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LABORATORY EVALUATION OF A LOW-POWER CMOS ELECTRONICS MONITOR IN RADON PROGENY AND THORON PROGENY ATMOSPHERES

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ABSTRACT

A miniaturized α-particle monitor using low-power CMOS electronics has been evaluated in a Radon/Thoron Test Facility (RTTF). The instrument was tested in radon/radon progeny atmospheres only, and in thoron/thoron progeny atmospheres only. The instrument was found to respond adequately to radon progeny. Its use in thoron progeny atmospheres is, however, limited to the case where the thoron progeny concentration does not change rapidly. Several instruments were tested simultaneously. The sensitivity was different for each instrument. A difference of ~45% was found between the most and the least sensitive instrument.

Key words: Radon progeny; Thoron progeny; Working Level; Monitor: Dosimeter; CMOS electronics.

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ÉVALUATION EN LABORATOIRE DE LA PERFORMANCE D'UN CONTRÔLEUR ÉLECTRONIQUE GMOS PEU PUISSANT DANS DES ATMOSPHÈRES CONTENANT DES DESCENDANTS DU RADON ET DU THORON

J. Bigu*

RÉSUMÉ

La performance du modèle miniature d'un contrôleur électronique CMOS peu puissant, sensible aux particules alpha, a été évalué à l'installation expérimentale radon/thoron. Le dispositif a été mis à l'essai dans des atmosphères contenant uniquement des descendants radon/radon et dans des atmosphères contenant seulement des descendants thoron/thoron. Le dispositif réagissait adéquatement aux descendants du radon. Cependant, dans les atmosphères contenant des descendants du thoron, il ne peut être utilisé que dans les cas où la concentration de descendants du thoron n'est pas sujette à des changements rapides. Plusieurs dispositifs ont été évaluées simultanément. Chacun d'entre eux possédait une sensibilité qui lui était propre. On a noté une différence de -45 % entre les dispositifs les plus sensibles et ceux qui l'était le moins.

Mots-clé : Descendants du radon; descendants du thoron; niveau d'activité; dispositif de contrôle; dosimètre, électroniques GMOS.

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INTRODUCTION

Personal dosimetry instrumentation for the measurement of radon progeny found in uranium mines and mills, and in certain building materials, is of great practical value for monitoring radiation levels to which radiation workers and general public alike are exposed. Standard techniques, such as track-etch and thermoluminescent detectors, are used extensively, but suffer from the problem of complicated reading procedures. The search for direct-reading, electronic α-detection methods has resulted in the development of portable systems using silicon-barrier detectors and large-area diffused junction semiconductor diode detectors. These detectors are well-established devices with known advantages and limitations, and represent, therefore, a good approach to the problem of miniaturization.

More recently, Dynamic Random Access Memory (DRAM) chips have been successfully used as α-particle detectors (1). The basic operating principle of the detector is by 'soft' errors produced in the memory of the DRAM chip by α-particles (2).

Several instruments that operate on the above principle have been developed such as the Radon Sniffer manufactured by Thomson and Nielsen Electronics Ltd. (Ottawa, Canada), and CIRAS manufactured by alphaNUCLEAR (Toronto, Canada). An early prototype of the Radon Sniffer was developed by Thomson and Nielsen under contract with CANMET (EMR), and the Department of Supply and Services (DSS). This early prototype, and a second, more advanced prototype were evaluated at the Elliot Lake Laboratory under laboratory controlled conditions and in an underground uranium mine (3). This report presents data on a technical evaluation of a somewhat modified version of the second prototype. Furthermore, the behaviour of the instrument in thoron/thoron progeny atmospheres only, in addition to the more conventional radon/

radon progeny atmosphere tests, has been investigated.

DESCRIPTION OF THE DOSIMETER

A description of the dosimeter has been given elsewhere (3), but it will be repeated here for the benefit of the reader.

The dosimeter consists of a sampling 'head' and an electronic reader all in one unit.

The sampling head consists of a DRAM chip, as detector, and its associated electronic circuitry, a small sampling pump, a battery power pack, and a sample holder where an absolute filter (0.8 μm Millipore, 25 mm diameter) is located. During air sampling, radon progeny and/or thoron progeny are deposited on the filter where they decay. Alpha-particles from the decay of radon (and/or thoron) progeny strike the detector and produce 'soft errors'.

The digital detector serves both to detect α-particles and to give an output of standard digital pulses whose number is proportional to the number of α-particles absorbed by the detector. The detector is insensitive to β- and γ-radiation. The number of pulses is stored in a register which is read by the reader. The detector is biased using a standard voltage supply used for the rest of the electronics.

A useful feature of the instrument is that the sampling pump can be switched off if so desired. This allows the decay of radioisotopes to be followed in detail. The reader uses a liquid crystal display (LCD) which indicates total accumulated α-count in real time. Figure 1 shows a simplified diagram of the sampling head/reader system. Some of the operating characteristics of the instrument are given below.

<u>Operating Voltage</u> : 6 V dc

<u>Power Consumption</u> : 985 mW

Air Flow Rate : 1 L/min (adjustable from 0.5 L/min to 3/5 L/min)

Battery Capacity : 15 h (6 V battery, 2.5 A-h sealed lead acid)

Detector Efficiency: $\geq$15%

Sampling Head Current Consumption: 50 mA

Reader Current Consumption : 2 mA

Pump Current Consumption : 112 mA

Total Current Consumption : 164 mA.

