FRCM CHAPTER 8
ALARA MANAGEMENT OF ACCELERATOR RADIATION SHIELDING

Revision History

Author	***Description of Change***	***Revision Date***
W. Schmitt and J. D. Cossairt	• Editorial changes to Article 813.7 clarifying existing practices pertaining to configuration control of radiation shielding.	October 2018
J. D. Cossairt	• Add Appendix 2 ESHQ-RPS-SA-0001 – Shielding Assessment Outline.	January 2018
J. D. Cossairt	1. Editorial changes to reflect labwide ESH&Q consolidation. 2. Removed provisions in Article 811 to document the need to use RP Form 105 in instances where active devices must be used in addition to passive shielding. These instances are already addressed in shielding assessment covered in Article 814.	February 2017
J. D. Cossairt	1. Changes to reflect the transformation of the FESHCom Shielding Assessment Review Subcommittee to the Shielding Assessment Review Panel reporting to the Radiation Safety Subcommittee. 2. Clarifications of details for the shielding assessment review process. 3. Remove references to obsolete organizational designation of centers. 4. Minor changes in technical details.	January 2016
J. D. Cossairt	• Editorial changes to reflect evolution of the ESH&Q organization.	July 2015
J. D. Cossairt	• Revise Article 811 to incorporate reference to new RP Form 105.	January 2013
J. D. Cossairt	1. Revised to incorporate establishment of the FESHCom Shielding Assessment Review Subcommittee (FSARS). 2. Improve consistency with FESHM Chapter 2010. 3. Set forth a procedure for obtaining approval for selecting active in lieu of passive shielding cross-referenced to the Director's Exceptions specified in FESHM Chapter 1010. 4. Improve statement of current practices. 5. Rename chapter to better reflect importance of ALARA program.	August 2011

CHAPTER 8 ALARA MANAGEMENT OF ACCELERATOR RADIATION SHIELDING

TABLE OF CONTENTS

Radiological control performance is affected by human performance and engineered design features. This Chapter sets forth the policies for the design of new facilities and major modifications to existing facilities.

For purposes of this chapter, "dose" means effective dose as defined by International Commission on Radiation Protection (ICRP) Publications 60, 61, 74, and 103. Likewise, the terms "quality factor", Q, and "effective quality factor", Q_{eff}, are considered to be equivalent to "radiation weighting factor", w_R, addressed in ICRP Publications 60, 61, 74, and 103 when comparing older shielding calculations and assessments to newer ones.

POLICIES AND PROCEDURES CONCERNING SHIELDING OF ACCELERATORS/BEAMLINES

811 Fermilab Policy on Accelerator Shielding Design

1. Shielding designs shall be well-engineered to maintain occupational and environmental radiation exposures as low as reasonably achievable (ALARA) and compliant with applicable Regulations and U. S. Department of Energy (DOE) Orders.

2. The first choice for initial designs of new facilities or significant modifications of accelerator shielding of existing facilities shall be passive shielding elements designed to achieve areas external to shielding to be classified as minimal occupancy or better in accordance with provisions of Article 236. Reliance on active systems such as radiation safety interlocks and/or beamline instrumentation to achieve radiation safety goals should be chosen only if passive elements cannot, in view of planned accelerator operations, reasonably achieve the level of protection required by the provisions of this Manual.

3. The design goal for dose rates in areas of continuous occupancy shall be less than an average of 0.05 mrem/hr and as far below this and as low as is reasonably achievable (ALARA). See Articles 234 and 236 and the Tables associated with those Articles. Dose rates for potential exposure to radiological workers in areas without continuous occupancy shall be ALARA and such that individuals do not receive more than 20% of the applicable limits as stated in Table 2-1.

4. Discharges of radioactive liquid to the environment are covered by provisions of DOE Order 458.1 as implemented under the DOE-Fermi Research Alliance contract. Further discussion is provided in FRCM Chapter 11. The concentrations should be kept ALARA and in conformance with other chapters of this Manual.

5. Materials and components should be selected to minimize the radiological concerns, both occupational and environmental and specified in facility design documents.

6. Where removable contamination might be associated with accelerator operations, provisions should be made in facility designs for the containment of such material.

7. Internal exposure shall be minimized in accordance with ALARA principles by the inclusion of engineered controls such as ventilation, containment, filtration systems, where practicable and with appropriate administrative procedures (see Article 316) in the facility designs.

