THE RADIATION HAZARD FROM THE TANTALUM DUMPS IN PENANG.

General

This report presents the results of the investigations by PUSPATI on the radiation levels in the vicinity of selected tantalum dump sites in Penang. This report covers only the external (or direct) radiation i.e. radiation exposure due to gamma rays. The extent of the potential internal hazards due to ingestion and inhalation of alpha and beta emitters will be presented in the final report which is under preparation.

Summary

The radiation level at the dumps are well above background. The readings taken on the dumps themselves range from 1000 mrem/year to 5860 mrem/year. The radiation levels in the houses close to the dump at Hill Railway Road were much lower, in the range of 160 mrem/year to 335 mrem/year. However, the level recorded at a house on Medan Tembaga is higher, being around 650 mrem/year.

It is worth noting that the maximum permissible dose as recommended by the International Commission on Radiological Protection for the general public is 500 mrem/year and the average background radiation level is around 80-90 mrem/year.

1.1 INTRODUCTION

The natural radionuclides in the environment are of two general classes, the primordial and the cosmogenic. The cosmogenic radionuclides are mainly produces through interaction of the cosmic rays with target atoms in the atmosphere and, to a much lesser extent, in the earth. The three main cosmogenic contributors to external radiation exposure at ground level are Be-7, Na-22, and Na-24.

Among the primordial radionuclides, the main contributors to external exposure are K-40, and the radioactive series of U-238 and Th-232. Since the tantalum dumps are the concentrated form of natural ore, the above mentioned primordial radionuclides and their daughter products are the main contributors to the external radiation exposure.

The decay of the radioactive series of U-238 and Th-232 produces alpha, beta and gamma radiation. Because the alpha and beta radiation given off by the natural radionuclides have short range in air and also the human organs and tissues in which the doses are normally calculated for are shielded by at least a few millimetres of skin and tissue, which absorbs practically all of the energy of the alpha and beta radiation, only the gamma contribution will be considered here.

The objective of this section in the present study was to measure the external radiation level at the dump sites and at houses in the vicinity of the dumps and thus to estimate the annual dose equivalent from external radiation exposure at these places were estimated.

1.2 METHODS

The external radiation exposure presented in this report

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was measured with BGS-4 Gamma-Ray Scintillation Counter and PDR1 Geiger-Muller Low level Radiation Monitor. BGS-4 Gamma-Ray Scintillation Counter gives reading in cps (full range from 0 - 19,990 cps) and PDR1 Geiger-Muller Low Level Radiation Monitor gives reading in urad/hr and mrad/hr (full range from 1 µrad/hr to 10 mrad/hr on a log scale). Both instruments were calibrated to give results in µR/hr and mR/hr with 5mCi (1977) Cs-137 standard source. (See appendix A).

Five dump sites were investigated. The external radiation measurement was takrn at different points as indicated in Figures 1 - 5. Measurements were taken twice at each point, one at near contact with the surface and the other one at a distance of 1 meter above the surface.

1.3 RESULTS

Table 1 - 5 give the readings of the measurements taken at the five dump sites. All the readings are uncorrected for background which is generally 10 to 25 µR/hr.+ The two instruments used for the measurements do not all yield the same readings but in agreement between one another within 15 percent. Both readings are presented here.

In the above tables, Column 1 and 2 give the readings as indicated by the two instruments at the appropriate points. Column 3 and 4 give the actual radiation exposurres rate in air corrected for the calibration factors of the two instruments, while column 5 and 6 give the average radiation exposure rate in air and the average annual dose equivalent rate in tissue respectively. Calculations and formula used for the conversion of external radiation exposure rate in air into annual dose equivalent rate in tissue is given in appendix B.

+ PDR1 measurements gave 15 µR/hr at the Penang International Airport and 25 µR/hr in room 501 Oriental Hotel, Penang.

