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ARMS-69.6.11

AERIAL RADIOLOGICAL MEASURING SYSTEM

AIRBORNE ALPHA SPECTROMETER:
SYSTEMS AND PROCEDURES IN
SUPPORT OF THE APOLLO PROGRAM

U. S. Atomic Energy Commission

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AIRBORNE ALPHA SPECTROMETER: SYSTEMS AND PROCEDURES IN SUPPORT OF THE APOLLO PROGRAM

by

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EG&G, Inc., Las Vegas, Nevada

November 1969

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This report is part of a series on the continuing activities of the Aerial Radiological Measuring System operated for the U. S. Atomic Energy Commission. The ARMS program is managed by the Civil Effects Branch, Division of Biology and Medicine, and is a cooperative effort among various offices and divisions of the Commission.

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1. INTRODUCTION

The use of plutonium-238 in thermoelectric generators for future Apollo missions has required the development of a high-sensitivity plutonium detector. Escaping plutonium from a ruptured plutonium capsule would be an extreme health hazard and, therefore, the rapid detection of minute quantities of plutonium in the atmosphere is a necessity.

Since alpha particles have a very short range in air, their detection is difficult. To determine the plutonium concentration in the atmosphere, the air must be filtered to remove the particulate plutonium matter. The filter must then be analyzed with special detection equipment. The presence of radon and thoron daughters in the atmosphere interferes with any determination of plutonium concentrations using gross counting techniques. Alpha spectroscopy must be used to distinguish the plutonium from the natural daughters of radon and thoron. A high-volume air sampler is used to increase the minimum detectable activity so that low concentrations of plutonium can be detected.

The alpha spectrometer can be operated from the ARMS aircraft, which already has a high-volume air sampler and high-sensitivity gamma detection equipment. The plutonium emits a low-energy gamma ray less than one percent of the decay scheme; however, large quantities of plutonium could be detected with the gamma ray detection system.

The aircraft navigational equipment is used to determine the location and size of a radioactive cloud that is detected with the radiation measurement equipment.

A $^{10}\text{BF}_3$ gas neutron counter will be used to locate the source capsule if it has not ruptured.

2. DETECTOR SYSTEM

2.1 DETECTOR AND ELECTRONIC EQUIPMENT

An array of seven detectors (Figure 1) is used to optimize the analysis of the area used on the 4-inch diameter air filter. Each detector is a large-area silicon surface-barrier diode. The silicon diode consists of an extremely thin p-type layer on the sensitive face of a high-purity, n-type silicon wafer. The electrical contact to the p-type surface is a thin gold film $40 \mu\text{g}/\text{cm}^2$ thick. The n-type surface contact is a $40 \mu\text{g}/\text{cm}^2$ aluminum film. The individual detectors have an active surface area of 450 square millimeters and a depletion depth of 100 microns.

Since the detector output pulse-height is proportional to the energy of the charged particle, the alpha particle must deposit all of its energy in the sensitive region of the detector. The 100-micron depletion depth enables the detector to measure, with linear pulse height versus energy, alpha particles up to 12 MeV in energy.⁽¹⁾

Individual charge sensitive preamplifiers are used with each detector to keep the detector noise and capacitive load on the preamplifiers at a minimum.

Figure 2 shows the equivalent circuit for each surface barrier detector and first preamplifier stage. The symbols in Figure 2 are defined as follows:

- C_d = detector capacitance
- R_l = reverse leakage in the diode
- R_s = diode series resistance
- R_b = bias resistor
- V_b = bias voltage
- C_s = stray capacitance in cables

The signal from the first stage preamplifier of each detector is summed in a summing amplifier. The output of the summing amplifier is then analyzed in a pulse height analyzer.

The Technical Measurements Corporation 400-channel analyzer, used in the system (Figure 3), can print, punch, or plot the activity of each channel. Integration between specific energies can also be performed when looking for a particular isotope such as plutonium.

Figure 4 shows the detector system and first preamplifier stage mounted in the carrying case.

Figure 1. Detector array.

