FRCM CHAPTER 11
ENVIRONMENTAL RADIATION MONITORING AND CONTROL

Revision History

Author	Description of Change	Revision Date
J. D. Cossairt, M. Quinn, C. Greer, E. Mieland, and E. Korzeniowski	1. Addition of Article 1106 "Management of Environmental Waterborne Radioactivity" 2. Addition of Article 1107 "Management of Environmental Airborne Radioactivity" 3. Switching of Sections 2 and 3 in Appendix 11A to maintain "parallelism" with new Articles 1106 and 1107. 4. Replacing reference to ESH&Q Section with ES&H Section following the reorganization of February 1, 2019. 5. Editorial corrections as needed.	January 2020
J. D. Cossairt	6. Reformulated in light of Fermilab-wide ESH&Q consolidation and reorganization 7. 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.	November 2012

	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.	
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

TABLE OF CONTENTS

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). Technical details of the environmental radiation physics of accelerator radiation fields are discussed in the Appendices to this chapter.

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 (See Appendix 11A);

   b. 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;

c. Airborne radioactivity produced at high intensity beam loss points and released outdoors;

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.

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 3 (01-05-2013) supported by DOE-STD-1196-2011 (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 requirements 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. Managing the release of water containing radionuclides from laboratory operations to on-site surface waters (Industrial Cooling Water) is subject to boundary discharge limits specified in DOE's Derived Concentration Standards, DOE -STD-1196-2011 referenced by DOE Order 458.1. Additionally, compliance for tritium releases are subject to Fermilab's National Pollutant Discharge Elimination System (NPDES) permit issued by the Illinois EPA. In keeping with the principles of ALARA and to ensure limits are being met at boundary discharge points, internal action limits have been established for on-site surface water bodies (see Articles 1105, 1106 and Appendix 11C).

5. Releases of radionuclides to sanitary sewers are governed by the provisions of DOE Order 458.1. Further details are provided in Article 1106 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 programs administered by the ES&H 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. ES&H Section

The ES&H 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.

(1) Control of penetrating radiation produced by accelerator operations (prompt radiation) is discussed in FRCM Chapter 8.

(2) Control of penetrating radiation due to induced radioactivity in storage locations, principally outdoors is addressed by other FRCM Chapters.

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.

h. Assessing the potential impact of new sources of environmental radiation by means of detailed analysis that considers both the effect of large volume, relatively low concentration sources as well as smaller volumes with higher concentrations; i.e, the "load" of delivery of significant amounts of activity to a particular environmental medium, from which the resultant concentrations may be calculable. See Article 1106, 1107, Appendices 11A, 11B, and 11C and FESHM chapter 8025 and 8026.

2. Divisions/Sections

Divisions/Sections who manage, design, maintain, operate, or use processes and facilities that result in environmental radiological impacts are responsible coordinating with the ES&H 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 ES&H 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 ES&H Section. Approval for temporary releases onto the ground, into the ICW system or sanitary sewer systems above the DCS or 5xDCS levels is required prior to the release, depending on the known or expected level. The approval levels are specified below:

(1) At or above onsite Action Levels (see Appendix 11C): approval of the assigned RSO and the SRSO (and subsequent notification of the Director).

(2) For higher levels, notification of the Director and approval of assigned RSO and SRSO and others based on level and disposition:

1. Above 5xDCS (9,500 pCi/ml) to sanitary sewer: approval of CSO and Division Head.

2. Above 0.001 Ci in a day to sanitary sewer: approval of SRSO.

3. Above DCS (1.900 pCi/ml) to ground or ICW system: approval of RSO.

f. Coordinate within the ES&H 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. Notify and inform the Chief Safety Officer or ES&H Section staff and the Chair of the Tritium Task Force of the identification of new sources or operational changes to existing sources that potentially can affect the releases of environmental radioactivity to the environment. Notification for past releases should follow the level-based approval guidance in Section 2.e. above.

h. Coordinate with the ES&H Section on the solutions and mitigations to environmental radiological issues as they arise.

