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Technical Manual, Redesigned ARC-2A Automatic Radon Counter

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ADMINISTRATIVE INFORMATION

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Released by
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EXECUTIVE SUMMARY

OBJECTIVE

Repair and redesign the ARC-2A Automatic Radon Counter, and interface the system to a computer. The ARC-2A is necessary to ongoing electro-optic propagation studies and is no longer available from the manufacturer.

RESULTS

The ARC-2A Automatic Radon Counter was redesigned and thoroughly tested. It performed successfully in two field experiments. This manual provides updated information and instructions for the redesigned system.

RECOMMENDATIONS

Data from the ARC-2A Automatic Radon Counter should continue to be collected and compared with meteorological data and condensation nuclei data to determine whether any correlations exist.

CONTENTS

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

The ARC-2A Automated Radon Gas Monitoring System is used to measure extremely low levels of airborne radon gas (as low as 1 picoCurie per cubic meter). The original ARC-2A system consisted of a blower to intake an air sample, a motor mechanism to move the sample, a 12-stage photomultiplier tube (PMT) fitted with a conversion scintillometer to sense the beta particles emitted from the sample, a hand-held terminal to program sample times, and a small printer to record data.

The ARC-2A (Serial No. 87003) was manufactured in 1987 by Ocean Communication Systems, Inc. (OCSI), 2430 Industrial Drive, Panama City, FL. 32405. The original OCSI manual states that the system was based on a design by co-inventors Reginald E. Larson and David J. Bressan of the Naval Research Laboratory. OCSI built the ARC-2A to be self-contained; it was microprocessor-based with a resident EPROM program that the operator could run, but not change.

The ARC-2A was plagued with problems and a lack of documentation. Appendix A lists a repair history of the machine. In May, 1992, it was concluded that OCSI would not be able to repair the ARC-2A, and that NCCOSC RDT&E Division (NRaD) would need to redesign the entire system.

The machine need not be entirely self-contained, and should be externally computer-driven for ease of programming control. A Metrabyte CTM-05 Multi-Function Counter-Timer Digital Expansion Board was used to count pulses from the photomultiplier tube. The CTM-05 input/output ports relay voltages necessary for system control. A listing of the program RADON.BAS that now controls the ARC-2A is found in Appendix B.

2.0 SYSTEM DESCRIPTION

2.1 DESCRIPTION

The ARC-2A measures the beta-producing radon decay products which are attached to aerosols. A photomultiplier-based scintillometer detects the beta particles which have been deposited on a 2-inch diameter spot of filter paper from the passage of 15.1 cubic meters of ambient air through it.

2.2 DETECTION SENSITIVITY

The system measures levels of radon gas as low as 1 picoCurie per cubic meter. It is unaffected by the presence of other gases or smoke which do not produce beta particles.

2.3 SAMPLING/MEASURING TIME

An air sample of approximately 15 cubic meters is drawn through a 2-inch diameter spot of filter paper for 20 minutes. Simultaneously, a background count is performed on a clean filter-paper spot which determines a baseline noise level for the PMT. The background count will vary for different tubes, but remains generally constant for a particular tube.

After the 20-minute collection time, the sample spot is moved under the PMT and a collection count is done for another 20 minutes. The collection count is broken down into three 6.67-minute counting segments. This allows an additional check on the proper decay times of the beta particles.

One complete cycle takes 40 minutes. The program begins a new cycle every 45 minutes. This allows time for paper transport and winding down of the blower motor. The program could be changed to eliminate the background count for a collection count every 20 minutes. However, the consistent background count is another good accuracy check.

2.4 FILTER PAPER

OCSI recommends using Borosilicate fiber filter paper produced by Hollingsworth and Vose Corp., East Walpole, MA, 02032 (Type 1120, Model #HE-1022, 1-1/2 inch inside core size, 3-inches wide, 150-foot lengths). The proper porosity of filter paper is important because it directly affects the pressure drop and volume of air passing through it, which in turn affects the calculated density of radon gas in the air sample.

NRaD's experience shows a roll of filter paper to last approximately 7 days of continuous sampling when using both background and collection counts at 45-minute intervals. If the background counts were not taken, only half as much paper would be used, and a roll could last twice as long.

2.5 THEORY

An explanation of the instrument concept and radon decay theory is contained in Appendix C. The information is copied directly from the original OCSI ARC-2A manual.

3.0 REDESIGN OF THE SYSTEM

The majority of the problems encountered with the ARC-2A Radon Counter were the direct result of the pre-programmed ROM chip. The firmaware program, permanently burned into the chip, had a series of checks and overrides that were designed to protect the device in the absence of an operator. The overrides have never worked properly and repeatedly shut down the system.

A secondary source of problems was the array of wiring. Handling of wiring during maintenance and troubleshooting often lead to shorts and breaks.

The entire microprocessor card was removed, (including the EPROM), as well as the counter card, the interface card, the hand-held terminal, and the printer. This redesign eliminated over half of the wiring in the system.

The functions of the microprocessor board and the counter board were replaced by a computer with a Metrabyte CTM-05 interface card. The motor control board, which receives and conditions the signals from the PMT, was retained from the original design. Also retained were the paper transport mechanism, the wiring to the blower motor, the OCSI-built high voltage supply for the PMT, and the 12V power supply. The board and wiring used for sensing the presence of filter paper was left intact, although it is not currently connected.

The schematics and sketches of the redesigned system are shown in Figures 1 through 5.

Two changes were made to the motor control board (Figure 5). The +5V DC supply for the relays was changed from the ARC-2A's power supply to the CTM-05 interface card's output voltage. The second change was in the resistor ladder used to set the gain for the PMT signal. The 1 MΩ resistor at switch 8 was removed and replaced with a 15 KΩ resistor. This allowed more combinations of resistance in the range close to that needed for the proper gain. Table 1 lists several switch combinations to produce gains necessary for proper calibration.

The complete program RADON.BAS is listed in Appendix B. (The program is written in an older version of BASIC, GW BASIC 3.2. This is necessary per instructions with the CTM-05 counter card.) The program operates in the following sequence:

a) Upon initiation, the paper transport motor moves the paper in place.

b) The program turns on the blower for the sample collection and at the same time a background count is performed. Results are shown on the screen and sent to a file.

c) After 20 minutes, the blower turns off and the sample is moved directly under the PMT.

d) Pulses from the PMT are counted for 20 minutes, during which the results are sent to the screen and to a file in three 6.67-minute intervals.

e) Raw count is converted to picoCuries per cubic meter and air mass factor.

f) This cycle is repeated every 45 minutes until the user interrupts.

TABLE 1

Equivalent Resistances for Various Switch Combinations

Switches On	Resistors (KΩ)	Equivalent Resistance (KΩ)
1, 2	2.2 // 5.6	1.58
1, 3, 4	2.2 // 12 // 33	1.76
1, 3, 5	2.2 // 12 // 75	1.81
1, 3, 6	2.2 // 12 // 250	1.85
1, 3	2.2 // 12	1.86
1, 5, 8	2.2 // 75 // 15	1.87
1, 6, 8	2.2 // 250 // 15	1.90
1, 8	2.2 // 15	1.92
1, 4, 5, 6	2.2 //33 //75 //250	1.99
1, 4, 5	2.2 // 33 // 75	2.00
1, 4	2.2 // 33	2.06
1, 5	2.2 // 75	2.13
1, 7	2.2 // 750	2.19
2, 3, 4, 8	5.6 //12 // 33 //15	2.79
2, 3, 5, 8	5.6 //12 // 75 //15	2.92
2, 3, 8	5.6 // 12 // 15	3.04