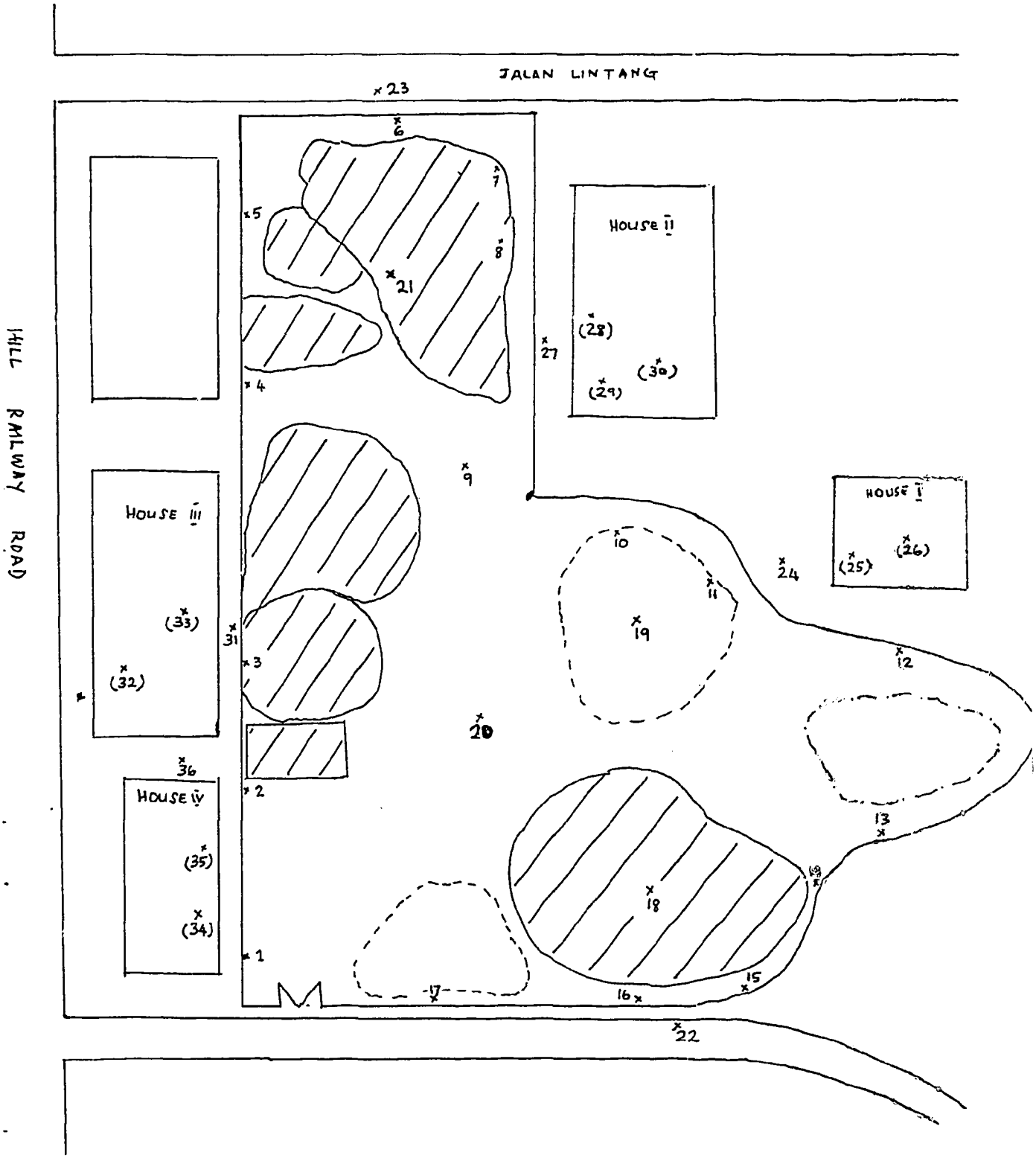


FIG. 1. DUMP SITE No. 1

TABLE 1 EXTERNAL RADIATION MEASUREMENTS AT DUMP SITE NO. 1

LOCATION	BGS-4 READING (cps)	PDRI READING (mrad/hr)	CORRECTED BGS-4 READING (mR/hr)	CORRECTED PDRI READING (mR/hr)	AVERAGE EXPOSURE RATE (mR/hr)	AVERAGE ANNUAL DOSE EQUIVALENT RATE (mrem/yr)
1	2650	0.18	0.150	0.19	0.170	1430
	1950	0.10	0.110	0.11	0.110	925
2	5850	0.30	0.330	0.32	0.325	2733
	4750	0.35	0.268	0.37	0.319	2683
3	9250	0.55	0.522	0.59	0.556	4676
	6950	0.40	0.392	0.43	0.411	3456
4	7800	0.50	0.440	0.54	0.490	4121
	5600	0.35	0.316	0.37	0.343	2884
5	10,450	0.60	0.590	0.64	0.615	5172
	6650	0.35	0.375	0.37	0.373	3137
6	8000	0.55	0.452	0.59	0.521	4381
	4750	0.30	0.268	0.32	0.294	2472
7	7250	0.50	0.409	0.54	0.475	3995
	4350	0.25	0.246	0.27	0.258	2170
8	6700	0.50	0.378	0.54	0.459	3860
	5500	0.35	0.310	0.37	0.340	2859

TABLE 1 (CONT'D) (1b)

LOCATION	BGS-4 READING (cps)	PDRI READING (mrad/hr)	CORRECTED BGS-4 READING (mR/hr)	CORRECTED PDRI READING (mR/hr)	AVERAGE EXPOSURE RATE (mR/hr)	AVERAGE ANNUAL DOSE EQUIVALENT RATE (mrem/yr)
9	8600	0.50	0.485	0.54	0.513	4314
	6500	0.35	0.367	0.37	0.369	3103
10	8600	0.60	0.485	0.64	0.563	4735
	5300	0.30	0.299	0.32	0.310	2607
11	8750	0.45	0.494	0.48	0.487	4095
	5700	0.30	0.322	0.32	0.321	2699
12	1150	0.045	0.065	0.048	0.057	479
	1320	0.055	0.075	0.059	0.067	563
13	2300	0.10	0.130	0.11	0.120	1009
	2100	0.095	0.119	0.10	0.110	925
14	4780	0.28	0.270	0.30	0.285	2397
	2800	0.17	0.158	0.18	0.169	1421
15	4220	0.25	0.238	0.27	0.254	2136
	2900	0.18	0.164	0.19	0.177	1488
16	2650	0.10	0.150	0.11	0.13	1093
	2650	0.15	0.150	0.16	0.155	1303

TABLE 1 (CONT'D) (1c)

