DOE/DP/62349--T1

TESTING OF THE EBERLINE PCM-2

A Research Project Presented to the

Faculty of Colorado Christian University

in partial fulfillment of the requirements

for the Bachelor's degree

by

KENNETH L. HOWE

Professor: William Talboys

MHR 91

December 23, 1994

Certification Page

This is to certify that he Research Project prepared

By Kenneth L. Howe

Entitled Testing Of The Eberline PCM-2

Has been accepted by the Faculty of Colorado Christian University

Signed:

Project Professor ________________________________ Date __________

Director ______________________________________ Date __________

This Research Project is not to be regarded as confidential, and its use as a sample in future classes is not restricted.

Abstract

The PCM-2 manufactured by Eberline Instruments is a whole body monitor that detects both alpha and beta contamination. The PCM-2 uses an IBM compatible personal computer for all software functions. The PCM-2 has 34 large area detectors which can cover approximately 40% of the body at a time. This requires two counting cycles to cover approximately 80% of the body. With the normal background seen at Rocky Flats, each count time takes approximately 15-20 seconds. There are a number of beta and gamma whole body monitors available from different manufacturers, but an alpha whole body monitor is a rarity. Because of the need for alpha whole body monitors at The Rocky Flats Environmental Technology Site, it was decided to do thorough testing on the PCM-2. A three month test was run in uranium building and a three month test in a plutonium building to verify the alpha capabilities of the PCM-2.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

CHAPTER 1

Purpose Statement

For years the standard way to check a person leaving a contaminated area was to hand frisk the person with a portable instrument. This process is slow and inaccurate. Using a whole body monitor would be much faster and more accurate. However, most people still think that hand frisking is the better method. The purpose of this research project is to show that whole body alpha monitoring is not only possible but desirable using the Eberline Personnel Contamination Monitor Two (PCM-2). The PCM-2 can check the entire body for alpha contamination in less than one minute and do a better job than hand frisking taking ten minutes or more.

This is important because many people think that hand frisking is a better way of checking for alpha contamination on an individual. Those people do not understand that a machine can accomplish this task with greater reliability and at a faster pace than a human using a portable instrument.

Problem Statement

The problem being studied for this project is that people think a human being with a portable instrument is able to locate alpha contamination on the body of an individual better than a whole body monitor, such as the PCM-2. A person using a portable instrument with a probe area of 100 cm^2 or smaller will require many times longer to check the individual with the same amount of confidence. This is because the PCM-2 has 34 detectors with the most common size detector being approximately 500 cm^2. These 34 detectors are all looking for contamination at the same time, while the person with a portable instrument is using one detector that is much smaller.

This is a problem because personnel are being released from a contamination area with some amount of contamination on their body that the person with portable instrumentation is not locating. The PCM-2 would greatly reduce the amount of missed contamination leaving a contaminated area. Some people are worried about losing their jobs and so fight against anything that might replace them. Other people do not want to see changes in their work area. Others think that the human factor of knowing where to look for contamination outweigh the advantages of the whole body monitor.

Whole body monitors for beta and gamma radiation have been around for a number of years and have been accepted in most work places, but alpha whole body monitors are a new product. Alpha whole body monitors are harder to design because of the limited distance that an alpha particle travels in air. The monitor must conform to the body if it is going to be able to find alpha contamination on a large percentage of the body. Most whole body monitors for beta and gamma radiation did not conform very well to the body and therefore were not good prospects for locating alpha contamination.

Furthermore, most facilities that deal with radiation are not interested in alpha whole body monitors. The need for alpha whole body monitors is not nearly as large as beta and gamma whole body monitors. Therefore, few companies have been interested in trying to develop such a system. Eberline is one of the few companies that has decided to try and develop an alpha whole body monitor.

Hypothesis

Hypothesis 1: An alpha whole body monitor can check a person for contamination faster than frisking with a portable instrument.

Hypothesis 2: An alpha whole body monitor can locate lower levels of contamination than a person using a portable instrument in the same amount of time.

Hypothesis 3: An alpha whole body monitor can operate cheaper than using a person to check for contamination.

Hypothesis 4: An alpha whole body monitor can check a person leaving a contaminated area more consistently than a person using a portable instrument.

Definition of Terms

Alpha Particle - A positively charged composite particle, indistinguishable from a helium atom nucleus and consisting of two protons and two neutrons (Morris, 1969).

Alpha and Beta Efficiency - The percentages of real activities which are actually reported by this detector and its associated electronics (Eberline, 1992).

Alpha and Beta High Fail - Detectors which show background levels above these limits will be considered too noisy or contaminated to use, and will remove the instrument from service (Eberline, 1992).

Alpha and Beta Low Fail - Detectors with backgrounds below these levels are assumed to have failed. The instrument will not count if this occurs (Eberline, 1992).

Alpha and Beta RDA - These are Reliably Detectable Activities used to compute alarm set points for alpha and beta channels (Eberline, 1992).

Alpha and Beta Sensitivity - A ratio above and below the mean of background counts beyond which a single detector's background is determined to be indicative of a detector. The default value is 0.5, meaning that a detector with more than twice or less than half as many counts as the system average is considered suspect (Eberline, 1992).

Alpha Threshold - Particles which cause the detector to produce a pulse exceeding this voltage will be counted as alpha particles. Lower amplitudes register as betas (Eberline, 1992).

Alpha and Beta Weight Factor - This parameter controls the speed with which the computed average background rate will follow changes in actual background count rates (Eberline, 1992).

Background Sigma Factor - If a background update count differs from the previous background rate by this many standard deviations, the new rate will immediately replace the old. If the detector(s) on which this occurs alarmed on the last measurement, they are assumed to be contaminated (Eberline, 1992).

Beta Particle - A high-speed electron or positron, especially one emitted in radioactive decay (Morris, 1969).

Beta Shield Factor - When the instrument is occupied, some detectors may be shielded from local radiation sources which account for part of the observed background. The shield factor is defined as background while occupied divided by background while unoccupied. Note: alpha channel shield factors are always equal to 1 (Eberline, 1992).

Beta Threshold - Particles which produce pulses below this amplitude will not be counted as either alpha or beta (Eberline, 1992).

Contamination - Radioactive materials being in areas where they should not be.

Gamma Ray - Electromagnetic radiation emitted by radioactive decay and having energies in a range overlapping that of the highest energy x rays, extending up to several hundred thousand electron volts (Morris, 1969)

Max Count Time - The longest acceptable count time which the PCM-2 may use for measurements. If increases in background levels require a measurement time exceeding this value, a high background alarm condition occurs (Eberline, 1992).

Radiation - The emission and propagation of waves or particles (Morris, 1969).

RDA Confidence - This is the probability of detecting contamination of the specified RDA. Possible values are 50%, 75%, 90%, 95%, 99%, 99.9% (Eberline, 1992).

Sigma Factor - A multiplier of the count rate standard deviation which influences the false alarm rate (Eberline, 1992).

Sum Channel Sigma Factor - Sum channel alarms occur only when whole-body radiation is significantly elevated, but no single detector or sum zone alarms. This sigma factor controls the sum channel false alarm rate (Eberline, 1992).

Sum Zone Sigma Factor - A similar parameter used to determine the false alarm rate for sum zones rather than individual detectors (Eberline, 1992).

Summary

This project will look at the need for replacing the hand held portable radiation monitoring instruments with whole body monitors when checking personnel leaving a radiation contamination area for alpha and beta contamination. The whole body monitor can check personnel at a much faster pace and with more accuracy than someone using a portable instrument. Whole body monitors for beta and gamma have been accepted as a standard way of checking personnel, but whole body monitors for alpha contamination have not been thoroughly tested and therefore not been accepted. The Eberline PCM-2 has been selected by EG&G, Rocky Flats, as the machine to test for whole body alpha monitoring.

CHAPTER II

Wade and Cunningham (1967) stated, "If radiation had no effect on the surrounding material, we might regard it merely as an interesting phenomenon. But radiation does affect the material exposed to it; this fact becomes very important when the exposed material is a person." (p. 243)

Some radiation is not harmful while other radiation can do great harm. Wade and Cunningham (1967) go on to say, "External radiation presents little hazard because the alpha articles usually cannot penetrate the outer layer of dead skin. Since the outer skin layer is composed of dead cells, the amount of radiation they receive is little cause for concern." (p. 243)

Concerning internal radiation Wade and Cunningham (1967) state:

> Since the body cannot distinguish chemically between radioactive materials can be chemically incorporated into the body if they are swallowed or inhaled. The result is a problem of radiation from sources internal to the body. If this happens, alpha radiation becomes very important; internally deposited alpha-emitting radioisotopes can be a severe problem. (p. 244)

We need to be able to locate all contamination on the body. The International Commission on Radiological Protection (1968) stated, "One contribution to external irradiation of the body is that from skin contamination. Some of the contamination may also be transferred into the body, causing internal exposure." (p. 18) If we allow personnel to leave a contaminated area with some contamination still on their body, we are allowing them to increase their exposure level without anyone knowing it. Why should these workers take additional risk to both internal and external exposures? Those who understand the danger involved have a duty to push for better monitoring of each person leaving a contamination area.

> It is essential, in order to restrict the spread of radioactive contamination and to protect employees, that all personnel leaving areas of potential radioactive contamination are monitored for the presence of such contamination on their person. Inadequate monitoring could result in either an expensive clean-up programme or litigation, or both, as well as jeopardising the health of the worker. Monitoring is difficult to supervise and is often regarded as a chore by those undertaking the procedure. The ideal equipment must therefore be simple to use by all personnel without supervision and without giving false or confusing information. (Dray, 1981, p. 1)

One difficulty of measuring radioactive decay is it's randomness. Knoll (1979) states, "Radioactive decay is a random process. Consequently, any measurement based on observing the radiation emitted in nuclear decay is subject to some degree of statistical fluctuation." (p. 65)

Frisking the whole body with a hand held instrument is not a reliable method. Something better was required. Neuschaefer (1989) stated, "The use of WB [whole body] friskers has proven to be very effective at detecting personnel contamination." (p. 2)

> Two recent surveys conducted by *Radiation Protection Management* indicated that a significant number of power reactor health physicists had unrealistic beliefs in the sensitivity of hand-probe frisking and that highly-sensitive portal monitors, "frisking booths", and trash monitors were not being used to their full advantage (see the January 1985 and April 1985 issues of *RPM*). Compounding these two problems is the fact that regulators and evaluators have been extremely reluctant (to put it mildly) to allow licensees to substitute highly-sensitive contamination monitors for hand-probe frisking. (Bunker, 1985, p. 85)

We have for too long relied on old approaches to a continuing problem, when new instrumentation could do a better job. Because of our unwillingness to move ahead in the field of personnel radiation monitoring, we are behind the times at finding radioactive contamination on workers leaving a contaminated area.

> Radiation detection instruments of greater sensitivity have resulted in the ability to detect smaller and smaller quantities of radioactivity in the environment. This in conjunction with the fact that more emphasis has been placed on reducing the amount of radioactivity introduced into the environment or leaving controlled areas has resulted in the need for more sensitive portal monitors. (Georgeson and Nichols, 1981, p. 1)

> UNC Nuclear Industries' experience in operating the Hanford N Reactor, located near Richland, WA., has shown the necessity of automatically monitoring plant personnel for contaminant after they have passed through the procedurally controlled radiation zones. This final check insures that each radiation zone worker has been properly monitored before leaving company controlled boundaries. (Sterling, 1982, p. 1)

"However, one drawback of using these more sensitive instruments is that they are alarming due to radon daughters. Additionally, most alarms due to radon daughters cannot be verified with normal hand frisking." (Shaccio, 1989, p. 2)

Reliable alarm activation required that microprocessors be incorporated into personnel monitors. The older-design monitors sometimes use a count-down method to activate an alarm. The sites's calibration personnel would turn a dial to a previously-determined value based on the detector's efficiency and the required alarm setting. A count time was entered and once initiated, the value "dialed in" would be the start point. Counts seen during the count cycle would be subtracted from the entered value and if zero were reached, an alarm would sound. These monitors were not quite as elaborate as today's but they worked. (Chiaro, 1994, p. 2)

There are a few machines available for locating external contamination on personnel leaving a contaminated area. Blanton (1988) talked about one of these machines, "The Eberline Personnel Contamination Monitor is a microprocessor-based, stand-and-count mode portal monitor that was designed as an alternative to hand-probe frisking. It contains 15 independent gas-flow proportional detectors arranged as follows: four each (eight total) stacked vertically along both sides of the monitor frame to view the front and back of the body, three stacked vertically on the inside wall of the monitor to view the calf, thigh, and upper arm, two inside a hand/forearm cavity, and one each at the top and bottom of the frame to view the head and feet, respectively." (p. 44) The Eberline Personnel Contamination Monitor (PCM-1) is a beta-gamma instrument used in many power plants and Department of Energy (DOE) sites.

