FRCM CHAPTER 5
RADIOLOGICAL HEALTH SUPPORT OPERATIONS

Revision History

Author	Description of Change	Revision Date
M. Quinn	• Added article 514 Passive Area Monitoring Dosimeters. • Removed procedures from Article 522. • Added additional clarification to requirements for surveys to Part 5. • Removed Part 7 so that procedures can be added to dosimetry program procedures. • Removed Appendix 5E parts A,B to be added to ES&H standard operating procedures. • Reviewed and updated uses of "should" vs "shall". • Added clarification throughout.	January 2022
J. D. Cossairt	Editorial change made to fix a broken web link in Appendix E.	October 2017
J. D. Cossairt	Reformulated in light of Fermilab-wide ESH&Q consolidation and reorganization.	February 2017
J. D. Cossairt	Changes to reflect evolution of Fermilab's ESH&Q Section.	July 2015
J. D. Cossairt	• Incorporate suggestions made since the last revision. • Incorporate modifications needed to implement amendments of 10 CFR 835 finalized on April 13, 2011 pertaining to Derived Air Concentrations (DACs). • Incorporate modifications to implement the new Derived Concentration Standards announced in DOE-STD-1196-2011 April 2011.	September 2011

CHAPTER 5 RADIOLOGICAL HEALTH SUPPORT OPERATIONS

TABLE OF CONTENTS

PART 1 EXTERNAL DOSIMETRY

511 Requirements

Unless stated otherwise, “dosimeter” or “primary dosimeter” refers to the dosimeter of record known as the personnel dosimetry monitoring badge. Due to past habits, the personnel dosimetry monitoring badges of record are commonly, and incorrectly, called "TLD badges" or even "film badges" reflecting past usage of a now obsolete dosimetry technology. Other dosimeters called “supplemental dosimeters” may be used in conjunction with the personnel dosimetry monitoring badge to provide additional information about workplace radiological conditions. Recordkeeping requirements for the external dosimetry program are found in Chapter 7, Part 2 of this Manual.

1. Personnel dosimetry shall be required for:

    a. Radiological workers who, under typical conditions, are likely to receive a total effective dose to the whole body of 0.1 rem (0.001 sievert) or more in a year or an equivalent dose to the extremities, lens of the eye, or skin of 10 percent or more of the corresponding limits specified in Table 2-1;

    b. Declared pregnant workers who are likely to receive from external sources a dose to the embryo/fetus in excess of 10 percent of the applicable limit stated in Table 2-1 (See Article 213).

    c. Occupationally exposed minors likely to receive a dose in excess of 50% of the applicable limit contained in Table 2-1 in a year from external sources. (See Articles 212 and 931.)

    d. Members of the public entering a controlled area likely to receive a dose in excess of 50% of the appropriate limit in Article 212.3 in a year from external sources.

    e. Individuals entering a Radiation Area, High Radiation Area or Very High Radiation Area.

    f. Extremity monitoring, as determined by the assigned Radiation Safety Officer (RSO).

2. To maximize the efficiency of the personnel dosimetry program, the issuance of permanent dosimeters to personnel who are not radiological workers is discouraged.

3. Radiological Worker training is the minimum training necessary for those using a personnel dosimetry monitoring badge. Exceptions shall be made only with the approval of the assigned RSO. Written justification of the exception shall be provided to the Dosimetry Program Manager.

4. Personnel shall return dosimeters for processing as scheduled or upon request.

5. Personnel shall wear their primary dosimeters on the chest area, or between the waist and the neck, in the manner prescribed by the Radiological Control Organization. Compliance with this sub article will be encouraged by reinforcement during training sessions.

6. The practice of taking dosimeters off site is discouraged.

7. Exposures of the dosimeters to sources of radiation not related to Fermilab work should be prevented.

    a. Personnel shall not wear dosimeters issued by Fermilab while being monitored at another radiological facility.

    b. Personnel shall not knowingly expose their dosimeters to security X-ray devices, excessive heat, or medical sources of radiation. (See Article 962.)

    c. If the potential for such exposures is discovered, the dosimeter must be returned to the ES&H Section with an account of the non-occupational source of exposure.

    d. Should such an exposure be discovered in the course of an exposure investigation or the examination of a suspect dosimetry report, the Dosimetry Program Manager should notify the appropriate division/section personnel and the assigned RSO.

8. A person whose dosimeter is lost or damaged in a Radiological Area should place work in a safe condition, immediately exit the area and report the occurrence to the assigned RSO or designee. Reentry of the person into radiological areas should not be made until a review has been conducted and line supervision has approved reentry with appropriate replacement dosimetry provided.

9. Technical details of integrating personnel dosimeters that have been used at Fermilab are described in Appendix 5A. These devices do not provide a measurement in "real time".

512 Technical Requirements for External Dosimetry

1. Accreditation of personnel external dosimetry monitoring programs by the DOE Laboratory Accreditation Program (DOELAP) is mandated in 10 CFR 835. Fermilab performs extremity monitoring on a discretionary basis and the dosimeter used for that purpose is accredited by DOELAP. Program details are maintained by the Radiological Control Organization in a technical basis document *Technical Basis for External Dosimetry at Fermilab* (RP Note 124).

2. In the absence of specific monitoring, the equivalent dose to the lens of the eye is taken to be equal to the dose equivalent at a tissue depth of 300 mg/cm^2.

3. Multiple dosimeters should be issued to personnel to assess whole body exposure in non-uniform radiation fields as recommended by the authorized members of the Radiological Control Organization, in most situations the assigned RSO, or as required on Radiological Work Permits. For example, ring badges have been found to be especially helpful in certain types of radiological work where exposures to the hands are anticipated. Non-uniform radiation fields exist when the dose to a portion of the whole body will exceed the dose to the primary dosimeter by more than 50 percent and the anticipated whole body dose is greater than 100 millirem.

4. An exposure investigation (dose assessment) shall be performed for each instance of a lost, damaged, or contaminated personnel dosimeter.