Figure 2. Equivalent circuit for detector.

Figure 3. Block diagram of detector system.

Figure 4. Detector system and first preamplifier stage.

2.2 VACUUM CHAMBER

Alpha spectroscopy of the air filter must be performed in a vacuum chamber (Figure 5) to increase the mean-free path of the alpha particles. The mean-free path of the alphas must be greater than the filter-to-detector distance. If it is not, the elastic collision of the alpha particles with air molecules would distort the spectra and give a continuum rather than a sharp peak. The vacuum chamber is evacuated with a mechanical pump which has a free-air displacement of 35 liters per minute. Operating pressure is obtained in approximately 45 seconds. The filter is positioned 1/16 of an inch away from the detector active surface.

The chamber pressure can vary between 1 to 5 millimeters with negligible effect on the array resolution and efficiency.

Figure 5. Vacuum chamber.

3. AIR SAMPLING

3.1 AIR SAMPLER

The ARMS air sampler, already installed in the aircraft, takes the outside air and forces it across a 4-inch diameter paper air filter. The air sampler has a nominal flow rate of 150 cfm, dependent on the airspeed of the plane.

3.2 AIR FILTER

The IPC-1478 filter paper was developed by the Institute of Paper Chemistry for use in the High-Altitude Sampling Program (HASP). The filter paper is impregnated with Kronisol (dibutylphthalate) to increase particulate collection efficiency and reduce the pressure drop at the filter in the air sampler. The IPC-1478 filter has an efficiency of essentially 100 percent for particles larger than 1.17 μ in diameter.⁽²⁾

4. DETECTION OF PLUTONIUM-238

4.1 PARAMETERS OF THE SPECTROMETER

Four alpha sources were used to determine the maximum and minimum energies of alpha particles the spectrometer could detect. The alpha sources used to calibrate the spectrometer were thorium-230, americium-241, plutonium-238, and polonium-214.

<u>Isotope</u>	<u>Predominate Alpha Energy ⁽³⁾</u> (MeV)
^{230}Th	4.684
^{241}Am	5.486
^{238}Pu	5.499
^{214}Po	7.687

Using the 4 sources, it was determined that Channel Number 0 represented 2.000 MeV and Channel Number 200 represented 10.000 MeV. The spectrometer can identify any alpha emitters between 2.000 and 10.000 MeV, with a channel coefficient of 0.040 MeV/channel. The detector array has a resolution of 0.150 MeV at FWHM, or 2.7% at 5.477 MeV.

The calibration source, used to set the individual amplifier gains so the alpha peak would be in the appropriate channel, was americium-241. The ^{241}Am and ^{238}Pu differ in energy by only 0.013 MeV and the pulse height analyzer will place the alpha peak of both isotopes in the same channel. Therefore, the ^{241}Am was chosen as the calibration standard because of its availability and ease of production of a custom-made source.

The ^{241}Am was electroplated to a 4-inch diameter nickel plate and has an activity of 2.920×10^4 dpm. However, the activity of the source is not uniformly distributed on the surface of the nickel plate, which makes it undesirable for efficiency measurements.

4.2 MINIMUM DETECTABLE ACTIVITY

Using a 10-minute air sampling time and 4 minutes to analyze the filter, the minimum detectable activity will be 2.18×10^{-13} $\mu\text{Ci/cc}$. This minimum detectable activity level was determined as follows:

1. The 4-inch (101.6 mm) diameter paper has an active filter area of 8107 mm².

2. The sensitive area of the 7 detectors is 7 x 450 mm².

3. Percentage of filter covered by detectors $\frac{3150}{8107} = 38.89\%$.

4. For 2 π counting geometry, the detector efficiency is $\frac{38.89\%}{2} = 19.45\%$.

5. For positive identification of the ²³⁸Pu, 16 counts are necessary in the 5.495-MeV energy channel.

6. For the above counting efficiency: $\frac{16}{0.1945} = 82.4$ disintegrations are needed on the filter.

7. If the filter is counted for 4 minutes, then $\frac{82.4}{4} = 20.6$ disintegrations per minute are needed.

8. This gives $\frac{20.6 \text{ dpm}}{2.22 \times 10^6 \text{ dpm}/\mu\text{Ci}} = 9.28 \times 10^{-6} \mu\text{Ci}$ on the filter.