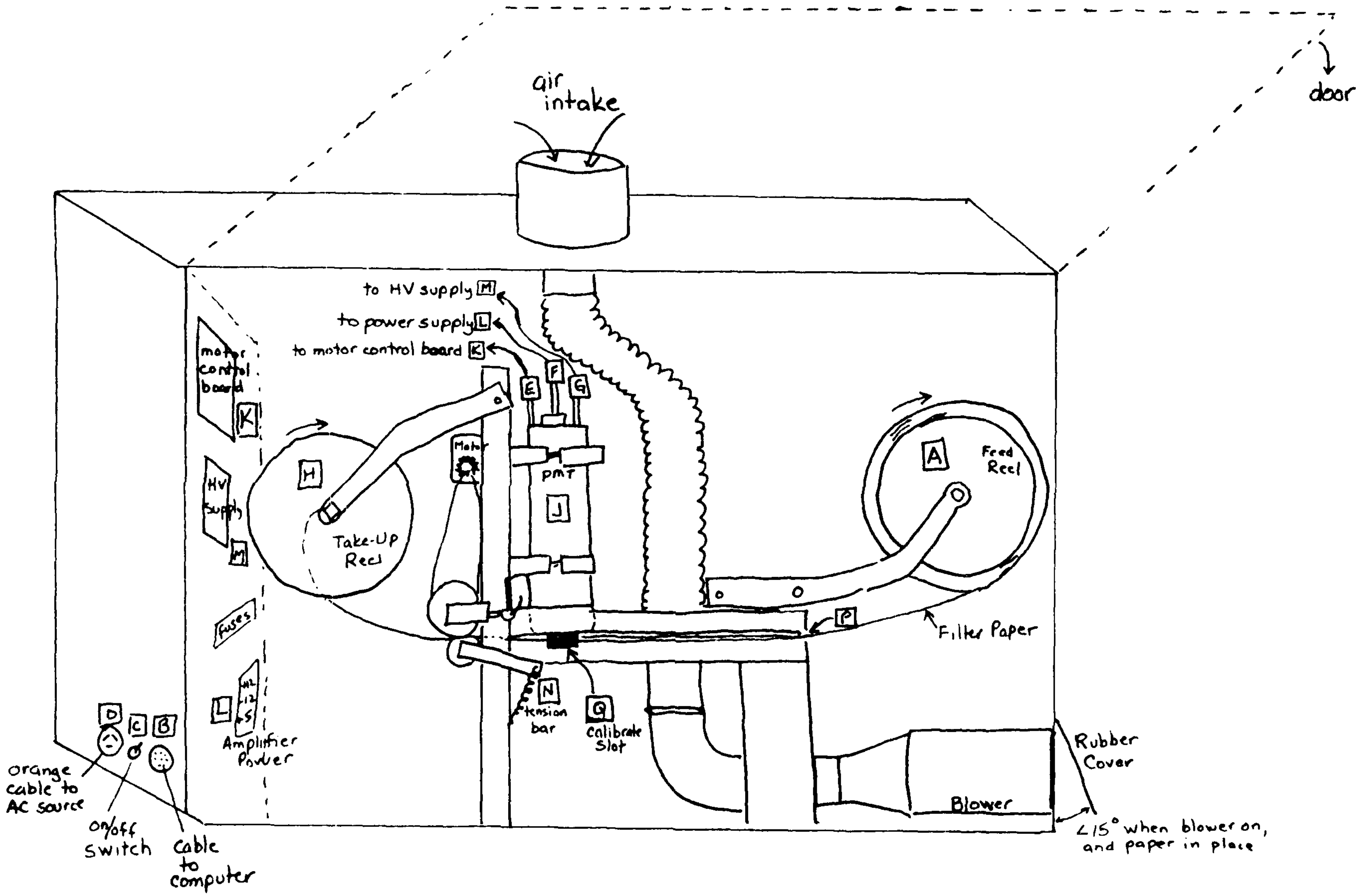


Figure 1. Sketch of the ARC-2A Radon Counter

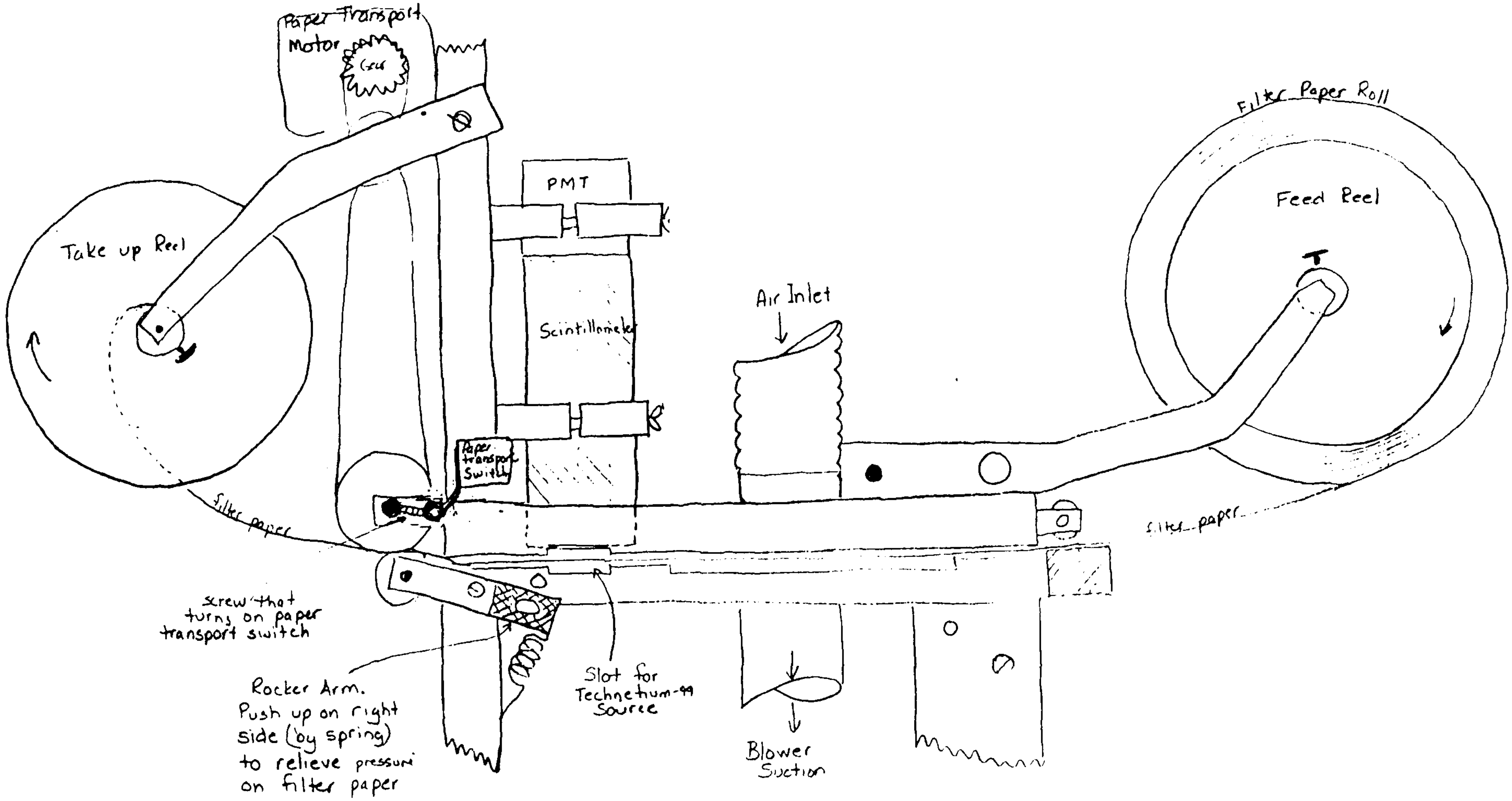
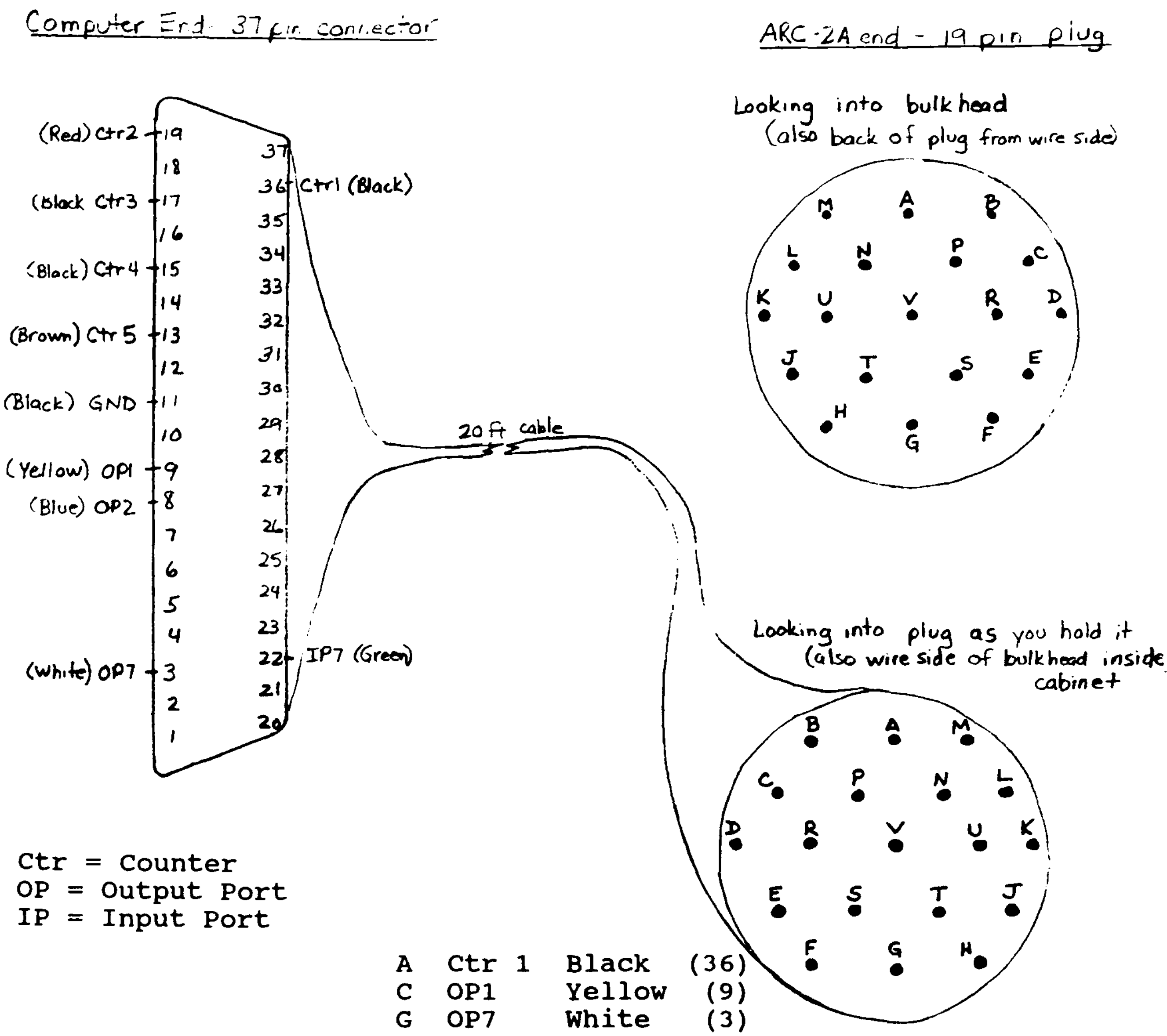


Figure 2. ARC-2A Paper Transport System



Ctr = Counter
OP = Output Port
IP = Input Port

A	Ctr 1	Black	(36)
C	OP1	Yellow	(9)
G	OP7	White	(3)
H	IP7	Green	(22)
J	Ctr 5	Brown	(13)
K	Ctr 2	Red	(19)
L	Ctr 3	Black	(17)
M	GND	Black	(11)
R	OP2	Blue	(8)
U	Ctr 4	Black	(15)

Figure 3. Cable from computer to ARC-2A

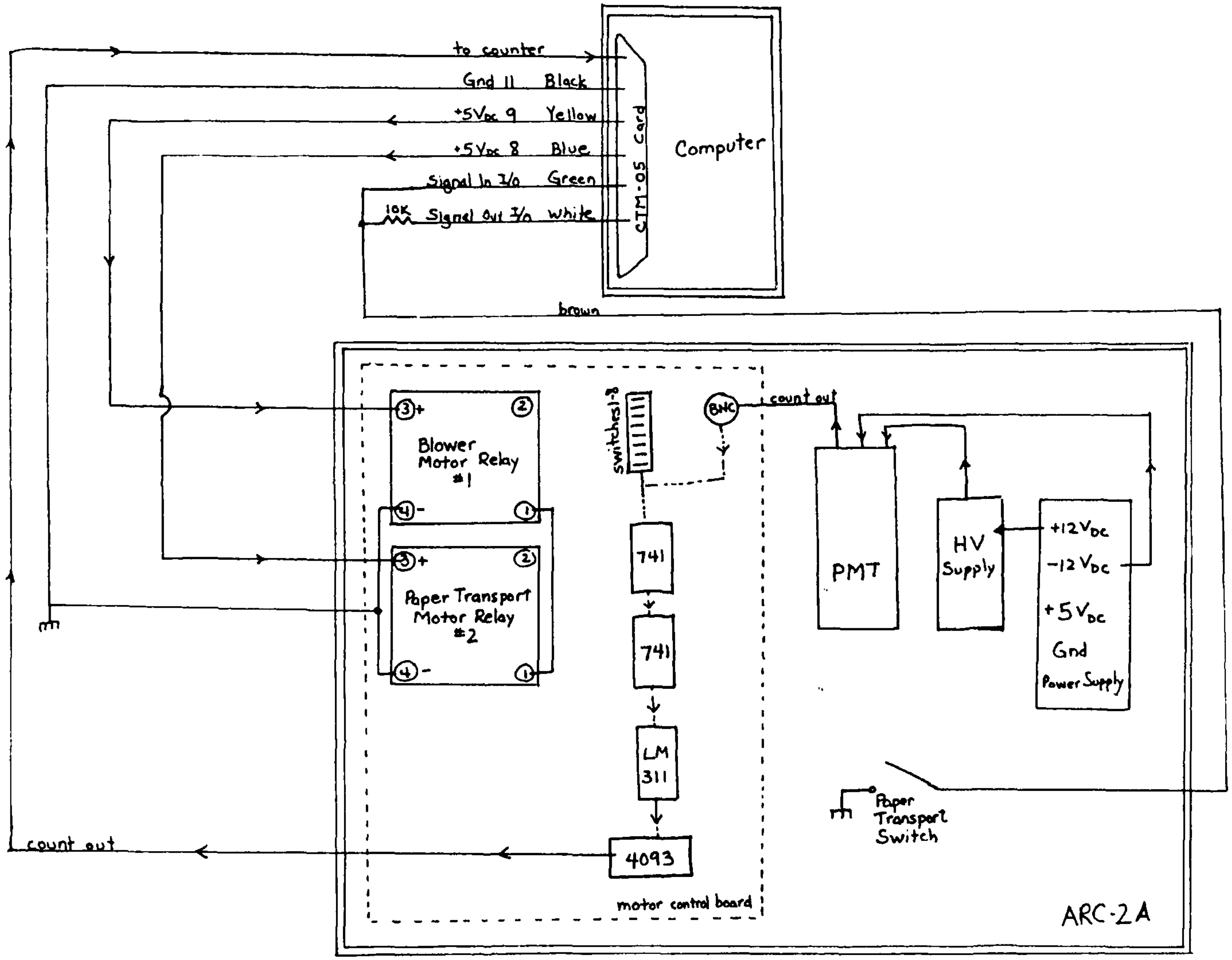


Figure 4. ARC-2A System Block Diagram

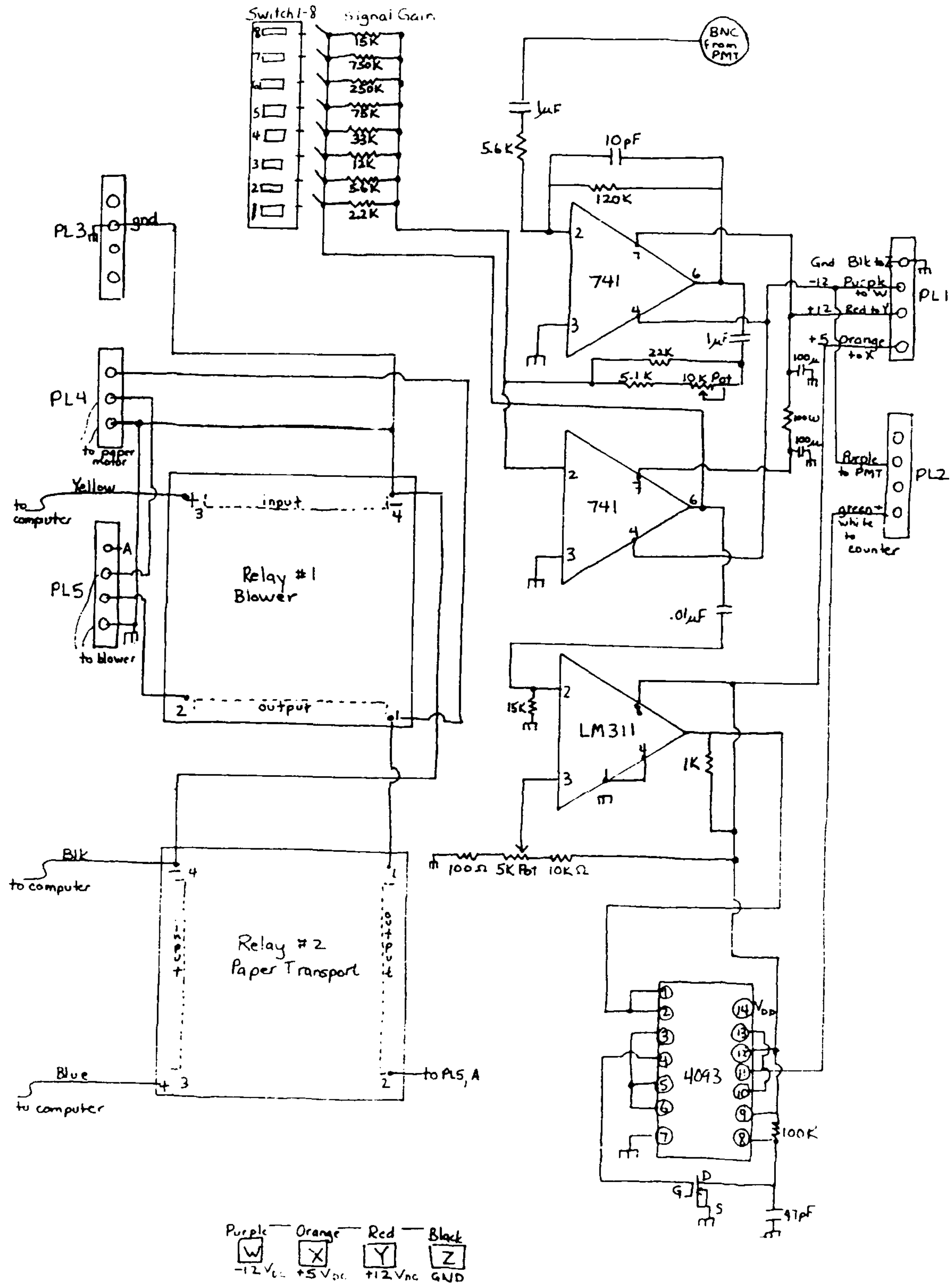


Figure 5. Motor Control Board Schematic

4.0 USER INSTRUCTIONS

4.1 SETUP OF SYSTEM

WARNING

Ensure power is off and machine is unplugged before touching anything inside cabinet!

Note: All letters in parentheses refer to Figure 1.

1. Check that the photomultiplier tube is in place (J). If not, insert PMT carefully, following OCSI instructions in Appendix C.
2. Ensure the three leads on the top of the PMT are properly attached: cable (E) to signal output BNC on motor control board (K); cable (F) to amplifier power (L); and cable (G) to high voltage source (M).
3. Ensure there is an adequate filter paper supply on the feed reel (A). If not, see "Changing Filter Paper" in Section 4.5.
4. Ensure paper is attached to take-up reel (H).
5. The 10-ft. computer cable, figure 3, has a rectangular 37-pin connector at one end and a circular 19-pin connector at the other. Attach the 37-pin connector to the computer at the slot closest to the edge on back. Plug the circular end of the cable into (B) at the outer left edge of the ARC-2A.
6. Attach the orange cable to (D) on the outer left side of the ARC-2A, and plug other end into AC source.

