FRCM CHAPTER 2:
RADIOLOGICAL STANDARDS

Revision History

Author	Description of Change	Revision Date
M. Quinn	• Clarified dose terminology throughout. • Clarified RCO responsibility for posting areas. • Added Article 221 Personnel Contamination Control • Removed entry control requirements from Article 3. Entry control requirements will be added to a concurrent update to Chapter 3. • Added Article 237 for posting of Radiological Buffer Areas • Updated Article 241 to be consistent with DOE O458.1 requirements. • Removed Article 242 for inclusion in appropriate ESH procedure.	March 2022
J. D. Cossairt	• Revised Article 236 to incorporate existing practice related to the posting of interlocked radiation enclosures for which personnel access with the beam enabled is prohibited and excluded by the Radiation Safety Interlock System.	January 2018
J. D. Cossairt	• Updated Article 242 to implement iTrack item 94532 of Tripartite Assessment on "Experiment Decontamination and Decommissioning" (iTrack Review # 44929)	April 2017
J. D. Cossairt	• Language pertaining to the DOE approval authority levels for Accelerator Safety Envelopes related to accidental doses potentially exceeding 1 rem does not match that stated in DOE O420.2C. Corrected App. 2C to match wording of the Order.	February 2017
J. D. Cossairt	• Updated to reflect Fermilab-wide ESH&Q reorganization. • Added a requirement for SRSO approval of doses over 10 mrem in a year to persons under the age of 18 years.	July 2016
J. D. Cossairt	• Editorial changes to reflect ESH&Q organization changes.	July 2015
J. D. Cossairt	• Modify Article 231.4 to better clarify requirements pertaining to outdoor radiological postings. • Modify Article 236 to clarify Fermilab's approach to the posting of accelerator/beamline enclosures.	February 2015

J. D. Cossairt	• Correct the first sentence of Article 231 to refer to Chapter 3, Part 3, not Chapter 3, Part 1. • Add Article 231.4.j to implement a DOE-FSO suggestion. • Modify Article 232.3 to incorporate clarifications proposed by the Radiation Safety Subcommittee • Modify Article 234.9 for consistency with the November 2012 revision to Article 312. • Modify Article 236.2 to incorporate the methodology for including machine controls in the determination of maximum dose to an individual. • Add Appendix 2C now referenced in Article 236.2.	November 2012
J. D. Cossairt	• Modify Article 214 to insert a cross reference to the design goals of Article 811 to improve consistency with the requirements of 10 CFR 835.1002(b).	December 2011
J. D. Cossairt	• Incorporate suggestions made since the last revision. • Provide clarification concerning accidental beam loss criteria. • Improve cross-referencing to FRCM Chapter 8 concerning accelerator radiation shielding assessments.	August 2011

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CHAPTER 2 RADIOLOGICAL STANDARDS

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PART 1 DOSE LIMITS AND ADMINISTRATIVE GOAL

211 Dose Limits

1. A worker who is not classified as a radiological worker shall not be allowed to routinely receive an effective dose of greater than 100 mrem in a year.

2. Dose limits provided in Table 2-1 shall not be exceeded by individuals. For purposes of compliance with this document, effective dose equivalent to the whole body may be used as effective equivalent dose for external exposures. All occupational exposure received during the current year, with the notable exceptions of Emergency Exposures (Article 922), Planned Special Exposures (Article 921), and the Non-Uniform Irradiation of the Skin over areas of less than 10 cm^2 (Appendix 2B), shall be included when demonstrating compliance with the Table 2-1 limits. Further information as to the definitions of dosimetric terms is found in the Glossary and Chapter 8 of this Manual.

3. Radiological workers from DOE or other DOE contractor facilities may receive occupational exposure as a radiological worker if they fulfill the requirements stated in Article 612.2 and, if possible, provide a record of the total radiation dose received during the current calendar year and previous accumulated lifetime dose.

4. If it is determined that a radiological worker's occupational exposure has exceeded any of the applicable limits specified in Table 2-1, the employee shall not be permitted to return to work in radiological areas during the current calendar year. A radiological worker whose occupational dose has exceeded the numerical value of any of the limits specified in Table 2-1 as a result of an authorized emergency exposure may be permitted to return to work in radiological areas during the current year providing that all of the following conditions are met:

   a Written approval has been obtained from the Senior Radiation Safety Officer, the Laboratory Director and the Manager of the DOE Fermi Site Office (DOE-FSO).

   b The individual has received counseling from radiological protection and medical personnel regarding the consequences of receiving additional occupational exposure for the year. The topics discussed during this session shall be retained as part of the individual's exposure history.

   c The affected individual has expressed, in writing, a desire to return to radiological work.

   d Consideration is given to establishing special control levels (see Article 215).

   e All occupational exposures received during the calendar year by the individual shall be recorded in the affected individual's occupational exposure history.

5. 10 CFR 835.202, 1301, and 1302 give provisions for planned special exposures and authorized emergency exposures. These shall be followed. See also Article 645.6.

Table 2-1 Summary of Dose Limits

None of the limits shall be exceeded in a year. Exposures should be well below the limits in this table and maintained as low as reasonably achievable (ALARA). The Fermilab Administrative Goal for limiting exposure is described in Article 214.

In accordance with the *Federal Register* Notice Vol. 72, No. 100, page 31908, issued June 8, 2007 that amended 10 CFR Part 835, "…historical doses recorded and reported to individuals and dosimetry results acquired from other institutions (both DOE and non-DOE) prior to complete implementation of the new system of radiation dosimetry should still be considered to be the official doses of record."

TYPE OF EXPOSURE	ANNUAL LIMIT
Radiological Worker: Whole Body (total effective dose)	5 rem
Radiological Worker: Lens of Eye (equivalent dose)	15 rem
Radiological Worker: Sum of the equivalent dose to the whole body for external exposures and the committed equivalent dose to any organ or tissue other than the skin or the lens of the eye	50 rem
Radiological Worker: Sum of the equivalent dose to the skin or to any extremity for external exposures and the committed equivalent dose to the skin or to any extremity.	50 rem
Declared Pregnant Worker: Embryo/Fetus (equivalent dose) for entire gestation period	0.5 rem
Minors and Students (under age 18): Whole body (internal + external) (total effective dose)	0.1 rem

Notes to Table 2-1:

1. Internal dose to the whole body shall be calculated as committed effective dose. The committed effective dose is the resulting dose committed to the whole body from internally deposited radionuclides over a 50-year period after intake. See Appendix 2A for the weighting factors to be used in converting organ equivalent dose to total effective dose for the whole body and Appendix 8A for radiation weighting factors to convert from absorbed dose to effective dose.
2. Doses from background, therapeutic and diagnostic medical radiation, and participation as a subject in medical research programs shall not be included in either personnel radiation dose records or assessment of dose against the limits in this Table.
3. Concerning dose to the embryo/fetus, substantial variation above a uniform exposure rate that would satisfy the stated limit shall be avoided. If it is likely that the embryo/fetus is determined to have already exceeded 0.5 rem (0.005 Sv) by the time a worker declares her pregnancy, the declared pregnant worker shall not be assigned to tasks where additional occupational exposure is likely during the remaining gestation period.
4. See Appendix 2B for guidance on non-uniform exposure of the skin.
5. Separate Lens of Eye doses are only measured on a case-by-case basis where appropriate. In the absence of specific monitoring, the equivalent dose to the lens of the eye is taken to be equal to the equivalent dose at a tissue depth of 300 mg/cm^2.