Not only can the PCM-1 find lower levels of contamination, but also monitor personnel faster. Desrosiers and Zavadoski (1985) stated, "With a maximum expected monitoring time of 30 seconds per frisk (10 seconds each side plus 10 seconds entering and exiting), the PCM-1 has a 4-to-1 time savings advantage over conventional frisking using the standard guidance of 120 seconds for a complete frisk." (p. 38)

CHAPTER III

Purpose Statement

For years the standard way to check a person leaving a contaminated area was to hand frisk the person with a portable instrument. This process is slow and inaccurate. Using a whole body monitor would be much faster and more accurate. However, most people still think that hand frisking is the better method. The purpose of this research project is to show that whole body alpha monitoring is not only possible but desirable using the Eberline Personnel Contamination Monitor Two (PCM-2). The PCM-2 can check the entire body for alpha contamination in less than one minute and do a better job than hand frisking taking ten minutes or more.

This is important because many people think that hand frisking is a better way of checking for alpha contamination on an individual. Those people do not understand that a machine can accomplish this task with greater reliability and at a faster pace than a human using a portable instrument.

Problem Statement

The problem being studied for this project is that people think a human being with a portable instrument is able to locate alpha contamination on the body of an individual better than a whole body monitor, such as the PCM-2. A person using a portable instrument with a probe area of 100 cm^2 or smaller will require many times longer to check the individual with the same amount of confidence. This is because the PCM-2 has 34 detectors, with the most common size detector being approximately 500 cm^2. These 34 detectors are all looking for contamination at the same time, while the person with a portable instrument is using one detector that is much smaller.

This is a problem because personnel are being released from a contamination area with some amount of contamination on their body that the person with portable instrumentation is not locating. The PCM-2 would greatly reduce the amount of missed contamination leaving a contaminated area. Some people are worried about losing their jobs and so fight against anything that might replace them. Other people do not want to see changes in their work area. Others think that the human factor of knowing where to look for contamination outweigh the advantages of the whole body monitor.

Whole body monitors for beta and gamma radiation have been around for a number of years and have been accepted in most work places, but alpha whole body monitors are a new product. Alpha whole body monitors are harder to design because of the limited distance that an alpha particle travels in air. The monitor must conform to the body if it is going to be able to find alpha contamination on a large percentage of the body. Most whole body monitors for beta and gamma radiation did not conform very well to the body and therefore were not good prospects for locating alpha contamination.

Furthermore, most facilities that deal with radiation are not interested in alpha whole body monitors. The need for alpha whole body monitors is not nearly as large as beta and gamma whole body monitors. Therefore, few companies have been interested in trying to develop such a system. Eberline is one of the few companies that has decided to try and develop an alpha whole body monitor.

Research Population

It needs to be determined if the PCM-2 can be used as a complete exit monitoring device for personnel leaving an alpha contamination area. In the past a number of whole body monitors have been used at various nuclear facilities, but none have been able to detect alpha contamination sufficiently to be used as the only tool needed to check for alpha. Because of alpha's limited range and the fact that most nuclear facilities are not concerned about looking for alpha, no manufacturer has concerned themselves to any great extent. The PCM-2 was designed to find alpha contamination as well as beta contamination. Other whole body monitors can locate beta, so the distinction of the PCM-2 is its alpha capabilities. These capabilities must be pursued to determine how well this machine will actually locate alpha contamination on the radiation worker's body. Not only must the PCM-2 find alpha contamination, but it must locate the alpha contamination reliably.

One of the few places where alpha contamination abounds is at the Rocky Flats Plant in Golden, Co. This is due to the extensive work at Rocky Flats with plutonium. Rocky Flats is the ideal place to test the PCM-2 alpha capabilities, because of the number of buildings with plutonium contamination and the size of the work force in those same buildings. The personnel at Rocky Flats are also familiar with alpha radiation which should help in the testing of the PCM-2. Their familiarity with alpha contamination should help in determining if the PCM-2 will accomplish the task of locating alpha and also the personnel should be able to give suggestions for the improvement of the PCM-2.

Data Collection

The test of the PCM-2 must be in a alpha environment and also a beta environment to check the machine fully. There will need to be tests done on the detectors for uniformity. There will need to be tests done on the machine to see if it will alarm on a 500 DPM source on a consistent basis. There will also need to be tests done with the PCM-2 in an alpha contaminated building to see how well it works in the real world.

Detector Uniformity

To test the detectors for uniformity, a two inch diameter source will be placed on different areas of each size detector and the results of the test will be recorded. Then a 100 cm^2 (10 X 10) source will be placed on each size detector and the results will be recorded. During this test, any large change in detector efficiency needs to be noted. A decrease in efficiency is expected along the edges of the detectors due to the high voltage wire being spaced a half an inch from the edge. These tests need to be run using both an alpha and a beta source.

Field Tests

The first field test of the PCM-2 will be in a building which has a large amount of depleted uranium. The test will last for three months. During those three months the radiation worker exiting the contaminated area will be checked by the Radiation Control Technician (RCT) using a Ludlum 31 with a pancake probe. After the radiation worker has been checked by the RCT, he will then remove his coveralls and step across the contaminated area boundary. While stepping across the boundary the RCT will check his feet again after the radiation worker has removed his booties. Then the radiation worker will step into the PCM-2 to see if there is any contamination still present on his body. During this testing, a Health Physics Instrumentation worker will be present to assist the radiation worker and the RCT with the PCM-2. The Health Physics Instrumentation worker will also log all information concerning an alarm or other circumstances which could effect the outcome of the test. If the PCM-2 alarms, then the radiation worker will go back to the RCT for verification of the alarm. The RCT will check the radiation worker with a Bicron Frisk-Tech with either an A-100 (alpha probe) or a B-50 (beta probe) depending on the type of alarm on the PCM-2. The results of this second check by the RCT will be recorded by the Health Physics Instrumentation worker. The RCT will determine the disposition of the radiation worker by his instrumentation, not by the readings on the PCM-2.

The second field test will be done in a building containing plutonium. The test will last three months. During the test the radiation worker will be checked by the RCT with a Ludlum 12-1A with an air proportional probe. After the radiation worker has been checked by the RCT, the radiation worker will step across the boundary of the contaminated area as he removes his booties. The RCT will check the shoes of the radiation worker after he has removed his booties and before he steps on the non-contaminated side of the boundary. After these checks by the RCT, the radiation worker will step into the PCM-2 to determine if he has any contamination on his body. During this testing, a Health Physics Instrumentation worker will be present to assist the radiation worker and the RCT with the PCM-2. The Health Physics Instrumentation worker will also log all information concerning an alarm or other circumstances which could effect the outcome of the test. If the PCM-2 alarms, the radiation worker will go back to the RCT, who will check the radiation worker with Bicron Frisk-Tech. The Bicron Frisk-Tech will have either an A-100 (alpha) probe or a B-50 (probe)depending on what the PCM-2 alarm indicates. If the RCT is unable to locate the contamination, the radiation worker will use the PCM-2 again. The second reading on the PCM-2 will be logged by the Health Physics Instrumentation worker. The disposition of the radiation worker will be determined by the RCT and his instrumentation and not by the PCM-2

Treatment of the data

Once the data has been collected from the above tests, a comparison of the PCM-2 to the hand frisking method must be done. A comparison of how much of the body is checked using hand frisking and how much is checked using the PCM-2. A comparison of what levels of contamination can each method find must be done. The length of time required to survey the entire body for 500 DPM of alpha and/or 5000 DPM of beta using each method must be compared. A determination of which method is more consistent in locating contamination on the human body. A comparison of which method will save the company the most money in checking personnel from leaving the contamination area with contamination on their bodies.

CHAPTER IV

Problem Statement

The problem being studied for this project is that people think a human being with a portable instrument is able to locate alpha contamination on the body of an individual better than a whole body monitor, such as the PCM-2. A person using a portable instrument with a probe area of 100 cm^2 or smaller will require many times longer to check the individual with the same amount of confidence. This is because the PCM-2 has 34 detectors with the most common size detector being approximately 500 cm^2. These 34 detectors are all looking for contamination at the same time, while the person with a portable instrument is using one detector that is much smaller.

This is a problem because personnel are being released from a contamination area with some amount of contamination on their body that the person with portable instrumentation is not locating. The PCM-2 would greatly reduce the amount of missed contamination leaving a contaminated area. Some people are worried about losing their jobs and so fight against anything that might replace them. Other people do not want to see changes in their work area. Others think that the human factor of knowing where to look for contamination outweigh the advantages of the whole body monitor.

Whole body monitors for beta and gamma radiation have been around for a number of years and have been accepted in most work places, but alpha whole body monitors are a new product. Alpha whole body monitors are harder to design because of the limited distance that an alpha particle travels in air. The monitor must conform to the body if it is going to be able to find alpha contamination on a large percentage of the body. Most whole body monitors for beta and gamma radiation did not conform very well to the body and therefore were not good prospects for locating alpha contamination.

Furthermore, most facilities that deal with radiation are not interested in alpha whole body monitors. The need for alpha whole body monitors is not nearly as large as beta and gamma whole body monitors. Therefore, few companies have been interested in trying to develop such a system. Eberline is one of the few companies that has decided to try and develop an alpha whole body monitor.

General Results

The PCM-2 was tested in a uranium building for three months, March, April, and May of 1993. During that time, 1126 Radiation Workers used the machine. There were thirty-seven alarms (other than testing) of which 49% were confirmed as some amount of contamination on personnel with the others being too low for present instrumentation to detect. There did not appear to be any false alarms. There was minimal down time for repairs or maintenance. Most personnel came to accept the machine as a very good indicator of contamination. The PCM-2 was tested for its detector uniformity.

Figure 1 and Figure 2 on the following page show the body positions where contamination was found. Figure 1 deals with the plutonium building and shows that the highest number of alarms were on the respirator pocket. Figure 2 deals with the uranium building and shows that the highest number of alarms were on the hands. Because of the high number of alarms on the hands, the radiation workers began wearing surgeon gloves to protect themselves.

During the three-month test in a plutonium building, the PCM-2 performed well. The test started February 7, 1994 and ended May 7, 1994. During the three months, there were 4055 transactions and 73 alarms. Of the 73 alarms, 90.5 percent were confirmed either by the Radiation Control Technician (RCT) or by having the individual repeat the use of the PCM-2. The longest down time was caused by a technician installing two computer chips in backwards, which caused the Front Panel Board to fail.

