Fermilab
ES&H Section

RP. NOTE 153
Estimation of the Air Emissions from the Main Injector
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(December 2008)

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Distribution via Electronic Mail*

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I. Introduction

Slip-stacking of the Booster's 8 GeV proton bunches in the Main Injector is used to increase the beam intensity to support the experiments at the neutrino beam lines and the Tevatron. In order to improve the quality of this beam in the Main Injector a set of collimators have been designed and installed. In addition to localizing the losses at 8 GeV, the collimators' shielding will absorbed a significant amount of the lost beam [1]. This note describes the calculations for the air activation levels caused by the interaction of the radiation, which leaks out of the collimator shielding, with air at 500 kW beam power.

The air activation is due to the estimated 5% beam loss on the collimators which are located in the Q230 to Q310 region [1]. The collimators span a region of about 500 feet. The sector has one air supply (MU-3) and two air exhaust fans (EF-2 and EF-3) rated at 5000 cfm each. The distance between the air exhaust locations that straddles the collimators is 1706 ft. The air supply is located in the middle of the collimators region (Q305). The air flowing into the tunnel splits in two 2500 cfm currents flowing in opposite directions in the tunnel. Each half of the supply air will flow over half of the collimators region (250ft.) and travels a total distance of 853 ft. to the nearest exhaust [2].

This note will briefly describe the calculations, results and conclusions.

Calculations

Although the slipstacking of the Booster protons bunches in the main injector is done at very high efficiency, a small amount of the beam ends up as a halo and is lost on the beam pipe or at tight apertures around the Main Injector ring. The purpose of the MI-300 collimators is to intercept this halo and therefore localize the losses and contain them via shielding. Figure 1 shows the hadron fluxes in the air due to loss of 1.25E12 protons/sec. on the collimators, calculated using the MARS Monte Carlo code [3]. The details of modeling and the results are given in TM-2391-AD [4]. These fluxes were used for the airborne radio-nuclides production calculations. It is assumed that the Main Injector operates 2E7 seconds per year (63.5%), and the tunnel has a cross section of 80 squared feet.

The composition of the air is given in Table 1. Table 2 gives values of decay constants and radio-nuclide production cross sections from different elements. The production cross sections are conservative choices taken from the references by Barbier [5] and

Thomas and Stevenson [6]. ^{41}Ar has a large cross section for production by thermal neutrons. It is usually difficult and time consuming to estimate the thermal neutron flux densities using MARS, and thus a scaling factor is used. The value of the concentration of ^{41}Ar is conservatively taken to be 2.5 % of the sum of the concentrations of ^{11}C and ^{13}N calculated within a given enclosure. This choice is conservative in that typical measured values at Fermilab are about 1% to 2%. ^{41}Ar, ^{13}N and ^{11}C tend to be the radionuclides of concern, although this methodology also calculates the levels of ^{15}O, ^{7}Be and ^{3}H.

Table 1. The isotopic composition of air in fractional volume and atom density.

Nuclide	Atomic weight	Fractional volume	Atoms/cm3
^{14}N	14	7.82E-01	4.20E+19
^{16}O	16	2.00E-01	1.07E+19
^{15}N	15	2.90E-03	1.56E+17
^{18}O	18	4.00E-04	2.15E+16
^{40}Ar	40	4.67E-03	1.25E+17

The number of radionuclides of each type produced is calculated by summing over the contributions from different target nuclides in air: The concentration of the radionuclide "i" is calculated using

$$a_i(Bq/yr)=\sum_j (N_j\sigma_{ij}\ \phi\ N_p O_s)\left[e^{-\lambda_i t_{cool}}\right]\left[\left(\frac{\lambda_i}{\lambda_i+r}\right)\left(1-e^{-(\lambda_i+r)t_{irrad}}\right)\right]\left[\left(e^{-\lambda_i t_{transit}}\right)D\right]$$

N_p is the number of protons per second.
ϕ is the hadron flux density (hadrons/cm^2/proton).
N_j is the number of target atoms per unit volume (atoms/cm^3).
σ_{ij} is the cross section for production of radionuclide i from target atom j (cm^2).
λ_i is the inverse mean lifetime of radionuclide i (seconds^{-1}).
t_{cool} is the time after beam-off at which one is calculating the release; typically this is zero as one calculates for a continuous beam-on release.
t_{irrad} is the irradiation time of the air volume.

r the ventilation term, is the number of air changes per unit time.

$$r=\frac{D}{V}$$

D is the ventilation rate in the external air volume per unit time.
V is the volume of region (cm^3).
O_s is the number of operational (beam-up) seconds year.

$t_{transit}$ is the ventilation system travel time, from the production region to the release point:

$$t_{transit} = \frac{V}{D}$$

Table 2. Decay constants and the cross sections for the production of various airborne radioisotopes from air.

