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RADIATION DETECTION INSTRUMENTATION			
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Reviewed By: CTK 08/14/201	2; MDG 08/14/2012; JWC	Final Approval:	

1.0 PURPOSE

2/9/2013; CTK 06/13/2013; CTK 07/09/2013

The purpose of this Standard Operating Procedure (SOP) is to provide procedures for maintaining proper function of radiation detection instruments used at the Lost Creek ISR (LC-ISR) project. To ensure information obtained from instruments is correct they must be calibrated regularly and maintained. Efficiency calculation is also an integral part of routine operation.

2.0 **RESPONSIBILITIES**

The Radiation Safety Officer (RSO) will be responsible for:

• Ensuring that the HPT is competent in instrumentation duties.

The Health Physics Tech (HPT) will be responsible for:

- Ensuring instrument manufacturer calibrations remain current;
- Maintaining manufacturer calibration records; and
- Ensuring regular battery and function checks are performed.
- Determining daily efficiencies, posting action limits and setting alarms

3.0 PREREQUISITES AND TRAINING

Individuals who perform instrumentation checks will have read and understood this SOP and shall be knowledgeable with the use and safe handling of each radiation detection instrument.

4.0 **DEFINITIONS**

<u>Check source</u>: A radioactive source of known activity and type used for constancy checks.

<u>Constancy</u>: reproducibility in measuring the activity of a known (check source) source over a long period of time.

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<u>Detector</u>: Component attached by a cable to the meter that detects the radiation and sends an electrical signal to the meter.

<u>Data logger</u>: Component of a detection instrument that can process the signal from a detector and record data over time.

<u>Efficiency</u>: The disintegrations that a detector actually measures divided by the disintegrations a radiation source emits, reported as a percent.

Lower Limit of Detection (LLD): This is the lowest amount of radiation that a detector can distinguish from background radiation. RG 8.30: smallest concentration of radioactive material that has a 95% probability of being detected. Radioactive material is "detected" if the value measured on an instrument is high enough to conclude that activity above the system background is probably present.

<u>Meter</u>: The component of a radiation detection instrument that processes the signal from a radiation detector and displays the measurement – does not record the measurements.

5.0 HAZARD ASSESSMENT AND PPE

When unplugging cables or replacing batteries the instrument must be turned off to prevent the possibility of electric shock or damage to the instrument.

When accessing the instrument's internal components, or when cleaning the instrument, the instrument should be turned off, unplugged and allowed to sit for one minute before proceeding.

No PPE is required when operating a detection instrument; however, PPE may be required based on the location where the survey is being conducted.

6.0 PROCEDURE

6.1 Battery Check

Before using an instrument, a battery test must be performed to ensure that there is enough power for the instrument to function properly. There are different ways of



performing a battery test depending on the model of instrument. Here are a few battery test methods:

- Using the range selector switch (knob with multipliers, for scaling the measurement units) select BAT. The display needle should be in the "BAT ok" (or "BAT test") region.
- Some instruments will have a switch or button for putting the instrument in BAT mode.
- Newer instruments (Model 26 Frisker) may show a low battery symbol on the display screen when the batteries need to be replaced.

If the battery is outside the acceptable range as indicated by the instrument, the instrument may not be used until the batteries are replaced. A battery check may be performed by any individual trained to use the instrument.

6.2 Background Check

Background radiation is measured for each instrument for both long term and short term. The long term background values will be measured on the order of minutes to hours to use for the calculation of detection limits (see Section 6.7). Short term backgrounds shall be taken on a daily basis with count times on the order of minutes and will be used for daily control charts.

Background determination should be performed under conditions that replicate actual sample measurement conditions (i.e. similar sample containers or measurement geometry) as close as practicable. Variations in background levels may mask radiation levels that might not ordinarily be discovered. To measure background values:

- 1. Place instrument in a pre-designated location free from non-ambient sources of radiation.
- 2. If sample containers or media is used, count background values using representative blanks.
- 3. Allow instrument to automatically record background reading or record measurement manually for a duration equivalent to normal measurements.
- 4. Record and chart background values for reference. Background trends may indicate problems and should be included in ALARA reports.

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6.3 Check Source Values

Each instrument may require a different check source to check the constancy of measurements, based on type of radiation the detector is calibrated for. A constancy check shall be performed on a daily basis or prior to instrument use. The RSO or HPT shall determine the acceptable range for each check source for each instrument and ensure the range of values is posted for the instrument user. The acceptable range should be easily accessible for reference when performing function checks on an instrument to quickly determine if a check is successful.