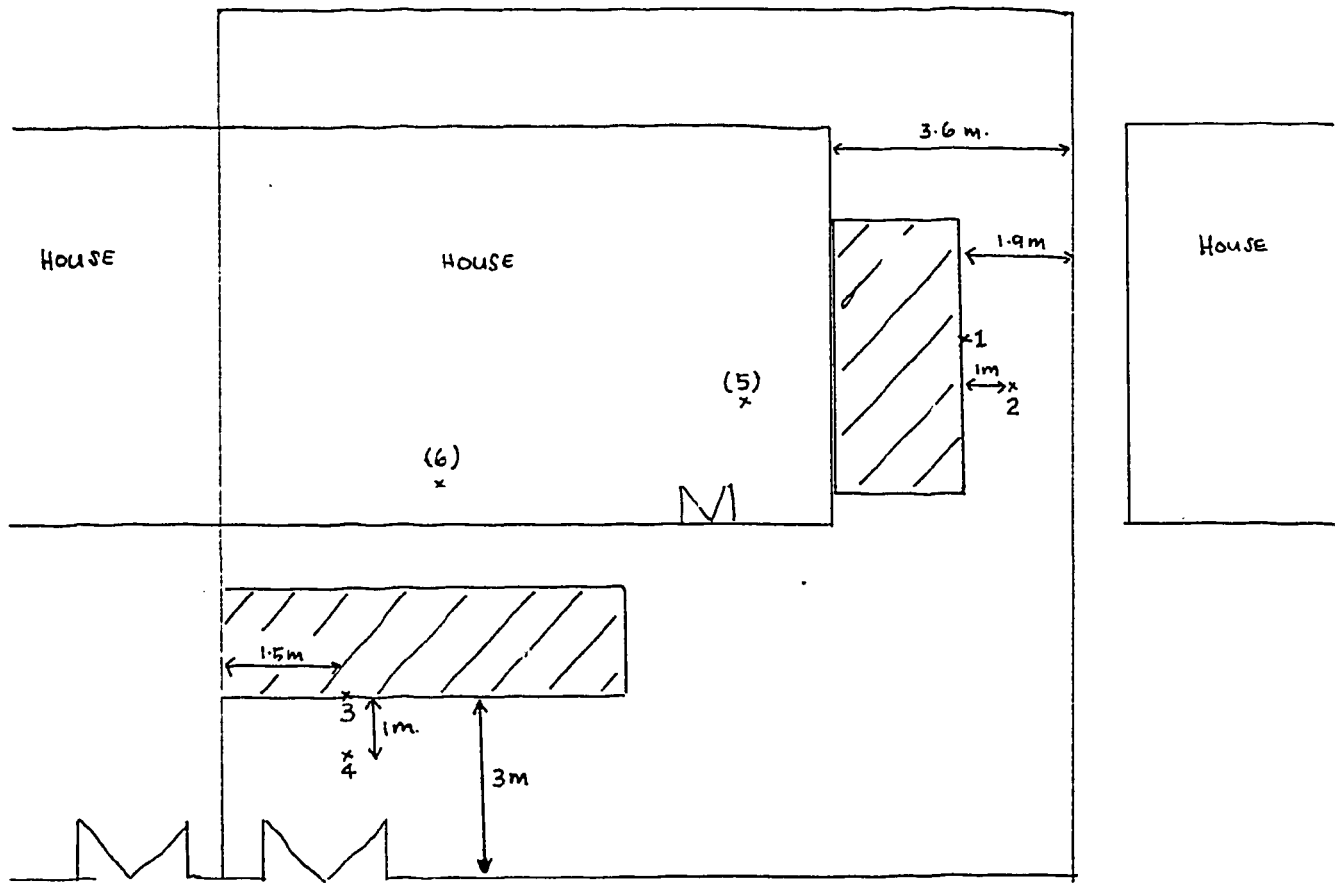
LOCATION	BGS-4 READING (cps)	PDRI READING (Mrad/hr)	CORRECTED BGS-4 READING (mR/hr)	CORRECTED PDRI READING (mR/hr)	AVERAGE EXPOSURE RATE (mR/hr)	AVERAGE ANNUAL DOSE EQUIVALENT RATE (mrem/yr)
17	6300	0.35	0.356	0.37	0.363	3053
	4150	0.20	0.234	0.21	0.222	1867
18	10700	0.65	0.604	0.70	0.652	5483
	6400	0.25	0.361	0.27	0.316	2657
19	11400	0.70	0.643	0.75	0.697	5862
	8850	0.50	0.499	0.54	0.520	4373
20	5740	0.30	0.324	0.32	0.322	2708
	4900	0.25	0.277	0.27	0.274	2304
21	9050	0.55	0.511	0.59	0.551	4634
	7300	0.45	0.412	0.48	0.446	3751
22	1070	0.045	0.060	0.048	0.054	454
	1380	0.055	0.078	0.059	0.069	580
23	720	0.025	0.041	0.027	0.034	286
	980	0.040	0.055	0.043	0.049	412
24	550	0.025	0.031	0.027	0.029	244
	590	0.020	0.033	0.021	0.027	227

TABLE 1 (CONT'D) (1d)

LOCATION	BGS-4 READING (cps)	PDRI READING (mrad/hr)	CORRECTED BGS-4 READING (mR/hr)	CORRECTED PDRI READING (mR/hr)	AVERAGE EXPOSURE RATE (mR/hr)	AVERAGE ANNUAL DOSE EQUIVALENT RATE (mrem/yr)
25	460	0.020	0.026	0.021	0.024	202
	575	0.025	0.032	0.027	0.030	252
26	360	0.017	0.020	0.018	0.019	160
	360	0.017	0.020	0.018	0.019	160
27	910	0.040	0.051	0.043	0.047	395
	1720	0.080	0.097	0.086	0.092	774
28	490	0.025	0.028	0.027	0.028	235
	585	0.030	0.033	0.032	0.033	278
29	370	0.020	0.021	0.021	0.021	177
	460	0.022	0.026	0.024	0.025	210
30	540	0.030	0.030	0.032	0.031	261
	640	0.040	0.036	0.043	0.040	336
31	3180	0.21	0.179	0.22	0.200	1682
	4950	0.25	0.279	0.27	0.275	2313
32	490	0.025	0.028	0.027	0.028	235
	500	0.030	0.028	0.032	0.030	252