8. Efficiency of maintenance, decontamination, operations, and decommissioning should be maximized to the extent practicable in facility designs.

9. Criteria for the conduct and review of shielding assessments are set forth in other articles of this chapter.

10. The requirements of this chapter apply to accelerators covered by FESHM Chapter 2010 that are included within the scope of coverage of DOE Order 420.2c, "Safety of Accelerator Facilities".

11. The Radiological Control Organization will determine on a case-by-case basis the applicability of the requirements of this chapter to equipment that accelerates charged particles that qualify for the exemptions or equivalencies of DOE Order 420.2c and those that are considered to be Radiation Generating Devices as specified by FRCM Article 362.

812 Special Technical Considerations Pertaining to Accelerator Radiation Shielding Design

It is imperative to continue to design accelerator facilities at Fermilab in a way that provides adequate shielding against prompt radiation fields and, to the extent practicable, minimizes the production of residual radioactivity. Adequate protection of the environment as discussed in other FRCM and FESHM chapters is also required before a given facility is constructed or modified both to assure safe operation and fiscal economy. There are certain technical considerations that apply to accelerator radiation shielding design among which are the following:

1. Radiation weighting factors for various particles that should be used in shielding designs are specified in Table 8-1 unless more detailed energy spectrum information is available. The MARS code system includes the proper weighting factors and dose coefficients.

2. The design of facilities where neutron radiation is anticipated should use a radiation weighting factor of 20 unless measurements or calculations demonstrate that a specific value of radiation weighting factor is appropriate for a particular radiation

field as determined by the Radiological Control Organization. The radiation weighting factors for neutrons to be used are those given in ICRP Publication 103 and given in Table 8-2 and Fig. 8-1. The results of Ref. 2 listed in Appendix 1 of this chapter provide examples of typical neutron energy spectra generated by the accelerators at Fermilab. While shielding calculations pertinent to actual conditions are preferred, such examples may be used to quantify radiation weighting factors used to support shielding assessments.

3. Temporary conditions involving facilities under construction including associated parking lots should be evaluated and criteria of this Manual applied where practicable. Deviations from these criteria for such transient conditions shall be approved by the SRSO.

4. Locating parking lots, eating areas, office space, rest rooms, drinking fountains, showers and similar facilities and devices within radiological areas as defined by this Manual and 10 CFR Part 835 is strongly discouraged. Unless office space is essential to support radiological work, steps should be taken to preclude unnecessary occupancy in such areas.

5. As is reasonably possible, shielding assessment calculations and shielding integrity should be verified by comprehensive measurements of the radiation fields as soon as practicable after commencement of operations. Such verifications shall be documented and retained, preferably in ESH&Q DocDB or an equivalent electronic document retrieval system, along with the shielding assessment documentation.

6. Appendix 1 of this chapter gives a summary and short bibliography on the design of accelerator radiation shielding.

Table 8-1 Radiation Weighting Factors for Various Particles

Radiation Type	Radiation Weighting
Photons	1
Electrons and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy, see See Table 8-2 and Figure 8-1.

Table 8-2 Neutron Radiation Weighting or Quality Factors According to ICRP Publication 103

E_n (MeV)	w_R	E_n (MeV)	w_R	E_n (MeV)	w_R
1.0×10^{-9}	2.50	0.20	14.3	30	6.04
1.0×10^{-8}	2.50	0.30	16.8	40	5.69
2.5×10^{-8}	2.50	0.50	19.3	50	5.50
1.0×10^{-7}	2.50	0.70	20.3	60	5.36
2.0×10^{-7}	2.50	0.90	20.7	75	5.16
5.0×10^{-7}	2.50	1.0	20.7	100	4.86
1.0×10^{-6}	2.50	1.2	20.0	130	4.57
2.0×10^{-6}	2.50	1.5	18.9	150	4.40
5.0×10^{-6}	2.50	2.0	17.3	180	4.20
1.0×10^{-5}	2.50	2.5	16.0	200	4.08
2.0×10^{-5}	2.50	3.0	15.0	300	3.66
5.0×10^{-5}	2.50	4.0	13.3	400	3.40
1.0×10^{-4}	2.50	5.0	12.0	500	3.23
2.0×10^{-4}	2.50	6.0	11.1	700	3.01
5.0×10^{-4}	2.50	7.0	10.3	1.0×10^{3}	2.84
1.0×10^{-3}	2.51	8.0	9.72	1.5×10^{3}	2.70
2.0×10^{-3}	2.53	9.0	9.22	2.0×10^{3}	2.63
5.0×10^{-3}	2.67	10	8.81	3.0×10^{3}	2.57
1.0×10^{-2}	3.03	12	8.16	5.0×10^{3}	2.53
2.0×10^{-2}	3.92	14	7.67	1.0×10^{4}	2.51
3.0×10^{-2}	4.84	15	7.47	2.0×10^{4}	2.50
5.0×10^{-2}	6.58	16	7.30	5.0×10^{4}	2.50
7.0×10^{-2}	8.10	17	7.14	1.0×10^{5}	2.50
0.10	10.0	18	7.00	1.0×10^{6}	2.50
0.15	12.5	20	6.76	1.0×10^{7}	2.50

