# Setting Up of
# Radiation Calibration Laboratory
# in
# Hospital Environment

28-Apr-2016

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PMH

Hospital Environment

Block H, Oncology Building, Princess Margaret Hospital – 2005

H 座 6/F

Office area

Calibration Lab 較對輻射儀器
Approved by Radiation Health Unit, Department of Health

H 座 5/F

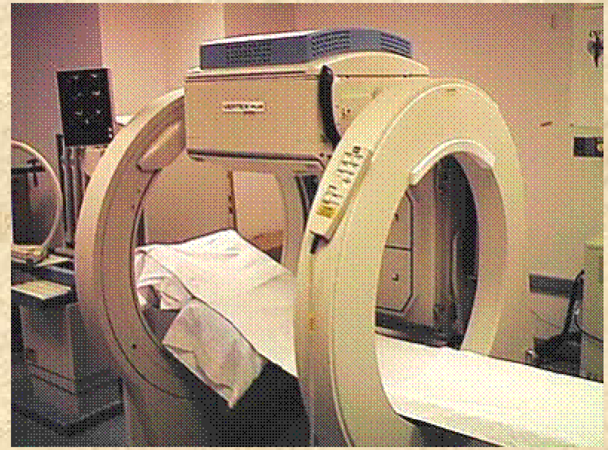
短距離放射治療
Brachytherapy
12 Ci (444 GBq) Ir-192
Half-life: 74 days
Average energy: 370KeV

H 座 4/F

碘-131 甲狀腺治療 Thyroid cancer 3 or 5.5 GBq (80 mCi or 150 mCi)
Thyroid remnant ablated by I-131 (short-range beta particle 2mm)
Half-life: 8 days gamma energy: 360 KeV Beta mean energy 190 KeV

放射診斷 Diagnostic

H 座 2/F



Gamma Camera

X光造影
Nuclear Medicine
核子醫學

H 座 LG1

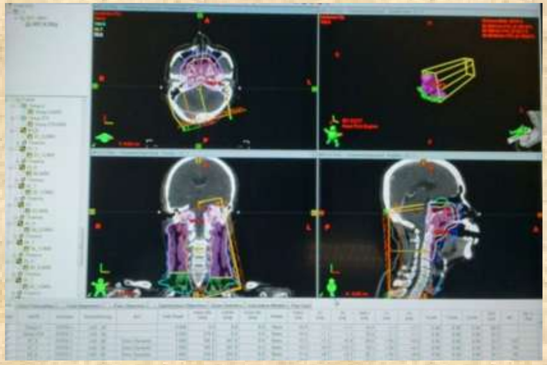
Diagnostic CT 電腦掃描 Treatment Planning

H 座 LG2

Radioactive waste store

# H 座 LG3　放射治療 Radiation Therapy (RT)

1.5m wall: 1m concrete + 0.5m steel




電療機 (直線加速器)
(6 MV / 15MV)

# Statistics

- After Fukushima Radiation Incident, HA purchased numerous radiation detectors for each cluster, e.g. pocket dosimeters & contamination monitors in every A&E and medical physics unit.

- In 2015, KWC has performed:

| | |
|---|---|
| (a) Meter Calibration | x 49 times (32 survey meters, 93 pocket dosimeters) |
| (b) Leakage Test | x 5 times |
| (c) Wipe Test | x 5 times |

- A proper calibration facility is essential for more efficient calibration and less occupational exposure for calibration personnel.