The acceptable range for a check source is determined following each successful manufacturer's calibration of instrument by the following method:

- 1. Select calibrated instrument.
- 2. Select the appropriate source for the instrument (see examples in table below)
- 3. Determine the background value (Section 6.2)
- 4. Take 20 separate readings of the check source at a count time equivalent to a typical count time for operational use.
- 5. Determine the average value of the measurements
- 6. Subtract the background value
- 7. The tolerance threshold for constancy check acceptance is the average value minus background +/- 10%.

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Check sources for beta detecting instruments should use a radionuclide with similar maximum beta energy as is expected in the field. Examples of check source information for several types of detectors are provided on the following table:

Instrument	Radiation Types	Check Source	Predicted Reading
43-93 scintilator	alpha	Po210 0.1uCi	29600cpm @ 6cm
	beta	Sr90 0.1uCi	81460cpm @ 6cm
44-9 Pancake Probe	alpha	Po210 0.1uCi	29600cpm @ surface
	beta	Sr90 0.1uCi	95000cpm @ surface
	gamma	Cs137 1uCi	109cpm @ 10cm β shielded
Model 26 Pancake Probe	alpha	Po210 0.1uCi	20300cpm @ 6cm
	beta	Sr90 0.1uCi	69300cpm @ 6cm
	gamma	Co60 1uCi	25400cpm @ surface
44-2 Nal	gamma	Cs137 1uCi	5700cpm @ 10cm
Rem Ball	neutron	n/a	
44-10 Nal	gamma	Cs137, 1uCi	29700cpm @ 10cm
Model 19 Nal	gamma	Cs137, 1uCi	33cpm @ 10cm

6.4 Efficiency Determination

Efficiency determinations should be performed using certified (NIST-traceable) calibration sources. These should be compared to efficiency values provided by the calibration facility immediately following calibration. Using a certified calibration source, take the counts per minute recorded by an instrument and divide by the disintegration per minute value of the calibration source. An uncertified check source can be used to determine efficiency provided an efficiency correction factor has been determined for the check source immediately following calibration or upon comparison of check source efficiency with the efficiency of a certified check source. This will be the efficiency for the day of use.

E = cpm/dpm * 100

E: Efficiency value in percent cpm: counts per minute the detector indicates dpm: disintegration per minute value of the calibration source

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6.5 Instrument Calibration

Most calibrations will be performed by the manufacturer or other approved vendor. Some instruments may be calibrated "in-house" using a NIST-traceable calibration source according to manufacturer's specification. Calibration frequency is specified in the Owner's Manual of the instrument. A notification system may be incorporated via electronic means to send e-mails or other alerts to the EHS staff of calibration due dates.

The procedure for sending an instrument in for manufacturer's calibration is as follows:

1. Fill out a generic order form (Ludlum for example), or use previous form for specific instrument. Save an electronic copy of request under the instrument specific folder. The forms and folders are in the following file:

Active Calibration

- 2. Include on the form the following information:
 - a. The price of the instrument for insurance values. Price listings can be found in the following file:

Instrument Price Listings

- b. 12 month calibration per manufacturer's specifications
- 3. Remove the batteries.
- 4. Put the instrument in the case, and pack the instrument. Some LC-ISR instruments have packaging that is reused for specific types of instrument cases.
- 5. Contact the Calibrator, and inform them that instruments are being sent for calibration (email calibration form for Ludlum to repair@ludlums.com)
- 6. Ship to appropriate address.
- 7. Mark the following spreadsheet to show that the calibration is in progress:

Instrumentation Log

8. When an instrument returns, review the calibration documents to determine if any action is required. Use a check source and determine if the instrument is giving a reasonable response. One method to check the instruments response is





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to use the predicted check source reading from Table 1 and see if the measured value is close.

- 9. Prepare source check baseline data for instrument function check, which may be used for developing a Shewhart-CUSUM control chart.
 - a. Perform 20 background readings and 20 measurements with relevant check source. If the instrument is going to be used for gamma, then a function check must be performed with any of the Cs-137 check sources selected for use. For alpha and beta use Po-210 and Sr-90 check sources respectively.
 - b. Record results in the following spreadsheet (edited appropriately): <u>Function Check Baseline Sheet Format</u>
 - c. Create a control chart for the background and each radiation source that will be utilized for the function checks. Use Appendix A procedure for setting up the control chart.
 - d. Post the range of acceptable readings for specific check sources on the survey instrument.
- 10. Store calibration documents in the Radiation Instruments binder, and if calibration is relevant then store it also in the PFN RPP field notebook.
- 11. Record the new calibration date in the following spreadsheet:

Instrumentation Log

6.6 Function Check

A function check shall be performed, either daily or prior to periodic use, for each instrument to ensure that the instrument is operating properly. The procedure for performing an instrument function check is as follows:

- 1. Perform a battery test.
- 2. If applicable, turn the audio switch to on. Using a check source, ensure that the detector is audible. A chirping or clicking noise should be heard when the instrument detects radiation.
- 3. If the instrument has fast/slow response setting (may be depicted by a rabbit and turtle), ensure there is a difference in the response time between the two settings.





