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USE AND CALIBRATION OF THE AUTOMATIC
COLUMBIA RIVER MONITORING STATION
IODINE MONITOR
DECEMBER 1970

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USE AND CALIBRATION OF THE AUTOMATIC
COLUMBIA RIVER MONITORING STATION IODINE MONITOR

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Radiation Protection Department
Operations and Services Division

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USE AND CALIBRATION OF THE AUTOMATIC COLUMBIA RIVER MONITORING STATION IODINE MONITOR

INTRODUCTION

The ACRMS has been described in some detail in earlier documents^(1,2,3,4), so an elaborate description of the system is not included here. Columbia River water is pumped from 135 feet offshore through the nominally 200 gallon ACRMS tank. (Figure 1.) Two detectors measure radioactivity in water flowing through the tank. This document concerns primarily the Iodine Monitor, whose detector is submerged in the tank (Figure 2), and describes in more detail than earlier documents the use and calibration of that instrument. However, the iodine-131 response of the Gross Gamma Monitor, which utilizes a 3 inch diameter by 3 inch thick bioplastic scintillator located just above the surface of the water, will be discussed briefly. Previously reported calibration data and operating instructions for the Iodine Monitor are superseded by this document.

SUMMARY

The described calibration indicates that the ACRMS Iodine Monitor is capable of reasonably accurate measurements of iodine-131 at concentrations above 1000 picocuries per liter, 10 times the Concentration Guide for sustained intake by a suitable sample of the exposed population. A single day's intake of drinking water at such a concentration would imply a thyroid dose to the maximum Richland infant (2 gram thyroid) of 14 mrem. The Gross Gamma Monitor, which is capable of detecting iodine-131 concentrations several hundred times greater than the Concentration Guide for a suitable sample of the exposed population, provides backup for the Iodine Monitor. While neither instrument is capable of monitoring iodine-131 concentrations as low as those normally found in the Columbia River (approximately 2 picocuries per liter), both instruments should adequately detect a significant release of iodine-131 at an upstream location.

While periodic calibration with iodine-131 solutions would be appropriate, perhaps once every two or three years, interim calibration with mock iodine in the case of the Iodine Monitor and with radium-226 in the case of the Gross Gamma Monitor should be adequate. Routine maintenance and calibration of the Iodine Monitor should be performed as described in Appendix I.

THE ACRMS IODINE MONITOR

Description

The Iodine Monitor consists basically of a Hamner Model Na-11 amplifier, Model NC-11 single channel analyzer, and Model NR-10 linear ratemeter (Figure 3) fed by a 3 inch diameter by 2 inch thick NaI(Tl) detector. During normal operation the detector is supported in a 0.034 inch thick copper canister such that the detector is about 6 inches below the water surface but is not in contact with the water. One part of the calibrating procedure to be described later requires that the detector be inverted as in Figure 4.

Energy Response

The first step in calibrating the Iodine Monitor was to determine the energy response of the system. As shown in Figure 5, the energy response of the system is quite linear. Although not presently calibrated for other radionuclides, the Iodine Monitor could be used to observe radionuclides other than iodine-131 in river water.

The energy response to iodine-131 and to mock iodine was investigated in somewhat more detail. Figure 6 shows the apparent energy spectrum of a mock iodine source placed upon the inverted detector. Prior to making this and all other measurements of this type, the coarse and fine gain were adjusted to place the mock iodine photopeak within a window of width $\Delta E = 10/1000$ at $E = 360/1000$. These values were chosen rather arbitrarily; however, the value $10/1000$ for ΔE represents about the narrowest window that can be reproducibly obtained. The value $360/1000$ for E was chosen to correspond to the approximate 0.36 MeV photopeak energies of iodine-131 and mock iodine (barium-133). The resolution for the mock iodine photopeak is about 15 percent. With a little care it was repeatedly possible to adjust the fine gain such that a count rate of about 380 counts per second, representing the barium-133 photopeak maximum, could be obtained at $\Delta E = 10/1000$ and $E = 360/1000$. This fact becomes a useful part of the calibration as will be discussed later.

