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Technical Basis Document for Inapplicability of Internal Dosimetry Monitoring Program at Jefferson Lab

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Introduction

The purpose of this technical note is to document that Jefferson Lab does not need to monitor individual individual exposure to internal radiation or have an internal dosimetry monitoring program.

Jefferson Lab has the following requirement under 10 CFR 835.402(c):
"For the purpose of monitoring individual exposures to internal radiation, internal dosimetry programs (including routine bioassay programs) shall be conducted for:
(1) Radiological workers who, under typical conditions, are likely to receive a committed effective dose equivalent of 0.1 rem (0.001 sievert) or more from occupational radionuclide intakes in a year:
(2) Declared pregnant workers likely to receive an intake or intakes resulting in a dose equivalent to the embryo/fetus in excess of 10 percent of the limit stated at 835.206(a);
(3) 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; or
(4) 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."[1].
Additionally, 10 CFR 835.402(d) requires that:
"Internal dose monitoring programs implemented to demonstrate compliance with 835.402(c) shall be adequate to demonstrate compliance with the dose limits in Subpart C of this part and shall be:
(1) Accredited, or excepted from accreditation, in accordance with the DOE Laboratory Accreditation Program for Radiobioassay; or,
(2) Determined by the Secretarial Officer responsible for environment, safety and health matters to have performance substantially equivalent to that of programs accredited under the DOE Laboratory Accreditation Program for Radiobioassay."[1]

Various Jefferson Lab health physics personnel (and qualified professionals external to Jefferson Lab) have performed and documented calculations indicating that none of the aforementioned limits triggering the requirement for internal dosimetry could occur during typical Jefferson Lab accelerator operations. These calculations and assertions have been verified to a large degree through airborne activation monitoring measurements (documented in annual NESHAPS reports). The intent of this Technical Basis Document is to synthesize previous calculations and data into a

coherent technical basis document that clearly explains why an internal dosimetry program is not currently required at Jefferson Lab. Additionally, this document lists several factors that would trigger a re-evaluation of the need for a DOELAP accredited internal dosimetry program.

Background Information

From the 10 CFR 835.402 internal dosimetry requirements an internal dosimetry program would be required for:

(1) Radiological workers, under typical conditions, likely to receive a committed effective dose equivalent (CEDE) of 100 mrem or more in a year
(2) Declared pregnant workers likely to receive a dose to the fetus in excess of 50 mrem
(3) Occupationally exposed minors likely to receive a dose in excess of 50 mrem CEDE from all radionuclide intakes in a year
(4) Members of the public entering a controlled area likely to receive a dose in excess of 50 mrem CEDE from all radionuclide intakes in a year

DOE Standard for Internal Dosimetry[2] Example 5.3 "Circumstances Not Requiring Routine Individual Monitoring" states that routine individual monitoring is not necessary when "Quantities of radioactive materials in process are less than 2% of an ALI" (i.e., 40 DAC-hrs.)

Operational Conditions for Experimental Halls:

Accelerator Beam is produced and run in the Halls almost continuously with the exception of stops for short entries to replace failed accelerator components, or to make minor adjustments, calibrations, etc. Additionally there are typically 2 scheduled accelerator down maintenance periods (SADs) annually, each approximately 4 weeks in duration, in which maintenance is performed (and no activated air is produced.) Under these conditions, we can devise an extremely conservative exposure scenario involving the following assumptions: (1) entries to the accelerator enclosure occur on the order of once per operational day (2) the same individual is present for each entry, and (3) the individual is present in the area for one hour, during which there is no radioactive decay and no removal by ventilation of radioactivity (i.e., airborne concentration remains at beam-on operational level during access). This results in a total exposure time of approximately 310 hours per year to the maximum concentration of accelerator-produced airborne radioactivity.