212 Dose Limits for Visitors, Individuals Under 18 Years of Age, and Members of the Public

1. Visitors to Fermilab shall be limited to a total effective dose of 100 mrem in a calendar year. Occupational doses are not to be included in this total.

2. A person under the age of 18 shall not be employed in any radiological areas in such a manner that he/she has the potential to receive doses of greater than 100 mrem in a year total effective dose, and/or 10% of the other dose limits established in Table 2-1 for radiological workers (see Article 931).

3. Doses to a person under the age of 18 may not exceed more than 10 mrem total effective dose in a year without approval of the SRSO.

4. The total effective dose received by any member of the public shall not exceed 100 mrem in a year as a result of all DOE activities.

By order of the Director as a long-standing policy, off site exposures due to Laboratory operations have been subject to a guideline of 10 mrem in a calendar year. The Senior Radiation Safety Officer (SRSO) shall notify the Director when the accumulated off-site dose rate is measured or estimated to have exceeded 7.5 mrem in any calendar year. See occurrence reporting criteria of FESHM 3010.

213 Embryo/Fetus Dose Limits

The equivalent dose limit for the embryo/fetus from conception to birth (entire gestation period) is 500 mrem. In the absence of fetal monitoring, the embryo/fetal equivalent dose is equal to the total effective dose received by the declared pregnant worker for the gestation period. See notations pertaining to Table 2-1. Article 951 contains detailed information regarding Fermilab's prenatal policy and procedures.

214 Administrative Goals

1. The Fermilab Director has established an Administrative Goal of 1,500 mrem total effective dose for a calendar year for occupational radiation exposures. The Fermilab ALERT System has been established to ensure the Administrative Goal is not inadvertently exceeded.

2. Any individual who meets or exceeds 350 mrem whole body (deep) dose by primary dosimeter in a calendar quarter will be assigned to the ALERT list.

4. Exposure limits and controls for individuals assigned to the ALERT List will be developed on a case-by-case basis by the assigned Radiation Safety Officer (RSO) and the individual's supervisor. These agreements will be documented using R.P. Form 3. In addition, these instructions will include a reference to this section of the Fermilab Radiological Control Manual. Additional controls may include, but are not limited to:

    a. A pocket dosimeter to be worn at all times while in areas controlled for radiological purposes.

    b. An electronic dosimeter worn in addition to a pocket dosimeter while in High Radiation Areas.

    c. More restrictive stay times.

    d. Increased radiological surveillance of the work area.

    e. Use of engineered controls.

    f. Additional dosimetry, such as ring dosimetry badges.

    g. Change to or modification of assigned tasks.

5. The individual and his/her supervisor will be instructed by the assigned RSO on dose minimizing techniques.

6. Before exceeding 1,500 mrem in a calendar year, an individual must have the written approval of the Laboratory Director.

7. Administrative design goals for accelerator radiation shielding are specified in FRCM Article 811.

215 Special Control Levels

Certain situations may require lower individualized exposure goals. These goals may be developed for individuals who have received substantial occupational exposure in the past. Individualized exposure goals may also be developed for individuals who are receiving diagnostic or therapeutic nuclear medicine or external radiation treatments and who desire to minimize their total exposure. If the Radiological Control Organization is made aware of these circumstances, the establishment of special control levels can be considered. In addition to recommendations from radiological control and medical personnel, advice from human resources personnel and legal counsel may be sought in establishing such special control levels. Special control levels shall be approved by the Senior Radiation Safety Officer and the relevant Division/Section/Project Head.

PART 2 CONTAMINATION CONTROL AND CONTROL LEVELS

Control of removable radioactive contamination at Fermilab is achieved by containing contamination at the source. At Fermilab, the hazard due to removable contamination is generally much smaller than the hazard due to induced radioactivity. Nevertheless, it is good management practice to control removable radioactive contamination to the extent possible.

221 Personnel Contamination Control

1. Article 336 establishes contamination monitoring requirements for personnel exiting Contamination Areas, High Contamination Areas, or Airborne Radioactivity Areas established for contamination control. These requirements do not apply to personnel exiting areas containing only radionuclides, such as tritium, that cannot be detected using hand-held or automatic frisking equipment.

2. Monitoring for contamination should be performed using frisking equipment that under laboratory conditions can detect total contamination at or below the values specified in Table 2-2 of this *Manual*. Use of automatic monitoring units that meet the above requirements is encouraged.

3. Personnel found with detectable contamination on their skin or personal clothing, other than radon daughter products or other natural background radioactivity, should be promptly decontaminated as described in Article 541.

222 Contamination Control Levels

1. A surface shall be considered contaminated if either the removable or total radioactivity is detected above the levels in Table 2-2. If an area cannot be decontaminated promptly, then it shall be posted as specified in Article 235 and controlled in a manner commensurate with the physical and chemical characteristics of the contaminant, the radionuclide(s) present and the fixed and removable contamination levels. Refer to Chapter 3 for more details.

2. Surfaces exceeding the values of Table 2-2 for total contamination may be covered with a fixative coating to prevent the spread of contamination. However, reasonable efforts should be made to decontaminate an area before a coating is applied. Volume activated material is not considered to be fixed contamination. A fixative coating shall not be applied without the approval of the SRSO.

3. In addition to the posting criteria in Article 235, appropriate administrative procedures are to be established and exercised to maintain control of Fixed Contamination Areas. These procedures shall include all of the following:

    a. Periodic radiological surveys shall be performed to detect contamination that may become removable over time.

b. A formal inventory of Fixed Contamination Areas shall be maintained by the Radiological Control Organization.

c. The area shall be conspicuously marked to warn individuals of the contaminated status. Markings shall be kept legible.

d. Markings should include the standard radiation symbol, be clearly visible from all directions and contrast with the colors of the surface coatings and include the words "CAUTION - FIXED CONTAMINATION."

4. A Fixed Contamination Area may be located outside Controlled Areas unless unrestricted access is likely to result in a dose to any person greater than 100 mrem in a year or the dose rate at 30 cm from the source requires posting as a radiological area.

223 Airborne Radioactivity Control Levels

1. Personnel should not be exposed unnecessarily to airborne radioactivity and the potential for such exposure must be evaluated before allowing entry into areas where airborne radioactivity may be present. Through the use of engineering and administrative controls, personnel exposure to airborne radioactivity at Fermilab is rare. (See Article 316 and 334.)

