**R. P. NOTE #7**

# FERMILAB INTERNAL DOSIMETRY

# TECHNICAL BASIS DOCUMENT

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# FERMILAB INTERNAL DOSIMETRY TECHNICAL BASIS DOCUMENT

## I. Summary

The purpose of this paper is to document Fermilab's internal dose evaluation program in accordance with the requirements of 10CFR835. In 2007, 10CFR835 was incorporated to use the newer radiation dosimetry system instituted by the ICRP beginning in ICRP Report 60. This has led to new terminology being used for radiation dosimetry. Most of the analytical work used in this paper was performed at Fermilab's Radionuclide Analysis Facility (RAF). Although Fermilab does continue to utilize these same services provided by Argonne National Laboratory. Results from both laboratories were reviewed. The RAF continues to have a robust blind audit program, and participates in intercomparison studies with ANL. 10CFR835.402c requires monitoring of individual exposures to internal radiation, and hence, implementing a routine internal dosimetry program (including routine bioassay programs) for the following[1]:

- "Radiological workers who, under typical conditions, are likely to receive a committed effective dose of 0.1 rem (0.001 sievert) or more from all occupational radionuclide intakes in a year."
- "Declared pregnant workers likely to receive an intake or intakes resulting in an equivalent dose to the embryo/fetus in excess of 10 percent of the limit stated in § 835.206(a)."
- "Occupationally exposed minors who are likely to receive a dose in excess of 50 percent of the applicable limit stated at § 835.207 from all radionuclide intakes in a year."
- "Members of the public entering a controlled area likely to receive a dose in excess of 50 percent of the limit stated at § 835.208 from all radionuclide intakes in a year."

Fermilab policy addresses these requirements, as there are no radiological workers who, under typical conditions, are likely to receive a committed effective dose (CED) of 100 mrem or more from all occupational radionuclide intakes in a year; no declared pregnant worker is likely to receive an intake or intakes resulting in an equivalent dose to the embryo/fetus of 50 mrem, which is 10% of the stated limit in § 835.206; no occupationally exposed minors who are likely to receive an equivalent dose of 50 mrem, which is 50% of the stated limit in § 835.207 from all radionuclide intakes in a year; and no members of the public entering a radiologically controlled area who are likely to receive an equivalent dose of 50 mrem, which is 50% of the stated limit in § 835.208 from all radionuclide intakes in a year. Should the operational or radiological conditions at the Laboratory change, such that routine monitoring of individual exposures to internal radiation is necessary, Fermilab will implement an internal dosimetry program to ensure that the equivalent dose limits established in 10CFR835, subpart C are not exceeded. Fermilab's internal dose evaluation program provides for discretionary monitoring on a case-by-case basis to address special circumstances and accidental or emergency exposures. Under these circumstances, bioassay and/or whole body counting services are

obtained from Argonne National Laboratory under an existing memorandum purchase order arrangement or from another DOELAP accredited provider. The results would be the basis of a dose assessment using the ICRP Publication 60 model(s) and subsequent revisions of its methodology by ICRP. The dose assessment will be incorporated into the exposed individual's personnel exposure history.

## II. Potential Sources of Exposure and Exposure Pathways

Identifying radionuclides that may be inadvertently taken into the body and the amount of intake may be inferred using workplace monitoring data (e.g., airborne contamination concentration measurements, surface wipes, application of resuspension factors to measured surface contamination levels, etc.). Airborne radioactive material concentration data may be used as a direct indication of intake, especially if information on particle size distribution can be obtained. The sources of potential internal exposure at Fermilab consist of airborne radioactivity, radioactivated water, radioactivated materials, and surface contamination. Principally, the radioactive materials that are of concern are those produced in the course of accelerator operations and maintenance activities and the exposure pathways considered in this evaluation are inhalation and ingestion.

At Fermilab, radiation workers are very rarely exposed to airborne radioactivity levels that require a routine internal dosimetry program. Currently, Fermilab has no enclosures or areas that are required to be posted as an Airborne Radioactivity Area as defined in 10CFR835. Beam line enclosures where increased airborne radioactivity concentrations may be present during beam operations are not accessible to workers while the beam is enabled. As soon as beam operation ceases, further production of airborne radioactivity ceases. Air activation products can also be an external exposure immersion hazard, and with the exception of H-3, are readily detected using hand-held radiation instruments, and personnel dosimeters in use at Fermilab. In cases where the initial airborne radioactivity concentrations are high enough to present a radiological hazard, the area would be appropriately posted and administrative controls would be in place that would require a cool-off time before workers are allowed to enter, should that be necessary.

Other than the radioactivation of air, the most common accelerator-produced radionuclides present at Fermilab are Co-57, Co-60, Mn-54, Be-7, Na-22, Na-24 and Tritium (H-3). These radioisotopes can be present in the form of dust deposited on surfaces.