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- 4. While maintaining distance from any source, measure the background. If background is high enough to affect the source check measurement, then the difference between present background and recorded source check background is subtracted from the source check reading.
- 5. Perform a source check using the appropriate source(s) for the instrument and task. Place the source (Cs-137, Po-210, or Sr-90) in a central location as close to the part of the instrument detecting the radiation as possible. Some instruments will have dimples in the instrument housing, which show best locations for lining up the source. The check source measurement should be within the limits for the specific source, posted on the side of the detector. If a radionuclide is used that has a short half-life (such as Po-210), the check source value measured will need to be decay corrected for comparison to baseline mean. Record the background and source measurements. These results may be analyzed using a Shewhart-CUSUM control chart.

6.7 Control Charts

The function check measurements are analyzed with control charts to statistically determine if the radiation detection instruments are functioning correctly. See Appendix A for how to set up the control chart.

6.8 Detection Limits

Detection limits in the form of Minimum Detectable Activity (MDA), Minimum Detectable Concentration (MDC), or Lower Limit of Detection (LLD) shall be calculated for each instrument as applicable. A spreadsheet of calculations for each instrument shall be calculated and maintained electronically.

The calculations should be done at the following times:

- Initially when an instrument is acquired
- Following instrument calibration
- Following instrument repair and calibration
- When conditions dictate such as in response to changes or trends in control chart data

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The MDA or the MDC is an *a priori* (i.e. before measurement) estimate of the minimum activity or minimum concentration on a surface or within a material volume that an instrument is expected to detect with a 95% confidence. The equation that LC-ISR uses to calculate MDA is:

$$MDA = \frac{2.71 + 3.29 \sqrt{R_{b} t_{s} \left[1 + \frac{t_{s}}{t_{b}}\right]}}{(t_{s})(E)}$$

MDA = minimum detectable activity in dpm

R_b = background count rate in cpm

t = sample counting time in minutes

 t_{b} = background counting time in minutes

E = detector efficiency in counts per disintegration

The MDA for 100 cm² spot surface surveys is the same calculation with the exception that the unit area is factored into the equation:

MDA =
$$\frac{2.71 + 3.29 \sqrt{R_{b} t_{s} \left[1 + \frac{t_{s}}{t_{b}}\right]}}{(t_{s})(E) \frac{A}{100}}$$

MDA = minimum detectable activity in dpm

R_b = background count rate in cpm

t_ = sample counting time in minutes

t = background counting time in minutes

E = detector efficiency in counts per disintegration

A = active probe area in cm²

Similar to MDA, the Lower Limit of Detection (LLD) is an *a priori* estimate of detection capability at 95% confidence based on characteristics of an instrument and sample-specific parameters. The LLD calculation is typically used for air sampling.



6.9 Troubleshooting and General Guidance

Reg Guide 8.30 explains how to create a beta correction factor using yellowcake that is over 100 days old. Read both section 8 and appendix C. A beta correction factor is used when an instrument is calibrated for gamma but not beta and you want to know what the beta dose is. For pancake probes, instead of putting the axis 2 cm from the source the probe could be turned upside down.

When performing measurements, start on the highest scale. For some instruments that will be x100. When it is clear that the radiation measurement is in a lower range, the range selector can be switched to a lower level. This is to prevent damage to the instrument.

7.0 DOCUMENTS AND RECORDS

The following records shall be maintained in health physics files either electronically or in hard copy for duration of at least the life of the project:





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- Calibration records are currently stored in the Radiation Instrument binder in the EHS offices. During operations, the manufacturer and user calibration reports will be kept in the EHS offices.
- Instrument-specific calculations of MDA, MDC, or LLD.
- Calibration status for all the instruments is stored in the following spreadsheet:

Instrumentation Log

• Constancy checks and control charts.

8.0 REFERENCES

Refer to the appropriate instrument Owner's Manual for more details

Ludlum, newsletter, Steinmeyer Jr., Paul, *The Ludlum Report Volume 13 Number 1 –* Part I and Part II, December 1998, March 1999

MARLAP, Multi-Agency Radiological Laboratory Analytical Protocols (MARLAP) Manual, July 2004, <u>http://www.epa.gov/rpdweb00/marlap/manual.html</u>

NRC, NUREG-1507: Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions, January 1998

NRC, NUREG/CR-5849: Manual for Conducting Radiological Surveys in Support of License Termination, June 1992

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Appendix A: Setting Up a Shewhart-CUSUM Control Chart

Analysis of Data:

The Shewhart-CUSUM Control Chart is a statistical method for determining if there is contamination. This method is designed to show, on one chart, if there is a significant increase in the measurement indicating contamination or if there is a gradual increase in the sample measurements over time. The following procedure describes how the statistic is performed, but will not be necessary information for everyone who produces relevant information for use in the control chart. The user of the procedure in this section will need to be familiar with statistics.