9. If 1500 ft³ (4.25 x 10⁷ cc) of air is sampled in 10 minutes, then $\frac{9.28 \times 10^{-6} \mu\text{Ci}}{4.25 \times 10^7 \text{ cc}} = 2.18 \times 10^{-13} \mu\text{Ci/cc}$ concentration in air can be detected (assuming 100% filter collection efficiency).

This means that the maximum permissible concentration (MPC) value of 1 x 10⁻¹² $\mu\text{Ci/cc}$ for uncontrolled areas can be detected by sampling for 2.0 minutes and counting for 4 minutes. A concentration of twice MPC could be detected when sampling the air for 2 minutes and analyzing the filter for 2 minutes. Using this procedure, activity concentration could be reported every 5 minutes.

An interesting point would be to assume a release in a cylindrical volume that was 5,000 meters in diameter and 3,000 meters high for a total volume of 5.89 x 10¹⁶ cc. Then assuming uniform distribution within this volume and a detection limit of 1 x 10⁻¹² $\mu\text{Ci/cc}$, the minimum detectable amount of material released would be

$$1 \times 10^{-12} \mu\text{Ci/cc} \times 5.89 \times 10^{16} \text{ cc} = 5.89 \times 10^4 \mu\text{Ci} \text{ or } 58.9 \text{ mCi}$$

The radon and thoron daughters do not contribute sufficient activity to the Pu-238 window, when sampling at any altitude, to interfere with the detection of plutonium at the MPC level.

The theoretical efficiency of 19.45% was checked with the Beckman Wide Beta II. The Wide Beta has an extremely thin 4.5-inch diameter gold-milar window for counting alpha particles. An IPC-1478 air filter was used to sample a large volume of air, then a gross count of the alpha particles was made with the Wide Beta. A gross count of the filter with the detector array was performed to check the theoretical efficiency calculations. Using the theoretical efficiency, both counting systems were within 6% of each other. The theoretical efficiency will be used to determine the alpha activity concentrations.

Table I shows the alpha particle and gamma ray emission of Pu-238.⁽³⁾

Table I. Plutonium decay scheme.

<u>Emission</u>	<u>Energy</u> (MeV)	<u>Percentage</u>
α	5.499	72
α	5.456	28
γ	0.0435	0.038
α	5.358	< 1
γ	0.0998	8×10^{-3}

Large quantities of plutonium could also be detected by gamma-ray spectroscopy. The 0.100-MeV gamma has sufficient energy to be detected by the gamma detection system in the aircraft.

Figure 6 is a radon-thoron daughter background spectrum taken from an IPC-1478 air filter. The air was sampled for 10 minutes with a flow rate of approximately 150 cubic feet per minute. A plutonium-238 peak is superimposed on the background spectrum to indicate the background to plutonium ratio, with the plutonium activity in the air at MPC. Figure 7 shows the americium-241 calibration spectrum.

The signal out of the detector array is also analyzed by a single-channel pulse-height analyzer which has a window set at 5.499 (± 0.060) MeV. The count rate in the plutonium window is displayed on a count rate meter and on a nixie tube display. The count rate is also printed by a digital printer and punched on a binary tape, along with navigational information such as: leg number, long track, cross track, radar altitude, and direction.

SPECTRUM NO. 9
 DATE 10-17-69
 LIVE TIME 4.00
 INTEGRATED CT. 1193
 TYPE FILTER SAMPLE-IPC 1478
 ALTITUDE 1200
 AIRCRAFT (ARMS)

Figure 6. Radon-Thoron daughter background on air filter.

SPECTRUM NO. 10
DATE 10-15-69
LIVE TIME 4.00
INTEGRATED CT. 22197
TYPE CALIB.-DIRECT EMISSION
ALTITUDE 8000
AIRCRAFT (ARMS)

Figure 7. Americium-241 calibration spectrum.