The above characteristics were determined under laboratory and field conditions. The detector efficiency was determined using a ^{241}Am source and filters loaded with radon progeny from a source model Rn-190 manufactured by Pylon Electronics Development (Ottawa, Canada).

EXPERIMENTAL PROCEDURE

The instrument was tested and calibrated under laboratory-controlled conditions in a large Radon/Thoron Test Facility (RTTF) of the walk-in type.

Three units were evaluated in the RTTF, namely, Sniffer No. 1, No. 2, and No. 3, over a period of two weeks. Only Sniffer No. 1 and No. 2 were tested in thoron/thoron progeny only atmospheres, whereas all three instruments were evaluated in radon/radon progeny only atmospheres.

The instruments were tested in the RTTF under a variety of aerosol concentration conditions ranging from $<1 \times 10^3$ cm^{-3} to $\sim 1.5 \times 10^4$ cm^{-3} in order to investigate plate-out effects. Tests were conducted at low and moderately high radiation levels.

Data obtained with the instruments were compared with grab-sampling data by the Thomas-Tsivoglou method (4) for radon progeny, and by a method developed at the Elliot Lake Laboratory for thoron progeny (5). The following radiation variables were measured: [^{218}Po], [^{214}Pb], [^{214}Bi], [^{212}Pb] and [^{212}Bi], where the square brackets are used to indicate activity concentration. In addition, the radon progeny Working Level, WL(Rn), and the thoron progeny Working Level, WL(Tn), were determined.

EXPERIMENTAL RESULTS AND DISCUSSION

Tables 1 to 4 and Figures 1 to 5 summarize the experimental data obtained. The behaviour of the Sniffers in radon progeny atmospheres and radon progeny data by grab-sampling are shown in Tables 1 and 2, and Figures 1 to 4. Similar data for thoron progeny are shown in Tables 3 and 4, and Figure 5.

Two test conditions in the RTTF were chosen in each case, namely low aerosol concentration ($<1-3 \times 10^3$ cm^{-3}), and hence, low radon (thoron) progeny concentration. and moderate aerosol concentration ($>5-7.5 \times 10^3$ cm^{-3}), and hence, relatively high radon (thoron) progeny concentration (see Table 1).

For radon progeny, the daily average WL(Rn) was in the range 0.03 to 0.043 under low aerosol concentration conditions. The average radon progeny disequilibrium ratios were also rather low, namely: $[^{214}Pb]/[^{218}Po]$ ~0.11, and $[^{214}Bi]/[^{218}Po]$ <0.07. At moderate aerosol concentrations, the daily average WL(Rn) was in the range 0.17 to 0.23, whereas the disequilibrium ratios were $[^{214}Pb]/[^{218}Po]$ ~0.44, and $[^{214}Bi]/[^{218}Po]$ ~0.30. Low disequilibrium ratios are indicative of high plate-out of decay products to large surfaces, e.g., RTTF walls.

Figures 1 and 2 show that the Sniffers followed WL(Rn) changes well when no abrupt changes occurred. i.e., when no aerosol injection took place. When aerosols were injected, sudden changes in WL(Rn) occurred and the dynamic behaviours of the Sniffers were somewhat different (see Figures 3 and 4). Aerosol injection was effected at about 8:00 h causing WL(Rn) to increase rapidly by at least a factor of 3 to 5. In general, however, changes in WL(Rn) were followed by the Sniffers although, as theoretically predicted, with some delay.

The performance of the Sniffers for radon progeny is shown in Table 2. In this table, N_α is the instruments α-count during the period Δt. The sensitivity of the instrument is indicated by S, which is defined as the α-count rate, in counts per hour (cphr), per milli Working Level (mWL). The average values for S under low and moderate aerosol concentration conditions are shown below.

Sniffer No.	S cphr $(mWL)^{-1}$	N cm^{-3}
1	2.57	Low
2	3.84	"
3	3.59	"
1	3.75	Moderate
2	5.38	"
3	4.63	"

The above table indicates:

a) there were substantial differences in S for the different instruments tested which cannot be ascribed to pump flow rate differences alone, but to differences in the sensitivity of the detector and associated electronic circuitry used; and

b) the sensitivity of the instruments was significantly lower (29-46%) when they were exposed to low aerosol concentration atmospheres than when they were exposed to moderate concentrations. This effect is attributed to the plate-out of radon progeny on the sampling head and other surfaces of the instrument.

Table 3 shows the average thoron progeny conditions in the RTTF under which the Sniffers were exposed. (It should be noted, as previously indicated, that only two Sniffers were tested in this case, namely, Sniffers No. 1 and No. 2.) The average daily thoron progeny Working Level, WL(Tn), in the RTTF was approximately, WL(Tn) ~10. The thoron progeny disequilibrium ratio was, $[^{212}Bi]/[^{212}Pb]$ ~0.45. The values given in Table 3 were for $N > 3 \times 10^3$ cm^{-3}, for which grab-sampling data, i.e., WL(Tn), $[^{212}Pb]$, and $[^{212}Bi]$ are available. The corresponding values prior to aerosol injection (~8:00 h) and up to about 2 hours later are significantly lower (not shown) than the values quoted in Table 3.