Pocket dosimeters

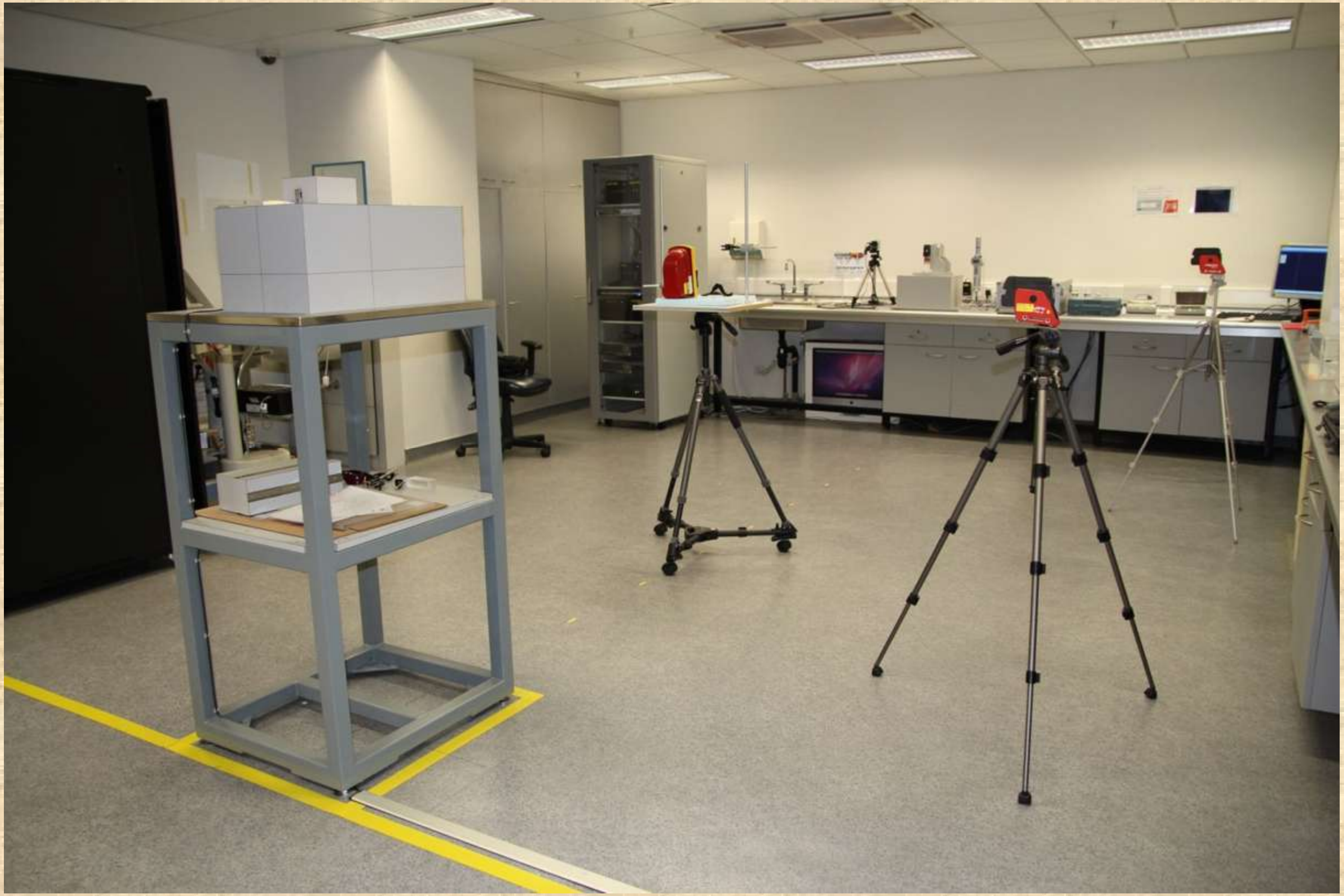
Radeye for Daya Bay Contingency Plan

# Essence of Radiation Calibration Lab

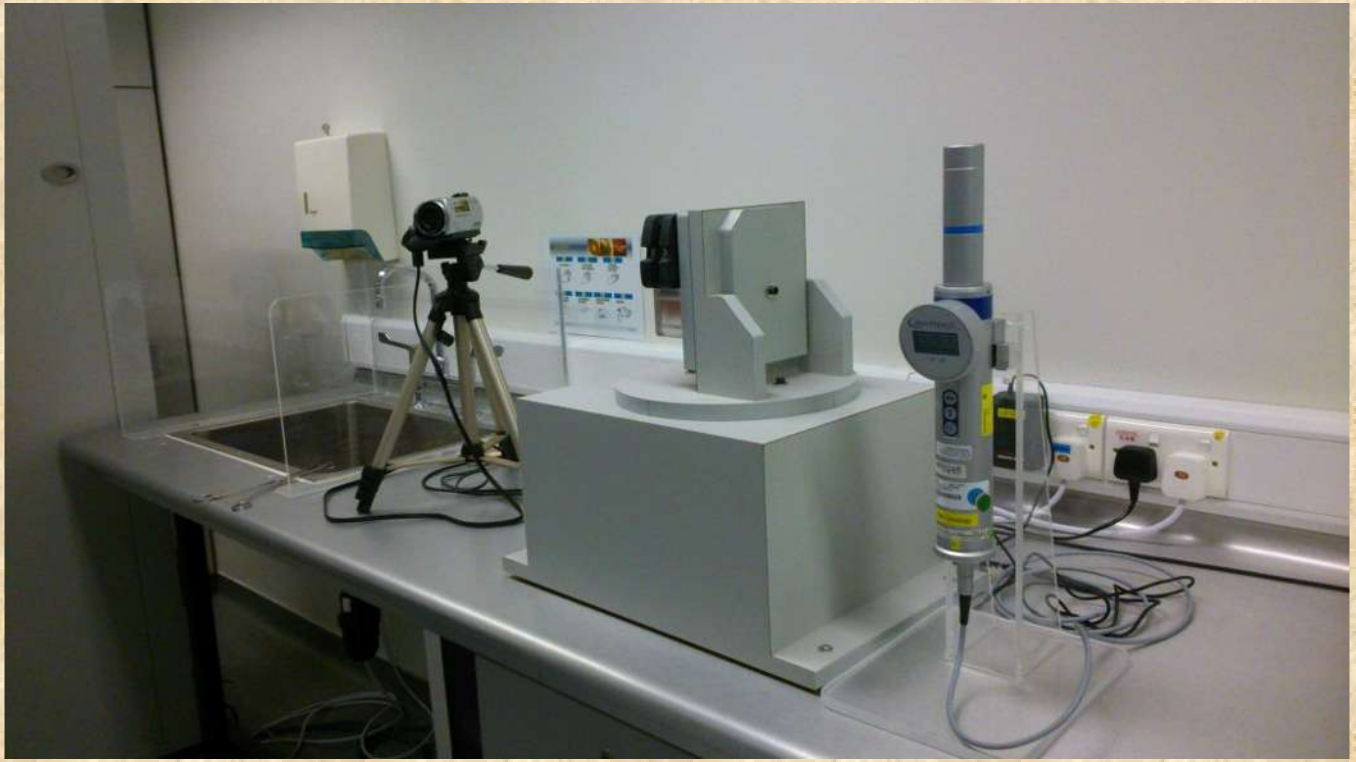
- The use and handling of radioactive substances in Hong Kong is controlled by the Radiation Ordinance (cap.303)
- Radiation Board, a regulatory authority set up by this ordinance, grants licences for the possession, usage, manufacturing, dealing in or dealing with radioactive substances.
- Application for or renewal of such licence will require demonstrations to the Radiation Board that the radioactive sources are leakage free (integrity test of radioactive sources) and the radiation detection instruments are functioning properly (calibration of radiation detection instruments).
- The Radiation Board Licensing Committee operates a Recognition programme (RP) to prequalify laboratories with regards to their competence in carrying out and certifying these tests, with an aim to assist licence holders to conduct the tests required for licence application or renewal purposes.

# Calibration Lab in PMH Oncology

# Calibration Lab in PMH Oncology



# Equipment



From left to right:

(1) Video cam for capturing reading
(2) Laser for alignment
(3) Area monitoring with bleep sound

# Calibration Bench available in the market


Cost over HK$1M!