Volume of Experimental Halls A and C[3]: A - 4.19E4 cubic meters
C – 2.99E4 cubic meters

Ventilation rate[3]: 1000cubic feet/minute (0.472 m^3s^{-1})

Calculations/Explanations:

Table 1
Typical radionuclide production from 2001 to 2004 NESHAP reports (average and maximum) based on NESHAP Tech note[4]:

Radionuclide	Annual Maximum Total (Ci)	Annual Average Total (Ci)	Annual Maximum Total (Bq)	Annual Average Total (Bq)
N-13	9.19	6.71	3.4E11	2.48E11
H-3	3.49E-1	1.02E-1	1.29E10	1.29E10
Be-7	3.88E-3	2.95E-3	1.44E6	1.09E8
C-11	1.21	8.86E-1	4.48E10	3.27E10
O-15	4.9	3.58	1.81E11	1.32E11
Cl-38	5.14E-2	3.77E-2	1.9E9	1.39E9
Cl-39	6.2E-1	4.56E-1	2.29E10	1.69E10
Ar-41	2.51E-3	1.84E-3	9.29E7	6.8E7

NOTE: This is the total released from all high air activation points on site (Hall A, Hall C, and BSY.)

Table 2
DACs from 10 CFR 835 for typical airborne radionuclides[1]

radionuclide	Inhalation DAC (Bq/m^3)	Immersion DAC (Bq/m^3)
H-3 elemental	2E10	-
H-3 water	2E5	-
Be-7	3E5	-
C-11	1E7 (CO_2)	1E5
N-13	-	1E5
O-15	-	1E5
Cl-38	6E5	1E5
Cl-39	8E5	-
Ar-41	-	1E5

2.5 mrem/hr per each hour worked in a DAC concentration

Table 3
Worst Case Scenario Initial DAC Concentration for Entire Year in Hall C Assuming No Radioactive Decay or Ventilation

Radionuclide	Emission	Half – life	Column 4 Annual Maximum Total/Volume of Hall C (Bq/m^3)	Column 4/DAC (% DAC)
N-13	positron	10 minutes	11.4E6	114
H-3	Beta minus	12.3 years	4.31E5	2.2
Be-7	Gamma, electron capture	54 days	48	1.6E-4
C-11	positron	20.5 minutes	1.5E6	10
O-15	positron	2.1 minutes	6E6	60
Cl-38	Beta minus, gamma	37 minutes	6.35E4	0.635
Cl-39	Beta minus, gamma	55 minutes	7.65E3	9.56E-3
Ar-41	Beta minus gamma	1.8 hours	3.1E3	0.031
Total				186.9
Total for Radionuclides with Internal Dosimetry Ramifications (H-3, Be-7, Cl-38, Cl-39)				2.84

As one can see by inspection (and as noted in literature such as IAEA Technical Report 188[5] and FERMILAB-TM-1834[6]), the dominant airborne radionuclides are N-13, C-11 and O-15, all of which reduce to a total concentration of less than 1 DAC in slightly over an hour through radioactive decay (neglecting the complete air exchange in Hall C in 17.6 hours). These radionuclides, for which the basis for the DAC is external exposure from the gamma energy emission (or immersion dose) resultant from positron decay and subsequent annihilation with electrons, are not truly applicable as internal dosimetry concerns. Similarly, the noble gas Ar-41 has a DAC level based on external exposure from immersion dose. Note: DAC levels are based on a number of different factors, including radioactive decay, energy deposition, and chemical composition. Radionuclides presenting "true" internal hazards typically have longer half-lives (i.e., days to years) and/or have a significant particle emission (i.e., alpha or beta) and/or tend to concentrate in a particular region of the body due to biological reasons (e.g., I-131 in the thyroid). Radionuclides that do not filter into these categories (such as C-11, N-13, O-15 and Ar-41) have DACs calculated from immersion dose. Tech Note 97-017[7] provides more

detailed information on immersion dose , which is also summarized later in this document.

For radionuclides having an inhalation dose pathway, for which an internal dosimetry program would be applicable, we can propose an extremely conservative "worst case scenario" based on the following: (1) Table 1 Maximum Totals represent the sum of the highest total activity produced annually in Hall A, Hall C and the BSY, (2) all of the radioactivity is assumed to be produced in Hall C, and (3) the total annual activity is assumed to be present instantaneously in the hall. Table 3 gives the DAC value that would exist in Hall C under these conditions. In this scenario, if a person entered the hall and remained for one and a half workshifts, during which it is assumed the concentration is not reduced by radioactive decay or ventilation, the resulting dose from inhalation would be:

12 hours x 2.84 DAC x 2.5 mrem/DAC-hr = 85.2 mrem

Even under this physically impossible scenario, the total internal dose would be less than 100 mrem. Note that one full air-exchange period in Hall C is 17.6 hours.

