FRCM CHAPTER 11
ENVIRONMENTAL RADIATION MONITORING AND CONTROL

Revision History

Author	Description of Change	Revision Date
J. D. Cossairt	1. Reformulated in light of Fermilab-wide ESH&Q consolidation and reorganization 2. Editorial corrections made as needed.	June 2017
J. D. Cossairt	1. Editorial changes made to reflect evolution of the ESH&Q organization at Fermilab. 2. Other editorial changes as necessary.	July 2015
J. D. Cossairt	1. Revise to complete revisions needed to conform with DOE Order 458.1 Chg 2 (06-06-11) to reflect overall completion of the implementation of this Order. 2. Clarify the connection of the requirements of this chapter with those of FESHM 8000 series. 3. Document protocols for reporting releases of radionuclides to sanitary sewers required by DOE O458.1 in Article 1104.5 4. Designate selection of Maximally Exposed Individual (MEI) as the criterion for public dose assessments in Article 1104.8. 5. Establish criteria for calculations of collective dose in Article 1104.9. 6. Confirm the adequacy of provisions made for human radiation protection as adequate for radiation protection of biota in Article 1104.11. 7. Correct errors and improve clarity of writing since the last revision.	November 2012
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).	September 2011

	3. Incorporate modifications to implement the new Derived Concentration Standards announced in DOE-STD-1196-2011 April 2011. 4. Correct editorial errors.	

CHAPTER 11
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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 Fermilab's implementation of major features of DOE Order 458.1, "Radiation Protection of the Public and the Environment" Chg 3 (01-15-2013).

1102 Scope

1. Protecting the Public

   Fermilab will operate and conduct its activities in accordance with 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 in 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 outdoors;

   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. Discharges of radioactivity in water from the Laboratory's Industrial Cooling Water System;

e. Radioactivated soil in beam loss areas;

f. Radioactive materials stored on site, especially in outdoor areas;

g. Interconnections of water discharges from other sources into the sanitary sewage systems.

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

1104 Public Dose Limits

The DOE primary standards on dose limits to members of the public who are not occupational workers at Fermilab are addressed in DOE Order 458.1 Chg 2 (01-05-2013) 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. Releases of water to the Industrial Cooling Water (ICW) system of Fermilab including its surface water components are limited to the Derived Concentrations Standards (DCSs) specified in DOE-STD-1196-2011. See Article 346 for more details and Table 3-1 for Derived Concentration Standards (DCS) values for radionuclides that might be present in Fermilab water systems. Compliance with the requirements of Fermilab's National Pollutant Discharge Elimination System (NPDES) permit is also required (see FESHM Chapter 8010).

5. Releases of radionuclides to sanitary sewers are governed by the provisions of DOE Order 458.1. Details are provided in Article 346 and FESHM Chapter 8025.

Results of releases of radionuclides to sanitary sewers are made available to the DOE Fermi Site Office to support DOE-FSO in carrying the reporting responsibilities specified in DOE Order 458.1 Section 4.g.

6. 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.

7. DOE Order 458.1 includes additional monitoring requirements if the estimated total effective dose (TED) to representative members of the public is estimated to exceed 25 mrem in a year. Conditions that would lead to such doses are not anticipated at Fermilab and are supported by ongoing environmental monitoring progams administered by the ESH&Q Section.

8. DOE Order 458.1, Section 4.e states that dose evaluations to demonstrate compliance with the public dose limits specified by the Order and to assess collective dose may either be demonstrated by calculating dose to the representative person (RP) or to the maximally exposed individual (MEI). RP refers to "an individual receiving a dose that is representative of the more highly exposed individuals in the population". MEI refers to "a hypothetical individual who – because of realistically assumed proximity, activities, and living habits – would receive the highest radiation dose, taking into account all pathways, from a given event, process, or facility." Fermilab has chosen to calculate dose to the MEI for the following reasons:

   a. Doses due to airborne radionuclides releases under 40 CFR 61 Subpart H NESHAP using the required code CAP88 conservatively apply to the MEI.

   b. The dose due to radiation from radioactive materials stored on site conservatively apply to the MEI located at the nearest location to these materials on the site boundary.

   c. Prompt radiation dose due to high energy neutrons and muons emitted as result of the operation of Fermilab's accelerators decreases as distance increases from the Fermilab site boundary. Thus evaluation of these doses at the site boundary identifies the location of the MEI.

   d. Based on four decades of operational experience at Fermilab, the MEI for each of these individual sources of radiation dose is at a different location along the Fermilab site boundary. Thus summing the contributions of the individual sources assures a conservative estimate of the maximum dose delivered to a member of the public.

e. It is logistically impractical given the size and complexity of the Fermilab site to define the location that would be associated with the RP.