Work with sealed radioactive sources represents a less probable pathway. Common types of sealed radioactive sources used at Fermilab are Fe-55, Co-60, Ru-106, Sr-90, and Am-241. Typical activities of the various radioactive sources are listed in the Fermilab Radiological Control Manual (FRCM).[3] A number of stringent controls have been instituted to reduce the risk of sealed source breakage.

Work with depleted uranium (DU), mostly associated with the D0 Tevatron Collider Experiment, now no longer operational, is considered separately from this summary. The

Particle Physics Division (PPD) has special procedures for handling DU. When work with depleted uranium occurs in the future, these procedures will be followed. For example, this topic will be reviewed as part of the hazard assessment to be conducted for the decommissioning of the D0 Detector at the time when the schedule and work plan for that activity are being developed.

To perform this evaluation and determine the necessity of a routine internal radiation monitoring program, various types of radionuclide analysis reports from the RAF were reviewed for all Divisions, Sections and Centers. These sample reports included wipes, water samples and air filters.

### A. Airborne Radioactivity Pathway

10CFR835.403(a)(1) requires that "Monitoring of airborne radioactivity shall be performed: Where an individual is likely to receive and exposure of 40 or more DAC-hours in a year". Another way of expressing this is, air sampling shall be performed in occupied areas where, under typical conditions, an individual is likely to receive an annual intake of 2% or more of the specified DAC values. The Accelerator Division (AD) has identified enclosures and areas that require continuous airborne radioactivity monitoring and the data is electronically logged and readily retrievable[4].

Because of the relatively short half-lives of air activation products produced during normal operations at Fermilab, it is highly unlikely to have an area where an individual could receive an exposure of 40 or more DAC-hours in a year. However, it should be noted that exposure to airborne radioactivity at Fermilab is ultimately eliminated by controlling facility ventilation and imposing administrative procedures prohibiting personnel access to areas where airborne radioactivity is present[3], until concentrations of the short-lived radionuclides have been reduced to acceptable levels.

However, from the air sampling results it is possible to make a conservative estimate of the airborne radioactivity levels and compare them to the DAC listed in 10CFR835. Personal air monitor and air filter analysis results submitted by AD, PPD, Technical Division (TD), and Facilities Engineering Services Section (FESS) were reviewed from calendar year 2010 through calendar year 2012. The results showed no airborne radioactivity levels that were in excess of 2% of the derived air concentrations (DAC) in 10CFR835. For example, the highest radionuclide concentration found from an air filter, was Be-7 at $3x10^5$ pCi/ml. Assuming a sample flow rate of 10L/min and a sampling time of 24 hours[5], that would give an airborne radioactivity level of Be-7 of $2.1x10^{-8}$ µCi/ml. This can be done for the other radionuclides also. See Table 1 for these values and the corresponding DAC values.

Typical air samples would most likely contain a mixture of radionuclides. In that case, the sum of the ratio of the observed concentration of each radionuclide and its corresponding DAC, would be determined. If this sum exceeds unity, then the DAC has been exceeded. However, since each radionuclide was well below 2% of their respective DAC values, the calculation was performed with each radionuclide individually.

In some areas there may be low incidental levels of airborne Tritium, due to natural evaporation of low concentrations of Tritium from damp spaces, and water in the drain tiles, into the enclosed space where workers may be present. Fermilab has a method to estimate these airborne Tritium levels by measuring the condensate pulled from the air by dehumidifiers[6]. Studies have shown that the condensate would have to have a Tritium concentration higher than $1.17x10^6$ pCi/ml, assuming 68 degrees and 100% humidity, to exceed the DAC. To put this in perspective, this concentration is only slightly higher than the Fermilab guidance upper limit of $1x10^6$ pCi/ml for Tritium in the Radioactive Water Systems (RAW). Under these same conditions, the Tritium concentration in a dehumidifier condensate sample would need to be $2.3x10^4$ pCi/ml to exceed 2% of the DAC. It is also important to note that these calculations assumed that a worker is continuously present in the work space with these highly elevated airborne Tritium levels for 8 hours/day, over an entire 2000 hour work year. Fermilab does not have any plausible scenarios that could allow this to occur for airborne Tritium.

**B. Surface Contamination Pathway**

Considerable effort during both "Supervised and Controlled Access," is expended to keep personnel away from radioactive contamination areas. Areas in and around the beam line enclosures where contamination is present, are posted accordingly. Typically these correspond with High Radiation Areas, and they are roped off and posted as "High Radiation Area, Contamination Area and Keep Out". If an unusual localized contamination area is identified, it is then usually decontaminated, as it is more efficient to do so rather than post it and provide Radiological Control Technician coverage to oversee the work.

