Environmental Protection Note 9

Monitoring of Airborne Radionuclide Releases at FNAL

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Vernon Cupps, Kathy Graden, Kamran Vaziri, and Deb Grobe

Introduction:

A formal program for continuous monitoring of airborne radionuclide releases at selected Fermilab sites was initiated in 1987 as an information gathering process rather than a response to regulatory requirements. It had been known for some time that the passage of high energy particle beams through targets, ambient air, and beam stops/dumps produced gaseous radionuclides[1]. However, it was generally believed that these gaseous radionuclides were produced in such small quantities and with such short half lives that they posed no quantifiable health risk to the general public or to Fermilab workers operating under the appropriate administrative procedures. This belief was based on several items of general knowledge; (1) most gaseous radionuclides produced by high energy hadron collisions with ordinary matter have very short half lives, i.e., ≈ 2 hours or less, (2)most of the gaseous radionuclides are produced via spallation processes which typically have much smaller cross sections than single step nuclear reactions such as absorption, pickup, and stripping, (3) gaseous radionuclides produced in solid matrices have restricted mobility, (4) and gaseous radionuclides produced in gaseous media, such as ambient air, are produced in much lower quantities than those produced in equivalent thicknesses of liquids or solids.

Reference 2, article 61.93(b)(4)(i) requires facilities to continuously monitor the radionuclide emissions from a release point when those emissions have the potential to exceed 1% of the standard. The standard is that DOE facilities shall not exceed those amounts of airborne radionuclides which would cause an additional dose equivalent rate of 10 mrem/yr at the general public. This 10 mrem/yr is approximately equivalent to 3% of the background dose rate an average person receives from natural phenomena. With current technology, neither the 0.1 mrem/yr nor the 10 mrem/yr can be verified by direct measurement and as a consequence national laboratories must demonstrate compliance to a Federal Regulation with which full verifiable compliance through direct measurement is impossible, i.e., article 61.93(b)(5)(iii) of reference 2.

Since compliance with reference 2 cannot be established through direct measurements, Fermilab has elected to perform direct measurements at the major on-site sources for release of airborne radionuclides and extrapolate the impact of those releases to the site boundary using generally accepted dispersion and transport models such as are specified in article 61.93(a) of reference 2. This is the regulatory compliance mode adopted by virtually all the DOE laboratories to which the regulation applies. These models are typically conservative and hence often lead to significant over-estimates of the actual public dose equivalent rate resulting from a given release of airborne radionuclides.

The essential issue with which this note is concerned is the question of whether Fermilab is required by reference 2 to perform continuous monitoring of its airborne radionuclide emission sources. It is our belief that the evidence to date supports the thesis that Fermilab is not required by reference 2 to perform continuous air monitoring of our emission sources.

Data:

As mentioned in the introduction, Fermilab has had a formal program for evaluating our airborne radionuclide releases since 1987. The procedures used in performing these measurements and assessing the potential impact of the emissions on a member of the general public are set forth in reference 3. Reference 4 sets forth the structure for managing and administering the program. When feasible and applicable, the general procedures and guidelines found in references 5 and 6 were liberally consulted in putting together references 3 and 4.

A summary of the results from Fermilab's monitoring program since 1987 is presented in Table 1. It should be clearly noted that for a member of the general public to receive the dose equivalent rate indicated in column 3 of Table 1, he/she must spend 24 hours/day, 365 days/yr at the site boundary point where that maximum dose equivalent rate occurs. This scenario is highly improbable.

TABLE 1

Year	Targets or Dumps	Maximum Dose Equivalent Rate at the Site Boundary (mrem/yr)	Total number of AP0 targeted Protons (E17)	Total number of Fixed Targeted Protons (E17)	Collective Dose Equivalent (person-rem/yr.)	Modeling Code
1993	AP0	0.0065	65.78	0	0.0146	CAP88-PC
1992	AP0	0.0094	59.86	0	0.0227	CAP88-PC
1991	AP0 and Fixed Target Sources	0.028	21.75	20.2	0.21	CAP88-PC
1990	AP0, Magnet Debonding Oven (MDO), Fixed Target Sources	0.019	25.8	18.7	-	AIRDOS-PC
1989	AP0 and MDO	0.02	58.22	0	-	AIRDOS-EPA
1988	AP0, N01, and MDO	0.03	55.6	5	-	AIRDOS-EPA
1987	AP0, N01, and MDO	0.02	22.2	16.9	-	AIRDOS-EPA

In 1990 and 1991, the dose equivalent rate at the site boundary per targeted proton was approximately 7 x 10^{-21} mrem/yr/targeted proton. This fell to 1.6 x 10^{-21} in 1992 and 1.0 x 10^{-21} in 1993. The approximate dose equivalent rate per targeted proton dropped by almost a factor of 5 in 1992 due to a new set of measurements which showed that Fermilab's previous estimates were too conservative. Reference (3) contains the two Fermilab Radiation Physics Notes (#s 105 and 106) which document the procedures used in these measurements. Alterations made to the ventilation system at AP0 during 1993 further reduced the dose equivalent rate per targeted proton at the site boundary by forcing 100% of the exhausted air through the AP0 stack rather than only 73% as was the case in 1992.

