



ESH-doc-  
6164

Revision  
1

March  
2022

Page  
1

# External Dosimetry Quality Program Manual

## AUTHORIZATION

M. Vincent

---

Prepared by

Signature

Date

K. Graden

---

Reviewed by

Signature

Date

M. Vincent

---

Dosimetry Program Manager

Signature

Date

W. Schmitt

---

RPS Dept. Head

Signature

Date

### Revision History

Author	Description of Change	Revision Date
M. Vincent	<p style="text-align: center;">Revision 1</p> Added new role and training for Long Baseline Neutrino Facility-Far Site (LBNF-FS) Dosimetry Coordinator; updated procedures to incorporate LBNF-FS dosimetry; updated neutron accreditation category; addressed findings from previous internal assessment	March 2022
M. Vincent	<p style="text-align: center;">Revision 0</p> Quality Program Manual created	February 2021

## Table of Contents

PURPOSE.....	4
SCOPE.....	4
ORGANIZATION AND MANAGEMENT.....	5
PERSONNEL [FNAL-DP-01] .....	6
ROLES AND RESPONSIBILITIES.....	6
TRAINING AND STAFF COMPETENCY.....	14
<i>Dosimetry Program Manager</i> .....	14
<i>Backup Dosimetry Program Manager</i> .....	15
<i>External Dosimetry Program Administrative Support Assistant</i> .....	15
<i>LBNF Far Site Dosimetry Coordinator</i> .....	15
CONTINUITY OF OPERATIONS.....	16
QA OVERVIEW [FNAL-DP-02].....	16
BADGE RACKS.....	17
BLIND AUDIT PROGRAM.....	17
REPORT REVIEW, APPROVAL, AND RETENTION.....	17
NON-DESTRUCTIVE TESTING.....	17
OTHER PROCEDURAL QA CHECKS.....	17
INTERNAL AUDITS.....	18
MANAGEMENT REVIEW.....	18
DOCUMENT REVIEW.....	18
VENDOR OVERSIGHT.....	19
DOELAP ACCREDITATION [FNAL-DP-03].....	19
FERMILAB'S DOSIMETER OF RECORD.....	20
FERMILAB'S EXTREMITY DOSIMETER.....	23
CONTROL OF DOCUMENT.....	24
REFERENCES.....	24
ATTACHMENTS.....	26
A. FERMILAB ES&H SECTION ORGANIZATIONAL CHART.....	26
B. RP FORM 117 BACKUP DOSIMETRY PROGRAM MANAGER ANNUAL ASSESSMENT & TRAINING FORM.....	27
C. RP FORM 118 EDP ADMINISTRATIVE SUPPORT ASSISTANT ANNUAL ASSESSMENT & TRAINING FORM.....	29
D. RP FORM 129 EDP LBNF-FS DOSIMETRY COORDINATOR ANNUAL ASSESSMENT & TRAINING FORM.....	31



## Purpose

Fermilab is required by the U.S. Department of Energy (DOE) to monitor and document the exposure of personnel to ionizing radiation due to certain known and well-characterized radiological hazards at Fermilab, such as work with radioactivated materials and sealed radioactive sources. Fermilab's Environment, Safety, and Health (ES&H) Section has the overall responsibility for the laboratory's External Dosimetry Program (EDP). The purpose of this *External Dosimetry Quality Program Manual* (QPM) is to demonstrate the quality assurance protocols underlying the operation and administration of the program; these protocols are in accordance with 10 CFR 835 [1], DOE-STD-1095-2018 [2], and the *Fermilab Radiological Control Manual* (FRCM) [3], thus fulfilling the requirements to maintain Department of Energy Laboratory Accreditation Program (DOELAP) accreditation while ensuring that the EDP operates in a safe, methodical, accurate, and efficient manner.

## Scope

Fermilab is currently accredited by DOELAP for the following dosimeters and fields:

Whole Body Dosimeter: Landauer InLight Model 2T

Testing Categories:

- IA Accident, photons: General
- IIA Photons/photon mixtures: General
- IIIA Betas: General
- IIID Betas: Uranium slab
- IVA-1 Photon/beta mixtures: IIA + IIIA
- IVD-1 Photon/beta mixtures: IIA + IIID
- VB-1 Neutron/photon mixtures: IIA + Bare Neutrons

Extremity Dosimeter: Landauer Saturn Ring

Testing Categories:

- IA High-Dose, photons: General
- IIA Photons: General
- IIIA Betas: General
- IIID Betas: Uranium slab

Note that beginning with the next DOELAP accreditation cycle, Fermilab will seek accreditation in category VA-1, Neutron/photon mixtures: IIA + General Neutrons in place of category VB-1 due to the addition of neutron generators at both Fermilab and LBNF-FS.

This Quality Program Manual describes the External Dosimetry Program's organizational structure, roles and responsibilities, operational procedures, and the quality assurance and quality control protocols that ensure external dosimetry results are accurate, repeatable, verifiable, and properly recorded. The External Dosimetry Program's numerous operational procedures may be found in the *External Dosimetry*



*Procedures Manual* (EDPM) [4]. More detailed information about the technical aspects of the EDP can be found in Fermilab Radiation Physics (RP) Note 124, *Technical Basis for External Dosimetry at Fermilab* [5], also known as the *Technical Basis Manual*.

Environmental dosimetry is not addressed in this document, as devices used for environmental dosimetry are not required to be accredited by DOELAP. In addition, any dosimetry devices used for individuals who are not required to be monitored under 10 CFR 835.402 are not subject to DOELAP accreditation and thus are not addressed in this manual.

It should be noted that while almost all Radiological Workers are assigned dosimetry, only certain individuals are provided dosimetry pursuant to 10 CFR 835.402. These individuals are identified through ongoing dose tracking as well as identification of radiological work that has the potential to result in doses approaching the threshold for required monitoring under 10 CFR 835.402. These same individuals form the population who would be considered eligible for participation in a Planned Special Exposure pursuant to 10 CFR 835.204.

## Organization and Management

Fermilab is a Department of Energy facility with ongoing research, construction, commissioning, maintenance, and repair activities being conducted under contract by Fermi Research Alliance (FRA) at its primary site in Batavia, Illinois as well as at the Long-Baseline Neutrino Facility Far Site (LBNF-FS) located at the Sanford Underground Research Facility (SURF) in Lead, South Dakota. (The SURF areas and facilities in Lead that are under Fermilab's direct management are collectively referred to as the LBNF Far Site, while the rest of SURF falls under the authority of the South Dakota Science and Technology Authority.)

Within Fermilab's management structure are several Divisions, Sections, and Centers; among these is the ES&H Section, overseen by the Chief Safety Officer (CSO). Within the ES&H Section reside the Radiation Physics Science (RPS), Radiation Physics Operations (RPO), and Radiation Physics Engineering (RPE) departments. These departments work closely with one another to oversee all aspects of radiation safety at the laboratory. The heads of these three departments report to the Senior Radiation Safety Officer (SRSO), who in turn reports to the CSO. An organizational chart for the ES&H Section [6] is attached to this document (see Attachment A).

