Pacific Northwest
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PNNL-31968

Analysis and Recommendation of Alpha-Beta Continuous Air Monitor Alarm Setpoints for the RPL Stack Exhaust

September 2021

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

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Abstract

The Radiochemical Processing Laboratory (RPL) alpha-beta continuous air monitor (CAM) is used for real-time detection of "artificial"[1] alpha-beta particulates from the stack exhaust. The CAM interfaces with software developed by the Pacific Northwest National Laboratory—called the "PNNL OS3300 Alpha-Beta Monitoring Software"—that provides real-time estimates of alpha-beta air concentrations and integrated activities that are calculated from measured CAM counts. The OS3300 software has alarm setpoints that can be used to provide an early indication of larger releases, that if allowed to persist, could approach defined dose limits.

This report performs a detailed review of historical and current alarm setpoints used at RPL, including discussion of the technical basis used in their development, analysis of alarm frequencies using measured historical data, and performs a detailed dose assessment using more realistic release scenarios, meteorology, and adjustment factors used in estimating released stack activity. Based on the results, the alpha and beta air concentration alarm setpoints will remain 1.77×10^{-8} µCi/ml and 3.47×10^{-8} µCi/ml, respectively; and the alpha and beta integrated activity alarm setpoints will remain 70.22 µCi and 137.63 µCi, respectively. These setpoints achieve the right operational balance in identifying larger releases from planned radiological work at RPL, without being overly conservative so as to cause nuisance alarming. Furthermore, implied doses associated with these setpoints are below defined and regulatory limits.

[1] From man-made sources other than natural background and radon/radon progeny.

Acronyms and Abbreviations

ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
Bq	becquerel [i.e., one nuclear disintegration per second]
CAM	continuous air monitor
Ci	curie [equals 3.7×10^{10} Bq]
cps	counts per second
DOE	U.S. Department of Energy
EDE	effective dose equivalent
EPA	U.S. Environmental Protection Agency
HEPA	high-efficiency particulate air
HPS	Health Physics Society
ICRP	International Commission on Radiological Protection
MEI	maximally exposed offsite individual
mrem	millirem [i.e., 1×10^{-3} rem]
NCRP	National Council on Radiation Protection and Measurements
NRC	U.S. Nuclear Regulatory Commission
PCE	particle collection efficiency
PNNL	Pacific Northwest National Laboratory
rem	unit of dose (Roentgen equivalent man)
RPL	Radiochemical Processing Laboratory
SAF	self-absorption factor
scfm	standard cubic feet per minute
WAC	Washington Administrative Code
WDOH	Washington State Department of Health

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1.0 Introduction

Pacific Northwest National Laboratory (PNNL) operates the Radiochemical Processing Laboratory (RPL) for the U.S. Department of Energy at the Hanford Site, Washington. The RPL is a three-story building, with over 13,000 m^2 of space consisting of offices, laboratories, and specialized areas such as high bays, hot cells, shops, and waste treatment units. The mission of the RPL is to create and implement innovative processes for environmental cleanup and the beneficial use of radioactive materials, including ways to advance the cleanup of radiological and hazardous wastes, the processing and disposal of nuclear fuels, and the production and delivery of medical isotopes. Projects conducted in the facility frequently change. Consequently, inventories of radioactive material in the building also change and can include microgram to kilogram quantities of fissionable materials and up to megacurie quantities of other radionuclides.

RPL is classified as a major emission point (Barnett and Snyder 2018). Environmental regulations require the use of a continuous air monitor (CAM) for real-time monitoring of radioactive particulates in the exhaust from the main stack. A six-nozzle rake probe that spans the stack diameter is used to obtain a representative exhaust sample at a well-mixed location. The sample probe is connected to a transport line that extends downward and terminates in the facility sample room where it enters an EG&G Berthold LB150D alpha-beta CAM (Berthold 1993 [Berthold Technologies U.S.A. LLC, 99 Midway Lane, Oak Ridge, TN 37830]). The CAM uses a 200 mm diameter glass-fiber filter to collect particles from the sample stream. The filter is exchanged monthly. Particulate samples are collected continuously to measure real-time alpha and beta particulate emissions from the facility. The CAM operates in conformance with American National Standards Institute/Health Physics Society (ANSI/HPS) N13.1–2011 (HPS 2011) standard requirements; additional information about the RPL emission unit and CAM system can be found in the “PNNL Facility Radionuclide Emission Points and Sampling Systems” report (Barnett and Snyder 2018).

Within the CAM, three gas-flow proportional counters in a stacked configuration independently count the number of alpha, beta, and gamma emissions on the sample collection filter. Nearly simultaneous alpha and beta emissions occurring on the filter are measured at a timing gate so interference from naturally occurring radon is taken into account. Referred to as the “alpha-beta-pseudo-coincidence-difference method”, this method uses the nearly simultaneous (i.e., pseudo-coincident) alpha-beta decay transitions in the radon decay chains as a means of distinguishing naturally occurring radionuclides from artificial radionuclides deposited on the sample filter (Berthold 1993). The number of pseudo-coincident events times a scaling factor is subtracted from the gross alpha and gross beta counts to yield the net event detections attributed to “artificial” sources; that is, sources other than naturally occurring radon and associated progeny.

Software developed by the Pacific Northwest National Laboratory (PNNL), called the “PNNL OS3300 Alpha-Beta Monitoring Software”, uses the measured counts to calculate real-time “artificial” alpha-beta air concentrations and integrated activities (Rishel et al. 2019). The OS3300 software uses alarm setpoints to provide an alarming capability. The setpoints are used to provide an early indication of larger releases, that if allowed to persist, could begin to approach defined release limits. The current OS3300 alpha-beta alarm setpoints have been used operationally at RPL since 2006. Because the building environment (e.g., radon and background) and permitted radiological work activities at RPL have changed over time, the alarm setpoints, and their associated technical basis, are being reviewed to verify that they are still appropriate and meet programmatic needs.

This report is organized into five sections, including this introduction. Section 2 documents the historical and current alarm setpoints used at RPL, including a discussion of the technical basis used in their development. Section 3 compares the current RPL alpha-beta alarm setpoints against a range of potential alarm setpoints based on more recent calibration data. These alarm setpoints are then analyzed for their impact on alarm frequency using 5-years of measured historical data. Section 4 provides a detailed dose assessment to include more realistic release scenarios and meteorology used in the calculation of dose factors. In addition, further consideration is given to appropriate adjustment factors used in the calculation of stack activity, including the filter self-absorption factor and particle collection efficiency, which directly affect dose estimates. Section 4 concludes with additional considerations of the dose constraint used in the development of the alarm setpoints. Finally, Section 5 provides a summary and recommendation on appropriate alpha-beta CAM alarm setpoints to use at RPL.

2.0 Alpha-Beta Stack CAM Alarm Setpoints

This section documents the original and current RPL alpha-beta stack CAM alarm setpoints as well as their associated technical basis.

2.1 Original Alpha-Beta Stack CAM Alarm Setpoints

The RPL alpha-beta stack CAM alarm setpoints are documented in a 2004 memorandum, “Adjustment to Alpha CAM Alarm Setpoint” (Ballinger 2004 [Appendix A]), which cites a 1995 unpublished, internal report “Maximum Alarm Setpoints for Tritium and Particulate Airborne Radionuclide Emissions Monitors at PNL Nuclear Facility Stacks” (Sula 1995 [unavailable]) as the original technical basis. According to the Ballinger 2004 memorandum, the original setpoints were calculated based on an acute 2-mrem dose consideration to a public receptor (i.e., maximally exposed offsite individual [MEI]) using ^{239}Pu (alpha) and ^{90}Sr (beta) as the worst-case emitters; this resulted in setpoints of 13 counts per second (cps) alpha and 570 cps beta. The setpoints were set conservatively lower to 5 cps alpha and 250 cps to meet as low as reasonably achievable (ALARA) objectives. The 1995 setpoints addressed “artificial” particulate emissions only; no consideration was given to radon.