Because of the relatively long half-lives of ^{212}Pb (~10.6 h) and ^{212}Bi (~60.6 min), there is a time delay of about 2 hours before the Sniffers start to react to any sudden change in WL(Tn). However, the time required to detect the full impact of the change is considerably longer (>10 h), i.e., the time required by the instrument to attain a new steady-state or equilibrium condition after the radiation level is changed and maintained constant at the new level. This behaviour is to be expected on theoretical grounds, and has been amply documented by the author elsewhere ((6), and in other references).

Because of the above, and because of time constraints, a full technical evaluation of the Sniffer under thoron/thoron progeny atmospheres could not be completed. Figure 5 and Table 4 show data on the steady-state and transient behaviour of the instruments after injection of aerosols, i.e., sudden change of WL(Tn). From these data it is also possible to calculate approximate values for the sensitivity of the instrument, S, to thoron progeny. This can be done by taking the α-count rate at the end of the day (~16:00 h) as the final steady-state condition of the instrument. However, it should be clear that by doing so, S will be underestimated by some unknown amount, but it will, nevertheless, provide a lower limit for S. The slopes of the graphs permit a comparison of the two instruments to be made.

Inspection of Table 4 and Figure 5 show the following interesting features:

a) The minimum time taken for the Sniffers to react to any sudden change in WL(Tn) was ~2 h. However, the time taken by the instruments to reach a steady-state (equilibrium) condition under the new (constant) value for WL(Tn) exceeded a working day by a wide margin. It is estimated that it takes in the neighbourhood of 15 h for the instrument to 'read' the new WL(Tn).

b) From item a) and Table 4 it may be concluded that S for thoron progeny may not be much different to that for radon progeny.

c) As for the case of radon progeny S was different for different instruments. Sniffer No. 2 was more sensitive than Sniffer No. 1.

From items a) and b) one may surmise that the Sniffers may underestimate or overestimate WL(Tn) considerably if changes in the latter occur faster than the instrument reaction time. It should be stressed, however, that this is a problem common to all monitoring devices operating on time integrating principles. The instrument, is therefore, of limited use in rapidly changing thoron progeny atmospheres.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are suggested:

1. In radon progeny atmospheres, the instruments responded adequately to dynamic radiation conditions.
2. For thoron progeny atmospheres, the response of the instruments is much more limited unless WL(Tn) does not change rapidly.
3. As previously indicated elsewhere (3), and for precise measurements, the use of a servo-controlled sampling pump is strongly recommended.
4. The instruments have a serious drawback that severely limits their use:

namely, they have no data storage capabilities. Because of this, a fair amount of data manipulation is required. Furthermore, the readings are given in α-count and not in Working Level.

Because of item 4, and the lack of sampling programmability capabilities, information during unattended periods of time is not available.

The lack of electronic sophistication in this instrument is rather surprising because, to the knowledge of the author, any other solid-state electronic monitor available on the market has programmability and data storage capabilities incorporated in it as part of its selling and high technology features. However, the author has learned that the company that manufactures the Sniffer has recently incorporated the above features in its latest model.

ACKNOWLEDGEMENT

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Table 1 - Radon progeny grab-sampling data in the RTTF