FIGURE 1

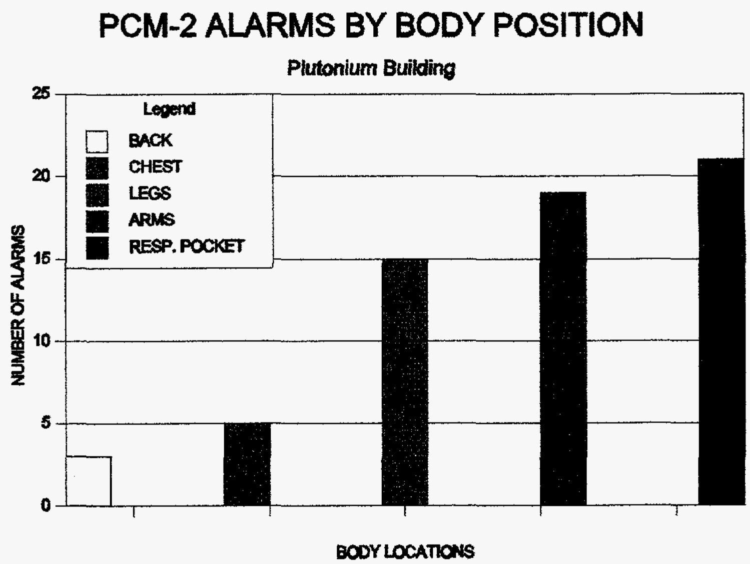
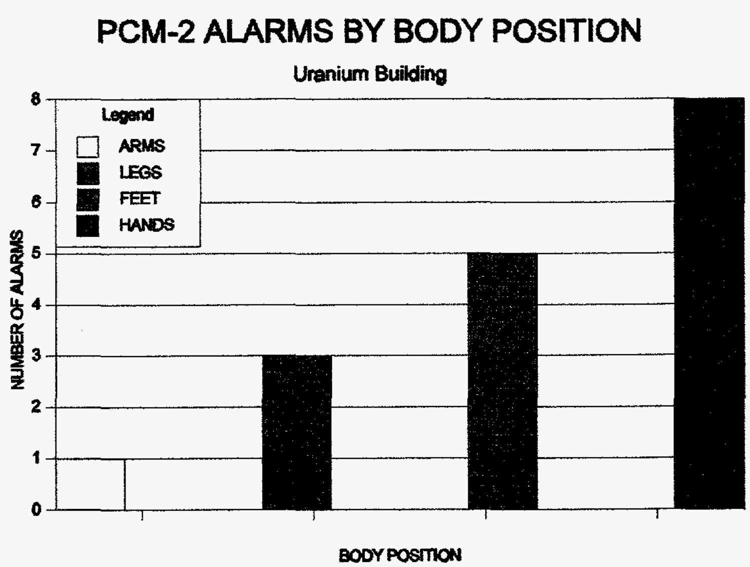


FIGURE 2



Hypothesis

Hypothesis 1: An alpha whole body monitor can check a person for contamination faster than frisking with a portable instrument.

Hypothesis 2: An alpha whole body monitor can locate lower levels of contamination than a person using a portable instrument in the same amount of time.

Hypothesis 3: An alpha whole body monitor can operate cheaper than using a person to check for contamination.

Hypothesis 4: An alpha whole body monitor can check a person leaving a contaminated area more consistently than a person using a portable instrument.

Results

Detectability in a Uranium Building

During the three-month test the PCM-2 alarmed thirty seven times. Of those alarms seventeen were confirmed by other instrumentation as contamination but below release limits, one was confirmed by other instrumentation as contamination and above release limits, nineteen were unconfirmed by other instrumentation. All alarms were after the individuals had

detectors, which showed 4998 DPM beta and 2506 DPM alpha. These detector positions were on the back of his pants between the knee and his hip. The Bicron B-50 and A-100 were used to confirm the alarm. The B-50 read 4900 DPM beta and the A-100 read 2700 DPM alpha. A smear of his pants was done and the Eberline SAC-4 showed less than 20 DPM removable. The count was then considered Radon and the individual was released. The individual was requested to come back in two hours to make sure that the count had decreased. At 10:41 a.m., the individual came back and the PCM-2 still alarmed with a reading of 1894 beta and 1521 alpha. The Bicron showed 900 DPM beta and 303 DPM alpha at the same location. At 10:54 a.m. another reading was taken on the PCM-2 and this time it read 1509 DPM beta and 945 DPM alpha. At 2:20 p.m., the individual came back and this time the PCM-2 did not alarm. The rapid decrease in count is comparable to Radon being electrostatically attached to the pants.

On April 2, 1993, an individual alarmed the PCM-2 on the back of his left leg. The PCM-2 showed a reading of 4641 DPM beta and 476 DPM alpha. The Bicron Frisk-tech showed 517 DPM beta and 200 DPM alpha. The Ludlum Model 31 showed no increase over background. Differences in readings will depend on how the contamination is spread over the surface of the individual. The PCM-2 has three different detector sizes: 776 cm^2, 500 cm^2, and 330 cm^2. The Bicron Frisk Tech with beta probe is 50 cm^2 and with an alpha probe is 100

cm^2. The Ludlum 31 with a pancake probe is 17 cm^2. Because of these different probe sizes it is difficult to get a reading that compares with all three instruments unless the radioactive source is smaller than 17 cm^2. The most common probe size on the PCM-2 is 500 cm^2, which is the one that alarmed on April 2, 1993. Therefore, it is possible for each instrument to read something different and all to be reading accurately with respect to the detector and source size.

On April 16, 1993, an individual alarmed the PCM-2 on his left hand with a reading on the PCM-2 of 429 DPM alpha. A check with the Bicron Frisk Tech showed a reading of 104 DPM alpha.

On April 22, 1993, an individual alarmed the PCM-2 on the front of his right leg with a reading on the PCM-2 of 483 DPM alpha. A check with the Bicron Frisk Tech showed a reading of 71 DPM alpha.

On April 27, 1993, an individual alarmed the PCM-2 on the bottom of his left shoe with a reading on the PCM-2 of 418 DPM alpha. A check with the Bicron Frisk Tech showed a reading of 83 DPM on the front half of his shoe and a reading of 60 DPM on the rear half.

On May 6, 1993, an individual alarmed the PCM-2 on both of his hands with an average reading on the PCM-2 of 463 DPM alpha. A check with the

Bicron Frisk Tech showed a reading of 200 DPM alpha. After the individual cleaned his hands he could go through the PCM-2 with no further alarms.

Confirmed above release limits

The one alarm that was above release limits occurred on May 5, 1993. An individual alarmed the PCM-2 on his right hand and arm with a reading on the PCM-2 of 505 DPM alpha and 2778 DPM beta. A check with a Ludlum 31 showed a reading between 500 and 750 DPM beta; no alpha reading was taken. After the individual decontaminated his right hand and arm, he could go through the PCM-2 without alarming.

Unconfirmed

Concerning the alarms where the readings were unconfirmed, there were different reasons why the alarms were unconfirmed: the RCT's did not have the alpha Bicron instrument available, the individual alarmed the PCM-2 on an off shift and it was not reported to the RCT's, the individual from Health Physics Instrumentation did not log the information, and the user kicked the machine causing the alarm.

On March 21, 1993, an individual alarmed the PCM-2 three times at approximately 20:00 on his left foot with a reading of 738 DPM alpha. This occurred on a Sunday evening with no one from Health Physics Instrumentation (HPI) present. A check with Radiological Operations later in the week showed that they were unaware of the alarm on Sunday evening. No further investigation was done.

On March 26, 1993, an individual alarmed the PCM-2 on his right hand with a reading on the PCM-2 of 618 DPM alpha. A check with the Bicron showed no contamination. A second pass through the PCM-2 did not produce an alarm.

On April 8, 1993, an individual alarmed the PCM-2 on his right foot with a reading of 4692 DPM beta. Because the individual was angry with the machine and kicked it with his foot, it was felt that the alarm was probably caused by the sharp blow to the detector. A second count on the PCM-2 was taken and the individual passed with no further problems. No disciplinary action was taken against the individual because he came back and apologized for losing his temper.

On April 14, 1993, at 11:02 an individual alarmed the PCM-2 on his left hand with a reading on the PCM-2 of 485 DPM alpha. A check with the Bicron showed no contamination and the individual was released. At 13:52 the same individual alarmed the PCM-2 on both of his hands with a PCM-2 reading of 684 DPM alpha on his left hand and 924 DPM alpha on his right hand. These readings could not be confirmed by the Bicron and the individual was allowed to leave.

On April 28, 1993, an individual alarmed the PCM-2 on his left foot with a PCM-2 reading of 443 DPM alpha. No information was logged by HPI personnel and therefore no further information is available.

On April 29, 1993, two different individuals alarmed the PCM-2 on their right hands with readings of 406 DPM and 437 DPM. No information was logged either time by HPI personnel.

On April 30, 1993, an individual alarmed the PCM-2 on the bottom and side of his right foot with a PCM-2 sum zone reading of 7680 DPM beta. A check with the Bicron revealed no count, so the individual wiped his shoe off and was counted with the PCM-2 with no alarm.

On May 5, 1993, an individual alarmed the PCM-2 on his right hand with a PCM-2 reading of 385 DPM. A check with the Bicron instrument showed no contamination and a second try on the PCM-2 passed.

On May 6, 1993, an individual alarmed the PCM-2 with her left hand with a PCM-2 reading of 388 DPM alpha. A check with the Bicron instrument showed no contamination, but since the individual had just removed a pair of contaminated coveralls, it was decided to decontaminate her hand to be sure. A second try through the PCM-2 after the decontamination was successful.

Reliability

During its three-month test in an uranium building, the PCM-2 checked 1126 persons and alarmed thirty-seven times (other than testing). During those three months there were three problems with the PCM-2: a hole in one of the detectors, the microswitch for the hand not always activating, and a technician accidentally shutting down the machine. The only down time for the machine was caused when a technician was in the menu of the program and went into DOS. When he came back from DOS the screen for displaying count times would not update. Therefore, the PCM-2 would not release the machine for use because it did not have count time for each detector. This problem was resolved by powering down the PCM-2 and restarting it. The total downtime for this problem was two hours.

The most persistent problem was a hole in the detector that monitors the side of the foot. The original hole was very small and showed up right after moving the PCM-2 to the uranium building. It was decided to patch the hole with fingernail polish through the metal screen rather than taking the detector out of the machine to repair it. At that time no spare parts were available to replace the detector. Because the detector was repaired through the screen, every time the screen is kicked hard the hole is ripped again because the fingernail polish glued the screen to the Mylar of the detector. This required the use of three bottles of P-10 gas during these three months and to repair the leak often. If there are no leaks, a bottle of P-10 gas should last six months. In the future all holes will be repaired by replacing the detector instead of patching it. This was the only hole in any of the 34 detectors during the three-month test.

The third problem was the adjustment for the hand microswitch. It was adjusted twice during the three months. It never totally failed, but it would occasionally not work properly. When this happened, the PCM-2 thought that the individual had not inserted their left hand and would continue to tell them to insert it.

Of these three problems only one gave us any downtime, the one caused by the technician. This speaks loudly about the durability of the PCM-2 and demonstrates a much higher reliability than what was expected for a new machine. The percentage of downtime for the PCM-2 located in the uranium building for the three months it was in operation was 0.38%.

Detectability in a Plutonium Building

During the three-month test in the plutonium building, the PCM-2 alarmed 73 times. Of those alarms, 56 were confirmed by instrumentation as contamination but below release limits, two were confirmed by other instrumentation as contamination above release limits, eight were from watches and sources, and seven were unconfirmed by other instrumentation. All alarms were after the individuals had passed the RCT's initial frisking and the RCT was unable to find contamination using the Ludlum 12-1A with an air proportional probe.

Confirmed above release limits

There were two alarms that were confirmed above release limits. The first one occurred on February 10, 1994. An individual alarmed the PCM-2 with a reading of 998 DPM on the respirator pocket. A check by the RCT with a Bicron indicated no contamination. The individual reentered the PCM-2 and alarmed again on the respirator pocket with a reading of 743 DPM. A second RCT did a more careful search for contamination in the suspected area and found a contamination level of 508 DPM.

On February 23, 1994, an individual alarmed the PCM-2 with a reading of 699 DPM on the respirator pocket. A check by the RCT with the Ludlum 12-1A showed a reading of 500 DPM. A check by the RCT with the Bicron showed a reading of 700 DPM.

Confirmed below release limits

There were 56 alarms confirmed, but below release limits. Because of the large number of alarms in this category, a table was created to display the information. Please refer to Table 1 on the following pages.