The Ballinger 2004 memorandum (Appendix A) provided further consideration of the RPL alpha-beta CAM alarm setpoints, including radon. According to the Ballinger 2004 memorandum, levels of naturally occurring radon had remained steady (3–5 cps) and had not been high enough to trigger an alpha alarm. However, a buildup of naturally occurring radon from a climatological inversion in October 2002 triggered a total alpha alarm. In addition, an isotope separation project involving the emission of radon gas that began in December 2002 had triggered several alpha alarms. These were considered “false” alarms because the original alarm setpoints were based on ^{239}Pu dose considerations, not radon. Radon and its daughter products have a much lower dose potential—several orders of magnitude less than ^{239}Pu. As the Ballinger 2004 memorandum noted, there were no radon release scenarios that could result in an acute 2-mrem dose equivalent to the MEI.

The Ballinger 2004 memorandum reaffirmed the use of the original 1995 artificial setpoints in addition to providing suggested “total” alpha and beta setpoints, which included both “artificial” contributions and naturally occurring radioisotopes (e.g., radon and thoron). Table 1 provides a summary of the alpha and beta “artificial” and “total” alarm setpoints from the Ballinger 2004 memorandum.

The acute dose calculations used to support the setpoints listed in Table 1 were not included in the Ballinger 2004 memorandum, but were documented in a separate, unpublished calculation package. The calculations, which are included here for completeness, estimated the alpha or beta activity that would result in an acute 2-mrem dose (i.e., 20 percent of the 10 mrem/year standard (40 CFR 61, Subpart H [2002]; WAC 246-247 [2019])) to the hypothetical MEI. The calculation used acute unit dose factors from an “RPL Safety Analysis Report” (Rhoads and Aaberg 1999) that assumed a ground-level release for 2-hours during worst-case meteorological conditions (i.e., 95th percentile atmospheric dispersion conditions). ^{239}Pu and ^{90}Sr were selected as the highest alpha- and beta-emitting dose resulting radionuclides, with unit dose factors of 9,400 mrem/Ci and 6.3 mrem/Ci, respectively. The required activity (Ci) for an acute 2-mrem dose to the hypothetical MEI was calculated as:

$$Activity\ (Ci) = \frac{Dose\ (mrem)}{Dose\ Factor\ \left(\frac{mrem}{Ci}\right)} \tag{1}$$

and results in a release of 2.1 × 10^{-4} Ci alpha or 3.2 × 10^{-1} Ci beta.

The alpha or beta activity (Ci) needed to be released from the stack (A_{stack}) for a 2-mrem dose to the hypothetical MEI also can be expressed in terms of the net alpha or beta count rate (i.e., cps) that would be measured by the CAM, along with some adjustment factors (Equation 2; PNNL 2019a):

$$A_{stack} = \frac{C_{net} \times \frac{Stack\ Flow}{Sample\ Flow} \times \frac{Release\ Time}{Count\ Time}}{DE \times PCE \times SAF \times (3.7 \times 10^{10})} \tag{2}$$

where the following definitions and values apply:

C_{net}	=	The net count rate (cps) of artificial alpha or beta activity measured on the CAM filter in one count interval, with contributions from background and naturally occurring radon subtracted.
$\frac{Stack\ Flow}{Sample\ Flow}$	=	Scaling factor to account for differences between the stack and sample flow. The RPL stack flow values used in the calculation were 140,000 scfm and the CAM sample flow of 22 scfm.
$\frac{Release\ Time}{Count\ Time}$	=	In this case, the release time was assumed to be 120 minutes (2 hours), and the CAM count time was set to 10 minutes to provide an early indication of the 2-hour release.
DE	=	Detector efficiency. A unitless correction factor (i.e., counts per disintegration) used to account for the CAM detector efficiency in measuring alpha or beta decay. The detector efficiency was conservatively set to 0.23 for alpha and 0.44 for beta based on 5 years of CAM calibration records.
PCE	=	Particle collection efficiency (PCE). A unitless correction factor used to account for the fraction of collected particles that are transported through the sampler and deposited onto the CAM filter. The PCE for the RPL sampler was conservatively set to 0.50 based on output from the “DEPO” line-loss code.
SAF	=	Self-absorption factor (SAF). A unitless correction factor used to account for the fraction of particles absorbed onto the surface of the filter medium and not available for counting. The SAF was set to 0.85 based on studies with plutonium aerosols (Higby 1984).
3.7×10^{10}	=	Conversion factor used to convert cps to Ci.

Substituting the above values into Equation 2, along with activities of 2.1 × 10^{-4} Ci alpha or 3.2 × 10^{-1} Ci beta from Equation 1, results in net count rates of 10 cps alpha or 29,000 cps beta. These are the net count rates that would be required on the CAM filter in a 10-minute counting interval to achieve an acute 2-mrem dose to the hypothetical MEI from a larger-than-normal, 2-hour release during nearly worst-case meteorological conditions (i.e., 95th percentile atmospheric dispersion conditions). As noted previously, the “artificial” alpha and beta alarm set points listed in Table 1 (i.e., 5 cps [alpha] and 250 cps [beta]) were set conservatively lower than the calculated values of 10 cps and 29,000 cps. Consequently, the setpoints listed in Table 1 result in doses lower than the 2-mrem criteria considered, especially for beta.

Table 1. Suggested "Total" and "Artificial" Alpha-Beta Alarm Setpoints from the Ballinger 2004 Memorandum (Appendix A).

Alarm	Suggested Setpoint (cps)
Total Beta	500
Artificial Beta[a]	250
Total Alpha	100
Artificial Alpha[b]	5

[a] The suggested setpoint of 250 cps "artificial" beta over a 10-minute count time is based on ALARA considerations and is a factor of 100 times less than the conservatively calculated 29,000 cps that would be required to achieve a 2-mrem dose to the hypothetical MEI within 2 hours of a larger-than-normal release.
[b] The suggested setpoint of 5 cps artificial alpha over a 10-minute count time is based on ALARA considerations and is half the conservatively calculated 10 cps that would be to achieve a 2-mrem dose to the hypothetical MEI within 2 hours of a larger-than-normal release.

2.2 Current Alpha-Beta Stack CAM Alarm Setpoints

In 2006, new alpha-beta CAM software—called the "OS3300 Alpha-Beta Monitoring System Software"—was made operational at RPL (Barnett et al. 2006[2]). In short, the OS3300 software converts the measured total (gross) alpha-beta counts on the CAM filter to real-time estimates of "artificial" activity on the filter. The alpha-beta filter activities are then converted to in-stack air concentrations and integrated activities, which have accompanying alarm setpoints. Thus, with the introduction of the OS3300 software, there was a transition from alarm setpoints based on measured counts to alarm setpoints based on calculated activity. However, the same release assumptions (i.e., 2-hour release) and dose considerations (i.e., 20 percent of the 10 mrem/year standard) were used. The 2006-derived alpha-beta alarm setpoints continue to be used in the OS3300 software at RPL; a discussion of their derivation follows.

The alpha or beta filter activity during a single count interval is calculated by the OS3300 software using Equation 3 (Barnett et al. 2006):

$$A_{filter} = \frac{C_{net}}{DE \times (3.7 \times 10^{10})} \quad (3)$$

Equation 3 is similar to Equation 2, the difference being Equation 2 contains additional factors to scale the filter activity to the total stack activity over the release period, whereas Equation 3 only pertains to the measured activity on the CAM filter during a single count interval. C_{net} (Equation 4) is given by:

$$C_{net} = C_{total} - C_{bkg} - C_{radon} \quad (4)$$

where:

C_{total} = The total alpha or beta count rate (cps) measured on the CAM filter during a count interval.[3]

[2] The OS3300 software was updated in 2019 (Rishel et al. 2019) to run on more recent operating systems, however the software functionally is identical to the 2006 version.
[3] The OS3300 count time is 1 minute. Thus, C_{total} is the total number of alpha or beta counts measured by the CAM over a 1-minute period.