TABLE 1 (CONT'D) (1e)

LOCATION	BGS-4 READING (cps)	PDRI READING (mrad/hr)	CORRECTED BGS-4 READING (mR/hr)	CORRECTED PDRI READING (mR/hr)	AVERAGE EXPOSURE RATE (mR/hr)	AVERAGE ANNUAL DOSE EQUIVALENT RATE (mrem/yr)
33	560	0.025	0.032	0.027	0.030	252
	850	0.030	0.048	0.032	0.040	336
34	490	0.020	0.028	0.021	0.025	210
	760	0.035	0.043	0.037	0.040	336
35	380	0.018	0.021	0.019	0.020	168
	475	0.025	0.027	0.027	0.027	227
36	1200	0.050	0.068	0.054	0.061	513
	2050	0.15	0.116	0.16	0.138	1161



MEDAN TEMBAGA.

FIG. 2. DUMP SITE NO. 2.

TABLE 2

SITE NO. 2

LOCATION	BGS-4 READING (cps)	PDRI READING (mrad/hr)	CORRECTED BGS-4 READING (mR/hr)	CORRECTED PDRI READING (mR/hr)	AVERAGE EXPOSURE RATE (mR/hr)	AVERAGE ANNUAL DOSE EQUIVALENT RATE (mrem/yr)
1	11600	0.80	0.655	0.86	0.758	6374
	9700	0.70	0.547	0.75	0.649	5458
2	5050	0.30	0.285	0.32	0.303	2548
	5750	0.35	0.325	0.37	0.348	2927
3	9200	0.60	0.519	0.64	0.580	4878
	7800	0.50	0.440	0.54	0.490	4121
4	3250	0.17	0.183	0.18	0.182	1531
	3800	0.22	0.214	0.24	0.227	1909
5	1200	0.055	0.068	0.059	0.064	538
	1500	0.060	0.085	0.064	0.075	631
6	750	0.040	0.042	0.043	0.043	362
	1350	0.080	0.076	0.086	0.081	681