4.2 POWER ON

1. Turn toggle switch (C) on. You should hear a hissing sound which indicates the high voltage supply is on.
2. Turn on computer and monitor.
3. Type BASICA at C-prompt.
4. Type F3 RADON.BAS <-' F2 <-'.

4.3 ACCURACY CHECKS

There are a few checks that can be conducted to determine if the system is working properly. It is a good idea to monitor these often.

1. Program CALIBRAT.BAS
   a. Use this program to get a calibration count as described in Section 6.2. For the current PMT, the count should be approximately 5800 for a 20-minute period.

   b. Use this same program to get a background count as described in Section 6.3. For the current PMT, the count should be approximately 207 for a 20-minute period.

2. Background Count
   The background count will be given each cycle while the program RADON.BAS is running. Monitor it to make sure it stays around 207 (plus or minus 15%) for the current PMT.

3. Collection Count
   The collection count is divided into three 6.67-minute intervals. For a properly calibrated system, the count should be decreasing slightly in each of the three intervals. This is due to the decay of the daughter products.

4. Program LARSON.BAS
   The daughter products of radon have a 45-minute half life. To monitor this decay, run the program LARSON.BAS as described in section 6.4. The original count should be reduced by half somewhere between the 40 and 50-minute point.

5. Blower Exhaust Cover
   On the exterior right side of the cabinet, there is a rubber cover over the blower exhaust hole. For a properly running system, the angle between the cover and the cabinet should be approximately 15 degrees when the blower is on and the paper is in place. If there is no paper in place and the blower is on, the correct angle is approximately 40 degrees.

4.4 TURNING OFF SYSTEM

1. Hit F10 to terminate program.

NOTE: Data will be stored in a file Rxxxxxxx.DAT based on the time and date the program started. First position will always be an "R" for Radon. Second position is the last digit of the year, 3rd and 4th are the month, 5th and 6th are the day, and 7th and 8th are the hour begun. Summarizing:

```
R  x  x  x  x  x  x  x  . D A T
   Yr Mo Mo Da Da Hr Hr
```

2. Turn off toggle switch (C) on ARC-2A.

3. Turn off computer and monitor.

4. Before any maintenance, disconnect both ARC-2A and computer from AC power.

4.5 CHANGING FILTER PAPER

NOTE: All letters in parentheses refer to Figure 1.

1. Ensure that both ARC-2A and computer are unplugged.

2. To remove old paper from take-up reel (H), unscrew the front plate and pull it off the roll. Pull the paper roll off of the wooden roller. If the paper was taped directly to the wooden roller, it will be a little harder to remove.

3. Unscrew feed reel (A) and remove front plate. If the cardboard spool is empty, remove it. If there is still paper on the feeder roll, you will need to remove the paper beneath the PMT.

4. To remove paper beneath the PMT, push up on tension bar (N) with the left hand to release tension on the paper. With the right hand, gently pull the paper through.

5. Put new paper roll on feed reel (A) with paper leaving under the roll in a clockwise direction, as shown in Figure 1. Use the filter paper described in Section 2.4.

6. Taper the end of the paper slightly with scissors to ease feeding paper through slot.

7. Align the paper roll on the roller so that paper feeds exactly through the guides. Feed the tapered end through the slit (P) and push it in a few inches to the left.

8. With left hand, raise tension bar (N) while continuing to feed paper through with right hand. The paper should come out on the left side just above the tension bar.

9. Tape the paper's tapered end to the take-up roller.

10. Raise tension bar (N) again, this time with the right hand, and wind the take-up roller clockwise with the left hand to ensure the paper is aligned and feeding properly. Release the tension bar when paper is perfectly aligned.

11. Replace front plate on both the take-up reel and feed reel, then replace screws in each reel.

5.0 TROUBLESHOOTING

Table 2 describes some problems that may occur, and their possible causes and solutions.

TABLE 2 Troubleshooting		
Problem	**Possible Cause**	**Solution**
Background count too high or too low	Change in AC source at different location.	Need to adjust gain by using switches 1-8 on the Motor Control Board (K in figure 1). See Table 1 for resistance values. If count is too high, use lower resistance value; if too low, use higher value.
	High voltage source is low. **WARNING** High voltage. Use extreme caution when measuring.	Measure the H.V. source. It should be approximately 1300 Vdc. If not substantially lower, adjusting the gain is a viable solution. If the voltage is too low, the high voltage source should be replaced.
	PMT is bad.	If count is way off and H.V. source is good, the PMT may be bad. Best check is to run program LARSON.BAS as described in section 6.4.
Calibration Count with Technetium-99 source is too high or too low.	Possible causes and solutions are the same as in above section on Background count.	

TABLE 2 (continued) Troubleshooting		
Problem	**Possible Cause**	**Solution**
Count always shows zero.	Toggle switch (D in figure 1) is off.	Turn switch on and start over.
	Counter on CTM-05 card is blown.	Attach input to another of the 5 counters on the CTM-05 card. (See wiring diagram in figure 3.) If that doesn't work, the CTM-05 counter board may need to be replaced.
	Cable between computer and ARC-2A not connected.	Connect cable.
ARC-2A won't power up when toggle switch turned on.	Not plugged into AC source.	Plug into AC source.
	Fuse blown.	Check fuses on inner left side of ARC-2A cabinet. Replace if needed.
Blower sounds different or louder than usual	Out of filter paper or failed to re-thread filter paper after calibration check.	Replace filter paper.
	Motor brushes worn down.	Replace motor brushes.
Paper won't move and blower won't come on.	Cable between computer and ARC-2A not connected.	Connect cable.
	ARC-2A not plugged into AC source.	Plug into AC source.
	Toggle switch (D in figure 1) not on.	Turn toggle switch on.

6.0 CALIBRATION

6.1 Technetium-99 Calibration Source

To properly calibrate the system, both the background count and the collection count must be monitored. A calibration source of known radioactive strength, Technetium-99, is used. NRaD's Technetium-99 source measures 13 picoCuries.

The program CALIBRAT.BAS, listed in Appendix B, produces a calibration count using the Technetium-99 source, or can alternately give a background count. It is sometimes necessary to adjust the signal gain to maintain the proper calibration. Switches 1-8 on the motor control board determine the gain, which is highly sensitive to slight variations in AC sources. Table 1 lists equivalent resistances for various switch combinations.

6.2 Calibration Count

To use the program CALIBRAT.BAS to get a calibration count, do the following:

1. Remove the filter paper from beneath the PMT.
2. Insert the Technetium-99 source into calibration slot (Q) in Figure 1.
3. Ensure that PMT leads, computer cable, and AC power cable are properly attached as described in Section 4.1.
4. Turn on toggle switch (D, Figure 1) on the ARC-2A. Also turn on computer and monitor.
5. Type BASICA at the C-prompt.
6. Type F3 CALIBRAT.BAS <-' F2 <-'

6.3 Background Count

To use CALIBRAT.BAS to get a background count, do the following:

1. Ensure filter paper is in place beneath the PMT.
2. Properly attach PMT leads, computer cable, and AC power cable as described in Section 4.1.

3. Turn on toggle switch (D, Figure 1) on the ARC-2A. Also turn on computer and monitor.

4. Type BASICA at the C-prompt.

5. Type F3 CALIBRAT.BAS <-' F2 <-'

The Hamamatsu tube presently in our system produces an average calibration count of 5800 for a 20-minute period (1934 counts per 6.67-minute interval). We had an average background count of 207 (69 counts per 6.67-minute interval). These averages should remain fairly constant for this particular tube, although any given individual count can vary by as much as 15%.

6.4 Monitoring 45-Minute Half-Life

A further check on the calibration can be made using the program LARSON.BAS, also listed in Appendix B. This program checks for the proper 45-minute half-life for the daughter products. It counts in 10-minute intervals for one hour. For a properly calibrated system, the original count will decrease by half between 40 and 50 minutes. Figure 6 shows a graph of two such runs. The program is run as follows:

1. Ensure PMT and filter paper are in place.

2. Properly attach PMT leads, computer cable, and AC power cable as described in Section 4.1.

3. Turn on toggle switch (D, Figure 1) on the ARC-2A. Also turn on computer and monitor.

4. Type BASICA at C-prompt.

5. Type F3 LARSON.BAS F2

The equation used to convert the raw count into picoCuries per cubic meter is:

$$pCi = .00746\ (C - B)$$

where **pCi** is the measurement in picoCuries, **C** is the collection count, and **B** is the background count. A number known as the air mass factor (amf) is a function of pCi as follows:

$$amf = (pCi\ /\ 4) + 1$$

RUN #	TIME	INTERIM COUNT
1	08:08:09	502
	08:18:09	417
	08:28:09	397
	08:38:09	316
	08:48:09	280
	08:58:09	209
2	09:30:10	613
	09:40:10	503
	09:50:10	423
	10:00:10	356
	10:10:10	317
	10:20:10	266

NOTE: Count shown has been adjusted. Background count has already been subtracted out.

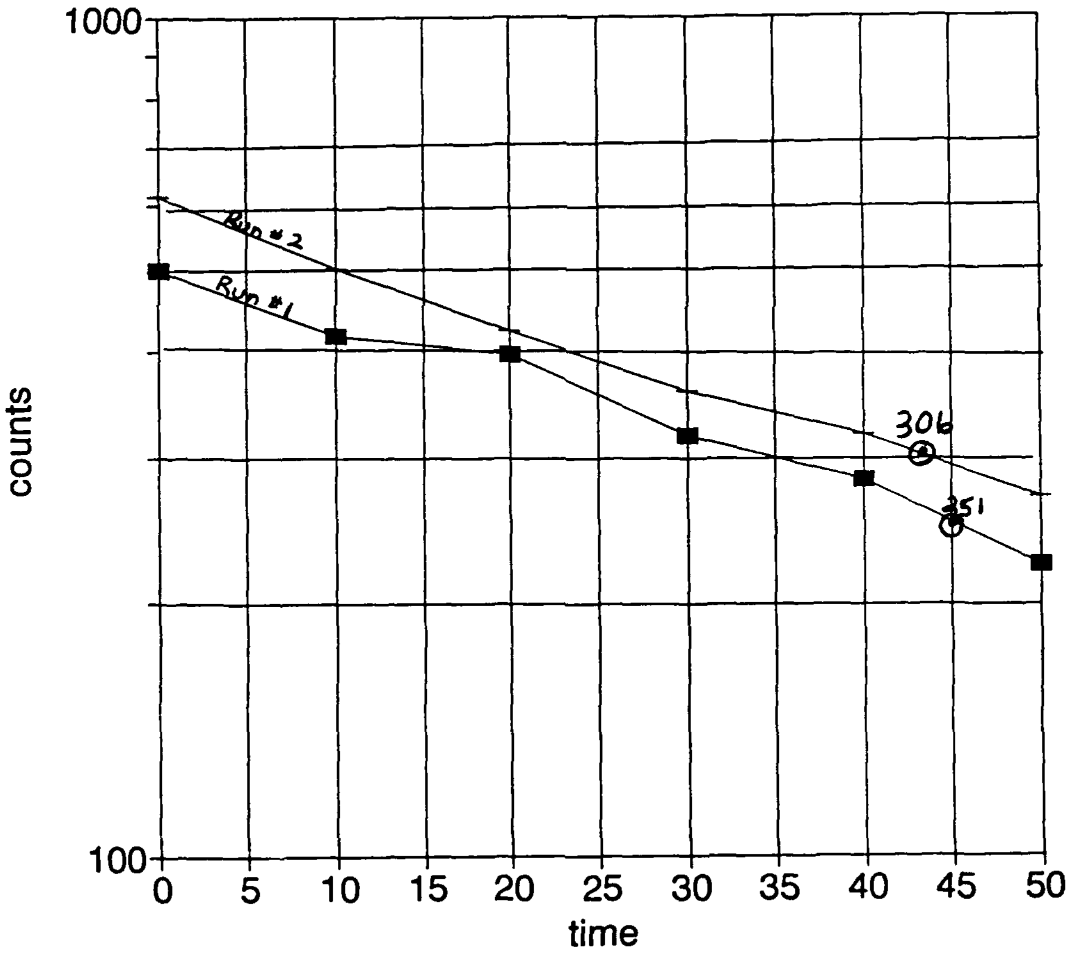


FIGURE 6. Calibration graph using LARSON.BAS, showing 45-minute half-life for two separate runs on 21 July 1992

7.0 REFERENCES

1987. User's Interim Manual for the Model ARC-2A Automated Radon Gas Monitoring System, Version 1.1. Ocean Communication Systems, Inc., Panama City, Florida.

APPENDIX A

Repair History of the ARC-2A Radon Counter

June, 1987	Arc-2A delivered to NRaD.
19 October 1987	ARC-2A returned to OCSI to repair parts broken during shipment.
7 January 1988	Parts fixed and ARC-2A returned to NRaD.
17 January 1989	Logic/HV Circuit Board returned to OCSI for repairs.
9 February 1989	3 logic CPU boards returned to OCSI for repairs.
6 November 1989	Entire unit sent to OCSI for repair and calibration problems.
17 January 1990	Control keyboard and display sent to OCSI to aid in repair of unit.
June 1991	ARC-2A sent to OCSI for repair after being struck by lightning during IRAMMP-91.
January 1992	Unit returned to NRaD; OCSI still has possession of the control boards.
7 February 1992	3 control boards returned to NRaD.
27 April 1992	NRaD engineer accompanies the ARC-2A to OCSI. System inoperable.
10 June 1992	Unit returned to NRaD. Still inoperable with program looping error that cannot be bypassed.
July 1992	System redesigned at NRaD.