C_{bkg} = The alpha or beta background count rate (cps); treated as a fixed value throughout the year based on annual CAM calibration measurements.
C_{radon} = The alpha or beta count rate (cps) from naturally occurring radon progeny accumulated on the CAM filter.

The radon count rate (C_{radon}) varies as environmental radon levels fluctuate; it is determined by a timing circuit within the CAM that detects the nearly simultaneous alpha-beta decay (i.e., pseudo-coincident decay) associated with radon. Baseline pseudo-coincident factors, which are determined at calibration, are used to account for additional alpha and beta decay from radon progeny that are not counted by the pseudo-coincidence timing circuit. A complete discussion of the alpha-beta CAM pseudo-coincidence radon theory was documented by Berthold (1993). Accordingly, the count rate contribution from radon, C_{radon}, is given by Equation 5 (Barnett et al. 2006):

$$C_{radon\ a,b} = P_s \times F_{a,b} \times F_k \times \left(1 + M_{a,b} \times \left[\frac{P_s - P_{so}}{P_{so}}\right]\right) \quad (5)$$

where:

P_s = Pseudo-coincidence rate (cps) measured by the CAM during each counting interval.
$F_{a,b}$ = Pseudo-coincidence rate factor for alpha (F_a) or beta (F_b) (unitless) determined at calibration; used to account for the radon/thoron emissions that are not counted by the pseudo-coincidence counting circuit.
F_k = Correction factor to account for the time required for the radon progeny to reach transient equilibrium upon filter change (unitless); approximately 1.25 immediately after the filter is changed and decreasing linearly to 1.0 after the first 2.5 hours of filter use and until the next filter change.
$M_{a,b}$ = Rate factor for alpha (M_a) or (M_b) beta (unitless) determined at calibration; used to account for fluctuations in the ratio of various radon/thoron progeny on the filter as a result of changes in environmental radon levels.
P_{so} = Lowest pseudo-coincidence rate (cps) measured during calibration using a clean filter.

Substituting Equations 4 and 5 into Equation 3 results in an estimate of the artificial alpha-beta filter activity (Equation 6) during a given count interval:

$$A_{filter\ a,b} = \frac{(C_{total\ a,b} - C_{bkg\ a,b}) - P_s \times F_{a,b} \times F_k \times \left(1 + M_{a,b} \times \left[\frac{P_s - P_{so}}{P_{so}}\right]\right)}{DE_{a,b} \times (3.7 \times 10^{10})} \quad (6)$$

where the "a" and "b" subscripts refer to alpha or beta, respectively. This equation is used by the OS3300 software to calculate the alpha-beta filter activity during a given count interval (Barnett et al. 2006). Dividing Equation 6 by the sample flow gives the alpha-beta air concentration (Equation 7):

$$Conc_{\ a,b} = \frac{A_{filter\ a,b}}{Sample\ Flow} \quad (7)$$

As a final step, the OS3300 software multiplies the alpha-beta filter activity by a ratio of the stack flow to sample flow to calculate the stack activity[4] (Equation 8) as:

$$A_{stack\ a,b} = A_{filter\ a,b} \times \frac{Stack\ Flow}{Sample\ Flow} \tag{8}$$

The stack activity (Equation 8) can be summed over several count intervals to estimate the integrated stack activity over a release period. The OS3300 count interval is set to 1 minute (referred to as a short-count) and the activity is integrated up over a 3-minute period (referred to as a long-count).

Using Equations 6 through 8, alarm setpoints on alpha-beta air concentration and stack activity were calculated for use in the OS3300 software. Because the calculation was not documented in a published report, it is included here for completeness. Table 2 lists each parameter and the associated value that was used in 2006 for both alpha and beta. The total counts are the suggested total setpoint values from the Ballinger 2004 memorandum (from Table 1) and include contributions from radon. The background counts, radon pseudo-coincident parameters, and detector efficiencies (shaded parameters) are the 2005 annual CAM calibration values; these values are assumed to be generally representative of the detector and facility. Finally, the sample and stack flows are fixed values.

Table 2. Parameter Values Used to Calculate Alpha-Beta Air Concentration and Stack Integrated Activity Alarm Setpoints in the OS3300 Software.

Parameter	Alpha Value	Beta Value	Data Source
$Stack\ Flow$ (scfm)	140,000	140,000	PNNL-15992
$Sample\ Flow$ (scfm)	22.8	22.8	PNNL-15992
$C_{total\ a,b}$ (cps)	100	500	Ballinger, 2004
$C_{bkg\ a,b}$ (cps)	0.53	2.83	2005 Calibration Record
P_s (cps)	8	8	2005 Calibration Record
P_{so} (cps)	0.42	0.42	2005 Calibration Record
$F_{a,b}$	3.14	0.28	2005 Calibration Record
F_k	1	1	2005 Calibration Record
$M_{a,b}$	-0.06	2.95	2005 Calibration Record
$DE_{a,b}$	0.240	0.453	2005 Calibration Record

Using the parameter values from Table 2 in Equation 6 provides an estimate of the resulting alpha-beta filter activity. The alpha-beta filter activity then was used to calculate the corresponding air concentration (Equation 7) and stack activity (Equation 8) alarm setpoints that are listed in Table 3; these are the alarm setpoints that have been used in the OS3300 software at RPL since 2006 (PNNL 2019b).

[4]Equations 7 and 8 do not include correction factors for line loss and filter absorption, which would be used to calculate the air concentration and total activity from the stack.

Table 3. Current OS3300 Alpha-Beta Air Concentration and Stack Activity Alarm Setpoints Since 2006.

Alarm Setpoint	Alpha	Beta
$Conc_{a,b}$ (µCi/ml)[a]	1.77×10^{-8}	3.47×10^{-8}
$A_{stack\ a,b}$ (µCi)[b]	70.22	137.63

[a] Air concentration is calculated by the OS3300 software using a 1-minute count interval. At the end of 1-minute, the calculated alpha-beta concentration is compared to the air concentration alarm setpoint for alarming purposes.
[b] The stack activity is integrated by the OS3300 software using a 3-minute count interval. At the end of a 3-minute count, the integrated activity is conservatively compared to the 1-minute stack activity alarm setpoint for alarming purposes. When an alarm setpoint is exceeded, the long-count is set to the short-count so both concentration and stack activity are calculated at the same 1-minute time interval.

2.2.1 Current Alpha-Beta Stack CAM Alarm Setpoints Technical Basis

Table 3 lists the 2006 OS3300 alpha and beta alarm setpoints that were derived starting with the 2004 “total” count alarm setpoints (i.e., 100 cps total alpha and 500 cps total beta) and subtracting representative facility radon and background contributions that were calculated using Table 2 parameters following the methodology in described in Section 2.2. This method assumed the net “artificial” counts would be comparable to the original 1995/2004 “artificial” alpha and beta setpoints (i.e., 5 cps alpha and 250 cps beta), thereby resulting in comparable doses.

To verify this assumption, the net counts ($C_{net\ a,b}$) resulting from the 2006 data were calculated by subtracting the background ($C_{bkg\ a,b}$) and estimated radon ($C_{radon\ a,b}$) contributions from the assumed total counts ($C_{total\ a,b}$). These values, which are presented in Table 4, can be compared to the 2004 alpha-beta “artificial” alarm setpoints, which were based on counts.