1106 Management of Environmental Waterborne Radioactivity

More details of the environmental protection requirements pertaining to sanitary sewers and surface waters are established in FESHM Chapters 8025 and 8026, respectively.

1. Discharges to surface waters from any sources other than stormwater or cooling systems, or as specified in a National Pollution Discharge Elimination System (NPDES) permit, are strictly prohibited. Numerous sumps located throughout the site collect and drain storm water from building footings and from under beamline tunnels. Water collected by these sumps often contains detectable concentrations of radionuclides (primarily tritium) that have been leached by rainwater from radioactive soil near beam targets and absorbers or accidentally released to the sumps from beamline cooling water systems.

2. Allowable releases of various radionuclides to surface waters beyond the Outfalls specified in the NPDES permit are referenced in DOE Order 458.1 and set-forth in DOE-STD-1196-2011 as Derived Concentration Standards (DCSs). Selected values of DCS's and related quantities are presented in Table 11-1. A hypothetical person who uses water having a concentration at the DCS as their household water supply on a full-time basis will receive a dose of 100 mrem in a year.

3. When multiple radionuclides are encountered, for the water to be considered to be less than one DCS, the set of individual radionuclide concentrations in the water, C_i, must satisfy the following inequality, commonly called the weighted-sum rule:

$$\sum_i \frac{C_i}{DCS_i} \leq 1,$$

where DCS_i is the DCS value for the i^{th} radionuclide.

4. Protection of groundwater resources is of high priority. Public drinking water supplies are bound by the requirements of U. S. EPA Drinking Water Regulations embodied in 40 CFR Part 141. Furthermore, Fermilab is also subject to Illinois Administrative Code (IAC) requirements pertaining to “non-degradation” of Class 1 resource groundwater found at the saturated zone at the top of the bedrock underlying the Fermilab site. Table 11-1 also gives radionuclide concentrations in water that would result in a dose of 4 mrem in a year to a hypothetical individual who uses such water as their full-time household water supply. A synopsis of the methodology used to make groundwater calculations at Fermilab is provided in Appendix 11B

5. Because of its relatively rapid mobility and favorable nuclear reaction production cross sections, tritiated water (H-3) is of paramount interest and is always, by far, the dominant radionuclide in water at particle accelerators. Fermilab has established Internal Action Levels, subject to future modification by the ES&H Section, for management of tritium in air and water resources provided here in Appendix 11C.

6. DOE Order 458.1 specifics the limit on concentrations that can be released to public sewer systems to be 5 times the tabulated DCS value and such discharges are also subject to an annual discharge limit of 5.0 Ci. See further discussion in Appendix 11C.

Table 11-1 Derived Concentration Standards* for Accelerator-produced Radionuclides in Water

		Derived Concentration Standard (pCi/ml)	
Isotopes	Half-life	Surface Water*	Groundwater
H-3	12.3 y/4506 d	1900	20**
Be-7	53.3 d	1100	44
C-11	20.3 min	1300	52
Na-22	2.6 y/949 d	10	0.40
Ca-45	165 d	38	1.52
Mn-54	312 d	44	1.76
Co-57	270 d	130	5.2
Co-58	71.3 d	39	1.56
Co-60	5.27 y/1924 d	7.2	0.29
Zn-65	245 d	8.3	0.33
Cs-137	30 y	3.0	0.12
Au-195	183 d	110	4.4
U-238	4.47×10^9 y	0.75	0.03

*Derived Concentration Standards (DCS) taken from DOE-STD-1196-2011 (April 2011).
**Taken from USEPA regulations 40 CFR 141 where a specific numerical limit is stated for this nuclide for public drinking water supplies. This value was determined by USEPA using an older dosimetric model to result in an annual dose of 4 mrem y^{-1} to a household user of such water. All other value are 4% of the DCS to obtain a dose 4 mrem y^{-1} to the user of such water as set-fourth in DOE Order 458.1.

