ENVIRONMENTAL RADIATION MONITORING AND CONTROL

Revision History

Author	Description of Change	Revision Date
J. D. Cossairt	1. Incorporate suggestions made since the last revision. 2. Incorporate modifications needed to implement amendments of 10 CFR 835 finalized on April 13, 2011 pertaining to Derived Air Concentrations (DACs). 3. Incorporate modifications to implement the new Derived Concentration Standards announced in DOE-STD-1196-2011 April 2011. 4. Correct editorial errors.	September 2011

CHAPTER 11 ENVIRONMENTAL RADIATION MONITORING AND CONTROL

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PART 1 REQUIREMENTS

1101 Purpose

The purpose of this chapter is to state standards and requirements for Fermilab activities with respect to protection of members of the public and the environment against undue risk from radiation. This includes a synopsis of the major features of DOE Order 458.1, "Radiation Protection of the Public and the Environment" (April 2011). *This Order is, as of September 2011, not yet in full implementation at Fermilab. This chapter may be revised as the implementation plan for this Order is developed.*

1102 Scope

1. Protecting the Public

   Fermilab will operate and conduct its activities so that radiation exposures to members of the public are maintained within the limits established in DOE Order 458.1 so that radiation exposure to members of the public is controlled through the management of Fermilab activities. Fermilab objectives are that potential exposures to members of the public be as low as reasonably achievable (ALARA) and that the Laboratory maintains the capabilities, consistent with the types of operations conducted, to monitor routine and non-routine releases and to assess doses to members of the public.

2. Protecting the Environment

   In addition to providing protection to members of the public, it is Fermilab's goal to protect the environment from radiation exposure and radioactive contamination in accordance with the ALARA principle. Fermilab's ALARA program is specified in more detail on Chapter 3 Part 5 of this Manual.

1103 Introduction

1. Several types of sources at Fermilab may potentially contribute to off-site population radiation dose or environmental radiological exposure. Examples of these are:

   a. Penetrating radiation such as muons, gamma rays, and neutrons created through beam interaction with targets and beamline components;

   b. Airborne radioactivity produced at high intensity beam loss points and released from ventilation stacks;

   c. Radioactivity in water that has leached through radioactivated soil in beam loss areas and collected in beam enclosure underdrains. Article 346 specifies the control measures to be utilized. This water is commonly discharged by means of sump pumps;

d. Radioactivated soil in beam loss areas.

2. Appendices 11A & 11B contain technical information from various sources concerning environmental monitoring methods and their utilization at Fermilab.

3. Appendix 5E, Part C provides the procedures for submitting samples to the Radionuclide Analysis Facility (RAF).

1104 Public Dose Limits, ALARA, and Best Available Technology (BAT)

The DOE primary standards on dose limits to members of the public who are not occupational workers at Fermilab are DOE Order 458.1 (April 2011) supported by DOE-STD-1196-2100 (April 2011).

1. The DOE primary standard is 100 mrem (1 mSv) dose to members of the public in a year.

2. These standards also include requirements concerning the release of liquid effluent discharges to surface waters, sewers, groundwater, and on radioactive air emissions.

3. Air releases are governed by IEPA/USEPA permits and regulations and also by 40 CFR 61 Subpart H (NESHAP). The primary public dose limits include consideration of exposure modes from all Fermilab activities.

4. Since 1971 the Laboratory, as proclaimed by the Director, has implemented a goal of limiting the dose at the site boundary to a maximum of 10 mrem in any given calendar year due to all Fermilab sources. This “fencepost” dose serves as an upper limit to that which could possibly have been received by an actual person.

5. DOE Order 458.1 includes additional monitoring analysis requirements if the estimated total effective dose (TED) to representative members of the public is estimated to exceed 25 mrem in a year.

1105 Responsibilities

General responsibilities for environmental protection are set forth in Chapters 1030 & the 8000 series of chapters of the Fermilab ES&H Manual. Specific responsibilities as they pertain to environmental radiation are as follows:

1. <u>ES&H Section</u>

The ES&H Section is responsible for:

a. Monitoring off site exposure due to penetrating radiation.

b. Coordinating the environmental radiation protection program.

c. Performing various line functions including:

(1) Conduct sitewide confirmatory environmental monitoring to meet reporting requirements, and to track environmental issues sitewide. Effluent monitoring shall comply with applicable regulations and shall be conducted to provide representative measurements of the quantities and concentrations of radiological pollutants in liquid and airborne discharges as prescribed by the individual regulations.

(2) Collect sufficient data to enable the preparation of required reports.

(3) Compile division/section/center input for various reports that are submitted to governmental agencies including DOE.

(4) Generate the various reports on environmental protection topics that are requested by DOE and regulatory agencies.

d. Assisting division/section/center in program development, and in auditing of division/section/center compliance in accord with the Fermilab Environmental Management System (EMS).

e. Coordinating applications and renewals of environmental permits.

f. Maintaining adequate formal plans, procedures and data to demonstrate the effectiveness of environmental protection at Fermilab.