While the 2004 starting setpoint values were 13 cps alpha and 570 cps beta, the conservatively assigned historical setpoint values were 5 cps alpha and 250 cps beta. As noted in Section 2.1, the reduced count rates were determined to be ALARA at the time. Nevertheless, as can be seen in Table 4, the 2006 methodology results in higher net alpha and beta counts as compared to the historically used values. Specifically, the 2006 net alpha counts are 101.55 cps, which is 20.3 times higher than the 2004 historical 5 cps setpoint. The 2006 net beta counts are 375.67 cps, which is 1.5 times higher than the 2004 historical 250 cps setpoint.

Further inspection of the counts listed in Table 4 reveals the 2006 calculated representative radon contribution, as given by $C_{radon\ a,b}$, are not a significant contribution to the “total” counts, especially for alpha. Thus, when the background ($C_{bkg\ a,b}$) and radon ($C_{radon\ a,b}$) counts are subtracted from the total counts ($C_{total\ a,b}$), the net counts ($C_{net\ a,b}$) using the 2006 methodology remain higher than the previously assumed 5 cps. The higher 2006 net counts result is because the total counts (as shown in Table 4) include both natural and anthropogenic sources of radon, and the resultant calculated radon counts used in the 2006 methodology only account for natural sources of radon. This difference in approach highlights both the differences in net counts and implied dose between the 2004 and the 2006 results shown in Table 4.

Table 4. Comparison of 2004 and 2006 Counts Used in the OS3300 Alarm Setpoints.

Description	Alpha (cps) 2006	Alpha (cps) 2004[a]	Beta (cps) 2006	Beta (cps) 2004[b]
Total Counts $C_{total\ a,b}$ (cps)[c]	100	100	500	500
Background Counts $C_{bkg\ a,b}$ (cps)	0.53	≤95	2.83	≤250
Radon Counts $C_{radon\ a,b}$ (cps)	-2.08[d]	≤95[e]	121.50[d]	≤250[e]
Artificial Counts $C_{net\ a,b}$ (cps)	101.55	5.00	375.67	250.00
Implied Dose (mrem)	186.37[f]	0.99	0.24[f]	0.02

[a] The 2004 Ballinger memorandum sets total alpha counts to 100 cps and net artificial counts to 5 cps, which implies the sum of the background and radon contribution to total can be no more than 95 cps.
[b] The 2004 Ballinger memorandum sets total alpha counts to 500 cps and net artificial counts to 250 cps, which implies the sum of the background and radon contribution to total can be no more than 250 cps.
[c] Includes background, natural and anthropogenic radon, and artificial radiation.
[d] Includes natural radon contributions only.
[e] Includes natural and anthropogenic sources of radon.
[f] Includes a factor of 10 increase in dose due to the use of a 1-minute count time as opposed to a 10-minute count time assumed in the derivation of the original setpoints.

It is important to note that the derivation of the1995/2004 alpha-beta setpoints also used a 10-minute count interval, whereas the 2006 setpoints used a 1-minute count interval. This time difference means the 2006 alarm setpoints result in alpha-beta doses 10 times higher than initially assumed, because the entirety of the net counts is occurring in 1 minute as opposed to 10 minutes. Therefore, the 2006 setpoints actually result in an implied dose of 186.37 mrem (alpha) and 0.24 mrem (beta); this is 91.9 times higher (alpha) and 0.12 times lower (beta) than the 2-mrem dose constraint used to derive the original alarm setpoints.

Clearly, the implied alpha dose using the 2006 methodology is well in excess of the desired dose constraint, whereas the implied beta dose still has reasonable margin. Nevertheless, as will be shown, using more realistic assumptions in the dose calculation—specifically the underlying dose factors, the filter absorption factor, and the particle collection efficiency—results in an implied alpha dose estimate that still meets the 2-mrem target dose constraint for a larger-than-normal, short-duration release, without requiring a change to the OS3300 alarm setpoints.

3.0 Alpha-Beta Stack CAM Alarm Setpoints Evaluation

This section compares the current RPL alpha-beta stack CAM alarm setpoints and associated doses against a range of potential values calculated using more recent (2017–2021) calibration data. The resulting setpoints are then evaluated against 5-years of historical data to examine their impact on alarm frequency (planned and unplanned).

3.1 Alarm Setpoint Range of Values

Because representative building radon and background values can change over time based on natural causes and research impacts, the alarm setpoints were recalculated using the same methodology described in Section 2.2, except the shaded parameters in Table 2 are updated with more recent calibration values from years 2017 through 2021. Table 5 and Table 6 list the relevant alpha and beta parameters, respectively, from annual calibration records. Table 7 and Table 8 provide the corresponding calculated alpha-beta concentration and integrated activity alarm setpoints. Also listed are the resulting implied doses.

Table 5. Calibration Parameter Values Used to Calculate Alpha Air Concentration and Integrated Activity Alarm Setpoints.

Alpha Variable	Current (2006)	2017	2018	2019	2020	2021
$Stack\ Flow$ (scfm)	140,000	140,000	140,000	140,000	140,000	140,000
$Sample\ Flow$ (scfm)	22.8	22.8	22.8	22.8	22.8	22.8
$C_{total\ a}$ (cps)	100	100	100	100	100	100
$C_{bkg\ a}$ (cps)	0.53	2.33	1.79	1.83	8.10	3.71
P_s (cps)	8	8	8	8	8	8
P_{so} (cps)	0.42	3.69	3.51	9.07	10.68	3.13
F_a	3.14	2.76	2.79	2.64	2.58	3.04
M_a	-0.06	-0.06	-0.06	-0.05	-0.05	-0.07
DE_a	0.24	0.24	0.24	0.23	0.24	0.23

Note: Stack and sample flow are representative values of the monitoring system. The total alpha counts are from the Ballinger 2004 memorandum (see Appendix A). Shaded parameters are from annual (2017–2021) calibrations.

Table 6. Calibration Parameter Values Used to Calculate Beta Air Concentration and Integrated Activity Alarm Setpoints.

Beta Variable	Current (2006)	2017	2018	2019	2020	2021
$Stack\ Flow$ (scfm)	140,000	140,000	140,000	140,000	140,000	140,000
$Sample\ Flow$ (scfm)	22.8	22.8	22.8	22.8	22.8	22.8
$C_{total\ b}$ (cps)	500	500	500	500	500	500
$C_{bkg\ b}$ (cps)	2.83	7.08	6.44	15.69	17.40	28.52
P_s (cps)	8	8	8	8	8	8
P_{so} (cps)	0.42	3.69	3.51	9.07	10.68	3.13
F_b	0.28	0.06	3.45	4.38	3.73	8.67
M_b	2.95	3.53	-0.06	-0.02	0.04	-0.15
DE_b	0.45	0.45	0.45	0.45	0.47	0.47

Note: Stack and sample flow are representative values of the monitoring system. The total beta counts are from the Ballinger 2004 memorandum (see Appendix A). Shaded parameters are from annual (2017–2021) calibrations.