Radioactive particulate materials can exist as dust deposited on a surface or dispersed in the air. The main radiation hazard that can result from surface contamination arises from skin contamination and subsequent ingestion. Although the potential exists for the inhalation of the airborne particulates as a result of surface dust becoming airborne, experience has shown that typical resuspension factors are quite small ($\approx 1X10^{-6}\ m^{-1}$)[9], and as a result, this particular pathway does not present a significant internal radiation hazard. The hazards associated with short-lived and long-lived particulates are quite different. The long-lived particulates, such as Be-7, a radioisotope potentially deposited on surfaces at accelerator facilities, presents a much greater internal hazard than the short-lived particulates. Surface contamination levels have been evaluated for several long- lived radionuclides. Wipe sample results were used to determine if any areas have levels of surface contamination which indicate that action should be taken to avoid possible radiation dose from inhalation, ingestion or skin absorption. These decision levels are based on an estimated dose equal to the limits for workers (5 rem per year whole body, bone marrow or gonads).

To correlate baseline decision levels that correspond to an annual total effective dose of 100 mrem, 2% of the decision level values are used. These levels are compared with actual wipe survey results and used for determining whether an internal dosimetry program is necessary at Fermilab. Contamination wipe survey results from CY2010 to CY2012 of areas within AD, PPD, TD, FESS and the Business Services Section (BSS) were reviewed. These records show that Fermilab does not have sufficient levels of contamination which could lead to the potential for workers to inhale or ingest amounts of radionuclides which would result in a 100 mrem committed effective dose (CED). The radionuclide that has been found in the highest concentration is Be-7 at MI-12B. MI-12B is an enclosure for the MiniBoone Neutrino experiment. Wipe samples were obtained throughout the enclosure and the concentration of Be-7 was fairly uniform with an average concentration of 10,000 pCi/100cm$^2$. Calculations have shown that ingesting this amount of Be-7 would result in a CED of 1.3 μrem[5]. As mentioned earlier, inhalation or ingestion of radioactive material from resuspension of surface contamination is unlikely. However, using a resuspension factor[9] of $1 \times 10^{-6}$ m$^{-1}$, gives a potential airborne concentration of Be-7 to be $1.71 \times 10^{-3}$ pCi/100cm$^3$ or $1.71 \times 10^{-11}$ μCi/ml. This is significantly less than 2% of the DAC for Be-7, which is $2 \times 10^{-7}$ μCi/ml.

Therefore, no significant surface contamination levels exist to cause an annual total effective dose of 100 mrem from intake via inhalation or ingestion. In addition, there are engineering and administrative controls in place for entry into an area determined to be a Contamination Area that would prevent any radiological worker to receive one DAC, and ultimately, the Annual Limit on Intake (ALI) of any radionuclide as outlined in the FRCM.

## C. Immersion

As stated previously, an immersion dose could potentially result due to radioactivated air. Typically the airborne radionuclides that could result in an immersion dose in the Fermilab enclosures, consists mostly of the radioisotopes N-13, C-11, O-15 and Ar-41 may also be produced if there is a large flux of thermal neutrons present. However, due to the short half-lives of N-13, C-11 and O-15, and the administrative controls that are in place that prevent personnel from entering beam line enclosures right after the beam is shut off, this hazard is avoided.

It's possible for H-3 to also be present. This is also not a consideration for an immersion dose because while H-3 does have a 12 year half-life, it emits beta radiation that is too weak to penetrate the outer layer of the skin, therefore, the inhalation pathway is the greater concern.

## D. Pathway Involving Ingestion of Water Containing Tritium and Exposure to Other Miscellaneous Materials during Accelerator Maintenance and Operation

As previously mentioned, the ingestion pathway is even less likely than inhalation or immersion. RAF water sample analysis results taken from cooling water were reviewed. Specifically samples taken from NuMI RAW system, which has been shown consistently over time to contain the highest radionuclide levels produced as a result of routine accelerator operations. Of the accelerator produced radionuclides found in cooling systems, Tritium is found to have the highest concentration[5]. The following calculation shows that personnel only under extreme, accidental and, completely implausible, conditions will have an intake that results in a CED of 53 mrem. The dose estimate is based on an ingestion of 1000 ml of water containing H-3, and the breathing volume of Reference Man for one working year.

<u>Internal Dose Calculation for a Single Ingested Intake of Tritium using ICRP Methodology</u>

We can determine the ALI for Tritium for ingestion, from the DAC for Tritium for inhalation. The DAC = $2x10^{-5}$ µCi/ml and the breathing volume = 2400 $m^3$ = $2.4x10^9$ ml.