TABLE 1

DATE	PCM-2 READING	RCT MONITORED READING	CONTAMINATED AREA	INSTRUMENT USED	COMMENTS
02/09/94	480 DPM	<MDA	Right leg	Ludlum 12-1A	Second PCM-2 reading 394 DPM
02/11/94	421 DPM	271 DPM	Respirator pocket	Bicron A100	
02/14/94	398 DPM	138 DPM	Left leg	Bicron A100	
02/17/94	468 DPM	140 DPM	Respirator pocket	Bicron A100	
02/21/94	429 DPM	160 DPM	Left shoulder	Bicron A100	
02/21/94	448 DPM	Not done	Left leg	None	No check done, person assumed to be contaminated
02/23/94	410 DPM	434 DPM	Left shoulder	Bicron A100	
02/23/94	466 DPM	186 DPM	Respirator pocket	Bicron A100	

TABLE 1

DATE	PCM-2 READING	RCT MONITORED READING	CONTAMINATED AREA	INSTRUMENT USED	COMMENTS
02/24/94	584 DPM	315 DPM	Right Shoulder	Bicron A100	
03/10/94	439 DPM	99 DPM	Respirator pocket	Bicron A100	Second PCM-2 reading 252 DPM
03/10/94	381 DPM	< MDA	Respirator pocket	Bicron A100	Second PCM-2 reading 222 DPM
03/10/94	1681 DPM	< MDA	Respirator pocket	Bicron A100	Second PCM-2 reading 1728 DPM
03/11/94	402 DPM	160 DPM	Respirator pocket	Bicron A100	
03/15/94	424 DPM	< MDA	Right leg	Bicron A100	Second PCM-2 reading 289 DPM
03/17/94	459 DPM	165 DPM	Right leg	Bicron A100	
03/17/94	408 DPM	275 DPM	Right leg	Bicron A100	
03/17/94	359 DPM	< MDA	Respirator pocket	Bicron A100	Second PCM-2 reading 199 DPM

TABLE 1

DATE	PCM-2 READING	RCT MONITORED READING	CONTAMINATED AREA	INSTRUMENT USED	COMMENTS
03/17/94	408 DPM	110 DPM	Respirator pocket	Bicron A100	
03/17/94	375 DPM	110 DPM	Left shoulder	Bicron A100	
03/18/94	425 DPM	150 DPM	Right chest	Bicron A100	
03/22/94	384 DPM	123 DPM	Respirator pocket	Bicron A100	
03/28/94	448 DPM	< MDA	Respirator pocket	Bicron A100	Second PCM-2 reading 119 DPM
03/28/94	539 DPM	75 DPM	Respirator pocket	Bicron A100	Second PCM-2 reading 240 DPM
03/30/94	352 DPM	105 DPM	Right leg	Bicron A100	Second PCM-2 reading 69 DPM
03/30/94	438 DPM	165 DPM	Left leg	Bicron A100	Second PCM-2 reading 171 DPM
03/30/94	416 DPM	47 DPM	Respirator pocket	Bicron A100	Second PCM-2 reading 313 DPM

TABLE 1

DATE	PCM-2 READING	RCT MONITORED READING	CONTAMINATED AREA	INSTRUMENT USED	COMMENTS
04/04/94	333 DPM	70 DPM	Respirator pocket	Bicron A100	Second PCM-2 reading 69 DPM
04/04/94	345 DPM	65 DPM	Left shoulder	Bicron A100	Second PCM-2 reading 32 DPM
04/04/94	449 DPM	8.5 DPM	Left leg	Bicron A100	Second PCM-2 reading 430 DPM
04/04/94	382 DPM	17 DPM	Respirator pocket	Bicron A100	
04/04/94	390 DPM	31 DPM	Respirator pocket	Bicron A100	
04/05/94	365 DPM	125 DPM	Left shoulder	Bicron A100	Second PCM-2 reading 424 DPM
04/05/94	381 DPM	110 DPM	Left shoulder	Bicron A100	Second PCM-2 reading 223 DPM
04/18/94	411 DPM	106 DPM	Respirator pocket	Bicron A100	
04/19/94	364 DPM	45 DPM	Right arm	Bicron A100	

TABLE 1

DATE	PCM-2 READING	RCT MONITORED READING	CONTAMINATED AREA	INSTRUMENT USED	COMMENTS
04/25/94	347 DPM	None	Right shoulder	None	Second PCM-2 reading 117 DPM
04/25/94	479 DPM	None	Right hand	None	Second PCM-2 reading 127 DPM
04/25/94	391 DPM	None	Right leg	None	Second PCM-2 reading 160 DPM
04/25/94	406 DPM	50 DPM	Left chest	Bicron A100	
04/26/94	540 DPM	250 DPM	Left back	Bicron A100	
04/26/94	411 DPM	40 DPM	Left arm	Bicron A100	
04/27/94	504 DPM	130 DPM	Left arm	Bicron A100	
04/28/94	424 DPM	120 DPM	Left leg	Bicron A100	
04/28/94	593 DPM	181 DPM	Left leg	Bicron A100	
04/29/94	408 DPM	114 DPM	Right back	Bicron A100	
05/02/94	413 DPM	55 DPM	Left leg	Bicron A100	

TABLE 1

DATE	PCM-2 READING	RCT MONITORED READING	CONTAMINATED AREA	INSTRUMENT USED	COMMENTS
05/02/94	735 DPM	60 DPM	Left abdomen	Bicron A100	Second PCM-2 reading 357 DPM
05/02/94	469 DPM	85 DPM	Left chest	Bicron A100	
05/03/94	509 DPM	158 DPM	Left shoulder	Bicron A100	
05/03/94	359 DPM	35 DPM	Left back	Bicron A100	
05/03/94	326 DPM	20 DPM	Left shoulder	Bicron A100	
05/04/94	359 DPM	58 DPM	Respirator pocket	Bicron A100	
05/05/94	380 DPM	46 DPM	Left leg	Bicron A100	
05/06/94	383 DPM	70 DPM	Left shoulder	Bicron A100	

TABLE 1

DATE	PCM-2 READING	RCT MONITORED READING	CONTAMINATED AREA	INSTRUMENT USED	COMMENTS
			BETA ALARMS		
03/21/94	10,044 DPM (Sum Zone)	< 100 CPM	Both legs	Ludlum 31	Second PCM-2 reading 10,813 DPM
04/26/94	5400 DPM	None	Right leg	No beta instrument available at step-off pad	RCT used Bicron with A100 probe, it read 83 DPM
	5058 DPM		Left leg		

Alarms from sources and watches

On February 15, 1994, an individual alarmed the PCM-2 with a reading of 92,860 DPM beta on the respirator pocket. The individual from Safeguards Measurements was carrying a ^{133}Ba source in the respirator pocket. The Health Physics Instrumentation (HPI) technician warned the individual about carrying a gamma source in his pocket, but the individual did not seem concerned.

On February 24, 1994, an individual alarmed the PCM-2 with a reading of 118,000 DPM beta on the respirator pocket. The individual from Safeguards Measurements was carrying a ^{133}Ba source in the respirator pocket. The Health Physics Instrumentation (HPI) technician warned the individual about carrying a gamma source in his pocket, but the individual did not seem concerned. Since this was the second incident, an Radiological Deficiency Report was written to correct this deficiency. No further alarms were detected from this type of incident.

On March 25, 1994, an individual alarmed the PCM-2 with a reading of 400 DPM on the right hand. It was discovered that the individual was carrying an alpha source in his hand to test the machine.

On March 31, 1994, an individual alarmed the PCM-2 with a reading of 7447 DPM beta on the left hand. It was discovered that the individual was wearing a radiation-dial watch. The watch was removed and the individual passed the PCM-2 with no further alarms.

On April 18, 1994, an individual alarmed the PCM-2 with a reading of 4854 DPM beta on the left hand. It was discovered that the individual was wearing a radiation-dial watch. The watch was removed and the individual passed the PCM-2 with no further alarms.

On April 25, 1994, an individual alarmed the PCM-2 with a reading of 5452 DPM beta on the left hand. It was discovered that the individual was wearing a radiation-dial watch. The watch was removed and the individual passed the PCM-2 with no further alarms.

Unconfirmed alarms

On February 8, 1994, an individual alarmed the PCM-2 with a reading of 431 DPM on the upper right arm. A check by the RCT with the Bicron failed to disclose any contamination. The person entered the PCM-2 a second time and it did not alarm. No reading was taken during the second count in the PCM-2.

On February 16, 1994, an individual alarmed the PCM-2 with a reading of 432 DPM on the upper left arm. A check by the RCT with the Bicron failed to disclose any contamination. The person was not counted a second time in the PCM-2.

On March 8, 1994, an individual alarmed the PCM-2 with a reading of 3831 DPM on the respirator pocket. A check by the RCT with the Bicron failed to disclose any contamination. The person was not counted a second time in the PCM-2.

On March 23, 1994, an individual alarmed the PCM-2 with a reading of 345 DPM on the upper left arm. A check by the RCT with the Bicron failed to disclose any contamination. The person was counted a second time in the PCM-2 with a reading of 0 DPM.

On March 24, 1994, an individual alarmed the PCM-2 with a reading of 354 DPM on the upper left chest. A check by the RCT with the Bicron failed to disclose any contamination. The person was counted a second time in the PCM-2 with a reading of 0 DPM.

On April 18, 1994, an individual alarmed the PCM-2 with a reading of 556 DPM on the upper right leg. A check by the RCT with the Bicron failed to disclose any contamination. The person was counted a second time in the PCM-2 with a reading of 0 DPM.

On April 22, 1994, an individual alarmed the PCM-2 with a reading of 339 DPM on the upper left shoulder. No check by the RCT was done nor was the individual checked in the PCM-2 again because the HPI person did not notice the alarm until after the individual had left the area.

On May 5, 1994, an individual alarmed the PCM-2 with a reading of 11,125 DPM beta on sum zone covering the upper legs. A check by the RCT with the Bicron A-100 failed to disclose any alpha contamination. No beta instrument was available for the RCT on the step-off pad.

Reliability

Shortly after placing the PCM-2 into Building 771, on January 25, 1994, it was assumed someone cut a one inch gash in the foot detector. Safeguards and Security personnel were called and they conducted an investigation into the incident. The one inch gash did not shut down the PCM-2; it continued to work until the hole was patched. The gas system watches for leaks and increases the P-10 gas flow to compensate for holes in the detectors. On February 21, 1994, the foot probe was replaced due to a rip in the Mylar. Downtime was one hour.

On March 18, 1994, the screen on detector 17 was identified to be damaged. It was assumed that this damage was from normal use of the machine. The sharp edges on the screen were trimmed and the screen was left in place.

On March 21, 1994, the hip switch stopped functioning. After further inspection, it was determined that the return spring had broken. On May 7, 1994, the return spring broke again. The vendor determined that the operating rod for the spring pushed against the side of the spring and broke the spring. A modification to the operating rod has been done by the vendor to solve this problem. Down time caused by the hip switch return spring was only 4.5 hours, because the software allows you to bypass any required presence switch.

On March 29, 1994, the detector for checking the hand area had to be replaced due to a hole in the Mylar. This caused a down time of 4 hours.

On April 5, 1994, while installing a software upgrade, two computer chips were installed backwards, causing the Font Panel Board on the PCM-2 to fail. The PCM-2 down time was ten days until spare parts were received from the vendor and installed.

On May 6, 1994, PCM-2 shut itself done because it was not receiving gas from either bottle. Further investigation showed the hoses from both bottles were kinked between the bottle cabinet and the PCM-2. Hoses were straightened and the alarm cleared. Downtime was 30 minutes.

Approximately every two weeks during the test, the six detectors where the body rubs against the detectors had to be cleaned. This was required due to lint buildup from the white coveralls rubbing against the screens protecting the detectors. Downtime for cleaning detectors was 15 hours.

Daily performance test required approximately one half hour per day.

The downtime for the three months of operation consists of five hours for detector repair, 4.5 hours for hip switch spring replacement, 15 hours for cleaning, 28 hours for performance testing, and 240.5 hours due to technician error. Failure downtime consists of detector repair and hip switch spring breakage for a total of 9.5 hours or 0.4% (9.5 hours ÷ 2184 hours). Cleaning downtime equaled 0.7% (15 hours ÷ 2184 hours). Performance test downtime equaled 1.2% (28 hours ÷ 2184 hours). Technician error (installing computer chip backwards) downtime equaled 11% (240.5 hours ÷ 2184 hours). The three-month test was performed mostly on the day shift and the maintenance was performed mostly on the P. M. shift. Actual down time during the day shift was less, but normally this down time would be during operational hours. The long downtime due to technician error should be a one-time problem because spare parts will be on hand in the future. In the future, instruction for working on the PCM-2 will include how to replace computer chips.