Date	Time	WL(Rn)	$[^{218}Po]$ pCi/L	$[^{214}Pb]$ pCi/L	$[^{214}Bi]$ pCi/L	$\frac{[^{214}Pb]}{[^{218}Po]}$	$\frac{[^{214}Bi]}{[^{218}Po]}$
Sept. 17/87	8:38	0.030	14.38	1.63	1.97	0.11	0.14
"	9:49	0.033	17.05	1.87	1.59	0.11	0.09
"	10:46	0.036	18.58	2.11	1.57	0.11	0.08
"	11:33	0.034	16.92	2.32	1.18	0.14	0.07
"	12:37	0.041	21.18	2.86	1.35	0.13	0.06
"	13:31	0.047	24.68	2.89	1.82	0.12	0.07
"	14:30	0.058	26.95	4.45	1.97	0.16	0.07
"	15:23	0.066	28.08	5.45	2.61	0.19	0.09
	Ave:	0.043±0.013	20.98±5.09	2.95±1.34	1.76±0.44	0.13±0.03	0.08±0.03
Sept. 18/87	8:30	0.032	17.68	2.21	0.67	0.12	0.04
"	9:30	0.029	14.97	1.30	1.77	0.09	0.12
"	10:30	0.029(k)	-	-	-	-	-
"	11:30	0.036	20.89	2.41	0.65	0.11	0.03
"	12:35	0.035	18.40	2.20	1.26	0.12	0.07
"	13:30	0.033	17.86	1.84	1.31	0.10	0.07
"	14:30	0.031	16.26	1.49	1.75	0.09	0.11
"	15:30	0.038	23.69	2.66	-	-	-
	Ave:	0.033±0.003	18.54±2.9	2.02±0.49	1.14±0.66	0.11±0.01	0.07±0.04
Sept. 21/87	8:07	0.027	14.68	1.72	0.79	0.12	0.05
"	9:21	0.027	16.21	1.71	0.50	0.10	0.03
"	10:31	0.025	15.23	1.52	0.38	0.10	0.02
"	11:32	0.028	17.04	1.83	0.31	0.11	0.02
"	12:33	0.021(k)	-	-	-	-	-
"	13:32	0.039	21.45	3.11	0.12	0.14	∿0.01
"	14:33	0.040	21.75	2.90	0.82	0.13	0.04
"	15:27	0.031	17.04	1.96	1.04	0.11	0.06
	Ave:	0.030±0.007	17.62±2.85	2.11±0.63	0.57±0.33	0.12±0.02	0.03±0.02
Sept. 22/87	9:36	0.149	37.51	15.09	9.17	0.40	0.24
"	10:27	0.155	35.05	15.82	10.42	0.45	0.30
"	11:26	0.148	36.17	14.09	10.46	0.39	0.29
"	12:32	0.141	27.56	13.31	11.93	0.48	0.43
"	13:28	0.167	34.23	16.48	12.93	0.48	0.38
"	14:33	0.214	44.98	22.52	14.18	0.50	0.31
"	15:25	0.244	54.41	24.50	17.01	0.45	0.31
	Ave:	0.174±0.04	38.56±8.67	17.40±4.34	12.30±2.68	0.45±0.04	0.32±0.06
Sept. 23/87	8:32	0.092	31.10	9.26	3.55	0.30	0.11
"	9:22	0.135	36.89	13.64	7.37	0.37	0.20
"	10:22	0.154	36.96	14.62	11.20	0.40	0.30
"	11:22	0.184	39.97	18.36	13.26	0.46	0.33
"	12:24	0.204	44.63	21.00	13.88	0.47	0.31
"	13:22	0.213	48.47	21.00	15.26	0.43	0.31
"	14:20	0.231	43.11	24.23	17.02	0.56	0.39
"	15:20	0.246	48.97	25.56	17.69	0.52	0.36
	Ave:	0.195±0.04	41.26±6.20	18.42±5.54	12.40±4.86	0.44±0.08	0.29±0.09
Sept. 24/87	8:24	0.075	32.76	6.64	2.04	0.20	0.06
"	9:18	0.141	33.02	14.33	9.09	0.43	0.27
"	10:33	0.186	42.50	18.87	12.46	0.44	0.29
"	11:15	0.192	40.78	18.30	15.19	0.45	0.37
"	12:38	0.221	48.77	22.41	15.38	0.46	0.31
"	13:24	0.228	44.44	21.99	18.88	0.49	0.42
"	14:22	0.256	53.28	25.60	19.14	0.48	0.36
"	15:27	0.270	60.57	28.22	17.27	0.47	0.28
	Ave:	0.226±0.034	44.52±9.57	19.55±6.77	13.68±5.77	0.43±0.09	0.30±0.11

Notes: k indicates measurement by the Kusnetz method.

Table 2 - Sniffers and radon progeny grab-sampling data.

Date	Sniffer No.	N_α (α-count)	Δt (h)	$\overline{WL(Rn)}$	N (cm^{-3})	S $cphr(mWL)^{-1}$	Q ($L\ min^{-1}$)
Sept. 18/87	1	684	7.67			2.70	1.05
"	2	1027	7.67	0.033±0.003	$<3x10^3$	4.06	1.10
"	3	990	7.67			3.91	1.05
Sept. 21/87	1	551	7.50			2.45	1.05
"	2	814	7.50	0.030±0.007	$<3x10^3$	3.62	1.10
"	3	736	7.50			3.27	1.05
Sept. 22/87	1	3901	5.97			3.76	1.05
"	2	5368	5.97	0.174±0.004	$>5x10^3$	5.17	1.10
"	3	4652	5.97			4.48	1.05
Sept. 23/87	1	4773	6.50			3.77	1.05
"	2	7073	6.50	0.195±0.004	$>5x10^3$	5.58	1.10
"	3	6130	6.50			4.84	1.05
Sept. 24/87	1	4207	5.00			3.72	1.05
"	2	6092	5.00	0.226±0.034	$>7.5x10^3$	5.39	1.10
"	3	5155	5.00			4.56	1.05

Notes: [1] S stands for sensitivity, Q for air flowrate, N_α for α-count, N for aerosol concentration, Δt for time interval, and $\overline{WL(Rn)}$ for daily WL(Rn) average.

Table 3 - Thoron progeny grab-sampling data in the RTTF.

Date	Time	WL(Tn)	[^{212}Pb] pCi/L	[^{212}Bi] pCi/L	[^{212}Bi]/[^{212}Pb]	N cm^{-3}
Sept. 2/87	13:00	9.97	76.19	32.01	0.42	$5-7x10^3$
"	15:00	10:07	78.21	34.29	0.44	"
Sept. 3/87	13:00	9:07	70.45	31.29	0.44	$3-5x10^3$
"	15:00	9:20	71.51	31.17	0.44	"
Sept. 4/87	13:00	9:89	76.58	36.02	0.47	$4-8x10^3$
"	15:03	10:85	83.93	40.72	0.48	"
	Ave:	9.81±0.64	76.15±4.88	34.25±3.69	0.45±0.02	

Notes: Aerosols were injected continuously every morning at about 8:00 h.
N before aerosol injection was in the approximate range $1-2x10^3$ cm^{-3}.
N stands for aerosol concentration.

Table 4 - Sniffers and thoron progeny, WL(Tn), grab-sampling data.