Fermilab also has a Quality Section under the auspices of the laboratory's Chief Operating Officer (COO), which works with the various other divisions and sections to implement the laboratory's Quality Assurance (QA) program. The *Fermilab Quality Policy* [7], developed and maintained by the Quality Section, establishes the quality-related goals and expectations for programs and personnel across the laboratory. The *Fermilab Quality Assurance Manual* [8] describes the overarching QA program for the laboratory and addresses how the expectations of the Fermilab Quality Policy shall be met.



Fermilab has a series of subcommittees commissioned by the Laboratory Director, including the Radiation Safety Subcommittee (RSSC). The RSSC is responsible for coordinating the implementation and improvement of the FRCM. The RSSC reports to the Laboratory Director through the Fermilab ES&H Committee (FESHCom). The RSSC meets to discuss both occupational and environmental radiation protection issues and develop solutions that will promote compliance and uniform implementation lab wide. The RSSC serves as Fermilab's ALARA committee.

### **Personnel [FNAL-DP-01]**

The functions of the External Dosimetry Program generally include monitoring the external exposure of workers to ionizing radiation, analyzing radiation monitoring and personnel dosimeter measurement data, performing blind audits of designated dosimeters for quality control (QC) purposes, advising management, preserving dosimetry records, and reporting external radiation doses to workers.

The analysis of workplace radiation and personnel dosimeter data and the evaluation of external dose involve complex evaluation and professional judgment. It is important that external dosimetry specialists be capable of recognizing conditions warranting follow-up actions and dose reevaluation. The Dosimetry Program Manager (DPM) has final responsibility for external dose evaluation and thus should have the necessary expertise and skill to perform the assigned duties. Although certain activities including some related to QA may be delegated, final responsibility remains with the programmatically assigned individual.

Additionally, the DPM and Backup DPM should remain familiar with the relevant external dosimetry literature and the recommendations of national and international scientific organizations with regard to evaluation of dose from external exposures.

Note that the roles of Dosimetry Program Manager, Backup Dosimetry Program Manager, and External Dosimetry Program Administrative Support Assistant may sometimes be collectively referred to as the "Dosimetry Program Office," an informal designation that does not appear on organizational charts, in job descriptions, etc. The physical location of the Dosimetry Program Office at Fermilab is on the east side of the 7th floor of Wilson Hall.

### **Roles and Responsibilities**

Detailed descriptions of various roles and responsibilities pertaining to the EDP are listed below. Table 1 shows a functional responsibility matrix for various aspects of the program.

- **Laboratory Director**
  - is ultimately responsible for all aspects of the Radiological Control Program, of which the EDP is a part
  - appoints the Chief Safety Officer
  - assigns responsibility for leading and conducting the Radiological Control Program to the Environment, Safety, and Health Section



- **Chief Safety Officer**
  - serves as or appoints a Senior Radiation Safety Officer
  - ensures adherence to the FRCM
  - informs the Director of any serious violations of the FRCM, Federal or State regulations, or the commitments made in the Fermilab Radiation Protection Program
  - participates in the annual EDP Management Review if the Senior Radiation Safety Officer is unavailable
  
- **Senior Radiation Safety Officer (SRSO)**
  - ensures that the External Dosimetry Program is adequately staffed
  - participates in the annual EDP Management Review
  - ensures frequent periodic reviews of the Radiological Control Program take place, including for the External Dosimetry Program
  - ensures the implementation of the laboratory's program for maintaining radiation exposures as low as reasonably achievable (ALARA)
  - ensures the provision of external dosimetry services
  - ensures the proper maintenance of radiological protection records as specified in the FRCM and in Fermilab policies on records management and document control
  - fosters an active program for the development and refinement of radiation detectors, dosimetry systems, measurement methods, and accelerator shielding methodology
  - approves all exposure investigations that require a subtraction from an individual's dose record
  
- **RPS Department Head**
  - with input from the SRSO and other members of the laboratory's Radiological Control Organization, provides direction for and oversight of the day-to-day work of the Dosimetry Program Manager
  - initiates the annual internal assessment of the EDP
  - along with a member of the Quality Section and either the SRSO or the Chief Safety Officer, participates in the annual EDP Management Review
  - approves EDP documentation



- **Dosimetry Program Manager**

- is a member of the RPS Department and reports to the RPS Department Head
- holds a position of at least Radiation Physicist II and is located at Fermilab in Batavia
- has a Bachelor's degree in Health Physics or a related field, or equivalent experience
- has a minimum of 3 years of radiation protection experience (an advanced degree may be substituted for a portion of this requirement)
- is considered a Subject Matter Expert (SME) as well as both the Technical Lead and the QA Lead for the external dosimetry program
- maintains current training in the following courses:
  - FN000470/CR Radiological Worker - Classroom
  - FN000471/OJ Radiological Worker - Practical Factors
  - FN000048/CR Radioactive Source Training
  - FN000428/CR Issuing Temporary Dosimetry Badges
- serves as an authorized instructor for FN000428/CR Issuing Temporary Dosimetry Badges, ESRP0001/CR Annual Assessment for Administrative Support Assistant, ESRP0002/OJ Annual Assessment for Backup DPM, and ESRP0003/CR Annual Assessment for LBNF-FS Dosimetry Coordinator
- oversees all aspects of the EDP and manages its day-to-day operation, including dosimetry badge assignment, distribution, and collection, timely processing of dosimeters, handling occupational exposure history requests, placing individuals on the ALERT list when necessary, and initiating, tracking, and approving all exposure investigations
- serves as the primary point of contact for the dosimetry vendor
- reviews all dosimetry data and has final responsibility for external dose evaluation
- conducts quality assurance assessments of the dosimetry vendor, including onsite audits, QC reviews, and blind audits
- is ultimately responsible for the development and maintenance of all EDP documentation and records, including this document
- provides dosimetry data to the RSOs on at least a quarterly basis
- updates the quarterly collective dose spreadsheet and the annual plot of collective dose normalized to the number of 8 GeV protons in the ES&H Section Document Database
- trains the Backup DPM, the EDP Administrative Support Assistant, and the LBNF-FS Dosimetry Coordinator
- participates in Management Reviews and internal and DOELAP assessments of the EDP
- suggests improvements to the laboratory's dosimetry database applications via the Service Desk ticket system as well as communications with the Core Computing Division Business Applications Department, and participates in the testing of upgraded applications prior to their publication
- utilizes the shared Outlook calendar or an equivalent tool to set reminders and communicate significant dosimetry program events