Cost Savings

The following table demonstrates the possible cost savings using the PCM-2. The savings projection does not consider removing the Radiation Control Technician from the step-off pad. The savings projection looks at the cost savings based on the time saved per Radiation Worker using the PCM-2 versus being scanned by the Radiation Control Technician using a portable instrument. The PCM-2 is able to check 80% - 90% of the body with a 95% confidence level. The Radiation Control Technician using a 100 cm^2 probe is able to check approximately 100% of the body with a 50% confidence level within five to eight minutes.

TABLE 2

PCM-2 SAVINGS PROJECTION

ADDITIONAL MONITORING COSTS FOR PORTABLE INSTRUMENTATION

* 4959 Radiation Workers
* (5 days/week) (50 weeks/year) (4 trips/day) (4 minutes additional scan time) (4959 Radiation Workers X 25%)
* (4,959,000 minutes/year) ÷ (60 minutes) X ($40.00/hour) =

TOTAL $3,306,000/year

* Additional scan time is required to meet new lower limits set by Radiological Control Manual.

NOTE

The 4 minute additional scan time is the difference of using portable instrumentation (Bicron or Electra) versus the PCM-2. The PCM-2 has 34 detectors counting simultaneously compared to one detector with portable instrumentation.

TABLE 2 (continued)

PCM-2 OPERATING COSTS

Assume 1 Health Physics Instrumentation Technician (HPIT) per 8 units

Assume $82.09/hour fully burdened cost

Assume 2080 hours/year/technician

Additional 4 HPIT's will be needed in full-time support

Labor cost for PCM-2 support -

(4 HPIT's) X (2080 hours) X ($82.09/hour) = $682,989/year

Assume replacement parts for one year = $110,000/year

Total operating costs for one year = $792,989/year

PCM-2 ANNUAL COST SAVINGS

* $3,306,000 - $792,989 = **$2,513,011/YEAR**

SAVINGS PER YEAR PER PCM-2

* $2,513,011/year ÷ 34 PCM-2's = $73,912/year/PCM-2

Detector Uniformity

A detector uniformity test was performed for alpha and beta on each size detector. The results of this test are in Tables 3 through 13. The first page of each table shows the source test locations on each detector. The following pages in each table show test locations, counts per minute (CPM) for that location, and the measured efficiency.

Tables 3, 4, and 5 show detector uniformity for each size detector using a 1.875 inch diameter alpha source and a 1.6875 diameter beta source. The source was placed in each of the number locations shown on page one of each table, with the source even with the outer edge of the detector where possible.

Tables 6, 7, and 8 show detector uniformity for each size detector using a 100 cm^2 (10 X 10) alpha source. The source was placed in each of the number locations shown on page one of each table, with the source even with the outer edge of the detector.

Tables 9 and 10 show detector uniformity for the large detector at 0.5 inches and at 1 inch respectively. The source was placed in each of the number locations shown on page one of each table, with the source even with the outer edge of the detector.

Tables 11, 12, and 13 show detector uniformity for each size detector at 0 inches and at 1 inch using a 1.6875 inch diameter beta source. The source was placed in each of the number locations shown on page one of each table, with the source centered on each section.

Summary

The PCM-2 would make an ideal instrument for Rocky Flats because of its alpha detecting capabilities. Any alpha with an energy level greater than 3.0 MeV that enters the detector will be counted. Since the alphas for ^{238}U have an energy greater than 4.0 MeV and the alphas for ^{239}Pu have an energy greater than 5.0 MeV, both of these radionuclides should be counted by the PCM-2. The testing performed at Rocky Flats in the Uranium area and in the Plutonium area verifies this. Low levels of Plutonium and Uranium were detected on a consistent basis with the PCM-2.

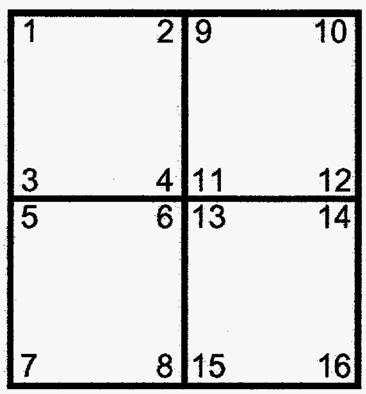
Table 3

Uniformity
Testing of Detector
SMALL

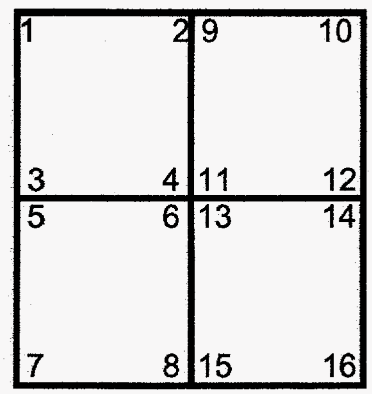
Readings in CPM with % of efficiency

Alpha	
CSL	601190
DPM	36180
DUE	03/95

Beta	
CSL	603472
DPM	17337
DUE	10/94



Alpha



Beta

Table 3

Uniformity
Alpha Testing of Detector

Detector # 20

Readings in CPM with % of efficiency

CSL # 601190
DPM 36180
Due Date 03/95

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Overall CPM	Overall % Eff.
1	5503	15.2				
2	6581	18.2	7183.75	19.85		
3	8137	22.5				
4	8514	23.5				
5	8173	22.6				
6	8752	24.2	7582.75	20.95		
7	6915	19.1				
8	6491	17.9			7462.563	20.675
9	6095	16.8				
10	3730	10.3	6676	18.425		
11	8478	23.4				
12	8401	23.2				
13	8178	23.6				
14	8875	24.5	8407.75	23.475		
15	7918	21.9				
16	8660	23.9				

Table 3

Uniformity
Beta Testing of Detector

Detector # 20

Readings in CPM with % of efficiency

CSL # 603472
DPM 17337
Due Date 10/94

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Overall CPM	Overall % Eff.
1	3232	18.7	5278	30.475	5577.875	32.20625
2	4138	23.9				
3	6912	39.9				
4	6830	39.4				
5	6916	39.9	5593.75	32.275		
6	6726	38.8				
7	3124	18.0				
8	5609	32.4				
9	3669	21.2	4802.75	27.75		
10	1810	10.5				
11	6833	39.5				
12	6899	39.8				
13	6430	37.1	6637	38.325		
14	6855	39.6				
15	6896	39.8				
16	6367	36.8				

Table 4

Uniformity
Testing of Detector

Medium

15.5 cm X 49 cm (active area = 728 cm^2)

Readings in CPM with % of efficiency

Alpha

CSL	601190
DPM	36180
DUE	03/95
SIZE	1.875" DIA.

Beta

CSL	603472
DPM	17337
DUE	10/94
SIZE	1.6875" DIA.

1	2	17	18
3	4	19	20
5	6	21	22
7	8	23	24
9	10	25	26
11	12	27	28
13	14	29	30
15	16	31	32

1	2	17	18
3	4	19	20
5	6	21	22
7	8	23	24
9	10	25	26
11	12	27	28
13	14	29	30
15	16	31	32

Alpha

Average Reading

Beta

Average Reading

Table 4

Uniformity
Alpha Testing of Detector

Detector # 29

Readings in CPM with % of efficiency

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.
1	4390	12.1		
2	7039	19.5	6862.75	18.975
3	6937	19.2		
4	9085	25.1		
5	6478	17.9		
6	8769	24.1	7509.5	20.725
7	6317	17.5		
8	8474	23.4		
9	6886	19.0		
10	8715	24.1	7679	21
11	6304	17.5		
12	8811	23.4		
13	5931	16.4		
14	8766	24.2	6707	18.525
15	5001	13.8		
16	7130	19.7		
17	6202	17.1		
18	1616	4.5	5940.5	16.4175
19	9102	25.2		
20	6842	18.9		
21	8932	24.7		
22	7360	20.3	7935.5	21.925
23	8504	23.5		
24	6946	19.2		
25	8571	23.7		
26	6724	18.6	7728.75	21.375
27	9009	24.9		
28	6611	18.3		
29	8899	24.6		
30	6711	18.5	7126.25	19.675
31	7504	20.7		
32	5391	14.9		

	CPM	% Eff.
Detector Avg	7186.156	19.82719

CSL #	601190
DPM	36180
Due Date	03/95

Table 4

Uniformity
Beta Testing of Detectors

Detector # 29

Readings in CPM with % of efficiency

CSL #	603472
DPM	17337
Due Date	10/94

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.
1	3942	22.8		
2	6979	40.3	6410.5	37.025
3	5950	34.4		
4	8771	50.6		
5	5578	32.2		
6	8633	49.8	7200	41.55
7	6096	35.2		
8	8493	49.0		
9	6592	38.1		
10	8660	50.0	7553.75	43.625
11	6407	37.0		
12	8556	49.4		
13	6386	36.9		
14	8544	49.3	6735.75	38.9
15	4462	25.8		
16	7551	43.6		
17	5379	31.1		
18	1847	10.7	5488.25	31.7
19	8456	48.8		
20	6271	36.2		
21	8769	50.6		
22	6439	37.2	7529.5	43.475
23	8488	49.0		
24	6422	37.1		
25	8662	50.0		
26	6256	36.1	7574.5	43.725
27	8580	49.5		
28	6800	39.3		
29	8668	50.0		
30	6594	38.1	6770	39.075
31	6811	39.3		
32	5007	28.9		

	CPM	% Eff.
Detector Avg	6907.781	39.88438

Table 5

Uniformity
Testing of Detectors

Large

Alpha

Det.#12	1	2	17	18	
	3	4	19	20	
	5	6	21	22	
	7	8	23	24	
	9	10	25	26	
	11	12	27	28	
	13	14	29	30	
	15	16	31	32	
Det.#11	33	34	49	50	Average
	35	36	51	52	
	37	38	53	54	
	39	40	55	56	
	41	42	57	58	
	43	44	59	60	
	45	46	61	62	
	47	48	63	64	
Det.#10	65	66	81	82	Average
	67	68	83	84	
	69	70	85	86	
	71	72	87	88	
	73	74	89	90	
	75	76	91	92	
	77	78	93	94	
	79	80	95	96	
					Average

Total
Average Reading

Beta

Det.#12	1	2	17	18	
	3	4	19	20	
	5	6	21	22	
	7	8	23	24	
	9	10	25	26	
	11	12	27	28	
	13	14	29	30	
	15	16	31	32	
Det.#11	33	34	49	50	Average
	35	36	51	52	
	37	38	53	54	
	39	40	55	56	
	41	42	57	58	
	43	44	59	60	
	45	46	61	62	
	47	48	63	64	
Det.#10	65	66	81	82	Average
	67	68	83	84	
	69	70	85	86	
	71	72	87	88	
	73	74	89	90	
	75	76	91	92	
	77	78	93	94	
	79	80	95	96	
					Average

Total
Average Reading

Table 5

Uniformity
Alpha Testing of Detector

Detector # 12

Readings in CPM with % of efficiency

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.
1	6922	19.1	8154.25	22.525
2	8978	24.8		
3	7876	21.8		
4	8841	24.4		
5	7504	20.7	8089.25	22.35
6	8677	24.0		
7	7657	21.2		
8	8519	23.5		
9	8103	22.4	8265.75	22.85
10	8932	24.7		
11	7439	20.6		
12	8589	23.7		
13	3708	10.2	5403.75	14.925
14	7384	20.4		
15	3220	8.9		
16	7303	20.2		
17	8009	22.1	7957	21.975
18	6729	18.6		
19	8865	24.5		
20	8225	22.7		
21	8559	23.7	8063.75	22.3
22	7494	20.7		
23	8861	24.5		
24	7341	20.3		
25	8543	23.6	8068	22.3
26	7369	20.4		
27	8729	24.1		
28	7631	21.1		
29	8598	23.8	8152.5	22.55
30	8004	22.1		
31	8571	23.7		
32	7437	20.6		