Date	Sniffer No.	$(N_\alpha/\Delta t)_0$ (cphr)	$N_\alpha/\Delta t$ (cphr)	$\overline{WL(Tn)}$	S (cphr/mWL)	N cm^{-3}	m cpm/min
Sept. 3/87	1	11613	18900	9.13	>2.07	$3\text{-}5 \times 10^3$	0.333
"	2	16108	27000	9.13	>2.96	"	0.489
Sept. 4/87	1	12229	19800	10.37	>1.91	$4\text{-}8 \times 10^3$	0.327
"	2	17400	28500	10.37	>2.74	"	0.520
Sept. 2/87	1	-	-	9.93	-	$5\text{-}7 \times 10^3$	0.557
"	2	-	-	9.93	-	"	0.782

Notes: a) Aerosols were injected continuously every morning at about 8:00 h. The aerosol concentration, N, in the RTTF before injection was in the range $1\text{-}2 \times 10^{-3}$ cm^{-3}.

b) S stands for sensitivity, N_α for α-count, and Δt for time interval. THe indices 0 and 1 are used to indicate the count rate under steady-state condition before injection of aerosols, and at the end of the day (∿16: 00 h), respectively.

c) m is the slope of the graphs. The horizontal bar is used to denote daily average value.

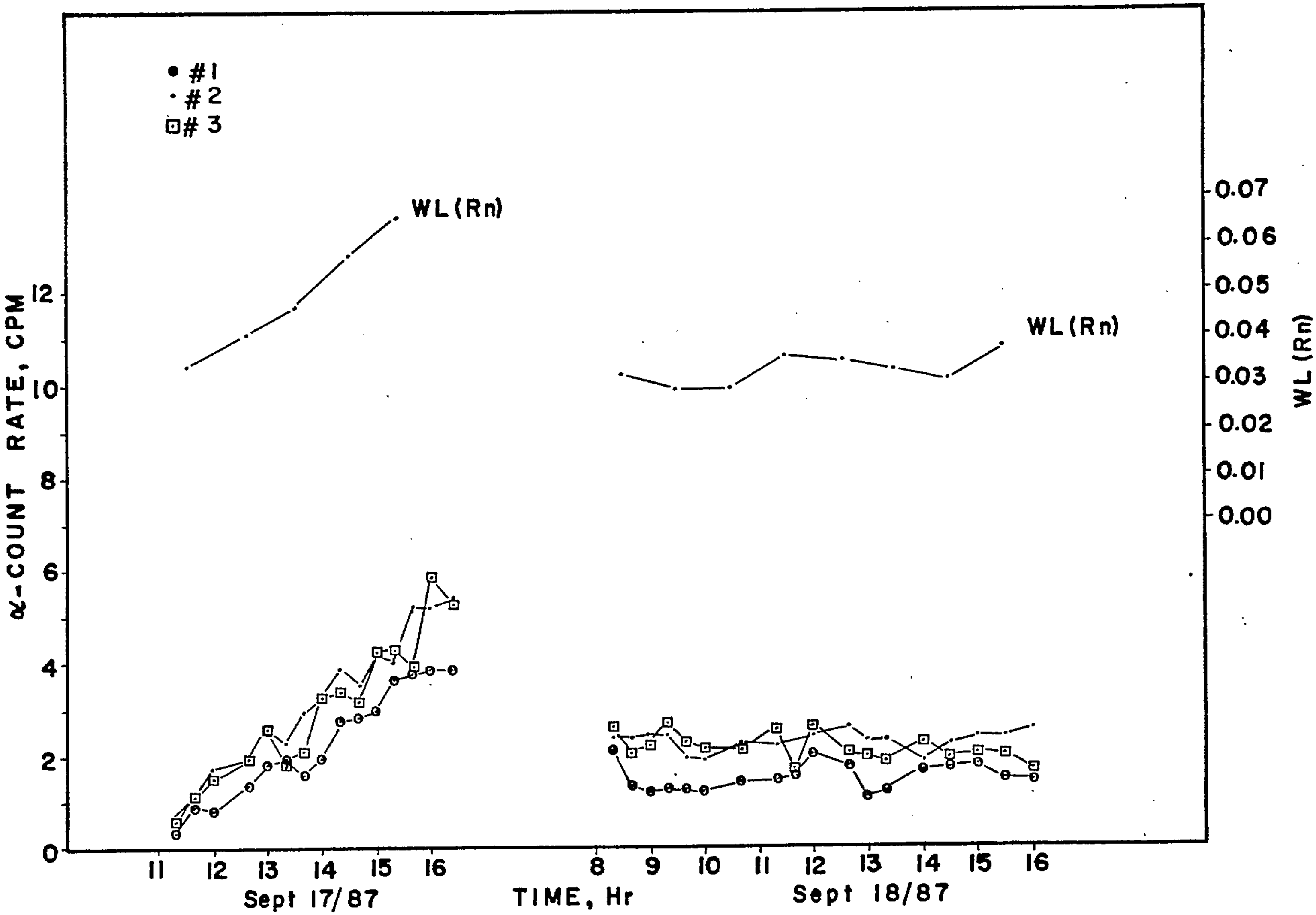

Fig. 1 - Response of the Sniffer monitors No. 1, 2 and 3 to a radon/radon progeny atmosphere.