- **Backup Dosimetry Program Manager**
  - is a member of the laboratory's Radiological Control Organization
  - holds a position of at least Radiation Physicist II and is located at Fermilab in Batavia
  - has a Bachelor's degree in Health Physics or a related field, or equivalent experience
  - has a minimum of 3 years of radiation protection experience (an advanced degree may be substituted for a portion of this requirement)
  - is considered a Subject Matter Expert (SME)
  - maintains current training in the following courses:
    - FN000470/CR Radiological Worker - Classroom
    - FN000471/OJ Radiological Worker - Practical Factors
    - FN000048/CR Radioactive Source Training
    - FN000428/CR Issuing Temporary Dosimetry Badges
  - serves as an authorized instructor for FN000428/CR Issuing Temporary Dosimetry Badges
  - maintains readiness to step into the role of DPM at any time should the DPM become unable to serve
  - receives annual training from the DPM, which is documented with RP Form 117 and ESRP0002/OJ Annual Assessment for Backup Dosimetry Program Manager
  - participates in Management Reviews and internal and DOELAP assessments of the EDP
  - reviews all EDP documentation
  - subscribes to the shared EDP Outlook calendar or equivalent
  
- **External Dosimetry Program Administrative Support Assistant**
  - is a member of the ES&H Administrative Support Department
  - holds a position of at least Administrative Support Assistant II and is located at Fermilab in Batavia
  - assists the DPM with various administrative duties pertaining to the EDP, including dosimetry badge rack checking, records filing, and Listserv maintenance
  - receives training from the DPM, which is documented with RP Form 118 and ESRP0001/CR Annual Assessment for Administrative Support Assistant
  - subscribes to the shared EDP Outlook calendar or equivalent



- **LBNF Far Site Dosimetry Coordinator**
  - is a member of the laboratory's Radiological Control Organization
  - holds a position of at least Radiation Physicist II and is located at the LBNF Far Site in Lead, SD
  - is responsible for receipt, verification, distribution, collection, and return of dosimeters at LBNF-FS
  - uses dosimetry data provided by the DPM for management of dose to LBNF-FS personnel
  - performs exposure investigations for personnel at LBNF-FS
  - monitors individuals at LBNF-FS who report having undergone nuclear medicine procedures
  - reviews new requests for permanent badge service at LBNF-FS, verifying that training requirements have been satisfied
  - maintains current training in FN000428/CR Issuing Temporary Dosimetry Badges
  - receives training from the DPM, which is documented with RP Form 129 and ESRP0003/CR Annual Assessment for LBNF-FS Dosimetry Coordinator
  - subscribes to the shared EDP Outlook calendar or equivalent
  
- **Radiation Safety Officers (RSOs)**
  - with support from the Radiological Control Technician group, use dosimetry data provided by the DPM for management of dose to laboratory personnel
  - perform exposure investigations, including for personnel on the ALERT list
  - monitor individuals who report having undergone nuclear medicine procedures
  - review new requests for permanent badge service, verifying that training requirements have been satisfied
  - provide input to the Dosimetry Program Manager as to the dosimetry needs of personnel working in their assigned Division, Section, or Center
  - maintain current training in FN000428/CR Issuing Temporary Dosimetry Badges
  
- **Radiological Control Technicians (RCTs)**
  - assist the RSOs in management of dose to laboratory personnel
  - are responsible for distribution and collection of area monitoring dosimeters
  - perform exposure investigations
  - provide input to the DPM as to which racks new permanent badge service dosimeters should be assigned
  
- **Temporary Dosimetry Badge Issuers**
  - maintain current training in FN000428/CR Issuing Temporary Dosimetry Badges
  - use the data entry webpage or information card to issue temporary dosimetry badges to Fermilab employees, users, and visitors



- **Deputy Security Chief and Physical Security Department Supervisor**
  - maintain current training in and serve as authorized instructors for FN000428/CR Issuing Temporary Dosimetry Badges
  
- **Core Computing Division Business Applications Department**
  - maintains Fermilab's local dosimetry program database system and its associated computer applications in accordance with *Fermilab ES&H Manual* (FESHM) Chapter 2090 (Development, Maintenance, Procurement, and Usage of Software Products Related to Environment, Safety, and Health) [9], as well as Chapters 12003 (Fermilab Software Quality Assurance Program) [10] and 12090 (Software Quality Assurance Grading & Inventory Procedure) [11] of the *Fermilab QA Manual*
  - implements upgrades to the dosimetry database systems and applications as requested by the DPM

**Table 1: External Dosimetry Program Functional Responsibility Matrix**

*A=Approve; D=Develop; M=Maintain; P=Perform; R=Review*

*(Note that the Backup DPM is trained and authorized to perform all DPM tasks, but these are omitted for clarity.)*

Item	RPS Dept. Head	DPM	Backup DPM	Admin. Support Asst.	LBNF-FS Dosimetry Coord.	RSOs	SRSO	Core Computing Division	Dosimetry Vendor
Training of Backup DPM (FNAL-DP-01)		D, M, P	P						
Training of EDP Administrative Support Assistant (FNAL-DP-01)		D, M, P		P					
Training of LBNF-FS Dosimetry Coordinator (FNAL-DP-01)		D, M, P			P				
Shared EDP Calendar (FNAL-DP-01)		M	R	R	R				
Ensures EDP Staffing and Vendor Services (FNAL-DP-01)							P		
Oversight/Management of DPM (FNAL-DP-01)	P								
Vendor QA/QC Documentation (FNAL-DP-02)		P, R	P, R						D, M, R
Triennial Vendor Assessment (FNAL-DP-02)		P	P						
Annual Internal Assessments (FNAL-DP-02)	P, R	R	R						
Annual Management Review (FNAL-DP-02)	P	P	P				P		
Quality Program Manual & Supporting Documentation (FNAL-DP-02)	A	D, M	R						
External Dosimetry Procedures Manual & Supporting Documentation (FNAL-DP-02)	A	D, M	R						
Dosimeter Documentation (FNAL-DP-02)		R	R						D, M, R
Technical Basis Manual (FNAL-DP-02)	A	D, M	R						



Item	RPS Dept. Head	DPM	Backup DPM	Admin. Support Asst.	LBNF-FS Dosimetry Coord.	RSOs	SRSO	Core Computing Division	Dosimetry Vendor
DOELAP Assessments (FNAL-DP-03)		R	R						
Dosimetry Contract, Including Exhibit B (FNAL-DP-04)		D, M	R						R, A
Permanent Service Badge Requests (FNAL-DP-05)		P, R, A		P	P	P			
Fetal Monitoring Badges (FNAL-DP-05)		P, R, A			P	P			
Issuing Temporary Badges Training (FNAL-DP-06)		D, M, P	R, P		P	P			
Dosimeter Processing (FNAL-DP-05 & FNAL-DP-06)									P
Badge Rack Setup and Maintenance (FNAL-DP-07)		P		P	P				P
Updating Vendor Database (FNAL-DP-07)		P							
Updating EDP Listserv (FNAL-DP-07)		P		P					
Generating Absent Badge Lists (FNAL-DP-08)		P		P					
Exposure Investigations (FNAL-DP-09)		R, A			P	P	A		
Exposure History Requests (FNAL-DP-10)		R, P							
Blind Audit Program (FNAL-DP-11)		P, R							R
Dosimeter Results & Quarterly Report Generation (FNAL-DP-12)		R, A			R	R			P, R, A
Collective Total Effective Dose Plots (FNAL-DP-12)		P						M	
Annual Report Generation and Distribution (FNAL-DP-12)		P, R		P					