Source: http://www.ptw.de/

# Example of a collimated gamma facility (IAEA)

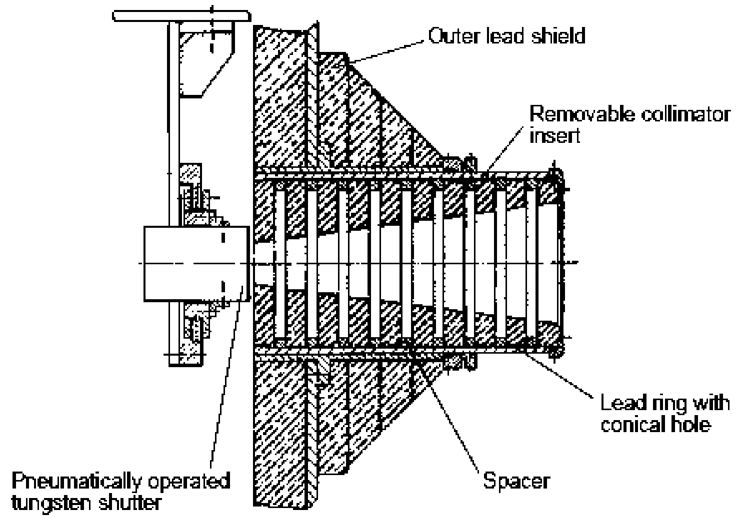
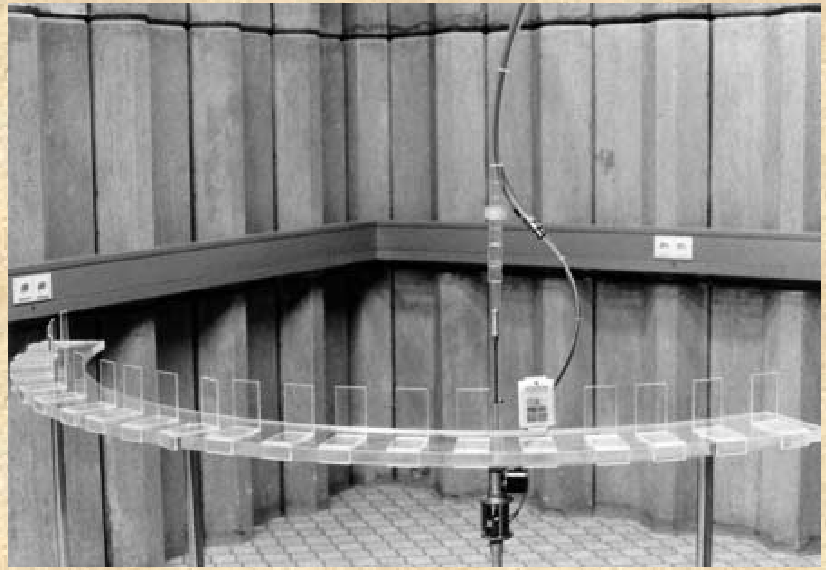




*FIG. 11. Example of ring collimator and shutter assembly of a collimated source system.*

source: www.**iaea**.org

# Example of a uncollimated gamma facility (IAEA)



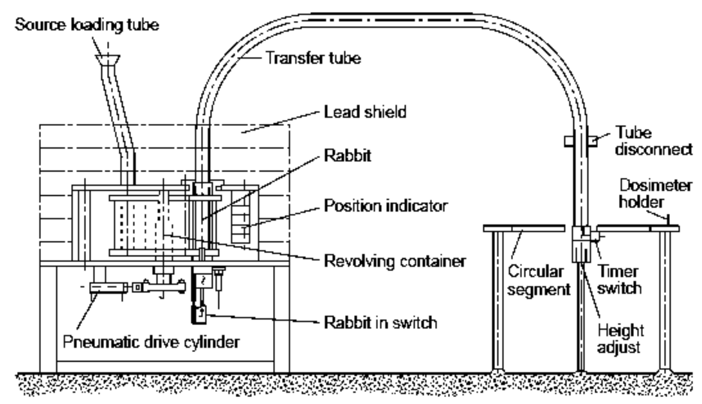



*FIG. 18. Schematic design of an example of an uncollimated irradiation system [37].*

source: www.**iaea**.org

# Equipment

1-litre Ionization Chamber as reference chamber (calibrated with Co-60)