513 Real Time Supplemental Dosimeters

Pocket and electronic dosimeters are supplemental dosimeters that provide real-time indication of exposure to radiation. While they are not the dosimeter of record, such dosimeters can help to maintain worker doses ALARA, to indicate the presence of unanticipated radiological hazards, or assist in the completion of an exposure investigation in the event that a primary dosimeter is lost or damaged. Technical details of these devices are given in Appendix 5B.

1. Real time supplemental dosimeters shall be issued to personnel prior to entry into a radiological area in which a person's dose could exceed 40 mrem from external radiation in 1 workday, when entering a High or Very High Radiation Area, or when required by a Radiological Work Permit (RWP).

2. Real time supplemental dosimeters shall be worn close to the primary personnel dosimetry monitoring badge and located in accordance with Article 511.5 and Articles 333 and 334.

3. Use of electronic dosimeters is encouraged for entry into High Radiation Areas when planned doses greater than 100 mrem in 1 workday are expected. An electronic dosimeter provides an early warning of elevated exposure through the use of alarm set points at specified dose rates or integrated doses. Several types of electronic dosimeters, each with somewhat different features, are now in use at Fermilab. These are supplied and maintained by the ES&H Section. Such devices may not function properly in Very High Radiation Areas (See Article 333 for VHRA entry requirements).

4. Supplemental dosimeters should be read periodically while in use and should not be allowed to exceed 75 percent of full scale. Work authorized by an RWP should be stopped when supplemental dosimeter readings indicate dose rates or integrated dose greater than limiting

radiological conditions, or substantially greater than planned. The Radiological Control Organization should be consulted prior to restart of work.

An exposure investigation shall be initiated by the Dosimetry Program Manager or assigned RSO to explain certain discrepancies between pocket and electronic dosimeter readings and the primary dosimeter result.

514 Passive Area Monitoring Dosimeters

Fermilab uses a passive area monitoring program to help demonstrate compliance with regulations in 10 CFR 835; document radiological conditions; detect changes in radiological conditions; detect the gradual buildup of radioactive material; verify the effectiveness of engineering and process controls in containing radioactive material and reducing radiation exposure; and identify and control potential sources of individual exposure to radiation and/or radioactive material.

1. The establishment and maintenance of a comprehensive area monitoring program can minimize the number of areas requiring the issuance of personnel dosimeters and demonstrates that doses outside radiological areas are negligible.

2. Area monitoring dosimeters should be used to record and document radiation levels in routinely occupied areas adjacent to areas where radiation or operations with radiation exist.

PART 2 INTERNAL DOSIMETRY

521 Participation in Internal Dosimetry Program

1. In accordance with the requirements of 10 CFR 835 for monitoring individual exposures to internal radiation, internal dosimetry programs (including, but not limited to, bioassay programs) shall be conducted for:

    a. Radiological workers who, under typical conditions, are likely to receive a committed effective dose of 0.1 rem (0.001 sievert) or more in a year, from all occupational radionuclide intakes in a year.

    b. Declared pregnant workers likely to receive an intake or intakes resulting in a committed effective dose to the embryo/fetus in excess of 10 percent of the limit stated in Table 2-1.

    c. Occupationally exposed minors who are likely to receive a dose in excess of 50 percent of the applicable limits stated at Table 2-1 from all radionuclide intakes in a year.

    d. Members of the public entering a controlled area likely to receive a dose in excess of 50 percent of the limit in Article 212.3 from all radionuclide intakes in a year.

2. Radiation Physics Note #7, *Fermilab Internal Dosimetry Technical Basis Document,* documents for normal operations that no individual approaches the criteria defined above in paragraph (1) and thus, no routine internal dosimetry program is necessary. Fermilab may still perform discretionary internal monitoring when:

    a. the assigned RSO requests such a measurement to verify the effectiveness of engineered and administrative controls designed to prevent internal exposure;

    b. imposed engineered and/or administrative controls designed to prevent internal exposure inadvertently fail; or

    c. someone is exposed under accidental or emergency conditions, in particular those requiring the use of the Decontamination or Beam-On Dose Assessment Facility.

3. Personnel shall participate in follow-up monitoring when their bioassay results or alternative assessment method indicates an uptake greater than the decision level.

522 Programmatic Requirements

1. Fermilab's internal dosimetry measurements are presently provided under an arrangement with Argonne National Laboratory. Argonne National Laboratory (ANL) has been accredited by the Department of Energy Laboratory Accreditation Program for Radiobioassay. Should Argonne be unable to provide such services, Fermilab is committed to securing another DOELAP accredited vendor.

2. When it has been determined that internal monitoring is required, the Dosimetry Program Manager shall be notified to make the appropriate arrangements for submitting bioassay samples or whole body counting at Argonne National Laboratory.

523 Dose Assessment

1. The estimation of internal dose shall be based on bioassay data rather than air concentration values unless bioassay data are:

    a. unavailable;

    b. inadequate;

    c. internal dose estimates based on representative air concentration values are demonstrated to be as or more accurate.

2. Interpretations of bioassay results and subsequent dose assessments will be documented and should include the following:

    a. Characteristics of the radionuclide(s), such as chemical and physical form.

    b. Initial and follow-up bioassay results and the person's previous exposure history to the extent known.

    c. Exposure information, such as the route of intake and time and duration of exposure.

    d. Biological models used for dosimetry of radionuclides.

    e. Calculations used to estimate intake or deposition and to assess committed equivalent dose to any organ or tissue of concern and the committed effective dose.

3. Affected personnel shall be notified promptly of bioassay results and the results of any dose assessment.

4. The interpretations of bioassay results and subsequent dose assessments shall be incorporated into the affected individual's exposure history and maintained and reported according to the requirements in Chapter 7 of this Manual.

5. For exposures that could be mitigated though medical intervention, the Fermilab Medical Office shall be notified.

6. Exposures that exceed the Fermilab Administrative Goal for radiological workers or any of the limits stated in Part 1 of Chapter 2 of this Manual will be reported in accord with the requirements in Fermilab ES&H Manual Chapter 3010.