Item	RPS Dept. Head	DPM	Backup DPM	Admin. Support Asst.	LBNF-FS Dosimetry Coord.	RSOs	SRSO	Core Computing Division	Dosimetry Vendor
ALERT List (FNAL-DP-13)		P			R	R			
Medical Exposures (FNAL-DP-14)		R, A			P	P			
Review Terminations (FNAL-DP-15)		P		P					
Annual Badge Rack Audit (FNAL-DP-15)		P							
EDP Records Searches (FNAL-DP-16)		D, M, P		P					
Non-Destructive Testing (FNAL-DP-17)		P							
Rack Monitors (FNAL-DP-18)		P							
Fermilab's Online EDP Database System (FNAL-DP-19)		D, R, A						D, M	

### **Training and Staff Competency**

Persons responsible for carrying out the provisions of the EDP must be trained in the duties and tasks assigned by the DPM. In addition, once this initial training is completed, staff competency shall be assessed on an annual basis. This section describes how Fermilab's EDP accomplishes and documents both training and staff competency assessments.

#### Dosimetry Program Manager

Should the position of Dosimetry Program Manager need to be filled, the Backup DPM would ideally take over as DPM, and another Radiation Physicist would be assigned to the Backup DPM role; however, it is recognized that it is not always possible for the transition to occur in this fashion.

In any case, the oncoming DPM must be trained in all aspects of the EDP before taking on the role in an official capacity. Such training should be provided by the current DPM when possible, or by the Backup DPM in cases where the outgoing DPM is unavailable. RP Form 117, the Backup Dosimetry Program Manager Annual Assessment & Training Form, should be used to document the initial training of a new DPM, but its use for this purpose must be clearly stated in the Notes section of the form. Completed forms are retained in the Dosimetry Program Office.

	External Dosimetry Quality Program Manual	March 2022	Rev. 1
--	---	------------	--------

### Backup Dosimetry Program Manager

The Dosimetry Program Manager is responsible for training the Backup DPM in all aspects of the laboratory's EDP. As noted above, the Backup DPM must maintain readiness to step into the role of DPM at any time, and the training of the Backup DPM must ensure this capability.

Both the initial training of the Backup DPM as well as their annual competency assessments are documented using RP Form 117, the Backup Dosimetry Program Manager Annual Assessment & Training Form [12] (see Attachment B).

During the annual assessment, the Backup DPM must demonstrate familiarity to the DPM with each topic on RP Form 117. An observation of performance is required for each applicable signoff on the form.

The Backup DPM should have ESRP0002/OJ Annual Assessment for Backup Dosimetry Program Manager added to their Individual Training Needs Assessment (ITNA). This course is considered to be complete, and the training current, when the DPM has signed off on all of the topics on RP Form 117. This training remains valid for one year, after which another competency assessment must be performed. Completed forms are retained in the Dosimetry Program Office.

### External Dosimetry Program Administrative Support Assistant

The Dosimetry Program Manager is responsible for training the Administrative Support Assistant in all relevant aspects of the laboratory's EDP. The pertinent topics are listed on RP Form 118, the EDP Administrative Support Assistant Annual Assessment & Training Form [13], which is to be used to document both the initial training of an Administrative Support Assistant as well as their annual competency assessments (see Attachment C).

During the annual assessment, the Administrative Support Assistant must demonstrate to the DPM familiarity with each relevant procedure. An observation of performance is required for each applicable signoff on the form.

The Administrative Support Assistant should have ESRP0001/CR Annual Assessment for Administrative Support Assistant added to their Individual Training Needs Assessment (ITNA). This course is considered to be complete, and the training current, when the DPM has signed off on all of the topics on RP Form 118. This training remains valid for one year, after which another competency assessment must be performed. Completed forms are retained in the Dosimetry Program Office.

### LBNF Far Site Dosimetry Coordinator

The Dosimetry Program Manager is also responsible for training the LBNF Far Site Dosimetry Coordinator in all relevant aspects of the laboratory's EDP. The pertinent topics are listed on RP Form 129, the LBNF-FS Dosimetry Coordinator Annual Assessment & Training Form [14], which is to be used to document both the initial training of the LBNF-FS Dosimetry Coordinator as well as their annual competency assessments (see Attachment D).

During the annual assessment, the LBNF-FS Dosimetry Coordinator must demonstrate to the DPM familiarity with each relevant procedure. An observation of performance via video teleconference is



required for each applicable signoff on the form, and the Backup DPM is encouraged to also attend these teleconferences whenever possible.

The LBNF-FS Dosimetry Coordinator should have ESRP0003/CR Annual Assessment for LBNF-FS Dosimetry Coordinator added to their Individual Training Needs Assessment (ITNA). This course is considered to be complete, and the training current, when the DPM has signed off on all of the topics on RP Form 129. This training remains valid for one year, after which another competency assessment must be performed. Completed forms are retained in the Dosimetry Program Office.

### **Continuity of Operations**

The main ways in which Fermilab ensures continuity of operations within the External Dosimetry Program are as follows:

- designating a Backup Dosimetry Program Manager who receives periodic, documented on-the-job training from the Dosimetry Program Manager, and who is thus prepared to step into the role of DPM at any time if necessary
- having a robustly documented set of procedures and practices for the EDP, of which this manual is an integral part, and which are periodically reviewed by the Backup DPM
- in addition to receiving training and undergoing annual competency reviews, the EDP Administrative Support Assistant is involved in many day-to-day dosimetry program tasks, ensuring that institutional knowledge is retained upon the departure of a DPM
- continually striving to make Fermilab's online dosimetry database applications more functional, intuitive, and user-friendly, thus reducing the chance of error in its use
- having an electronic calendar in Outlook or an equivalent tool to set reminders and communicate significant dosimetry program events to the DPM, Backup DPM, EDP Administrative Support Assistant, and LBNF-FS Dosimetry Coordinator; this calendar is maintained by the DPM

### **QA Overview [FNAL-DP-02]**

This section summarizes the planned and systematic quality assurance aspects associated with dosimeter handling and processing, all of which have been incorporated procedurally into the EDP. Quality assurance criteria are addressed in all pertinent operating procedures to ensure that activities are well-organized, controlled, and consistent with the Fermilab Quality Policy; these procedures are located in the *External Dosimetry Procedures Manual*. The completion of the quality assurance requirements provides documented verifiable evidence to support the reliability and effectiveness of the External Dosimetry Program and ensures compliance with 10 CFR 835.



**Badge Racks**

The setup and maintenance of the dosimetry badge racks is a key aspect of the EDP's quality assurance processes, as it serves to ensure that all permanent-service dosimeters are accounted for. Dosimetry Program Procedure FNAL-DP-07 in the EDPM outlines various processes related to the badge racks and their shipping trunks, including physical maintenance, adding and removing racks from service, making quarterly changes, shipment to and from the vendor, and distribution in the field.