	CPM	% Eff.
Detector # Avg	7769.281	21.47188

CSL #	601190
DPM	36180
Due Date	03/95

Table 5

Uniformity
Alpha Testing of Detector

Detector # 11

Readings in CPM with % of efficiency

Location	CPM	% Eff.
33	7852	21.7
34	8638	23.9
35	8332	23.0
36	8916	24.6
37	8308	23.0
38	8824	24.4
39	7851	21.7
40	8990	24.0
41	7650	21.1
42	8706	24.1
43	7940	21.9
44	9058	25.0
45	4667	12.9
46	8146	22.5
47	3551	9.8
48	7788	21.5
49	8346	23.1
50	7296	20.2
51	8881	24.5
52	7752	21.4
53	9079	25.1
54	7718	21.3
55	9260	25.6
56	8079	22.3
57	9077	25.1
58	7536	20.8
59	8860	24.5
60	7681	21.2
61	9031	25.0
62	7132	19.7
63	9057	25.0
64	7106	19.6

Zone Avg (Locations)	CPM	% Eff.
33–36	8434.5	23.3
37–40	8493.25	23.275
41–44	8338.5	23.025
45–48	6038	16.6775
49–52	8068.75	22.3
53–56	8534	23.575
57–60	8288.5	22.9
61–64	8081.5	22.325

	CPM	% Eff.
Detector # Avg	8034.625	22.17219

CSL #	601190
DPM	36180
Due Date	03/95

Table 5

Uniformity
Alpha Testing of Detector

Detector # 10

Readings in CPM with % of efficiency

CSL # 601190
DPM 36180
Due Date 03/95

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.
65	7530	20.8	8075.25	22.325
66	8823	24.4		
67	7305	20.2		
68	8643	23.9		
69	7928	21.9	8227.75	22.75
70	8425	23.3		
71	8024	22.2		
72	8534	23.6		
73	7893	21.8	8245.75	22.775
74	8789	24.3		
75	7502	20.7		
76	8799	24.3		
77	5196	14.4	5970	16.515
78	8187	22.6		
79	3168	8.8		
80	7329	20.3		
81	8078	22.3	7801.5	21.575
82	7078	19.6		
83	8968	24.8		
84	7082	19.6		
85	9246	25.6	8350.75	23.1
86	7355	20.3		
87	9321	25.8		
88	7481	20.7		
89	8563	23.7	7956.75	22
90	6945	19.2		
91	8986	24.8		
92	7333	20.3		
93	8946	24.7	8116.5	22.425
94	7361	20.3		
95	8755	24.2		
96	7404	20.5		

	CPM	% Eff.
Detector # Avg	7843.031	21.68313

Table 5

Uniformity
Beta Testing of Detector

Detector # 12

Readings in CPM with % of efficiency

CSL # 603472
DPM 17580
Due Date 10/94

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.
1	7299	42.2		
2	8609	49.7	7836.5	45.25
3	6500	37.5		
4	8938	51.6		
5	6227	36.0		
6	8895	51.4	7629.5	44.075
7	6391	36.9		
8	9005	52.0		
9	6643	38.4		
10	8670	50.1	7685.75	44.4
11	6727	38.8		
12	8703	50.3		
13	4269	24.7		
14	7583	43.8	5594.5	32.325
15	3220	18.6		
16	7306	42.2		
17	8674	50.1		
18	6779	39.1	7949.25	45.9
19	8963	51.8		
20	7381	42.6		
21	8700	50.2		
22	6400	37.0	7685	44.5
23	8635	49.9		
24	7005	40.9		
25	8991	51.9		
26	7467	43.1	7967	45.975
27	8320	48.0		
28	7090	40.9		
29	8676	50.1		
30	7521	43.4	8112.75	46.85
31	8481	49.0		
32	7773	44.9		

Detector Avg.: CPM 7557.531, % Eff. 43.65938

Table 5

Uniformity
Beta Testing of Detector

Detector # 11

Readings in CPM with % of efficiency

CSL # 603472
DPM 17580
Due Date 10/94

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.
33	6478	37.4		
34	8570	49.5	7844.5	45.3
35	7547	43.6		
36	8783	50.7		
37	6974	40.3		
38	8749	50.5	7933.25	45.8
39	7296	42.1		
40	8714	50.3		
41	7285	42.1		
42	8627	49.8	8003	46.225
43	7223	41.7		
44	8877	51.3		
45	4249	24.5		
46	7794	45.0	5616	32.425
47	3165	18.3		
48	7256	41.9		
49	8345	48.2		
50	7428	42.9	7887.25	45.425
51	8745	50.0		
52	7031	40.6		
53	8690	50.2		
54	7468	43.1	7921.25	45.75
55	8740	50.5		
56	6787	39.2		
57	8618	49.8		
58	6057	35.0	7721.25	44.6
59	8854	51.1		
60	7356	42.5		
61	8721	50.4		
62	6173	35.7	7545	43.575
63	8612	49.7		
64	6674	38.5		

Detector Avg.	CPM	% Eff.
	7558.938	43.6375

Table 5

Uniformity
Beta Testing of Detector

Detector # 10

Readings in CPM with % of efficiency

CSL #	603472
DPM	17580
Due Date	10/94

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg. CPM	Detector Avg. % Eff.
65	7698	44.5				
66	8761	50.6	8218.25	47.475		
67	7435	42.9				
68	8979	51.9				
69	7714	44.6				
70	8896	51.4	8288.5	47.875		
71	7590	43.8				
72	8954	51.7				
73	7366	42.5				
74	9037	52.2	8166.5	47.175		
75	7317	42.3				
76	8946	51.7				
77	5589	32.3				
78	7916	45.7	6150	35.525		
79	3516	20.3				
80	7579	43.8			7877.375	45.5
81	8622	49.8				
82	6144	35.5	7750	44.75		
83	8866	51.2				
84	7368	42.5				
85	8974	51.8				
86	6888	39.8	8043	46.45		
87	8910	51.5				
88	7400	42.7				
89	8789	50.8				
90	7473	43.2	8133	47		
91	8915	51.5				
92	7355	42.5				
93	8908	51.4				
94	6754	39.0	8269.75	47.75		
95	8989	51.9				
96	8428	48.7				

Table 6

Uniformity
Testing of Detector

Small With Large Source

15.5 cm X 21.5 cm (active area = 325 cm^2)

Readings in CPM with % of efficiency

Alpha	
Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm^2

1	2
3	4

Alpha

Table 6

Uniformity
Alpha Testing of Detector

Detector : 20

Small With Large Source

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm^2

Location	CPM	% Eff.
1	109	20.7
2	103	19.5
3	123	23.3
4	105	20.0

Zone Avg	CPM	% Eff.
Locations 1–2	106	20.1
Locations 3–4	114	21.65
Overall	110	20.875

Table 7

Uniformity
Testing of Detector

Medium With Large Source

15.5 cm X 49 cm (active area = 728 cm^2)

Readings in CPM with % of efficiency

Alpha	
Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm^2

1	2
3	4
5	6
7	8

Alpha

Average Reading

Table 7

Uniformity
Alpha Testing of Detector

Detector # 29

Medium With Large Source

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm²

Location	CPM	% Eff.
1	92.2	17.5
2	92.2	17.5
3	166	22.1
4	113	21.5
5	99.2	18.8
6	126	23.9
7	109	20.8
8	113	21.5

Zone Avg	CPM	% Eff.
Locations 1–2	92.2	17.5
Locations 3–4	139.5	21.8
Locations 5–6	112.6	21.35
Locations 7–8	111	21.15

	CPM	% Eff.
Detector Avg	113.825	20.45

Table 8

Uniformity
Testing of Detector

Large With Large Source
16 cm X 90 cm (active area = 1368 cm^2)

Alpha

Det.#12	1	2	
	3	4	
	5	6	
	7	8	
Det.#11	9	10	Average
	11	12	
	13	14	
	15	16	
Det.#10	17	18	Average
	19	20	
	21	22	
	23	24	

Average

Total
Average Reading

Table 8

Uniformity
Alpha Testing of Detector
Detector # 12
Large With Large Source

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm²

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg CPM	Detector Avg % Eff.
1	99.3	18.8	97.3	18.45	106.45	20.2125
2	95.3	18.1				
3	102	19.4	114.5	21.8		
4	127	24.2				
5	105	19.9	112	21.25		
6	119	22.6				
7	101	19.2	102	19.35		
8	103	19.5				

Table 8

Uniformity
Alpha Testing of Detector

Detector # 11

Large With Large Source

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm²

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg CPM	Detector Avg % Eff.
9	96.9	18.4	107.95	20.5	114.8625	21.8
10	119	22.6				
11	120	22.8	117	22.2		
12	114	21.6				
13	108	20.5	118.5	22.5		
14	129	24.5				
15	105	19.9	116	22		
16	127	24.1				

Table 8

Uniformity
Alpha Testing of Detector

Detector # 10

Large With Large Source

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm²

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.
17	118	22.4	118.5	22.5
18	119	22.6		
19	114	21.6	117.5	22.3
20	121	23.0		
21	102	19.4	101.5	19.3
22	101	19.2		
23	98	18.6	103	19.55
24	108	20.5		

Detector Avg CPM	Detector Avg % Eff.
110.125	20.9125

Table 9

Uniformity
Testing of Detector

Large With Large Source at 0.5 inches
16 cm X 90 cm (active area = 1368 cm²)

Alpha

Detector			
Det.#12	1	2	
	3	4	
	5	6	
	7	8	Average
Det.#11	9	10	
	11	12	
	13	14	
	15	16	Average
Det.#10	17	18	
	19	20	
	21	22	
	23	24	Average

Total
Average Reading

Table 9

Uniformity
Alpha Testing of Detector

Detector # 12

Large Detector With Large Source At .5 Inches

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm²

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg CPM	Detector Avg % Eff.
1	56.9	10.8	64.4	12.2	60.275	11.43375
2	71.9	13.6				
3	54.9	10.4	56.4	10.7		
4	57.9	11.0				
5	73.9	14.0	67.4	12.8		
6	60.9	11.6				
7	55.9	10.6	52.9	10.035		
8	49.9	9.5				

Table 9

Uniformity
Alpha Testing of Detector
Detector # 11
Large Detector With Large Source At .5 Inches

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm²

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.
9	56.3	10.7	66.8	12.7
10	77.3	14.7		
11	67.3	12.8	65.3	12.4
12	63.3	12.0		
13	60.3	11.5	53.3	10.145
14	46.3	8.8		
15	64.3	12.2	73.8	14
16	83.3	15.8		

Detector Avg	CPM	% Eff.
	64.8	12.31125

Table 9

Uniformity
Alpha Testing of Detector

Detector # 10

Large Detector With Large Source At .5 Inches

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm²

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg CPM	Detector Avg % Eff.
17	65.5	12.4	67.5	12.8	60.625	11.49875
18	69.5	13.2				
19	72.5	13.8	64	12.15		
20	55.5	10.5				
21	57.5	10.9	54	10.24		
22	50.5	9.6				
23	47.5	9.0	57	10.805		
24	66.5	12.6				

Table 10

Uniformity Testing of Detector

Large With Large Source at 1 inch

16 cm X 90 cm (active area = 1368 cm²)

Alpha

Det.#12	1	2	
	3	4	
	5	6	
	7	8	
			Average
Det.#11	9	10	
	11	12	
	13	14	
	15	16	
			Average
Det.#10	17	18	
	19	20	
	21	22	
	23	24	
			Average

Total
Average Reading

Table 10

Uniformity
Alpha Testing of Detector

Detector # 12

Large Detector With Large Source At 1 Inch

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm²

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.
1	36.8	7.0	38.3	7.255
2	39.8	7.5		
3	27.8	5.3	31.8	6.025
4	35.8	6.8		
5	39.6	7.5	35.1	6.66
6	30.6	5.8		
7	34.6	6.6	32.6	6.185
8	30.6	5.8		

	CPM	% Eff.
Detector Avg	34.45	6.53125

Table 10

Uniformity
Alpha Testing of Detector

Detector # 11

Large Detector With Large Source At 1 Inch

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm²

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg CPM	Detector Avg % Eff.
9	37.4	7.1	38.9	7.385	37.15	7.055
10	40.4	7.7				
11	35.4	6.7	39.4	7.48		
12	43.4	8.2				
13	30.4	5.8	37.9	7.2		
14	45.4	8.6				
15	38.4	7.3	32.4	6.155		
16	26.4	5.0				