So the for ALI for Tritium = $2x10^{-5}$ µCi/ml x $2.4x10^9$ ml = $4.8x10^4$ µCi → which corresponds to 5000 mrem.

So then we can relate dose to uptake, with a dose conversion factor of:

5000 mrem/$4.8x10^4$ µCi = 0.104 mrem/µCi.

The RAW sample found with the highest concentration of Tritium was 513,000 pCi/ml. If one ingested 1000 ml, the total Tritium concentration ingested would be 513 µCi.

Resulting in a Committed Effective Dose of:

513 µCi x 0.104 mrem/µCi = 53 mrem

So, to determine the sample concentration of H-3 needed to result in 100 mrem,

100 mrem/0.104 mrem/µCi = 961.5 µCi

## E. Bioassay and Whole Body Counting Reports

Urine bioassay and whole body counting is conducted on a case-by-case basis depending on the operations involved. Each Division/Section/Center ES&H Group has the responsibility for determining when urine bioassay and/or whole body counting should be performed. If deemed necessary, urine bioassay and whole body counting will be arranged. All urinalysis and whole body counting is conducted under memorandum purchase order with Argonne National Laboratory (ANL). There has been no results of monitoring reports or events that have indicated the need to collect bioassay sample for approximately seven years.

### F. Evaluation for Declared Pregnant Workers, Minors, and Members of the Public

As required by its implementation of 10CFR835, Fermilab has a declared pregnant worker policy which provides options for the worker during pregnancy. All options outlined for the declared pregnant worker in this policy ensure that a declared pregnant worker will not receive an equivalent dose to the embryo/fetus in excess of 50 mrem per month during the pregnancy. This includes internal and external radiation doses combined.

Adult members of the public are not permitted to enter radiological areas unescorted. The FRCM provides detailed procedures for visitors to enter radiological areas, however in no case are they permitted to enter known contamination areas. The Fermilab Radiological Control Manual (FRCM) requires Senior Radiation Safety Officer approval for entry of minors into any radiological area. Requirements set forth in the FRCM preclude minors from entering radiological areas, thus preventing minors from intakes of radioactive material.

## III. Conclusion

Based on the above analysis, and with the current administrative and procedural controls in place, it is concluded that Fermilab does not have sources of surface contamination, water or airborne radioactivity levels such that workers could routinely inhale or ingest radionuclides that would cause personnel to receive an committed effective dose of 100 mrem to the whole body or 5 rem to any tissue or organ from all occupational radionuclide intakes. Therefore, a routine internal radiation monitoring program is not required.

**TABLE 1**

**The measured concentrations of radionuclides typically found at Fermilab and the Derived Air Concentrations (DAC)[1]**

| Radionuclide | Typical Concentration | DAC | 2% of DAC |
|---|---|---|---|
| | (μCi/ml) | (μCi/ml) | (μCi/ml) |
| | | | |
| Na-22 | $3.3x10^{-11}$ | $2x10^{-7}$ | $4x10^{-9}$ |
| Co-58 | $2.8x10^{-10}$ | $4x10^{-7}$ | $8x10^{-9}$ |
| Co-57 | $3x10^{-10}$ | $1x10^{-6}$ | $2x10^{-8}$ |
| Co-56 | $1.2x10^{-10}$ | $1x10^{-7}$ | $2x10^{-9}$ |
| Be-7 | $2.1x10^{-8}$ | $1x10^{-5}$ | $2x10^{-7}$ |
| Mn-54 | $5.5x10^{-11}$ | $5x10^{-7}$ | $1x10^{-8}$ |
| Mn-52 | $2x10^{-9}$ | $2x10^{-7}$ | $4x10^{-9}$ |
| Cr-51 | $1.1x10^{-10}$ | $1x10^{-5}$ | $2x10^{-7}$ |
| Co-60 | $5x10^{-12}$ | $3x10^{-8}$ | $6x10^{-10}$ |
| Sc-46 | $2.4x10^{-11}$ | $1x10^{-7}$ | $2x10^{-9}$ |
| V-48 | $2.1x10^{-11}$ | $2x10^{-7}$ | $4x10^{-9}$ |

## REFERENCES


1. 10CFR835; 2007

2. Draft DOE-G 441.1-3A *Internal Dosimetry Program Guide for Use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection*

3. Fermilab Radiological Control Manual

4. RP Note 128

5. RP Note 146

6. RP Note 157

7. "Limits for Intakes of Radionuclides by Workers," ICRP Publication 60

8. "Limiting Values of Radionuclide Intake And Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion," EPA Federal Guidance Report No. 11, September 1988.

9. USNRC NUREG/CR-5512, Vol. 3 SAND99-2148
*Residual Radioactive Contamination From Decommissioning Parameter Analysis*