.65	
	*1.5	1.35-1.65	
	0.5	0.35-0.65	

* Values are only recorded for As Shipped and New Calibrations.

TSI Incorporated hereby certifies that this equipment was found to meet or exceed manufacturing specifications. This equipment has been calibrated using standards whose accuracies are traceable to the National Institute of Standards and Technology (NIST) within the limits of the institute's calibration service.

B. Dloser — CHECKED BY
6-6-07 — DATE

TSI Incorporated
Alnor Products
500 Cardigan Road
Shoreview, MN 55126 USA
Toll: 1-800-424-7427
Tel: 1-651-490-2811
Fax: 1-651-490-3824

Form 119-003-000 REV 9

Appendix F

Procedures for sampling stack emissions for tritium using bubblers at installed locations

Kamran Vaziri, Vernon Cupps and John Larson

(December 2008)

- For the beam-on measurements make sure beam conditions are stable. Take into account the transit time from the source to the stack/sampling location.
- Note: Depending on weather conditions, the tritium sampler ice chest cover may be left on and closed, on and hatch open, or off completely to control inside temperature (Fig. F-1).
- When finished get the proton reports from Operations for the duration of the sampling. This is, of course, not necessary if doing beam-off sampling.

<u>Purging</u>

- Note: Tritium sampler “bypass” tube should still be in flow path from last use (see Fig. F-2).
- With pump power off, open the inlet and outlet valves located in the <u>lower</u> ice chest. When the valve handle is straight up, the valve is open (Fig. F-3).
- Make sure the bubbler flow-meter valve is open.
- Plug in the upper ice chest cord. This will start the pump.
- Set flow rate to approximately 0.3 lpm.
- Run for about 1/2 hour to purge all the plumbing.
- Turn off the pump by unplugging the upper ice chest cord.

<u>Start of sampling</u>

- Disconnect the bypass tube.
- Fill each bubbler with 250 ml of distilled deionized RAF water (Figs. F-4, F-5).
- **Record** the volume of water in each bubbler.
- Install retention springs on bubblers.
- Place the bubblers, <u>in order</u>, into ice chest holders.
- Connect the bubblers to each other using male / female quick-connects.
- Connect the end bubblers to the inlet and outlet quick-connects.
- Turn on the pump by plugging in the ice chest power cord.
- **Record** the start time.
- Adjust the flow rate to 0.3 lpm (300 ml per minute).
- **Record** the flow-meter setting.
- Allow to sample for the estimated time necessary to achieve desired concentration. The ideal would be to collect most of the tritium collected in the first in line bubbler, a small fraction in the second and very small fraction of the second or none in the third. This ensures that none or relatively insignificant amount of tritium was not captured in the third bubbler. This step may have to be repeated to estimate the optimal sampling time.

<u>Removal of samples</u>

- **Record** the flow-meter setting.
- Turn off the pump by unplugging the upper ice chest cord.
- **Record** the stopping time.

- Close inlet and outlet valves in the lower ice chest. When the valve handles are down (horizontal) the valve is closed (Fig. F-6).
- Disconnect the bubblers from each other, and inlet and outlet.
- Connect the bypass tube from inlet to outlet.
- Turn on the pump by plugging in the upper ice chest cord.
- Run for about an hour to purge/remove moisture from the tubing.
- Turn off the pump by unplugging the upper ice chest cord.
- Replace cover on ice chest.

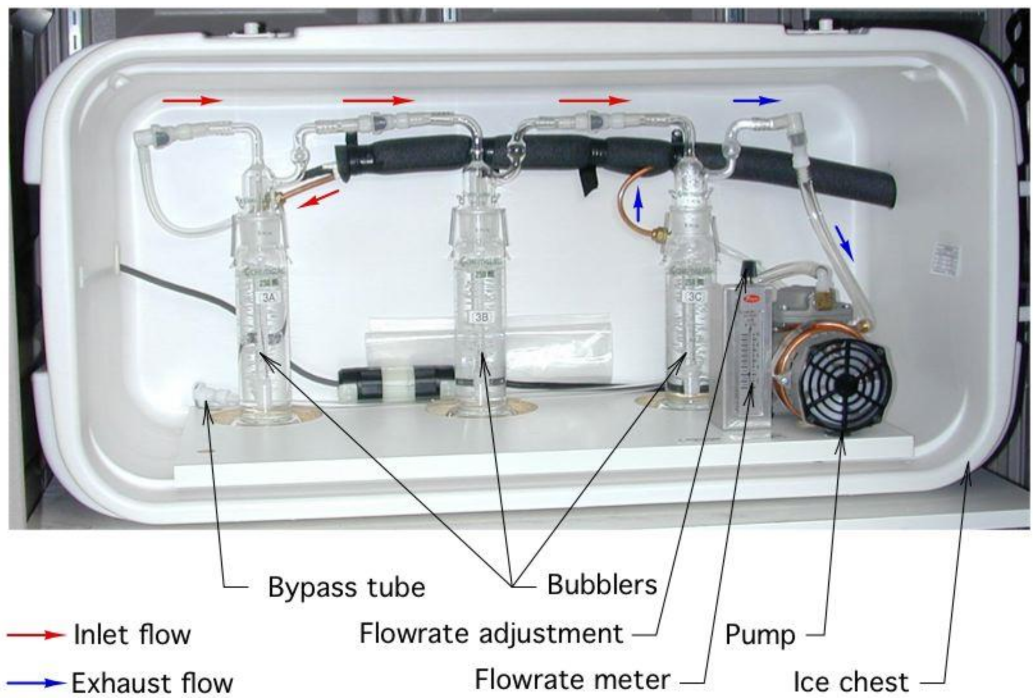


Figure F-1. Picture of tritium sampler ice chest, showing the three bubblers connected in-line with the pump and flowmeter. The disconnected bypass tube is is shown in the bottom left side.