4.3 NEUTRON EMISSION DETECTION

A Reuter-Stokes $^{10}\text{BF}_3$ gas filled neutron detector is used to detect neutrons emitted from the plutonium capsule. It has a thermal neutron sensitivity of 40 cps per neutron/cm²-second. The detector has a 2-inch polyethylene moderator to thermalize high-energy neutrons. The detector could be used to locate the capsule on land or under shallow water while flying at low altitudes.

4.4 GAMMA EMISSION DETECTION

High concentrations of ^{238}Pu could be detected with sodium iodide crystals. The detectors used in the aircraft instrumentation system (Figure 8) consist of fourteen 4 in. x 4 in. NaI (Tl) detectors. The signal output from each unit is routed to a common junction from which point the signals are routed simultaneously into a gamma-ray energy spectrometer and the gross counting rate system. The individual detectors are closely spaced to minimize scattering losses and are enclosed in several inches of polyurethane thermal insulation.

Figure 8. Aircraft gamma instrumentation.

The signals from the detectors are amplified and then routed to a special purpose radiation computer. Utilizing a baseline discriminator, all signals of energies less than 50 keV are rejected. After processing the incoming signal, the radiation computer generates a print command signal which controls the readout function for a digital printer and punch.

The spectral data are collected by routing the signal from the scintillation detectors to a pulse-height analyzer where the incoming signals are sorted into their respective energy positions. Selectable collection times are available to control the buildup of the gamma-energy spectrum over whatever time is needed to provide a useful display of photopeak energies. The spectral data are punched on paper tape for processing at a later time.

5. AIRCRAFT POSITIONING SYSTEM

The aircraft position is determined by a Doppler radar navigation system used in conjunction with a J-4 compass and track navigation computer. The Doppler unit determines the ground speed and drift angle of the aircraft relative to a reference line set into the track navigation computer. The along-track and across-track distances traveled by the aircraft relative to the reference line and to an initial ground point are continuously computed to provide a real-time display of aircraft position. An analog position indicator permits the navigator to visually monitor the current aircraft location at all times during flight. After processing the data signals through proper analog-to-digital conversion steps, all data are recorded digitally. The read-out system is driven by command signals generated within the radiation computer which supplied signals to two data recorders: a digital printer and a binary tape punch. The data recorded on each are: ground location indicator, flight leg number, along-track distance, across-track distance and direction, radar altitude, and gross counting rate. The information is recorded every 2.0 seconds giving data points approximately 0.10 mile apart along the flight line. The gross counting rate is also recorded as an analog trace on a strip chart recorder as a backup means of monitoring the intensity levels. Data points can be plotted within $\pm 0.001^\circ$ longitude and latitude.

6. OPERATIONAL PROCEDURES

Temperature operating range - $20 (\pm 10)^{\circ}$ centigrade.

Pressure operating range - $2.0 (\pm 0.5)$ millimeters.

Address 200 channels on the TMC, pulse-height analyzer.

Base line set at 400.

6.1 SYSTEM CALIBRATION AND BACKGROUND

1. Place calibration source in holder and put holder on the base of vacuum chamber (Source AM-241). Do not touch plated surface of source.

CAUTION

To prevent damage to detectors, bias voltage must be "OFF" when vacuum chamber pressure is altered.

2. Insert holder and base into vacuum chamber and pump system down to $2.0 (\pm 0.5)$ mm of Hg pressure.
3. Turn bias voltage on.
4. Adjust individual gains separately and place peak in channel 87.
5. Turn all detectors on and run a 4-minute live-time spectra.
6. Connect count rate meter to output of array. Adjust discriminator in single-channel pulse-height analyzer to look at plutonium peak, $5.495 (\pm 0.060)$ MeV.
7. System Background - remove source and return to its container. Run a 4-minute spectra.

6.2 AIR FILTER SAMPLING PROCEDURE

After paragraph 6.1 has been completed, air sampling can start.