2. Accessible areas with airborne concentrations of radioactivity that are greater than, or potentially greater than, 1 DAC, or where an individual without respiratory protection could exceed 12 DAC-hours per week, shall be posted as specified in Article 235.

3. Derived Air Concentrations or DACs are provided in 10 CFR 835 and shall be used in the control of occupational exposures to airborne radioactive material. The concept of working level shall not be employed for the consideration of radon concentrations.

Table 2-2 Summary of Contamination Values[1]

NUCLIDE	REMOVABLE (dpm/100 cm^2)[2,4]	TOTAL (FIXED + REMOVABLE)[2,3] (dpm/100 cm^2)
U-natural, U-235, U-238 and associated decay products	1,000 alpha[7]	5,000 alpha[7]
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	20	500
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	200	1,000
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above[5].	1,000 beta-gamma	5,000 beta-gamma
Tritium and STCs[6]	10,000	See Footnote 6

Notes:

1. The values in this Table, with the exception noted in footnote 6 below, apply to radioactive contamination deposited on, but not incorporated into the interior or matrix of the contaminated item. Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides apply independently.
2. As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.
3. The levels may be averaged over one square meter provided the maximum surface activity in any area of 100 cm^2 is less than three times the value specified. For purposes of averaging, any square meter of surface shall be considered to be above the surface contamination value if: (1) from measurements of a representative number of sections it is determined that the average contamination level exceeds the applicable value; or (2) it is determined that the sum of the activity of all isolated spots or particles in any 100 cm^2 area exceeds three times the applicable value.
4. The amount of removable radioactive material per 100 cm^2 of surface area should be determined by swiping the area with dry filter or soft absorbent paper, applying moderate pressure, and then assessing the amount of radioactive material on the swipe with an appropriate instrument of known efficiency. (Note - The use of dry material may not be appropriate for tritium.) When removable contamination on objects of surface area less than 100 cm^2 is determined, the activity per unit area shall be based on the actual area and the entire surface shall be wiped. It is not necessary to use swiping techniques to measure removable contamination levels if direct scan surveys indicate that the total residual surface contamination levels are within the limits for removable contamination.
5. This category of radionuclides includes mixed fission products, including the Sr-90 which is present in them. It does not apply to Sr-90 which has been separated from the other fission products or mixtures where the Sr-90 has been enriched.
6. Tritium contamination may diffuse into the volume or matrix of materials. Evaluation of surface contamination shall consider the extent to which such contamination may migrate to the surface in order to ensure the surface contamination value provided in this table is not exceeded. Once this contamination migrates to the surface, it may be removable, not fixed; therefore, a "Total" value does not apply. In certain cases, a “Total” value of 10,000 dpm/100 cm^2 may be applicable either to metals of the types from which insoluble special tritium compounds are formed, that have been exposed to tritium, or to bulk materials to which insoluble special tritium compound particles are fixed to a surface.
7. These limits apply only to the alpha emitters within the respective decay series.

PART 3 POSTING

231 Posting Requirements

1. Radiological postings shall be used to alert personnel to the presence of radiation and radioactive materials and to aid them in minimizing exposures and preventing the spread of contamination. Areas may be exempted from the posting requirements of Articles 233-236 for periods less than 8 continuous hours when placed under continuous observation and control of an individual knowledgeable of, and empowered to implement, required access and exposure control measures.

2. Signs shall contain the standard radiation warning trefoil colored black or magenta on a yellow background. Lettering shall be either black or magenta. Black on yellow is the recommended Laboratory standard.

3. Rope, tape, chain and similar barriers used to designate the boundaries of posted areas should be yellow and black or magenta in color whenever possible.

4. Signs shall be conspicuously posted at each access point, clearly worded, and, where appropriate, may include radiological control instructions. Radiological postings should be displayed only to signify actual or likely radiological conditions. Signs used for training should be clearly marked "For Training Purposes Only."

5. Posted areas should be as small as practicable.

6. Signs shall be conspicuously posted, maintained in a legible condition and should be updated based upon the results of the most recent surveys. Signs may include radiological control instructions.

7. If more than one radiological condition, such as contamination and high radiation, exists in the same area, each condition shall be identified.

8. Physical barriers should be placed so that they are clearly visible upon approach to the area and, when necessary, at various elevations. They should not be easily walked over or under, except at identified access points. These barriers shall be set up such that they do not impede the intended use of emergency exits or evacuation routes (NFPA 101 - The Life Safety Code).

9. Postings of doors should be such that the postings remain visible when doors are open or closed. If the area is bounded by warning barriers such as fences, ribbons or ropes, signs shall be placed in a conspicuous manner around the perimeter so that the signage is visible to those that encounter these barriers.

11. For radiological postings located outdoors:

    a. Their visibility should not be obstructed such that an approaching person could reasonably fail to see them. Such obstructions may include, but are not limited to, overgrown vegetation or snow accumulations.

    b. If the required placement of such postings makes this impractical, then provisions must be made to relocate or remove any obstruction, provided this can be done safely. (In particular, this provision does not require unsafe snow removal from roofs.)

    c. If responsible Radiological Control Organization personnel cannot promptly identify such conditions, then collaborative arrangements with FESS should be made to assure an organized surveillance program.

    d. The Radiological Control Organization, with the support of the Division/Section that is responsible for the activity for which the posting is required, is responsible for making arrangements for removing such obstructions, most likely with the FESS Roads and Grounds Department.

    e. For outdoor areas the signs shall generally be spaced about 50 feet apart or at an appropriate spacing as determined by the assigned RSO.

12. A radiological posting signifying the presence of an intermittent radiological condition may include a statement specifying when the hazard is present, such as "CAUTION: RADIATION AREA WHEN RED LIGHT IS ON." Note that posting of accelerator/beamline enclosures is treated in Article 236, however the assigned RSO may post specific beam line areas with a contingency statement (e.g., “Radiation Area when beam enabled”, “Radiation Area when RF is ON”, etc.) with SRSO approval.

13. Postings and barricades shall not interfere with routes of emergency egress or local security requirements.

14. All radiological signs and labels shall be disposed of as radioactive waste.

15. Qualified RCTs shall perform posting, except during abnormal situations, or other special circumstances when temporary postings may be installed by personnel who are qualified radiological workers and approved by the assigned RSO.

232 Posting Controlled Areas

1. Areas within the site boundary should be clearly posted to alert personnel to the presence of radiation and radioactive materials above natural background levels. Each access point to such an area shall be posted “CAUTION, CONTROLLED AREA” whenever one or more radiological

areas or radioactive material areas exist within a larger area that is accessible to Laboratory personnel.

2. Persons who enter only the Controlled Area without entering any radiological areas are not expected to receive more than 100 mrem in a year.