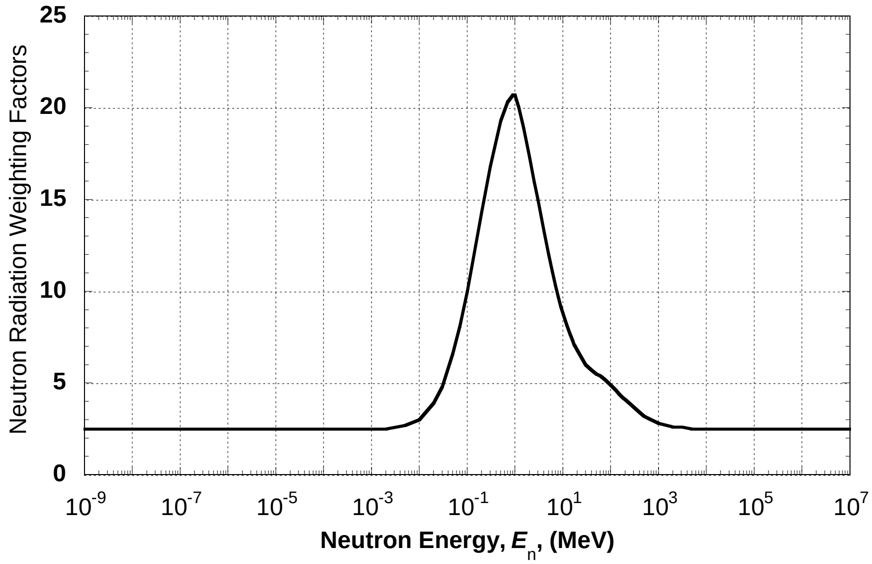

Figure 8-1 Neutron Radiation Weighting (Quality) Factors as a function of neutron energy. (Based on ICRP Publication 103.)

813 Responsibilities for Configuration Control of Radiation Shielding

Division/Section Heads, with the support of the assigned RSO(s), are responsible for management of radiation shielding pertaining to the accelerators, beamlines and associated experiments, or other radiological areas designed, constructed, and operated by them as assigned by the Fermilab Director. Coordination between different organizations is common, required, and naturally expected. The Head of the Facilities Engineering Services Section (FESS) has special responsibilities pertaining to accelerator/beamline/experiment radiation shielding specifically attributed to that organization in the list below that require coordination with the responsible Division/Section(s). The Fermilab Shielding Assessment Review Panel (SARP), the Chair of which is a member of the Radiation Safety Subcommittee of FESHCom, has a key role in the reviews of shielding assessments as specified elsewhere in this Chapter.

In partnership with the ESH&Q Section the responsibilities of the Division/Section(s), and where necessary coordinated with FESS, include these program elements:

1. Develop and maintain a comprehensive inventory of accelerator/beamline/experiment shielding against ionizing radiation in the areas assigned to them by the Director, and assure that the shielding complies with provisions of this manual. The inventory most likely will take the form of a set of civil construction drawings overlaid with beamline components maintained in an accessible electronic format. Portable or movable shielding and devices installed either temporarily or permanently within larger, permanent facilities that are

required to achieve a given level of radiation protection shall be documented, perhaps on overlays to civil construction drawings.

2. Assure the conduct of appropriate shielding assessments when new accelerators, beamlines, radiological facilities, or experiments are designed as specified further in subsequent Articles in this chapter.

3. Assure the conduct of revised shielding assessments when accelerator/beamline/experiment operating conditions <u>change</u> significantly, including those that affect the approved Accelerator Safety Envelope or could result in a change to the posting levels (see Article 236) applicable to a given area, or would affect the existing shielding assessment. FESHM 2010 specifies the unreviewed safety issue determination (USID) process and where it is applicable.

