# CALIBRATION OF INSTRUMENT AND PERSONNEL MONITORING IN RADIOLOGICAL PROTECTION

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## ABSTRACT

It is difficult to choose radioprotection equipments that is not too expensive and suit the purpose. Some of the dosimetric characteristics of good dosemeters outlined by ISO 4071-1978 (E) namely scale linearity, energy dependence, radiation quality dependence and angular dependence for some of the commercially available dosemeters are discussed. The calibration procedures practiced at the National Secondary Standard Dosimetry Laboratory (SSDL), of the Nuclear Energy Unit (NEU) is also explained.

The radiological equipments for personnel monitoring such as film badge and TLD are widely used to estimate the radiation dose delivered to the whole or partial body of a personnel. Both of a personnel monitoring procedures have been established at the NEU. The objective, use and maintenance of the devices are also discussed in detail. The evaluation of the monthly dose received by a personnel from various establishment in the country are also presented.

## 1.0 Calibration of Instrument in Radiological Protection

### 1.1 Requirement of Calibration

Calibration of a dosemeter means determining its response to a known radiation exposure (rate) or known absorbed dose (rate) and this always involves the use of at least one standard or reference instrument. Even with some of the best available dosemeters, measurements will only at best give an approximation of the dose (rate). Calibration of dosemeters is [1],

- to ensure that the instrument is working properly.
- to ensure that errors in the instrument readings are revealed for an instrument with no calibration adjustment and that overall accuracy of the measurement is improved for instruments provided with calibration adjustment.
- to undertake detailed investigations of the instrument including energy dependence, directional response, environmental effects etc.
- to collect informations about the performance of dosemeters and in turn to give guidance to the users concerning the best available instruments for their requirements and finally to inform them of any design features which are important when using the equipment. The informations are also useful to improve the design of dosemeters in the future.

### 1.2 Instrument Calibrations At The SSDL of Malaysia

#### 1.2.1 Procedures and facilities

Instruments received for calibration will undergo certain procedures in sequence as shown in figure 1 [2]. The application form will be sent to users on request. The users are requested to provide as much information as possible about the instrument. For portable instruments, weight, strength and ease of handling and servicing are important physical characteristics. Human engineering features such as ease of meter reading, availability of controls and physical stability are always considered as the essential informations. The electrical evaluation includes tests of the sensitivity, linearity, voltage dependence, stability and power supplies (including battery lifetime etc).

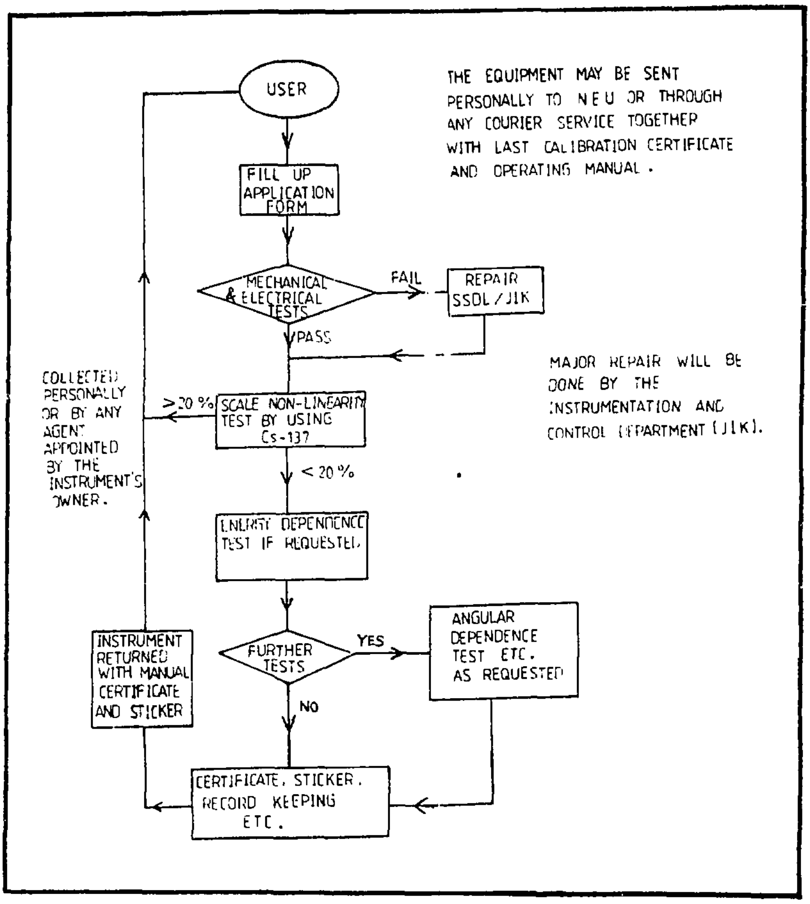



Figure 1: Flow chart indicating the sequence of calibration procedures at The SSDL, Nuclear Energy Unit.

The calibration of environmental and protection level dosemeters in X-ray beam is performed in air by using simultaneous irradiation technique [3]. Both standard dosemeter and dosemeter to be calibrated are positioned at the same distance from focus and they are completely irradiated by using uniform beam. The arrangement of standard dosemeter and dosemeter to be calibrated in the beam is shown in figure 2a.

For $\gamma$-ray the dosemeter to be calibrated is placed at a position in the pre-calibrated beam and the reading is compared with pre-determined exposure (rate). Standardization of $\gamma$-ray measurements at various distances is performed twice yearly with accuracy of better than ±2%. Dosemeter calibration in $\gamma$-ray beam is shown in figure 2b (refer also table 3).

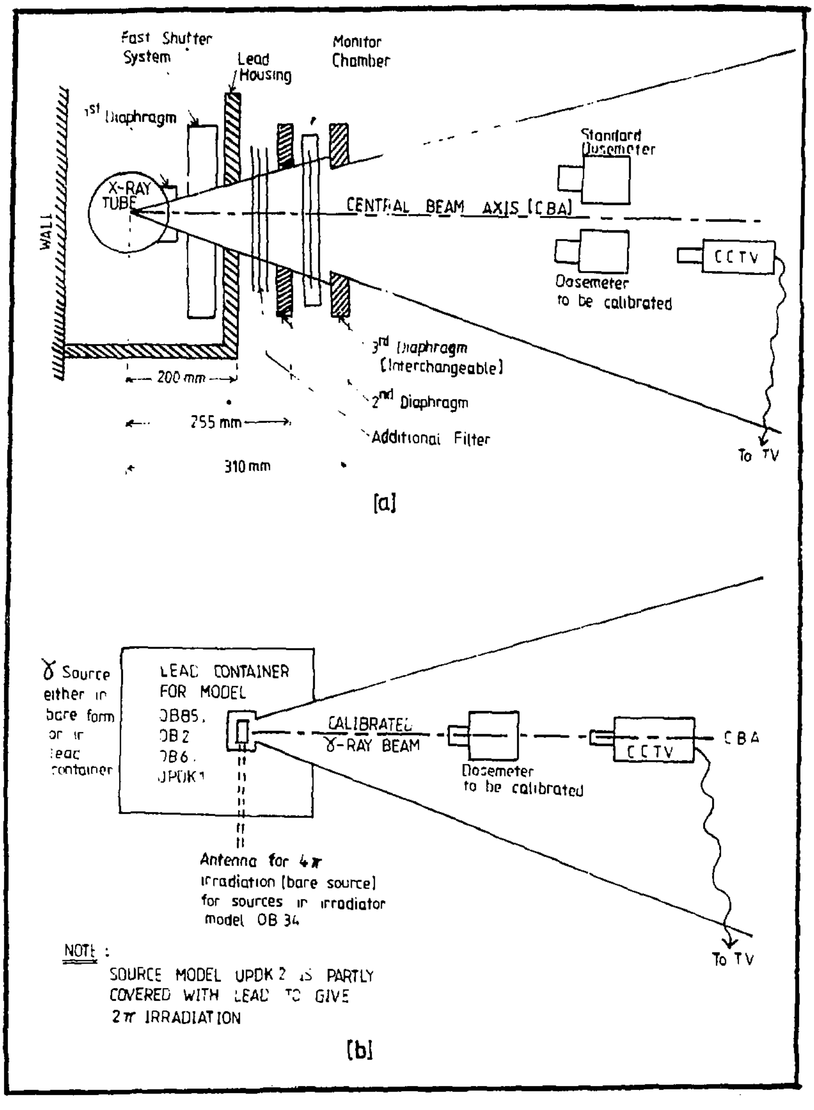



Figure 2: Set-up of Standard dosemeter and dosemeter to be calibrated in X-ray beam [a] and calibration of dosemeter in ɣ-ray beam [b].