APPENDIX B

Listings of Programs RADON.BAS, CALIBRAT.BAS, and LARSON.BAS

Listing of RADON.BAS

```
100 'Program RADON.BAS                          K. Littfin  6-30-92
102 'This program uses the Metrabyte CTM-05 card.
104 PRINT : PRINT "This program runs the ARC-2A Radon Counter.  "
105 PRINT "There will be a 20 minute background count and a 20 minute collection
 "
106 PRINT "count, each with 3 interim counts.  Cycle repeats every 45 minutes."
:PRINT
107 PRINT "Data is stored in a filename based on the date and time started."
109 '
110 '------Initialize CTM5 ------
120 NAME1$ = DATE$
130 NAME2$ = TIME$
140 FILENAME$ = "R" + MID$(NAME1$, 10,1) + MID$(NAME1$,1,2) + MID$(NAME1$,4,2) +
 MID$(NAME2$,1,2) + ".DAT"
202 OPEN FILENAME$ FOR OUTPUT AS #1
203 ON KEY(10) GOSUB 10000
204 PRINT "The filename for this run will be "; FILENAME$
205 PRINT: PRINT "To quit the program at any time, hit F10 key." :PRINT:PRINT
206 KEY(10) ON
207 PRINT #1, USING "ARC-2A RADON COUNT                                 &";DATE$ : PRIN
T #1, ""
208 PRINT #1, "CYCLE    DATE       GMT     TOTAL BKGD  INTERIM   TOTAL COLL  PCI
 per     AMF"
209 PRINT #1, "                            COUNT      COUNT      COUNT      cu.
 meter "
210 PRINT #1, "----- ---------- -------- ---------- -------  ---------- ---
------   ---"
211 PRINT #1, ""
220 DEF SEG = &H4000
260 BLOAD "CTM5.BIN", 0
270 DIM DIO%(9)
280 'Initialize using mode 0, also sets master mode register
290 DIO%(0) = &H300      'I/O address
300 DIO%(1) = 10         'Fout ratio of 10
310 DIO%(2) = 15         'Fout source = F5(100Hz) for Fout = 10 Hz
320 DIO%(3) = 0
330 DIO%(4) = 0
340 DIO%(5) = 0
350 CTM5 = 0
360 FLAG% = 0
361 COUNTER = 1
370 MD% = 0
380 CALL CTM5(MD%, DIO%(0), FLAG%)
390 IF FLAG% <> 0 THEN PRINT "Error in installing CTM5.BIN": STOP
400 '
410 '------Setting up system to have 5V supply and all other channels zero---
420 DIO%(0) = &H80          '1000 0000 sets 5V supply
430 MD% = 6
440 CALL CTM5(MD%, DIO%(0), FLAG%)
450 IF FLAG% <> 0 THEN PRINT "Error in output data, see p.31": STOP
460   '
470 '------User starts program ------
480 INPUT "Type 1 to start program, F10 to quit. "; GO$
490 IF GO$ = "1" THEN GOTO 560
510 IF GO$ <> "1" THEN
520    PRINT "Wrong entry, try again."
530    GOTO 480
540 END IF
550 '
```

```
560 '------Turning on paper transport motor------
561 THOUR! = TIMER
564 FLAG = 0
565 BKGD = 0
566 COLL = 0
570 PRINT
590 DIO%(0) = &H84      '1000 0100
600 MD% = 6
610 CALL CTM5(MD%, DIO%(0), FLAG%)
620 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg 31.": STOP
630 '------doing a 10 second wait to complete voltage change------
640 T1! = TIMER
650 T2! = 0
660 WHILE T2! < 10
670   T3! = TIMER
680   T2! = T3! - T1!
682   IF T2! < 0 THEN T3! = T3! + 86400!
684   IF T2! < 0 THEN GOTO 680
690 WEND
700 '------check for input voltage change------
710 MD% = 5
720 CALL CTM5(MD%, DIO%(0), FLAG%)
730 IF FLAG% <> 0 THEN PRINT "Error in input data, see pg. 31.": STOP
740 IF DIO%(0) <> &H7F THEN GOTO 710
750 'pass through 1st time around, allowing 10 seconds for voltage change
760 T1! = TIMER
770 T2! = 0
780 WHILE T2! < 10
790   T3! = TIMER
800   T2! = T3! - T1!
802 IF T2! < 0 THEN T3! = T3! + 86400!
804   IF T2! < 0 THEN GOTO 800
810 WEND
820 ' check for second voltage change
830 MD% = 5
840 CALL CTM5(MD%, DIO%(0), FLAG%)
850 IF FLAG% <> 0 THEN PRINT "Error in input data, see pg 31": STOP
860 IF DIO%(0) <> &H7F THEN GOTO 830
870 '------Stop paper transport at second low------
890 DIO%(0) = &H80
900 MD% = 6
910 CALL CTM5(MD%, DIO%(0), FLAG%)
920 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg. 31": STOP
921 PRINT : PRINT : PRINT USING "CYCLE NO. ###            &      &"; COUNTER; DA
TE$; TIME$
930 '-----Turning on blower and starting background count
950 DIO%(0) = &H82     '1000 0010
960 MD% = 6
970 CALL CTM5(MD%, DIO%(0), FLAG%)
980 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg. 31": STOP
990 '------initialize counter mode register for counter using mode 1
1010   DIO%(0) = 5       'counter number
1020   DIO%(1) = 0
1030   DIO%(2) = 0
1040   DIO%(3) = 5       ' input from SCR
1050   DIO%(4) = 0
1060   DIO%(5) = 0
1070   DIO%(6) = 1             'count repetitively
1080   DIO%(7) = 0
1090   DIO%(8) = 1             'count up
```

```
1100   DIO%(9) = 0
1110   MD% = 1
1120   CALL CTM5(MD%, DIO%(0), FLAG%)
1130   IF FLAG% <> 0 THEN PRINT "Error in setting counter 1 mode": STOP
1150 '
1160 ' ------Zero all counters -----
1170 GOSUB 55000
1230 '
1240 ' ------Timing blower ------
1241 PRINT: PRINT "  GMT        Interim Background Count     Total Thus Far"
1242 PRINT "--------     ------------------------     --------------"
1250 T1! = TIMER
1260 T2! = 0
1261 T4! = 0
1270 WHILE T2! < 1200
1280   T3! = TIMER
1290   T2! = T3! - T1!
1291   IF T2! < 0 THEN T3! = T3! + 86400!
1292   IF T2! < 0 THEN GOTO 1290
1295   T4! = T2!
1296   IF T4! > 399.96 AND T4! < 400.04 THEN FLAG = 1
1297   IF T4! > 799.96 AND T4! < 800.04 THEN FLAG = 1
1298   IF T4! > 1198.96 AND T4! < 1199.04 THEN FLAG = 1
1299   IF FLAG = 1 THEN GOSUB 60000
1301   BKGD = COUNT - HOLD
1303   HOLD = COUNT
1305   IF FLAG = 1 THEN PRINT USING "&            ######                 ######
"; TIME$, BKGD; COUNT
1307   FLAG= 0
1308 WEND
1309 'Read and display contents of counter which will be background count
1310 '------Turning off blower and reading counters
1321 PRINT
1322   PRINT USING "                                         ######   TOTAL B
ACKGROUND COUNT"; COUNT
1323 PRINT #1, USING "###   &  &  ######"; COUNTER; DATE$;TIME$; COUNT
1330 DIO%(0) = &H80
1340 MD% = 6
1350 CALL CTM5(MD%, DIO%(0), FLAG%)
1360 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg. 31": STOP
1370 T1! = TIMER
1380 T2! = 0
1390 WHILE T2! < 15
1400   T3! = TIMER
1410   T2! = T3! - T1!
1412   IF T2! < 0 THEN T3! = T3! + 86400!
1414   IF T2! < 0 THEN GOTO 1410
1420 WEND
1421 BPCI = COUNT
1430 'Read and display contents of counter which will be background count
1462 BKGD = 0
1463 HOLD = 0
1464 COUNT = 0
1480 '------Move paper in place for collection count ----
1500 DIO%(0) = &H84
1510 MD% = 6
1520 CALL CTM5(MD%, DIO%(0), FLAG%)
1525 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg 31.": STOP
1530 '10 second wait for voltage change to settle
1531 T1! = TIMER
```

```
1532 T2! = 0
1533 WHILE T2! < 10
1534   T3! = TIMER
1535   T2! = T3! - T1!
1536   IF T2! < 0 THEN T3! = T3! + 86400!
1537   IF T2! < 0 THEN GOTO 1535
1538 WEND
1540 MD% = 5
1550 CALL CTM5(MD%, DIO%(0), FLAG%)
1560 IF FLAG% <> 0 THEN PRINT "Error in input data, see pg 31.": STOP
1570 IF DIO%(0) <> &H7F THEN GOTO 1540
1580 'stopping motor
1590 DIO%(0) = &H80
1600 MD% = 6
1610 CALL CTM5(MD%, DIO%(0), FLAG%)
1620 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg 31.": STOP
1630 '------ collection count ------
1641 PRINT: PRINT "  GMT        Interim Collection Count     Total Thus Far"
1642 PRINT "--------     ------------------------       --------------"
1650 GOSUB 55000     'zero counter out to start collection count
1660 T1! = TIMER
1670 T2! = 0
1671 T4! = 0
1680 WHILE T2! < 1200
1690   T3! = TIMER
1700   T2! = T3! - T1!
1701   IF T2! < 0 THEN T3! = T3! + 86400!
1702   IF T2! < 0 THEN GOTO 1700
1709   T4! = T2!
1710   IF T4! > 399.96 AND T4! < 400.04 THEN FLAG = 1
1711   IF T4! > 799.96 AND T4! < 800.04 THEN FLAG = 1
1712   IF T4! > 1198.96 AND T4! < 1199.04 THEN FLAG = 1
1713   IF FLAG = 1 THEN GOSUB 60000
1714   COLL = COUNT - HOLD
1715   HOLD = COUNT
1716   IF FLAG = 1 THEN PRINT USING "&              ######                  ######
"; TIME$; COLL; COUNT
1717   IF FLAG = 1 THEN PRINT #1, USING "                  &              ######"
; TIME$; COLL
1718   FLAG = 0
1719 WEND
1720 CPCI = COUNT
1721 'read and display contents of counter which will be collection count
1749 PRINT
1750 PRINT USING "                                          ###### * TOTAL COL
LECTION COUNT *"; COUNT
1751 PCI! = .00746 * (CPCI - BPCI)       'per Bud Larson 7-20-92
1752 AMF! = (PCI! / 4) + 1
1753 PRINT #1, USING "                 &                    ######      ###
.#     ###.#"; TIME$; COUNT; PCI!; AMF!
1754 PRINT : PRINT USING "                                           ###.#    P
CI/cu. meter"; PCI!
1755 PRINT USING "                                          ###.#    AMF"; AMF
!
1756 BPCI = 0
1757 CPCI = 0
1758 COLL = 0
1759 HOLD = 0
1760 COUNTER = COUNTER + 1
1761 COUNT = 0
```

```
1762 PRINT : PRINT : PRINT
1763 PRINT #1, ""
1764 PRINT: PRINT "NOTE: To quit program at any time, hit the F10 key."
1770 '
1780 ' Put this whole program in bigger loop that repeats every 45 min
1790 '
7000 TEND! = 0
7001 WHILE TEND! < 2700
7002   TWATCH! = TIMER
7003   TEND! = TWATCH! - THOUR!
7004   IF TEND! < 0 THEN TWATCH! = TWATCH! + 86400!
7005   IF TEND! < 0 THEN GOTO 7003
7008 WEND
7009 GOTO 560
10000 CLOSE #1
10001 PRINT: PRINT: PRINT "NOTE: Data is stored in a file called "; FILENAME$
10010 PRINT :PRINT :PRINT "END OF PROGRAM"
10020 END
55000 '--- Subroutine to reset (zero ) counter  --------
55010 'Disarm the counter (stop counting) using mode 2
55020 DIO%(0) = 6   ' disarm counter
55021 DIO%(1) = 0
55022 DIO%(2) = 0
55023 DIO%(3) = 0
55024 DIO%(4) = 0
55030 DIO%(5) = 1
55040 MD% = 2
55050 CALL CTM5(MD%, DIO%(0), FLAG%)
55060 IF FLAG% <> 0 THEN PRINT USING "Error in disarming counter #"; COUNTER: ST
OP
55070 '
55080 'Load zero into load register using mode 3
55100   DIO%(0) = 5
55110   DIO%(1) = 0
55120   MD% = 3
55130   CALL CTM5(MD%, DIO%(0), FLAG%)
55140   IF FLAG% <> 0 THEN PRINT USING "Error in loading load register #"; COUNT
ER: STOP
55160 '
55170 'Arm (enable) counter using mode 2
55180 DIO%(0) = 3
55190 DIO%(5) = 1
55200 MD% = 2
55210 CALL CTM5(MD%, DIO%(0), FLAG%)
55220 IF FLAG% <> 0 THEN PRINT "Error in enabling counters": STOP
55230 RETURN
55240 '
60000 '---- Subroutine to latch and read counter ----
60010 'This does not interfere with counting or change data
60020 'Latch counter to hold register using mode 2
60030 DIO%(0) = 5    'latch to hold
60031 DIO%(1) = 0
60032 DIO%(2) = 0
60033 DIO%(3) = 0
60040 DIO%(4) = 0
60041 DIO%(5) = 1
60050 MD% = 2
60060 CALL CTM5(MD%, DIO%(0), FLAG%)
60070 IF FLAG% <> 0 THEN PRINT "Error in latching counters": STOP
60080 '
```

```
60090 'Read hold register and return count in COUNT using mode 4
60110 DIO%(0) = 5
60120 MD% = 4
60130 CALL CTM5(MD%, DIO%(0), FLAG%)
60140 IF FLAG% <> 0 THEN PRINT USING "Error in reading counter #"; COUNTER: STOP
60150 COUNT = DIO%(1)  'return data range -32768 to +32768
60160 'correct for 2's compliment (negative integers)
60170 IF COUNT < 0 THEN COUNT = 66536! + COUNT
60190 RETURN
```