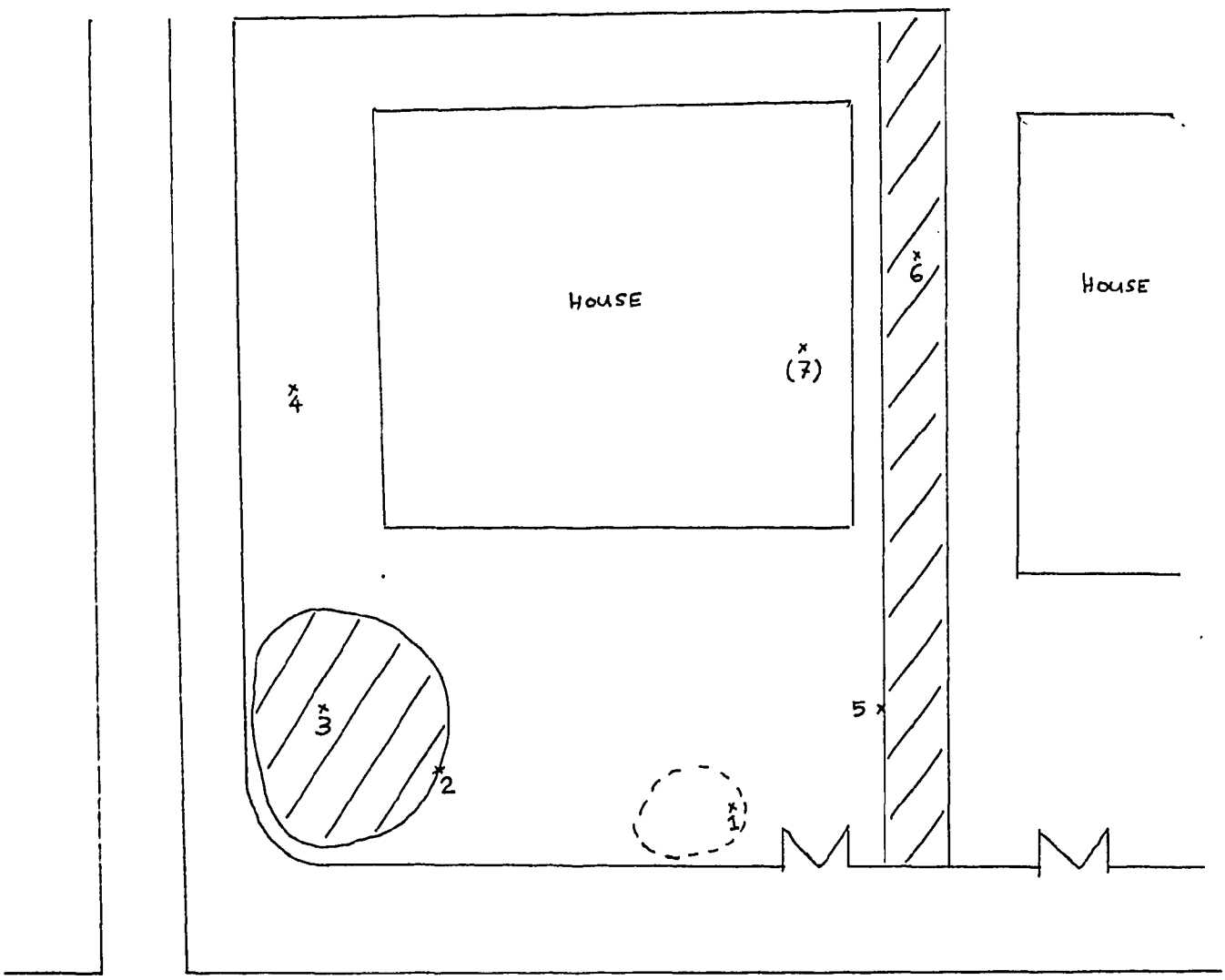


FIG. 3. DUMP SITE NO. 3

EXTERNAL RADIATION MEASUREMENTS AT DUMP

TABLE 3 SITE NO. 3

LOCATION	BGS-4 READING (CPS)	PDRI READING (mrad/hr)	CORRECTED BGS-4 READING (mR/hr)	CORRECTED PDRI READING (mR/hr)	AVERAGE EXPOSURE RATE (mR/hr)	AVERAGE ANNUAL DOSE EQUIVALENT RATE (mrem/yr)
1	1170	0.065	0.066	0.070	0.068	572
	1150	0.060	0.065	0.064	0.065	547
2	2800	0.20	0.158	0.21	0.184	1547
	1850	0.10	0.104	0.11	0.107	900
3	2300	0.15	0.130	0.16	0.145	1219
	1650	0.10	0.093	0.11	0.102	858
4	750	0.035	0.042	0.037	0.040	336
	500	0.030	0.028	0.032	0.030	252
5	4150	0.20	0.234	0.21	0.222	1867
	4400	0.25	0.248	0.27	0.259	2178
6	11400	0.75	0.643	0.80	0.722	6072
	5700	0.30	0.322	0.32	0.321	2699
7	460	0.025	0.026	0.027	0.027	227
	810	0.035	0.046	0.037	0.042	353

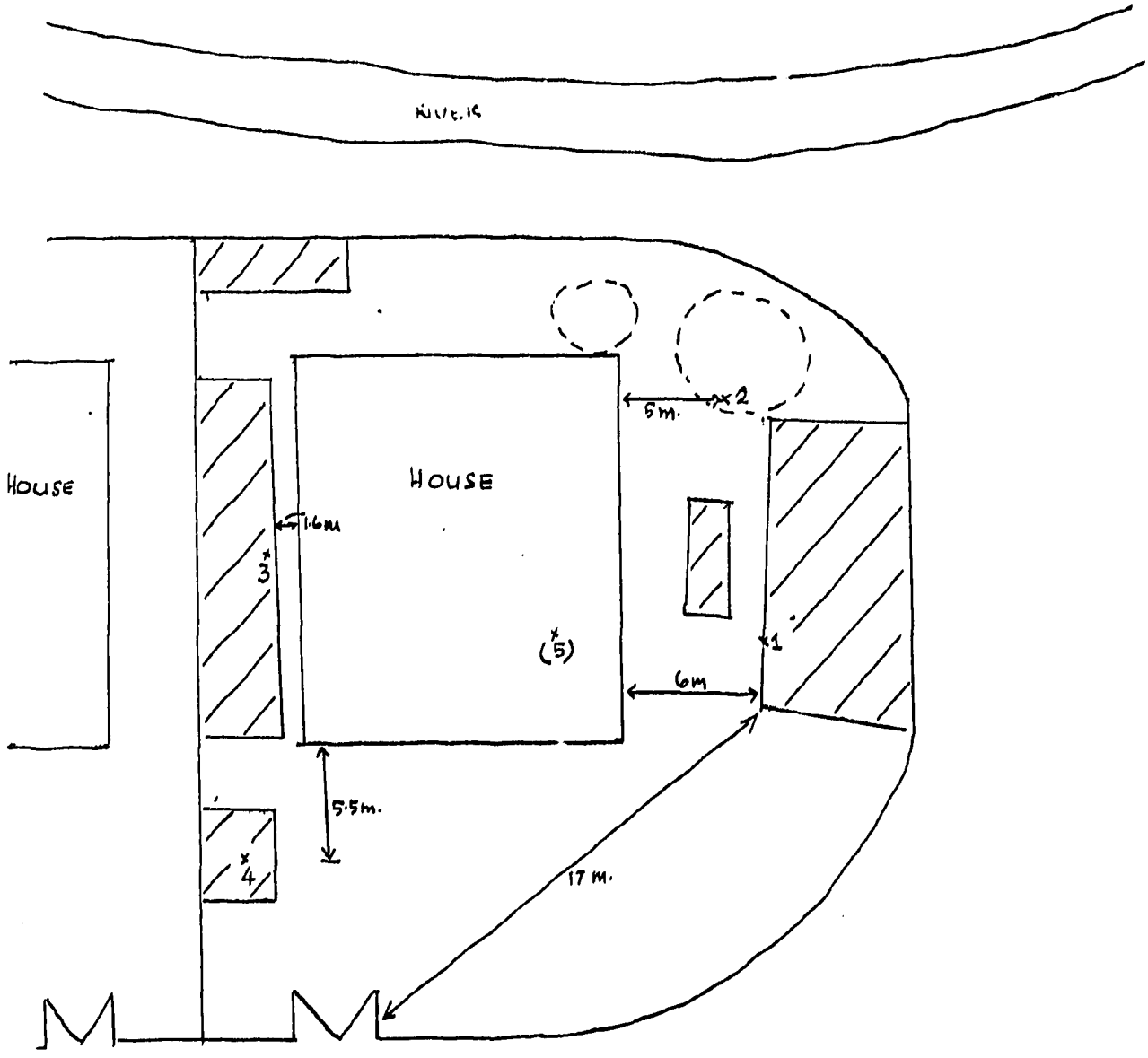


FIG. 4. DUMP SITE NO. 4.