Secondary standard and reference dosemeters used for calibration of environmental and protection level radiation detecting instruments are shown in table 1.

| ELECTROMETER, MODEL, SERIAL NO. | CHAMBER, MODEL, SERIAL NO. | VOLUME [cc] | TRACEABILITY | YEAR OF CALIBRATION | GRADE | ACCURACY |
|---|---|---|---|---|---|---|
| DIGITAL CURRENTINTEGRATOR, NP2100, No. 7809 | ND1001 No. 7804 | 20 | ARC (i) | 1984 | SECONDARY STANDARD | ±2% |
| | ND1000 No. 7818 | 1000 | ARC | 1984 | | ±2% |
| | LS 10 No. 124 | 10,000 | ARC | 1985 | | ±2% |
| | | | | | | |
| FARMER, NE 2570A, No. 535 | NE2575 No. 287 | 600 | NRPB (ii) / NE (iii) | 1985 | REFERENCE INSTRUMENT | ±2%/±5% |
| | NE2530 No. 489 | 35 | NRPB / NE | 1985 | | ±2%/±3% |
| | | | | | | |
| DOSIMENTOR DL4, DI4/775 No. 268, 7751 No. 230 | M23361 No. 038 | 35 | PTW (iv) | 1985 | REFERENCE INSTRUMENT | ±2% |

(i) AUSTRIAN RESEARCH CENTRE, AUSTRIA.
(ii) NATIONAL RADIOLOGICAL PROTECTION BOARD, U.K.
(iii) NUCLEAR ENTEPRISE, U.K.
(iv) PHYSIKALISCH-TECHNISCHE WERKSTAETTEN, GERMANY.

Table 1: Secondary standard and reference instruments used for calibration of radiological protection instruments.

The X-ray is produced by Philips machine model MG320D and metal ceramic tube model MCN 321. The inherent filtration of the tube is 2.2mm.Be. The filtered X-reference radiations used for calibration of protection and environmental level dosemeters at the SSDL are based on the recommendation of the ISO 4037-1979(E)[4] and the ISO 4037/DAM 1 (1982)[5]. The radiation qualities of the 'narrow spectrum series' are normally preferred but for higher or lower output i.e. for calibration and energy dependence measurements for dosemeters designed for higher or lower doserates measurements, the 'wide spectrum series' or 'low doserate series' are also offered respectively. The three series of filtered X-ray qualities are shown in table 2. Gamma and beta sources available for calibration are listed in table 3.

| SERIES | EFFECTIVE ENERGY (keV) | RESOLUTION % (QUOTED) | CONSTANT POTENTIAL (kVp) | ADDITIONAL FILTRATION (mm) | | | | FIRST HVL (mm Cu) | | HOMOGENEITY COEFFICIENT (H.C) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Al | Cu | Sn | Pb | QUOTED | MEASURED | |
| NARROW SPECTRUM | 29 | 30 | 40 | 4 | 0.2 | - | - | 0.09 | 0.067 | 0.80 |
| | 44 | 36 | 60 | 4 | 0.62 | - | - | 0.24 | 0.20 | 0.77 |
| | 81 | 28 | 100 | 4 | 5.04 | - | - | 1.16 | 1.02 | 0.98 |
| | 118 | 36 | 150 | 4 | - | 2.5 | - | 2.40 | 2.33 | 0.96 |
| | 170 | 32 | 200 | 4 | 2.0 | 3.0 | 1.0 | 3.90 | 4.10 | 1.00 |
| | 222 | 30 | 250 | 4 | - | 2.0 | 3.0 | 5.20 | 5.35 | 1.00 |
| WIDE SPECTRUM | 41 | 48 | 60 | 4 | 0.3 | - | - | 0.18 | 0.17 | 0.88 |
| | 52 | 54 | 80 | 4 | 0.5 | - | - | 0.35 | 0.33 | 0.80 |
| | 77 | 57 | 110 | 4 | 2.0 | - | - | 0.94 | 0.91 | 0.83 |
| | 105 | 56 | 150 | 4 | - | 1.0 | - | 1.86 | 1.82 | 0.86 |
| | 141 | 58 | 200 | 4 | - | 2.0 | - | 3.11 | 3.20 | 0.97 |
| | 180 | 58 | 250 | 4 | - | 4.0 | - | 4.30 | 4.35 | 0.98 |
| LOW DOSERATE | 28 | 20 | 35 | 4 | 0.25 | - | - | 2.38* | 1.78* | 1.00 |
| | 45 | 21 | 55 | 4 | 1.2 | - | - | 0.25 | 0.21 | 1.00 |
| | 58 | 22 | 70 | 4 | 2.5 | - | - | 0.48 | 0.44 | 1.00 |
| | 85 | 21 | 100 | 4 | 0.5 | 2.0 | - | 1.28 | 1.15 | 0.96 |
| | 110 | 20 | 125 | 4 | 1.0 | 4.0 | - | 2.14 | 2.01 | 1.00 |
| | 150 | 18 | 170 | 4 | 1.0 | 4.0 | 1.0 | 3.67 | 3.45 | 0.99 |
| | 190 | 18 | 210 | 4 | 0.5 | 3.0 | 3.0 | 4.91 | 4.65 | 0.9[illegible] |
| | 230 | 16 | 240 | 4 | 0.5 | 3.0 | 5.0 | 5.89 | 5.50 | 1.00 |

* -> THE UNIT IS IN mm Al.

Table 2: Calibration conditions of filtered X-reference radiations based on recommendations of the ISO 4037-1979(E) and ISO 4037/DAM1-1982. The inherent filtration is 2.2mm Be and FDD is 1 meter.

| MODEL | NUCLIDE | ACTIVITY RANGE | NUMBER OF SOURCES | COVERED DOSE RATE RANGE | SOURCE TO DETECTOR DISTANCE (m) | HALF-LIFE (year) | FIELD SIZE AT 1metre |
|---|---|---|---|---|---|---|---|
| | | | | IN mSv/hour | | | |
| OB 34 | Cs-137 | 7.4 MBq - 7.4 GBq | 4 | $2.0 \times 10^{-4}$ — 2.68 | 0.5 — 2.0 | 30.1 | 4π irra. |
| OB 34 | Co-60 | 3.7 MBq - 370 MBq | 3 | $4.0 \times 10^{-4}$ — 0.46 | 0.5 — 2.0 | 5.27 | 4π irra. |
| OB 85 * | Cs-137 | 740 GBq | 1 | 4.1 — 726.7 | 0.3 — 4.0 | 30.1 | 10/40 cm ϕ |
| OB 85 * | Co-60 | 37 GBq | 1 | 0.8 — 144.2 | 0.3 — 4.0 | 5.27 | 10/40 cm ϕ |
| OB 85 * | Ra-226 | 37 MBq | 1 | $5.0 \times 10^{-4}$ — $8.8 \times 10^{-2}$ | 0.3 — 4.0 | 1602 | 10/40 cm ϕ |
| OB 85 * | Am-241 | 11.1 GBq | 1 | $3.0 \times 10^{-3}$ — 0.53 | 0.3 — 4.0 | 458 | 10/40 cm ϕ |
| OB 2 | Co-60 | 3.7 GBq | 1 | 0.02 — 1.29 | 0.75 — 6.0 | 5.27 | 14 cm ϕ |
| UPDK 1 ** | Cs-137 | 11.5 GBq | 1 | 0.02 — 1.63 | 0.75 — 6.0 | 30.1 | 12.5 cm ϕ |
| OB 6 | Cs-137 | 74 GBq | 1 | 0.16 — 10.86 | 0.75 — 6.0 | 30.1 | 26 cm ϕ |
| UPDK 2 ** | Am-241 | 11.1 GBq | 1 | 0.018 — 0.097 | 0.5 — 1.3 | 458 | 2π irra. |
| ALDORADO 8 | Co-60 | 129.5 TBq | 1 | $7.074 \times 10^{2}$ - $5.737 \times 10^{4}$ | 0.8 - 7.0 | 5.27 | 5 X 5 — 25 X 25 $cm^2$ |
| | | | | IN μGy/second | | | |
| BS1 | Tl-204 | 18.5 MBq | 1 | 0.27 | 0.3 | 3.78 | 2π irra. |
| BS1 | Sr-90/Y-90 | 74 MBq | 1 | [illegible] | 0.3 | 28.5 | 2π irra. |
| BS1 | Sr-90/Y-90 | 1.85 GBq | 1 | 539.5 / 74.4 / 26.8 | 0.11 / 0.3 / 0.5 | 28.5 | 2π irra. |
| BS1 | Pm-147 | 518 MBq | 1 | 0.32 | 0.2 | 2.62 | 2π irra. |

* → STANDARDIZATION OF THE SOURCES IS ON PROGRESS AND NOT YET READY. THE OUTPUTS PRESENTED HERE ARE BASED ON THE SUPPLIER'S MEASUREMENT.

** → THE SOURCE WAS BOUGHT IN BARE FORM AND INSTALLED IN THE HOME-MADE LEAD CONTAINER.

Table 3: Specifications of gamma and beta sources at The SSDL Malaysia. Model BS1 is beta emitters and the rest are gamma emitters.