Listing of CALIBRAT.BAS

```
100 'Program CALIBRAT.bas
200 'This program calibrates the Arc2A using the Technitium-99 source.
280 ' Initialize using mode 0, also sets master mode register
300 'There is a 20 minute count in three even intervals.
310 PRINT "ARC-2A Calibration Program.
350 PRINT: PRINT "If calibrating with the Technetium-99 source, then be sure tha
t"
351 PRINT "the paper is removed from beneath PMT. "
352 PRINT: PRINT "If doing a background count, keep the paper beneath the PMT.
353 PRINT
400 '
500 DEF SEG = &H4000
600 BLOAD "ctm5.bin", 0
700 DIM DIO%(9)
800 ' Initialize using mode 0, also sets master mode register
900 DIO%(0) = &H300
1000 DIO%(1) = 10
1100 DIO%(2) = 15
1200 DIO%(3) = 0
1300 DIO%(4) = 0
1400 DIO%(5) = 0
1500 CTM5 = 0
1600 FLAG% = 0
1700 MD% = 0
1800 CALL CTM5(MD%, DIO%(0), FLAG%)
1900 IF FLAG% <> 0 THEN PRINT "Error in installing ctm5.bin":STOP
2000 '
2100 'Setting up system to have 5V supply and all other channels zero ---
2200 DIO%(0) = &H80          '1000 0000 sets 5V supply
2300 MD% = 6
2400 CALL CTM5(MD%, DIO%(0), FLAG%)
2500 IF FLAG <> 0 THEN PRINT "Error in output data, see pg 31": STOP
2600 '
2700 'User starts program
2800 INPUT "Type 1 to start calibration count, 2 to quit. "; GO$
2900 IF GO$ = "1" THEN GOTO 4000
3000 IF GO$ = "2" THEN GOTO 10000
3100 IF GO$ <> "1" AND GO$ <> "2" THEN
3200    PRINT "Wrong entry, try again."
3300    GOTO 2800
3400 END IF
3500 '
4000 'Initialize counter mode register for counter using mode 1
4100 DIO%(0) = 5           'counter number
4200 DIO%(1) = 0
4300 DIO%(2) = 0
4400 DIO%(3) = 5           'input from scr
4500 DIO%(4) = 0
4600 DIO%(5) = 0
4700 DIO%(6) = 1           'count repetitively
4800 DIO%(7) = 0
4900 DIO%(8) = 1           'count up
5000 DIO%(9) = 0
5100 MD% = 1
5200 CALL CTM5(MD%, DIO%(0), FLAG%)
5300 IF FLAG% <> 0 THEN PRINT "Error in setting counter mode":STOP
5400 '
5500 'Zero out the counter
5600 GOSUB 55000
5650 PRINT: PRINT: PRINT USING "Starting calibration count at & "; TIME$
```

```
5651 PRINT
5700 'Timing count for 20 minutes in three 6.67min intervals
5800 T1! = TIMER
5900 T2! = 0
6000 T4! = 0
6100 WHILE T2! < 1200
6200   T3! = TIMER
6300   T2! = T3! - T1!
6310 IF T2! < 0 THEN T3! = T3! + 86400!
6320 IF T2! < 0 THEN GOTO 6300
6400   IF T2! < 0 THEN T3! = T3! + 86400!
6500   IF T2! < 0 THEN GOTO 6300
6600   T4! = T2!
6700   IF T4! > 399.968 AND T4! < 400.032 THEN FLAG = 1
6800   IF T4! > 799.9675 AND T4! < 800.0325 THEN FLAG = 1
6900   IF T4! > 1198.9675# AND T4! < 1199.0325# THEN FLAG = 1
7000   IF FLAG = 1 THEN GOSUB 60000
7100   BKG' = COUNT - HOLD
7200   HOLD = COUNT
7300   IF FLAG = 1 THEN PRINT USING "&          ######"; TIME$; BKGD
7400   FLAG = 0
7500 WEND
7600 PRINT: PRINT USING "TOTAL CALIBRATION COUNT:  ######" ; COUNT
7700 BKGD = 0
7800 COUNT = 0
7900 HOLD = 0
8000 PRINT: PRINT: PRINT "Calibration count complete.  Remove source."
8100 PRINT:PRINT "End of Program."
8200 '
10000 END
55000 '---Subroutine to reset (zero) counter ---
55010 ' Disarm the counter (stop counting) using mode 2
55020 DIO%(0) = 6
55021 DIO%(1) = 0
55022 DIO%(2) = 0
55023 DIO%(3) = 0
55024 DIO%(4) = 0
55030 DIO%(5) = 1
55040 MD% = 2
55050 CALL CTM5(MD%, DIO%(0), FLAG%)
55060 IF FLAG <> 0 THEN PRINT "Error in disarming counter" : STOP
55070 '
55080 'Load zero into load register using mode 3
55100 DIO%(0) = 5
55110 DIO%(1) = 0
55120 MD% = 3
55130 CALL CTM5(MD%, DIO%(0), FLAG%)
55140 IF FLAG <> 0 THEN PRINT "Error in loading load register." : STOP
55150 '
55170 'Arm (enable) counter using mode 2
55180 DIO%(0) = 3
55190 DIO%(5) = 1
55200 MD% = 2
55210 CALL CTM5(MD%, DIO%(0), FLAG%)
55220 IF FLAG% <> 0 THEN PRINT "Error in enabling counter." :STOP
55230 RETURN
55240 '
60000 '--- Subroutine to latch and read counter ---
60010 ' This does not interfere with counting or change data.
60020 ' Latch counter to hold register using mode 2
```

```
60030 DIO%(0) = 5       'latch to hold
60031 DIO%(1) = 0
60032 DIO%(2) = 0
60033 DIO%(3) = 0
60034 DIO%(4) = 0
60040 DIO%(4) = 0
60041 DIO%(5) = 1
60050 MD% = 2
60060 CALL CTM5(MD%, DIO%(0), FLAG%)
60070 IF FLAG% <> 0 THEN PRINT "Error in latching counter." : STOP
60080 '
60090 'Read hold register and return count in COUNT using mode 4
60110 DIO%(0) = 5
60120 MD% = 4
60130 CALL CTM5(MD%, DIO%(0), FLAG%)
60140 IF FLAG% <> 0 THEN PRINT "Error in reading counter." :STOP
60150 COUNT = DIO%(1)  'return data range -32768 to +32768
60160 ' correct for 2's compliment (negative integers)
60170 IF COUNT < 0 THEN COUNT = COUNT + 66536!
60190 RETURN
```

Listing of LARSON.BAS

```
100 'Program LARSON.BAS                              K. Littfin  7-15-92
102 'This program uses the Metrabyte CTM-05 card.
104 PRINT : PRINT "This program runs the ARC-2A Radon Counter.  "
105 PRINT "To monitor half-life, program counts for 1 hour in 10-minute interval
s.
106 PRINT "Cycle repeats every hour." : PRINT
107 PRINT "Data is stored in a file called LARSON.TXT." : PRINT
108 PRINT "To quit the program at any time, hit F10 key." :PRINT:PRINT
109 '
200 '------Initialize CTM5 ------
202 OPEN "LARSON.TXT" FOR OUTPUT AS #1
203 ON KEY(10) GOSUB 10000
206 KEY(10) ON
207 PRINT #1, USING "ARC-2A RADON COUNT                                  &";DATE$ : PRIN
T #1, ""
208 PRINT #1, "CYCLE    DATE        TIME    TOTAL BKGD  INTERIM   TOTAL COLL  PCI
 per     AMF"
209 PRINT #1, "                                  COUNT       COUNT       COUNT      cu.
 meter "
210 PRINT #1, "----- ----------  --------  ----------  -------   ----------  ---
------   ---"
211 PRINT #1, ""
220 DEF SEG = &H4000
260 BLOAD "CTM5.BIN", 0
270 DIM DIO%(9)
280 'Initialize using mode 0, also sets master mode register
290 DIO%(0) = &H300       'I/O address
300 DIO%(1) = 10          'Fout ratio of 10
310 DIO%(2) = 15          'Fout source = F5(100Hz) for Fout = 10 Hz
320 DIO%(3) = 0
330 DIO%(4) = 0
340 DIO%(5) = 0
350 CTM5 = 0
360 FLAG% = 0
361 COUNTER = 1
370 MD% = 0
380 CALL CTM5(MD%, DIO%(0), FLAG%)
390 IF FLAG% <> 0 THEN PRINT "Error in installing CTM5.BIN": STOP
400 '
410 '------Setting up system to have 5V supply and all other channels zero---
420 DIO%(0) = &H80          '1000 0000 sets 5V supply
430 MD% = 6
440 CALL CTM5(MD%, DIO%(0), FLAG%)
450 IF FLAG% <> 0 THEN PRINT "Error in output data, see p.31": STOP
460   '
470 '------User starts program ------
480 INPUT "Type 1 to start program, F10 to quit. "; GO$
490 IF GO$ = "1" THEN GOTO 560
510 IF GO$ <> "1" THEN
520    PRINT "Wrong entry, try again."
530    GOTO 480
540 END IF
550 '
560 '------Turning on paper transport motor------
561 THOUR! = TIMER
564 FLAG = 0
565 BKGD = 0
566 COLL = 0
570 PRINT
590 DIO%(0) = &H84     '1000 0100
```

```
600 MD% = 6
610 CALL CTM5(MD%, DIO%(0), FLAG%)
620 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg 31.": STOP
630 '------doing a 10 second wait to complete voltage change------
640 T1! = TIMER
650 T2! = 0
660 WHILE T2! < 10
670   T3! = TIMER
680   T2! = T3! - T1!
682   IF T2! < 0 THEN T3! = T3! + 86400!
684   IF T2! < 0 THEN GOTO 680
690 WEND
700 '------check for input voltage change------
710 MD% = 5
720 CALL CTM5(MD%, DIO%(0), FLAG%)
730 IF FLAG% <> 0 THEN PRINT "Error in input data, see pg. 31.": STOP
740 IF DIO%(0) <> &H7F THEN GOTO 710
750 'pass through 1st time around, allowing 10 seconds for voltage change
760 T1! = TIMER
770 T2! = 0
780 WHILE T2! < 10
790   T3! = TIMER
800   T2! = T3! - T1!
802 IF T2! < 0 THEN T3! = T3! + 86400!
804   IF T2! < 0 THEN GOTO 800
810 WEND
820 ' check for second voltage change
830 MD% = 5
840 CALL CTM5(MD%, DIO%(0), FLAG%)
850 IF FLAG% <> 0 THEN PRINT "Error in input data, see pg 31": STOP
860 IF DIO%(0) <> &H7F THEN GOTO 830
870 '------Stop paper transport at second low------
890 DIO%(0) = &H80
900 MD% = 6
910 CALL CTM5(MD%, DIO%(0), FLAG%)
920 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg. 31": STOP
921 PRINT : PRINT : PRINT USING "CYCLE NO. ###              &      &"; COUNTER; DA
TE$; TIME$
930 '-----Turning on blower and starting background count
950 DIO%(0) = &H82    '1000 0010
960 MD% = 6
970 CALL CTM5(MD%, DIO%(0), FLAG%)
980 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg. 31": STOP
990 '------initialize counter mode register for counter using mode 1
1010   DIO%(0) = 5       'counter number
1020   DIO%(1) = 0
1030   DIO%(2) = 0
1040   DIO%(3) = 5       ' input from SCR
1050   DIO%(4) = 0
1060   DIO%(5) = 0
1070   DIO%(6) = 1             'count repetitively
1080   DIO%(7) = 0
1090   DIO%(8) = 1             'count up
1100   DIO%(9) = 0
1110   MD% = 1
1120   CALL CTM5(MD%, DIO%(0), FLAG%)
1130   IF FLAG% <> 0 THEN PRINT "Error in setting counter 1 mode": STOP
1150 '
1160 ' ------Zero all counters -----
1170 GOSUB 55000
```

```
1230 '
1240 ' ------Timing blower ------
1241 PRINT: PRINT "  Time       Interim Background Count     Total Thus Far"
1242 PRINT "--------    -----------------------    --------------"
1250 T1! = TIMER
1260 T2! = 0
1261 T4! = 0
1270 WHILE T2! < 1200
1280   T3! = TIMER
1290   T2! = T3! - T1!
1291   IF T2! < 0 THEN T3! = T3! + 86400!
1292   IF T2! < 0 THEN GOTO 1290
1295   T4! = T2!
1296   IF T4! > 399.96 AND T4! < 400.04 THEN FLAG = 1
1297   IF T4! > 799.96 AND T4! < 800.04 THEN FLAG = 1
1298   IF T4! > 1198.96 AND T4! < 1199.04 THEN FLAG = 1
1299   IF FLAG = 1 THEN GOSUB 60000
1301   BKGD = COUNT - HOLD
1303   HOLD = COUNT
1305   IF FLAG = 1 THEN PRINT USING "&             ######                ######
"; TIME$, BKGD; COUNT
1307   FLAG= 0
1308 WEND
1309 'Read and display contents of counter which will be background count
1310 '------Turning off blower and reading counters
1321 PRINT
1322   PRINT USING "                                               ######   TOTAL B
ACKGROUND COUNT"; COUNT
1323 PRINT #1, USING "###   &  &  ######"; COUNTER; DATE$;TIME$; COUNT
1330 DIO%(0) = &H80
1340 MD% = 6
1350 CALL CTM5(MD%, DIO%(0), FLAG%)
1360 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg. 31": STOP
1370 T1! = TIMER
1380 T2! = 0
1390 WHILE T2! < 15
1400   T3! = TIMER
1410   T2! = T3! - T1!
1412   IF T2! < 0 THEN T3! = T3! + 86400!
1414   IF T2! < 0 THEN GOTO 1410
1420 WEND
1421 BPCI = COUNT
1430 'Read and display contents of counter which will be background count
1462 BKGD = 0
1463 HOLD = 0
1464 COUNT = 0
1480 '------Move paper in place for collection count ----
1500 DIO%(0) = &H84
1510 MD% = 6
1520 CALL CTM5(MD%, DIO%(0), FLAG%)
1525 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg 31.": STOP
1530 '10 second wait for voltage change to settle
1531 T1! = TIMER
1532 T2! = 0
1533 WHILE T2! < 10
1534   T3! = TIMER
1535   T2! = T3! - T1!
1536   IF T2! < 0 THEN T3! = T3! + 86400!
1537   IF T2! < 0 THEN GOTO 1535
1538 WEND
```

```
1540 MD% = 5
1550 CALL CTM5(MD%, DIO%(0), FLAG%)
1560 IF FLAG% <> 0 THEN PRINT "Error in input data, see pg 31.": STOP
1570 IF DIO%(0) <> &H7F THEN GOTO 1540
1580 'stopping motor
1590 DIO%(0) = &H80
1600 MD% = 6
1610 CALL CTM5(MD%, DIO%(0), FLAG%)
1620 IF FLAG% <> 0 THEN PRINT "Error in output data, see pg 31.": STOP
1630 '------ collection count ------
1641 PRINT: PRINT "  Time       Interim Collection Count     Total Thus Far"
1642 PRINT "--------    -----------------------     --------------"
1650 GOSUB 55000    'zero counter out to start collection count
1660 T1! = TIMER
1670 T2! = 0
1671 T4! = 0
1680 WHILE T2! < 3600
1690   T3! = TIMER
1700   T2! = T3! - T1!
1701   IF T2! < 0 THEN T3! = T3! + 86400!
1702   IF T2! < 0 THEN GOTO 1700
1703   T4! = T2!
1704   IF T4! > 599.96 AND T4! < 600.04 THEN FLAG = 1
1705   IF T4! > 1199.96 AND T4! < 1200.04 THEN FLAG = 1
1706   IF T4! > 1799.96 AND T4! < 1800.04 THEN FLAG = 1
1707   IF T4! > 2399.96 AND T4! < 2400.04 THEN FLAG = 1
1708   IF T4! > 2999.96 AND T4! < 3000.04 THEN FLAG = 1
1709   IF T4! > 3598.96 AND T4! < 3599.04 THEN FLAG = 1
1713   IF FLAG = 1 THEN GOSUB 60000
1714   COLL = COUNT - HOLD
1715   HOLD = COUNT
1716   IF FLAG = 1 THEN PRINT USING "&              ######                   ######
"; TIME$; COLL; COUNT
1717   IF FLAG = 1 THEN PRINT #1, USING "                     &                ######"
; TIME$; COLL
1718   FLAG = 0
1719 WEND
1720 CPCI = COUNT
1721 'read and display contents of counter which will be collection count
1749 PRINT
1750 PRINT USING "                                                ###### * TOTAL COL
LECTION COUNT *";  COUNT
1751 PCI! = .00746 * (CPCI - BPCI)
1752 AMF! = (PCI! / 4) + 1
1753 PRINT #1, USING "                &                               ######        ###
.#        ###.#"; TIME$; COUNT; PCI!; AMF!
1754 PRINT : PRINT USING "                                                   ###.#    P
CI/cu. meter"; PCI!
1755 PRINT USING "                                              ###.#    AMF"; AMF
!
1756 BPCI = 0
1757 CPCI = 0
1758 COLL = 0
1759 HOLD = 0
1760 COUNTER = COUNTER + 1
1761 COUNT = 0
1762 PRINT : PRINT : PRINT
1763 PRINT #1, ""
1770 '
1780 ' Put this whole program in bigger loop that repeats every 45 min
```

```
1790 '
7000 TEND! = 0
7001 WHILE TEND! < 2700
7002   TWATCH! = TIMER
7003   TEND! = TWATCH! - THOUR!
7004   IF TEND! < 0 THEN TWATCH! = TWATCH! + 86400!
7005   IF TEND! < 0 THEN GOTO 7003
7008 WEND
7009 GOTO 560
10000 CLOSE #1
10010 PRINT :PRINT :PRINT "END OF PROGRAM"
10020 END
55000 '--- Subroutine to reset (zero ) counter --------
55010 'Disarm the counter (stop counting) using mode 2
55020 DIO%(0) = 6   ' disarm counter
55021 DIO%(1) = 0
55022 DIO%(2) = 0
55023 DIO%(3) = 0
55024 DIO%(4) = 0
55030 DIO%(5) = 1
55040 MD% = 2
55050 CALL CTM5(MD%, DIO%(0), FLAG%)
55060 IF FLAG% <> 0 THEN PRINT USING "Error in disarming counter #"; COUNTER: ST
OP
55070 '
55080 'Load zero into load register using mode 3
55100   DIO%(0) = 5
55110   DIO%(1) = 0
55120   MD% = 3
55130   CALL CTM5(MD%, DIO%(0), FLAG%)
55140   IF FLAG% <> 0 THEN PRINT USING "Error in loading load register #"; COUNT
ER: STOP
55160 '
55170 'Arm (enable) counter using mode 2
55180 DIO%(0) = 3
55190 DIO%(5) = 1
55200 MD% = 2
55210 CALL CTM5(MD%, DIO%(0), FLAG%)
55220 IF FLAG% <> 0 THEN PRINT "Error in enabling counters": STOP
55230 RETURN
55240 '
60000 '---- Subroutine to latch and read counter ----
60010 'This does not interfere with counting or change data
60020 'Latch counter to hold register using mode 2
60030 DIO%(0) = 5    'latch to hold
60031 DIO%(1) = 0
60032 DIO%(2) = 0
60033 DIO%(3) = 0
60040 DIO%(4) = 0
60041 DIO%(5) = 1
60050 MD% = 2
60060 CALL CTM5(MD%, DIO%(0), FLAG%)
60070 IF FLAG% <> 0 THEN PRINT "Error in latching counters": STOP
60080 '
60090 'Read hold register and return count in COUNT using mode 4
60110 DIO%(0) = 5
60120 MD% = 4
60130 CALL CTM5(MD%, DIO%(0), FLAG%)
60140 IF FLAG% <> 0 THEN PRINT USING "Error in reading counter #"; COUNTER: STOP
60150 COUNT = DIO%(1)  'return data range -32768 to +32768
```

```
60160 'correct for 2's compliment (negative integers)
60170 IF COUNT < 0 THEN COUNT = 66536! + COUNT
60190 RETURN
```