TABLE 4

EXTERNAL RADIATION MEASUREMENTS AT DUMP SITE NO. 4

LOCATION	BGS- 4 READING (cps)	PDRI READING (mrad/hr)	CORRECTED BGS-4 READING (mR/hr)	CORRECTED PDRI READING (mR/hr)	AVERAGE EXPOSURE RATE (mR/hr)	AVERAGE ANNUAL DOSE EQUIVALENT RATE (mrem/yr)
1	6550	0.35	0.370	0.37	0.370	3112
	6600	0.40	0.373	0.43	0.402	3381
2	4950	0.30	0.279	0.32	0.300	2523
	4800	0.25	0.271	0.27	0.271	2279
3	6350	0.40	0.358	0.43	0.394	3313
	7600	0.45	0.429	0.48	0.455	3826
4	3650	0.18	0.206	0.19	0.198	1665
	4400	0.25	0.248	0.27	0.259	2178
5	440	0.025	0.025	0.027	0.026	219
	480	0.030	0.027	0.032	0.030	252

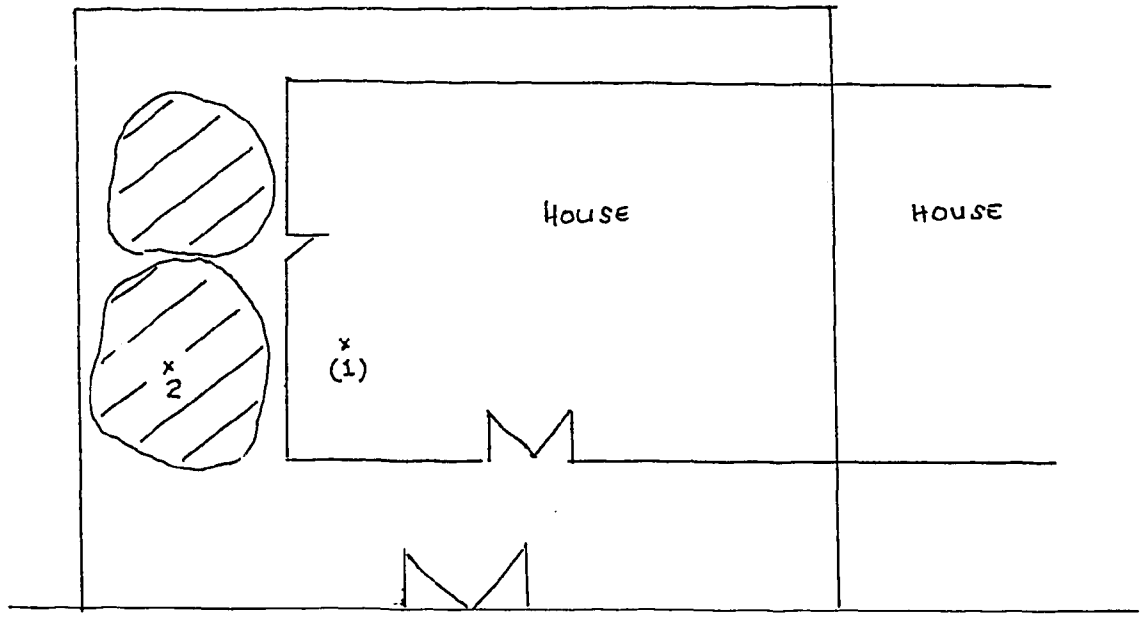


FIG. 5. DUMP SITE NO. 5

TABLE 5 EXTERNAL RADIATION MEASUREMENTS AT DUMP

SITE NO. 5

LOCATION	BGS-4 READING (cps)	PDRI READING (mrad/hr)	CORRECTED BGS-4 READING (mR/hr)	CORRECTED PDRI READING (mR/hr)	AVERAGE EXPOSURE RATE (mR/hr)	AVERAGE ANNUAL DOSE EQUIVALENT RATE (mrem/yr)
1	440	0.025	0.025	0.027	0.026	219
	690	0.040	0.039	0.043	0.041	34[illegible]
2	2700	0.15	0.152	0.16	0.156	1312
	1680	0.080	0.095	0.086	0.091	765

1.4. DISCUSSION

1.4.1 External Exposure

The annual external radiation levels obtained from recent surveys carried out at the five dump sites are given in the previous Section (Table 1-5). A total of 21 points at the first dump site i.e. the main dump near Hill Railway Road were measured for external radiation. In many parts of the dump area, external radiation level was in the range of 1000 mrem/yr to 5960 mrem/yr. A Considerable amount of the tantalum pile was dumped close to the fence and therefore external radiation level near the fence was in the same large as above.