### 1.2.2 Scale non-linearity test

According to recommendations of the ISO 4071-1978(E)[6], repeatability of the instrument readings between successive evaluations obtained with the same method under the same conditions should not exceed 10%. The instrument should maintain its calibration for a long period of time.

The instrument must have the sensitivity and range of sensitivities necessary to make the required measurements. Furthermore, it must has a sensitivity adjustment enclosed so that it cannot be fiddle by untrained personnel. The exactness of the reading to a reference radiation which is verified at half scale deflection on the different scales should not exceed 5%. The scale linearity is verified at the entire range of dosemeter reading and should be better than 5%. The parallax error of an instrument should not exceed ±5%.

The instrument devices must not saturate in the dose (rate) range in which it is to be used. This requirement limits the application of certain instruments such as GM counter etc. For ionisation chamber types, the recombination and saturation losses must be negligible.

At the SSDL, scale non-linearity test is performed to ensure that the instrument responses linearly with various doses (rates) in the working range. All different selectable ranges are tested by using $\gamma$-ray from Cs137. At least, three calibration points are selected for each range i.e 30%, 50% and 70% of the full scale reading. The exactness of the instrument reading is determined and improved if necessary, by adjusting the sensitivity of the instrument as recommended by the corresponding operating manual. Instruments which show scale non-linearity of exceeding 20% will be rejected and returned to user without any futher test. Typical result of such a test for Victoreen dosemeter model 492 and Ludlum dosemeter model 3 (with external GM detector model 44-9) is shown in figures 3 and 4 respectively.

This linearity test was performed by using X-rays 41 keV and $\gamma$-rays from Cs137. The former dosemeter was accepted by the SSDL for energy dependence test whereas the later was declared faulty and returned to the user. The decision was made based on the SSDL specification that the scale linearity of a dosemeter should be better than 20% with reference to the $\gamma$-ray of Cs137.

### 1.2.3 Energy dependence test

Insofar as practicable the instrument should provide a response that is independent of the energy of radiation. The energy dependence of the response should be better than ±20% relative to the mean response in the whole working energy range. Further, the intrument should respond to only one type of radiation at a time if it is to be used for a measurement of dose (rate) of mixed radiations i.e. the response of the instrument should not be modified by the presence of mixed radiation field.

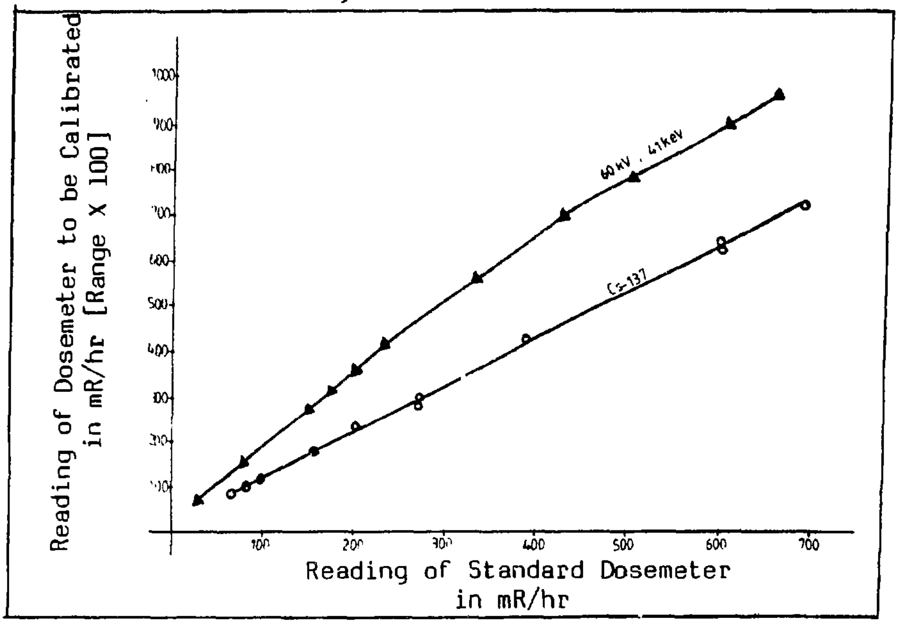



Figure 3: Result of scale non-linearity test for Victoreen dosemeter model 492 in 41keV X-rays of the ISO wide spectrum series and γ-rays of Cs 137. Standard dosemeter, NP 2100 with an ionisation chamber, NP 1000 were used.

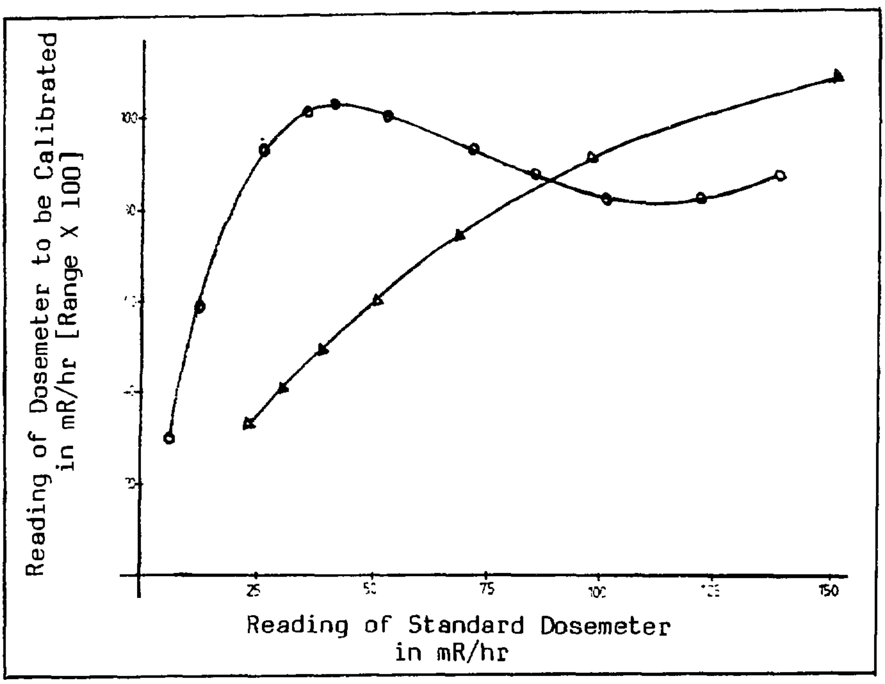



Figure 4: Result of scale non-linearity test for Ludlum dosemeter model 3 with external GM probe model 44-9 in 41keV X-rays of the ISO wide spectrum series (o—o) and in -rays of Cs 137 (Δ—Δ). Standard dosemeter, NP 2100 with ionisation chamber, ND 1000 were used.

Energy dependence of responses for some popular dosemeters is shown in figures 5, 6 and 7[7]. Figure 5 gives typical energy-response curve for dosemeters with internal GM detector types such as Victoreen model 492, Graetz model X50, Victoreen model 1490 and Nuclear Enterprise model PDR-1 in an energy range from 31 keV to 1250 keV. It is obvious that this type of dosemeter cannot be used for measuring low energy photons of below 50 keV due to the large energy dependence. The metal casing attenuates the low energy X-rays significantly. The energy-response dependence is improved with increasing energy and satisfy the ISO 4071 requirement from 50 keV to 1250 keV. Figure 6 shows the energy-response dependence curve for dosemeters with external GM detector such as Technical Associates dosemeter model SML-2, model PUG-1AB and model PUG-1 with probe model P-7, model P-11 and model P-10 respectively, in an energy range from 29 keV to 1250 keV. It is clear that the energy compensation shield (cap) improves the energy dependence of the response significantly especially in the low energy region.