2. Divisions/Sections/Centers

Divisions/sections/centers who manage, design, maintain, operate, or use processes and facilities that result in environmental radiological impacts are responsible for developing programs to:

a. Assure compliance with Fermilab policies.

b. Demonstrate compliance with commitments made in Environmental Impact Statements, Environmental Assessments, or other official documents.

c. Identify potential environmental problems and evaluate the need for remedial actions or mitigative measures.

d. Cooperate with the ES&H Section in establishing a routine monitoring program to monitor effluents at certain sources based on current operational conditions. Additional objectives are to:

   (1) Evaluate the effectiveness of radiological effluent treatment and control.

   (2) Monitor compliance with permit conditions and provide data for permit revision/renewal.

   (3) Detect, characterize and report unplanned releases.

e. Develop solutions to environmental pollution problems, taking steps to ensure that releases are kept ALARA (Chapter 3 of this manual).

f. Develop programs to sample and monitor environmental radiation contamination sources in areas that result from their activities and determine the amounts released. Determination of sampling frequency and type shall be based upon specific facility needs. Sampling shall be conducted in a manner that adequately characterizes effluent streams. Standard collection and analysis methods shall be used. Auditable monitoring records shall be kept in accordance with the requirements of Chapter 7 of this Manual.

g. Report monitoring results, as requested, to the ES&H Section.

Appendix 11A Sources, Measurement, and Control of Environmental Radiation

A. Penetrating Radiation

1. Operation of the accelerator inevitably results in production of some penetrating radiation (primarily neutrons and muons) outside the shielding (see Chapter 8). The shielding has been designed to be adequate for routine operation. There may be some locations that are thinly shielded and which rely on radiation-activated interlocks for personnel protection. On and off-site monitoring for purposes of determining actual radiation levels is to be implemented as necessary to assure compliance.

2. The ES&H Section uses a Mobile Environmental Radiation Laboratory (MERL) to locate accelerator-produced penetrating radiation sources and to measure radiation levels at different distances from a source to determine dose equivalent rates at the site boundaries. The MERL is equipped for neutron, gamma ray and charged particle detection.

3. For neutron detection, the MERL has a DePangher long counter. For more detail measurements of the neutron spectra outside the shields, the ES&H Radiological Protection Group uses a set of Bonner spheres.

4. For charged particle detection (muon and hadron), the MERL has a set of plastic scintillation counters with coincidence electronics to determine the direction and time of the event. A telemetry system is used to relay information on beam intensity and spill to the MERL.

5. For airborne radioactivity, a thin window GM detector installed in a lead shielded air sampler is used in a multi-channel scaling mode to establish a decay curve (see Chapter 5, Appendix 5F). The decay curves of the radionuclides possibly present are individually adjusted in magnitude to best fit the measured curve and thus establish the mixture present in a grab sample of the air collected from a ventilation stack.

6. To augment the single mobile laboratory, a large network of fixed radiation detectors (“Hippo,” “Chipmunk” and “Scarecrow” detectors — see Chapter 5, Appendix 5D) send information back to a central data collecting area. The primary function of most of these is as area monitors. Environmental gamma measurements are also made at various locations on site to determine both background and induced radiation levels.

B. Airborne Radioactivity

Under normal operation, airborne radioactivity is produced in the vicinity of most beam absorbers and target stations (see Chapters 5 and 8). Monitoring of such activation is being carried out for purpose of estimating releases of airborne radionuclides. Fermilab radioactive air releases are regulated by a NESHAPs permit issued by the Illinois Environmental Protection Agency and by 40 CFR 61, Subpart H.

C. Waterborne Radioactivity

1. In some cases, the earth shielding around high intensity beam loss areas becomes activated (see Chapters 5 and 8). Leaching of radionuclides into water provides a possible mechanism for transport of radioactivity to the surface water and groundwater. Appendix 11B contains a technical discussion of the standard and approved methods of estimating groundwater activation at Fermilab.

   Water sampling locations have been chosen to monitor two groundwater systems:

   a. Surface and Near-Surface Waters — these samples are taken from sumps which collect water in the vicinity of accelerator components and from on site streams and industrial holding ponds that they discharge into. Shallow monitoring wells are also used to monitor the concentrations of radionuclides in water at selected locations.

   b. Silurian Aquifer — these samples are taken from monitoring wells screened in the Silurian dolomite aquifer. The top of this aquifer is at an elevation that varies over the Fermilab site. It typically is about 35 to 40 feet below the ground surface.

2. Closed-Loop Systems- During accelerator operations, water in the closed-loop magnet, target, and absorber cooling systems becomes radioactive primarily as a result of spallation of oxygen nuclei (see Article 335 and Chapter 8).

3. Radionuclide Deposition and Buildup – During accelerator operations, radionuclides emitted from air stacks and discharge from sumps can potentially buildup in soils and sediments. Samples of soil and sediment should be taken at locations close to air and water discharge locations and monitored for buildup of accelerator-produced radionuclides.