Outside the first dump area, external radiation level ranged from 227 mrem/yr to 2313 mrem/yr, where the highest level was at about half a meter from The fence close to a tantalum pile (point 31). In the compound of houses in the vicinity of the first dump site, the highest radiation level measured was 774 mrem/yr.

Indoor measurements for external radiation were also done in four of the houses adjecent to the first dump site. Radiation levels here are much lower in the order of 160 mrem/yr to 336 mrem/yr.

The second, third, fouth and fifth dump sites are located in the compounds of houses. The measurements taken close to the tantalum pile and bags containing tantalum indicated radiation levels in the range of 1200 mrem/yr to 6374 mrem/yr. The highest level was recorded at dump site no.2 (Medan Tembaga) which was 6374 mrem/yr at near contact and 2548 mrem/yr at a distance of one meter away.

Indoor measurements indicated external radiation levels between 219 mrem/yr to 345 mrem/yr, except in the house at the

Second site (Medan Tembaga) where the observed rates were about twice as high in the region of 630 mrem/yr to 680 mrem/yr.

The radiation levels at the dump sites is shown to be ten to sixty times higher when compared to that of background radiation (refer table 6). However, readings in most of the houses are only slightly above the background radiation level, except for the house in site no. 2 (Medan Tembaga) which has radiation level higher than background level. This may be attributed to the fact that the radiation levels at the dumps which are placed at the side of the house shows the highest reading among all the five dumps investigated. The radiation levels at the tantalum dumps can also be compared to that of radiation exposure from medical diagnostis and treatment (refer table 7).

However, the most important deduction that can be derived from external radiation measurement is the dose equivalent received by individuals, in particular those living in vicinity of the dump site. The maximum dose limit (MPD) for the general public set by the International Commission for Radiological Protection (ICRP) is 500 mrem/yr. For example, the highest radiation level recorded which is 6374 mrem/yr will result in a whole body irradiation of 12.75 times higher than the MPD. Therefore, a person will receive the masimum permissible dose if he/she stays in contact with the dump for about 1.88 hours every-day throughout the year. However, the external dose received will decrease with distance from the dump as shown from readings in the houses. In the case of dump site no. 2 (Medan Tembaga), the occupants of the house will receive radiation dose of about 650 mrem/yr which 30% above the MPD, assuming that they are in the house 24 hours per day.

1.4.2 Internal Exposure

As mentioned ealier, the tantalum dumps contain radio-nuclides which emit alpha and beta radiation in addition to gamma-rays. While the gamma radiation results in an external dose, the

alpha and beta emitters pose an internal hazard when inhaled or ingested. The sources of the harard are in the form of the radioactive gases namely radon and thoron and other radioactive materials in the form of particulates in the air (dust). Since the dumps are in the open, they could pose a serious problem especially during the dry season.

The determination of amounts of alpha and beta radionuclides are in the proses of analysis and results will be p presented and discussed in the detail report.

TABLE 6 NATURAL BACKGROUND LEVELS

AREA	POPULATION INCLUDED	BACKGROUND LEVEL (mrem/yr)
U.S. (Atlantic & Gulf Coast)	6,760,000	65 - 70
U.S. (Non-coastal plains)	46,780,000	80 - 95
U.S. (Colorado Plateau)	1,070,000	125 - 160
U.S. (Leadville,Colorado)	10,000	235
U.S. (Central Florida & New England Areas)	?	200
Brazil (Coastal strips)	30,000	500
France (Granite rock areas)	7,000,000	180 - 350
India (Kerala & Madras states)	100,000	1300
Niue Island (Pacific)	3,000	1000
Egypt (Northern Nile Delta)	Densely Populated	300 - 400
World (Calculated average)	2 billion	80 - 90

TABLE 7 USUAL DOSES FOR MEDICAL EXPOSURES

PROCEDURE	DOSE TO SELECTED SITES (mrem)				
	SKIN	THYROID	BONE MARROW	GONADS	EMBRYO
Chest X-ray (PA)	30	1.2	3.1	0.05	0.03
Chest X-ray (Lateral)	50	5.8	2.2	0.05	0.10
Thoracic Spine X-ray(AP)	500	59.5	21.5	0.90	0.70
Thoracic Sp. X-ray (Lat)	1000	8.9	28.0	0.40	0.40
Skull X-ray (AP)	100	30.5	1.4	-	-
Skull X-ray (Lateral)	100	13.9	3.8	-	-
Pelvis X-ray (AP)	500	-	23.5	131	176.5
Pelvis X-ray (Lateral)	1000	-	33.0	73	56
Pelvis Fluoroscopy	7000	-	100	786	1059
Lumbar Spine X-ray(AP)	1000	-	46	238	309
Lumbar Spine X-ray(Lat)	2000	-	54	116	78
Upper G.I. Series	900	100	530	170	100
Barium Enema Series	1000	-	870	900	1170
Thyroid Uptake (I-131) (10 microcuries)	-	30,000	35	45	NA

NOTES: Above data derived from HEW Publication 76-8030, Libassi report & 1972 EPA report

INSTRUMENTS USED

1. BGS-4 Gamma-ray Scintillation Counter
(Serial No. 8004299)

This instrument consists of a thallium activated sodium iodide crystal detector and a photomultiplier assembly which is sealed, magnetically shielded and encapsulated to keep temperature and mechanical shocks to a minimum. The instrument is designed to detect all gamma rays with energies greater than 0.05 ueV. The ratemeter output is converted to digital form and displayed on a four-digit Liquid Crystal Display (LCD) in counts per second, with full range up to 19,990 cps. count rate accuracy ± 5%. The calibration result of this instrument is attached.