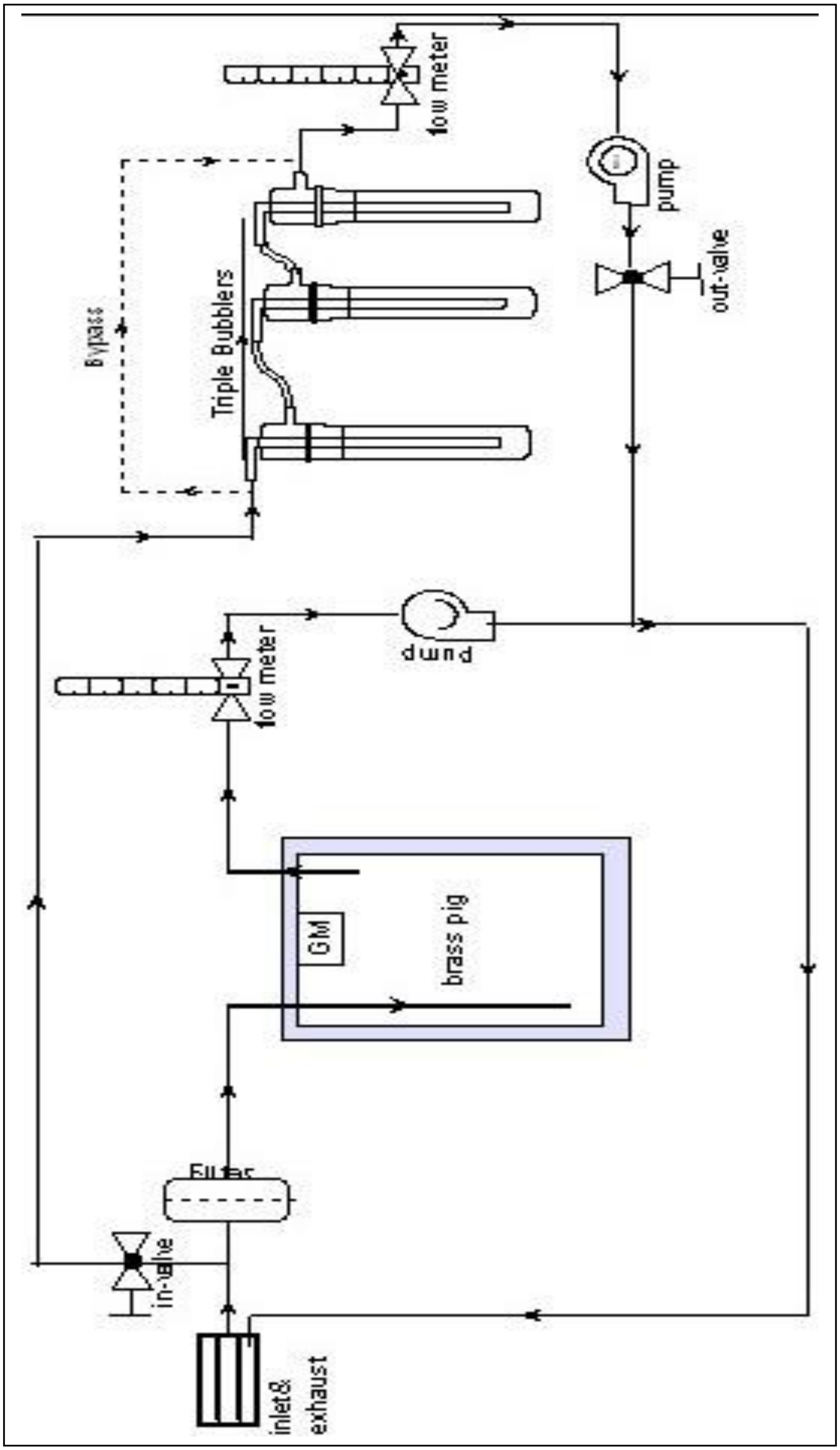


Figure F-2. Schematic drawing of the triple bubbler connection to the stack.

Figure F-3. Picture of the valves connecting the inlet and outlet of the sample tubes to the tritium sampler. When open the handles are in the vertical position.

Figure F-4. Picture of the three bubblers connected in series.

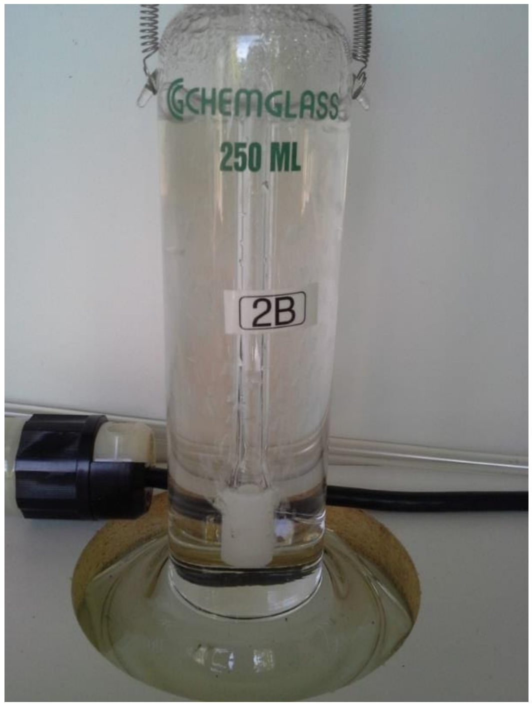


Figure F-5. Picture of a single bubbler with the two retention springs on top.

Figure F-6. Picture of the valves connecting the inlet and outlet of the sample tubes to the tritium sampler. When closed the handles are in horizontal position.