Table 10

Uniformity
Alpha Testing of Detector

Detector # 10

Large Detector With Large Source At 1 Inch

Readings in CPM with % of efficiency

Srce S/N	DK792
DPM	527
CAL'D	04/16/93
SIZE	100 cm²

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg CPM	Detector Avg % Eff.
17	36.5	6.9	33.5	6.36	31.875	6.0525
18	30.5	5.8				
19	41.5	7.9	38	7.215		
20	34.5	6.6				
21	29.5	5.6	25.5	4.845		
22	21.5	4.1				
23	29.5	5.6	30.5	5.79		
24	31.5	6.0				

Table 11

Uniformity
Testing of Detector

Small Detector With Small Source At 0 And 1 Inch

15.5 cm X 21.5 cm (active area = 325 cm²)

Readings in CPM with % of efficiency

Alpha

CSL	603472
DPM	17337
DUE	10/94

1	2
3	4

Beta

Table 11

Uniformity
Beta Testing of Detector
Detector # 20

Small Detector With Small Source At 0 Inches

Readings in CPM with % of efficiency

CSL	603472
DPM	17337
DUE	10/94

Location	CPM	% Eff.
1	9016	52.1
2	8131	47.0
3	8793	50.8
4	8571	49.5

Zone Avg	CPM	% Eff
Locations 1–2	8573.5	49.55
Locations 3–4	8682	50.15
Overall	8627.75	49.85

Table 11

Uniformity
Beta Testing of Detector
Detector # 20
Small Detector With Small Source At 1 Inch

Readings in CPM with % of efficiency

CSL	603472
DPM	17337
DUE	10/94

Location	CPM	% Eff.
1	4503	26.0
2	4110	23.8
3	4829	27.9
4	4750	27.5

Zone	CPM	% Eff.
Zone Avg (1–2)	4306.5	24.9
Zone Avg (3–4)	4789.5	27.7

4548	26.3

Table 12

Uniformity
Testing of Detector

Medium Detector With Small Source At 0 And 1 Inches

15.5 cm X 49 cm (active area = 728 cm^2)

Readings in CPM with % of efficiency

	Beta
CSL	603472
DPM	17337
DUE	10/94

1	2
3	4
5	6
7	8

Beta

Average Reading

Table 12

Beta Testing of Detector

Detector # 29

Medium Detector With Small Source At 0 inches

Readings in CPM with % of efficiency

CSL	603472
DPM	17337
DUE	10/94

Location	CPM	% Eff.
1	8052	46.5
2	6974	40.3
3	8065	46.6
4	8441	48.8
5	7960	46.0
6	8327	48.1
7	7281	42.1
8	8418	48.6

Zone Avg	CPM	% Eff
Locations 1–2	7513	43.4
Locations 3–4	8253	47.7
Locations 5–6	8143.5	47.05
Locations 7–8	7849.5	45.35

	CPM	% Eff.
Detector Avg	7939.75	45.875

Table 12

Uniformity
Beta Testing of Detector

Detector # 29

Medium Detector With Small Source At 1 inches

Readings in CPM with % of efficiency

CSL	603472
DPM	17337
DUE	10/94

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg CPM	Detector Avg % Eff.
1	4260	24.6	3742.5	21.6	4188.375	24.2125
2	3225	18.6				
3	4426	25.6	4503.5	26.05		
4	4581	26.5				
5	4342	25.1	4524.5	26.15		
6	4707	27.2				
7	3817	22.1	3983	23.05		
8	4149	24.0				

Table 13

Uniformity
Testing of Detector

Large Detector With Small Source At 0 And 1 Inches
16 cm X 90 cm (active area = 1368 cm^2)

Beta

Det.#12	1	2	
	3	4	
	5	6	
	7	8	
Det.#11	9	10	Average
	11	12	
	13	14	
	15	16	
Det.#10	17	18	Average
	19	20	
	21	22	
	23	24	
			Average

Total
Average Reading

Table 13

Uniformity
Beta Testing of Detector

Detector # 12

Large Detector With Small Source At 0 Inches

Readings in CPM with % of efficiency

CSL	603472
DPM	17337
DUE	10/94

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg CPM	Detector Avg % Eff.
1	8627	49.9	8801.5	50.9	8356	48.3125
2	8976	51.9				
3	8923	51.6	8855	51.2		
4	8787	50.8				
5	8784	50.8	8820	51		
6	8856	51.2				
7	5303	30.6	6947.5	40.15		
8	8592	49.7				

Table 13

Uniformity
Alpha Testing of Detector

Detector # 11

Large Detector With Small Source At 0 Inches

Readings in CPM with % of efficiency

CSL	603472
DPM	17337
DUE	10/94

Location	CPM	% Eff.
9	8440	48.8
10	8744	50.5
11	8509	49.2
12	8810	50.9
13	8526	49.3
14	8676	50.1
15	5571	32.2
16	8768	50.6

Locations	CPM	% Eff.	
9–10	8592	49.65	Zone Avg
11–12	8659.5	50.05	Zone Avg
13–14	8601	49.7	Zone Avg
15–16	7169.5	41.4	Zone Avg

CPM	% Eff.
8255.5	47.7
Detector	Avg

Table 13

Uniformity
Alpha Testing of Detector

Detector # 10

Large Detector With Small Source At 0 Inches

Readings in CPM with % of efficiency

CSL	603472
DPM	17337
DUE	10/94

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg CPM	Detector Avg % Eff.
17	8712	50.4	8781.5	50.8	8550.5	49.4375
18	8851	51.2				
19	9148	52.9	9016.5	52.15		
20	8885	51.4				
21	8905	51.5	8879.5	51.35		
22	8854	51.2				
23	6184	35.7	7524.5	43.45		
24	8865	51.2				

Table 13

Uniformity
Beta Testing of Detector

Detector # 12

Large Detector With Small Source At 1 Inch

Readings in CPM with % of efficiency

CSL	603472
DPM	17337
DUE	10/94

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.	Detector Avg CPM	Detector Avg % Eff.
1	4518	26.1	4448.5	25.7	4290.25	24.7875
2	4379	25.3				
3	4499	26.0	4515	26.1		
4	4531	26.2				
5	4519	26.1	4508.5	26.05		
6	4498	26.0				
7	3359	19.4	3689	21.3		
8	4019	23.2				

Table 13

Uniformity
Alpha Testing of Detector

Detector # 11

Large Detector With Small Source At 1 Inch

Readings in CPM with % of efficiency

CSL	603472
DPM	17337
DUE	10/94

Location	CPM	% Eff.
9	4382	25.3
10	4432	25.6
11	4618	26.7
12	4608	26.6
13	4651	26.9
14	4348	25.1
15	3586	20.7
16	4126	23.8

Locations	CPM	% Eff.	
9–10	4407	25.45	Zone Avg
11–12	4613	26.65	Zone Avg
13–14	4499.5	26	Zone Avg
15–16	3856	22.25	Zone Avg

CPM	% Eff.
4343.875	25.0875
Detector	Avg

Table 13

Uniformity
Alpha Testing of Detector

Detector # 10

Large Detector With Small Source At 1 Inch

Readings in CPM with % of efficiency

CSL	603472
DPM	17337
DUE	10/94

Location	CPM	% Eff.	Zone Avg CPM	Zone Avg % Eff.
17	4497	26.0	4353.5	25.15
18	4210	24.3		
19	4676	27.0	4602.5	26.6
20	4529	26.2		
21	4515	26.1	4550.5	26.3
22	4586	26.5		
23	3648	21.1	3899.5	22.55
24	4151	24.0		

	CPM	% Eff.
Detector Avg	4351.5	25.15

CHAPTER V

Conclusions

It is concluded that a whole body monitor can check a person for contamination faster than frisking with a portable instrument. During the entire testing of the PCM-2 in both the uranium building and the plutonium building, the longest time for checking the person was one minute. The normal time for checking the person was approximately 40 seconds. Hand frisking takes a minimum of two minutes and is unable to check for contamination below approximately 800 DPM alpha.

It is concluded that the whole body monitor can locate lower levels of contamination than a person using a portable instrument in the same amount of time. The PCM-2 was set to check for contamination at 500 DPM alpha with a 95% confidence level. The time it required to check the person was normally about 40 seconds. Hand frisking using a portable instrument with a 100 cm^2 probe would require five to eight minutes to check the person with a 50% confidence level.

It is concluded that the whole body monitor can operate cheaper than using a person to check for contamination. Because the PCM-2 checks a person in less than one minute and hand frisking takes at least four minutes longer, the cost savings in checking for contamination will pay for the PCM-2 in less than one year.

It is concluded that the whole body monitor can check a person leaving a contaminated area more consistently than a person using a portable instrument. The PCM-2 checks between 80% and 90% of the body while a two minute frisk using a 50 cm^2 probe will check only 20% of the body.

Other Conclusions

Ease of Calibration

The PCM-2 uses an IBM 286 microprocessor to process information for calibration and user parameters. There are no manual potentiometers to adjust when a calibration is performed, because everything is done by computer. The computer performs detector plateaus and sets high voltages. The computer program also sets discriminators, confidence levels, count time, reliably detectable activity (RDA), etc. This allows a complex machine to be calibrated accurately without a complex procedure, although understanding the method which the computer uses statistics to select automatic settings is needed if one is to understand the program of the computer.

To begin the calibration, P-10 gas (90% Argon and 10% Methane) must be purged through the detectors. After a complete purging of three to four hours, the technician performs a background plateau. This plateau is plotted using just the background radiation. The computer will process this, once it has been set properly by a technician, without any intervention. Therefore, the background plateaus can be performed unattended overnight. The computer varies the high voltage to each detector as determined by the technician and plots high voltage versus counts per minute on a graph. All detector voltages are varied at the same time and all detector counts are retained by the computer, thereby allowing a long count time at each voltage for a more accurate count. After the background plateau is complete, it is used to help set the high voltage by determining the detector plateau voltage and/or if there is a noisy detector.

The next part of the calibration is to perform source plateaus on at least two detectors using both alpha and beta sources. This plateau is done similarly to the background plateau except the PCM-2 does only one detector at a time. This plateau will show more accurately than the background plateau where to set the high voltage. By doing both the alpha and beta sources, the system will show at what voltage beta particles are counted as alpha and at what voltage alpha particles are counted as beta. Both the background plateau and the source plateau are shown in graph form on the computer screen for each detector and can also be printed out for comparison and for a permanent record.

Once the optimum high voltage has been determined, it is set using the computer so that the technician does not have to go to every detector board and adjust the high voltage. Then efficiency for each detector is decided by logging into the computer the activity of the sources (beta and alpha). Sources are then placed on each detector and the computer calculates efficiency for both alpha and beta. These efficiencies are stored in the computer as directed by the technician. SrY-90 sources used for beta calibration have an efficiency that is approximately 5% higher than the beta from the U-238 decay chain. After the calibration this information is printed out in a calibration report.

Three more minor sections of the calibration are performed next. First, shield factors are decided by the computer with it counting background with no one in the PCM-2 and then with someone standing in the counting position. Second, a statistical variance test is run to check for a noisy channel. Third, a false alarm test is performed to determine how many times the PCM-2 will false alarm within a set number of counting intervals.

The PCM-2 prints out a calibration report for a permanent record. This printout contains the following information:

INSTRUMENT CONFIGURATION PARAMETERS

Count rate units, activity units, count mode, identification entry method, radiation work permit entry method, alarm hold time, system address, system baud rate, voice delay time, anti-coincidence enabled, radon compensation enabled, status logging enabled, printer initialization string, printer type, uses before background update, background update after alarm (Y or N), store transactions (Y or N), print transactions (Y or N), display midway results (Y or N), hand switch required (Y or N), hip switch required (Y or N), left foot switch required (Y or N), right foot switch required (Y or N), and access control option (Y or N).

SYSTEM PARAMETERS

Alpha RDA, beta RDA, alpha sensitivity, beta sensitivity, RDA confidence, count time, sigma factor, background sigma factor, alpha sum zone alarm, beta sum zone alarm, alpha sum channel alarm, and beta sum channel alarm.

OVERRIDE PARAMETERS

High voltage, alpha threshold, alpha efficiency, alpha RDA, alpha high fail counts, alpha low fail counts, alpha weight factor, beta threshold, beta efficiency, beta RDA, beta high fail counts, beta low fail counts, beta weight factor, and beta shield factor.