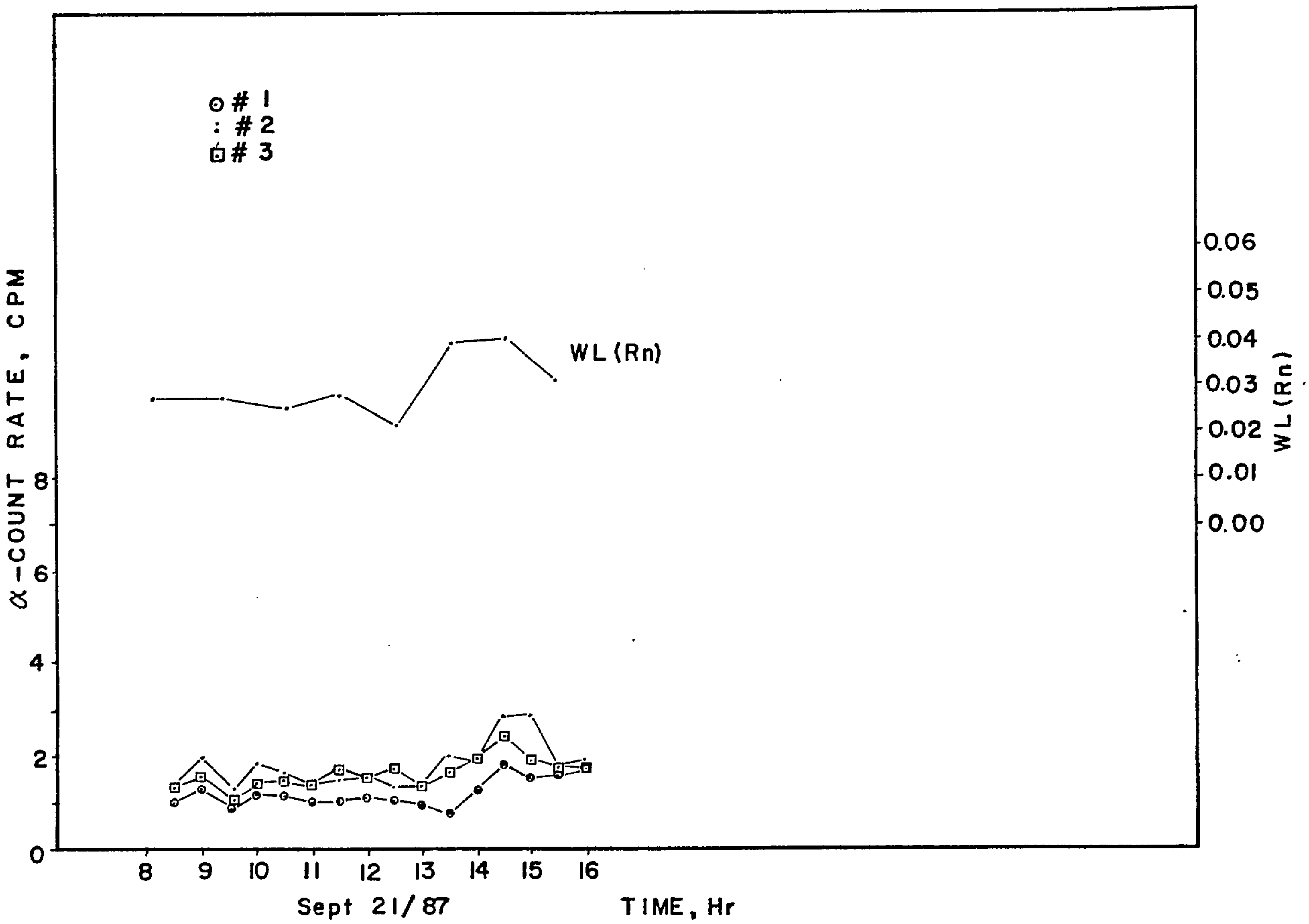

Fig. 2 - Response of the Sniffer monitors No. 1, 2 and 3 to a radon/radon progeny atmosphere.