APPENDIX C

INSTRUMENT CONCEPT AND RADON DECAY THEORY

NOTE: This section is taken directly from the original OCSI manual, sections 6.1-6.3, A.2.0-A.2.2, A.9.1, A.10.2, and A.14.

PHOTOMULTIPLIER SCINTILLOMETER OPERATIONAL DETAILS

The 12-stage photomultiplier tube (PMT) is the heart of the ARC-2A system and literally makes such an instrument possible. It is a complex, analog system with a number of important idiosyncrasies regarding which, many first-time users may be unaware. This unwanted "baggage" is a necessary evil to be accepted in return for the service of this truly remarkable tool. First and foremost, always keep in mind the extreme fragility of the PMT. If its replacement cost isn't sufficient to deter rough or careless handling, the loss of the instrument's service certainly should be. Furthermore, no two PMT's can be made identical. Therefore, unless one is extremely fortunate, any replacement will normally require field "retuning" of the signal conditioner. This usually requires the service of a qualified electronic technician, or return of the signal conditioner printed circuit board to OCSI for matching to the new tube.

GENERAL CONSIDERATIONS FOR INSTALLATION OF PHOTOMULTIPLIER TUBE

As previously noted, the extreme fragility of the glass envelope of the photomultiplier tube (PMT), and the susceptibility of its complex, internal electron optics to mechanical shock, makes shipment of the instrument risky, with tube installed. For this reason, OCSI makes it a practice to ship the system with the tube packed separately. This requires the owner to install the tube after receiving the instrument. This is not a difficult task, but it must be conducted with care, in the manner to be described here. The instructions given here for tube installation are provided in two steps: first, this qualitative overview, followed by a detailed step-by-step procedure.

TUBE SOCKET DETAILS

A relatively heavy and complex tube socket is provided for the photomultiplier tube (PMT) and it is into this 14-pin (tetdecaedral) socket into which the photomultiplier tube must be plugged. This socket provides critical electrical signal-conditioning preamplifiers, line drivers, high-voltage dividers, focus voltage controls, and amplifier gain control. It also provides coaxial connections for the PMT high-voltage supply, the output signal line, and a test signal connection.

This important socket is a heavy, physical mass which could inflict serious damage on the PMT, itself, under conditions of mechanical shock in a portable instrument, unless protective measures are taken to prevent this. For this reason, independent mechanical supports are provided for both the PMT and its socket.

PMT MOUNTING DETAILS

The sketch in Figure 7 illustrates the mounting, which has been designed to minimize the mechanical shock and vibration hazards to the PMT in its operational environment. The tube is mounted with its delicate face inserted into the "counting chamber". The latter is merely a recessed opening in the upper filter paper guide. There is a step in the lower edge of this recessed opening which controls the minimum separation distance (termed the "calibration distance") between the filter paper "dirt spot" and the mylar shield on the tube face.

The tube is retained in a split yoke similar to the "arm and head holes" of the prisoner stocks of colonial times.

In a single tube system, the PMT is installed above the filter paper strip.

The surfaces of the two yokes and the internal step which sets the tube-filter separation distance are lined with foam rubber to provide a compliant support which resists angular rotation of the PM tube and its base and reduce peak shock load.

Captive thumb wing-nuts apply pressure to the two yokes in order to secure the tube-base system against slippage or rotation, during either normal operations, or user transportation of the ARC-2A.

DETAILED INSTALLATION INSTRUCTIONS FOR THE PHOTOMULTIPLIER TUBE

The photomultiplier tube is shipped in the container provided by its manufacturer. The tube may be of either Japanese (Hamamatsu) or Dutch (Phillips-Amperex) manufacture. Either represent state-of-the-art devices and either are suitable for use in the sampler.

Before removing the tube from its box, the cabinet should be opened and prepared for tube installation.

In the following discussion, the item identity letters refer to those in Figure 7. Upon opening, it will be noted that the proprietary tube base (CANBERRA No. 2007P) is installed within the cabinet in its approximate operating position. Two small coax cables (signal and HV) are plugged into it. The gain control in the base has been set and immobilized by a daub of silicone rubber. The DB-9 power plug has also been plugged in and locked into place by a pair of snap clips.

The two thumb wing nuts, D, have been made finger-tight, thereby securing the socket near to its installed position by the split yoke. A shipping safety tie has been added to restrain the socket in the event of a severe shipping jolt. The steps in tube installation are listed here.

The shipping restraint tie should be removed from the socket,preparatory to tube installation, and the two thumb wing-nuts, D, on the socket loosened until the socket can be moved up and down and rotated readily.

Loosen the hose clamp on the lower end of the flexible inlet air base and remove the hose end from its fitting. Temporarily tie the hose out of one's working room at the tube yoke.

Loosen and remove the screws and captive thumb wing-nut on the TUBE-RETAINING yoke, C, (lower).

Place the removable half of the tube yoke in a convenient, safe place, where it will be ready for installation when the tube has been fitted to its socket. At reassembly, take care not to omit the single, important, 1/16-inch spacing washer which fits between the yokes. This washer is critical for limiting the maximum safe hoop stress which can be imposed on the PMT. If the washer is left out, it is possible to break the PMT with excessive compressive stress.

Loosen the two thumb wing-nuts on the SOCKET YOKE, C, (upper) so that the socket can be moved slightly upward.

Next, move the socket up until only about 1/4-inch of the chrome portion of its metal shell extends below the bottom edge of the socket yoke. This provides clearance for introduction of the PMT. Tighten the thumb wing-nuts slightly, until the socket can be rotated with a slight twist, but will not slip downward of its own weight. Carefully unpack the PMT and unwrap the tube from inside its cushion-paper wrapping.

Hold the PMT only over soft cushion surfaces on which it cannot roll. Mover's blankets are ideal. If it becomes necessary to lay the tube down, return it to its wrapping and replace in its manufacturer's container.

Inspect the tube upon removal. It may look somewhat less than professional, at first, since the black PVC tape wrapping and the mylar face cover are unlovely additions to a truly exquisite piece of glassware and electron optics. In this case, however, appearances must take second place to performance.

The tape wrapping serves a dual purpose of: a) providing a multilayer seal against light leaks; and b) providing a shock-and-nick-resistant barrier for protection of the tube.

The mylar film is made somewhat loose fitting so that the seating of the tube face in the scintillometer hole can be made with some tolerance of position without directly stressing the scintillometer-face seal.

Please note well: - UNDER NO CIRCUMSTANCES SHOULD THE FACE PLASTIC, ALUMINUM FACE OR THE PVC TAPE BE REMOVED FROM THE TUBE! THESE ARE NOT SHIPPING AMENITIES, BUT RATHER ARE VITAL ELEMENTS OF THE SCINTILLOMETER, ITSELF. See Figure 8. Their removal can cause permanent damage to the tube and will require recalibration.

Note that the 14-pin base of the tube consists of an outer rim of 14-pins which surround a center plastic post. This post is designed to engage a matching hole in the CANBERRA socket. A raised key on the center post, when fitted in a mating keyway, permits one, and only one, angular orientation of the tube in its 14-pin socket.

In this way, the individual pins of the tube can form electrical contact with only the intended mates in the socket.

It is a useful exercise to determine the approximate angular orientation of the socket keyway, before attempting to "socket" the PMT in the manner described next. In this way, the angular searching to socket the tube, i.e. to have its keyed plug engage the socket correctly, can be kept to a minimum. The chrome-plated CANBERRA socket has been marked with a RED, VERTICAL STRIPE to indicate the angular position of the keyway. A RED DOT has been placed on the base of the PM tube to mark the key position.

With the tube socket raised, and the PM yoke, C, (lower) open, as described previously, there is ample space to introduce the PMT into its yoke without striking any part of the PMT, especially its fragile face, on any part of the structure. The tube should be introduced with its key on the post at approximately the same orientation as the keyway on the base. There should be approximately a half-inch clearance between the tube face and the top deck of the scintillometer chamber. Holding the tube with both hands, try slowly rotating the tube in a small angular arc about its longitudal axis of symmetry. It is necessary to maintain a very light pressure between the tube socket post and the socket center hole when rotating the tube. If you're fortunate, and rotating the tube slowly enough, the key on the center post will drop approximately 1/8-inch when it coincides with the center-hole keyway on the tube socket. If on this attempt the tube doesn't align, carefully recheck the alignment of the socket keyway, using the red guidemarks. Then retry to seat the guide key in the socket mate.