3. Radiation levels in normally occupied areas such as offices and workbenches shall be maintained at 0.05 mrem/hr or less, time-averaged over 8 consecutive hours. Areas designated for work on radioactive material that are not continuously occupied may, on occasion, be temporarily maintained at higher dose rates at the discretion of the assigned RSO provided that the dose to individuals in adjacent areas would not exceed 100 mrem in a year. For areas subject to prompt radiation fields, such as some experiment control rooms (see also Article 236), the time-averaged effective dose rate, normally over a period of 8 consecutive hours, shall be maintained at less than 0.25 mrem/hr provided that the dose to any one individual is unlikely to exceed 100 mrem/year. Additional controls shall be imposed by the assigned RSO to ensure Article 232.2 is satisfied along with other requirements such as training (see Chapter 6) and dosimetry monitoring (see Chapter 5) that are tied to the effective dose that might be received during one calendar year.

4. If the boundaries of the Controlled Area and Radiological Area or Radioactive Material Area are congruent, the appropriate sign identifying the greater hazard is considered to be sufficient. However, if multiple Radiological Areas (Articles 234, 235) or Radioactive Material Areas (Articles 233) are found within a given Controlled Area, the latter may be specifically posted. If there is the potential for prompt radiation to be present in an area, additional posting specified in Article 236 is also required.

233 Areas Containing Radioactive Materials

1. The definition of, and labeling requirements for, discrete items of radioactive material are in Chapter 4, Part 1 of this Manual.

2. Areas within a Controlled Area (see Article 232) accessible to individuals in which items or containers of radioactive material in quantities exceeding the values provided in Appendix E of 10 CFR 835 exist shall be posted "CAUTION -- RADIOACTIVE MATERIAL" or "CAUTION, RADIOACTIVE MATERIAL AREA", unless:

   a. the area boundary is congruent with a Radiological Area boundary, in which case the Radiological Area posting is sufficient;

   b. each item or container is labeled in accordance with Article 413 such that individuals entering the area are made aware of the hazards;

   c. the radioactive material of concern consists solely of structures or installed components which have been activated; or

d. the area contains only packages of radioactive material received from radioactive material transportation while awaiting monitoring in accordance with Article 423.3.

3. Cabinets, boxes, bins and other such items used to segregate radioactive material from nonradioactive material shall be labeled "CAUTION -- RADIOACTIVE MATERIAL."

4. Radioactive material area perimeters that are painted on floors may be a good choice in some circumstances. If this is done, proper maintenance to assure visibility and readability shall be conducted.

234 Posting Radiation Areas for Beam-Off Conditions

This article addresses the posting of Radiation, High Radiation, and Very High Radiation Areas created by the presence of sealed sources and other radioactive material. It also addresses the posting of accelerator/beamline enclosures during beam-off conditions. In situations where gamma ray sources from residual activation dominate the radiation field, the exposure unit "Roentgen (R)" is considered equivalent to the unit of effective dose, the "rem", or the absorbed dose, the “rad”, despite the technical difference between the three quantities. See Article 236 for posting of accelerator/beamline enclosures during beam-on conditions.

1. Areas shall be posted to alert personnel to the presence of external radiation in accordance with Table 2-3 or Article 236. General entry/exit requirements may be included on the sign. The definitions of the radiological areas in Table 2-3 are consistent with the specific definitions of 10 CFR Part 835.

Table 2-3 Criteria for Posting Radiation Areas

AREA	DOSE RATE CRITERIA	POSTING
Radiation Area	≥ 5 mrem in one hour and < 100 mrem one hour	CAUTION-RADIATION AREA
High Radiation Area	≥ 100 mrem in one hour and <500 rad in one hour	DANGER-HIGH RADIATION AREA or CAUTION-HIGH RADIATION AREA
Very High Radiation Area	≥ 500 rad in one hour	GRAVE DANGER-VERY HIGH RADIATION AREA

2. Consistent with the specific definitions of 10 CFR Part 835, dose measurements (rems) used to classify areas as Radiation and High Radiation Areas shall be made at a distance of 30 centimeters (~1 ft) from the radiation source or from any surface through which the radiation penetrates. Absorbed dose measurements (rads) used to determine if the criteria for a Very High Radiation Area are satisfied shall be made at a distance of 1 m from the radiation source or from any surface that the radiation penetrates.

3. Measures should be taken to identify sources of elevated radiation levels while conducting routine surveys or opening up radiation surveys of accelerator/beamline enclosures.

4. An appropriate exposure rate sticker/label marking the location of areas with elevated dose rates should be placed on or near the spot. These stickers should be signed (using FNAL ID) and also dated by the surveyor.

   a. In beam enclosures, to keep survey doses ALARA, it is common to establish a minimum posting level of 20 mR/hr.

   b. To keep exposures to personnel conducting the survey ALARA, it is often desirable to not label individual hot components in areas in which no one is scheduled to work. This may be done provided the area is roped off and posted with signs indicating the unlabeled area and the radiological hazard present. Should the dose rates exceed 100 mrem/hr, the requirements in Article 234.6 are applicable.

5. At certain times, radiation may in fact not be present in what is posted as a radiation area because fixed, rather than real-time signs are used. However, as long as signs are present their instructions and associated requirements are to be strictly adhered to by all personnel.

6. When dose rates exceeding 100 mrem/hr are confined to a small region inside a much larger area, ribbons or ropes and suspended signs shall be used to demark the High Radiation Area.

7. See also additional work controls specified in FRCM Chapter 3.

8. "Occupancy Time" labels are used in accelerator/beamline radiation areas on normally stationary objects as a guide in determining the length of time one could work in a particular area and keep doses below 100 mrem per week.

Table 2-4 Occupancy Time per week Labels Used in Accelerator and Beamline Enclosures

Dose Rate	Maximum Occupancy Time
20-50 mrem/hr	2 hours
Over 50 - 100 mrem/hr	1 hour
Over 100 - 200 mrem/hr	30 minutes
Over 200 mrem/hr	Contact Assigned RSO

235 Posting Contamination, High Contamination and Airborne Radioactivity Areas

1. Accessible areas shall be posted to alert personnel to the presence of contamination in accordance with Table 2-5. Further technical information is provided in Chapter 5. Signs may include specific entry/exit requirements.

3. Areas having concentrations of radionuclides exceeding one Derived Air Concentration (DAC) shall be posted as Airborne Radioactivity Areas only if they are occupied by personnel under such conditions. In other words, beamline enclosures are only posted as Airborne Radioactivity Areas if levels exceeding one DAC are present during access or if personnel present could receive an intake exceeding 12 DAC-hours in one week. Normally, allowance for decay of the short-lived accelerator-produced radionuclides is the preferred approach in accordance with ALARA.

4. DAC values for use with Table 2-5 are found in 10 CFR 835, Appendices A and C. Those in 10 CFR 835 Appendix C may be modified to account for submersion in an atmospheric cloud of finite dimensions. Values of DAC's for airborne radionuclides encountered at Fermilab are listed in Table 3-2. Further technical information is provided in Chapter 5.