4. Assure the review and approval of shielding assessments in accordance with the process described in Article 814.

5. Maintain documentation of the shielding of beamlines in their area of responsibility. Determine and document appropriate beam operating parameter limits required to meet ES&H requirements specified both in the FRCM and in FESHM Chapter 2010. This includes the Accelerator Safety Envelope (ASE) elements that are connected with radiological shielding.

6. Prepare shielding assessment addenda to reflect minor changes to a given area covered by a previously approved shielding assessment. Such changes include those that do <u>not</u> affect the approved Accelerator Safety Envelope (see FESHM 2010), do not significantly change operating conditions such as the available intensity, energy, or particle type, etc., or do not reduce the level of safety as defined by the various posting levels of Article 236. At the discretion of the SRSO, these addenda, commonly called “post assessment documents” shall be documented by the Radiological Control Organization or sent to the SARP for further review. They are to be permanently documented along with the approved Shielding Assessment in a permanently maintained document retrieval system.

7. The placement of temporary shielding and beam absorbers, as described by the shielding assessment, in or near accelerator/beamline enclosures shall be controlled by some or all of the following provisions:

   a. Providing appropriate labeling and securing of such shielding to prevent its inadvertent removal,

   b. Applying standard labels and/or locks and chains, or other devices and equipment approved by the assigned RSO where practical,

c. Developing appropriate procedures for evaluating its effectiveness, and integrity,

d. Developing and retain appropriate documentation inventory, which becomes part of the permanent record of the operation.

8. Responsibilities for required as-built shielding documents and drawings are as follows:

a. FESS shall prepare and maintain the original set of “as-built” drawings documenting the status of radiation shielding for civil structures.

b. Divisions/Sections, with the assistance of the Radiological Control Organization, shall augment such drawings to encompass required portable shielding or devices and provide this documentation to FESS.

c. The drawings shall be approved by the Radiological Control Organization personnel at 3 stages; conceptual design (meaning development of specifications), prior to bidding, and as-built. These approvals are congruent with the shielding assessment process discussed in Article 814.

d. Thereafter FESS will maintain the up-to-date originals of the civil drawings (and retain archival drawings of past conditions) that will be made available to the ESH&Q Section and Divisions/Sections as required.

814 Shielding Assessment Preparation, Review, and Approval Process

The flowchart shown in Fig. 8-2 illustrates the shielding assessment, review, and approval process. It applies to upgrades as well as new designs.