DETECTOR PARAMETERS - ALPHA CHANNELS

Detector number, high voltage, threshold, efficiency, RDA, high fail counts, low fail counts, and weight factor.

DETECTOR PARAMETERS - BETA CHANNELS

Detector number, high voltage, threshold, efficiency, RDA, high fail counts, low fail counts, weight factor, and shield factor.

Hard copies of source plateau graphs, background plateau graphs, and the statistical variance test can also be printed.

The menu driven program makes calibrating the PCM-2 easy to step through and the printed reports give the technician a hard copy of the entire calibration process. These features make the PCM-2 easier to calibrate than other much less sophisticated instruments. The computer allows the technician to perform other duties while the PCM-2 is running parts of the calibration, such as the background plateaus. The calibration sources for the PCM-2 are 100 cm^2 with a handle on the back and an inset on the front to protect the sources. No other test equipment is required to calibrate the PCM-2 since it is self contained and the computer can store all data.

Flexibility

The computer system in the PCM-2 allows for flexibility in setting up the machine. Two of the areas of flexibility are the three operating modes and the summing channels.

In the **Preset All** mode, the alpha and beta RDA's, confidence factor, sigma factors and count time are set by the technician. In the **Fixed Count Time** mode, the confidence factor, sigma factors and count time are set by the technician. In the **Minimum Count Time** mode, the alpha and beta RDA's, confidence factor and sigma factors are set by the technician. In each of these modes, if background becomes too high, the PCM-2 will shut down and display a high background message.

The PCM-2 also allows for summing of individual detectors together to electronically form a theoretical integrated detector. The computer can handle up to 75 sum zones made up of two or more adjacent detectors. This allows for detecting low level contamination spread over a wide area which is difficult to find with present instrumentation at Rocky Flats.

Undetected Areas

The PCM-2 monitors approximately 90% of the body within one inch, but does miss some areas of importance depending on how the individual being monitored stands in the machine. One area where the PCM-2 does not monitor adequately is on top of the shoe in the shoe lace area. The PCM-2 checks the top of the shoe but not back as far as the top of the shoe lace area. If the beta count is large enough it would be possible for the PCM-2 to find the contamination. Another area that has no detectors is at the cuff area just above the shoe. The PCM-2 has a three-inch gap between the detector for the side of the shoe and the detector for the leg because of a leg positioning switch located between them. The face area detection depends on the individual using the machine. If the individual puts his/her face up close to the detector then it will detect the contamination, but the machine will allow the individual to hold his face away from the detector. All three of these areas have been discussed with Eberline and they are considering changes. These areas could be monitored by the RCT with a minimum of time.

RDA and Confidence Level

The following is a brief overview of Reliably Detectable Activity (RDA) and Confidence Level. RDA is an Eberline term for the level of activity of interest. Confidence level is the probability of alarming on the stated activity. If a PCM-2 is set up to alarm on a net count rate of 500 DPM, then, by random fluctuation of source and background count rates an alarm will occur approximately half the time. In a single interval there is a 50% probability that the composite count rate observed will exceed the average and a like probability that it will be less. In this case, there exists a 50% confidence level. A higher confidence level is created by setting the alarm set point at some count rate lower than 500 DPM. If the instrument's RDA is set at 500 DPM and the confidence level is set to 95%, then the PCM-2 calculates that the alarm should be approximately 380 DPM to give you a 95% confidence that an activity of 500 DPM will cause an alarm. Therefore, an activity of 380 DPM has a probability of causing an alarm 50% of the time.

On March 10, 1993 at 10:54 a.m., the PCM-2 alarmed on an individual's right hand with a count of 604 DPM alpha and 3456 DPM beta. The RDA set points of the PCM-2 at that time were 700 DPM alpha and 5000 DPM beta. The confidence level was 95%. The minimum alarm points calculated by the computer were 598 DPM alpha and 4202 DPM beta. The individual was questioned and said he was sure it was contamination. The employee had come in contact with some machining coolant on his hand. Neither the Ludlum 31 nor the Bicron B-50 could detect the beta count. There was no alpha survey instrument at the step-off pad to check the individual's hand. The hand was decontaminated and then checked in the PCM-2 and it passed.

Because of the statistics involved in such a low level of activity, it is difficult to say whether this alarm was above release limits using the PCM-2. A RCT with calibrated portable instrumentation will be needed to check whether an alarm on the PCM-2 is above or below release limits. The PCM-2 can provide a good level of confidence on whether contamination is present above release limits, but it will also alarm sometimes on contamination that is below release limits. (The PCM-2 establishes a level of confidence that an area is free of contamination and identifies areas which it cannot establish with a prescribed level of confidence. The "alarm" areas are in need of further evaluation not specifically that contamination exists.)

Recommendations

The PCM-2 should be used as a final check of personnel leaving a contaminated area or building. It is able to locate contamination on a more consistent basis and at lower levels than someone using a portable instrument.

However, a person with a portable instrument should still be used for checking a person for gross contamination as the PCM-2 would require a lot of work to decontaminate versus a portable instrument probe. Also, even though the PCM-2 checks a much larger portion of the body on a more consistent basis, an individual with a portable instrument usually knows where contamination will be located on the body (hands, knees, elbows, etc.). The individual with a portable instrument will not normally check 80% to 90% of the body, but he will check those areas of the body that normally have contamination.

Further studies need to be done using the PCM-2 in other situations to determine how well the machine will work in different environments and with different isotopes. This study done at Rocky Flats should only be the beginning.

Summary

The PCM-2 would make an ideal instrument for Rocky Flats because of its alpha detecting capabilities. Any alpha with an energy level greater than 3.0 MeV that enters the detector will be counted. Since the alphas for ^{238}U have an energy greater than 4.0 MeV and the alphas for ^{239}Pu have an energy greater than 5.0 MeV, both of these radionuclides should be counted by the PCM-2. The testing performed at Rocky Flats in the Uranium area and in the Plutonium area verifies this. Low levels of Plutonium and Uranium were detected on a consistent basis with the PCM-2.

The PCM-2 has been widely accepted in other DOE sites and commercial nuclear power plants as a beta detecting unit. Even though the PCM-2 has excellent beta detecting capabilities, there have been few beta alarms during the testing at Rocky Flats, except for sources and watches. The reason for the low number of alarms is that the beta to alpha ratio for ^{238}U is about two to one. Therefore, the alarm for alpha at 500 DPM occurs most of the time instead of the alarm for beta which is set at 5000 DPM.

The PCM-2 also provides a consistent check of 80-90% of the body. Each person is checked in the same consistent manner. The PCM-2 will check for a level of 500 DPM alpha and 5000 DPM beta in approximately 20 seconds per side with a 95% confidence level. This provides for a much faster check for contamination than can be done using portable instruments which would require a 5-8 minute check with a 50% confidence level for alpha contamination only.

The PCM-2 while in the plutonium building demonstrated its ability to find low level alpha contamination spread over a portion of the body. The RCT's using the Ludlum 12-1A are not able to locate 500 DPM/100 cm^2 very easily if at all. The RCT's using the Bicron Frisk Tech had a difficult time locating these low levels also, but with patience could find the contamination the PCM-2 was alarming on.

When either the 15 second or 30 second count time per side is compared to the two minutes required by the RCT's to accomplish their frisking, there is the possibility of saving a large amount of personnel time and removing a mundane task from the RCT and allowing him to do other tasks.

The PCM-2 is not able to check the top of the head and between the legs or arms of the person it is checking. These areas need to be considered before placing the PCM-2 at the step-off pad. However, the PCM-2 does check a much larger portion of the body in one minute than the RCT can within two minutes using a 50 cm^2 probe on the Ludlum 12-1A.

The PCM-2 adds an additional safety factor into preventing any contamination from leaving the RCA. This machine checks approximately 80% of the body for alpha contamination in less than one minute to a level of 500 DPM with a 95% confidence level. Using a Bicron Frisk Tech with a 100 cm^2 probe would require 5-8 minutes to check for 500 DPM at a 50% confidence level. Each person is checked in the same consistent manner while using the PCM-2.

REFERENCE

Blanton, J. D. (1988, November/December). Gamma sensitivity of the Eberline PCM-1. Radiation Protection Management, pp. 43-46.

Bunker, A. S. (1985, July). The death of frisking. Radiation Protection Management, pp. 21-26.

Chiaro, P. J. (1994, May). Trust versus confidence: Microprocessors and personnel monitoring. Paper presented at the PCM User's Meeting, Santa Fe, NM. p. 2.

Desrosiers, A. E. & Zavadoski, R. W. (1985, January). Operational experience with the Eberline PCM-1 frisking booth. Radiation Protection Management, pp. 33-45.

Dray, C. H., (1987, December). Monitoring of personnel for external contamination: An advanced approach. Paper presented at the Health Physics Society Mid-Year Meeting, San Antonio, TX. p. 1.

Eberline (1992). Personnel contamination monitor technical manual. Santa Fe, NM: Eberline.

Georgeson, M. A. , & Nichols, C. E. (1981). A new ICPP portal monitor. (Contract No. DE-AC07-791DO1675). Idaho Falls, ID: Department of Energy. p. 1. (NTIS No. ENICO-1083/HDM)

International Commission on Radiological Protection. (1968). General principles of monitoring for radiation protection of workers. Oxford, England: Pergamon Press. p. 18.

Knoll, G. F. (1979). Radiation detection and measurement. New York: John Wiley & Sons. p. 65.

Morris, W. (1969). The American heritage dictionary of the English language. New York: American Heritage Publishing Co., Inc.

Neuschaefer, E. K., (1989). Evaluation of the nuclear enterprises IPM-7 and the Helgeson HECM-2A whole body friskers in use at the shearon harris nuclear project. Unpublished manuscript.

Shaccio, F. P. (1989). IPM-7 alarms due to radon daughter contamination. Unpublished manuscript.

Sterling, S. G., (1981). An automated Personnel Radiation Monitor. (Contract No. EY-76-C-06-1857). Richland, WA: Department of Energy. p. 1. (NTIS No. UNI-SA-82)

Wade, J. E. & Cunningham, G. E. (1967). Radiation monitoring: A programmed instruction book. Oak Ridge, TN: USAEC Division of Technical Information Extension. pp. 243-244.

APPENDIX A

Concrete Experiences

My involvement in testing of the Eberline PCM-2 has taken place over the last two years. This test has been most of my working schedule at Rocky Flats during that time. There was times when I was ready to give up because of difficulty in getting things done. There were delays due to the manufacturer's problems with some of the detectors having too high of a background count. There were delays because of difficulty in moving the PCM-2 from building to building. Each time it was moved, there was damage to the machine, which had to be fixed. There were delays because of myself and the technicians not understanding how to solve problems or mistakes made by us because we did not know how to do something.

Generalizations

When we were told that we would have to do a research project of this magnitude, I had no idea what I was going to write on. Bob Kennard, my manager, suggested I write on the PCM-2. At first, I hesitated, but then it did seem like a good idea. One difficulty that I knew I would have is getting this paper cleared for release from Rocky Flats. On the other hand, I had practically lived with the PCM-2 for the year before embarking on this research paper. The final testing of the PCM-2 would fit into the time frame for completing this paper and so I decided to do it.

Skills Acquired

I spent many hours in the Colorado University library in Boulder doing research on this paper. During those hours I learned a lot about the resources available to each of us in that library. I have also learned during the last year how to write technical papers. My skills at technical writing have improved greatly because of the number of pages I have written not only for this paper, but also, for all the papers I wrote for Rocky Flats dealing with the PCM-2.

Personal Reflections

I am deeply indebted to a number of people who have been involved in the research that has gone into this project. I want to thank Bob Kennard for his inspiration in having me write on the PCM-2 for this project and for his encouragement and assistance throughout. I want to thank Mike Dighero and Elton Cannon for their help in maintaining and testing of the PCM-2. This project of testing the PCM-2 has been a long one, but now that the testing is over the work of installing and maintaining a large number of PCM-2's is beginning.

Writing a thesis was not one of those items on my priority list. Now that it is completed, I see the benefit to a large number of people who want to know all they can about the machine. My hope is that the information presented here will be of value to those reading it.