PART 3 RADIOLOGICAL RESPIRATORY PROTECTION PROGRAM

Respiratory protective devices include respirators with particulate or gas-filtering cartridges, supplied air respirators, self-contained breathing apparatus and airline supplied-air suits and hoods, excluding nuisance level dust mask sometimes, incorrectly, called "respirators". The use of such respiratory equipment is governed by industrial hygiene considerations covered in Fermilab ES&H Manual Chapter 4050, which should also be consulted before the use of such equipment as the requirements of that chapter are only summarized here to assure their application to radiological work in accordance with the principals of integrated safety management. Fermilab requirements for addressing heat stress hazards are given in detail in Fermilab ES&H Manual Chapter 4250

531 Requirements

1. Use of respiratory protection shall be reduced to the minimum practicable by implementing engineering controls and work practices to contain radioactivity at the source.

2. Respirators shall be issued only to personnel who are trained, fitted and medically qualified to wear the specific type of respirator. Training and fit testing shall be performed annually. Medical qualification testing shall be performed every two years.

3. Positive controls shall be maintained for the issue, use and return of respirators to ensure that only qualified personnel wear respirators.

4. Facility safety analyses should not take credit for the use of respiratory protection for routine work involving potential exposure to airborne radioactive materials. Engineering controls should be designed to control radioactive materials at the source, so that the use of respiratory protection can be reduced.

532 Half-Face Respirators

1. Half-face respirators shall not be used on a routine basis as a precautionary measure for protecting workers from potential airborne radioactive materials.

2. The use of half-face respirators may be permitted in situations where intakes of radioactive material are expected to be low and where industrial and safety considerations warrant, such as during the operation of heavy equipment.

PART 4 HANDLING RADIOLOGICALLY CONTAMINATED PERSONNEL

541 Skin Contamination

1. Survey techniques are described in Appendix 3C (Chapter 3) to determine the extent of skin contamination.

2. When personnel detect skin contamination, they shall call the Emergency phone number, ext. 3131. If injuries are also involved in a contamination incident, the medical treatment of injuries takes precedence over decontamination. National Council on Radiation Protection and Measurements Report Number 161, *Management of Persons Contaminated with Radionuclides: Handbook*, contains applicable information.

3. The extent of skin contamination should be determined prior to initiating decontamination procedures.

4. Skin decontamination procedures have been established at Fermilab. These are posted at the Decontamination Facility at Site 39 South [adjacent to the Radionuclide Analysis Facility (RAF)] for use by those individuals specifically trained to perform personnel decontaminations.

5. Levels of skin contamination that identify candidates for dose assessments have been established for site-specific radionuclides (see Radiation Physics Note No. 7).

6. Individuals with skin contamination that triggers the need for dose assessment should be informed of the initial dose estimate to their skin as soon as practicable. An injured individual should be counseled promptly on the medical and radiological implications resulting from contaminated wounds that are likely to result in internal doses greater than 2 percent of the FRCM Table 2-1 limits. The counseling should be performed by senior radiological control and medical professionals

542 Exposures to Airborne Radioactivity

The most common form of airborne radioactivity at Fermilab is activated air. Activated air typically contains a variety of short-lived radionuclides that produce an external immersion hazard rather than an internal exposure hazard (see Articles 347 and 554). Airborne radioactive particulates are less common but may exist under special conditions, such as machining radioactive materials. If intakes of radioactive material which could result in an individual receiving a committed effective dose greater than 100 millirem or an exposure of 40 DAC-hours or more in a year are suspected by the assigned RSO, the following actions should be taken:

1. Identify personnel potentially exposed to airborne radioactivity.

2. Obtain nasal smears for qualitative indication of intakes, where appropriate.

3. Analyze air samples to determine airborne concentrations, where appropriate.

4. Determine duration of potential exposure to airborne radioactivity.

5. Perform bioassay appropriate for the type and quantity of radionuclides involved.

6. Use dose evaluation as soon as practicable to determine what actions, if any, are to be taken.

PART 5 RADIOLOGICAL MONITORING AND SURVEYS

Radiological Control Programs require the performance of radiation, airborne radioactivity and contamination surveys to determine existing conditions in a given location. Maps with sufficient detail to permit identification of original survey and sampling locations should be maintained. Records shall contain sufficient detail to be meaningful even after the originator is no longer available. Appendix 5C contains summary technical descriptions of portable survey instruments used at Fermilab.

551 Requirements

1. Radiological monitoring of radiation exposure levels, contamination and airborne radioactivity shall be conducted to:

    a) Characterize workplace conditions and detect changes in those conditions

    b) Verify the effectiveness of engineered and administrative controls

    c) Demonstrate regulatory compliance

    d) Detect the gradual buildup of radioactive material in the workplace

    e) Identify and control potential sources of personnel exposure

    f) Determine exposure rates during each entry to a high or very high radiation area

2. Monitoring shall be performed only by trained and qualified personnel using properly calibrated instruments which are appropriate for the type(s), levels and energies of the radiation(s) encountered and appropriate for the existing environmental conditions in which the instruments will be used. Consideration should be given to the possible presence of hard to detect radionuclides (7Be, 3H, etc.)

3. Surveys for radiation, contamination and airborne radioactivity shall be performed as specified by the assigned RSO in Radiological Work Permits, standard operating procedures, or other technical documents.

4. The assigned RSO should review the adequacy of sampling and monitoring systems when facility or operational changes occur. Records shall be maintained to document changes in monitoring equipment, techniques, and procedures.

5. Instruments used to perform radiation surveys shall be response-checked daily if in regular use or prior to operation if used intermittently. When response checks are not within the labeled

tolerance specified for the particular instrument, the instrument should be taken out of service. When response checks are not feasible, such as with instruments used to measure neutrons or tritium, alternate methods should be established to ensure proper instrument performance.