Table 7. Alpha Air Concentration and Integrated Activity Alarm Setpoints Calculated Using Table 5 Parameter Values and the Resulting Implied Doses

Alpha Setpoint	Current (2006)	2017	2018	2019	2020	2021
$Conc_a$ (µCi/ml)	1.77×10^{-8}	1.89×10^{-9}	1.37×10^{-8}	1.37×10^{-8}	1.40×10^{-8}	1.22×10^{-8}
$A_{stack\ a}$ (µCi)	70.22	54.34	54.49	55.51	48.41	54.83
Implied Dose (mrem)	186.37	144.21	144.62	147.32	128.48	145.53

Table 8. Beta Air Concentration and Integrated Activity Alarm Setpoints Calculated Using Table 6 Parameter Values and the Resulting Implied Doses

Beta Setpoint	Current (2006)	2017	2018	2019	2020	2021
$Conc_b$ (µCi/ml)	3.47×10^{-8}	4.6×10^{-8}	4.38×10^{-8}	4.15×10^{-8}	4.03×10^{-8}	3.76×10^{-8}
$A_{stack\ b}$ (µCi)	137.63	182.80	173.47	164.35	159.85	149.13
Implied Dose (mrem)	0.24	0.33	0.31	0.29	0.28	0.27

Comparing the Table 7 alpha concentration and integrated activity alarm setpoints shows the 2017–2021 values are lower than the current setpoints. The largest reduction occurs in 2020, with a 31 percent decrease in both setpoints and implied dose. From Table 5, the decrease is a result of both facility background and radon contributions increasing, which when subtracted from the total counts, results in lower net counts and correspondingly lower alarm setpoints and implied doses. Nevertheless, implied alpha doses are still well above the 2-mrem dose constraint for all years evaluated. Section 4 performs a detailed dose assessment using more realistic release scenarios, meteorology, and adjustment factors used in the calculation of stack activity, to demonstrate implied doses are considerably lower.

Comparing the Table 8 beta concentration and integrated activity alarm setpoints shows the 2017–2021 values are higher than the current setpoints. The largest increase occurs in 2017, with a 33 percent increase in both setpoints and implied dose. From Table 6, the increase in the beta alarm setpoints is a result of the radon contributions decreasing more than the background values increasing, which when subtracted from the total counts, results in higher net counts and correspondingly higher alarm setpoints and implied doses. Although implied beta doses increase, they remain well below the 2-mrem dose constraint.

3.2 Alarm Frequency

This section examines the alarm frequency based on the range of setpoints listed in Table 7 and Table 8. Specifically, the Table 7 (alpha) and Table 8 (beta) concentrations and integrated activity alarm setpoints were evaluated against 5 years (2014–2018) of historical OS3300 data to examine alarm frequency. Note, this five-year window is slightly offset from the years evaluated in the previous section to include a variety of known radiological work activities that occurred at RPL. Planned work, such as nuclear fuel characterization and research, has resulted in anticipated alarms over the years using the current alarm setpoints. Indeed, many of the alarms result from anthropogenic releases of radon and associated progeny that are not entirely accounted for by the CAM's "alpha-beta-pseudo-coincidence-difference method" (Berthold 1993). The alarms tend to be of short duration, and independent continuous sampling confirmed radiological emissions remained well below regulatory requirements (see Section 4.4).

As noted in Section 2.2, air concentration is calculated by the OS3300 software using a 1-minute count interval. At the end of 1 minute, the calculated alpha-beta concentration is compared to the air concentration alarm setpoints. Additionally, the stack activity is integrated using a 3-minute count interval. At the end of a 3-minute count, the integrated activity is conservatively compared to the 1-minute stack activity alarm setpoints. In either case, when the alarm setpoint is exceeded, the OS3300 will alarm, thereby alerting the facility to the release.

Table 9 lists the current, maximum, and minimum alpha concentration and integrated activity alarm setpoints from Table 7, along with the associated count frequency (i.e., “Count”) and unique alarm days (i.e., “Days”) for each year evaluated. Count refers to the number of 1-minute alarms (and therefore alarm minutes) that occurred in that year. Days is the number of unique days that had at least one 1-minute alarm. The current alpha alarm setpoints listed in Table 9 are also the maximum setpoints in Table 7; these setpoints are 31 percent higher than the minimum alpha setpoints.

Table 9 shows the alpha “Count” is consistent across the range of setpoints for years 2014, 2015, and 2017, with a noticeable count difference between the minimum and maximum setpoints in years 2016 and 2018; these 2 years had substantially more counts corresponding to increased radiological work in the facility. However, the minimum and maximum setpoint “Days” are virtually the same, meaning the setpoint range, which includes the current setpoints, identifies the same work events. Thus, although the minimum setpoints result in longer duration alarms for a given work event, they do not meaningfully identify new events.

Table 9. Current, Maximum, and Minimum Alpha Concentration and Activity Alarm Setpoints from Table 7 and Associated Count Frequency and Unique Alarm Days by Year

Parameter	Setpoint	2014		2015		2016		2017		2018	
Concentration	(µCi/ml)	Count	Days	Count	Days	Count	Days	Count	Days	Count	Days
Current	1.77×10^{-8}	11	6	18	10	259	13	5	5	329	11
Maximum	1.77×10^{-8}	11	6	18	10	259	13	5	5	329	11
Minimum	1.22×10^{-8}	12	6	19	10	821	14	9	6	793	13
Activity	(µCi)	Count	Days	Count	Days	Count	Days	Count	Days	Count	Days
Current	70.22	31	6	40	10	284	13	13	5	411	12
Maximum	70.22	31	6	40	10	284	13	13	5	411	12
Minimum	48.41	32	6	41	10	862	15	22	6	882	13

Table 10 lists the current, maximum, and minimum beta concentration and activity alarm setpoints from Table 8, along with the associated alarm “Count” and “Days” for each year evaluated. The current beta alarm setpoints in the OS3300 software are the minimum setpoints in Table 8; these setpoints are 33 percent lower than the maximum beta setpoints. Table 10 shows the beta alarm “Count” is generally much lower, with years 2014 and 2018 having the greatest counts. In many cases, the maximum concentration and integrated activity setpoints resulted in no alarms for a given year. The minimum setpoints, which are the current setpoints, resulted in at least one alarm every year.

Comparing both Table 9 and Table 10, it is evident that the alpha alarm “Count” and “Days” are higher than beta for all years. Clearly, alarming will be dependent on the radiological work being performed and predominant decay pathway (i.e., alpha or beta). Nevertheless, the lower dose potential associated with beta decay necessarily results in higher alarm setpoints, which are less likely to be exceeded during a given work event. Finally, it is worth noting the integrated activity alarm setpoints generally result in a higher “Count,” but similar “Days,” as compared to the concentration alarm setpoint; this is because the activity is conservatively integrated over a 3-minute count interval and then compared to a 1-minute activity alarm setpoint.

Table 10. Current, Maximum, and Minimum Beta Concentration and Activity Alarm Setpoints from Table 7 and Associated Count Frequency and Unique Alarm Days by Year

Parameter	Setpoint	2014		2015		2016		2017		2018	
Concentration	(µCi/ml)	Count	Days	Count	Days	Count	Days	Count	Days	Count	Days
Current	3.47×10^{-8}	4	3	1	1	1	1	0	0	13	5
Maximum	4.61×10^{-8}	0	0	0	0	1	1	0	0	4	3
Minimum	3.47×10^{-8}	4	3	1	1	1	1	0	0	13	5
Activity	(µCi)	Count	Days	Count	Days	Count	Days	Count	Days	Count	Days
Current	137.63	24	5	14	4	5	1	1	1	19	6
Maximum	182.80	0	0	5	3	2	1	0	0	9	4
Minimum	137.63	24	5	14	4	5	1	1	1	19	6

4.0 Dose Assessment

This section performs a detailed dose assessment resulting from the current alpha-beta alarm setpoints as it relates to the selection of appropriate dose factors from more realistic release scenarios and meteorology. In addition, further consideration is given to adjustment factors used in the calculation of stack activity, including the filter self-absorption factor and particle collection efficiency, which directly affect dose estimates. The section concludes with additional considerations of the dose constraint used to develop the alarm setpoints.

4.1 Dose Factors

As discussed in Section 2.1, the original alpha-beta setpoints were derived using acute unit dose factors from an "RPL Safety Analysis Report" (Rhoads and Aaberg 1999) that assumed a ground level, 2-hour release during worst-case (i.e., 95th percentile) meteorology. ^{239}Pu and ^{90}Sr were selected as the highest alpha- and beta-emitting dose resulting radionuclides, with unit dose factors of 9,400 mrem/Ci and 6.3 mrem/Ci, respectively (Rhoads and Aaberg 1999). The alpha-beta activity alarm setpoints, in counts-per-second, were then calculated by requiring the resulting dose to be less than 2 mrem to the hypothetical MEI.