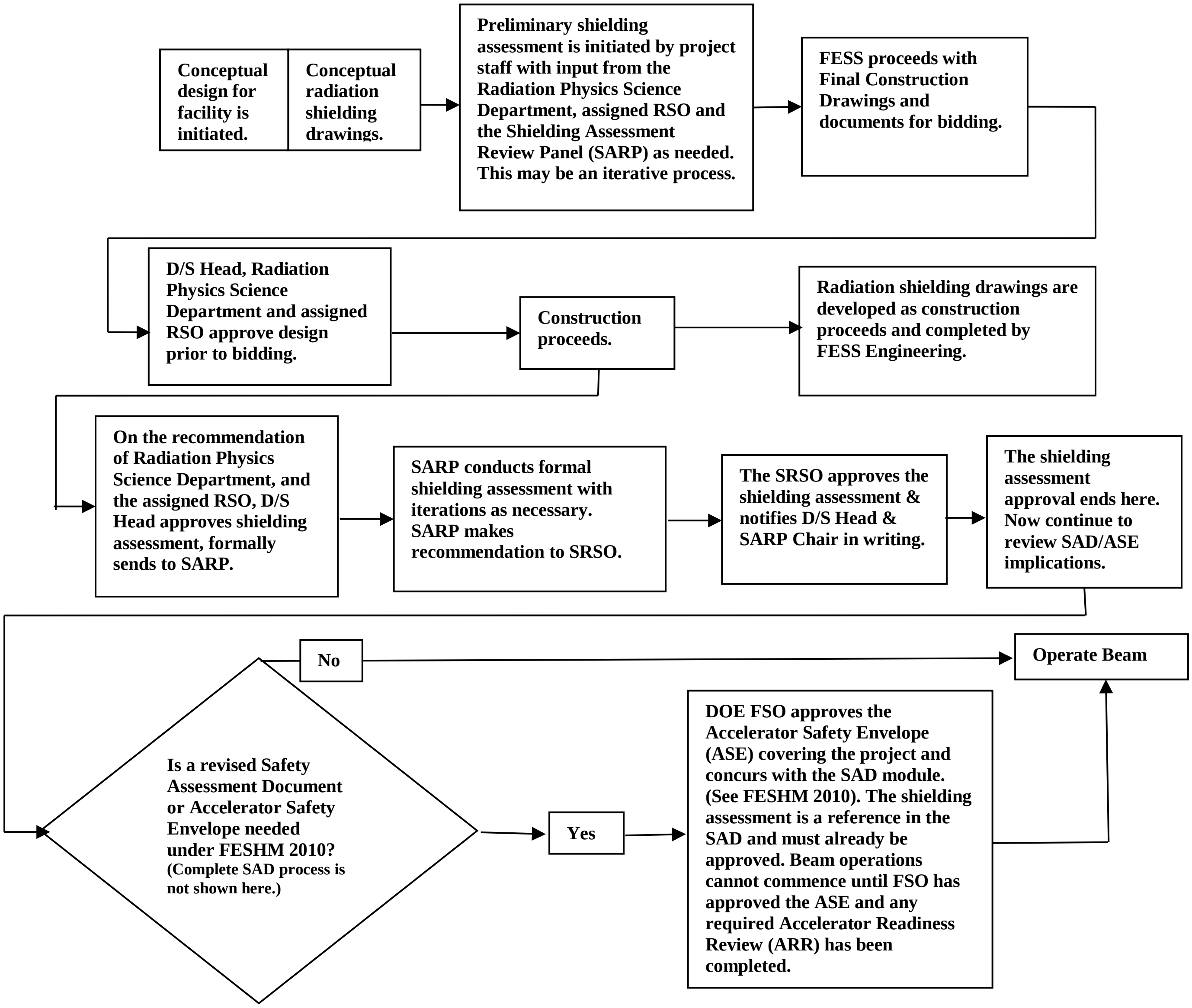

Fig. 8-2 Fermilab Radiation Shielding Design Review Process

1. Both Division/Section and Radiological Control Organization personnel shall be intimately involved in all stages of the process, from the conceptual stage through operations. All final designs, including construction packages ready for bid must

be reviewed and approved by Division/Section management, the Radiation Physics Science (RPS) department and by the assigned RSO(s).

2. A preliminary shielding assessment should be conducted and documented at the design specification stage of conceptual development and include project staff, the RPS department, the assigned RSO(s), and those responsible for designing the facility. Where civil construction is needed, representatives of FESS shall be included. This specification stage should identify the desired personnel occupancy state for the final design.

3. New or modified shielding configurations, including required moveable or portable shielding, shall be reviewed by FESS for structural engineering impact.

4. The shielding assessment, at least at a preliminary level, shall be approved by the RPS department and assigned RSO prior to the project being released for bid. Such a preliminary approval shall be clearly labeled as such and the criteria for final approval clearly documented. For complex installations, the process should be iterative, with the SARP consulted at the earliest practicable stage and is a responsibility of the Project Manager in accordance with FESHM Chapter 1010 Section 2.8.

5. The final assessment shall be reviewed internally within the originating Division/Section(s) and approved in writing by the responsible Division/Section Head(s) and the RPS department.

6. After approval of the final shielding assessment by the originating Division/Section(s), the assessment shall be formally transmitted to the SARP for review in a timely manner prior to the planned conduct of the operations covered in the assessment.

7. SARP shall review the shielding assessment in accordance with its charter embodied in the charter of the Radiation Safety Subcommittee. There may be iterations in this process with the affected Division/Section(s) as designs develop.

8. Upon successful completion of its review, the SARP shall transmit its recommendation for approval to the Senior Radiation Safety Officer (SRSO).

9. The SRSO shall:

    a. Review the report of SARP and the shielding assessment and approve of the shielding assessment if it is appropriate.

    b. Notify SARP and the originating Division/Section Head(s) and assigned RSO in writing of this approval or of reason for disapproval.

c. With the help of the RPS department, maintain records of such reviews including file copies of the "as-built" shielding documents including drawings and the shielding assessment documentation and review protocols.

10. All approvals of these documents may be done in electronic format. The electronic approvals shall clearly indicate the version being approved by document number, date, etc.