1. Start a 10-minute air-filter sample.
2. After sampling, remove filter from holder with tweezers and place it in the aluminum planchet.

CAUTION

To prevent damage to detectors, bias voltage must be "OFF" when vacuum chamber pressure is altered.

3. Place filter and sample holder in vacuum system and pump system down to 2.0 (± 0.5) mm of Hg pressure. (Start another air sample.)
4. Analyze filter for 4-minute live time.
5. Check spectrum for positive plutonium contact; any count over 16 in channel 87 can be reported as positive contact (99% confidence level).
6. Punch the spectrum on paper tape. Record the information requested on the Apollo Support Flight Data Sheet.

7. SUMMARY

The alpha particle spectrometer can detect plutonium-238 in air below the maximum permissible concentration of 10^{-12} $\mu\text{Ci/cc}$, without interference from natural occurring airborne alpha emitters. The air filter has a 100% collection efficiency for particles larger than 1.17 microns in diameter. The system is mobile and can be operated in the ARMS aircraft. The high sensitivity of the gamma-ray detection crystals could also be used to track large quantities of plutonium. The neutron detector will be used to locate the source capsule if lost.

The navigational equipment can be used to find the location and size of a radioactive cloud.

The aircraft will be airborne at Apollo launch time, holding in a predetermined pattern in order to be able to intercept the cloud within 5 minutes. Confirmation of positive plutonium contact at twice MPC could be given to the control center within 5 minutes by radio. If positive contact was established, the aircraft would track the cloud as far as possible and would attempt to outline the cloud dimensions. Activity concentration can be reported from the display of the TMC analyzer.

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Systems and Procedures in Support of

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P3319

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LAS VEGAS DIVISION

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1. The 4-inch (101.6 mm) diameter paper has an active filter area of 8107 mm².
2. The sensitive area of the 7 detectors is 7 x 450 mm².
3. Percentage of filter covered by detectors $\frac{3150}{8107} = 38.89\%$.
4. For 2 π counting geometry, the detector efficiency is $\frac{38.89\%}{2} = 19.45\%$.
5. For positive identification of the ²³⁸Pu, 16 counts are necessary in the 5.495-MeV energy channel.
6. For the above counting efficiency: $\frac{16}{0.1945} = 82.4$ disintegrations are needed on the filter.
7. If the filter is counted for 4 minutes, then $\frac{82.4}{4} = 20.6$ disintegrations per minute are needed.
8. This gives $\frac{20.6 \text{ dpm}}{2.22 \times 10^6 \text{ dpm}/\mu\text{Ci}} = 9.28 \times 10^{-6} \mu\text{Ci}$ on the filter.
9. If 1500 ft³ (4.25×10^7 cc) of air is sampled in 10 minutes, then $\frac{9.28 \times 10^{-6} \mu\text{Ci}}{4.25 \times 10^7 \text{ cc}} = 2.18 \times 10^{-13} \mu\text{Ci/cc}$ concentration in air can be detected (assuming 100% filter collection efficiency).

This means that the maximum permissible concentration (MPC) value of $1 \times 10^{-12} \mu\text{Ci/cc}$ for uncontrolled areas can be detected by sampling for 2.0 minutes and counting for 4 minutes. A concentration of twice MPC could be detected when sampling the air for 2 minutes and analyzing the filter for 2 minutes. Using this procedure, activity concentration could be reported every 5 minutes.

An interesting point would be to assume a release in a cylindrical volume that was 5,000 meters in diameter and 3,000 meters high for a total volume of 5.89×10^{16} cc. Then assuming uniform distribution within this volume and a detection limit of $1 \times 10^{-12} \mu\text{Ci/cc}$, the minimum detectable amount of material released would be

$$1 \times 10^{-12} \mu\text{Ci/cc} \times 5.89 \times 10^{16} \text{ cc} = 5.89 \times 10^4 \mu\text{Ci} \text{ or } 58.9 \text{ mCi}$$

The radon and thoron daughters do not contribute sufficient activity to the Pu-238 window, when sampling at any altitude, to interfere with the detection of plutonium at the MPC level.