6. Assessment of radiological conditions should include a sufficient number of survey points to characterize the radiation present and to verify boundaries.

7. Surveys should be performed, at the discretion of the RSO or RCT, before, during and after the completion of work that has the potential for causing changes in levels of radiation and radioactivity.

8. Survey frequencies should be established based on potential radiological conditions, probability of change in conditions and area occupancy factors.

9. Monitoring results should be reviewed by the assigned RSO. The review should ensure that all required surveys have been performed and that the documentation is accurate and complete.

10. Radiological surveys should be recorded on appropriate standard forms and include the following common elements:

    a. Date, time and purpose of the survey.

    b. General and specific location of the survey.

    c. Name of the surveyor.

    d. Pertinent special information needed to interpret survey results (e.g., unusual background levels, special survey distances, etc.).

    e. Reference to a specific Radiological Work Permit if the survey is performed to support the permit.

11. Results of current surveys or survey maps should be conspicuously posted or made otherwise available to inform personnel of the radiological conditions.

12. Monitoring results should be made available and used in support of pre- and post-job evaluations, ALARA preplanning, contamination control, and management of radiological control operations.

13. Radiation surveys should include, at the discretion of the RSO or RCT, dose rate measurements of the general area, dose rates at a distance of 30 centimeters from a source or surface of interest to evaluate potential whole body exposures, and dose rates on contact with potential sources of radiation where there is a potential for hands-on work.

14. Surveys should be conducted whenever operations are being performed that might result in personnel being exposed to small intense beams of radiation, such as those generated by shielded x-ray devices or due to removal or alteration of shielding.

15. Personnel shall check instruments for proper response, usually against a check source, and for being within their designated calibration period prior to use. No instrument shall be used for surveys used in personnel protection beyond their designated calibration period as indicated by the affixed label.

16. Technical details of the portable survey instruments used at Fermilab to accomplish these objectives are summarized in Appendix 5C.

552 Area Radiation Monitors

1. In addition to the requirements of Article 551, area radiation monitors (not to include area monitoring dosimeters) should be installed in frequently occupied locations with the potential for unexpected increases in dose rates and in remote locations where there is a need for local indication of dose rates prior to personnel entering remote locations. Summary technical descriptions of the stationary instruments used to monitor radiation fields at Fermilab are given in Appendix 5D, which includes both routinely used instruments and specialty instruments developed for the accelerator radiation environment.

2. Area radiation monitors should not be substituted for radiation exposure surveys in characterizing a workplace. They may be used to characterize the radiation fields associated with accelerator/beamline operations or radiation generating devices.

3. The need and placement of area radiation monitors should be documented and assessed by the assigned RSO when changes to facilities, systems or equipment occur.

4. Area radiation monitors shall be tested at least annually to verify audible alarm system operability and audibility under ambient working conditions and operability of visual alarms when so equipped and in circumstances in which the visible or audible alarm would actually be used.

5. If installed instrumentation is removed from service for maintenance or calibration, a radiation monitoring program providing at least equal detection capability shall be maintained, consistent with the potential for unexpected increases in radiation dose rates.

6. The incorporation of area radiation monitors into radiation safety interlock systems is described in Chapter 10 of this Manual.

7. Individuals are prohibited from defeating or modifying any area monitoring system feature unless authorized to do so by the assigned RSO as approved by the Senior Radiation Safety Officer (SRSO).

553 Contamination Surveys

Summary technical descriptions of instruments used for contamination surveys are given in Appendix 5C.

1. In addition to the requirements of Article 551, contamination surveys should be conducted in areas with the potential for the spread of contamination as follows:

    a. Prior to transfer of equipment and material from contamination or high contamination areas (see FRCM Chapter 4, Part 2).

    b. Prior to transfer of equipment and material irradiated at primary beam irradiation facilities.

    c. Monthly, or upon entry if entries are less frequent, in contamination areas and other areas where materials having removable contamination exceeding the Table 2-2 values are handled or stored.

    d. Monthly, or upon entry if entries are less frequent, where contamination area boundaries or postings are located.

    e. During initial entry into a known or suspected contamination area, periodically during work, at completion of job, or as specified in a Radiological Work Permit.

    f. After a leak or spill of contaminated materials or dispersible radioactive materials (e.g., dust, liquids).

2. Survey requirements for the release of materials are set forth in Articles 421 and 422.

3. Consideration should be given to the possible presence of hard to detect radionuclides (7Be, 3H, etc.). Measurement techniques shall be appropriate for type(s), levels and energies of the radiation(s) encountered.

4. Items with inaccessible surfaces which were located in known or suspected contamination areas and had the potential to become contaminated at levels likely to exceed Table 2-2 values should be treated as potentially contaminated and subject to administrative controls specified by the assigned RSO unless the items are dismantled and monitored or special survey techniques are used to survey all surfaces.

5. Wipe surveys for removable contamination should be reported in units of disintegrations per minute per 100 cm^2 (dpm/100 cm^2). For wipe surveys of small items covering less than 100 cm^2, the results should be reported in units of dpm per area wiped.

6. Large area wipes may be used to supplement standard wipe techniques in areas generally assumed not to be contaminated, as specified by the assigned RSO, in accelerator/beamline enclosures and at entrances to Contamination Areas. If an evaluation indicates that an area wiped is contaminated, a thorough contamination wipe survey should be performed.

7. In addition to the elements required by Article 551, records of surveys of removable contamination shall include, at a minimum, the following information:

    a. Model and serial number of counting equipment and calibration due date, if applicable.

    b. Contamination levels (using appropriate units) and appropriate supporting parameters including counting efficiency, counting time, correction factors, and type of radiation.

    c. Location of areas found to contain hot particles or high concentrations of localized contamination.

    d. Follow-up survey results for decontamination processes cross-referenced to the original survey.

8. Wipes that indicate the possible presence of contamination should be submitted promptly to the Radionuclide Analysis Facility (RAF) for standardized counting by an RSO or RCT.