Table 2-5 Criteria for Posting Contamination, High Contamination and Airborne Radioactivity Areas

AREA	CRITERIA	POSTING
Contamination	Levels (dpm/100 cm^2) > Table 2-2 Values but $\leq$ 100 times Table 2-2 values	CAUTION-CONTAMINATION AREA
High Contamination	Levels (dpm/100 cm^2) >100 times Table 2-2 values	DANGER-HIGH CONTAMINATION AREA or CAUTION – HIGH CONTAMINATION AREA
Fixed Contamination	Removable contamination below applicable levels Table 2-2	CAUTION-FIXED CONTAMINATION
Airborne Radioactivity	• Concentration exceeds the DAC value in Appendix A or C of 10CFR835; • Concentrations that could result in 12 DAC-hours in a week to an individual without respiratory protection	CAUTION-AIRBORNE RADIOACTIVITY AREA

236 Posting Requirements for Accelerator/Beamline Areas for Prompt Radiation

This article describes the posting criteria and the controls for Fermilab accelerator/beamline areas for beam-on conditions. Posting for areas where prompt radiation is not present is addressed in Article 234. In this section the term "dose" is applied to the effective dose to be assigned to an individual person based upon the appropriate radiation weighting (or quality) factor (see Tables 8-1 and 8-2) used to take the composition of the radiation field into account. See FRCM Chapter 8 for more details on the radiation dosimetry of prompt radiation fields.

2. The following general rules apply to the posting specified in this article.

   a. Given the nature of accelerator operations, it is often not feasible to remove radiological area postings when the beam is disabled even though lesser radiological hazards may exist. Radiation may in fact not be present in what is posted as a radiation area because fixed rather than real time signs are used. However, as long as signs are present their instructions and associated requirements are to be strictly adhered to by all personnel. The assigned RSO may also post specific beam line areas with a contingency statement (e.g., "Radiation Area when beam enabled" or "Radiation Area when RF is ON") with SRSO approval.

   b. This article is closely coupled with the radiation safety interlock systems which shall meet the requirements of FRCM Chapter 10 and thus must be used in conjunction with that Chapter.

   c. Where boundaries of the areas covered by this Article are identical with the boundaries of the corresponding Controlled Area, the Controlled Area posting is not required.

   d. Signs may be annotated to denote unusual radiation hazards.

   e. Accelerator/beamline enclosures to which personnel access is excluded during operations by the radiation safety interlock system are posted for the radiological conditions anticipated when the beam is off and personnel access is permitted.

   f. Entries to Exclusion Areas (see Glossary) shall be posted "Exclusion Area, No Access Permitted with Beam Enabled."

3. Posting Requirements

   a. Definitions

      (1) The maximum dose is that which can be delivered under the worst credible accident in that area, taking into consideration circumstances and controls, which serve to limit the intensity of the maximum beam loss and/or its duration. Some examples of accident scenarios are (1) beam intensity significantly greater than the nominal beam intensity; (2) unanticipated beam losses; and (3) single pulse full machine loss on an element.

      The maximum dose is to be determined through the safety analysis, which shall document calculations and measurements of possible radiation exposures, radiation shielding, beam optics and other relevant information. The safety analysis must be forwarded to the SRSO for a timely review prior to construction and/or operation of the beam. Chapter 8 of this Manual provides additional information concerning shielding design and the conduct of shielding assessments.

(2) Likely is a term that refers to the risk associated with a hazard, while potential is a term that implies the existence of a hazard. Once the hazard has been identified, it is more sensible to control the risk to personnel.

(3) Minimal occupancy area is any area which is not normally occupied by people more than 1 hour in 8 consecutive hours.

b. Required Controls

1) Because radiation levels can vary significantly with the operation of the accelerators and the impracticability of reposting every time the beam is turned on or off, accelerator/beamline enclosures are posted for the radiological conditions present when beam enclosures are rendered accessible to personnel. Physical controls, which render access impossible during operation, are imposed for those areas in which radiation levels could pose a significant danger to personnel.

2) Accelerator/beamline areas shall be posted and controlled for the normal operating conditions in accordance with Table 2-6 when the safety analysis documents that delivering the maximum dose to an individual is unlikely, or when the normal operating condition results in a higher posting level than Table 2-7.

3) Accelerator/beamline areas shall be posted and controlled in accordance with Table 2-7 when the safety analysis documents a scenario in which it is likely that the maximum dose may be delivered to an individual. Appendix 2C provides an approved methodology for taking into account the role of machine controls in determining the maximum dose that may be delivered to an individual to be used in the application of Table 2-7.

4) For roads over berms, culverts, parking areas adjacent to beamlines, and berm areas considered to be minimally occupied, if the safety analysis indicates an unlikely scenario which could result in a maximum dose corresponding to a posting status of no higher than a radiation area during the unlikely scenario, and no precautions are required for the normal operating condition, then no posting is required if the duration of the unlikely scenario is less than one hour.

5) Based on actual running conditions, the assigned RSO may impose additional controls.

c. With the prior approval of the SRSO, continuous coverage may be used as a substitute for fence and interlock requirements for up to 8 hours.

d. If the maximum dose is greater than 500 mrem, consideration should be given to performing a rigorous search and secure after each interlock trip if the assigned RSO determines that the presence of personnel exposed to a radiation dose of this magnitude is credible.

e. Table 2-7 includes the corresponding maximum dose permitted in any one hour. If after a single interlocked radiation detector trip, or multiple interlocked radiation detector trips, the maximum allowable dose in one hour is reached, the beam must remain disabled to that area for the remainder of the hour. It is the responsibility of the operating division/section to limit the number of allowable trips per hour of any interlocked detector based on the shielding assessment for that area. System hardware is the preferred method to control the number of trips per hour. However, administrative controls are allowed.

f. Appendix 2C provides the protocol for the use of machine controls to limit dose due to prompt radiation hazards in support of Article 236.

g. The interlocks referred to in the table must remove the beam, and thus the radiation, if any of the gates are opened.

h. The signs referred to in Table 2-6 and Table 2-7 must meet the requirements of Article 231.