With implementation of the OS3300 software in 2006, the alpha-beta alarm setpoints transitioned from counts to air concentration and integrated activity using the methodology described in Section 2.2. However, the same release assumptions (i.e., 2-hour release) and dose considerations were implicitly assumed. Nevertheless, as was discussed in Section 2.2.1, assuming an alpha dose factor of 9,400 mrem/Ci and a 1-minute count time results in implied alpha dose of 186.4 mrem, which is significantly higher than the defined 2-mrem dose constraint.

The original acute dose factors (Rhoads and Aaberg 1999) used to derive the alpha-beta alarm setpoints have since been revised (Cathey 2013). The revised factors include a range of release durations (3- to 120-minutes), release conditions (thermal buoyancy from fires), particle sizes (1-µm and 5-µm), 2013 meteorology, updated dose coefficients from the ICRP (2001) for inhalation and from the Environmental Protection Agency Federal Guidance Report 13 (2002) for air/ground submersion, and the use of a different dispersion model (Chanin and Young 1998). Both the Rhoads and Aaberg (1999) and the Cathey (2013) reports provide the 95th percentile (i.e., worst-case meteorological dispersion conditions) dose factors to the maximally exposed individual (570 m downwind).

Table 11 lists the 95th percentile alpha dose factors from the revised report (Cathey 2013). Also included are the implied 95th percentile dose (mrem) resulting from the current alpha alarm setpoints (Table 3). Implied 95th percentile doses range from 17.3 mrem to 70.0 mrem over the 12 release scenarios considered in Cathey (2013), which is a significant reduction over the 186.4 mrem implied alpha dose using the original dose factor in Rhoads and Aaberg (1999). Release scenarios 10 and 12 most closely match the 2-hour release duration used to derive alarm setpoints; these scenarios result in an implied dose of 21.8 mrem and 17.3 mrem, respectively. The lower dose factor and resulting dose is attributed mainly to the assumed heat release from a fire, leading to plume rise, whereas the original dose factors assumed a ground-level release. A fire scenario is the only probable scenario likely to allow for an appreciable radiological release, especially over 2 hours.

Table 11. RPL 95th Percentile Alpha Dose Factors for 1-µm Particles Over a Range of Release Scenarios (Cathey 2013) and the Resulting Implied Dose Using the Current (2006) Alpha Alarm Setpoints

Release Scenario	Release Duration (min)	Heat Released (MW)	95th Percentile Dose Factor (mrem/Ci)	Implied 95th Percentile Dose (mrem)	Dose Reduction[a] (%)
1	3	0	3,530	70.0	62.4
2	15	0	2,980	59.1	68.3
3	15	0.1	2,880	57.1	69.4
4	15	1	2,110	41.8	77.6
5	30	1	1,960	38.9	79.1
6	60	1	1,690	33.5	82.0
7	15	5	1,230	24.4	86.9
8	30	5	1,150	22.8	87.8
9	60	5	1,140	22.6	87.9
10	120	5	1,100	21.8	88.3
11	60	10	882	17.5	90.6
12	120	10	875	17.3	90.7

[a] Reduction (%) is relative to the dose calculated using the original RPL alpha dose factor of 9,400 mrem/Ci (Rhoads and Aaberg 1999).

The acute dose factors considered thus far are the 95th percentile values, which are normally used in documented safety analyses. By definition, these dose factors are intended to be very conservative because they are derived from meteorological conditions that are only expected 5 percent of the time. Acute dose factors can also be calculated using more realistic meteorology. For example, the U.S. Nuclear Regulatory Commission (NRC) uses 50th percentile dose factors when evaluating dose impacts from design-basis accidents in environmental reports for nuclear power stations (NRC 2018).

Table 12 lists the mean alpha dose factors that were extracted from the calculation package of the revised dose factor report (Cathey 2013). Also included are the implied mean dose (mrem) resulting from the current (Table 3) alpha alarm setpoints. Implied mean doses range from 2.5 mrem to 11.6 mrem over the 12 release scenarios considered. Again, release scenarios 10 and 12 most closely match the implied 2-hour release duration used in the derivation of the alarm setpoints; these scenarios result in an implied mean dose of 3.5 mrem and 2.5 mrem, respectively, and the resulting alpha doses are nearly consistent with the 2-mrem dose constraint.

Table 12. RPL Mean Alpha Dose Factors for 1-µm Particles Over a Range of Release Scenarios (Cathey 2013) and the Resulting Implied Dose Using the Current (2006) Alpha Alarm Setpoints

Release Scenario	Release Duration (min)	Heat Release (MW)	Mean Alpha Dose Factor (mrem/Ci)	Implied Mean Dose (mrem)	Reduction[a] (%)
1	3	0	585	11.6	93.8
2	15	0	534	10.6	94.3
3	15	0.1	489	9.7	94.8
4	15	1	303	6.0	96.8
5	30	1	292	5.8	96.9
6	60	1	288	5.7	96.9
7	15	5	207	4.1	97.8
8	30	5	199	3.9	97.9
9	60	5	193	3.8	97.9
10	120	5	175	3.5	98.1
11	60	10	143	2.8	98.5
12	120	10	128	2.5	98.6

[a] Reduction (%) is relative to the dose calculated using the original RPL alpha dose factor of 9,400 mrem/Ci (Rhoads and Aaberg 1999).

4.2 Filter Self-Absorption Factor

The filter self-absorption factor (SAF) is a value less than or equal to 1.0 that accounts for the fraction of sample material that is absorbed on or in the medium in which it is contained and therefore is unavailable for counting. The filter SAF is different for samples that are directly counted versus samples that are eluted, ashed, or dissolved. For direct counting, self-absorption is accounted for by applying a correction factor less than 1.0 to the activity result; this corrects the bias caused by the absorption of emitted radiation from the collected particles by dust/particles on the filter and the filter medium itself. For samples that are eluted, ashed, or dissolved, the self-absorption factor is set to 1.0 and results in no activity correction.

As discussed in Section 2.1, the SAF is used to correct the estimated released stack activity (Equation 2), which is used in dose calculations. In this report, the SAF is conservatively set to 0.85 based on earlier studies with plutonium aerosols (Higby 1984); this increases the calculated stack activity, and therefore the implied dose, by a factor of 1.18 (i.e., 1 ÷ 0.85). Because the value is conservative, a more representative SAF is reasonable to use in the activity calculation.

ANSI/HPS N13.1-2011 recommends a correction factor if the penetration of radioactive material into the filter collection medium or self-absorption of radiation by the material collected would reduce the count rate of radioactive particles by more than 5 percent (HPS 2011). More recent studies (Edwards and Barnett 2021) of alpha particle losses due to self-absorption by mass loading on radioactive particulate glass fiber filters argues that a SAF of 0.95 is a more appropriate value; this results in an activity increase of only 1.05 (i.e., 1 ÷ 0.95) instead of 1.18. Thus, the stack activity is reduced by nearly 11 percent, and the implied doses in Tables 11 and 12 can be reduced by an equivalent amount.

4.3 Particle Collection Efficiency

A particle sampling system consists of a collection of flow components such as probes, tubes, and bends that allow for the transport of particulates onto a sample medium. During transport, some fraction of particles will be lost to the walls of the system due to gravitational settling, turbulent diffusion, inertial impaction, or Brownian diffusion. Various software programs can be used to calculate sample line loss based on user-defined system inputs, such as tube length, diameter, and bend curvature. The software determines the fraction of particles of a given size that are conveyed from the system inlet to the outlet. The ANSI/HPS N13.1-2011 criterion for the PCE is no less than a 50 percent penetration based on a 10-μm monodispersed particle distribution (HPS 2011).