	Decay Constants, λ_i, and Derived Air Concentration[a] (DAC) Limits for Various Radionuclides					
Product =>	^{3}**H**	^{7}**Be**	^{11}**C**	^{13}**N**	^{15}**O**	^{41}**Ar**
λ (sec^{-1}) =>	1.79E-9	1.51E-7	5.69E-4	1.16E-3	5.67E-3	1.05E-4
DAC (Ci/cm3)	2E-11[b]	1E-11	5.9E-11	4.1E-11	2.7E-11	4.7E-11
Target Nuclide	**High Energy Hadron Cross Sections (mb)**					
^{14}N	30	14	20	4	0	
^{16}O	30	8	10	5	35	
^{40}Ar	1	10	1	1	1	610
^{15}N	30	14	20	4	0	
^{18}O	30	8	10	5	35	

[a] From Reference [9].

[b] This is the value for the tritiated water, which is a more conservative value than the DAC for the elemental form.

IV Analysis of the results

The activation products are ^{41}Ar, ^{11}C, ^{13}N, ^{15}O, ^{7}Be and tritium. The radioisotope ^{7}Be is 0.05% of total activity produced. Most of the ^{7}Be plates out near the production location and does not reach the release point. Tritium is 0.001% of the total activation products. The short half-life of ^{15}O and the small decay constant of ^{3}H usually result in radiologically insignificant levels of these two radionuclides. The released air activity is dominated by ^{11}C, ^{13}N, ^{41}Ar and ^{15}O. Figure 2. shows the amount of annual activated air released due to the operation of the collimators as a function of air flow rate in this region of the MI tunnel. The maximum annual release with the fans set at 5000 cfm is 17.5 Ci in a year.

In about a day of beam operations ^{41}Ar, ^{11}C, ^{13}N, ^{15}O have reached saturation. Under the current air flow scheme of the Main Injector, thirty minutes after the beam is shut off (after one day or longer of continuous operations) the residual radioactive air decays below 10% of DAC, which would not require any monitoring or "Air Contamination" posting [7].

IV. Conclusion

Operating the Main injector at 500 kW power with the current air flow rates will result in an annual release of about 17.5 Curies of activated air. Because of the large volumes of the air that flows in and out of the Main Injector tunnel in a year, the calculated air activity concentrations will be too far diluted for an accurate measurement. However, by keeping track of the losses on the collimators, the released activity can be estimated and accounted for in the annual NESHAP [8] report as unmonitored releases.

As shown in Figure 2. reducing the MU-3 air handler supply flow rate to 1000 cfm, will reduce the annual release to less than one Curie level for a 500 kW 8 GeV beam. For future Main Injector power increases, reducing the air supply and exhaust rates in this region is one way to lower the total annual releases.

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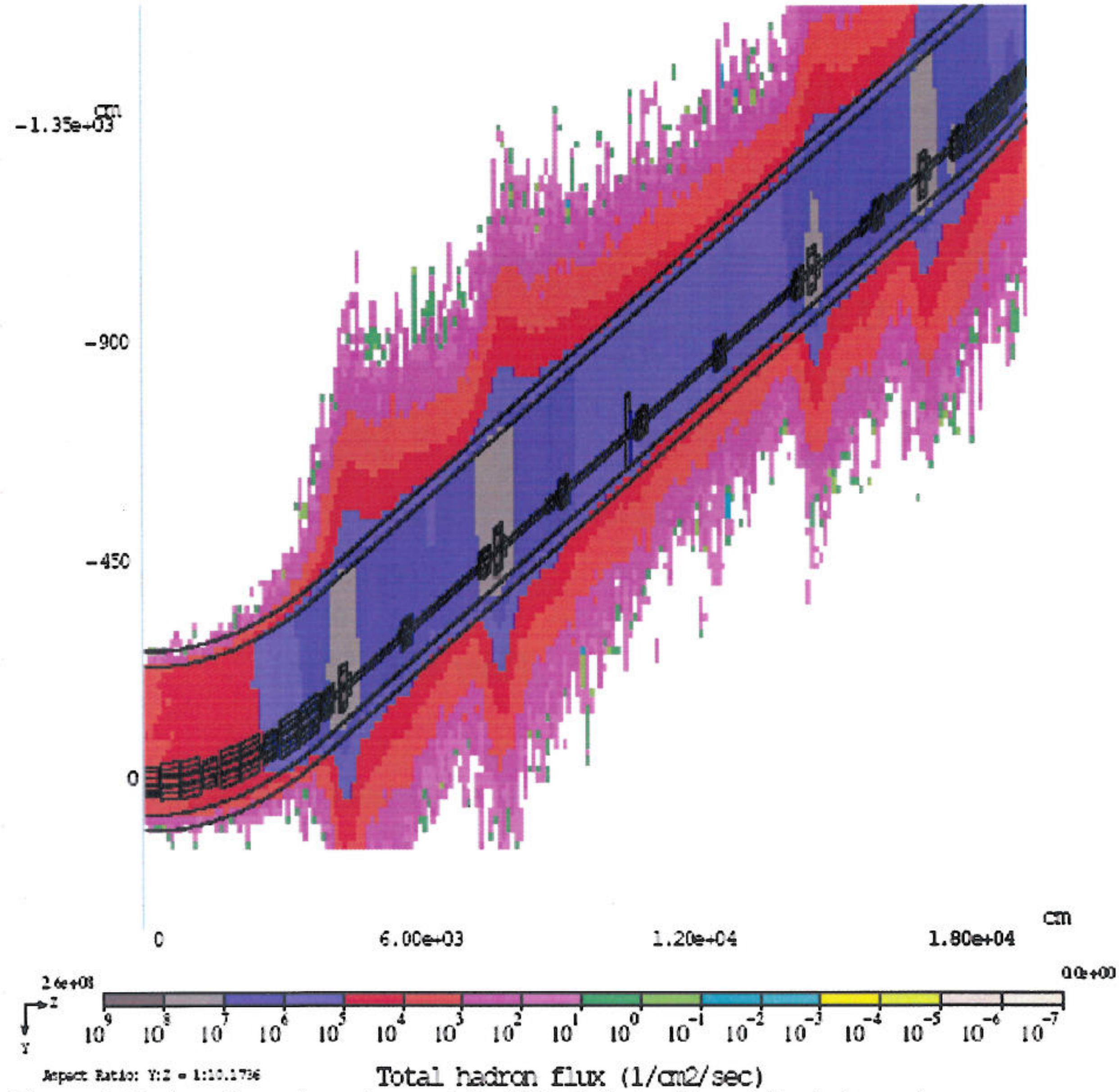