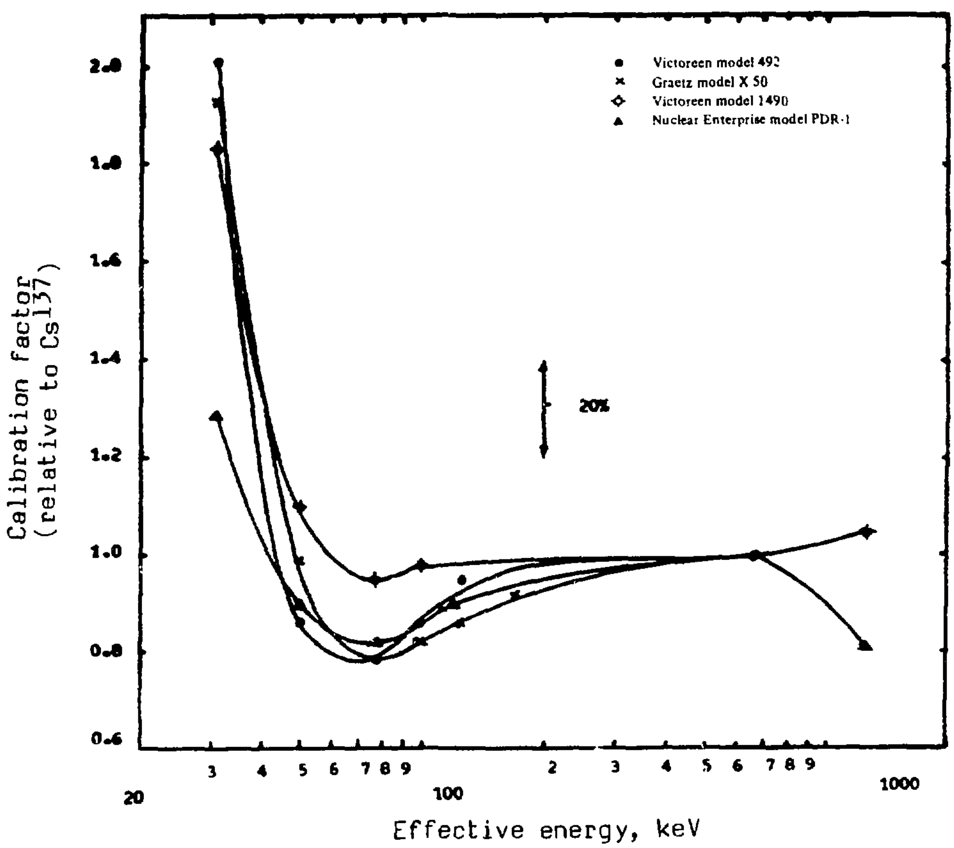



Figure 5: Typical energy-response curve for dosemeters with internal GM detector in 31 keV to 1250 keV photon beams.

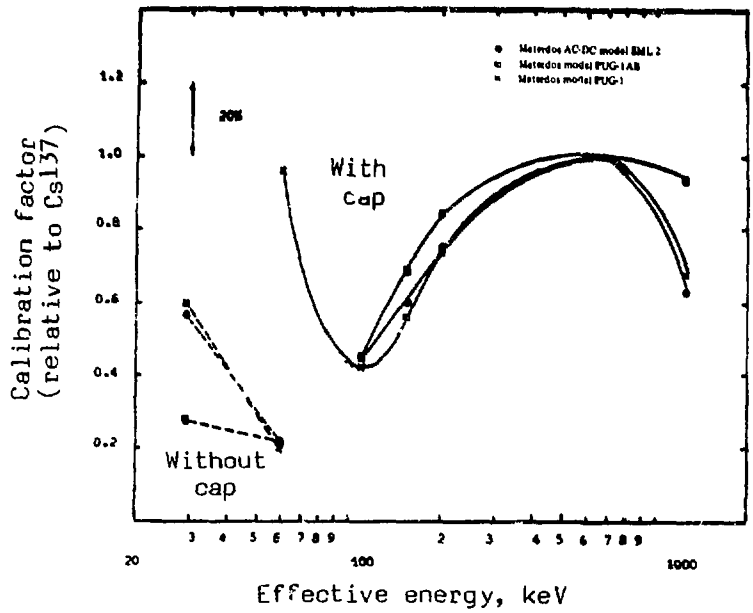



Figure 6: The energy-response dependence curve for dosemeters with external GM detector in photon energy range from 29 keV to 1250 keV.

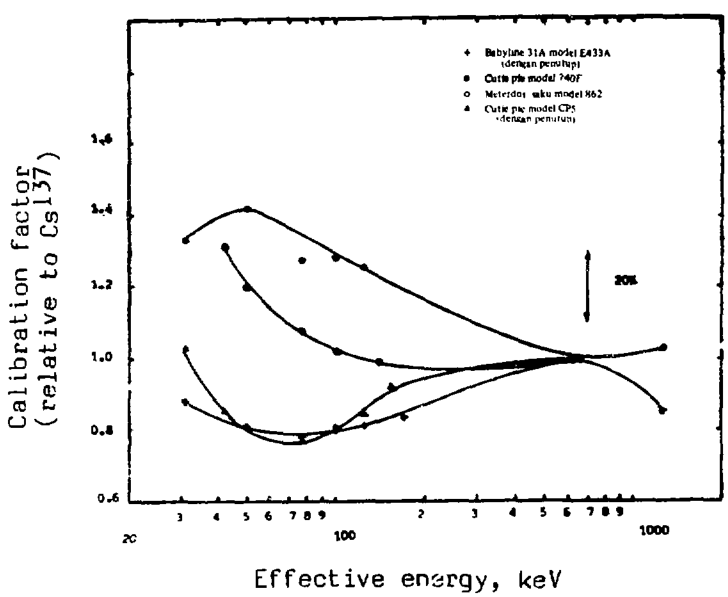



Figure 7: The energy-response dependence curve for dosemeters of ionisation chamber types in 31 keV to 1250 keV photon beams.

The dosemeters are also found to be more sensitive to the low energy photons compared to those in figure 5. However, accurate measurements of exposure (rate) are hardly achieved, unless a proper calibration of the dosemeter is performed for a particular radiation quality of interest. The best dosemeter quality is always of the ionisation chamber types but they are relatively more expensive. The energy-response curve for such dosemeters are shown in figure 7. The Babyline 31A model E433A, Cutie Pie model 740F, pocket dosemeter model 862 and Cutie Pie model CP5 (with build-up cap) satisfy the energy dependence criteria as outlined by the ISO 4071 in the entire range of energy tested i.e from 31 keV to 1250 keV. The only disadvantage of this kind of dosemeters is that they are less sensitive to low energy photons compared to dosemeters with external GM probe.

### 1.2.4 Quality dependence test

For the same effective energy, the dosemeter response is also dependent on the spectrum quality of radiation resulting from its energy dependence characteristics. The narrow spectrum and the low doserate series of the ISO radiation qualities were used for testing a Nuclear Enterprise dosemeter model PDR-1 and the result is shown in figure 8. The difference in response in the energy range of interest is as large as 20%. We believed that the magnitude varies with dosemeter model and make.

The best approach is to use the monoenergetic beam for calibration of a dosemeter throughout the whole energy range, but it is not possible. In a case where X-ray is used, it is recommended to use the narrow spectrum series which is the best simulation of monoenergetic beam quality. In addition, this quality is considered identical to the heavily filtered leakage radiation measured by the user of the instrument at site.

### 1.2.5 Angular Dependence test

Most survey instruments should not vary in directional response except for solid angle subtended by the surveyor by more than ±10%. However, some survey instruments are used to determine the direction of the source of ionising radiation by pointing the instrument in the direction to give the maximum reading. If such

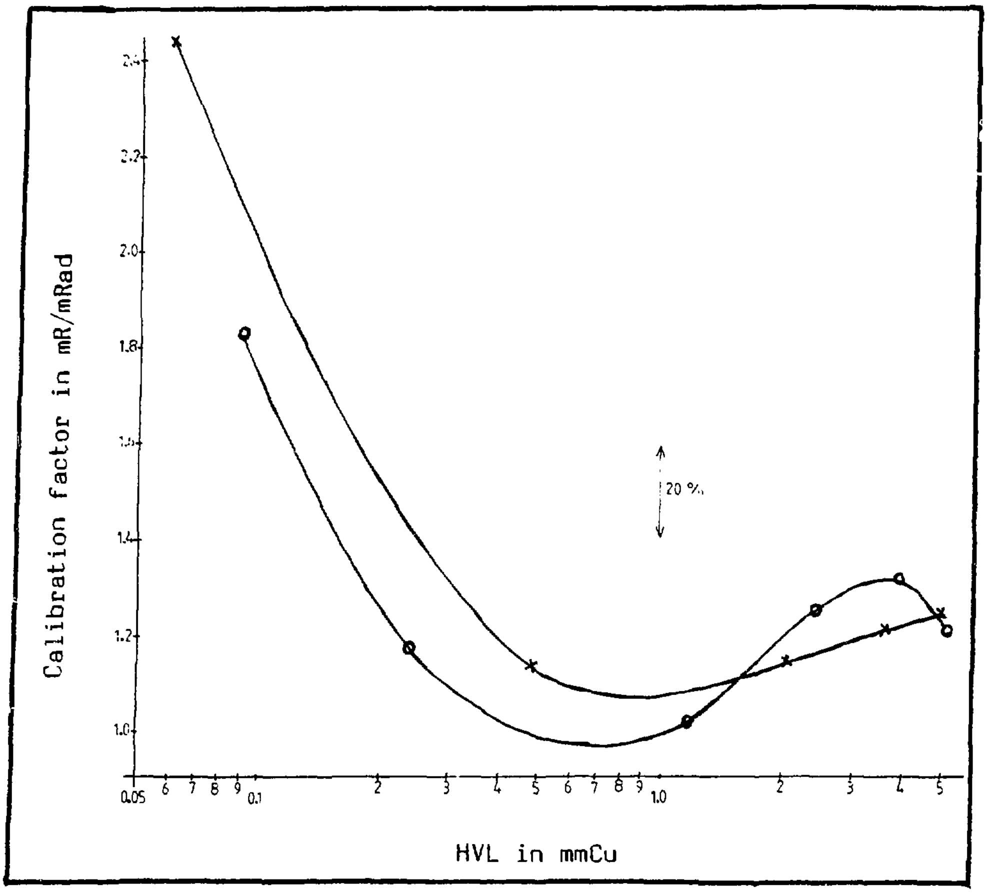



Figure 8: Calibration of Nuclear Enterprise dosemeter model PDR1 by using the narrow spectrum series (o—o) and the low doserate series (x—x) of the ISO filtered X-radiation qualities.

instruments are in used, this directional characteristic must be fully understood if the instrument is to give meaningful readings. The instrument should not be excessively geotropic. The error in reading due to turning the instruments at any angle should not be more than ±10%.