Appendix 11B Technical Description of Groundwater Activation Calculations Using the Concentration Model

Radioactivity induced in accelerator components or accessories as well as in shielding structures, mostly of steel and concrete, can be safely assumed to be retained within these structures. However, most often the outer part of the shield is soil that also forms an integral part of the terrain, e.g., the berm over Fermilab's Tevatron and the soil underneath the tunnel floor. Interaction of the beam with material results in hadronic cascades that will propagate through the soil and particle interactions with the soil will produce radioactivity. The concentration of these radionuclides produced is dependent upon the beam parameters (i.e., energy, particle type, intensity, and target configuration), while leachability of the radionuclides into groundwater, and subsequent migration to the aquifer are dependent upon the details of the local hydrogeology.

Some fraction of the produced radioactivity may leach into the groundwater, from where it may migrate to the Silurian aquifer and thus potentially into potable water wells. The time scale of this entire process is measured in years and an appropriate input into an estimate of groundwater activation is the annual average amount of beam used (see second bullet below). Structures such as beam absorbers and targets, where a large number of accelerated particles are directed, are specifically designed to keep groundwater activation below acceptable levels. Furthermore, the State of Illinois has classified certain strata as being “Class I groundwaters" subject to regulatory protection. The ES&H Section Environmental Protection staff can provide more information on this subject.

The only leachable radionuclides known to be produced in Fermilab soil are ^{3}H, ^{7}Be, ^{22}Na, ^{45}Ca, and ^{54}Mn (Bo72). Of these radionuclides, ^{3}H and ^{22}Na have the longest half-lives, significant production rates, and largest leachabilities into water flowing through the soil and therefore they pose the greatest potential hazard. Experience has found that a measurement or estimate that indicates that ^{3}H and ^{22}Na concentrations are at or below acceptable levels, guarantees that this will hold for the other radionuclides as well.

To estimate production of ^{3}H and ^{22}Na in the soil outside a given structure the computer program MARS is used to calculate the star density produced in the soil (Mo 95). These stars are transformed into numbers of ^{3}H and ^{22}Na atoms produced using simple conversion factors (see reference Go78). The activity in the soil is obtained by taking the highest value of the star density within the soil and averaging it over a volume, outside of which the star density has decreased to 1% of its maximum value in all directions.

In the past at Fermilab, the single resident well model (SRWM) was used to obtain the concentration of the nuclide of interest at the aquifer (Jo78). The model currently used for these calculations is the Concentration Model (CM), which presents a much more realistic picture of the actual phenomena present (see references WCC93, We93, Ma93, and Co94). The CM begins with a calculation of an initial concentration immediately external to the shielding. This concentration is then transformed into the estimated concentration at the aquifer (Class I ground water as defined by Illinois regulations) employing reduction factors described in reference (Co99). The CM was originally approved by the Fermilab Director on December 22, 1994 (Co94). The CM is to be used to design future shielding intended to protect groundwater. It is not required to reevaluate shielding configurations designed or evaluated using the SRWM prior to this date.

To calculate the concentration of accelerator-produced radioactive isotopes (^{3}H or ^{22}Na) leached into the groundwater and transported to the aquifer the guidelines given below should be followed:

- The CM is described in detail in reference (Ma93), and references therein. A summarized parameterization of the results is given in reference (Co99). For parameters not discussed specifically in Co99, Ma93 should be consulted.

- The value of N_p (Eq. 1, Co99) chosen should be representative of the average annual proton delivery. Given the nature of the Fermilab operations cycle, it is recommended that this average be taken over a three-year period.

- The elevation of the beginning of the Class I groundwaters should be determined from available drill logs as the beginning of the location of highly permeable material. This is not always the same as the elevation of the top of the Silurian dolomite as in many locations a hydraulically connected zone of highly permeable gravel occurs above the dolomite.

- The annual limit on protons (i.e., N_p) shall be the lower of the two values determined separately from the surface water and drinking water criteria. The criteria to be used are those listed in Table 3-1 of this Manual.

- Proponents of designs where the performance of radioactivation calculations is either intrinsically non-feasible or problematic in some other way shall carry out alternative documented methods of calculation. The resulting report shall be submitted to the Senior Laboratory Safety Officer for review. The Senior Laboratory Safety Officer will then make a recommendation for approval or disapproval to the Director. The Director shall make the final determination.

- Since boreholes can short-circuit the glacial till, they form a potential contamination pathway between soil activation areas and the aquifer. All plans for installation or disposition of wells and soil borings shall be submitted to the Environment, Safety, and Health Section for approval.

In the CM, sources are independent if they are separated by the projected plane of the 99% volume -- about 5 meters. That is, if multiple sources are spatially separated sufficiently to assure that their respective "99 % volumes" do not overlap, the combined concentrations due to mixing from the multiple sources will be less than that of the source producing the highest concentration. Thus, summing should only be done over radionuclides at each final location.

The CM has several conservative features. It assumes that there is instantaneous movement of the groundwater through the unsaturated zone; that the region of unprotected soil starts at the edge of the concrete; that the highest star density point is used. The ES&H Section should be consulted about particular applications of this model to assure compliance with all pertinent regulations.

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