554 Airborne Radioactivity Monitoring

1. Derived Air Concentrations (DAC) are listed in the appendices to 10 CFR 835 and summary values as provided in Article 347. Unless otherwise specified, DAC will be taken to mean the DAC for a radiological worker throughout this Manual.

2. Samples shall be taken as necessary to detect and evaluate the level or concentration of airborne radioactive material at work locations. Air sampling shall be performed where an individual is likely to receive an exposure of 40 or more DAC-hours in a year, or as necessary to characterize the airborne radioactivity hazard where respiratory protective devices for protection against airborne radionuclides have been prescribed.

3. Air monitoring equipment should be used in situations where airborne radioactivity levels can fluctuate and early detection of airborne radioactivity could prevent or minimize inhalation of radioactivity by personnel. Selection of air monitoring equipment should be based on the

specific job being monitored. Air monitoring equipment includes portable and fixed air sampling equipment and continuous air monitors.

4. Air sampling equipment should be positioned to measure air concentrations to which persons are exposed. If this cannot be achieved, a program of personal breathing-zone air sampling should be initiated.

5. Air monitoring equipment shall be routinely calibrated and maintained at a frequency of at least once per year. Continuous air monitors should be capable of measuring 1 DAC when averaged over 8 hours (8 DAC-hours) under laboratory conditions.

6. Real-time air monitoring equipment required by Article 554.2 shall have alarm capability and sufficient sensitivity to alert personnel if immediate action is necessary in order to minimize or terminate inhalation or immersion exposures.

7. In addition to the elements provided in Article 551, records of airborne radioactivity should include, at a minimum, the following information:

    a. Model and serial number of the sampler and laboratory counting instrument and calibration date if applicable; locations of fixed samplers may be used as identifiers where model and serial numbers are not available.

    b. Location of fixed air samplers.

    c. Location of portable air samplers used for a survey.

    d. Air concentrations in general airborne areas and breathing zones.

    e. Supporting parameters, including collection efficiency, flow rate, duration of sampling, correction factors and filter medium.

555 Collection and Analysis of Analytical Samples

Samples are collected and submitted for analysis to the Radionuclide Analysis Facility (RAF) for a variety of purposes to support the Laboratory's occupational and environmental protection programs as well as the Laboratory's primary mission of high energy physics research.

1. To ensure that the desired standard of quality assurance is met, these samples shall be submitted for analysis following rigorous procedures. These procedures are specified in Appendix 5E, Section A.

2. For activation analysis and unusual samples that do not appear to meet the standard requirements for analysis, the RAF Group Leader shall be consulted prior to submittal. This

step is necessary to avoid the potential for contaminating the equipment and compromising the results of analysis of other samples that might be underway.

3. Samples should be reasonably described in a manner that is unambiguous about their point of origin or the method or methods used in their collection.

556 Characterization of Accelerator Radiation Fields

A variety of techniques and instrumentation has been developed to characterize accelerator radiation fields. The technical details of the devices used at Fermilab to do this are within the realm of the professional expertise of the radiation safety personnel and include relevant aspects of radiation, nuclear, particle, and accelerator physics. In some cases, these special devices and techniques are used in combination with other devices discussed elsewhere in this chapter and its appendices.

PART 6 INSTRUMENTATION AND CALIBRATION

561 Inspection, Calibration and Performance Tests of Radiation Safety Instrumentation

1. Calibrations shall use National Institute of Standards and Technology (NIST) traceable sources or other acceptable standards. This program is implemented at Fermilab by the ES&H Section's Instrumentation Team at the Radiation Physics Calibration Facility (RPCF).

2. Calibration procedures have been developed by the ES&H Section for each instrument type and include frequency of calibration, precalibration requirements, primary calibration requirements, periodic performance test requirements, calibration record requirements and maintenance requirements.

3. Pocket and electronic dosimeters and area radiation monitors shall be calibrated at least annually.

4. Radiation instrumentation response to interfering ionizing and non-ionizing radiation and environmental conditions should be determined when a potential for such interference is credible. The effects of such interfering radiation or conditions has on an instrument shall be known prior to routine use by the general workforce.

5. Functional tests should be used to assess instrumentation designs that include alarms or that involve a process control. A functional test should be developed to test all components involved in an alarm or trip function and performed at least annually.

6. In unusual and limited situations, it may be necessary to use an instrument in an application other than that envisioned by the manufacturer. Special use calibrations should be performed for use of instrumentation outside manufacturer's specifications. The instrument should be adjusted, calibrated and labeled to identify the special conditions and used only under the special conditions for which it was calibrated.

7. Instruments should bear a label or tag with the date of calibration and the date the instrument is due for recalibration.

8. Instruments whose “as found” readings as measured at RPCF indicate that the instrument may have been actually used while its performance was outside of calibration specifications shall be reported to the assigned RSO for the organization to which the instrument was assigned. The Radiological Control Organization should review surveys performed with the instrument while it was believed to be out of calibration.

9. Calibration records for fixed, portable and laboratory radiation measuring equipment and individual monitoring devices shall be maintained and include frequencies, method, dates,

personnel, training and traceability of calibration sources to National Institute of Science and Technology or other acceptable standards.

10. Calibration records are maintained for the following equipment:

    a. Portable survey instruments.

    b. Laboratory, and fixed radiation measuring equipment.

    c. Process and effluent monitors and sampling equipment.

    d. Radiation area monitors.

    e. Personnel contamination monitors.

    f. Pocket and electronic dosimeters.

    g. Air sampling equipment.

562 Maintenance

1. A program for preventive and corrective maintenance of radiological instrumentation has been established and documented.

2. Preventive and corrective maintenance should be performed using components and procedural recommendations at least as stringent as those specified by the manufacturer of the instrument.

3. Radiological instruments shall undergo calibration prior to use following any preventive or corrective maintenance or any adjustment that voids the previous calibration. A battery change is not normally considered to be a maintenance activity. Batteries for these instruments shall be changed only by ESH&Q Instrumentation Technicians or Radiological Control Technicians or others who have received appropriate instruction.