The orientation of dosemeter being calibrated relative to the direction of incoming radiation is always explained in the calibration certificate and should be strictly followed when using the dosemeter on site. The angular responses of dosemeter for Babyline 31A model E433A (with build-up cap) to 42 keV X-rays and Cutie Pie model CP5 (with and without cap) to 31 keV X-rays were determined in an angle range from 0° to 180°

and results are shown in figure 9. It is obvious that the responsè of Cutie Pie with build-up cap is more angular dependence than that without build-up cap. The change in response is especially obvious when the dosemeter is tilted out of it reference position, 0° angle. At an angle of 30°, changes in response of the Babyline 31A to 42 keV X-rays is only 5% compared to the Cutie Pie with and without build-up cap to 31 keV X-rays of 15% and 27% respectively.

### 1.2.6 Calibration certificate

A calibration certificate issued by the NEU for radiological protection instruments is shown in figure 10. The validity of the certificate is one year. It is important to be informed that the calibration factor, CF is only valid under the calibration conditions as stated in the certificate. The presence calibration certificate at the place of measurement is necessary for easy reference.

## 1.3 Requirements of recalibration

An instrument should be recalibrated before expiry of the validity period. This is normally called regular periodic recalibration. Recalibration is also necessary if the instrument has suffered any damage or has been repaired. Sometimes, recalibration of the instrument is made at the request of the user for measuring exposure (rate) from a radiation quality that is not covered by the calibration certificate or because of the instrument giving suspicious reading.

Between the regular periodic annual recalibration, the user should carry out constancy checks by means of internal check sources built into the instruments (if available) or by means of the leakage radiation from a source under a fixed known condition. The constancy checks are especially important when the instrument is for high level radiation measurement or when the instrument is used only occasionally.

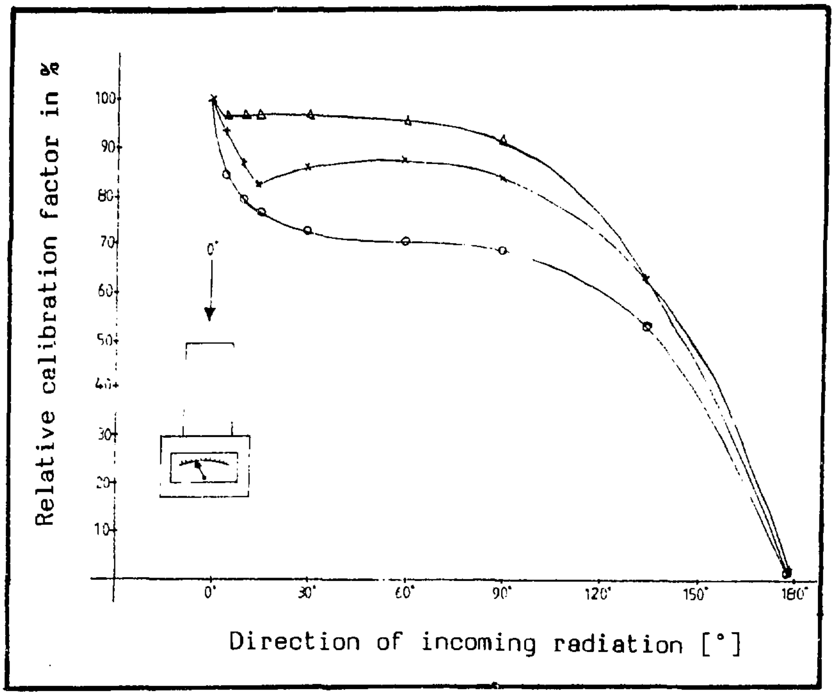
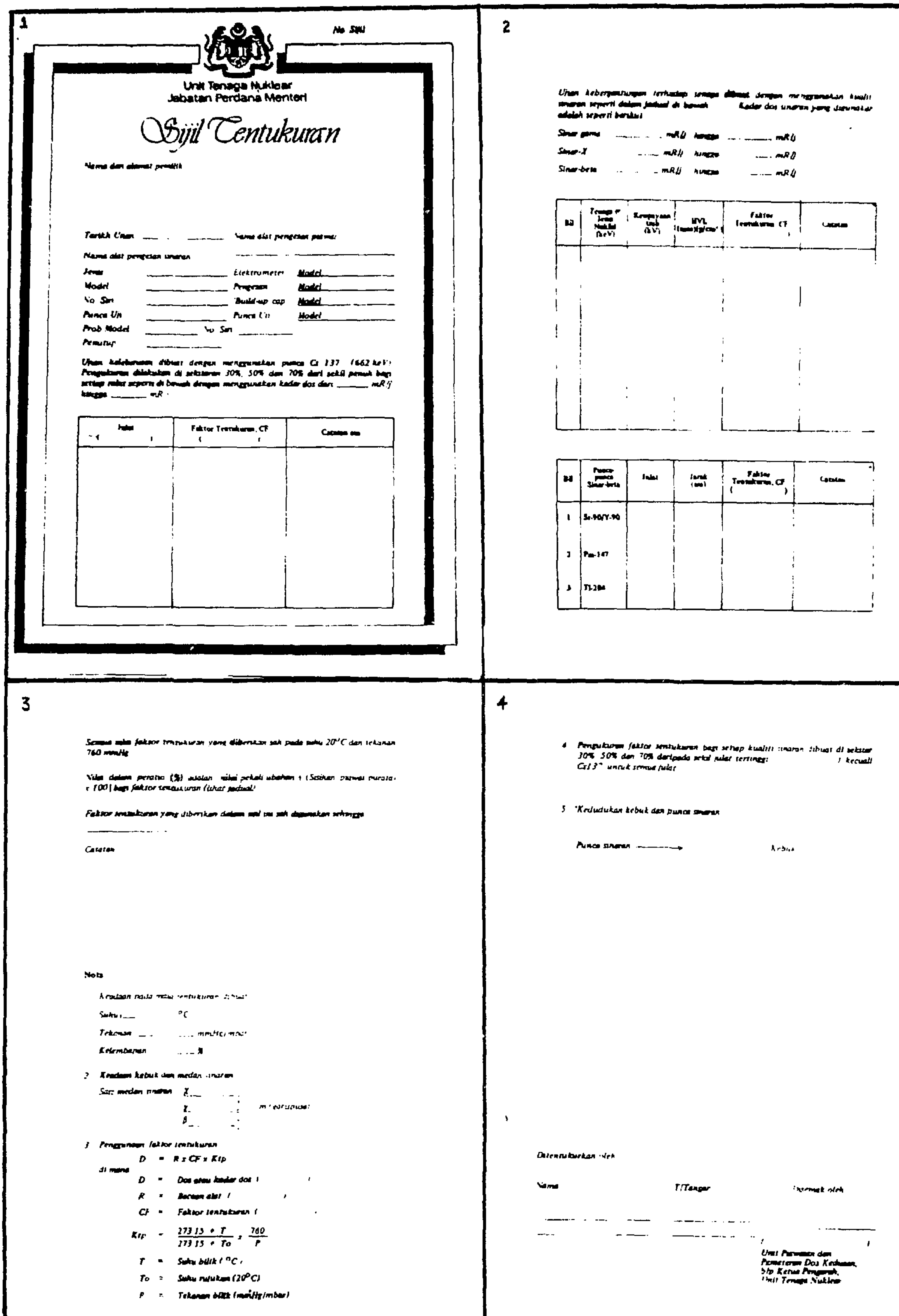



Figure 9: Typical result of angular dependence of the responce for Babyline 31A model E433A with build-up cap to 42 keV X-ray (Δ——Δ), for Cutie Pie model CP5 with and without build-up cap to 31 keV X-rays (x——x) and (o——o) respectively.