815 Content of Shielding Assessments

1. New or significantly modified accelerator/beamline/radiological facilities that do not constitute Radiation Generating Devices in accordance with FRCM Article 362 and addressed by provisions of that Article shall have a shielding assessment performed, as specified in Article 813. At the discretion of the Radiological Control Organization shielding assessments for facilities not covered by FESHM Chapter 2010 or FRCM Article 362 can be required. Many reference documents have been generated over the years at Fermilab and elsewhere that describe accelerator shielding design and radioactivation.

2. The shielding assessment shall be a written description that includes calculations and measurements of possible radiation exposures, radiation shielding, beam optics and other relevant information. It shall address soil and groundwater contamination, airborne radionuclide releases and any associated required monitoring activities. It may incorporate the analysis of non-radiological effects connected with the assessment of ionizing radiation hazards. A prominent example is structural analysis of heat-loading driven by energy deposition of energetic particles also connected with prompt radiation dose rates and/or residual radioactivity production.

3. Results of shielding assessments conducted using methodologies established prior to the amendments to 10 CFR 835 issued in June 2007 remain valid in view of the analysis of Ref. 2 in Appendix 1 of this chapter. Shielding assessments conducted after January 1, 2010 shall employ updated methodologies based upon ICRP Publication 103 (see Article 812).

4. Appendix 2 provides an established protocol for conducting such shielding assessments that should be used as a guidance document, were practicable, for conducting shielding assessments.

5. A modification to shielding which requires a new or revised shielding assessment under Article 813 is one that:

a. results in a significant change to operating conditions,

b. affects the approved Accelerator Safety Envelope, or

c. Permanently changes the level of personnel protection as defined in Article 236.

d. Affects the protection scheme of the existing shielding assessment.

Changes to shielding that do not require a new or revised shielding assessment under these criteria shall be documented in a shielding assessment addendum, also called a "post assessment document", and formally approved using the USID process of FESHM Chapter 2010 by the SRSO.

6. The shielding assessment must document the circumstances and controls that serve to limit the intensity of the maximum beam loss and/or its duration and the resulting dose. This specifically includes a description of required portable or movable shielding, beamline components, and interlocked detectors.

7. The final assessment shall establish the occupancy status and radiological posting requirements of areas with respect to the posting criteria of Articles 234 and 236.

8. Completed shielding assessments and their approvals are generally based upon design and construction drawings, inclusive of field modifications, and other related documents as they are developed during the construction process.

APPENDIX 1- Brief Synopsis of Methodologies for Assessing the Shielding of Particle Accelerators

At high energy particle accelerators, the design of adequate shielding becomes complex with increasing beam energy due to cascade phenomena. A high-energy hadron interacting with a nucleus typically creates a rather large number of short-lived particles (pions, kaons, etc.), as well as protons, neutrons and nuclear fragments. Another important result of high-energy hadron interactions is the production of muons, which can represent a significant shielding problem. The interactions of the high energy beams can also produce significant radioactivation of the beamline components, the prompt radiation shield, and the surrounding environment. Even hadrons of relatively low energies can produce significant radiation fields and the possibility of radioactivation of materials including environmental media.

Likewise, electrons of all energies can produce significant prompt radiation fields. At the lowest energies these radiation fields are dominated by photons. Above kinetic energies of a few MeV neutrons can be produced by electron interactions with matter while above 211 MeV muon radiation fields are possible. In the environs of electron radiation fields, residual radioactivity can be produced. Thus the shielding of radiation fields associated with electron beams and even muon beams can also be important at Fermilab, especially as the program of the Laboratory continues to be developed and future facilities designed, constructed, and operated.

Shielding design at Fermilab shall be performed in a high quality manner. A great deal of expertise on this topic is available in the ESH&Q Section and the SARP as well as individuals located elsewhere within the Laboratory. A large body of documentation is available on these issues in publications, Fermilab reports (TMs, FNs, Confs, and Pubs.) and in published literature in accelerator science and health physics.

Many practical problems are amenable to phenomenological approaches of longstanding use at Fermilab and elsewhere. Some of these approaches are clearly of benefit in job planning activities, etc. However, for new designs in most circumstances it is far better to perform calculations specific to the details of the shielding configuration encountered than it is to excessively employ generalized calculations and "rules of thumb". Thus, when practicable, modern shielding codes such as MARS should be used in accordance with FESHM Chapter 2090, "Usage of Computer Calculations Affecting Environment, Safety, and Health". Proper use of shielding computer models at the design stage can prevent design errors that are typically costly and difficult to correct.