1107 Management of Environmental Airborne Radioactivity

1. Derived Concentration Standards (DCSs) for airborne exposures for members of the public (corresponding to 100 mrem/year) are given in DOE-STD-1196-2011 referenced by DOE Order 458.1. For radionuclides not listed, DOE-STD-1196-2011 shall be consulted. Prominent examples for radionuclides commonly found at Fermilab are given in Table 11-2. For members of the public exposed to air having these concentrations of radionuclides, 100 mrem in a year would be received under conditions of full-time exposure at concentrations of 1.0 DCS.

2. Since mixtures of radionuclides are commonly encountered at accelerators, one evaluates the sum of the ratios of the concentrations of the individual radionuclides to their individual DAC or DCS values just as is specified for water in Article 1106, by means of the <u>weighted- sum rule</u>.

3. For airborne exposures to members of the public, the provisions of the 40 CFR Part 61 Subpart H including calculations required by that Federal Regulation using the specified program CAP-88.

4. 40 CFR Part 61 Subpart H limits exposures to member of the public to 10 mrem in a year due to operations of DOE facilities. Furthermore, this Regulation requires continuous monitoring of emissions when the annual dose to the MEI exceeds 0.1 mrem in a year. Fermilab continues to make every ALARA effort to keep the annual dose to the MEI <0.1 mrem. This standard is more stringent than that implied by the DCS with the latter useful for evaluating airborne radioactivity hazards within the boundaries of the Fermilab site accessible to members of the public on a short-time, not a full-time basis.

Table 11-2 Derived Concentration Standards (DCSs, DOE-STD-1196-2011) for the general population for airborne radionuclides commonly encountered at Fermilab.*

Isotope	**DCSs - General Population 0.1 rem/year 168 hours/week exposure**	
	(Bq m^{-3})	(pCi ml^{-1})
^{3}H (H_2O vapor)	**7.8E03[d]**	0.21[a]
^{7}Be	**2.4E03[d]**	0.064[a]
^{11}C	**6.9E02[e]**	0.019[b]
^{13}N	**6.9E02[e]**	0.019[b]
^{15}O	**6.9E02[e]**	0.019[b]
^{22}Na	**4.8[d]**	1.3E-04[a]
^{24}Na	**1.5E02[e]**	4.1E-03[b]
^{38}C	**4.3E02[e]**	1.2E-02[b]
^{39}Cl	**4.5E02[e]**	1.2E-02[b]
^{41}Ar	**5.2E02[e]**	0.014[b]
^{46}Sc	**20[d]**	5.5E-04[a]
^{51}Cr	**3.5E03[d]**	0.094[a]
^{77}Br	**1.4E03[d]**	0.038[a]
^{82}Br	**2.0E02[e]**	5.3E-03[b]

[a]Taken from DOE-STD-1196-2011 Table 5 (inhalation) using most conservative values.
[b]Taken from DOE-STD-1196-2011 Table 6 (immersion) using most conservative values.
*Due to the origin of these values from primary references published International Commission on Radiological Protection (ICRP), the values given in SI units (i.e. Bq m^{-3}) should be taken as the primary values. Due to "round-off" found in published regulations, the values in the customary units of pCi ml^{-1} do not constitute exact matches to the SI values via the conversion factor 2,703E-05 (pCi ml^{-1}/Bq m^{-3})

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

1. 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 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.

2. 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.

2. 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.

3. 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).

4. 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.

5. 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 water distribution system as defined by the NPDES permit.

6. 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.

3. 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 carried out for purpose of estimating releases of airborne radionuclides. Fermilab radioactive air releases are regulated by NESHAPs requirements and subject to 40 CFR 61, Subpart H.

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 accelerator tunnels and the soil underneath their floors. 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 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 ES&H Section should be consulted about particular applications of this model to assure compliance with all pertinent regulations.

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Appendix 11C Tritium Action Levels

Increases in tritium concentrations from present levels will be investigated and addressed by the Tritium Task Force Working Group. To help manage any risks from tritium levels that may continue to rise despite initial mitigation efforts, Fermilab has developed internal action levels that are a fraction of any regulatory criteria. These are the levels where, if reached, we will alert senior management and DOE FSO so that the potential impact to operations will be well understood and the need to shift resources may be done expeditiously before exceeding regulatory levels or losing the trust of our surrounding community.