9. DOE Order 458.1, Section 4.e states that for calculating the collective dose for members of the public due to DOE radiological activities only (excluding natural background sources and radon) may be truncated by the distance of 50 miles or the individual dose level of 10 microrem in a year when integration beyond such thresholds dose not significantly affect data quality objectives. These thresholds are adopted by Fermilab, justified by the operational experience of the Laboratory as documented in the set of Annual Environmental Reports to the Director.

10. Calculations of the doses to the MEI and collective doses since CY 2011 have been documented in the Annual Environmental Reports to the Director.

11. Fermilab's activities to protect humans from radiation and radioactive materials are determined to be adequate to protect biota. Thus, the separate evaluations of the radiation doses to biota discussed in DOE Order 458.1 Section 4.j. referencing DOE-STD-1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (July 2002) are not required due to the following considerations:

    a. DOE-STD-1153-2002, Section 1.2.2.1 states that "…appreciable effects in aquatic populations would not be expected at doses less than 1 rad/d (10mG/d) and that limiting the dose to maximally exposed individuals [i.e., individual aquatic organisms] to less than 1 rad/d would provide adequate protection of the population." All prompt radiation fields at Fermilab would expose biota to the same absorbed dose rates as received by the human MEI at the same location. Thus, meeting the requirements of DOE Order 458.1 in terms of dose limits for humans (see previous sections) much more than adequately protects biota.

    b. DOE-STD-1153-2002, Section 6 provides Biota Concentration Guides (BCGs) for a variety of radionuclides. Each BCG represents the limiting radionuclide concentration in an environmental medium which would not result in recommended dose standards for biota to be exceeded. The BCG values specified in this Standard are much larger than the corresponding DCS values specified for humans in DOE-STD-1196-2011 (April 2011). For example, for tritium, the dominant radionuclide found in water at Fermilab due to its operations, the DCS value is 1900 pCi/ml as compared with the BDG value of 300,000 pCi/ml. Thus, restricting concentrations to the DCS values represents a conservative approach for biota.

c. Fermilab has no environmental media where concentrations of radionuclides in soil, sediment, or water accumulate to levels remotely approaching the BCG with a resultant credible risk to biota.

1105 Responsibilities

General responsibilities for environmental protection are set forth in FESHM Chapter 1010 and the 8000 series of FESHM Chapters. Specific responsibilities as they pertain to environmental radiation are as follows:

1. ESH&Q Section

The ESH&Q Section is responsible for:

a. Leading the Fermilab-wide program to achieve ALARA in environmental radiological protection.

b. Monitoring off site exposure due to penetrating radiation.

c. Coordinating the environmental radiation protection program.

d. Performing various line functions including:

(1) Conduct site-wide confirmatory environmental monitoring to meet reporting requirements, and to track environmental issues site-wide. 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 input from division/sections 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.

e. Assisting divisions/sections in program development, and in auditing the compliance of divisions/sections in accord with the Fermilab Environmental Management System (EMS) (see FESHM chapter 8010).

f. Coordinating applications and renewals of environmental permits.

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

2. <u>Divisions/Sections</u>

Divisions/Sections who manage, design, maintain, operate, or use processes and facilities that result in environmental radiological impacts are responsible coordinating with the ESH&Q Section the development of 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 ESH&Q Section in establishing and implementing Fermilab's routine monitoring program to monitor effluents and prompt radiation 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 in coordination with the ESH&Q Section.

f. Coordinate within the ESH&Q Section and throughout the Laboratory 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. Coordinate with ESH&Q Section on the solutions and mitigations to environmental radiological issues as they arise.

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 ESH&Q 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 effective dose 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 detailed measurements of the neutron spectra outside the shields, the Radiological Control Organization 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.

5. For airborne radioactivity, a thin window GM detector installed in a brass 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. This is analysis is complemented with gamma-ray spectroscopic analysis.