Having established the energy response of the detector system, the apparent energy spectrum of iodine-131 in the ACRMS tank was measured. After placing the mock iodine photopeak in the window $\Delta E = 10/1000$ at $E = 360/1000$, the detector

was then placed into its normal submerged operating position. An aqueous, 100 milliliter, 50 microcurie iodine-131 source in a polyethylene bottle was then suspended in the water at the centerline depth of the detector. The apparent energy spectrum then was measured at a detector to source center-to-center distance of 8.8 centimeters. (Figure 7.) Similar measurements were then made at detector to source distances of 15.7 and 25.4 centimeters. These measurements were made to determine how badly the spectrum was degraded in passage through the water. Surprisingly, the iodine photopeak at close distances fell at a higher baseline (i.e., it appeared to be a higher energy) than the mock iodine photopeak. Although quite apparent, degradation of the spectrum is of little consequence, since the photopeak energy shift is only about 5 percent, while a considerable loss in photopeak count rate (i.e., counting efficiency) occurs as the source is moved from the detector. This suggests that most of the measured gammas originate in a volume of water near the detector, while the bulk of the water in the tank serves mainly as shielding. A respectable 16 percent resolution* of the iodine photopeak was obtained with the aqueous source at 8.8 centimeters.

After ensuring the Iodine Monitor's ability to resolve mock iodine photopeaks as well as iodine-131 photopeaks from discrete sources submerged in the tank, an aqueous solution of iodine-131 was then added incrementally to the nonflowing tank, as will be discussed in more detail, to obtain an actual calibration of the Iodine Monitor for iodine-131 in the tank. Following addition of the last increment, the apparent energy spectrum of iodine-131 solution in the tank was measured. The results are shown in Figure 8. The resolution of the iodine-131 photopeak obtained in this manner was again about 16 percent.

Calibration

The first attempt at an actual iodine-131 calibration was made on October 16, 1970. The addition to the tank of very small quantities of aqueous iodine-131 solution provided the data shown as circles in Figure 9. A second

* The full width at half-maximum of the total energy peak, divided by the total energy.

set of standard solutions, of higher iodine-131 concentration, were added to the tank on October 20; the data obtained being shown as squares in Figure 9.

While amplifier gain was adjusted and spectra were measured with a window width of $\Delta E = 10/1000$, the window was widened to $\Delta E = 50/1000$ for the calibration and for normal operation. Although ΔE was set at 50/1000 on both occasions, the baseline (E) on October 16 was set at 340/1000, while on October 20 it was set at 330/1000. The baseline was changed to 330 in order to obtain a little greater sensitivity; however, another set of measurements made on October 26 showed virtually no difference between measurements made at baselines $E = 330/1000$ and $E = 340/1000$ for window widths $\Delta E = 50/1000$.

The Iodine Monitor should respond to iodine-131 solution in the tank as shown in Figure 9, provided: (1) that the shape of the spectrum as measured by the Iodine Monitor has not changed significantly, and (2) that the response of the Iodine Monitor to mock iodine remains essentially as it was at the time of this calibration. Changes that might occur in the apparent spectrum would undoubtedly be in the direction of poorer resolution and reduced efficiency although, due to the fairly broad window used, the reduction in efficiency might not be great.

In any event, such a change should be detected through periodic measurement of the mock iodine source at $\Delta E = 10/1000$ and $E = 360/1000$. As mentioned earlier, count rates of about 380 counts per second were repeatedly obtained when the fine gain was adjusted with some care. Electronic or other difficulties should be revealed by inability to obtain such a count rate, except that the radioactivity of the mock iodine source decays with a 7.2 year half-life. Response to the mock iodine source over a period of several years should be as shown in Figure 10. The "Acceptable Calibration Boundaries" were set rather arbitrarily at 10 percent above and 20 percent below the expected count rate. Response within these boundaries indicates that the calibration curve shown in Figure 9 can be used directly. Response outside these boundaries suggests erroneous settings or instrument problems, and a mock iodine spectrum should be plotted for comparison with Figure 6.

THE ACRMS GROSS GAMMA MONITOR

Prior to performing the iodine calibration, the Gross Gamma Monitor was recalibrated, as it has been in the past, with radium-226. Previous documents have indicated that a full-scale response on the x10 range (i.e., 10,000 counts per minute) should be obtained at an exposure rate of 100 microroentgens per hour. Figure 11 shows that this is not so at the present time. It also shows a discrepancy between count rate meter and recorder. However, since calibration of the Gross Gamma Monitor was incidental to calibration of the Iodine Monitor, the Gross Gamma Monitor was assumed to be operating satisfactorily. During calibration of the Iodine Monitor, Gross Gamma Monitor readings were taken as each increment of iodine-131 was added to the tank. The results are shown in Figure 12. If the Gross Gamma Monitor's sensitivity should change from time to time, the instrument's new response to radium-226 could be used in conjunction with Figures 11 and 12 to develop a new iodine-131 response curve without actually adding iodine-131 to the ACRMS tank.