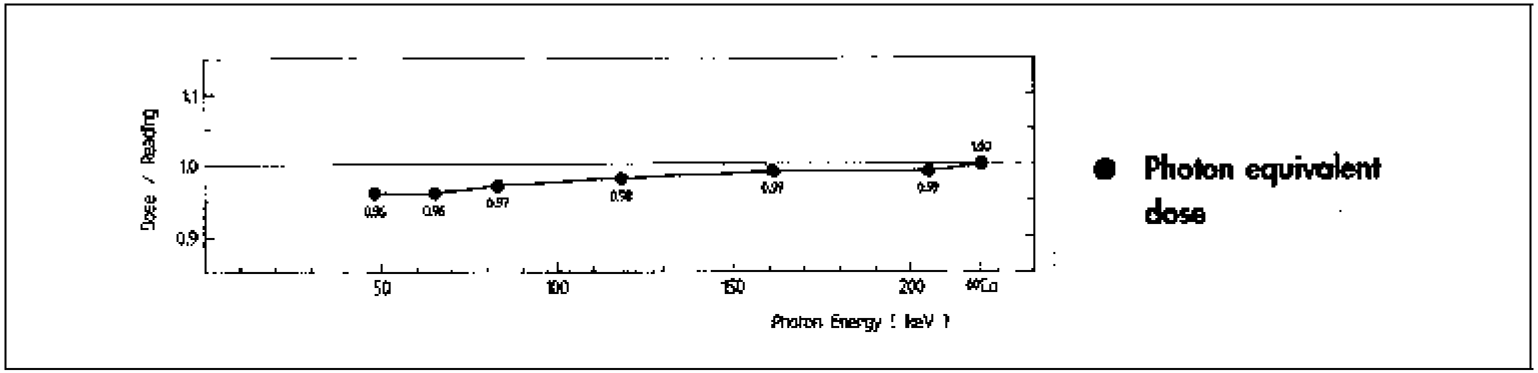



*Figure 4: Energy dependence type 32002*

# Equipment

Contamination monitor with wipe sample
Drawer (for alpha/Beta/Gamma measurement)

Prostate cancer:
I-125 seeds permanent implant (60 mCi)

MCA (NaI) for wipe/contamination test

Portable MCA with detachable Cs-137 check source

# Design Consideration?

- Budget

- Type of Radiation Used?
- X-ray? Gamma? Neutron? Beta?

- Radiation Range
- 3 uSv/hr to 100 uSv/hr?

- Radiation Protection

- Space?

# Recommendations from ISO-4037

Choice of Gamma Radiation:

| Radionuclide | Energy | Half-life (years) | Air kerma Rate Constant ($\mu Gyh^{-1}m^2MBq^{-1}$) | Specific Activity ($Bqkg^{-1}$) | Recommended chemical form |
|---|---|---|---|---|---|
| Co-60 | 1.17 MeV<br>1.33 MeV | 5.27 | 0.31 | $3.7x10^{15}$ | Metal |
| Cs-137 | 662 keV | 30.17 | 0.079 | $8.5x10^{14}$ | Chloride |
| Am-241 | 59.5 keV | 432.2 | 0.0031 | $1.1x10^{14}$ | Oxide |