The properties of shielding materials, especially their elemental composition and density is of high importance in the design of radiation shielding and should be carefully considered in the conduct of shielding calculations. For example, some backfill materials that are similar to concrete or soil in elemental composition may be of lower density than the "standard" values.

There is a large number of technical references that address the topics of this chapter. Two key ones are cited below and these contain numerous references to other related publications:

1. Fermilab TM-1834, “Radiation Physics for Personnel and Environmental Protection” by J. D. Cossairt, posted on the following website: https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=1007.

2. Cossairt and Vaziri, “Neutron Dose per Fluence and Weighting Factors for Use at High Energy Accelerators”, Health Physics 96 (2009)617-628.

APPENDIX 2 - Shielding Assessment Outline

Revision History

Author	Description of Change	Revision Date
W. Schmitt	Reformatted as an Appendix to FRCM Chapter with additional details provided concerning responsibilities, approvals, and quantitative estimation methods	12/05/2017
W. Schmitt	Accelerator Division Procedure ADSP-02-0110 – Outline for Performing Shielding Assessments	12/10/2015

1. Purpose

Activities at Fermilab related to the operation of certain equipment, machines, or facilities can create ionizing radiation hazards. A shielding assessment is a document containing the results of a systematic analysis of ionizing radiation hazards and their controls to identify associated on-site and off-site impacts to workers, the public, and the environment for both normal operation and credible accidents. Shielding assessments shall be conducted in accordance with provisions of this Manual.

Since the nature and magnitude of hazards specific to given situations can vary, a shielding assessment should follow a tailored approach to capture the relevant amount of detail. This document provides an outline to aid in developing a consistent, complete, and compliant shielding assessment.

The time needed to complete a shielding assessment varies based on the complexity and level of detail. Since some components of an assessment can differ from that outlined below, defining the appropriate format is important in optimizing the time and level of effort required.

If the assessment affects the existing approved Accelerator Safety Envelope (ASE), then the Fermilab Safety Assessment Document (SAD) [1] must be modified and be reviewed by the ESH&Q Section and approved by the Laboratory Director. In addition, DOE approval is required for the revised ASE before beam may be delivered to the affected area.

The overall shielding assessment, review, and approval process is described in Fig 8-2 of the Chapter.

2. Responsibilities

- Division/Section (D/S) Head

  The D/S Head is responsible for requesting that a Shielding Assessment be prepared by the Project Head or those responsible for designing, constructing, and operating a facility. The D/S Head is also responsible for approving an assessment and forwarding it to the ESH&Q Section for further approval. The D/S Head may request recommendations from the Shielding Assessment Review Panel of the Radiation Safety Subcommittee prior to approving an assessment.

- Project/Department Head

  The assigned Project/Department Head is charged by the D/S Head to prepare a shielding assessment and is responsible for ensuring that the assessment is conducted with the concurrence of the ESH&Q Section Radiation Physics Science Department and Area Radiation Safety Officer before submitting the completed assessment for further review and approval.

- Senior Radiation Safety Officer (SRSO)

  The SRSO is responsible for reviewing a shielding assessment and notifying the D/S Head and the Shielding Assessment Review Panel Chairperson in writing of approval or rejection.

- ESH&Q Section Radiation Physics Science Department (RPS)

  The RPS, in conjunction with the assigned Area Radiation Safety Officer, is responsible for providing the D/S Head with a recommendation as to whether the Shielding Assessment Review Panel should be convened, and for ensuring that the shielding assessment contains all required components, satisfies requirements stated in the FRCM, and has an appropriate format. Each assessment is unique and the format may need to be modified to provide the appropriate level of detail for review. When this occurs, the RPS will provide specific format guidance. Also, the RPS will ensure that the necessary Radiation Safety Drawings are produced or modified at the appropriate time and obtain any required approvals.

- Shielding Assessment Review Panel (SARP) Chairperson

  The SARP Chairperson is responsible for:

    - coordinating a shielding assessment review by the panel for methodology, completeness, and compliance with FRCM,

- o recommending acceptance or rejection of the assessment to the SRSO based on consensus of the panel, and

- o advising the D/S Head and the SRSO of effects the assessment may have on overall operations or other assessments.