6. To augment the single mobile laboratory, a large network of fixed radiation detectors (“Hippo,” “Chipmunk”, “Fox”, 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 subject to 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 and surface water 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. Radioactive Water Systems (RAW, also called closed-loop systems) – during accelerator operations, water in these systems used to cool magnets, some charged particle focusing devices, and beam absorbers becomes radioactive primarily as a result of spallation of oxygen nuclei (see Article 346).

3. Low Conductivity Water (LCW) systems – During accelerator operations, water in these systems, maintained at low conductivity to assure proper functioning of accelerator components becomes radioactive, also primarily as a result of spallation of oxygen nuclei (see Article 346). In general and by design the concentrations of radionuclides in LCW systems is far lower than in the RAW systems.

4. Industrial Cooling Water (ICW) systems – This system provides non-contact secondary cooling to the other systems mentioned herewith and includes both piping systems and surface water ponds and ditches within the boundaries of the Laboratory's process water system as defined by the NPDES permit.

5. 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 are 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 ESH&Q Section Environmental Protection staff can provide more information on this subject.

The only leachable radionuclides known to be produced in measurable concentrations in Fermilab soils are ^{3}H, ^{7}Be, ^{22}Na, ^{45}Ca, and ^{54}Mn (Bo72). This conclusion continues to be supported by results of the ongoing monitoring program. 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.

The MARS code system can calculate the number of radionuclides produced per proton in geological media. To estimate production of ^{3}H and ^{22}Na in the soil (glacial till) outside a given structure the computer program MARS can be 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). Normally 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. For cases where the structures are not located in glacial till (such deep beamlines like NuMI or there is sand backfill for example) then the conversion factors for glacial till should not be used.

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 annual number of protons to be used in these calculations should be chosen to 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 from boreholes 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 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 SRSO for review. The SRSO shall review the calculational methodology and recommend approval or disapproval to the Chief Safety Officer (CSO) who will make the final determination in consultation with the Laboratory Director as deemed necessary.

- 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 reviewed by the SRSO and the CSO.

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 shielding; that the highest star density point is used. The ESH&Q Section should be consulted about particular applications of this model to assure compliance with all pertinent regulations.

References

(Bo 72) T. B. Borak, M. Awschalom, W. Fairman, F. Iwami, J. Sedlet, "The Underground Migration of Radionuclides Produced in Soil Near High Energy Proton Accelerators," *Health Physics* **23** (1972) 679-687.

(Co 94) J. Donald Cossairt "Use of a Concentration Based Model for Calculating the Radioactivation of Soil and Groundwater at Fermilab," Environmental Protection Note EP-8, December 1, 1994.

(Co99) J. D. Cossairt, A. J. Elwyn, P. Kesich, A. Malensek, N. Mokhov and A. Wehman "The Concentration Model Revisited", Environmental Protection Note EP-17, June 24, 1999.

(Go 78) Peter J. Gollon, "Soil Activation Calculations for the Anti-Proton Target Area," Fermilab Report TM-816, September 1978.

(Jo 78) A.M. Jonckheere, "Aquifer Dilution Factors of Groundwater Activity Produced around Fermilab Targets and Dumps," Fermilab Report TM-838, December 1978.

(Ke 00) P. M. Kesich, K. Vaziri, and N. Grossman, "Chemical and Radiochemical Background Concentrations of Geological Materials Beneath Fermilab", TM 2102, June 2000.

(Ma 93) A. J. Malensek, A. A. Wehmann, A. J. Elwyn, K. J. Moss, and P. M. Kesich, "Groundwater Migration of Radionuclides at Fermilab," Fermilab Report TM-1851, August 1993.

(Mo 95) N. V. Mokhov, S. I. Striganov, "MARS15 Overview", Fermilab CONF-07/008-AD (2007).

(WCC 93) Woodward-Clyde Consultants, *Summary of Radionuclide Transport Modeling for Ground Water at the Fermi National Accelerator Laboratory, Batavia, Illinois,* Project 93C3073, Chicago, IL, August 1993.

(We 93) A. A. Wehmann, A. J. Malensek, A. J. Elwyn, K. J. Moss, and P. M. Kesich, "Data Collection for Groundwater Study," Fermilab Report TM-1850, November 1993.