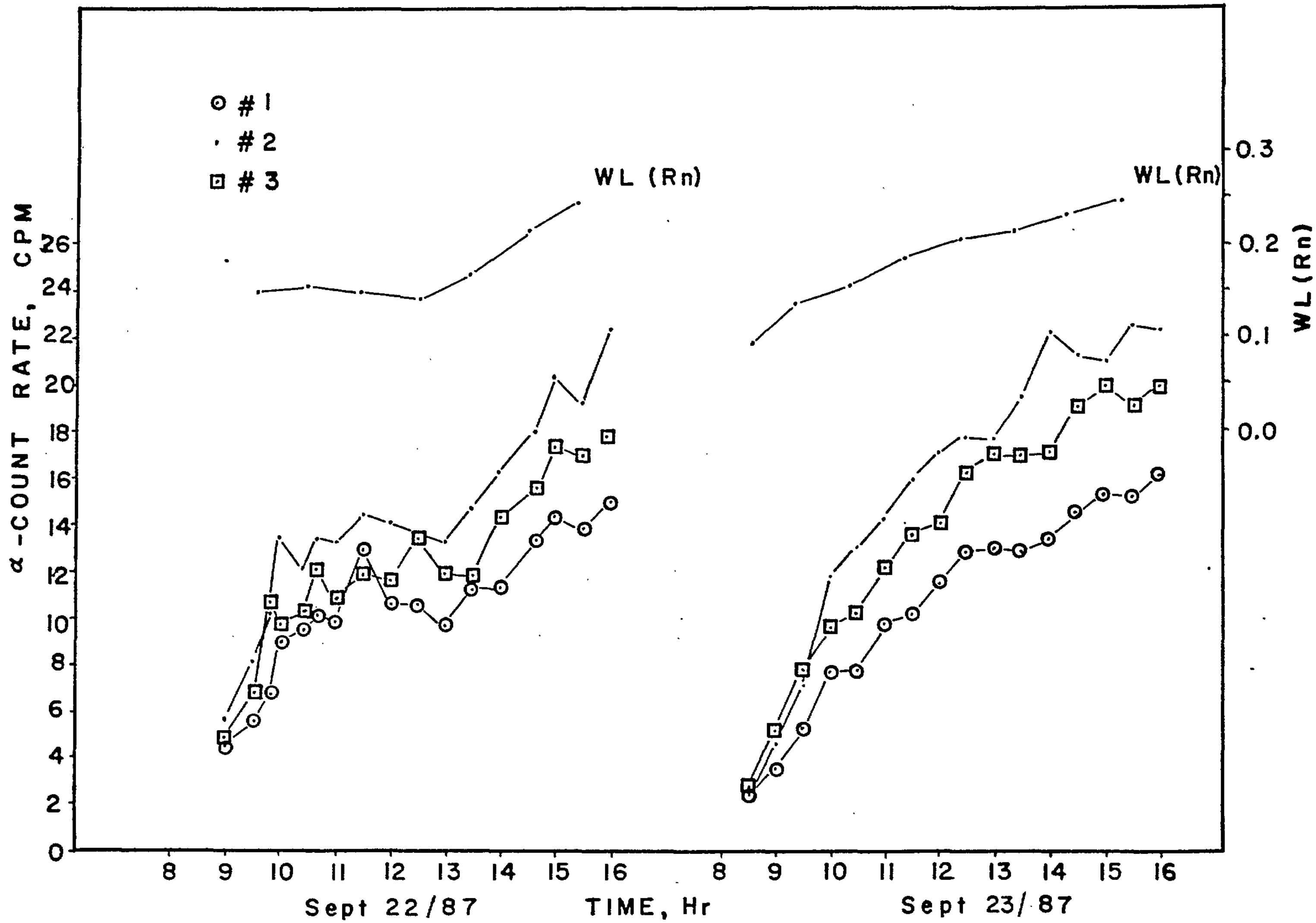

Fig. 3 - Response of the Sniffer monitors No. 1, 2 and 3 to a radon/radon progeny atmosphere.