4. Maintenance histories and calibration results for each instrument shall be created and retained. These records shall document the nature of any defects and corrective actions taken.

5. These records are maintained by the ES&H Section.

563 Calibration Facilities

1. Calibration facilities should perform inspections, calibrations, performance tests, calibration equipment selection and quality assurance in accordance with the recommendations of ANSI N323 and take the following actions:

    a. Locate activities in a manner that minimizes radiation exposure to operating personnel and to personnel in adjacent areas.

    b. Minimize sources of interference, such as backscatter, environmental and non-ionizing radiation, during the calibration of instrumentation and correct for interferences as necessary.

    c. Operate in accordance with the referenced standards.

    d. Generate records of calibration, functional tests and maintenance in accordance with the referenced standards.

    e. Maintain traceability of calibration sources and equipment to National Institute of Science and Technology or other acceptable standards.

2. Subcontracted calibration services, if utilized, should be performed in accordance with the referenced standards.

Appendix 5A Radiation Dosimeters Used at Fermilab

1. Comparison of Integrating Dosimeters

Table 5-1 contains a short comparison of some of the important characteristics of a number of passive integrating dosimeters in use at Fermilab and described in various sections of this chapter. These are devices used supplementary to the personnel dosimetry monitoring badge of record that is accredited by the Department of Energy Accreditation Program (DOELAP) to better characterize accelerator radiation fields. Not all of these devices are suitable for use as personnel dosimeters. None of these devices provides information on a "real time" basis.

Table 5-1 Integrating Radiation Dosimeters Used at Fermilab

Dosimeter Type	Used to Measure	Lower Limit of Sensitivity	Upper Limit of Usefulness	Comments
TLD-100 (Natural mixture of Li isotopes)	γ-Rays and charged particles	5 mrad	100 krad	Very sensitive to thermal neutrons.
TLD-600 (^{6}LiF)	Fast neutrons using Bonner Spheres, and thermal neutrons when bare	3 mrem	60 krem	Used in 25.4 cm Bonner Sphere to monitor typical accelerator neutrons.
TLD-700 (^{7}LiF)	γ-Rays and charged particles	5 mrad	100 krad	Also used in a TLD-600-700 pair inside a moderator (Bonner Sphere) to roughly measure β–γ component of a neutron radiation field.
Polycarbonate Track Etch	Fast neutrons and α's	20 mrem	25 rem	1 MeV to 10-15 MeV
CR-39 Track Etch	Fast neutrons and α's	20-30 mrem	25 rem	Useful energy ranges 150 keV to 10-15 MeV.
Elastic Polymer Bubble Detector	Fast neutrons	0.1 mrem	1 rem	0.1 MeV to 14 MeV. Also sensitive to thermal neutrons. Insensitive to γ-rays. Very rarely used at Fermilab.
PIN Diode (Silicon)	Fast neutrons	2 rad	2 krad	Sensitive to neutron energies $\geq$ 0.2 MeV. Very low sensitivity to γ-rays. Not suitable for measuring personnel exposures, very rarely used at Fermilab.
Foil Activation	High-energy hadron flux	10^{11} particles/cm^2 $\cong$ 10^5rads	10^{16} particles/cm^2 $\cong$ 10^{10} rads	Not sufficiently sensitive for measuring personnel exposures-See Appendix 5F

2. Personnel Dosimetry at Fermilab

The personal dosimetry badge of record currently in use at Fermilab, accredited by DOELAP, consists of an optically stimulated luminescence (OSL) dosimeter for gamma and charged particle detection and a track-etch detector for neutrons provided by a commercial vendor. OSL technology has replaced the use of thermoluminescence for the personnel dosimetry monitoring badge of record. However, thermoluminescent dosimeters (TLDs, see below) are still used for extremity dosimeters and for special measurements of radiation fields conducted at Fermilab. All personnel dosimeters are changed on the first working day of each calendar quarter.

a. Optically Stimulated Luminescence (OSL)

OSL dosimeters consist of a series of aluminum oxide crystal (Al_2O_3:C) detectors sandwiched between two layers of polyester, with various plastic and metal filters overlaid. Incoming ionizing radiation causes excited electrons to be entrapped between the valence and conduction bands in the crystal.

The readout process uses a light emitting diode (LED) array to stimulate the detectors, which frees some of the trapped electrons, which in turn emit photons due to radiative recombination. The photons emitted by the OSL material are detected and measured by a photomultiplier tube using a high-sensitivity photon counting system. The amount of light released during optical stimulation is directly proportional to the radiation dose and the intensity of stimulation light.

The OSL dosimeters used at Fermilab are capable of reporting dose from gamma, x-ray, and beta radiation with energies from 5 keV to 20 MeV, with a reporting range from 5 mrem to 1000 rem. Unlike TLDs, these dosimeters are capable of being re-read, as the LED array does not release all of the trapped electrons at once.

b. Thermoluminescent Dosimetry (TLD)

Lithium-7-enriched lithium fluoride (LiF) in the form of extruded ribbons cut in the shape of rectangles is used to measure dose in the range from 10 mrem to 1000 rem for photons and 10 mrem to 1000 rem for beta particles.

After exposure, the dosimeters are read by heating the LiF and measuring the light emitted by thermal luminescence using a photomultiplier tube and picoammeter. Within certain limits, the amount of light emitted is proportional to the dose absorbed. The dosimeters are prepared for reuse by annealing.

c. Track-Etch Neutron Dosimeters

The track-etch neutron dosimeter is manufactured from a commercially available plastic monomer known as allyl diglycol carbonate, more commonly by its trade name CR-39. The dosimeter consists of a piece of CR-39 plastic in contact with a charged particle radiator made of polyethylene. Recoil protons from this radiator damage the

CR-39. Chemical or electrochemical etching of the CR-39 will render visible these ion tracks, the number of which are proportional to the neutron dose. CR-39 is useful for fast, intermediate, and thermal neutrons with energies between 0.25 eV and 40 MeV and has a dose measurement range from 10 mrem (20 mrem for fast neutrons) up to 25 rem.