Table 2-6 Control of Accessible Accelerator/Beamline Areas for Prompt Radiation Under Normal Operating Conditions (refer to Article 236.2(b))

Dose Rate (DR) Under Normal Operating Conditions	Controls
All interlocked doors or gates leading from non-enclosures into an interlocked Exclusion Area	Signs (EXCLUSION AREA – No Access Permitted with Beam Enabled.)
DR < 0.05 mrem/hr	No precautions needed.
0.05 ≤ DR < 0.25 mrem/hr	Signs (CAUTION -- Controlled Area). Occupancy limits determined by assigned RSO.
0.25 ≤ DR < 5 mrem/hr	Signs (CAUTION -- Controlled Area) and minimal occupancy (occupancy duration of less than 1 hr).
5 ≤ DR < 100 mrem/hr	Signs (CAUTION -- Radiation Area) and rigid barriers (at least 4' high) with locked gates. For beam-on radiation, access restricted to authorized personnel. Radiological Worker Training required.
100 ≤ DR < 500 mrem/hr	Signs (DANGER -- High Radiation Area) and 8 ft. high rigid barriers with interlocked gates or doors and visible flashing lights warning of the hazard. Rigid barriers with no gates or doors are a permitted alternate. No beam-on access permitted. Radiological Worker Training required.
DR≥ 500 mrem/hr	Prior approval of SRSO required with control measures specified on a case-by-case basis.

Table 2-7 Control of Accessible Accelerator/Beamline Areas for Prompt Radiation Under Accident Conditions When It is Likely that the Maximum Dose Can Be Delivered (See Article 236.2b for more details)

Maximum Dose (D) Expected in 1 hour	Controls
All interlocked doors or gates leading from non-enclosures into an interlocked Exclusion Area	Signs (EXCLUSION AREA – No Access Permitted with Beam Enabled.)
D < 1 mrem	No precautions needed.
1 < D ≤ 5 mrem	Minimal occupancy only (duration of credible occupancy < 1 hr) no posting. See Article 236.2.b.(4)
1 ≤ D < 5 mrem	Signs (CAUTION -- Controlled Area). Occupancy limits determined by assigned RSO. Radiological Worker Training required.
5 ≤ D < 100 mrem	Signs (CAUTION -- Radiation Area) and minimal occupancy (duration of occupancy of less than1 hr). The assigned RSO has the option of imposing additional controls in accordance with Article 231 to ensure personnel entry control is maintained. Radiological Worker Training required.
100 ≤ D < 500 mrem	Signs (DANGER -- High Radiation Area) and rigid barriers (at least 4' high) with locked gates. For beam-on radiation, access restricted to authorized personnel. Radiological Worker Training required.
500 ≤ D < 1000 mrem	Signs (DANGER -- High Radiation Area) and 8 ft. high rigid barriers with interlocked gates or doors and visible flashing lights warning of the hazard. Rigid barriers with no gates or doors are a permitted alternate. No beam-on access permitted. Radiological Worker Training required.
D ≥ 1000 mrem	Prior approval of SRSO required with control measures specified on a case-by-case basis.

237 Posting Radiological Buffer Areas

Radiological buffer areas are intended to provide boundaries to minimize the spread of contamination and to limit doses to general employees who have not been trained as radiological workers.

1. A radiological buffer area should be established for contamination control adjacent to any entrance to or exit from a contamination, high contamination, or airborne radioactivity area. The size of the radiological buffer area should be commensurate with the potential for the spread of contamination. A radiological buffer area may also be established in areas such as Change Rooms, where low-level contamination may be present, but where radioactive material handling is not specifically authorized. Radiological buffer areas established for contamination control should be located within controlled areas.

3. A radiological buffer area is not warranted for:
   a. High contamination or airborne radioactivity areas that are completely within contamination areas
   b. Inactive contamination, high contamination, or airborne radioactivity areas (i.e., areas to which entry has been prohibited by posting or barricades)
   c. Exposure control, if other posted boundaries or controls provide equivalent employee protection
   d. Exposure control, if general employees who are not trained as radiological workers are restricted from unescorted entry to controlled areas.
   e. Exposure control, if general employees who are not trained as radiological workers are unlikely to be present in the area long enough to receive 100 mrem in a year.

4. The need for radiological buffer areas around radioactive material areas should be determined by the Radiological Control Organization based upon the potential for exposure of unmonitored individuals and the spread of contamination.

5. Posting of radiological buffer areas should be in accordance with Article 231 and contain the wording "CAUTION, RADIOLOGICAL BUFFER AREA."

PART 4 RELEASE CERTIFICATION PROGRAM FOR FACILITIES CONTAINING RADIOACTIVE MATERIALS

241 Release Procedures

1. The ES&H Section is responsible for implementation of the release certification program for facilities containing radioactive materials and for coordination of annual update of the list of such facilities. For purposes of this Article, facilities "released" include facilities that are demolished.

2. Laboratory facilities in which radioactive materials have been produced, used, processed (e.g., machined) or stored must be certified by the ES&H Section as meeting established standards before they may be released for uncontrolled use (i.e. "cleared").

3. In order to meet the Article 1104.12 dose limits (25 mrem/yr for real property, 1 mrem/yr for personal property), a radiation survey of the facility must be made, and removal of radioactive materials and decontamination must be carried out if needed in order to obtain the release certification. The surveys must indicate that the radiation and contamination levels throughout the facility meet the criteria stated in Article 422.

4. Real property under evaluation for clearance from Fermilab radiological control must be evaluated against the need for maintaining institutional controls or impacting long-term stewardship of adjacent DOE real property. In situations where transfer of the real property to other use would impact long-term radiological protection of adjacent DOE properties, it must be demonstrated that the impact of the property clearance would not result in noncompliance for the adjacent property with the requirements of applicable statutes, regulations or DOE directives.

5. The division/section to which the facilities are assigned is responsible for meeting standards for release. Documentation of surveys, measurements, decontamination, and all measures taken to meet release standards shall be performed by the Radiological Control Organization prior to certification for release.

6. The ES&H Section will provide technical assistance to divisions/sections in order to meet the requirements of this Article.

7. For the purpose of this Part, a given building or part thereof that contains several areas where radioactive materials are used or stored may be considered to be a single facility.

8. The intent of this Part is to specify the certification requirements for the permanent, or long-term release, of facilities containing radioactive materials to other uses. Individual radioactive materials areas may be created or deleted in accordance with other provisions of this Manual. Once such areas have been established, they shall remain on the list of facilities containing radioactive materials until they are certified as cleared in accordance with this Article.

9. Recycling of metals is covered separately in FRCM Article 424.

Appendix 2A: Weighting Factors for Organs and Tissues

ORGANS OR TISSUES	TISSUE WEIGHTING FACTOR, w_T
Gonads	0.20
Red bone marrow	0.12
Colon	0.12
Lungs	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surfaces	0.01
Remainder[1]	0.05
Whole body[2]	1.00

Notes:

1. "Remainder" means the following additional tissues and organs and their masses, in grams, following parenthetically: adrenals (14), brain (1400), extra-thoracic airways (15), small intestine (640), kidneys (310), muscle (28,000), pancreas (100), spleen (180), thymus (20), and uterus (80). The equivalent dose to the remainder tissues ($H_{remainder}$), is normally calculated as the mass-weighted mean dose to the preceding ten organs and tissues. In those cases in which the most highly irradiated remainder tissue or organ receives the highest equivalent dose of all the organs, a weighting factor of 0.025 (half of remainder) is applied to that tissue or organ and 0.025 (half of remainder) to the mass-weighted equivalent dose in the rest of the remainder tissues and organs to give the remainder equivalent dose.