Figure 1. Hadron fluxes in and around the Main Injector Tunnel due to beam losses on the collimators.

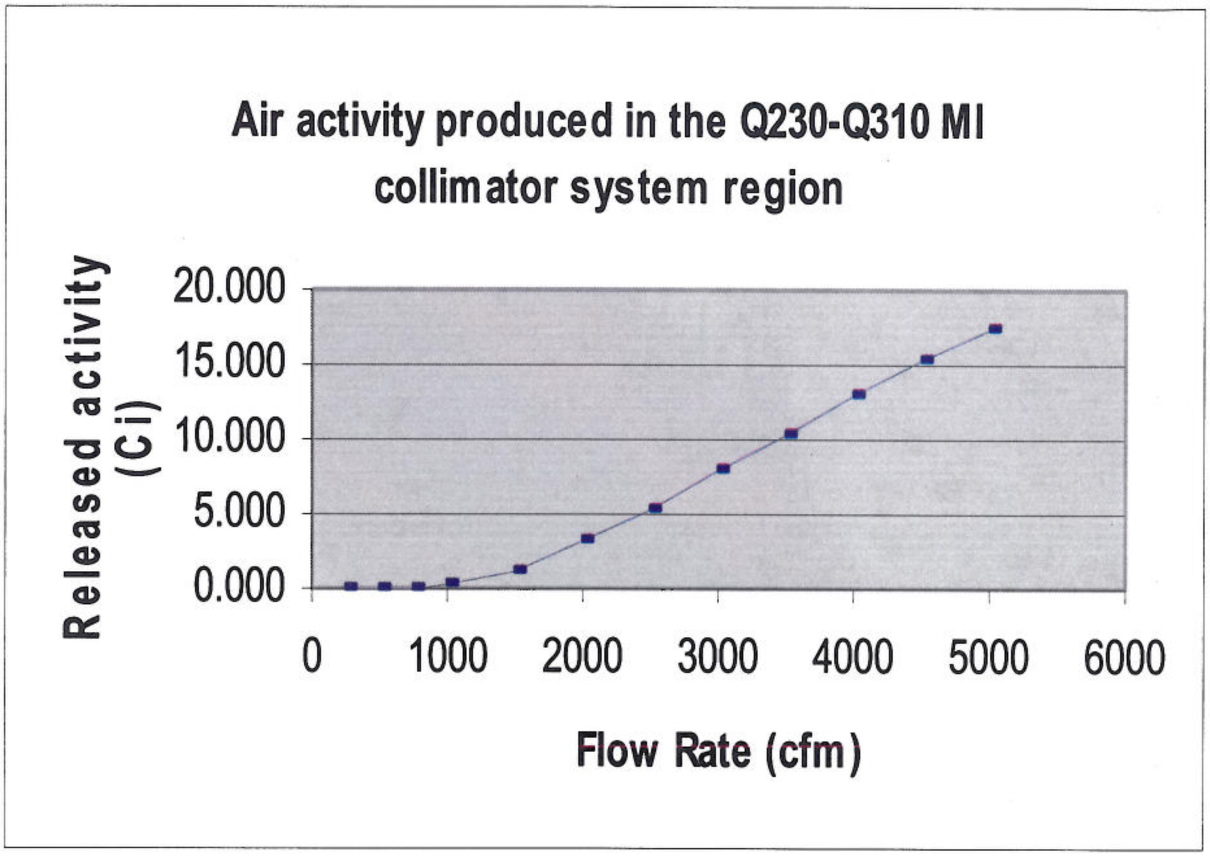

Figure 2. Annual radioactive air release from the MI-30 region as a function of supply air flow rate for the 500 kW operations.