A principal advantage of track etch neutron dosimeters is that they are not affected by moisture. The dosimeter badge used to measure gamma-ray exposure is paired with a track etch dosimeter to monitor neutron dose equivalent at Fermilab.

Appendix 5B Real Time Supplemental Radiation Dosimeters Used At Fermilab

1. **Pocket Dosimeters**:
   - Primarily used during beam-off conditions.
   - Designed for gamma and x-rays only.
   - Useful for beam-on exposures outside of thick shielding when the radiation field is dominated by muons.
   - Give questionable readings in neutron fields.
   - Detects gamma rays and charged particles.
   - Integrating dosimeter.
   - Small ion chamber.
   - Must be recharged.
   - Visual readout.
   - These are the cheapest, most common supplemental dosimeters.

2. **Electronic Dosimeters:**
   - Small Geiger counter used during beam-off conditions.
   - Primarily sensitive to gamma rays.
   - Has an LED readout displaying the exposure in mR (milliroentgen).
   - The instrument can be set to alarm audibly either once per mR or 30-40 times per mR.
   - Very useful for controlling exposure in High Radiation Areas.
   - These devices should not be used as a survey instrument or in prompt radiation fields.
   - There are various manufacturers and types of these instruments.

Appendix 5C Portable Radiation Survey Instruments Used At Fermilab

Note: The monitoring devices listed below are designated as being beam-on or beam-off (in some cases both). A beam-off instrument may not be suitable for beam-on use due to excessive dead time or insensitivity to particles of interest. A beam-on instrument may not be suitable for beam-off use.

1. **Geiger Counter:** Exposure rate meters, suitable for beam-off use only. Primarily sensitive to gamma and X-rays. The primary use is to check for residual activity and to measure exposure rates. The instrument consists of a portable box with a detachable probe. There are several major types of Geiger Counters used at Fermilab:

    a. **Ludlum 14C-1**: Side window, T-shaped energy compensated probe with minimal beta sensitivity. Ratemeter has 5 linear ranges.

    b. **LSM (Log Survey Meter)** Side window T-shaped energy compensated probe with minimal beta sensitivity. Displays 3 decades on 1 range.

    c. **Bicron Surveyor 50:** The instrument has a probe with an energy compensated housing. The housing provides a sliding beta-particle shield. It has a linear ratemeter with 3 ranges: 0-0.5, 0-5, and 0-50 mR/hr.

    d. **Teletector/Extender 1000W**: A Geiger counter dose ratemeter suitable for beam-off use only. Detects gamma/X-rays and some charged particles. A very useful instrument in high radiation fields due to its high range capabilities and the relative isolation provided by its integral 4 meter collapsible probe extension. It resembles a fishing pole when fully extended.

    e. **E140N**: A pulse ratemeter with associated 2 inch diameter thin end window Geiger counter probe. Beam-off use only. Detects charged particles and gamma/X-rays and is used primarily to detect low-levels of contamination. Average beta-gamma sensitivity is 10%. Minimum detectable activity is about 0.3 nCi per wipe (about 60 counts per minute). The calibration for a typical Fermilab contamination sample is 200 cpm/nCi.

2. **Smart Ion**: A programmable multi-use ion chamber for beam-off use. Digital display shows dose rate (mR/hr) or integrated dose (mR). Simulated analog display shows dose rate trend or dose. A movable shield can be adjusted for beta/X-ray or gamma sensitivity. Ion chamber is also sensitive to neutrons. Alarms at set point. Scale changes automatically when readings are outside of current range. The useful energy range for photons (±20%) is 10 keV to 1.3 MeV (shield open) or 22 KeV to 1.3 MeV (shield closed). Energy cutoff for betas is 70 keV (shield open) or 1 MeV (shield closed).

3. **Bicron Analyst:** A pulse ratemeter with single-channel analyzer calibrated as a count rate instrument (CPM), with associated NaI (Tl) scintillation probe sensitive to gamma-rays. For beam-off use only. The gamma ray energy detection threshold is about 60 keV.

4. **Bicron Micro Rem:** A light weight, top-handle, box shaped ratemeter with 5 linear ranges measuring photon tissue dose rate from background levels to 200 mrem/hr. The detector is an internally mounted organic scintillator yielding a tissue equivalent response to gammas and X-rays from 40 keV to 1.3 MeV.

5. **Eberline RO-2:** Thin window air ionization chamber for beta, gamma, X-ray detection. Dose rate only. 4 linear ranges from 5-5000 mR/hr full scale. Specifically designed for flat response into the X-ray region. Beam-off use only.

6. **HPI 1010:** This instrument uses a tissue-equivalent proportional chamber to measure integrated absorbed dose (mrads) or dose rates (mrads per hour) when exposed to neutrons, gamma rays, and charged particles under either beam-on or beam-off conditions. It is delicate and should be handled with care. They are the most appropriate instruments for beam-on surveys, with integration being the preferred measurement technique. This instrument consists of an electronics box with top mounted handle and a front mounted detector. The user should have a good understanding of its response in diverse radiation fields.

7. **Snoopy:** A heavy, portable neutron counter consisting of an Anderson/Braun type moderated BF_3 counter connected to a ratemeter body. This instrument should be used only in low dose rate accelerator produced fields with long spill times to avoid saturation of the proportional counter. An Eberline ESP-2 supplies HV and all data measurement functions. It can be operated in either dose rate (mrem/hr) or integrate (mrem) modes. Care needs to taken in the use of the meter in a pulsed radiation field. A scaler (with pulse shaper adaptor) should be attached to the AUDIO/SCALER connector and the pulses counted on the $X10^3$ range. Calibration is 7500 cts/mrem (AmBe response). Used for beam-on low dose rate neutron surveys.