**Blind Audit Program**

Fermilab has implemented a blind audit program to provide additional information regarding the accuracy of the reported results of the field dosimeters. These "blind spike" dosimeters are irradiated to known doses of gamma, beta, and neutron radiation (an Americium-241 x-ray source is also available for use) and processed with the field dosimeters each quarter. The results are evaluated using DOELAP performance testing criteria and are located in the ES&H Section Document Database (DocDB) [15]. The procedure for conducting the blind audit program is covered in Dosimetry Program Procedure FNAL-DP-11 in the EDPM.

**Report Review, Approval, and Retention**

The DPM is responsible for reviewing and approving the radiation exposure reports generated by the vendor and indicating that the data has been reviewed. This may be done by initials and date or another suitable method. After the reported data has been approved, Fermilab retains copies of all approved dose reports in the Dosimetry Program Office. Copies of the data may be sent to the RSOs or RCTs for additional review.

Electronic copies of all reported results may be obtained from the vendor's online database. Fermilab will continue to require the vendor to maintain permanent dose records, and all parameters associated with the equivalent dose calculation, for all individuals monitored for radiation exposure.

Dosimetry Program Procedure FNAL-DP-12 in the EDPM covers this topic in further detail.

**Non-Destructive Testing**

To test whether the dosimeters in each quarterly shipment have been constructed properly, five randomly chosen dosimeters not assigned to personnel are inspected and disassembled by the Dosimetry Program Manager to verify the presence of the OSL material and the CR-39 element, and that all filters are present and in the correct position. This process is also known as "component verification." Although this is a non-destructive test, these dosimeters are separated from the rest of the inventory and are sent back to Landauer as unused. An ongoing record of each quarter's results are recorded in the ES&H Section Document Database [16]. This procedure is described in FNAL-DP-17 in the EDPM.

**Other Procedural QA Checks**

The procedures in the EDPM contain numerous other additional QA checks, including:

- performing "rack checks" both prior to the badge racks being sent to the vendor (ensuring that the vendor will not have any problems loading the badges on the racks) as well as after they are

	External Dosimetry Quality Program Manual	March 2022	Rev. 1
---	---	------------	--------

sent back to Fermilab (verifying all of the badges are present and in their proper places on the racks)

- having all badges destined for the LBNF Far Site first delivered to the Dosimetry Program Office at Fermilab for verification before they are sent on to the LBNF-FS Dosimetry Coordinator for distribution
- using the vendor's unreturned dosimeters listing as a cross-check against the list generated by Fermilab's in-house Dosimetry Badge Database system
- auditing the badge racks on an annual basis in order to discover and remove from permanent service any overlooked badge holders who are no longer at the laboratory

### **Internal Audits**

The FRCM requires that internal audits of all functional elements of the radiation protection program shall be conducted no less frequently than every three years and shall include program content and implementation. In accordance with this requirement and with DOE-STD-1095-2018, the External Dosimetry Program shall undergo annual internal assessments that review at least one-third of the items on the current DOELAP onsite assessment checklist; a copy of this checklist may be found on the DOELAP website at <https://www.id.energy.gov/resl/doelap/doelap.html>.

These internal assessments of the EDP are to be performed by a qualified team of individuals, including at least one member of Fermilab's Radiological Control Organization. The RPS Department Head is tasked with assembling the assessor team. All findings are to be resolved and tracked in iTrack, the ES&H Section's assessment tracking database, which retains data for all assessments tracked. Copies of prior assessments not in iTrack, including their findings and subsequent resolutions, can be found in the *External Dosimetry Technical Basis Manual*.


### **Management Review**

Each year, once the Internal Audit is completed and its findings are adequately addressed, the DPM will schedule a Management Review session with, at minimum, the RPS Department Head, one member of the Quality Section, the Backup DPM, and either the Senior Radiation Safety Officer or the Chief Safety Officer. It is strongly encouraged to include the RPO Department Head as well.

This Management Review is to serve as a formal review of the EDP QA program, including a review of EDP performance from a quality perspective, the determination of any needs for improvement, and the evaluation of the suitability of EDP policies and objectives. A sample Management Review agenda template may be found on the DOELAP website at <https://www.id.energy.gov/resl/doelap/doelap.html>.

### **Document Review**

The Dosimetry Program Manager is responsible for reviewing the *Technical Basis Manual*, *Quality Program Manual*, and *External Dosimetry Procedures Manual*, along with all procedures and forms, every three

	External Dosimetry Quality Program Manual	March 2022	Rev. 1
---	---	------------	--------

years. These documents must be updated when changes are required, or whenever new procedures are put into effect.

**Vendor Oversight**

Fermilab contractually requires its dosimetry vendor to conduct all activities regarding dosimeter handling, storage, processing, and reporting to be done in accordance with their Quality Management System, ANSI/HPS N13.11-2009, and ANSI/HPS N13.32-2008. The vendor is also required to notify the DPM of any deviations from standard protocol for processing that might potentially affect Fermilab's reported dose results. This is verified through meetings or discussions with representatives from the vendor as necessary. A copy of the vendor's quality assurance manual [17] can be found in the Dosimetry Program Office. The vendor also documents on all dose reports all of the algorithms that were used to arrive at the reported dose, in addition to other information required by 10 CFR 835 and DOELAP.

In addition to the EDP documentation, the vendor's documentation is reviewed at least every three years to be sure that Fermilab has the most current versions on file. Other documents that are reviewed periodically are the vendor's quality assurance manual, blind audit data, and QC charts.

At least once every three years, the DPM and Backup DPM shall perform an onsite or remote assessment of the vendor. At minimum, the topics covered at this assessment will include all items on the DOELAP onsite assessment checklist relevant to the vendor.

**DOELAP Accreditation [FNAL-DP-03]**

Fermilab's External Dosimetry Program is mandated by 10 CFR 835 to be DOELAP accredited. This accreditation is valid for three years. Satisfactory performance testing of the dosimeters to be used in each field is required; copies of the vendor's performance testing results may be found in the ES&H DocDB [18]. In addition, site inspections by DOELAP-assigned assessors provide assurance that the administration of the EDP is in conformance with DOELAP requirements. Fermilab's dosimetry vendor is also required to have an onsite DOELAP assessment and is to assist Fermilab in maintaining DOELAP accreditation.

As part of the DOELAP accreditation process, Fermilab must address all findings resulting from the triennial DOELAP assessments. All deficiencies and concerns must be corrected, and observations will be addressed as time and resources permit. A formal response addressing all deficiencies and concerns will be sent to the DOELAP Senior Technical Manager (STM) within 45 days after the assessment. All findings from these assessments are documented and tracked in the ES&H Section's assessment tracking database, iTrack. The previous DOELAP assessment, the responses to any findings that were identified, and the status of the corrective actions can also be found in the *External Dosimetry Technical Basis Manual* binder in the Dosimetry Program Office.