THE FLOW RATE OF COLUMBIA RIVER WATER THROUGH THE ACRMS TANK

The ACRMS tank flow rate, which is not measured by any installed gauge, has been reported as being about 40 gallons per minute. The iodine calibration experiment provided an opportunity to measure the flow rate, provided good mixing occurs within the tank. Following the calibration experiment on October 20, when the ACRMS tank contained a total of about 200 microcuries of aqueous iodine-131 solution in a nonflowing tank, the rate of removal of the iodine from the tank following startup of the pump was measured. (Figure 13.) Upon startup of the pump, water was added to the tank, without significant mixing, to raise the surface of the water to its normal level as it overflows the weir. Until good mixing was established, water flowing over the weir contained iodine-131 at its original concentration. That plus the approach of "clean" water to the detector caused the count rate as measured by the Iodine Monitor to drop rapidly during the first several minutes. Once the mixing pattern had been established, the removal of iodine from the tank became exponential, thus indicating that good mixing was occurring. A straight line drawn through this portion of the curve shows the "half removal" time to be about four minutes. From this the flow rate was calculated to be 33 gallons per minute, which compares favorably with the 40 gallons per minute assumed in the past.

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FIGURE 1. INTERIOR OF ACRMS BUILDING

FIGURE 2. GROSS GAMMA MONITOR AND IODINE MONITOR DETECTORS

FIGURE 3. IODINE MONITOR INSTRUMENTATION

FIGURE 4. MOCK IODINE SOURCE ON INVERTED IODINE MONITOR DETECTOR

FIGURE 5. IODINE MONITOR ENERGY RESPONSE

FIGURE 6. APPARENT ENERGY SPECTRUM OF MOCK IODINE SOURCE
DETECTOR INVERTED

FIGURE 7. APPARENT ENERGY SPECTRUM OF ^{131}I AT THREE DISTANCES FROM DETECTOR IN NORMAL OPERATING POSITION

FIGURE 8. APPARENT ENERGY SPECTRUM OF ^{131}I SOLUTION IN THE ACRMS TANK

FIGURE 9. IODINE MONITOR RESPONSE

FIGURE 10. EXPECTED RESPONSE OF INVERTED DETECTOR TO (2.4 μ Ci ON 10-20-70) MOCK IODINE PHOTOPEAK (Ba-133) WITHIN WINDOW $\Delta E = 10/1000$ AT $E = 360/1000$

FIGURE 11. IN-PLACE EXPOSURE RATE CALIBRATION OF GROSS GAMMA MONITOR

FIGURE 12. "GROSS GAMMA MONITOR" RESPONSE
10-20-70

FIGURE 13. THE REMOVAL OF ^{131}I FROM THE ACRMS TANK BY NORMAL WATER FLOW

APPENDIX I

USE AND CALIBRATION OF ACRMS IODINE MONITOR

I. Use

Once the Iodine Monitor is calibrated (Section II.) such that the mock iodine (barium-133) photopeak maximum lies within $\Delta E = 10/1000$ at $E = 360/1000$, set ΔE to 50/1000 and E to 340/1000. Ensure that the alarm is set at 40 to 50 percent of recorder full scale. Set ratemeter range switches such that, with one K reactor operating, the recorder reads between 5 and 15 percent of full scale. Set the time constant at 40 seconds. Such an arrangement should provide adequate sensitivity while minimizing the chance of false alarms.

Operation of the instrument should be checked daily by observing its response to the cesium-137 source used to check the Gross Gamma Monitor. If response to this source changes significantly, more detailed calibration checks should be made as described in Section II.A. In any event, the calibration should be checked several times a year as described in Section II.A. A complete recalibration as described in Section II.B. should be performed every two or three years, or at any time the NaI crystal is replaced.

II. Calibration

Note: Calibrations should be performed with a clean ACRMS tank and, if possible when K reactors are not operating, in order to minimize the effects of background radiation on the calibration.

A. Mock Iodine Calibration Check

Invert the detector and stand the mock iodine source at the detector's center as shown in Figure 4. Set ΔE to 10/1000 and E to 360/1000. Slowly and carefully adjust the amplifier Fine Gain control for maximum count rate.

(Caution: The mock iodine source contains barium-133 and cesium-137. It is the 0.36 MeV photopeak of barium-133, not the 0.66 MeV photopeak of cesium-137, that is to be centered in the window $\Delta E = 10/1000$ at $E = 360/1000$.)