For another extremely conservative scenario, one can assume the saturation activity for each airborne radionuclide of concern has built up in each hall based on beam loss and hall air volume. The following table is extracted from CEBAF-TN-0157[3] for saturation activity for the radionuclides of interest:

Table 4
Nuclide Yields and Concentrations Using 2 W Source Term

Nuclide	End-Stations					
	A (r=26m)		B (r=15m)		C (r=23m)	
	MBq	Bq/m3	MBq	Bq/m3	MBq	Bq/m3
H-3	1.3	35	0.7	106	1.1	45
Be-7	0.3	7	0.1	21	0.2	9
C-11	2.6	71	1.5	212	2.3	90
N-13	36	989	21	2971	32	1264
O-15	15	396	8	1188	13	505
Cl-38	0.1	3.6	0.07	11	0.1	4.5
Cl-39	0.8	21	0.4	64	0.7	27
Ar-41	18	600	0.09	30	18	600

Table 5
Calculated Saturation Activity DAC-hr Totals for 1 Working Year

Nuclide	Hal C Saturation Activity (Bq/m3)/DAC (Bq/m3) = # DAC	Entire Year (2000 hrs) in Saturation Activity (DAC-hr)
H-3	2.25E-4	0.45
Be-7	3E-5	0.06
C-11	9E-5	0.18
N-13	1.26E-3	2.52
O-15	5.05E-3	10.1
Cl-38	4.5E-5	0.09
Cl-39	3.38E-5	0.068
Ar-41	6E-3	12
Total		25.5
	Total Dose	25.5 x 2.5 = 64 mrem

As one can see, even under entirely unrealistic scenarios (working an entire year in Hall C, and assuming saturation activity), the total dose to an individual would be 64 mrem. Comparing this with Example 5.3 "Circumstances Not Requiring Routine Individual Monitoring" of DOE Standard Internal Dosimetry[2] which states that routine individual monitoring is not necessary for "Quantities of radioactive materials in process are less than 2% of an ALI" (i.e., 40 DAC-hrs.), it is clear that this scenario cannot drive the requirement for an internal dosimetry program. A more realistic assumption for actual time in the hall (not including the bulk of maintenance periods, for which 100 percent of the air would be exchanged in the first 24 hours) would conservatively be approximately 310 hours. This would decrease the likely conservative dose to approximately 10 mrem. This is an order of magnitude below the 100 mrem annual threshold for radiation workers, and a factor of 5 lower for minors and members of the general public (neither of whom would spend more than 2 hours in any experimental hall.)

Threshold Limits with Internal Dosimetry Ramifications:

Because of the positron decay of the major radionuclides of interest, the dose also depends heavily on immersion dose which (as shown in Tech Note 97-017[7]) requires more than a 1 km diameter semi-infinite cloud of nuclide immersing an individual (an obvious impossibility given the size of the experimental halls) in order to meet the conditions necessary to achieve the gamma ray dose rate assumed by a semi-infinite cloud upon which the DAC values for these radionuclides was derived. Additionally, the same Tech Note[7] makes the cogent point that due to the size limitations of the halls, the shallow dose limits to the skin (50 rem) would be exceeded by charged particle exposure (positrons) prior to the whole body dose limit of 5 rem. Taking this into consideration, coupled with the fact that all workers entering the experimental halls are required to wear DOELAP accredited external TLD dosimetry, we have a "built-in" detection system for determining whether an "internal dosimetry" would be needed as a result of submersion in a cloud of positron emitting radionuclides. Taking the ratio of 50 rem shallow dose to