1

No Siri

Unit Tenaga Nuklear
Jabatan Perdana Menteri

Sijil Tentukuran

Nama dan alamat pemilik

Tarikh Ujian

Nama alat pengesan pemiat

Nama alat pengesan sinaran

Jenis

Model

No Siri

Punca Uji

Prob Model

Pemutur

Elektrometer Model

Pengesan Model

Build-up cap Model

Punca Uji Model

No Siri

Ujian kalebrasan dibuat dengan menggunakan punca Cs 137 (662 keV). Pengukuran dilakukan di sekitaran 30%, 50% dan 70% dari sekala penuh bagi setiap julat seperti di bawah dengan menggunakan kadar dos dari ______ mR/j hingga ______ mR

| Julat ( ) | Faktor Tentukuran, CF ( ) | Catatan |
|---|---|---|
| | | |

2

Ujian kebergantungan terhadap tenaga dibuat dengan menggunakan kualiti sinaran seperti dalam jadual di bawah. Kadar dos sinaran yang digunakan adalah seperti berikut

Sinar gama ______ mR/j hingga ______ mR/j

Sinar-X ______ mR/j hingga ______ mR/j

Sinar-beta ______ mR/j hingga ______ mR/j

| Bil | Tenaga/Jenis Nuklid (keV) | Keupayaan tiub (kV) | HVL (mm Al/Cu) | Faktor Tentukuran CF ( ) | Catatan |
|---|---|---|---|---|---|
| | | | | | |

| Bil | Punca-punca Sinar-beta | Julat | Jarak (cm) | Faktor Tentukuran, CF ( ) | Catatan |
|---|---|---|---|---|---|
| 1 | Sr-90/Y-90 | | | | |
| 2 | Pm-147 | | | | |
| 3 | Tl-204 | | | | |

3

Semua nilai faktor tentukuran yang diberikan sah pada suhu 20°C dan tekanan 760 mmHg

Nilai dalam peratus (%) adalah nilai pekali ubahan = (Sisihan piawai/purata × 100) bagi faktor tentukuran (lihat jadual)

Faktor tentukuran yang diberikan dalam sijil ini sah digunakan sehingga

Catatan

Nota

1 Keadaan pada masa tentukuran dibuat

Suhu ______ °C

Tekanan ______ mmHg/mbar

Kelembapan ______ %

2 Keadaan kebuk dan medan sinaran

Saiz medan sinaran X ______ γ ______ β ______ m (garispusat)

3 Penggunaan faktor tentukuran

D = R x CF x Ktp

di mana

D = Dos atau kadar dos ( )

R = Bacaan alat ( )

CF = Faktor tentukuran ( )

$$Ktp = \frac{273.15 + T}{273.15 + To} \times \frac{760}{P}$$

T = Suhu bilik (°C)

To = Suhu rujukan (20°C)

P = Tekanan bilik (mmHg/mbar)

4

4 Pengukuran faktor tentukuran bagi setiap kualiti sinaran dibuat di sekitar 30%, 50% dan 70% daripada sekal julat tertinggi ( ) kecuali Cs137 untuk semua julat

5 Kedudukan kebuk dan punca sinaran

Punca sinaran ——→ Kebuk

Ditentukurkan oleh

Nama

T/Tangan

Disemak oleh

Unit Pemantauan dan Pemeteran Dos Kakitangan,
b/p Ketua Pengarah,
Unit Tenaga Nuklear

Figure 10: Example of calibration certificate for radiological protection equipments issued by the SSDL, Nuclear Energy Unit.

## 2.0 PERSONNEL MONITORING IN RADIOLOGICAL PROTECTION

### 2.1 General

Any personnel who is engaged in working with ionizing radiation is inevitable to be exposed either directly or indirectly to the radiation. ICRP[8] has emphasised that all doses delivered to the personnel should be kept as low as practicable, that is unnesessary exposure should be avoided. Inevitable exposure should be justified by the benefits resulting from the procedure giving rise to the exposure.

To comply with the Malaysian regulation for the radiation workers, SSDL has established two types of external personnel monitoring i.e film badge for whole body dose monitoring and thermoluminescent dosemeter (TLD) for extremity/partial dose monitoring. The main purpose of personnel monitoring is to measure the dose received by the radiation workers and to ensure the workers expose to radiation to a reasonable achievable level and to ensure that nobody is exposed to the maximum permissible dose. The limitations of dose equivalent for a group of workers is shown in table 4.

| SITE/TYPE OF EXPOSURE: | ANNUAL DOS EQUIVALENT LIMIT FOR INDIVIDUALS | |
|---|---|---|
| | WORKERS | MEMBERS OF PUBLIC |
| WHOLE BODY-UNIFORM IRRADIATION. | 50 mSv | 5 mSv |
| PARTIAL BODY OR NON-UNIFORM IRRADIATION. | 50 mSv (EFFECTIVE DOSE EQUIVALENT) | 5 mSv (EFFECTIVE DOSE EQUIVALENT) |
| SKIN, HANDS, FOREARMS, FEET, ANKLES, AND ANY SINGLE ORGAN OR TISSUE OTHER THAN LENS. | 500 mSv | 50 mSv |
| LENS OF THE EYE. | 150 mSv | 50 mSv |
| PLANNED SPECIAL EXPOSURE. | 2 x RELEVANT LIMIT ABOVE IN ANY SINGLE EVENT | - |

Table 4: Summary of dose equivalent limits currently recommended by the International Commision on Radiological Protection (ICRP)[8].

## 2.2 Objectives of Personnel Monitoring

In general, individual/personnel monitoring is needed for the following purposes[9]:

- To provide the information needed for estimating the exposure of workers.
- To provide information about the trends of radiation exposures.
- To provide information in the event of excidental exposures.
- To provide information about the conditions of workplace.
- To improve the workers attitudes to radiation protection in order to reduce their exposures as a result of information given to them.
- To demonstrate the adequacy of supervision,training and engineering standards.
- To provide data for epidimiology studies, risk/benefit analyses (optimization procedures) and medical/legal purposes.

## 2.3 Film Badge

### 2.3.1 Basic Principle

The cross section of the personnel monitoring film used by the SSDL is shown in figure II. The films are covered by with black papers and enveloped with polyethylene film which is water and light tight. The most sensitive part of the film is the film emulsion. The emulsion is coated as a thin layer on both sides of the celulos acitate (film base). The emulsion consist of microscopic silver bromide (AgBr) crystals. The radiation absorbed by individual silver crystal will cause a latent image which appear as dark image after processing. The darkening of the film is due to the presence of silver and is proportional to the amount of radiation and depending on the type of radiation quality.

### 2.3.2 Film and Badge/Cassette (Film holder) Types

The Agfa-Gevaert type film with dimension of 30mm x 40mm is used in personnel monitoring service. Two films from structrix D10 and structrix D2 types with different sensitivity are packed together in one envelope.

Structrix D10 is 64 times as sensitive as structrix D2[12]. Both are coated on both sides with emulsion thicknesses (each side) of 21µm(D10) and 16µm(D2). The maximum detectable dose of structrix D10 is about 0.1 Sv while structrix D2 is up to 5 Sv[11]. In the case of films which were exposed to over 5 Sv, the evaluation still can be done by removal of the emulsion of one side of the less sensitive film (structrix D2).

The PTW-type film badges are used by SSDL. The badges are made of plastic and consist of two different types of filters i.e copper and lead. The badges consist of an open window, three portions of copper filters with different thicknesses (0.05mm, 0.3mm and 1.2mm) and lead strip of 0.8mm thickness between two of the copper filters. The number aparture and lead strip are symmetrical in front and back of the badge, the lead strip are somewhat offset (see figure 12).

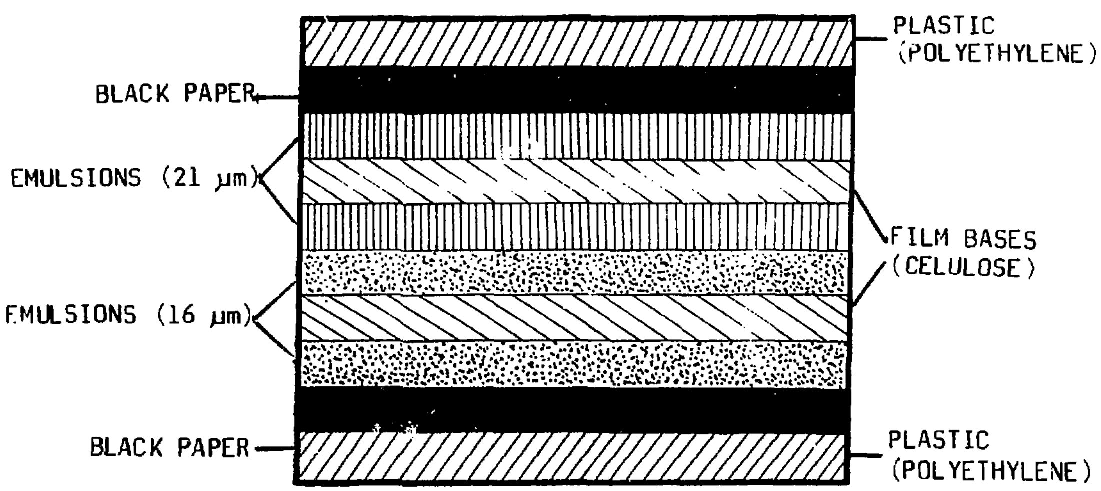



Figure 11: The cross section of personnel monitoring film type Agfa-Gevaert.