When success is signaled by the simultaneous drop-in of the 14 pins into their 14 mating socket holes, the tube should be seated by holding the socket against upward slip and gently urging the tube to seat in the socket above it. This does not take an excessive amount of force on the tube. The tube is grasped by the PVC black tape side at a point adjacent to its base, when applying this socketing pressure. This should be done with one hand securely holding the tube and the other holding the CANBERRA socket.

This socketing requires a gentle, deft touch, not a heavy hand. The tube should engage smoothly with reasonable and gentle urging. If it does not, there is something amiss, and the problem must be identified and corrected before continuing further. Do not try to force a reluctant tube, since this could lead to loss of the tube and possible personal injury.

When the PMT is seated in the CANBERRA socket, the wing-nuts on both sides of the socket yoke, C,(upper) should be loosened several turns while holding the tube with the free hand. Hold onto the tube! Do not let it drop as the socket is freed! It must be lowered, next, in a controlled and deliberate fashion.

Loosening the socket yoke will permit the now-paired tube and socket to be gently lowered to contact the small, white, compliant pads which ring the step near the bottom of the PMT tube hole in the scintillometer chamber (see Figure 6). The tube and socket should then be "backed-off" by moving it upward approximately 1/16-inch. This will reduce the contact pressure between the mylar face shield on the PMT and the white, compliant pads. Do not move more than the 1/16-inch since this can adversely affect the counting efficiency.

Next, tighten the socket yoke wing-nuts, D, (upper) while still holding the tube/socket pair in the position achieved by the previous step. Both sides of the socket yoke, C, (upper) should "bottom" on the mating face of the fixed part of the yoke.

Next, replace the half of the tube yoke, C, (lower) which was previously removed and be sure that the spacer washer, T, is inserted between the fixed and movable halves of the tube yoke on the outboard side of the yoke, as it was shipped. Remember, the purpose of this spacer is to limit the squeeze placed on the tube envelope to a safe level. It is important that it not be omitted when reassembling the tube yoke, above. Tighten the thumb wing-nut, D, (lower) on the inboard side of the tube yoke, C, (lower) first. This tightening should not be excessive. The main purpose of this yoke is to dampen vibrations of the tube and independent motion between it and the socket. The socket yoke provides the major support of the tube/socket pair. With the inboard wing-nut, D, (lower) tightened, the outboard wing-nut, D, (lower) is closed finger-tight until the tube yoke, C, (lower) is closed upon the 1/16-inch spacer, T.

Following a final check to see if all four wing-nuts are tight, this completes the PMT installation.

ANALOG SIGNAL CONDITIONING CIRCUIT DETAILS

This portion of the user's manual is tutorial in nature and is intended for the user for whom the use of a photomultiplier scintillometer may be a new or unfamiliar experience. The experienced reader may wish to skip this section.

The normal operation of the PMT, in the absence of optical signals, is characterized by spurious outputs, or "hash". This hash consists of randomly-occurring, discrete pulses which vary, both in amplitude and average recurrence rate. There is little distinguishable difference between these pulses and the desired, scintillometer-caused pulses which the system depends upon for its normal operation. For this reason, the thermal noise of the PMT is the factor which establishes the threshold sensitivity of any system which employs the PMT as the key detection element.

The thermal noise or so-called "background" output of the PMT is, therefore, an important system parameter which determines the lowest level of Radon which can be detected. It is usually referred to as the "background count" or simply "the background" for a particular tube. Any system which employs a PMT should provide a convenient means for regularly monitoring the background as a check on the health and well-being of the tube. The ARC-2A does so in a particularly convenient manner.

Between background noise floor and the saturation or maximum output current rating, the PMT exhibits an extended, analog counting response range usually referred to as its "dynamic range". In this region, pulse-amplitude discrimination can be usefully exercised. By keeping the electrical bandwidth as wide as practical, time-domain discrimination can also be exploited. Applications which are critically dependent upon these analog properties of the PMT can be disturbed by the changes which may occur in the critical analog parameters of the PMT, unless compensated.

The most common of these are the long-term decrease, with age, of the total, internal, multiplier gain, as well as the fluctuations in this gain caused by variations in power supply voltages. While the latter can be controlled reasonably well, the former is intrinsic to the tubes themselves and must be compensated for by periodic calibrations with known beta-particle, calibration sources. In the past, the most common means for compensation has been by occasional, manual adjustment gain of the pulse amplifiers which follow the PMT. With microprocessor-controlled systems, these compensation procedures can be automated.

The ARC-2A system presently relies on occasional manual correction of the system gain, where maximum precision is required.

PM TUBE STABILITY CONSIDERATIONS

Exposure of the unprotected tube to strong daylight should always be avoided, even though the tube is not in service and has no voltages applied to it at the time of such exposure. Therefore, the tube should be protected from intense ambient light whenever the aluminum face filters are being replaced or have had their light-tight integrity impaired. Some gain drift can be anticipated after any substantial light exposure.

Gain for a new tube may initially be higher than normal. A slow decrease by as much as a factor of two, over the first several thousand hours of operation, can be anticipated.

When changing PMT's, much larger changes can be anticipated and, hence, an initial setup procedure must be followed to assure operation within the proper limits. These are outlined in a separate service manual available from OCSI.

POST AMPLIFIERS AND DISCRIMINATOR

The output of the PMT is an impulse of charge for each detectable light flash which occurs in the scintillation medium. These flashes occur as the lattice excitations in the scintillation medium, which beta particle collisions create, decay and emit the stored energy as pulses of light.

These charge impulses are converted to voltage pulses by conversion through integration on a capacitor. A fast, isolation amplifier preserves the features of the pulse waveform and increases its amplitude. The charge converter, fast preamplifier, staircase voltage divider for the dynodes (accelerating electrodes and secondary emission multipliers), PMT beam focus control, and a line driver amplifier, are included in the proprietary (CANBERRA Inc.) socket into which the PMT is plugged.

Two, gain-controllable, IC, operational amplifiers provide further linear amplification after the foregoing preamplifier. The latter amplifiers provide switch-selectable, gain steps which assure a wide variation in available gain which can compensate for any normal variations in the PMT's photo-optical gain.

Following the last op-amplifier, an IC comparator is provided which has a variable reference threshold. This circuit is employed as a pulse-height discriminator, in order to exclude some of the smaller amplitude "background noise" generated within the PMT.

The signal chain concludes with a logic-level, CMOS IC, configured as a one-shot multivibrator, with input hysteresis. This one-shot delivers a logic-level, "standard" output which has a fixed amplitude and width, regardless of the waveform of the input signal, which triggers the one-shot.

Further sharpening for the leading edge of this digital output signal is provided before being applied to the high speed pulse counter in the instrument, by means of a very fast Schmitt trigger. This trigger is also of "CMOS architecture".

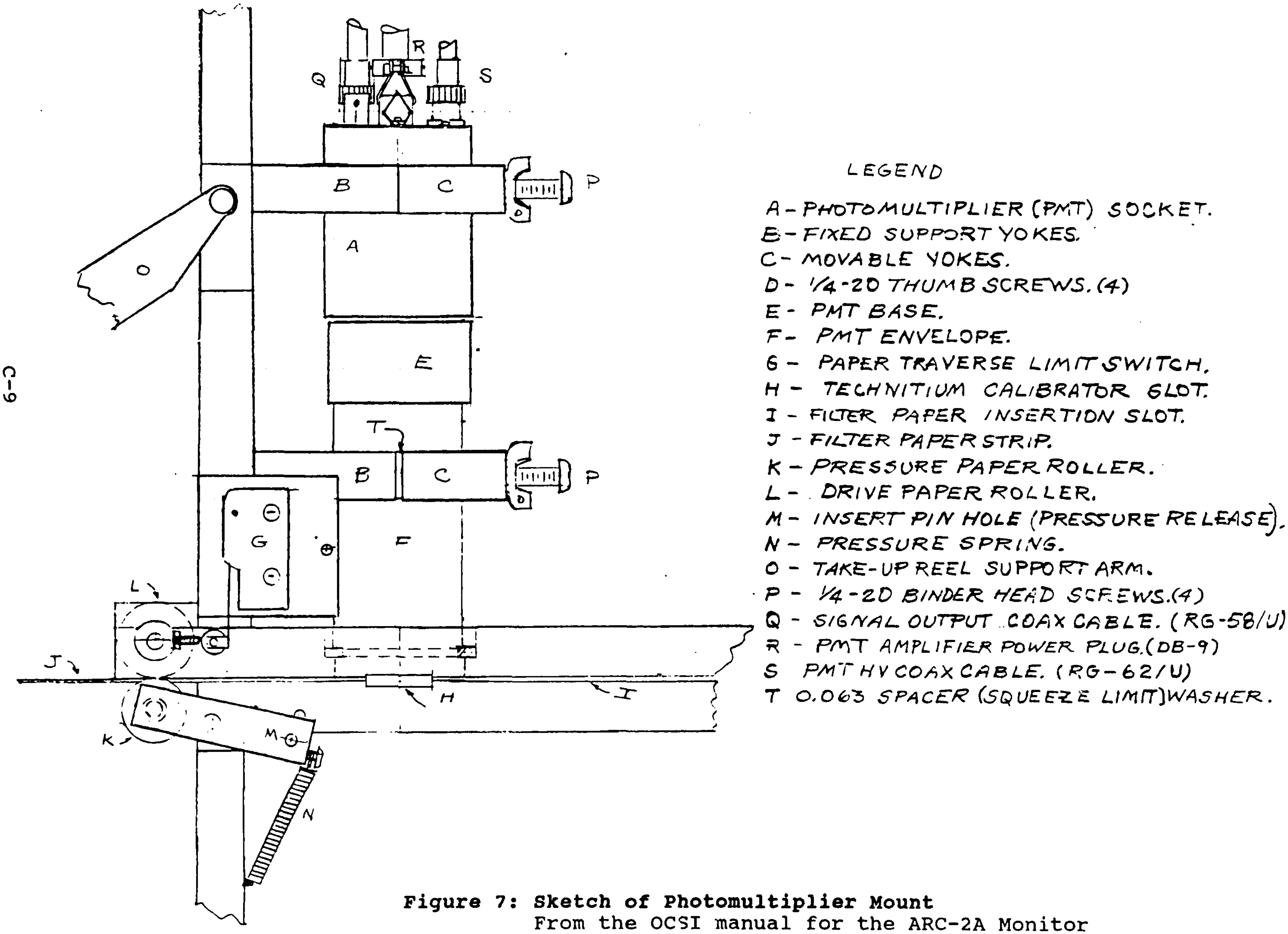


Figure 7: Sketch of Photomultiplier Mount
From the OCSI manual for the ARC-2A Monitor

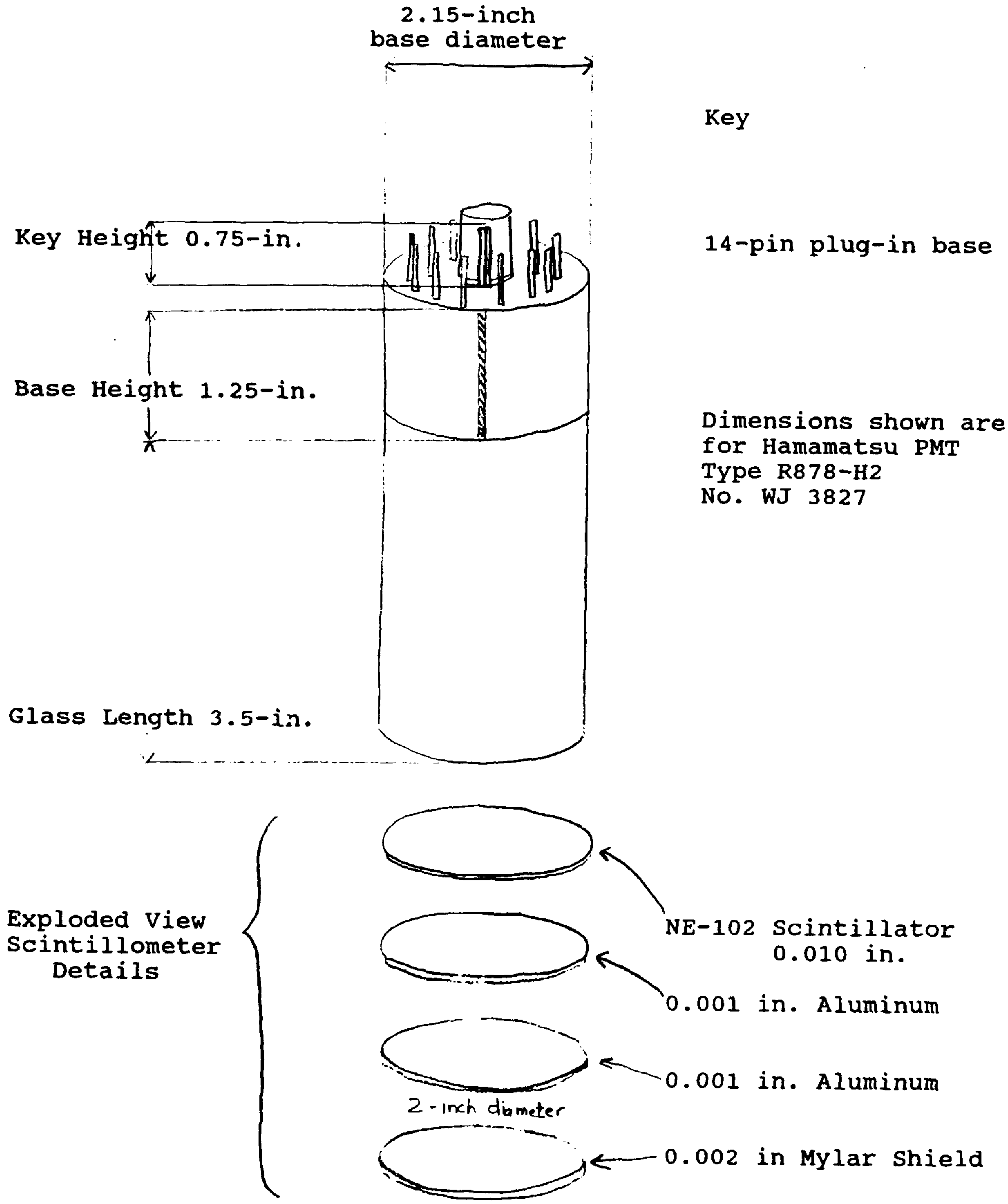


Figure 8: Photomultiplier Details
From the OCSI Manual for the ARC-2A Radon Monitor,
with figures corrected by Reginald Larson of NRL.