2. PDR 1 Low Level Radiation Meter
(Serial No. 247)

This is a portable low level gamma survey monitor with an internal Geiger-Muller detector. The dose rate is indicated in urad/hr and mrad.hr in air on a logarothmic scaled meter covering the range 1 urad/hr to 10 mrad/hr. It has an energy response from 40KeV to 6 MeV and a dose rate accuracy of ± 20%. The Calibration result of this instrument is attached.

Appendix B

CALCULATION OF ANNUAL DOSE EQUIVALENT

1. Both instruments readings were calibrated to give external radiation exposure rate ($\dot{X}$) in air (in unit μR/hr or mR/hr)

2. The absorbed dose rate ($\dot{D}$) in air can be derived from the exposure rate $\dot{X}$ as $\dot{D} = a\dot{X}$, where the value of the conversion factor a is 0.869 rad/R. The abdorbed dose rate in air will usually be expressed in microrad per hour or millirad per hour.

3. The absorbed dose rate in tissue can be derived from the absorbed dose rate in air as $\dot{D}$ tissue = b $\dot{D}$ air, where the value of the conversion factor b is 1.10.

4. The dose equivalent rate $\dot{H}$ can be derived from the absorbed dose rate in tissue as $\dot{H} = Q\dot{D}$ where Q is the quality factor. The dose equivalent rate will usually be expressed in microrem/hr or millirem/hr. By taking quality factor Q for gamma ray as 1, then the dose equivalent rate is numerically the same as the absorbed dose rate in tissue. The annual dose equivalent rate (mrem/yr) is then obtained by multiplying with the conversion factors 24 hours/day and 365 days/yr.

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Secondary Standard Dosimetry Laboratory

Perkhidmatan Tentu-ukur bagi alat pengesan Sinar

Tarikh: 22.11.82 & 29-11-82.

Nama Operator: BUSTAMI ABU.

Jabatan: UNIT FIZIK KESIHATAN PUSPATI.

Jenis alat pengesan sinar: PORTABLE DOSE RATEMETER. Model: TYPE - 1.

Jenis Sumber (Standard Source) yang digunakan: Cs - 137. Serial No: 247.

Kekuatan (aktivity) Sumber yang digunakan: 5m Ci pada 27-7-77.

Tenaga (Energy) dari Sumber yang digunakan: 0.662 MeV.

No:	Jarak alat pengesan dari Sumber (cm)	Cara (Mode) pengiraan daripada alat pengesan	Ukuran Sepenuh (Full Scale) dari alat pengesan m.rad/hr.	Bacaan Sebenar mR/hrs	Bacaan yang diberikan oleh alat pengesan m rad/hr.	Ketepatan (Accuracy) x100	Calibration Factor mR/hr / m rad/hr	Catitan Am
1.	50			5.89	5.20	11.71	1.13	
2.	60			4.09	3.80	7.09	1.08	
3.	70			3.00	2.60	13.33	1.15	
4.	80			2.30	2.00	13.04	1.15	
5.	90			1.82	1.68	7.69	1.08	
6.	100			1.47	1.33	9.52	1.11	
7.	110			1.22	1.18	3.28	1.03	
8.	120			1.02	0.95	6.86	1.07	
9.	130			0.87	0.80	8.05	1.09	
10.	140			0.75	0.72	4.00	1.04	
11.	150			0.65	0.68	4.62	0.96	
12.	160			0.58	0.60	3.45	0.97	

NILAI PURATA CALIBRATION FACTOR = 1.07

NOTA:

Calibration Factor = Nilai Dos yang sebenar / Bacaan yg didapati dari alat pengesan

Secondary Standard Dosimetry Laboratory

Perkhidmatan Tentu-ukur bagi alat pengesan Sinar

Tarikh: 22-11-82 & 24-11-82.

Nama Operator: BUSTAMI ABU.

Jabatan: UNIT FIZIK KESIHATAN PUSPATI

Jenis alat pengesan sinar: SCINTILLATION COUNTER (SCINTREX). Model: BGS-4.

Jenis Sumber (Standard Source) yang digunakan: Cs-137. Serial No: 8004299.

Kekuatan (aktivity) Sumber yang digunakan: 5mCi pada 27-1-77.

Tenaga (Energy) dari Sumber yang digunakan: 0.662 MeV.

No:	Jarak alat pengesan dari Sumber (cm)	Cara (Mode) pengiraan daripada alat pengesan	Ukuran Sepenuh (Full Scale) dari alat pengesan c.p.s.	Bacaan Sebenar mR/hrs	Bacaan yang diberikan oleh alat pengesan c.p.s.	Ketepatan (Accuracy) x100	Calibration Factor mR/hr / c.p.s.	Catitan Am
1).	110			1.22	18,450		6.612×10^{-5}	
2).	120			1.02	16,495		6.184×10^{-5}	
3).	130			0.87	14,965		5.914×10^{-5}	
4).	140			0.75	13,685		5.480×10^{-5}	
5).	150			0.65	12,810		5.074×10^{-5}	
6).	160			0.58	12,335		4.702×10^{-5}	

NILAI PURATA CALIBRATION FACTOR = $5,644 \times 10^{-5}$

NOTA:

Calibration Factor = Nilai Dos yang sebenar / Bacaan yg didapati dari alat pengesan