5 rem whole body dose, and further scaling that to 100 mrem, for whole body dose yields an "action limit" of 1 rem for shallow dose. In other words, if individuals working in the accelerator experimental halls began showing shallow dose exposures of 1 rem or greater over the course of a year, this would indicate a possibility for a need for an internal dosimetry program (although the argument can be made that because the dose as a result of "internal" exposure to positron emitting radionuclides is external, the "internal dosimetry program" is already in place.) It should be noted that for the vast majority of workers at Jefferson Lab, few receive any shallow dose, and when they do, it is on the orders of tens of mrem, which can be further traced to radiological work performed under the auspices of a specific Radiological Work Permit related to working in close proximity to highly activated beamline components (i.e., target area, burnthrough areas, and high power beam dump enclosures.) As a point of reference, the following table synthesized from previous years' external dosimetry reports delineates the number of externally monitored individuals at Jefferson Lab with external deep dose equivalent and shallow dose equivalent in excess of 100 mrem, as well as the highest total for an individual each year for calendar years 2002 through 2004:

Table 6
Jefferson Lab Annual Total of Individuals w/DDE and/or SDE > 100 mrem

Calendar Year	# monitored individuals >100 mrem DDE	Highest Individual DDE (mrem)	# monitored individuals >100 mrem SDE	Highest Individual SDE (mrem)
2002	4	159	4	189
2003	1	107	1	110
2004	1	104	1	106

As a side note, all six individuals listed performed work under the auspices of specific RWPs, and accumulated reported shallow dose equivalent near (i.e., in almost all cases, within 10 mrem) of reported deep dose equivalent.

To summarize: If a number of individuals working within the accelerator experimental halls exceeded 1000 mrem shallow dose during a one year period without performing work under the auspices of a job-specific radiological work permit, a DOELAP accredited internal dosimetry program should be initiated.

An additional possibility for concern exists concerning tritium exposure. Because this is a low energy beta emitter that disperses rapidly throughout the human body when inhaled or ingested (as opposed to being primarily a "submersion dose" concern), limits for this need to be treated somewhat differently. As noted previously, H-3 created in the accelerator experimental halls is insignificant because the saturation activity in the example Hall C created from typical beam loss and breathed for the unrealistic total of 2000 hours would result in only 0.45 DAC, or slightly over 1 mrem. This is even more unrealistic given the long half-life of H-3 (12.3 years), and the air exchange in the halls and accelerator, such that it is impossible to approach saturation activity levels of tritium. A realistic, but not currently applicable scenario, would be a situation in which large amounts of tritium would be brought into the experimental halls for use as a target

substance for an experiment. Currently, the Jefferson Lab Environmental Health and Safety Manual RadCon Supplement (Radiation Control Manual) excludes storing in excess of 10 mCi of tritium (as a compressed gas) in any experimental hall. This is to prevent (among other problems), exceeding tritium concentration limits (0.1 microcurie/ml) and daily total (10 mCi) releases of End Station Floor Sump water into the Hampton Roads Sanitation District (HRSD) sanitary sewer system. In the event of a tritium release within an experimental hall, approximately 1/3 of the released tritium is collected in the air conditioning system as condensate, which drains into the End Station Sump, where the discharge is periodically sampled. Currently, with the HRSD discharge restrictions (which is monitored in end station sump water discharges), it is impossible to release greater than 30 mCi in a hall without detection (even neglecting the 10 mCi gas administrative limit). Even if this limit were released every day in Hall C would only result in:

((0.030 Ci)(3.7E10 Bq/Ci)/(2.99E4 m3)/(2E10 Bq/m3))(2000hrs)(2.5 mrem/DAC-hr) = 9 microrem

For a person working 2000 hours in Hall C (which is unlikely given typical operating conditions), and a 30 mCi tritium gas release every day (which is unlikely due to the monitoring of discharges to HRSD), the total internal dose to an individual from tritium would be 9 microrem.