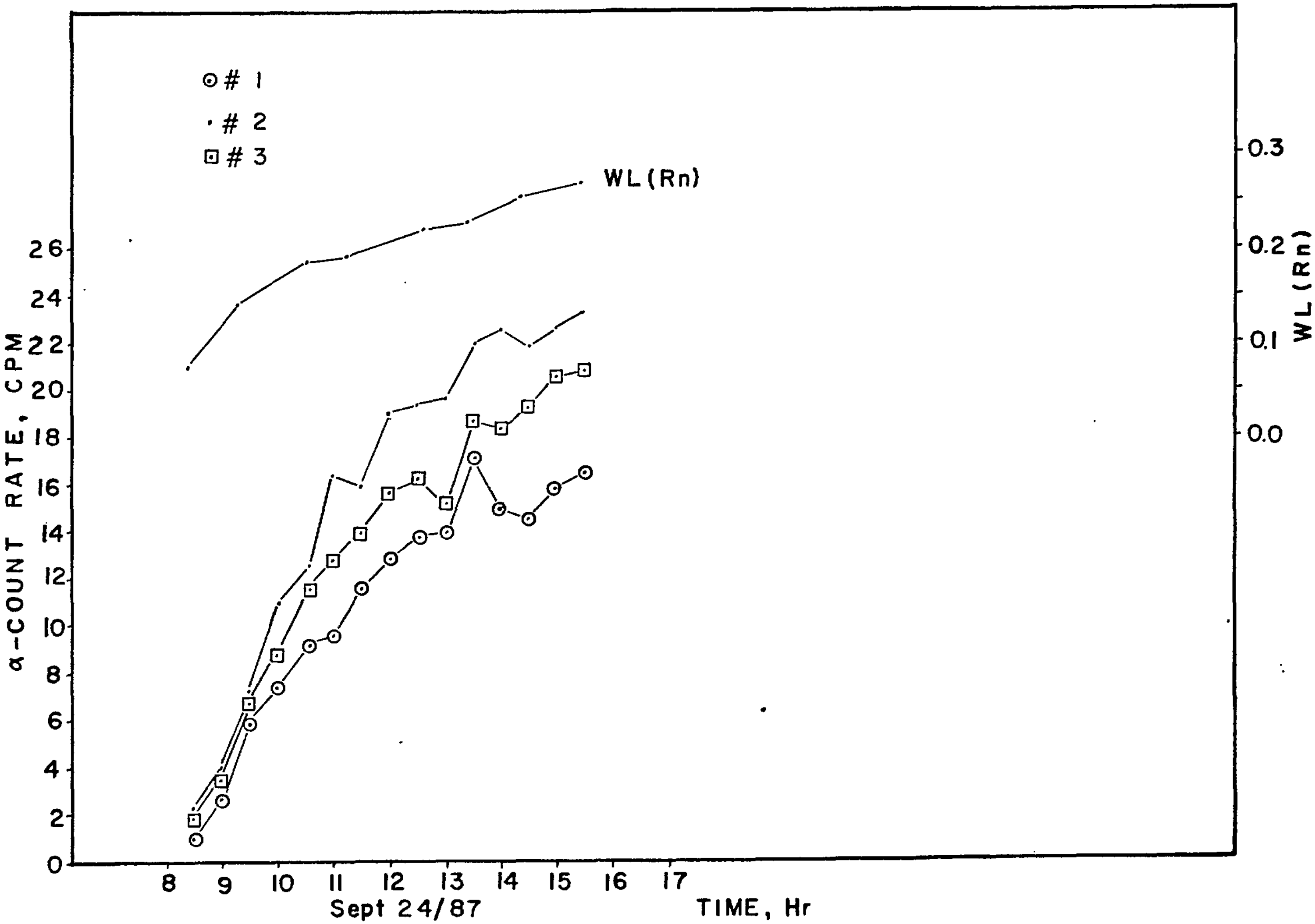

Fig. 4 - Response of the Sniffer monitors No. 1, 2 and 3 to a radon/radon progeny atmosphere.

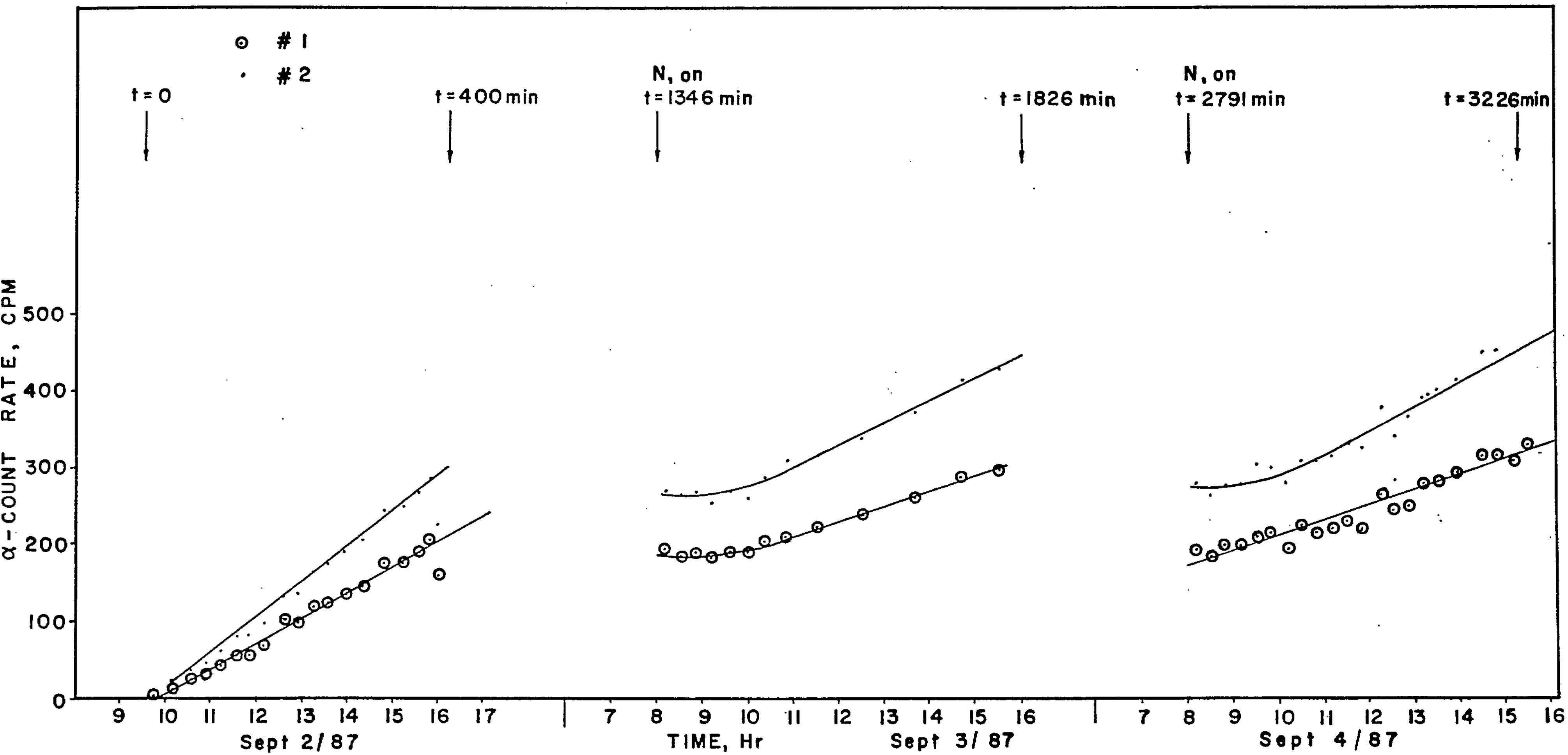

Fig. 5 - Response of the Sniffer monitors No. 1 and 2 to a thoron/thoron progeny atmosphere.
N, on stands for aerosol injection at the time indicated by the vertical arrows.
The symbol t indicates time elapsed since the beginning of the test.