### 2.3.3 Dose Evaluation

The optical density or degree of blackness of the processed film is measured by a digital densitometer. The optical density D is defined according to the following equation:

$$D = \log_{10}(I_0/I_t)$$

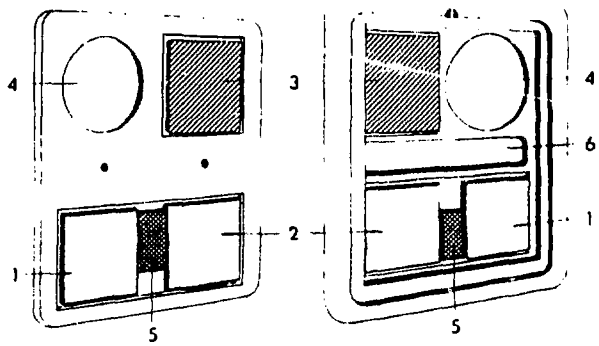
where; $I_0$ = Intial intensity of the light.

$I_t$ = Intensity of the transmitted light.

The fog density of the new film is normally in order of 0.2 and is increased with the storage time.

The dose delivered to the personnel is evaluated from the ratio of the exposures corresponding to the densities obtained in the open window area and under three copper filters, as a function of filter thickness. The apparent exposure (fig. 13) is first determine from the measured densities by use of characteristic calibration curve obtained at the most sensitive energy response to the film i.e. 41keV (fig.14). It is then corrected for the energy dependence of the film response with the aid of the plot of correction factors as a function of apparent exposures required for unit density under adjacent filter area as determine from the calibration curve. A representative plot of the correction factors is shown in fig. 15. The dose evaluation for high energy photon is reffered to the exposure corresponding to the density obtained under lead filter.

The film badge which are designed to both neutron and photon are also available. The filters which consist of tin (Sn) and cadmium (Cd) are added to the badge. In the absence of thermal neutron, the area under the equal weight of these filters show roughly the same density. The interaction of thermal neutron with Cd produce gamma rays and as a result give additional blackening under the Cd filter. The dose of thermal neutron is taken as a difference between the dose under Cd and the dose under Sn filter. Fast neutron can be monitored with nuclear track film such as Kodak NTA, which is added to the film badge. Irradiation of the film by fast neutrons results in proton recoil tracks due to elastic collisions between hydrogen nuclei in the paper wrapper, in the emulsion, and in the film base. Fast neutron exposure is estimated by scanning the processed film with high powered microcope i.e 400x and counting the number of proton tracks perunit area of the film. The number of proton tracks perunit area of the film is proportional to the absorbed dose.




| | | | |
|---|---|---|---|
| 1 : | 0.05 mm Cu | 4 : | open window |
| 2 : | 0.3 mm Cu | 5 : | 0.8 mm Pb |
| 3 : | 1.2 mm Cu | | |

Fig. 12: PTW-type film badge.

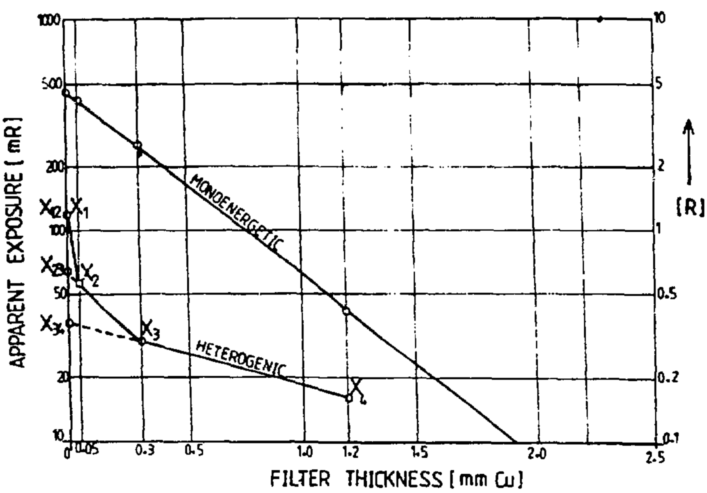



Fig. 13: Logarithm of apparent dose behind copper filters Vs thickness of these filters.

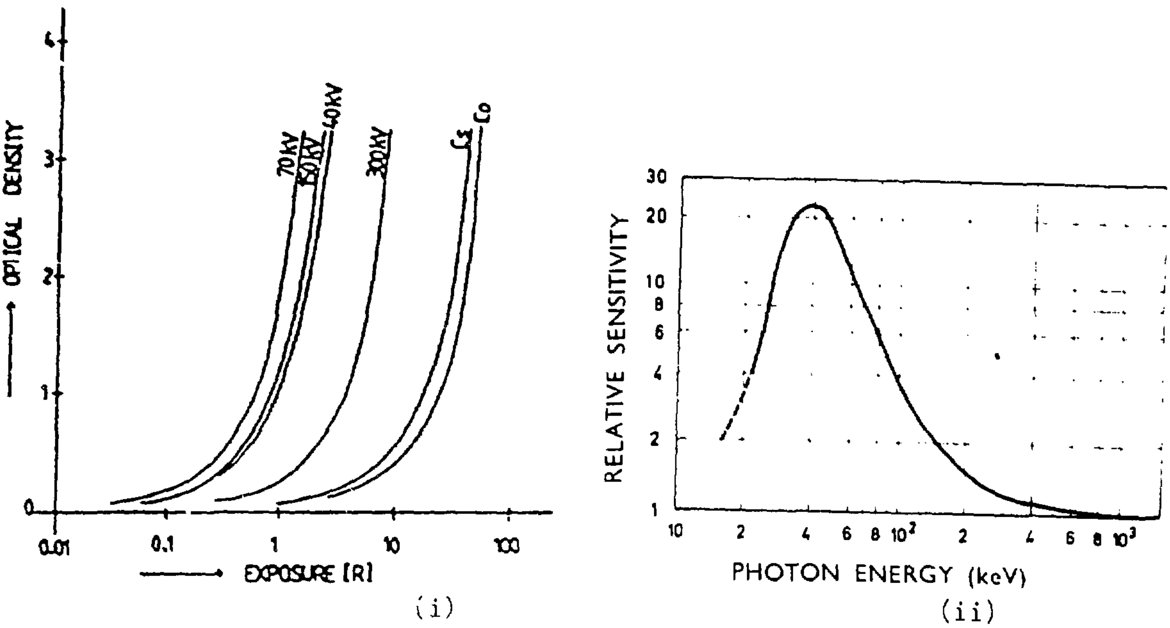



Fig. 14: i) Graph of film calibration curve (optical density Vs exposure) of different quality of radiation.

ii) Typical energy dependence of a radiation monitoring film.

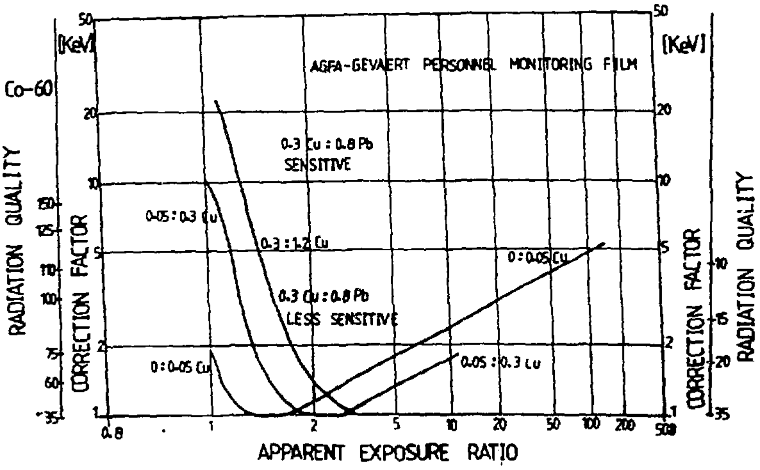



Figure 15: Effective energy and correction factor against apparent exposure ratio.

## 2.4 Thermoluminescent Dosemeter (TLD)

### 2.4.1 Basic Principle

Thermoluminescent dosimetry is based on the principle that certain material ('phosphors') can absorb and store radiation energy and is stable at room temperature. This stored energy can be released by heating, resulting in light emission. The schematic representation of the process involved is explained in fig. 16. The amount of light is proportional to the amount of energy absorbed from the radiation. The light can be measured by a TLD reader.