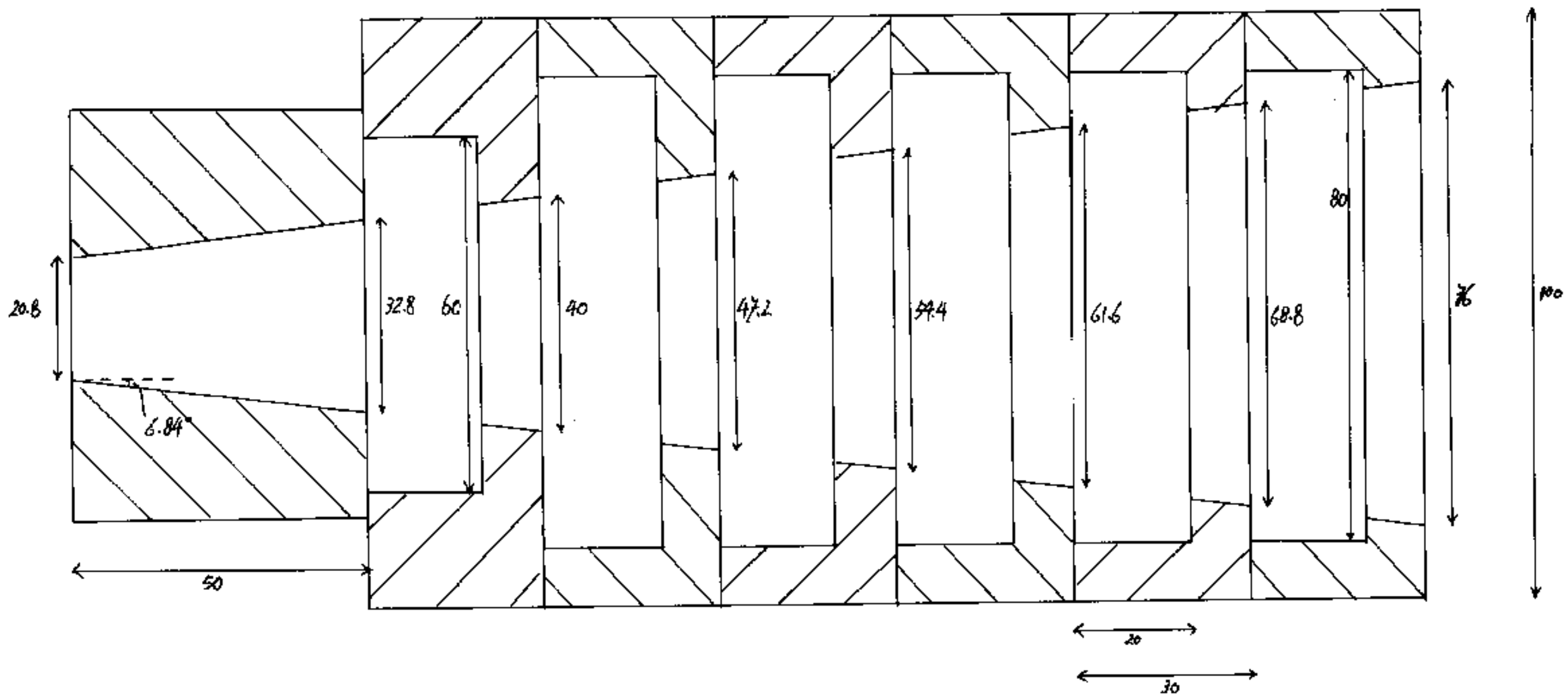
- Small source required, high specific activity preferred.
- Aged Cs-137 is preferred, since newly made Cs-137 may contain a significant amount of Cs-134 (half-life 2.06 yrs, mean energy 698 keV). Decay correction based on assumption of purely Cs-137 could be in error.
- Encapsulation should be sufficient thick to absorb beta radiation from the sources. Note that Air kerma rate constant only valid for unshielded point sources.

# Cal Lab using Radionuclides emitting Gamma Radiation

Requirement from ISO-4037:

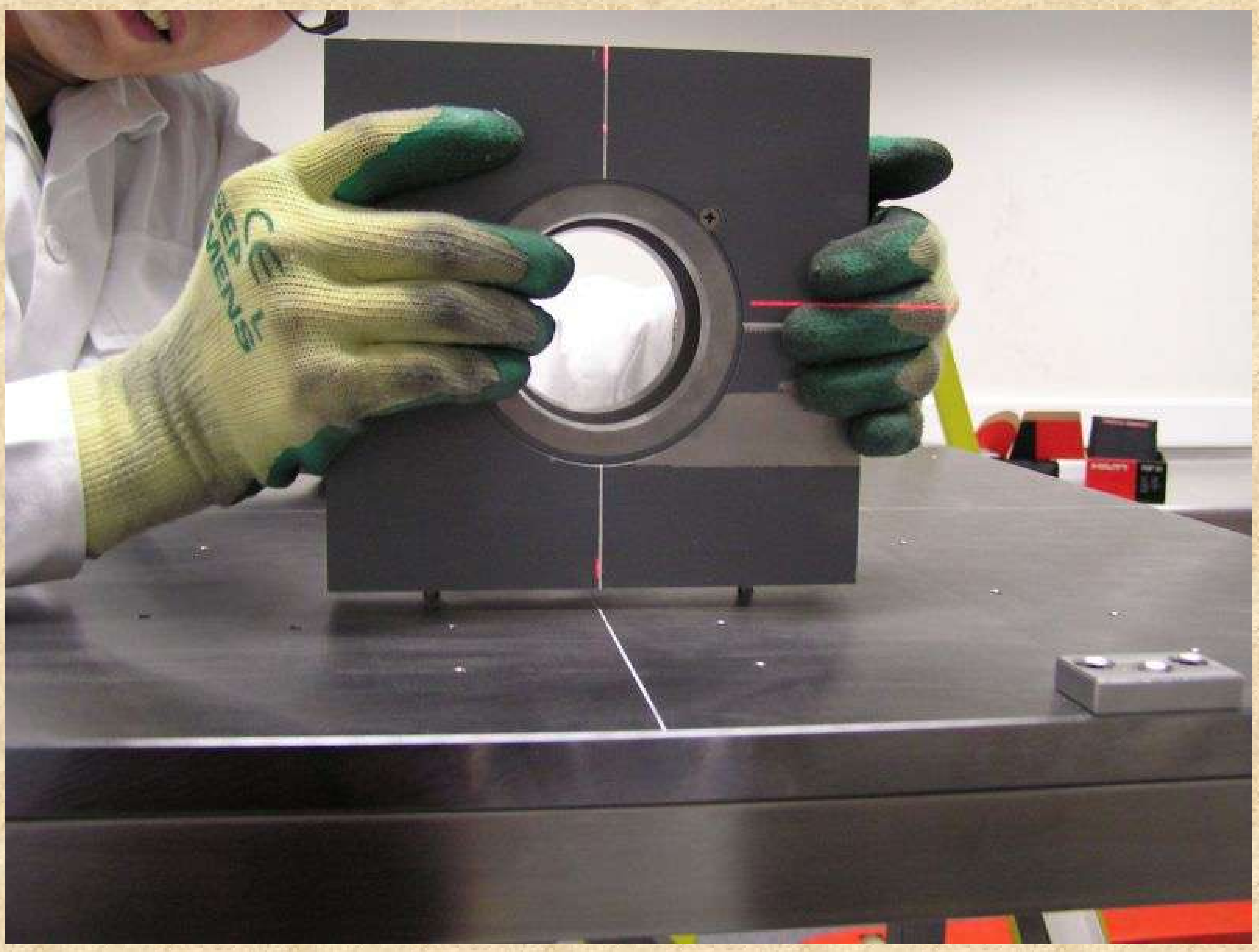
- Radiation scattered by environment shall not exceed 5% of that due to direct beam.
- To reduce scattering, minimum dimension of the room should be 4mx4mx3m high.
- Or, by making a collimator to define the size and the shape of the photon beam.
- The detector should be supported by low-Z material, e.g. plastic or aluminium.
- The detector should be positioned at half the height of the room.