Fermilab will be notified by the DOELAP STM when it is time to reapply for accreditation and subsequently participate in the next DOELAP testing session and onsite assessment. Each time Fermilab reapplies for accreditation, an official application for the whole-body dosimeter and the extremity



dosimeter must be filled out and submitted to the DOELAP STM. Concurrence from the DOE Fermilab Site Office (FSO) is required, which may be done electronically. The application indicates the dosimeters that Fermilab intends to use, along with the technical specifications and the fields for which they will be accredited. These dosimeters must be identical to those that will be used at the laboratory as the dosimeters of record once accreditation is granted.

The laboratory's dosimetry vendor must also be notified that Fermilab will be participating in the next DOELAP testing session and must confirm that they will coordinate the testing of the specific dosimeters with DOELAP to meet the performance testing schedule deadlines.

Provided that the specified dosimeters have passed all of the required DOELAP performance testing categories, the next step is the onsite assessment, which generally takes two days. Prior to the onsite assessment, the DOELAP STM will send the assessors a copy of the application, the previous DOELAP assessment and the relevant dosimeters' performance test results. The assessors will then request additional information from Fermilab, such as the *Technical Basis Manual*, *External Dosimetry Procedures Manual*, and *Quality Program Manual*.

During the assessment, the assessors will evaluate the actual implementation of the External Dosimetry Program against the DOELAP checklist and review any other relevant supporting documentation.

After the assessment, as noted above, if any deficiencies or concerns were identified, a written response to the DOELAP STM is required within 45 days outlining how these findings will be corrected. Concurrence from the Fermi Site Office is required. Deficiencies must be corrected immediately, with documented evidence sent to the DOELAP STM. Concerns must be corrected before the next DOELAP onsite assessment but should be adequately addressed within one year. Follow-up assessments to verify any corrective action plans is at the discretion of the STM.

Copies of all DOELAP accreditation documents can be found in the *External Dosimetry Technical Basis Manual* binder in the Dosimetry Program Office.

### **Fermilab's Dosimeter of Record**

Currently, the Fermilab dosimeter of record is Landauer's InLight Model 2T, referred to at Fermilab as the "dosimetry badge." Note that despite routine training, obsolete names such as "TLD" and "film badge" continue to be used by Fermilab personnel.

This dosimeter utilizes Optically Stimulated Luminescence (OSL) technology, and onsite studies have shown that this dosimeter is well suited for use at Fermilab. All InLight Model 2T badge documentation can be found in the Landauer documentation binder in the Dosimetry Program Office.

The InLight Model 2T dosimeter is designed for personnel monitoring of the whole body. It measures exposure to beta/gamma radiation. The placement of CR-39 within the holder, with boron-loaded Teflon over one half, allows for the additional measurement of thermal, intermediate, and fast neutron exposure. The InLight Model 2T has detection capabilities of 5 mrem to 1000 rem for photons (x-ray and gamma)



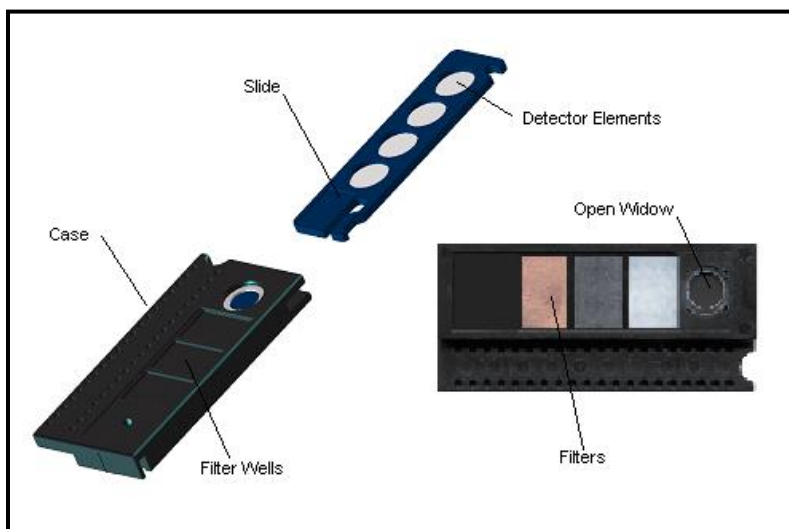
with energies between 5 keV and 20 MeV, and 5 mrem to 1000 rem for beta particles. The CR-39 element can measure neutrons with energies of 0.25 eV to 40 MeV, with a dose range of 10 mrem to 25 rem.

The InLight Model 2T consists of a plastic holder (cover and subcarrier), which snaps shut and contains the dosimeter (case and slide); see Figure 1. The dosimeter consists of a case that contains metal and plastic filters and a plastic slide holding the detector elements; see Figure 2. The detector element is a layer of  $Al_2O_3$  sandwiched between two layers of polyester for a total thickness of 0.3 mm. Optically Stimulated Luminescence (OSL) is the method used to obtain data from the detector.

Technical specifications for the InLight Model 2T detector elements are shown in 2.



*Figure 1: Components of the Landauer InLight Model 2T Dosimeter*



*Figure 2: Detector elements of the Landauer InLight Model 2T Dosimeter*



*Table 2: Technical Specifications for the Detector Elements of the Landauer InLight Model 2T Dosimeter*

<b>FRONT</b>							
Dosimeter Element	Density (g/cm <sup>3</sup> )	Thickness (mm)	Thickness (10 <sup>-3</sup> in)	Thickness (mg/cm <sup>2</sup> )			
				OW	PL	Al	Cu
Polycarbonate Cover	1.21	0.76	30.00		92	92	92
Label							
Polyester Film*	1.33	0.05	1.97	7	7	7	7
Acrylic Adhesive*	1.20	0.02	0.79	2	2	2	2
Laminate for Label							
Polyester Base*	1.26	0.03	1.00	3	3	3	3
Acrylic Adhesive*	1.20	0.02	0.79	2	2	2	2
Case Serial Number Label	1.20	0.02	0.79		2	2	2
Case Window	2.70	0.01	0.44	3			
Plastic Filter ABS	1.26	0.70	27.56		88		
Cu	8.96	0.40	15.75				358
Al	2.69	0.70	27.56			188	
Case Plastic ABS	1.26	0.70	27.56		88	88	88
Polyester Substrate	1.26	0.10	3.94	13	13	13	13
			<b>Total</b>	<b>30</b>	<b>298</b>	<b>398</b>	<b>568</b>
<b>BACK</b>							
Dosimeter Element	Density (g/cm <sup>3</sup> )	Thickness (mm)	Thickness (10 <sup>-3</sup> in)	Thickness (mg/cm <sup>2</sup> )			
				OW	Plastic	Cu	Al
Polycarbonate Cover	1.21	0.76	30.00		92	92	92
Case Serial Number Label	1.20	0.02	0.79		2	2	2
Case Window	2.70	0.01	0.44	3			
Plastic Filter ABS	1.260	0.70	28		88.20		
Cu	8.960	0.40	16			358.40	
Al	2.690	0.70	28				188.30
Case Plastic ABS	1.260	0.70	28		88.20	88.20	88.20
Polyester Substrate	1.260	0.10	4	12.60	12.60	12.60	12.60
			<b>Total</b>	<b>15.60</b>	<b>283.60</b>	<b>553.80</b>	<b>383.70</b>



### Fermilab's Extremity Dosimeter

Currently, Fermilab uses Landauer's Saturn Ring TLD as its extremity dosimeter; see Figure 3. This dosimeter consists of one Li-7 TLD-100 chip, which is processed using Landauer's laser-heated TLD reader. All Saturn Ring badge documentation can be found in the Landauer documentation binder in the Dosimetry Program Office.