2. For the case of uniform external irradiation of the whole body, a tissue weighting factor (w_T) equal to 1 may be used in determination of the effective dose.

Appendix 2B: Non-Uniform Exposure of the Skin

Non-uniform exposures of the skin from x-rays, beta radiation and radioactive materials on the skin, including hot particles shall be assessed and recorded as specified in the table below. In no case shall a value of less than 0.1 be used.

AREA OF SKIN IRRADIATED	METHOD OF AVERAGING, ADDING TO OTHER DOSES RECEIVED, AND RECORDING NON-UNIFORM SKIN DOSE
$\geq$ 100 cm^2	Averaged over the 100 cm^2 of skin receiving the maximum dose Added to any uniform equivalent dose also received by the skin Recorded as the equivalent dose (H) to any extremity or skin for the year
10 cm^2 < area < 100 cm^2	Averaged over the 1 cm^2 of skin receiving the maximum dose (D), reduced by the fraction (f) which is the irradiated area in cm^2 divided by 100 cm^2 (i.e. H=fD). In no case shall a value of f <0.1 be used. Added to any uniform equivalent dose also received by the skin Recorded as the equivalent dose to any extremity or skin for the year.
< 10 cm^2	Averaged over the 1 cm^2 of skin receiving the maximum dose Not added to any other dose equivalent, extremity or equivalent dose (skin) recorded for the extremity or skin for the year. Recorded in a person's radiation dose record as a special entry

Appendix 2C: Protocol for Use of Machine Controls to Limit Dose Due to Prompt Radiation Hazards in Support of Article 236

There is a wide variety of control mechanisms in place that also serve, in practice, to limit the duration of beam loss. These include such items as:

Administrative Controls

- Policies
- Procedures
- Signs
- Machine Operators

Machine Protection Systems

- Beam Permit System
  - ✓ Beam Alarms
  - ✓ Loss Monitor Inputs
  - ✓ Power Supply Monitoring
  - ✓ Vacuum Valve Positions
  - ✓ RF Systems
  - ✓ Safety System[1]
  - ✓ Control System Software Monitoring
- Elements of the Accelerator Control System

These items collectively are called **machine controls** in this Appendix to distinguish them from the Safety System based on **credited controls** that follows the policies of Chapter 10 of this Manual. In the context of this Appendix, machine controls are systems that are used to limit accidental beam losses. These systems may prevent a beam loss from occurring, may prevent subsequent beam losses from occurring, or may include monitoring secondary effects from significant beam losses such as loss of vacuum that then potentially result in actions that prevent further beam losses from occurring.

While all of these machine controls are capable of terminating beam operations upon discovery of an excessive beam loss, the laboratory recognizes full well that they all have failure modes and do not meet the level of rigor designed into to the Safety System. While not intending to provide a comprehensive litany of failure modes, several have been discussed by an expert based panel. Administrative controls are obviously subject to well-known human performance factors that can lead to failures. Likewise, the automated machine protection systems, unlike the redundant Safety System items are single output devices. Inputs to the machine protection system can be "masked" (i.e., taken off line) during beam tuning and troubleshooting activities and thus have the potential to not be "unmasked" when normal operations resume.

[1] To be clear, while the Safety System provides an input to the Beam Permit System for monitoring purposes, it will terminate the beam directly and independently of all other systems.

The expert-based review panel commissioned by the Fermilab Director, the Machine Beam Loss Scenarios Panel, arrived at the general conclusion that to use such machine controls as a supplement to the Safety System to limit doses due to accidental beam loss, is only feasible if a multiplicity of machine controls are used.

Likewise, it is clear that one should limit how much dose should be allowed in a given location should all machine controls fail. For example, especially given the public accessibility to the Fermilab site, it would not be reasonable for machine controls alone to accommodate a change in the posting status of Table 2-7 from the 1st row where only one mrem in an hour is possible to the 6th row where the dose could be between 500 and 1000 mrem. Furthermore, DOE Order 420.2C specifies that if the accident condition could result in a dose exceeding 1000 mrem at the site boundary, the Fermilab Accelerator Safety Envelope can no longer be approved by the DOE Fermi Site Office Manager and it must be approved by the Office of Science Program Secretarial Officer.

The review panel proposed and the Director has approved an approach, described below, that can be included as part of the shielding assessment and safety assessment document of a given area in addition to the protection afforded by the Safety System. In its discussions, and as used below, the panel found it more instructive to invert Table 2-7 with the highest dose at the top. Clearly, this only applies to accident conditions; normal operational doses will define the categories according to Table 2-6 as always.

The panel proposed to allow for the addition of machine controls as follows to move the accident condition posting and shielding requirements downward on this table by no more than 2 categories. Each accelerator area would develop a document that outlines the accelerator controls used to limit and protect against accidental beam losses. This document would list each machine control, a description of sufficient detail to justify its use, an estimate of the amount of protection provided, and possible failure modes. The document would be submitted for review and a request for approval by the director to reduce the required controls by one or two categories based on the machine controls and credible accident conditions. When possible, past accelerator operating experience should be included to demonstrate the effectiveness of the machine controls.

The machine controls for each accelerator segment would initially be assessed by the Machine Beam Loss Scenarios Panel and other system experts as called upon by the panel. This arrangement may be modified in the future dependent upon the experience gained with the use of this protocol.

Since machine controls may be different in various locations of the Fermilab accelerator, the panel uses the criteria that 2 – 3 machine controls are required for each category reduction on Table 2-7. The panel had considerable debate on this topic. Everyone believes there is value and additional safety provided by having the administrative control of a Main Control Room with trained operators. However, the panel also agrees that one would not want to use, for example, 5 administrative controls to allow for 2 beam loss category reductions. Thus, reliance should be placed on automated electronic controls, as opposed to administrative controls. When administrative controls are considered, only one administrative control would be allowed in each category reduction.

The machine beam loss controls documented for each accelerator segment or machine would be approved by the Directorate and become the credible accident condition basis for the shielding assessment and safety assessment documents for the machine or accelerator segment.

The following table showing FRCM Table 2-7 categories illustrates how this would be done.

Machine Controls Table

Maximum Dose (D) Expected in 1 Hour	Machine Controls
1000≤D mrem	SRSO Approval Required with Control Measures Specified on a Case-by-Case Basis
500≤D<1000 mrem	Credited Controls Always Required
100≤D<500 mrem	4-5 Machine Controls
5≤D<100 mrem	2-3 Machine Controls; 4-5 Machine Controls
1≤D<5 mrem	2-3 Machine Controls
1≤D<10 mrem	Special Category Not Normally Used
D<1 mrem	

Analysis of Hazards and Risk

To evaluate the hazards and risks from applying this proposed methodology for a given accelerator area, one must start with the assumption that there are no machine controls being used to look at the accident rate reduction. Next one needs to define the maximum acceptable risk. Under this proposal, machine controls are only allowed to protect against accident dose rates of less than 500 mrem in an hr. Any area with an accident dose rate greater than 500 mrem in an hour must always be protected against by the machine Radiation Safety System which is an established credited control.