By comparison, for a possible tritum containing target scenario, using the DAC for tritium (elemental) (that contained in a gas – a likely candidate for a Medium Energy Nuclear Particle Physics experiment at Jefferson Lab) results in:

Tritium (Ci) in Hall C = (2E10 Bq/m^3)(2.99E4 m^3)/(3.7E10 Bq/Ci) = 16,162 Ci

In other words, an activity of 16,162 Ci of tritium in Hall C air would need to be breathed for 40 hours to exceed 100 mrem. This quantity is many orders of magnitude above the 30 mCi of tritium that would prohibit daily discharge quantity limits to be exceeded for Jefferson Lab's HRSD permit. Jefferson Lab is not configured to run an experiment with a target containing more than a few millicuries of Tritium. This situation would require a complete re-working of discharges from the End Station Sump due to the fact that this much tritium gas, once collected in the experimental hall air condensate would definitely lead to an increase over the HRSD permit limit for concentration of 0.10 microcuries/ml (which is measured) and the total quantity allowed to be discharged. Additionally, such an experiment would require engineered safeguards, additional administrative controls, and an EPA approved effluent monitoring system due to the fact that such a target would result in release of radionuclides such that the maximally exposed individual offsite would receive a CAP88PC dose in excess of 0.1 mrem annually.

Conclusion:

An internal dosimetry program is not required because the "threshold" levels for which one would be needed per 10 CFR 835 cannot be realistically reached, even using extremely conservative assumptions. Additionally, the bulk air activation radionuclides

of concern at Jefferson Lab have a DAC based on immersion in a semi-infinite cloud, which, as stated previously would require a "cloud" of 1 km, much larger than the radius (less than 30 meters) for any of the 3 experimental halls. Additionally, because the immersion dose is an external dose, and all individuals entering the experimental halls are required to wear TLDs that record deep photon dose, and shallow positron or beta and photon dose, if for some inexplicable reason individuals entering the experimental halls were exposed to significant concentrations of the subject radionuclides, this would be recorded in the TLD readings. Historical records indicate that only a handful of people per year (i.e., typically 1 to 4)at Jefferson Lab receive a monitored deep dose equivalent or shallow dose equivalent in excess of 100 mrem. These doses for these individuals can always be traced back to work performed during a Radiological Work Permit. As also addressed, in some cases, for particular radionuclides, shallow dose would be the actual limiting factor. Historical TLD records indicate that is extremely rare for a person to receive a shallow dose, and certainly orders of magnitude beneath the 50 rem limit.

Concerning the issue of introducing tritium as a target gas: In the event of utilizing a physics target containing Tritium, many Radiological Control program elements would require evaluation and modification due to the repercussions to the current technical basis describing the inapplicability of an Internal Dosimetry Program, the HRSD discharge permit, and the NESHAP requirements per 40 CFR 61 for dose to the maximally exposed individual due to radioactive airborne releases, and EPCRA requirements for the relatively large quantity of Tritium involved. (Note: The specific activity for Tritium is approximately 29,000Ci/g, and 2 to 3 grams would be needed for a useful physics target, for a total of 60,000 to 90,000 Curies of Tritium). These issues would become limiting much before the need to implement a DOELAP accredited internal dosimetry program.

A re-examination of applicability of the need for a DOELAP accredited Internal Dosimetry Program should occur, if:

- Unexplained shallow dose equivalent in excess of 1000 mrem occurs on the TLD readings of radiation workers
- Jefferson Lab begins utilizing experimental targets containing Tritium gas

Endnotes

[1] 10 CFR 835 Code of Federal Regulations, Occupational Radiation Protection, 2004 edition.
[2] DOE-STD-1121-98, May 2003, Internal Dosimetry
[3] TN-94-031-Rev. B April 1997, Calculation of Radioactive Yields in Air from Electron Beam Experiments in CEBAF End Stations and the Dose to Surrounding Populations, R. May, S. Schwahn, G. Stapleton.
[4] CEBAF-TN-0157, August 1989, Air Activation in End-Stations, G. Stapleton.
[5] IAEA Technical Report 188, 1979, Radiological Safety Aspects of the Operation of Electron Linear Accelerators, William P.Swanson.
[6] FERMILAB-TM-1834, Revision 5A, November 2002, Radiation Physics for Personnel and Environmental Protection, J. Donald Cossairt.
[7] TN-97-017, May 12, 1997, Occupational and Environment Aspects of the Radiation Control Provisions at the Jefferson Lab, P. Degtiarenko, R. May, S. Schwahn, G. Stapleton.