The theoretical efficiency of 19.45% was checked with the Beckman Wide Beta II. The Wide Beta has an extremely thin 4.5-inch diameter gold-milar window for counting alpha particles. An IPC-1478 air filter was used to sample a large volume of air, then a gross count of the alpha particles was made with the Wide Beta. A gross count of the filter with the detector array was performed to check the theoretical efficiency calculations. Using the theoretical efficiency, both counting systems were within 6% of each other. The theoretical efficiency will be used to determine the alpha activity concentrations.

Table I shows the alpha particle and gamma ray emission of Pu-238.⁽³⁾

Table I. Plutonium decay scheme.

<u>Emission</u>	<u>Energy</u> (MeV)	<u>Percentage</u>
α	5.499	72
α	5.456	28
γ	0.0435	0.038
α	5.358	<1
γ	0.0998	8×10^{-3}

Large quantities of plutonium could also be detected by gamma-ray spectroscopy. The 0.100-MeV gamma has sufficient energy to be detected by the gamma detection system in the aircraft.

Figure 6 is a radon-thoron daughter background spectrum taken from an IPC-1478 air filter. The air was sampled for 10 minutes with a flow rate of approximately 150 cubic feet per minute. A plutonium-238 peak is superimposed on the background spectrum to indicate the background to plutonium ratio, with the plutonium activity in the air at MPC. Figure 7 shows the americium-241 calibration spectrum.

The signal out of the detector array is also analyzed by a single-channel pulse-height analyzer which has a window set at 5.499 (± 0.060) MeV. The count rate in the plutonium window is displayed on a count rate meter and on a nixie tube display. The count rate is also printed by a digital printer and punched on a binary tape, along with navigational information such as: leg number, long track, cross track, radar altitude, and direction.

SPECTRUM NO. 9
 DATE 10-17-69
 LIVE TIME 4.00
 INTEGRATED CT. 1193
 TYPE FILTER SAMPLE-IPC 1478
 ALTITUDE 1200
 AIRCRAFT (ARMS)

Figure 6. Radon-Thoron daughter background on air filter.

SPECTRUM NO. 10
DATE 10-15-69
LIVE TIME 4.00
INTEGRATED CT. 22197
TYPE CALIB.-DIRECT EMISSION
ALTITUDE 8000
AIRCRAFT (ARMS)

Figure 7. Americium-241 calibration spectrum.

4.3 NEUTRON EMISSION DETECTION

A Reuter-Stokes $^{10}\text{BF}_3$ gas filled neutron detector is used to detect neutrons emitted from the plutonium capsule. It has a thermal neutron sensitivity of 40 cps per neutron/cm²-second. The detector has a 2-inch polyethylene moderator to thermalize high-energy neutrons. The detector could be used to locate the capsule on land or under shallow water while flying at low altitudes.

4.4 GAMMA EMISSION DETECTION

High concentrations of ^{238}Pu could be detected with sodium iodide crystals. The detectors used in the aircraft instrumentation system (Figure 8) consist of fourteen 4 in. x 4 in. NaI (Tl) detectors. The signal output from each unit is routed to a common junction from which point the signals are routed simultaneously into a gamma-ray energy spectrometer and the gross counting rate system. The individual detectors are closely spaced to minimize scattering losses and are enclosed in several inches of polyurethane thermal insulation.

Figure 8. Aircraft gamma instrumentation.

The signals from the detectors are amplified and then routed to a special purpose radiation computer. Utilizing a baseline discriminator, all signals of energies less than 50 keV are rejected. After processing the incoming signal, the radiation computer generates a print command signal which controls the readout function for a digital printer and punch.

The spectral data are collected by routing the signal from the scintillation detectors to a pulse-height analyzer where the incoming signals are sorted into their respective energy positions. Selectable collection times are available to control the buildup of the gamma-energy spectrum over whatever time is needed to provide a useful display of photopeak energies. The spectral data are punched on paper tape for processing at a later time.