TABLE 2

Year	Run Type	Total Release (Ci)	Total Protons (XE18)	Release Rate (Ci/Proton) (XE-17)
1989	Collider	82	5.82	1.41
1990	Fixed Target	78	2.58	3.02
1991	Fixed Target	95.3	2.18	4.37
1992	Collider	19.5	5.99	0.33
1993	Collider	22.6	6.58	0.34

Table 2 shows the effect of the new measurements from the perspective of the number of Curies of radioactive gases released per targeted proton. The numbers listed in column 5 represent an average of all the emission sources and are similar only in cases where one emission source dominates the total releases for the year, e.g., as in 1992 and 1993. These numbers probably represent a more consistent measure of radioactivity released than the dose equivalent rate per targeted proton presented in TABLE 1, since the latter depends on the modeling code used and on the distance of a given stack from the site boundary. When the Collider runs in 1989 and 1992 are compared, it is clear that the new measurements and calibration have reduced the estimated release rate by somewhat more than a factor of 4. Changes to the ventilation system at AP0 completed between the 1992 and 1993 collider runs seemed to have little measurable impact on the release rate at the AP0 stack. As is typical of the fixed target mode of operation, several sources contributed significantly to the total released activity in 1990 and 1991. A breakdown of the individual contributions to the total release is presented in TABLE 3. Note that the fractions listed for 1990 in column 5 of TABLE 3 do not add to 100 % without a factor of 10% to account for all other unmonitored sources.

TABLE 3

Year	Stack Monitor	Calibration Factor (Ci/cts) (XE-5)	Activity Released (Ci)	Fraction of Total Activity Released (%)	Targeted Protons (XE17)
1990	Antiproton	7.817	22.7	26	18.3
	M05	2.421	27	31	4.99
	NM2	1.767	11.7	14	3.53
	PB4	2.144	16.6	19	3.62
1991	Antiproton	7.815	50	47	16.9
	M05	2.42	16	15	3.38
	NM2	1.767	21.3	20	5.4
	PB4	2.144	4.7	4	3.82
	NW8	1.767	3.3	3	1.05
	Unmonitored	2.42	11.8	11	4.87

Each exhaust stack at Fermilab has its own individual calibration factor which depends on the distance that the air must move before it reaches the stack, the average air velocity, and the type of target which is generating the airborne radionuclides. It is for this reason that the average release rates in column 5 of Table 2 for 1990 and 1991 are different.

In 1991, the Curies released per targeted proton (Ci/p) dropped to 1.2×10^{-17} Ci/p from the previous years (1990) number of 4.6×10^{-17} Ci/p. This change resulted from the installation of a deuterium target upstream from the original Be-air gap target. The reduced production of ^{11}C, ^{13}N, and ^{41}Ar results in fewer Curies per targeted proton, as expected.

The number of Curies per targeted proton and the number of protons incident on a given target or dump are empirical numbers, i.e., they are established and verified through measurements. However, translating those numbers into a potential dose equivalent rate (DER) at the Fermilab site boundary involves the use of a meteorological transport model. In 1989, the AIRDOS-EPA mainframe computer code from Oak Ridge National Laboratory was used for estimating the site-boundary DER. A desk top computer code named AIRDOS-PC was used to calculate the 1990 site-boundary DER. The site-boundary DERs for 1991 thru 1993 were all determined using the desk top computer code CAP88-PC. Each of these computer codes use the same basic model for atmospheric transport of airborne radionuclides, i.e., the gaussian plume model. However the codes are sensitive to weather data, population distributions, agricultural data, and values used for the model parameters. All of these factors vary with time and location. In fact when 1991 wind data was used to calculate the 1992 DER, a value of .0043 mrem/yr. was obtained; demonstrating at least a factor of 2 variability in the model with wind data. A conversion factor of 2.18×10^{-4} mrem/Ci would have been generated by this estimate. Hence any conversion factors generated using these estimates should be used with care.

TABLE 4

Year	Run Type	Release Rate (Ci/proton) (XE-17)	Particle Rate (protons/yr.) (xE18)	Conversion Factor (mrem/Ci) (xE-4)
1989	Collider	1.41	5.82	2.55
1990	Fixed Target	3.02	2.58	2.44
1991	Fixed Target	4.37	2.18	2.93
1992	Collider	0.33	5.99	4.74
1993	Collider	0.34	6.58	2.9

Approximate average conversion factors for each of the last five years are listed in Table 4. With the exception of 1992, these numbers are surprisingly consistent considering all the variables involved in calculating them. The average calibration factor for all five years is 3.11×10^{-4} mrem/Ci released from Fermilab exhaust stacks with a relative error of approximately 30%. This is of course a model dependent number. Rainfall in 1992 was 30% below the average for this area; meaning that there would have been less scavenging of the gaseous radionuclides on their way to the site boundary than normal. Excluding 1992, the average calibration factor would be 2.71×10^{-4} mrem/Ci released with a relative error of 10%. Thus for rough calculations, the DER can be estimated by multiplying the total activity released by 3×10^{-4} mrem/Ci.

Summary:

Reference (1) specifies that all release points with the 'potential' to exceed 1% of the 10 mrem/yr. standard must be directly monitored on a continuous basis. All other release points are subject only to periodic confirmatory measurements. Although it is always somewhat ambiguous exactly what 'potential' should mean, the data in Table 1 clearly show that even with the extremely conservative estimates prescribed by the CAAA regulations, the dose equivalent rate at the Fermilab site boundary there exists no reasonable potential for that dose rate to exceed 0.1 mrem/yr. as the accelerator is currently operated.

It has been projected that the main injector, when it is operational, will increase the available beam intensities by no more than a factor of 3 (ref. 7). Assuming that the quantities of radionuclides released at a given release point scale with the beam intensity the maximum dose equivalent rate at the Fermilab site boundary would be 0.03 mrem/yr. This is still more than a factor of 3 below the point at which continuous monitoring would be required. It can thus be concluded that there is no current or projected conditions at this date under which Fermilab would exceed the 0.1 mrem/yr. standard.

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