Regulatory Criteria, Action Levels and Tritium Levels at Fermilab Boundaries

Migration Route	Monitoring Location	Regulatory Limit	Fermilab DRAFT Action Level(s)	2018-October 2019 Levels
Sanitary Sewers	Batavia Autosampler	5 Ci in a year OR 9,500 pCi/ml (DOE)	2.5 Ci in a year 40 pCi/ml/month[1]	~0.5 Ci in a year (2018) ~30 pCi/ml (Feb 2019)
Surface Water[2]	Indian Creek	1,900 pCi/ml (DOE)	20 pCi/ml	<5 pCi/ml
	Kress Creek	1,900 pCi/ml (DOE)	20 pCi/ml	<1 pCi/ml
	Ferry Creek	1,900 pCi/ml (DOE)	20 pCi/ml	<3 pCi/ml
Groundwater (Class 1)[2]	Background Wells (Wilson Street)	Non-degradation (1.0 pCi/ml, IEPA)	0.5 pCi/ml	Not detected
	Meson/Neutrino Area	Non-degradation (1.0 pCi/ml, IEPA)	0.5 pCi/ml	Not detected
	NuMI Target Hall (immediately outside of activation zone)	Non-degradation (1.0 pCi/ml, IEPA)	0.5 pCi/ml	Not detected
Air[4]	All radionuclides, not just tritium, summed over all sources.	0.1 mrem in a year (USEPA)	0.08 mrem in a year (0.05 mrem from tritium)	0.0725 mrem (CY 2018; 0.0066 mrem from tritium)

Migration Route	Monitoring Location	Regulatory Limit	Fermilab DRAFT Action Level(s)	2018-October 2019 Levels
Sanitary Sewers	MC-1 Lift Station[5]	Not Applicable	1,900 pCi/ml/week	<1,600 pCi/ml
Surface Water[1]	Booster Pond	Not Applicable	190 pCi/ml	<30 pCi/ml
	Kidney Pond	Not Applicable	190 pCi/ml	<32 pCi/ml
	TeV Pond near A-0	Not Applicable	190 pCi/ml	<20 pCi/ml
	Indian Creek Outfall	Not Applicable	190 pCi/ml	<12 pCi/ml

Kress Creek Outfall	Not Applicable	190 pCi/ml	<3 pCi/ml
Ferry Creek Outfall	Not Applicable	190 pCi/ml	<3 pCi/ml
MI Ponds F[6] and C	Not Applicable	20 pCi/ml	<3 pCi/ml

Onsite Action Levels and Tritium Levels

Notes:
1. The offsite sanitary sewer discharge concentration is obtained from a monthly composite sample.
2. The 1,900 pCi/ml DOE standard applies to surface water released from the Fermilab property.
3. The U.S. EPA drinking water criteria for tritium is 20 pCi/ml, but Fermilab operates under the Illinois Administrative Code requirement of non-degradation of drinking water (non-detect at a reporting level of 1.0 pCi/ml). Illinois EPA defines the top of Class 1 resource groundwater at Fermilab as the saturated zone at the top of bedrock. As new wells are added to the monitoring network (such as adjacent to MI-12/BNB) they will be added to this action level table.
4. Note that the regulatory and internal action levels for air emissions are based on dose rates, not concentrations. The U. S. EPA has established National Emissions Standards for Hazardous Air Pollutants (NESHAPS) which limits the dose received by the maximally exposed hypothetical individual to 10 mrem in a year from release of all airborne radionuclides, not just tritium, from DOE facilities and a threshold of 0.1 mrem in a year above which EPA-approved continuous monitoring is required.
5. Starting in January 2019 the MC-1 LS concentration is obtained from a weekly composite sample.
6. Routine sampling at MI Pond F will be replaced with sampling at MI Pond G once the sump discharge is rerouted as part of the LBNF Site Prep construction in FY2020.