UNITS OF RADON MEASUREMENT

Since most existing Radon detection and measuring methods employed are either radio-chemical or integrating ionization chamber methods, it is important that the new concentrator-counter technique represented by the ARC-2A have its results expressible in comparable output units for purposes of comparison with these older techniques. Furthermore, since the ARC-2A measures the beta activity of Radon decay products, whereas many of the older techniques measure alpha activities of Radon gas, itself, the matter of equilibria between Radon and its daughters must be considered, if Radon, alone, is to be reported.

Most investigators of environmental Radon are concerned with its health implications. Since Radon is a gas, it is usual to express its radioactivity source strength in terms of the number of atomic decays per unit volume for the living or working environment of persons exposed. Volumes near the capacity of the human lung are of interest, so most health-oriented measurements utilize the liter as the standard volume.

The traditional unit of radioactivity is the Curie (Ci). It is such a large unit, being 3.7 x 10E+10 atomic decays per second, that, as a result, even for important "large" concentrations of Radon, and other radionuclides, the actual numbers involved appear vanishingly small to most readers. For this and other good reasons, the newer unit, the Becquerel, was introduced for specifying low-level sources of radioactivity. The Becquerel (Bq) is defined as a rate of one atomic decay per second, hence, is equal to 2.7027 x E-11 Curie.

The volume unit is usually taken as the cubic meter by physics-oriented investigators, and the cubic centimeter or milliliter by those who are chemistry-oriented. As noted previously, those with health concerns such as Government Regulatory Agencies like the liter. Therefore, source densities for Radon-Radon decay products are commonly given in:

Becquerels / cubic meter
Becquerels / mL or Becquerels / cc.
Picocuries / liter

The relationship between the picocurie and the Becquerel should also be kept in mind. The Becquerel is the larger unit, thus:

1 Becquerel = 27.027 picocurie
or
1 picocurie = 3.7 x 10E-2 Becquerel

RADON-RADON-DAUGHTER EQUILIBRIUM EFFECTS ON ARC-2A MEASUREMENTS OF RADON

The primary intended use of the ARC-2A device is to permit the tagging and tracking of air masses, especially in coastal environments. Marine air masses are largely Radon-free, provided their over-water residence time has been sufficiently great and intermixing with land air masses has not taken place. It was found that the indirect measurement of the Radon gas, an alpha emitter, by means of the direct measurement of the beta activity of its daughter products was a more practical alternative to the direct measurement of the alpha emissions from Radon gas. This is especially true where rapid, precise assessments are required at a remote or unmanned site, or where short-term, temporal variations in the Radon gas environment are significant to an investigation.

This latter fact may have played a role in the National Council of Radiological Protection and Measurements (NCRP) decision to base its exposure guidelines on the measurement of daughter products rather than on the Radon gas itself.

The use of the daughter products for measurement of Radon requires an assumption regarding the equilibrium (or lack of it) which exist between Radon and its daughters, in a given situation. For indoor measurements, the fraction expressing the quotient of daughter products to Radon present, normally range from about 0.3 to 0.6. This is largely the result of attachment of the daughter-bearing aerosols to walls, floors, ceilings and other objects found in interior spaces. This prevents their being collected by the system. The uncertainty in the equilibrium factor is probably the largest of those associated with determination of indoor Radon levels when using the ARC-2A.

External, free-air conditions are more likely to produce secular equilibrium between the Radon and its daughters. This is because the aerodynamic mixing is more complete and because of the short half lives of the daughters compared to Radon itself. Therefore, we usually assume equilibrium for outside atmospheric measurements.

It is our practice to employ an F value of 0.5 to 0.6 in estimating Radon gas from the ARC-2A measurements of the Beta-emitting daughters, since the higher F value provides a more conservative estimate of indoor Radon radioactivity exposure.

THE URANIUM - THORIUM RADIOACTIVE DECAY SERIES

There are three Radon isotopes: Rn-222, a product of the Uranium-238 series; Rn-220, a product of the Thorium-232 series; and Rn-219, a product of the Uranium-235 series. Since U-235 is present in only about 0.7 percent for most natural Uranium, Rn-219 is correspondingly rare. Some literature identifies Rn-222 as "Radon", Rn-220 as "Thoron", and Rn-219 as "Actinon". These designators have not been accepted by any international standards committee, however.

The diagram of Table 2 illustrates the decay within the three radioactive series which give birth to the Radon mothers and their subsequent daughters. By way of review and explanation of the diagrams, recall that when an alpha particle is emitted during decay of a radionuclide, its atomic weight decreases by four units and its atomic number, Z, decreases by two units.

When a beta particle is emitted during decay, the atomic weight remains unchanged, but its atomic number increases by one.

The half life, T(0.5), of a radionuclide is related to the usual negative exponential decay constant, λ , as follows:

$$T(0.5) = 0.693 / \lambda$$

where T and λ are in consistent units.

Table 3 summarizes the quantitative characteristics of the three, natural radioactive decay series of interest.

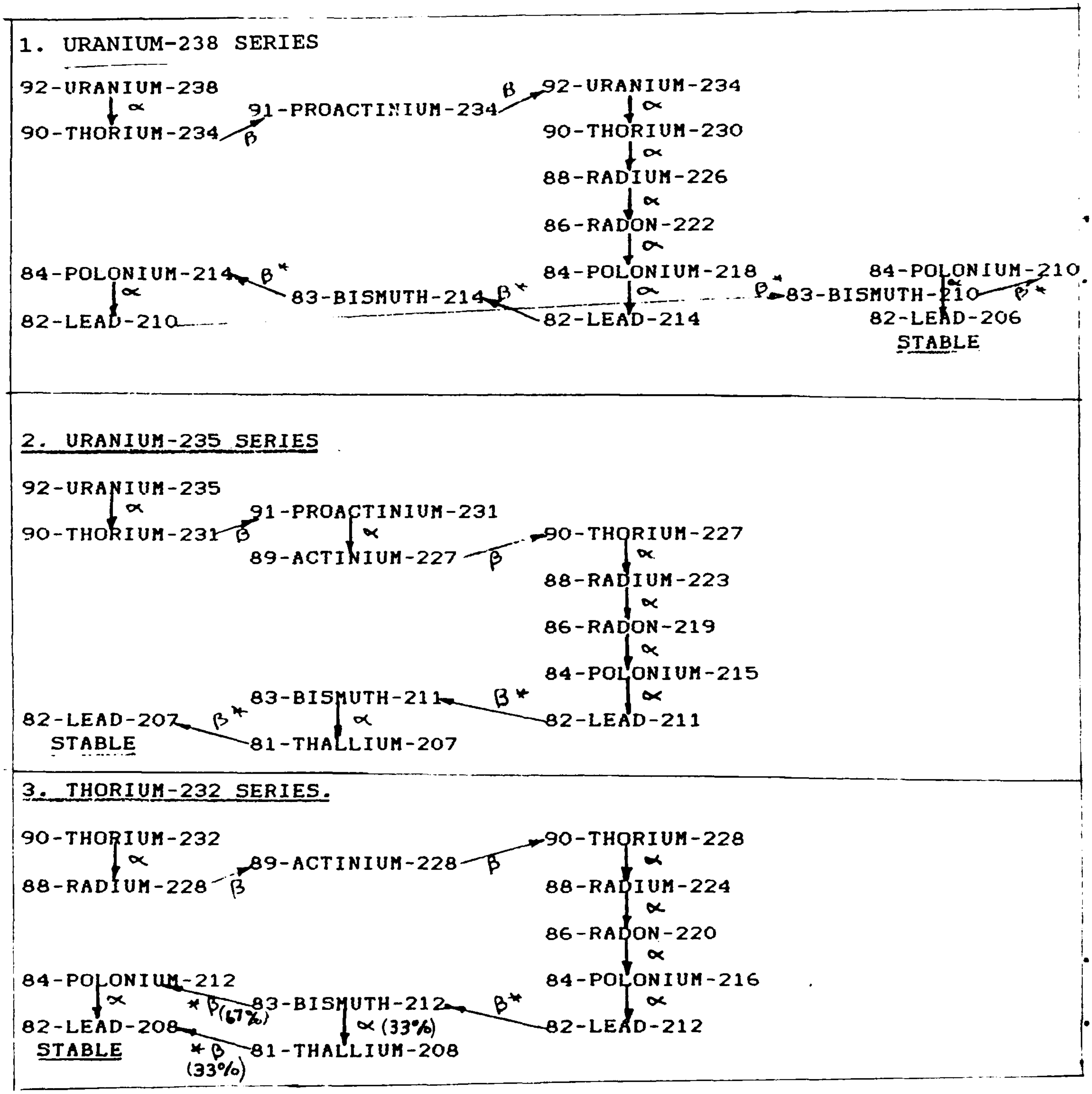


Table 3. The Uranium - Thorium Radioactive Series
From the OCSI Manual for the Arc-2A Radon Counter

DAUGHTERS OF THE URANIUM-238 RADIOACTIVE DECAY SERIES.

DECAY STEP	AT. NO.	SYM.	ELEMENT	AT. WGT.	HALF LIFE	EMITTED PARTICLE	PARTICLE ENERGY (MEV)
1	92	U	URANIUM	238	4.5X10E+9Y	ALPHA	4.2
2	90	TH	THORIUM	234	24D	BETA	0.1/0.2
3	91	PA	PROACTINIUM	234	1.2M	BETA	2.3
4	92	U	URANIUM	234	2.5X10E+5Y	ALPHA	4.7/4.8
5	90	TH	THORIUM	230	8.0X10E+4Y	ALPHA	4.6/4.7
6	88	RA	RADIUM	226	1600Y	ALPHA	4.8
7	86	RN	RADON	222	3.8D	ALPHA	5.5
8	84	PO	POLONIUM	218	3.05M	ALPHA	6.0
* 9	82	PB	LEAD	214	27M	BETA	0.7/1.0 *
* 10	83	BI	BISMUTH	214	20M	BETA	0.4/3.3 *
11	84	PO	POLONIUM	214	160X10-6S	ALPHA	7.7
* 12	82	PB	LEAD	210	22Y	BETA	0.06/0.2 *
* 13	83	BI	BISMUTH	210	5D	BETA	1.2 *
14	84	PO	POLONIUM	210	138D	ALPHA	5.3
15	82	PB	LEAD	206	STABLE END PRODUCT		

DAUGHTERS OF THE URANIUM-235 RADIOACTIVE DECAY SERIES.

1	92	U	URANIUM	235	7X10E+8Y	ALPHA	4.3/4.6
2	90	TH	THORIUM	231	26H	BETA	0.1/0.3
3	91	PA	PROACTINIUM	231	3X10E+4Y	ALPHA	5.0
4	89	AC	ACTINIUM	227	21.8Y	BETA	0.04
5	90	TH	THORIUM	227	18D	ALPHA	6.0
6	88	RA	RADIUM	223	11.4D	ALPHA	5.5/5.7
7	86	RN	RADON	219	3.9S	ALPHA	6.5/6.8
8	84	PO	POLONIUM	215	1.8X10E-3S	ALPHA	7.4
* 9	82	PB	LEAD	211	36M	BETA	0.6/1.4 *
10	83	BI	BISMUTH	211	2.2M	ALPHA	6.3/6.6
* 11	81	TL	THALLIUM	207	4.8M	BETA	1.4 *
12	82	PB	LEAD	207	STABLE END PRODUCT		

DAUGHTERS OF THE THORIUM-232 RADIOACTIVE DECAY SERIES.

1	90	TH	THORIUM	232	1.4X10E+10	ALPHA	4.0
2	88	RA	RADIUM	228	5.8Y	BETA	0.05
3	89	AC	ACTINIUM	228	6.1H	BETA	0.4/2.1
4	90	TH	THORIUM	228	1.9Y	ALPHA	5.3/5.4
5	88	RA	RADIUM	224	3.6D	ALPHA	5.7
6	86	RN	RADON	220	55S	ALPHA	6.3
7	84	PO	POLONIUM	216	0.16S	ALPHA	6.8
* 8	82	PB	LEAD	212	10.6H	BETA	0.34/0.58 *
* 9a)	83	BI	BISMUTH	212	60.5M	BETA(67%)	2.2 *
9b)	83	BI	BISMUTH	212	60.5M	ALPHA(33%)	6.1
10a)	84	PO	POLONIUM	212	0.3X10E-6S	ALPHA	8.8
11a)	82	PB	LEAD	208	STABLE END PRODUCT		
* 10b)	81	TL	THALLIUM	208	3.1M	BETA	1.0/1.8 *
11b)	82	PB	LEAD	208	STABLE END PRODUCT		

* = RADON DAUGHTERS MEASURED BY ARC-2A SCINTILLOMETER.

FROM THE OCSI MANUAL FOR THE MODEL ARC-2A RADON MONITOR.

PRODUCTS OF NATURAL RADIOACTIVE DECAY SERIES SHOWING THE PARTICLES EMITTED IN THE DECAYS AND THEIR KINETIC ENERGIES, IN MEV.

Table 4. Products of natural radioactive decay series for Radon

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13. ABSTRACT *(Maximum 200 words)*

The ARC-2A Automatic Radon Counter (Serial No. 87003) was manufactured in 1987 by Ocean Communication Systems, Inc, Panama City, Florida. It was designed as a stand-alone system, but was consistently plagued with problems. The manufacturer could not repair the machine.

The ARC-2A was completely redesigned at NCCOSC RDT&E Division. It is now interfaced to a computer. A new manual was written with updated information and user instructions.

The ARC-2A is an integral part of ongoing electro-optic propagation studies.

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