The Saturn Ring dosimeter consists of an LiF chip (TLD-100 or MTS-N), a ring label cap, and a ring base. The LiF chip (TLD-100) is encapsulated in a laser-etched identification ring label cap, which is ultrasonically welded over it. The TLD-100/MTS-N detector is composed of Li:Mg, Ti (TLD Poland Model Number MTS-N or TLD-100), and it is nearly tissue-equivalent, having an atomic number of 8.2 (the atomic number for tissue is 7.42).

This dosimeter configuration allows for detection of beta and photon radiation. The Hp(0.07) skin dose range is 10 mrem to greater than 1000 rem for photons, and 10 mrem to 1000 rem for energetic beta particles.

The Saturn Ring dosimeter can be analyzed on Landauer-designed laser-heated TLD readers. These readers use a CO<sub>2</sub> laser to heat the TLD chip and a photon counting system to measure the resultant luminescence from the TLD chip.

Technical specifications for the Saturn Ring TLD dosimeter detector elements are shown in Table 3.



*Figure 3: Landauer Saturn Ring TLD Dosimeter*

*Table 3: Landauer Saturn Ring TLD Specifications*

Material		Dimensions (LxW) (mm)	Weight (g)
LiF chip (TLD 100) + ring cap + ring base		22 X 19	1.07
Material	Density (g/cm <sup>3</sup> )	Thickness (mm)	Density Thickness (mg/cm <sup>2</sup> ) (E1)
Polyethylene	0.93	0.345	27.9
<b>Total</b>			27.9

### Control of Document

The most current version of this document shall be stored in the ES&H Section DocDB as ESH-doc-6164.

### References

1. 10 C.F.R. § 835
2. Department of Energy Laboratory Accreditation Program for Personnel Dosimetry DOE-STD-1095-2018, U.S. Department of Energy, October 2018
3. Fermilab Radiological Control Manual, <https://eshq.fnal.gov/manuals/frcm/>
4. External Dosimetry Procedures Manual, M. Vincent, ESH-doc-6167, March 2022
5. Technical Basis for External Dosimetry at Fermilab, M. Vincent, Fermilab RP Note 124, ESH-doc 2204, March 2022
6. ES&H Section Org Chart, A. Kenney, ESH-doc-1543, 07 February 2022
7. Fermilab Quality Policy, DIRECTORATE-doc-63, April 2020
8. Fermilab Quality Assurance Manual, <https://eshq.fnal.gov/manuals/qam/>
9. Development, Maintenance, Procurement, and Usage of Software Products Related to Environment, Safety, and Health, Fermilab ES&H Manual Chapter 2090, ESH-doc-394, November 2016