The RPL radiological permit requires the use of two high-efficiency particulate air (HEPA) filters in series as an abatement technology (i.e., filtration reduces the number of released particles available for sampling). The HEPA filters are defined by a "… minimum efficiency of 99.97% when tested with an aerosol of essentially monodispersed 0.3-μm diameter test aerosol particles" (ASME AG-1 1994). Particles larger or smaller are removed with an even higher efficiency. Annual testing is performed to verify the efficiency rating remains at least 99.95% for each filter (Shrank et al. 2020).

Nevertheless, PCE calculations for the RPL sample line were performed at larger particle sizes of 1-μm and 10-μm to represent the range of particles potentially found downstream of the HEPA filters in the exhaust stream and available for sampling. The PCE range was as low as 0.50 (unfiltered) to as high as 0.775 (filtered) over a range of flow conditions. As discussed in Section 2.1, the PCE is used to correct the estimated stack activity (Equation 2), which is used in the implied dose calculations. In this report, the PCE was conservatively set to 0.50, which increases the calculated stack activity and therefore the implied dose, by a factor of 2.00 (i.e., 1 ÷ 0.50). However, based on the PCE calculation package for RPL, a PCE of 0.70 is an appropriate value to use for the RPL exhaust; this results in an activity increase of only 1.43 (i.e., 1 ÷ 0.70) instead of 2.00. Thus, the stack activity is reduced by nearly 29 percent and the implied doses in Tables 11 and 12 can be similarly reduced by an equivalent amount.

4.4 Additional Dose Considerations

As discussed in Section 2, the alarm setpoints were developed assuming a short-duration (i.e., 2-hour) alpha or beta radiological release resulting in an implied dose of 2 mrem to the hypothetical MEI; this value is 20 percent of the 10 mrem annual standard (40 CFR 61, Subpart H [2002]; Washington Administration Code Chapter 246-247 [2019]). The DOE public dose limit is 100 mrem/year (DOE 2020).

The 2-mrem acute dose constraint is consistent with the Nuclear Regulatory Commission dose standard, which limits the handling and use of radioactive materials such that no member of the public will receive a radiation dose of 2-mrem in any 1 hour period from external radiation sources in an unrestricted area (10 CFR 20, Subpart D [1991]). For context, the ICRP Publication 103 (2007) recommends exposures to the general public in planned exposure situations should be limited to no more than 100-mrem annually (ICRP 2007). Indeed, the average annual radiation dose per person in the United States is 620 mrem (NCRP 2009), of which 228 mrem is from natural background (i.e., radon and thoron).

As noted in Section 3, the current alpha-beta concentration and integrated activity alarm setpoints have resulted in occasional, intermittent alarms at RPL during planned radiological work; these alarms are mostly due to anthropogenic releases of radon and associated progeny that are not entirely accounted for by the CAM's "alpha-beta-pseudo-coincidence-difference method" (Berthold 1993). Although there have been planned alarms, continuous sampling is performed at RPL to confirm that annual doses are below the 10-mrem regulatory limit (10 CFR 61, Subpart H [2002]; WAC 246-247 [2019]). Table 13 lists the annual gross-alpha and gross-beta doses from annual reports derived from continuous sampling. Clearly, annual doses are many orders of magnitude below 10-mrem, demonstrating radiological work within RPL is not challenging established regulatory dose limits.

Table 13. Annual (2016–2020) RPL Gross Alpha and Beta Doses Estimated from Continuous Sampling

Radioactivity Type	2016 Dose[a] (mrem)	2017 Dose[b] (mrem)	2018 Dose[c] (mrem)	2019 Dose[d] (mrem)	2020 Dose[e] (mrem)
Gross Alpha	2.9×10^{-6}	3.0×10^{-6}	4.7×10^{-6}	3.7×10^{-6}	4.1×10^{-6}
Gross Beta	1.6×10^{-6}	1.8×10^{-6}	1.3×10^{-6}	1.1×10^{-6}	8.9×10^{-7}

[a] DOE/RL-2017-17 (2017)
[b] DOE/RL-2018-05 (2018)
[c] DOE/RL-2019-09 (2019)
[d] DOE/RL-2020-08 (2020)
[e] DOE/RL-2021-12 (2021)

5.0 Summary and Recommendations

This report documents the historical and current alpha-beta stack CAM alarm setpoints used at the RPL. The initial alarm setpoints of 5 cps alpha and 250 cps beta were based on "artificial" alpha-beta counts (cps) and were designed to provide an early indication of a larger release, that if allowed to persist, could begin to approach established dose and ALARA objectives. In 2004, the initial artificial setpoints were reaffirmed for use at RPL. In addition, "total" alpha and beta setpoints were developed, which included both "artificial" contributions and naturally occurring radioisotopes (e.g., radon and thoron). Since there were no facility radon release scenarios that could lead to a 2-mrem dose, the total alarm setpoints were suggested, but not required.

In 2006, new software was made operational at RPL, called the "OS3300 Alpha-Beta Monitoring Software", that converts the measured total (gross) alpha-beta counts on the CAM filter to real-time estimates of "artificial" activity on the filter. The alpha-beta filter activities are then converted to stack air concentrations and integrated activities, which have accompanying alarm setpoints. Thus, with the introduction of the OS3300 software, there was a transition from alarm setpoints based on measured counts to alarm setpoints based on calculated activity. The 2006 derived setpoints continue to be used in the OS3300 software at RPL. The alpha and beta air concentration alarm setpoints are 1.77×10^{-8} µCi/ml and 3.47×10^{-8} µCi/ml, respectively. The alpha and beta integrated activity alarm setpoints are 70.22 µCi and 137.63 µCi, respectively.

The derivation of the OS3300 alarm setpoints utilized the 2004 "total" count alarm setpoints as the starting basis and subtracted representative facility radon and background contributions determined during CAM calibration to calculate representative alpha-beta air concentration and integrated activity alarm setpoints. This method implicitly assumed the resulting net "artificial" counts would be comparable to the original "artificial" alpha and beta setpoints, thereby resulting in comparable doses. However, this method omitted consideration of the anthropogenic radon contribution that was also included in the original total count alarm setpoints. Consequently, the natural background and radon contributions were not nearly as significant, resulting in larger net "artificial" counts and therefore higher concentration and activity alarm setpoints. As a result, implied doses are correspondingly higher, and were shown to be outside the 2-mrem dose constraint using the very conservative release assumptions.

The report then evaluated the current alarm setpoints by comparing them against setpoints calculated using more recent (2017–2021) calibration data. For alpha, the 2020 calibration data would result in a 31 percent decrease in both the alarm setpoints and implied dose, but the doses would still be well above the 2-mrem dose constraint. For beta, the 2017 calibration data would result in a 33 percent increase in both setpoints and implied dose, but implied beta doses would remain well below the 2-mrem dose constraint.

The resulting range (minimum and maximum) of alpha-beta setpoints were then evaluated against 5 years of historical data to examine the alarm frequency. For alpha, the lowest alarm setpoint resulted in substantially more alarms in 2 of the 5 years. However, the unique alarm days were virtually the same, meaning the evaluated setpoint range identified the same larger radiological work events. For beta, the alarm count frequency was much lower overall and, in many cases, the maximum concentration and integrated activity setpoints resulted in no alarms for a given year. In general, the alarms are mostly due to anthropogenic releases of radon and associated progeny that are not entirely accounted for by the CAM's "alpha-beta-pseudo-coincidence-difference method" (Berthold 1993).