Consistent with the draft Implementation Guide for DOE O 420.2C, Safety of Accelerator Facilities, the panel used ANSI/ASSE Z590.3-2011, Prevention through Design Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes to qualitatively assess the hazards and risks from this proposal. The standard uses qualitative terms to assess the probability of an occurrence and the severity of the consequences from an event to assess the risk.

The severity of an incident or exposure is expressed in terms such as Catastrophic, Critical, Marginal, Negligible, and Insignificant.

The following are typical definitions used for severity.

Incident or Exposure Severity Descriptions

Catastrophic: One or more fatalities, total system loss, chemical release with lasting environmental or public health impact.

Critical: Disabling injury or illness, major property damage and business downtime, chemical release with temporary environmental or public health impact.

Marginal: Medical treatment or restricted work, minor subsystem loss or damage, chemical release triggering external reporting requirements.

Negligible: First aid or minor medical treatment only, non-serious equipment or facility damage, chemical release requiring routine cleanup without reporting.

Insignificant: Inconsequential with respect to injuries or illnesses, system loss or downtime, or environmental chemical release.

The probability of an incident or exposure is expressed in terms such as Frequent, Likely, Occasional, Seldom, and Unlikely.

The following are typical definitions used for probability

Incident or Exposure Probability Descriptions

Frequent: Likely to occur repeatedly. Could occur annually.

Likely: Probably will occur several times. Could occur once in two years.

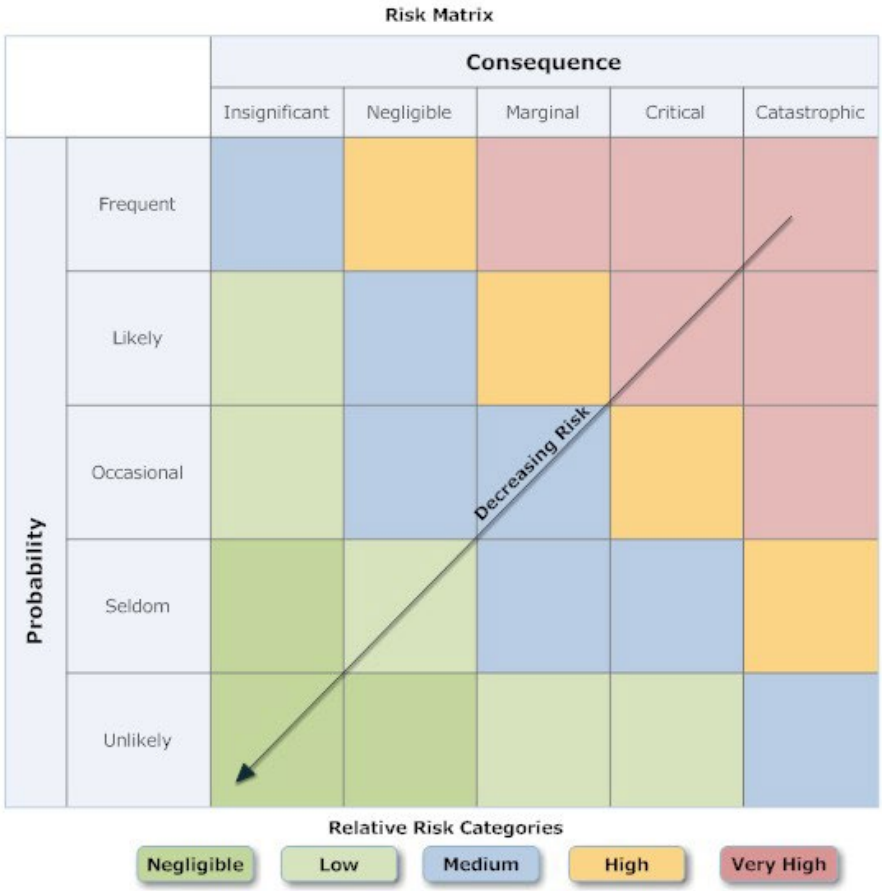
Occasional: Could occur intermittently. Could occur once in five years.

Seldom: Could occur, but hardly ever. Could occur once in ten years.

Unlikely: Improbable, may assume incident or exposure will not occur. Occurring not more than once in twenty years.

The risk from an activity is the product of the consequence and probability, which can be viewed on the following example risk matrix. The risk colors in the matrix are used to provide qualitative indicators of the relative risk using a word descriptive grading and scoring system. They only have value in showing the relative risk in the matrix in a qualitative way. For example, an activity that has an *Insignificant* consequence and a probability that it is *Unlikely* to occur would be a *Negligible* risk

activity generally not requiring any controls to mitigate the activity. When an activity has a *Catastrophic* consequence and a probability that it will *Frequently* occur would be a *Very High* risk activity with controls established to prevent its occurrence.



The consequence and probability descriptions along with the risk matrix provides a way to qualitatively analyze the risks and risk reductions from using machine controls to limit accidental beam loss events. Using the consequence criteria to assess the severity, the maximum possible hazard is up to a 500 mrem in an hr dose to an individual. The potential for health effects or environmental damage from this dose rate is very slight leading to a consequence description of *Negligible*. However, a dose greater than 100 mrem in an hour, should it actually occur, could require regulatory reporting, given the requirements of 10 CFR 835 and DOE O458.1. The regulatory reporting combined with the public perception from a reporting an accident beam loss event results in a consequence description of *Marginal*.

Using the probability criteria to assess the likelihood of occurrence, we need to look at how often an accident event might occur. Although all operating accelerator and beamline areas have a multitude of machine controls, we need to start with the assumption that there are no machine controls in place

to limit possible events to view the risk reduction from their use. A conservative assumption would be that accident events occur *frequently*.

The following risk matrix attempts to loosely map the FRCM Table 2-7 accidental beam loss dose rates and probability of occurrence rates to show the effects of using machine controls to limit accidental dose rate risks under this proposal. Beginning with an area that has an unmitigated accident dose rate between 100 – 500 mrem in an hr, applying different machine controls, shown as C1 & C2, could reduce the duration of events thus reducing the consequence from a beam loss event as depicted with the horizontal arrows. Examples of items that can reduce the duration of events are beam position monitors and beam loss monitors.

Another control, shown as C3, might reduce the probability of an occurrence moving down on the matrix. Examples of items that reduce the probability of events are trained operators in the Main Control Room and Vacuum Valve Position monitors. By applying additional machine controls, C4 & C5, the probability and/or duration of an accidental beam loss event can be further reduced thus reducing the relative risk from an event as shown in the risk matrix.