Requirements for using Shewhart-CUSUM Control Chart:

One of the requirements of this type of control chart is statistical independence. For this reason, duplicate and split samples should not be included in the chart. Also for maintaining statistical independence, the samples should not be collected too frequently, because this could cause autocorrelation.

Examine the background data for a seasonal cyclical pattern. If there is a clear seasonal pattern (determined graphically, or with a statistical test such as ANOVA) then the data should be adjusted for seasonal effects.

Control charts also assume temporal stationarity. There should be no apparent upward or downward trend in the background/baseline measurements. The data should not necessarily be de-trended because the future of the trend may be unknown. The situation should be investigated to determine the best course of action.

Control charts can be used for intra-sample location or inter-sample location testing. If inter-sample location is going to be used then inter-sample spatial stationarity must be demonstrated. The ANOVA is appropriate for demonstrating this.

Shewhart-CUSUM Basic Procedure:

1. Given *n* background measurements, estimate the baseline parameters by computing the baseline sample mean (\bar{x}_B) and baseline standard deviation (s_B) . The baseline data will be created by performing n=20 source check following



instrument calibration. The measurements will be performed spread out over a reasonable period of time to minimize autocorrelation.

2. For an operational monitoring measurement (x_i) collected during sampling event (T_i) , compute the standardized concentration (Z_i) :

$$Z_i = (x_i - \bar{x}_B)/s_B$$

- 3. Changing the value *k* will change how quickly the control chart will detect a shift in the average value of what you are measuring. To achieve a 95% confidence the control chart limit will be based on 2 standard deviations. The *k* value is half the desired standard deviation. The typical *k* value for control charts will be 1.
- 4. For each sampling event (T_i) , use the standardized concentration (Z_i) to compute standardized CUSUM values (S_i) with the following equation. The function $max[value_1, value_2]$ inserts the higher of the values in the listed series (0, or the calculated value in this case).

$$S_i = max[0, (Z_i - k) + S_{i-1}]$$

$$S_0 = 0$$
$$k = 1$$

5. Compute the non-standardized CUSUMS (S_i^c) with the following equation:

$$S_i^c = \bar{x}_B + S_i \cdot s_B$$

- 6. Determine the *h* value for use in determining the control limits. A Kemp nomogram (see Appendix B) will be used to determine the h value. Follow the following steps:
 - a. Locate the desired Average Run Lengths (ARL) on the in-control and outof-control ARL scales. Connect these two points with a line.
 - b. Note where the line crosses the k' scale, and solve for n using the equation:

$$k' = \frac{k}{\sigma/\sqrt{n}}$$





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- c. Round *n* up to the nearest integer.
- d. Connect the point on the k' scale with the point on the in-control ARL scale using a second line, and note where this line crosses the h' scale. Then use the following equation to solve for h:

$$h = \frac{\sigma \cdot h'}{\sqrt{n}}$$

7. Calculate the non-standardized control limit (h_c) used to assess compliance of both future measurements (x_i) and non-standardized CUSUMs (S_i^c) with the following equation:

upper
$$h_c = \bar{x}_B + h \cdot s_B$$

lower $h_c = \bar{x}_B - h \cdot s_B$

Some situations only need an upper control limit, such as contamination detection. When using control charts for instruments, it is important to have an upper and lower limit because an instrument failure could result in a low or a high measurement depending on the cause of failure.

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8. Construct the control chart by plotting both the sample measurements (x_i) and the non-standardized CUSUMs values (S_i) on the y-axis against the sampling events (T_i) along the x-axis. Include a horizontal line at the value equal to the control limit (h_c) . The following chart is an example of a control chart for Nickel, and only uses an upper control limit.

Figure A1: Example Control Chart





9. The control chart is potentially out-of-control if either sample measurements (x_i) or the non-standardized CUSUMs values (S_i) exceed the control limit (h_c) . If the sample measurement exceeds the control limit then there is a potentially contaminated instrument. If the CUSUMs value exceeds the control limit that indicates a gradual rise in the background, or a possibility of contamination that is not quantifiable above background, but is significant enough to effect measurements. There are other causes for an out of control situation, but they will have to be investigated based on the situation.

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Appendix B: Kemp's Nomogram for Determine *h* for CUSUM Control Charts