- Shielding Assessment Review Panel

  The SARP is responsible for reviewing shielding assessments for appropriate methodology, completeness, and compliance with the FRCM.

1. Outline

The following outlines a shielding assessment format that has been used successfully at Fermilab and elsewhere. Other formats may be more amenable to a specific facility, so long as they provide an appropriate level of content and detail. Unless otherwise noted, quantitative estimation methods should follow those described in TM-1834 [2].

Introduction – provides overview, context, and background information.

Boundaries – addresses scope, including specific regions or coordinates being assessed, and modifications to existing facilities or changes in conditions from previous assessments. This may also include a description of desired postings in affected areas.

Parameters – includes details concerning beam types, energies, maximum instantaneous and annual intensities, and destinations for and locations of both normal and accident conditions. This may include information concerning different modes of operation, and locations and designs of beam targets and/or absorbers.

Shielding Requirements – quantifies the passive shielding, active detectors, and barriers needed to safely operate within the parameters set forth in FRCM Chapter 2. This should include normal running condition losses, as well as accident condition losses. If the Incremental Shielding Assessment Methodology (ISM) [3] is used, then a set of spreadsheets must be included to scale from an established baseline [4]. If another assessment methodology is chosen, results shall be included in the assessment (see below). A set of calculation tools can be found at the ESH&Q Section Radiation Physics FermiPoint site.

> Passive shielding is preferred. If Total Loss Monitor (TLM) systems are intended, then they should be supported by simulation results and validated with *in situ* beam-on measurements.
>
> The shielding assessment shall demonstrate that any active detectors are sufficiently sensitive, have adequate response time, and have sufficient coverage to provide protection for all areas with insufficient passive shielding. Note that

machine protection systems cannot be used as safety devices, and are therefore insufficient to use as active detectors for purposes of a shielding assessment.

Penetrations/labyrinths – addresses the dose rates due to penetrations in bulk shielding and any mitigations required.

Monte Carlo (e.g., MARS) simulations – often defines the shielding requirements at target stations, decay regions, fixed aperture collimators, and/or pinhole collimators, as well as at primary, secondary, and tertiary beam absorbers. Presently, only the MARS [5] code is approved to be used for shielding assessment calculations (see ESHQ-doc-855).

Target/absorber integrity analysis – analyzes thermal effects from energy deposition to components, such as targets and absorbers, to avoid melting, sublimation, cracking, etc.

Ground and surface water activation calculations – estimates radionuclide (i.e., ^{3}H, ^{22}Na) concentrations and their migration in hydrated soils surrounding beam enclosures. For specific release points, suggest monitoring locations, if any.

Air activation – describes the effect of potential radionuclides produced in the beamline enclosure air when personnel access is permitted as well as any releases to the environment (see RP Note No. 128). For specific release points, suggest monitoring locations, if any. In addition, other potential hazards (e.g., ozone) induced by the irradiation of air should be described [6].

Other Beam Induced Hazards

Residual dose rates – estimates residual dose rates due to radioactivation from known loss locations.

Cooling water – estimates build-up and transport of radioactivity in cooling water systems (e.g., LCW, RAW).

Hydrogen gas – estimates hydrogen gas evolution from radiolysis in cooling water systems [6].

Air scattered radiation – also known as 'skyshine,' addresses prompt radiation scattered in air near thinly-shielded areas.

Muon production – estimates potential prompt dose rates due to muons both on-site and off-site.

Intended active shielding controls and monitoring – suggests locations for radiation monitoring devices (e.g., interlocked detectors) to control dose rates to personnel.

Conclusions – clear summary of shielding assessment conclusions and, if required, action items before beam is delivered to an area.

References – comprehensive list of references, including drawings, sketches, and documents used to support assessment conclusions.

4. References

[1] *Fermilab Safety Assessment Document*, ESHQ-doc-1066, https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=1066

[2] *Radiation Physics for Personnel and Environmental Protection*, J.D. Cossairt, FERMILAB-TM-1834, https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=1007

[3] *Incremental Shielding Assessment Methodology*, W. Higgins and P. Kasper, November 10, 1997, https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=3843

[4] *Update to the Generic Shielding Criteria*, D. Reitzner, FERMILAB-TM-2550-ESH, https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=2263

[5] *MARS Code*, https://mars.fnal.gov

[6] *Radiation Protection for Particle Accelerator Facilities*, National Council on Radiation Protection and Measurements (NCRP) Report #144, 2003