5. AIRCRAFT POSITIONING SYSTEM

The aircraft position is determined by a Doppler radar navigation system used in conjunction with a J-4 compass and track navigation computer. The Doppler unit determines the ground speed and drift angle of the aircraft relative to a reference line set into the track navigation computer. The along-track and across-track distances traveled by the aircraft relative to the reference line and to an initial ground point are continuously computed to provide a real-time display of aircraft position. An analog position indicator permits the navigator to visually monitor the current aircraft location at all times during flight. After processing the data signals through proper analog-to-digital conversion steps, all data are recorded digitally. The read-out system is driven by command signals generated within the radiation computer which supplied signals to two data recorders: a digital printer and a binary tape punch. The data recorded on each are: ground location indicator, flight leg number, along-track distance, across-track distance and direction, radar altitude, and gross counting rate. The information is recorded every 2.0 seconds giving data points approximately 0.10 mile apart along the flight line. The gross counting rate is also recorded as an analog trace on a strip chart recorder as a backup means of monitoring the intensity levels. Data points can be plotted within $\pm 0.001^\circ$ longitude and latitude.

6. OPERATIONAL PROCEDURES

Temperature operating range - $20 (\pm 10)^\circ$ centigrade.

Pressure operating range - $2.0 (\pm 0.5)$ millimeters.

Address 200 channels on the TMC, pulse-height analyzer.

Base line set at 400.

6.1 SYSTEM CALIBRATION AND BACKGROUND

1. Place calibration source in holder and put holder on the base of vacuum chamber (Source AM-241). Do not touch plated surface of source.

CAUTION

To prevent damage to detectors, bias voltage must be "OFF" when vacuum chamber pressure is altered.

2. Insert holder and base into vacuum chamber and pump system down to $2.0 (\pm 0.5)$ mm of Hg pressure.
3. Turn bias voltage on.
4. Adjust individual gains separately and place peak in channel 87.
5. Turn all detectors on and run a 4-minute live-time spectra.
6. Connect count rate meter to output of array. Adjust discriminator in single-channel pulse-height analyzer to look at plutonium peak, $5.495 (\pm 0.060)$ MeV.
7. System Background - remove source and return to its container. Run a 4-minute spectra.

6.2 AIR FILTER SAMPLING PROCEDURE

After paragraph 6.1 has been completed, air sampling can start.

1. Start a 10-minute air-filter sample.
2. After sampling, remove filter from holder with tweezers and place it in the aluminum planchet.

CAUTION

To prevent damage to detectors, bias voltage must be "OFF" when vacuum chamber pressure is altered.

3. Place filter and sample holder in vacuum system and pump system down to 2.0 (± 0.5) mm of Hg pressure. (Start another air sample.)
4. Analyze filter for 4-minute live time.
5. Check spectrum for positive plutonium contact; any count over 16 in channel 87 can be reported as positive contact (99% confidence level).
6. Punch the spectrum on paper tape. Record the information requested on the Apollo Support Flight Data Sheet.

7. SUMMARY

The alpha particle spectrometer can detect plutonium-238 in air below the maximum permissible concentration of 10^{-12} $\mu\text{Ci/cc}$, without interference from natural occurring airborne alpha emitters. The air filter has a 100% collection efficiency for particles larger than 1.17 microns in diameter. The system is mobile and can be operated in the ARMS aircraft. The high sensitivity of the gamma-ray detection crystals could also be used to track large quantities of plutonium. The neutron detector will be used to locate the source capsule if lost.

The navigational equipment can be used to find the location and size of a radioactive cloud.

The aircraft will be airborne at Apollo launch time, holding in a predetermined pattern in order to be able to intercept the cloud within 5 minutes. Confirmation of positive plutonium contact at twice MPC could be given to the control center within 5 minutes by radio. If positive contact was established, the aircraft would track the cloud as far as possible and would attempt to outline the cloud dimensions. Activity concentration can be reported from the display of the TMC analyzer.

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