Appendix 5D Stationary Radiation Instrumentation Used At Fermilab

Note: The monitoring devices listed below are designated as being beam-on or beam-off (in some cases both). A beam-off instrument may not be suitable for beam-on use due to excessive dead time or insensitivity to particles of interest. A beam-on instrument may not be suitable for beam-off use.

1. **Chipmunk:** The "standard" area monitor used in experimental areas. It is an AC powered beam-on or beam-off neutron, gamma ray and charged particle detector. The instrument consists of a tissue equivalent ion chamber mounted in a yellow box with a blue electronics/indicator box on top. The upper box contains visual and audible indicators (ratemeter, lights, alarm) to display dose rates and alarm levels. External signal connectors provide remote readout and interlock capability and a digital pulse train for dose integration (2.5 µrem/pulse). The quality factor may be set to values of 1, 2.5, 5, or 10. A built-in check source provides a background of about 0.6 mrem/hr on the quality factor 5 setting. Its portable analogs are the tissue equivalent survey meters (Appendix 5C). These instruments may be used as ratemeters or in an integrate mode.

2. **Scarecrow**: A high range version of the Chipmunk. The specifications are identical to those of the Chipmunk with the following exceptions: (1) the ion chamber enclosure is RED; (2) the quality factor is preset at 4; (3) background level from the check source is 100 mrem/hr (ratemeter zero); (4) the digital pulse train calibration is 25 µrem/pulse; and (5) the high level alarm is user adjustable.

3. **FOX:** An area monitor similar in function to a Chipmunk. It is an AC powered beam-on or beam-off X-ray, gamma ray and charged particle detector. The instrument consists of a 3.8 liter, desiccated, air filled ion chamber mounted in a Faraday type cage enclosure with a blue electronics box on the end. The blue box contains a visual indicator to display an output pulse. External signal connectors provide interlock capability and a digital pulse train for dose integration (1 µR /pulse). The quality factor is fixed to 1. A built-in check source provides a background of about 0.26 mR/hr.

4. **Hippo:** A very large detector consisting of a 55 gal. ion chamber and associated electrometer integrator. This instrument is used for detecting small amounts of accelerator-produced prompt radiation (principally muons) or gamma rays due to induced radioactivity far from the accelerator and experimental areas. It is primarily used as an environmental monitor near the site boundary.

5. **Wallflower**: A wall mounted, AC powered, Geiger counter ratemeter used for beam-off gamma ray detection. The instrument consists of a blue box with detachable probe. The instrument is generally mounted at labyrinth or enclosure exits and is used only to assign radioactivity classes (see Article 413) to radioactive items leaving beamline enclosures. The meter face displays an activity class rating that corresponds to labels found in the vicinity of the instrument. Its portable analog is the portable Geiger counter (Appendix 5C).

6. **Frisker**: An AC powered pulse ratemeter with detachable pancake type Geiger counter probe. It is normally used to check for low-levels of contamination on personnel and for radioactive material leaving enclosures. It possesses a pre-settable audible alarm level. It is similar in operation to the portable E140N. The instrument is generally mounted at labyrinth or enclosure exits.

Appendix 5E Procedures And Equipment Used To Measure Radioactivity Samples And Airborne Radioactivity Concentrations

A. Procedures for Submission of Analytical Samples to the Radionuclide Analysis Facility

In order to minimize the potential for sample cross contamination and to facilitate sample handling and analysis at the Radionuclide Analysis Facility (RAF), the following guidelines shall be followed. Exceptions to these guidelines must be approved by the RAF Group Leader before the samples in question are submitted to the RAF for analysis.

1. Samples submitted to the RAF for analysis must be delivered to the east entrance of the Annex at Site 39.

2. All samples submitted to the RAF for analysis must be accompanied by a properly completed Chain of Custody (COC) Radiation Physics Form No. 33 (see List of Radiation Physics Forms). Ensure that all parties who require analysis results are clearly communicated to the RAF staff member receiving the samples.

3. Any rush job must be cleared through the RAF Group Leader. Otherwise, analyses will be performed in the order of receipt. A routine gamma ray analysis requires a minimum of 1 business day and routine ^{3}H analyses require a minimum of 3 business days for preliminary results and 5 business days for final results.

4. Each sample submitted to the RAF must have a unique FNAL identification number associated with it as directed in the Fermilab RAF Procedure 100. This number and a brief description of the location from which the sample was taken must be clearly indicated on the sample and the COC form. The location from which the sample was taken must be explained clearly and in detail on the COC form.

5. Samples submitted for gamma ray analysis only or for gamma ray analysis and tritium analysis must be submitted in 250 ml sealed Nalgene plastic bottles obtainable at the Fermilab Stockroom. At least 200 mL of sample is required for most RAF gamma ray analyses. Smaller volumes may be acceptable but require prior authorization from the RAF Group Leader. Samples submitted for tritium analysis only may be submitted in 125 or 250 ml sealed Nalgene plastic bottles. At least 100 mL of sample is required for most tritium analyses.

6. **Prior** clearance from the RAF Group Leader must be obtained before any sample greater than Class 1 in radioactivity is brought to the RAF.

7. All integral solid samples, wipes, and filters should be contained in a sealed plastic bag to minimize the potential for cross contamination of samples. Such bags should be clearly marked with the sample's ID and location.

8. All sample containers must be sealed and the outside thoroughly cleaned before they are taken to the RAF.

9. Personnel entering the RAF must ensure that they carry no contaminated material into the building. A Frisker is provided in the RAF sample receiving room.

10. Only personnel trained on RAF standard operating procedures are allowed to transfer or in any other way alter samples after they have entered the RAF.

11. RAF normally disposes of samples after analysis is completed, through the ES&H Hazard Control Technology Team. If the sample requestor would like samples returned to them, they must indicate that on the COC before submitting samples. Once the report has been issued, the samples be disposed after 2 weeks unless advance arrangements are made with the RAF Group Leader. During sample return, the person picking up the samples should ensure that the corresponding COC is properly signed back to him/her by an RAF technician.