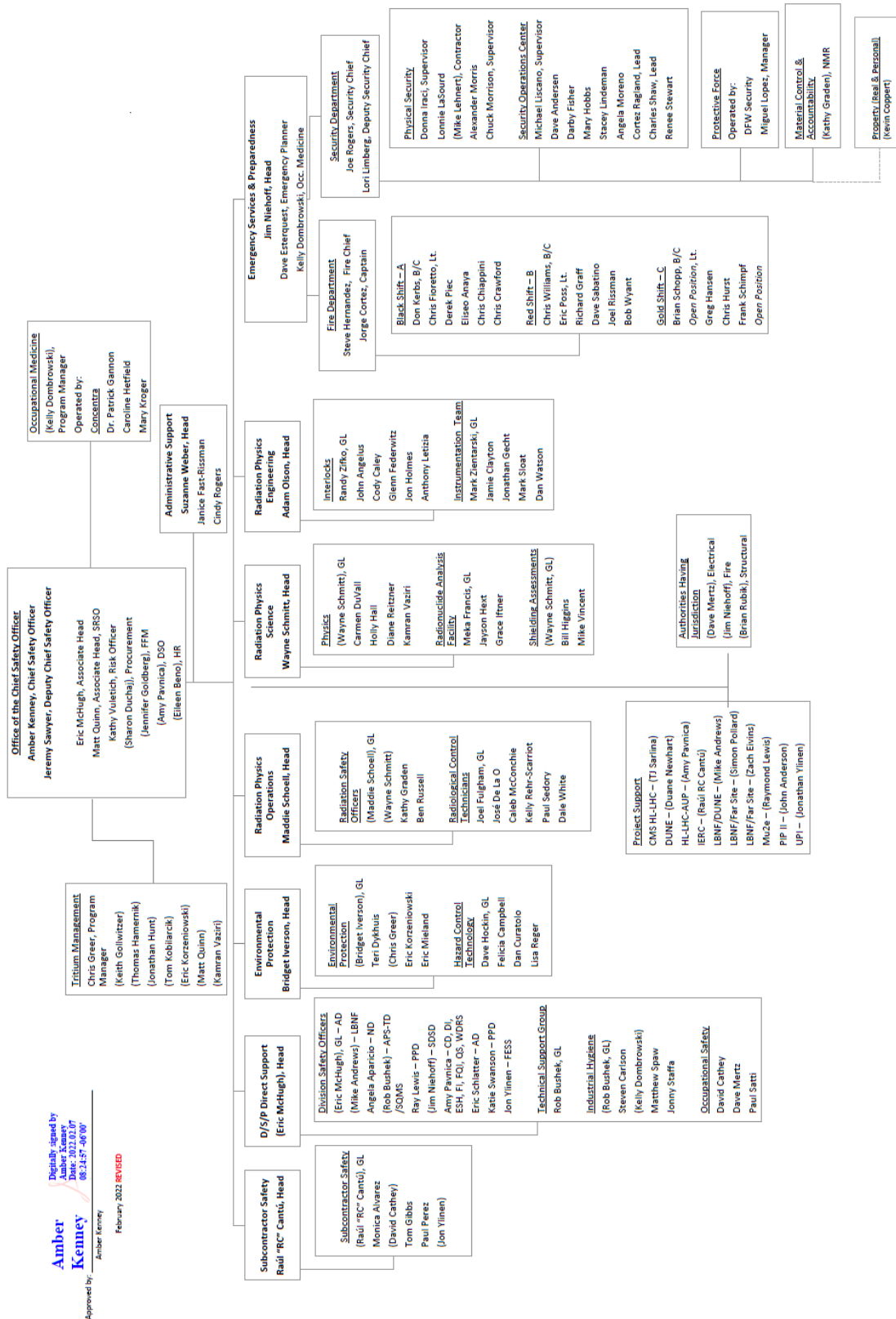


10. Fermilab Software Quality Assurance Program, Fermilab Quality Assurance Manual Chapter 12003, ESH-doc-3193, February 2021
11. Software Quality Assurance Grading & Inventory Procedure, Fermilab Quality Assurance Manual Chapter 12090, ESH-doc-3194, February 2021
12. FRCM: RP Form #117 - Backup Dosimetry Program Manager Annual Assessment Training Form, ESH-doc-6174, November 2020
13. FRCM: RP Form #118 - EDP Admin Support Assistant Annual Assessment Training Form, ESH-doc-6177, November 2020
14. FRCM: RP Form #129 - EDP LBNF-FS Dosimetry Coordinator Annual Assessment Training Form, ESH-doc-6843, February 2022
15. External Dosimetry Program Blind Audit Results, M. Vincent, ESH-doc-6882
16. External Dosimetry Non-Destructive Testing Records, M. Vincent, ESH-doc-6171
17. Quality Assurance Manual M001, Revision 12, Landauer, 2020
18. DOELAP Performance Test Results for Landauer Dosimeters, R.S. Landauer, Inc., ESH-doc-6714



Attachments

A. Fermilab ES&H Section organizational chart



**B. RP Form 117 Backup Dosimetry Program Manager Annual Assessment & Training Form**  
ESRP0002/OJ Annual Assessment for Backup Dosimetry Program Manager

**Backup Dosimetry Program Manager  
 Annual Assessment & Training Form**

**New Training**       **Annual Assessment**

**DPM Name:** \_\_\_\_\_      **Backup DPM Name:** \_\_\_\_\_

**DPM ID Number:** \_\_\_\_\_      **Backup DPM ID Number:** \_\_\_\_\_

**Notes:** \_\_\_\_\_

<b>DPM Signature</b>	<b>Date</b>	<b>Subject</b>
		<b>Technical Basis Manual</b>
		<b>Vendor Documentation</b>
		<b>Personnel [FNAL-DP-01]</b>
		<b>QA Overview [FNAL-DP-02]</b>
		<b>DOELAP Accreditation [FNAL-DP-03]</b>
		<b>Vendor Contract [FNAL-DP-04]</b>
		<b>Permanent-Service Dosimetry Badges [FNAL-DP-05]</b>
		<b>Temporary Dosimetry Badges [FNAL-DP-06]</b>
		<b>Badge Rack Shipping, Receiving, Distribution, and Packing List Data [FNAL-DP-07]</b>



## ESRP0002/OJ Annual Assessment for Backup Dosimetry Program Manager

<b>DPM Signature</b>	<b>Date</b>	<b>Subject</b>
		<b>Absent/Lost Dosimetry Badges</b> [FNAL-DP-08]
		<b>Exposure Investigations</b> [FNAL-DP-09]
		<b>Exposure Histories</b> [FNAL-DP-10]
		<b>Blind Audit Program</b> [FNAL-DP-11]
		<b>Radiation Dose Reporting and Report Distribution</b> [FNAL-DP-12]
		<b>ALERT List</b> [FNAL-DP-13]
		<b>Medical Exposures</b> [FNAL-DP-14]
		<b>Employee Terminations</b> [FNAL-DP-15]
		<b>Dosimetry Records Searches</b> [FNAL-DP-16]
		<b>Non-Destructive Testing</b> [FNAL-DP-17]
		<b>Rack Monitors</b> [FNAL-DP-18]
		<b>Dosimetry Badge Database, Applications, and Inventory System</b> [FNAL-DP-19]

**C. RP Form 118 EDP Administrative Support Assistant Annual Assessment & Training Form**

ESRP0001/CR Annual Assessment for Administrative Support Assistant

**EDP Administrative Support Assistant  
Annual Assessment & Training Form**

\_\_\_ **New Training**     \_\_\_ **Annual Assessment**

**DPM Name:** \_\_\_\_\_ **Administrative Support Assistant Name:** \_\_\_\_\_

**DPM ID Number:** \_\_\_\_\_ **Administrative Support Assistant ID Number:** \_\_\_\_\_

DPM Signature	Date	Subject
		<b>Personnel</b> [FNAL-DP-01]
		<b>DOELAP Accreditation</b> [FNAL-DP-03]
		<b>Permanent-Service Dosimetry Badges</b> [FNAL-DP-05]
		<b>Temporary Dosimetry Badges</b> [FNAL-DP-06]
		<b>Badge Rack Shipping, Receiving, Distribution, and Packing List Data</b> [FNAL-DP-07]
		<b>Absent/Lost Dosimetry Badges</b> [FNAL-DP-08]
		<b>Exposure Histories</b> [FNAL-DP-10]
		<b>Radiation Dose Reporting and Report Distribution</b> [FNAL-DP-12]
		<b>Employee Terminations</b> [FNAL-DP-15]



ESRP0001/CR Annual Assessment for Administrative Support Assistant

<b>DPM Signature</b>	<b>Date</b>	<b>Subject</b>
		<b>Dosimetry Records Searches</b> [FNAL-DP-16]
		<b>Rack Monitors</b> [FNAL-DP-18]
		<b>Dosimetry Badge Database, Applications, and Inventory System</b> [FNAL-DP-19]

**Notes:** \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**D. RP Form 129 EDP LBNF-FS Dosimetry Coordinator Annual Assessment & Training Form**

ESRP0003/CR Annual Assessment for LBNF-FS Dosimetry Coordinator

**EDP LBNF-FS Dosimetry Coordinator  
Annual Assessment & Training Form**

New Training       Annual Assessment

DPM Name: \_\_\_\_\_ LBNF-FS Dosimetry Coordinator Name: \_\_\_\_\_

DPM ID Number: \_\_\_\_\_ LBNF-FS Dosimetry Coordinator ID Number: \_\_\_\_\_

DPM Signature	Date	Subject
		<b>Personnel</b> <b>[FNAL-DP-01]</b>
		<b>DOELAP Accreditation</b> <b>[FNAL-DP-03]</b>
		<b>Permanent-Service Dosimetry Badges</b> <b>[FNAL-DP-05]</b>
		<b>Temporary Dosimetry Badges</b> <b>[FNAL-DP-06]</b>
		<b>Badge Rack Shipping, Receiving, Distribution, and Packing List Data</b> <b>[FNAL-DP-07]</b>
		<b>Absent/Lost Dosimetry Badges</b> <b>[FNAL-DP-08]</b>
		<b>Exposure Investigations</b> <b>[FNAL-DP-09]</b>
		<b>Radiation Dose Reporting and Report Distribution</b> <b>[FNAL-DP-12]</b>
		<b>Rack Monitors</b> <b>[FNAL-DP-18]</b>



ESRP0003/CR Annual Assessment for LBNF-FS Dosimetry Coordinator

<b>DPM Signature</b>	<b>Date</b>	<b>Subject</b>
		<b>Dosimetry Badge Database, Applications, and Inventory System [FNAL-DP-19]</b>

**Notes:** \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_