The count rate obtained should lie within the "Acceptable Calibration Boundaries" shown in Figure 10. If not, recheck instrument settings. If the count rate still lies outside the boundaries, an electronic

problem likely exists in one of the system components. If the count rate lies within the "calibration boundaries," the instrument's response to iodine-131 solution in the tank can be assumed to be as shown in Figure 9 with $\Delta E = 50/1000$ and $E = 340/1000$.

B. Calibration With Iodine-131 Solution

1. Thoroughly test the system to ensure proper operation of all components. (See manufacturer's operating manuals.)
2. Clean the tank to lower the background.
3. Restart water flow through tank. Allow to flow for at least 30 minutes.
4. Shut off water flow through tank. Close all valves. Allow sediments to settle for about 30 minutes.
5. While sediments are settling, perform the Mock Iodine Calibration Check described in II.A., above. Record the count rate obtained.
6. With $\Delta E = 10/1000$, measure the spectrum at E intervals of $10/1000$ and plot for comparison with Figure 6. (Note that ΔE is the interval above E . For example, $E = 360/1000$ and $\Delta E = 10/1000$ represents the interval between $E = 360/1000$ and $E = 370/1000$.) If the spectra are reasonably similar in both amplitude and width, proceed with calibration. Replace the detector into its normal operating position.
7. Set ΔE to $50/1000$ and E to $340/1000$.
8. Record background count rates on both the Iodine Monitor and the Gross Gamma Monitor.
9. Measure and record the response of both instruments to the cesium-137 source placed in its normal position.
10. Manually push a little water over the weir and out of the tank in order not to lose iodine-131 solution while mixing in tank. (Note: The difference in

water level between flowing and nonflowing tanks has no measurable effect on the Iodine Monitor calibration.)

11. Stir tank with a broom. Measure background. If significantly different from that measured in 8, above, consider the possible effect of background errors upon the calibration.
12. Add 1 microcurie aqueous (approximately 100 milliliters) iodine-131 to tank. Stir thoroughly. Measure and record count rate on both the Iodine Monitor and the Gross Gamma Monitor. Use a long time constant and measure on more than one range, if possible. [Caution: Avoid spillage or splashing from tank after iodine-131 is added. Follow provisions of Radiation Work Procedures.]
13. Continue this procedure, adding increments of 5*, 5, 10*, 10, 20*, 20, 50*, and 100* microcuries. Obtain quart samples from the tank after additions marked (*). Have at least one of these samples analyzed to verify the aqueous standards used.
14. After making the final addition and measurement, set ΔE to 10/1000, measure the spectrum at E intervals of 10/1000, and plot for comparison with Figure 8. If the spectrum indicates that $\Delta E = 50/1000$ and $E = 340/1000$ are not the best settings, reset ΔE and E to the better values, and remeasure the count rate. (This count rate and the one originally obtained after addition of the last increment can then be used to correct all the data obtained in 12 and 13, above.)
15. Obtain a 1-quart sample.
16. Flush tank until count rate reaches background. Shut off water flow as in step 4.
17. Stir tank and measure background as accurately as possible.

18. Again, push a little water over the weir.
19. Add the 1-quart sample obtained in step 15 to the tank. Stir thoroughly and measure count rate accurately. The concentration in the tank at this point should be $1/800$ times the concentration of the 1-quart sample. (The volume of the nonflowing tank is 200 gallons or 800 quarts.)
20. Determine iodine-131 concentrations in the tank at each measurement, and plot response as in Figure 9. Also, plot response of Gross Gamma Monitor as in Figure 12.

APPENDIX II

DESCRIPTION OF THE MOCK IODINE SOURCE

The mock iodine source presently being used for the ACRMS Iodine Monitor calibration is labelled "3 μ Ci on 5/10/68, Simulated I-131." Correcting for decay, the activity of the mock iodine source on October 20, 1970 should have been about 2.4 microcuries. The manufacturer's (Nuclear Supplies) catalog states that the source is a mixture of barium-133 and cesium-137 and that the source is usable for about 5 years. The usable lifetime must be controlled by spectrum shifting resulting from a shifting barium-133:cesium-137 ratio. It is doubtful, however, that the resolution of the Iodine Monitor is good enough to resolve such spectrum shifting, at least over a period of several years. Therefore, once compared to an iodine-131 calibration (i.e., iodine-131 solution in the Iodine Monitor tank), the mock iodine source should be usable for calibrating the Iodine Monitor for several years before replacement becomes necessary.

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