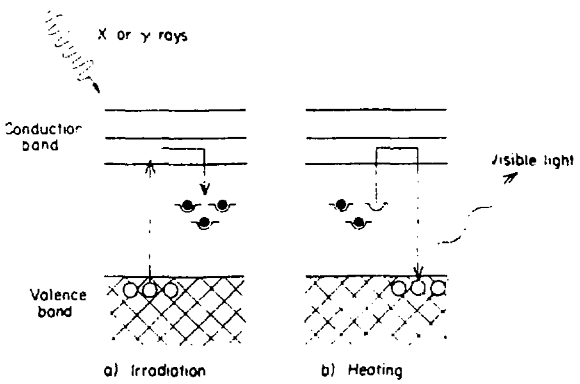



Figure 16: Schematic representative of the process involved in TLD.

### 2.4.2 TLD Service

SSDL has been equipped with the necessary facilities for the TLD service. The TLD reader Harshaw model 2000B & C and Victoreen 2800 are used for TLD evaluation. The reading system comprises of two basic devices, a heater and light detector. The SSDL offers TLD for the monitoring of personnel extremity dose and monitoring of the environment or working area. For extremity dose, TLD ring which consist of one TLD chip in one ring is used. At present about 200 personnels are provided with TLD for routine monitoring. These are from outside agencies and from NEU. The detector material made from natural LiF (Harshaw:TLD-100) is used for monitoring of personnel extremity dose which has a nearly tissue-equivalent composition. Other TLD's such as TLD-200, TLD-400, TLD-600, TLD-700 and TLD-800 are used for research and environmental/area monitoring.

## 2.5 Use and Care of Personnel Dosemeter Instruments

Such personnel dosemeter instruments should be used and maintained according to the standard procedures as follows[10]:

- It is advisable to position the film badge on the chest. The personnel should used the film with the same identification number for the whole working life time. This is necessary for proper record keeping and traceability.

- Dosemeters should be used when the personnel is working in the radiation area.

- Always keep the dosemeters away from the excessive heat and humidity.

- Dosemeters should be placed at the identified place, for example on the rack when not in use. This will avoid the dosemeter from being lost or false dose being recorded while it is not used.

- Care must be taken not to drop the dosemeters because they might be disloged or broken.

- The user should inform the SSDL if his dosemeter is lost or damaged is suspected.

- The user should inform the SSDL if he no longer needs a dosemeter (for example, if he no longer works in a radiation area, leaving the establishment etc.)

- The dosemeters should be replaced on a monthly basis. The used dosemeter should be returned to the SSDL for dose evaluation.

- The identification numbers of the dosemeter are identified by SSDL.

## 2.6 Comparison Between Film Badge and TLD

The use of film badge as an official personnel monitoring instrument has been introduced world wide. Since the introduction of TLD service. It has became an alternative to film badge for personnel dosimetry. The relative merit of film badge and TLD are listed as follows[11]:

| Film Badge | TLD |
|---|---|
| Reading can be rechecked (permanent record). | Only one reading possible. |
| Film must be replaced monthly. | Reuseability. |

| | |
|---|---|
| Additional information on radiation quality, direction of incident and possibly contamination. | Not possible |
| The accuracy of dose measurement is ±30% and not sensitive to low dose range. The minimum detectable dose is about 400 µSv. | The accuracy of dose measurement can be up to ±5% with the minimum detectable dose is about 10 µSv. |
| Can be stored up to maximum of two years period. | No limitation period. |
| Sensitivity to light. | No. |
| Fading is depend on the humidity, pressure, temperature and storage condition. | Fading is depend on the type of TLD, temperature, pressure and storage condition. |
| Direction dependent. | No. |
| Only need a dark room, developer/chemicals and film reader (densitometer). | Cost of establishment is very high. |

## 2.7 Quality Control

The quality control programme is designed to check traceability and realiability of dose measurement. Calibration of the films are done every three months or when a new stock of films are received. The calibration is done by using two photon energies, 41 keV and 1250 keV which give the highest and lowest sensitivity to the film. The dose delivered to the film is measured by means of secondary standard instruments i.e. Digital Current Intergrator model NP2100 # 7809 and Farmer Dosemeter model 2570 # 535. In addition, a detail calibration is also performed for the whole energy range, from 15 keV to 1250 keV. This is normally done once every six months. For the TLD, the calibration is done according to the everage energy where the users are working or with Cs-137 for the unknown radiation energy.

## 2.8 Record Keeping

The dose received by the personnel are evaluated by using a personnel computer. Two copies of the results are printed. The original copy is sent to the user and the other copy is kept as a record. An example of film badge dose report is shown in fig. 17. The radiation dose is calculated in SI unit; mSv (millisievert). The type and energy of radiation are also recorded in a dose report. The results are kept in a service file for a corresponding establishment and maintained for a period of at least 30 years, effective from the date issue of the dose report. The processed films will be kept for at least 5 years before they are disposed[8].

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JABATAN PERDANA MENTERI,
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43000 KAJANG,
SELANGOR.
TEL:8250510.

Ruj.tuan:
Ruj.kami:UTN:KHIDMAT/007-2/74/Jld.[illegible]
Tarikh :2nd. October 1987.

[illegible] Address

Laporan Penilaian Dos Untuk Bulan August 1987.
Nota: 1 mSv = 100 mrem

| No. Filem | Nama | Dos (mSv) | Sinar | Tenaga |
|---|---|---|---|---|
| 0001 | Personnel A | 1.6 | [illegible] | [illegible] |
| 0002 | Personnel B | [illegible] | 3 | [illegible] |
| 0003 | Personnel C | 2.2 | 1 | [illegible] |
| 0004 | Personnel D | 1.2 | 1 | [illegible] |
| 0005 | Personnel E | .4 | 1 | G |
| 0006 | Area Monitoring 1 | [illegible] | 1 | E |
| 0007 | Area Monitoring 2 | .4 | [illegible] | G |
| 0008 | Area Monitoring 3 | [illegible] | 3 | [illegible] |

Sinar: 1: Sinar-X/Sinar Gamma 2: Sinar Beta
3: Sinar Latarbelakang (Background radiation)
Tenaga: A: 10 keV (Very Soft) Tenaga: E: 200-400 keV (Very Hard)
B: 10-29 keV (Soft) F: 400 keV (Ultra Hard)
C: 30-74 keV (Medium hard) G: Tak dapat ditentukan
D: 75-199 keV (Hard) Latarbelakang

Nama Pegawai Bertugas: Disahkan oleh:

.......... ..............................

.......... Unit Pengawasan Pemeteran Dos Perseorangan,
Jabatan Kawalan Sinaran dan Keselamatan,
b/p: Ketua Pengarah,
Unit Tenaga Nuklear.

Fig.17: Example of monthly dose report for personnel/area monitoring film.

## 2.9 Some Survey of the Occupational Exposure During the One Year Period (Jun 1986 - May 1987).

Until September 1987, the number of films that are being processed on a routine basis are approximately 2300 which from about 113 agencies throughout the country. The number of agency is expected to increase soon. The demand for the film badge service for the period from June 1986 to May 1987 is shown in table 5. A significant increase in the number of agencies requiring the service for the first month of the year 1987 is mainly due to the exchange of service contract and effectiveness of enforcement body.

All agencies in table 5 were taken into account for the analyses. The occupational exposures to radiation workers in different activities is presented in table 6. It shows that the dose received by the personnel is strongly dependent on the type of agency activity. The agency dealing with NDT activities shows much higher percentage of the dose received that exceed the maximum permissible limit compare to other activities.

At present about 72% of the service are given to the factory sectors, 25% to the NDT companies and the rest is to other agencies such as universities and research institutes.

| MONTH (1986 - 1987) | NUMBER OF AGENCY | NUMBER OF PERSONNEL |
|---|---|---|
| JUNE '86 | 57 | 918 |
| JULY | 62 | 927 |
| AUGUST | 66 | 981 |
| SEPTEMBER | 71 | 1000 |
| OCTOBER | 73 | 1019 |
| NOVEMBER | 83 | 1100 |
| DECEMBER | 84 | 1113 |
| JANUARY '87 | 96 | 1593 |
| FEBRUARY | 97 | 1609 |
| MARCH | 101 | 1695 |
| APRIL | 104 | 1828 |
| MAY | 108 | 1840 |

Table 5: The number of agency/personnel during one year period.

| AGENCY | SERVICE FRACTION (%) | EXCEED MDP [4mSv/month] (%) | EXCEED 1/10 OF MDP [%] |
|---|---|---|---|
| NDT | 25 | 50 | 91 |
| FACTORY | 72 | 8 | 50 |
| OTHERS | 3 | NIL | 50 |
| OVERALL | 100 | 16 | 58 |

Table 6: Summary of the percentage dose received with respect to the activity of agency.

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