The implied dose associated with the current alarm setpoints was re-examined by reviewing the values to the selection of appropriate dose factors as well as other adjustment factors used in the calculation of stack activity, including the filter self-absorption factor and particle collection efficiency. Utilizing more recent 95th percentile acute dose factors that considered more representative release scenarios used in RPL safety basis calculations results in implied alpha dose reduction from 186.37 mrem to 17.3 mrem. Using more realistic (e.g., average) meteorology, similar to the method used by the NRC in evaluating environmental dose impacts from design-basis accidents for nuclear power stations, results in an implied alpha dose of 2.5 mrem. Finally, using a more appropriate filter self-absorption factor and particle collection efficiency in the calculated release activity results in implied alpha doses below the 2-mrem dose constraint. Indeed, independent continuous particulate sampling at RPL demonstrates that annual alpha-beta emissions and associated doses are well below regulatory standards.

Overall, the evaluation demonstrates current alpha-beta CAM alarm setpoints continue to meet permitted emission and established dose limits at RPL. Furthermore, operational experience demonstrates the current alarm setpoints are effective at identifying larger releases without causing nuisance alarming. Although the alpha alarm setpoints could be adjusted lower using more recent calibration data, the new setpoints would not identify significantly more radiological releases; they would simply increase the alarm duration of a given release. Implied alpha doses are below the 2-mrem dose constraint when using more realistic assumptions consistent with environmental analyses for calculating dose. The current beta alarm setpoints are more than adequate for RPL operations; very few releases are capable of causing a beta alarm and implied doses are well below the 2-mrem dose constraint at the existing alarm setpoint. Therefore, the current alpha-beta setpoints for concentration alarms (in µCi/ml) and integrated activity alarms (in µCi) are recommended for continued use at RPL, as they are meeting the stated objectives for current and expected future radiological work activity at the facility.

6.0 References

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Appendix A – Alpha-Beta Alarm Setpoint Technical Basis (Ballinger 2004 Memorandum)

ADJUSTMENT TO ALPHA CAM ALARM SETPOINT

Issued: 4/19/04

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ADJUSTMENT TO ALPHA CAM ALARM SETPOINT

Alarm setpoints for the Radiochemical Processing Laboratory (RPL) continuous air monitor (CAM) used for detecting releases of particulate material from the RPL stack were documented in 1995[1]. The actual setpoints shown in Table 1 were chosen based on the 1995 document combined with As Low As Reasonably Achievable (ALARA) objectives. According to this document, the maximum alarm setpoints calculated for the alpha and beta CAM are 13 and 570 cps, respectively. Pu-239 was used as the worst-case dose emitter for alpha and Sr-90 was used for beta; these calculations addressed non-radon emissions and are appropriate for the "artificial" alpha and beta alarm setpoints. The maximum alarm set points were established with respect to the derivation of a 2-mrem acute emission alarm level. As a conservative measure the artificial alpha and beta alarm set points were set below the maximum calculated levels (to 5 cps and 250 cps, respectively) for non-radon emissions. There is no documented basis for the setpoints currently used that include radon - total alpha and total beta alarms of 10 and 500 cps respectively.

Table 1. Summary of RPL Stack CAM Alarm Setpoints

Monitor	Setpoint	Comments
Total Beta	500 cps	
Artificial Beta	250 cps	Beta minus radon daughter products
Total Alpha	10 cps	
Artificial Alpha	5 cps	Alpha minus radon daughter products.

The alpha-beta detection system can measure and send alarm outputs for the following:

1. The total emissions, including both:
    a. "artificial" contributors that are non-natural radionuclides, and
    b. "pseudo-coincidence" contributors that are naturally occurring radioisotopes (e.g., radon and thoron).
2. Artificial contributors.

Historically the background radon levels have remained steady (usually 3-5 cps) and have not been high enough to trigger the total alpha CAM alarm (> 10 cps alpha). However, a buildup of naturally occurring radon from a climatological inversion in October 2002 triggered a total alpha alarm. In addition, the total alpha alarm was triggered several times from an isotope separation project involving radon gas that was initiated in December 2002 in the RPL. These "false" alarms tend to interfere with normal building operations and due to the radionuclides released, these emissions are not great enough to be of concern from an offsite dose perspective. To date, no alarms have been triggered by releases exceeding artificial alpha, artificial beta, or total beta criteria.

The decay chain for the parent material used in isotope separation contains an alpha-emitting radon daughter gas that decays with a short half-life. The radon daughter products are beta and alpha-emitting particles. Some of the radon gas passes through the building HEPA filters before it decays so that the total activity detected on the CAM is from a combination of the radon gas and particulate daughters.[2] The artificial alpha and beta measurements subtract activity from radon and its daughter products. Therefore, the artificial measurement does not show elevated activity during the medical isotope events. About a dozen medical isotope separation events have occurred since December 2002, with peak total alpha activity ranging from 13 to just over 50 cps.

Radon and its daughter products have a low dose potential, several orders of magnitude less than Pu-239. There are no radon acute release scenarios that would result in a 2 mrem dose equivalent to a member of

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[1] This internal (unpublished) document *Maximum Alarm Setpoints for Tritium and Particulate Airborne Radionuclide Emissions Monitors at PNL Nuclear Facility Stacks*, August 1995, was prepared by MJ Sula, and approved by SJ Jette, RK Woodruff, GW McNair, and MJ Bagaglio.

[2] In addition to radon and daughter products, total activity would also include any other releases that occurred at the same time as the medical isotopes work.

the public, thus there is no requirement for a CAM alarm based on total alpha or total beta. Removal of the total alpha alarm setpoint or resetting to a higher level (as a best management practice) is recommended to improve operational efficiency for the facility. The total beta alarm may also be increased to a higher level, but has not resulted in operational disturbances to date. The expected total alpha peak for radon releases from medical isotopes work is about 50 cps. Therefore, a setpoint of 100 cps for total alpha is proposed if an alarm is desired by research and operating staff as a best management practice. This setpoint would allow normal activities to take place in the building without the disruption of alarms, but would notify staff of releases that are higher than expected.

Radionuclide Air Emission Permit Limits

Radon isotopes were included in the RPL Notice of Construction (see http://wwwi.pnl.gov/em/permits/), and the annual maximum permitted releases of these radon isotopes are each individually limited to less than 0.1 mrem/yr. Activities resulting in radon emissions, other than those associated with the Th-232 Medical Isotope project, are conservatively calculated based on the source material and the duration of release. No credit is taken for the decay or deposition of radon and daughter products within the building. These calculations are used to report actual releases and to evaluate compliance with permit limits. Radon emissions resulting from the Th-232 Medical Isotope project are routed through a recovery system and sampled downstream of the record sampler; the Th-232 Medical Isotope project has not been placed into operation at the RPL.

Conclusion

An alarm setpoint for total alpha or total beta is not needed because there are no acute radon release scenarios that would result in a 2 mrem dose equivalent to a member of the public. Therefore, the total activity alarms may be removed, leaving the artificial alpha and beta alarms to detect all releases other than radon from the facility. Alternatively, if desired by building personnel as a best management practice, the total alpha alarm setpoint may be increased to 100 cps. At this setpoint, an alarm will not be triggered due to "routine" operations of the isotope separations project, but would notify staff of radon releases that are higher than expected. The artificial alpha alarm will remain at 5 cps, allowing facility operations to maintain alarm capability in the event that another (non-radon) project in the RPL (or a failure of the HEPA filter control technology) initiates a radiological release to the environment that, if continued, could result in a 2 mrem dose equivalent to a member of the public.

Table 2. Proposed Alarm Setpoints.

Monitor	Previous Setpoint	Suggested Setpoint	Comments
Total Beta	500 cps	500 cps	Alarm not required; suggested setpoint to be used if desired by management
Artificial Beta	250 cps	250 cps	No Change
Total Alpha	10 cps	100 cps	Alarm not required; suggested setpoint to be used if desired by management
Artificial Alpha	5 cps	5 cps	No Change

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