# Collimator Design

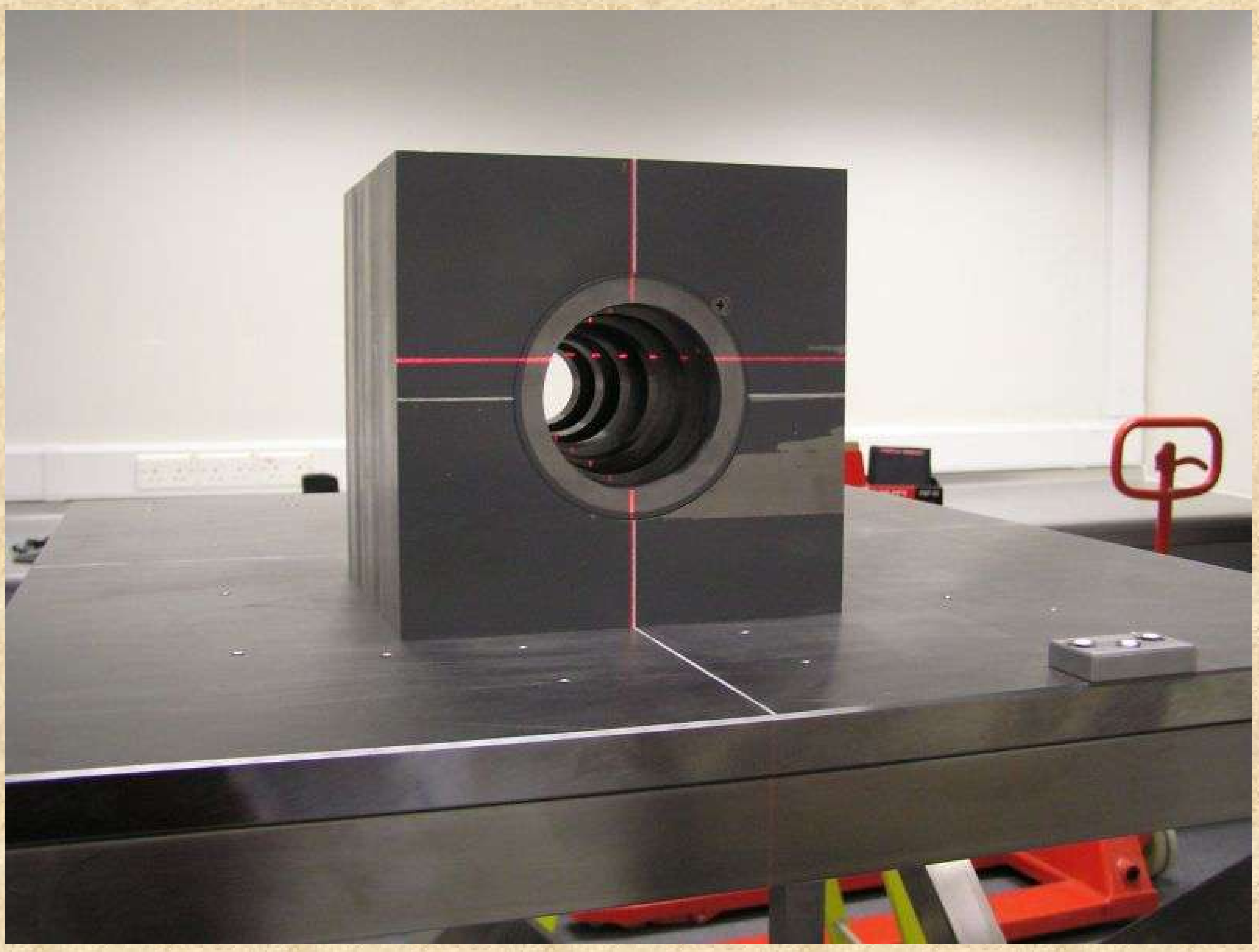



Unit: mm

The collimator is conical in shape and with the sources at the apex.
It is made up of a succession of six apertures each with thickness of 10 mm.



Mounting a collimator plate on steel table. The total weight of the irradiator is about 1000 pounds



Collimator is made of six pieces of steel plate with concentric circle opening, and separated from each other by 20-mm interstices which serve as traps for photons scattered by the the edges of the preceding aperture.

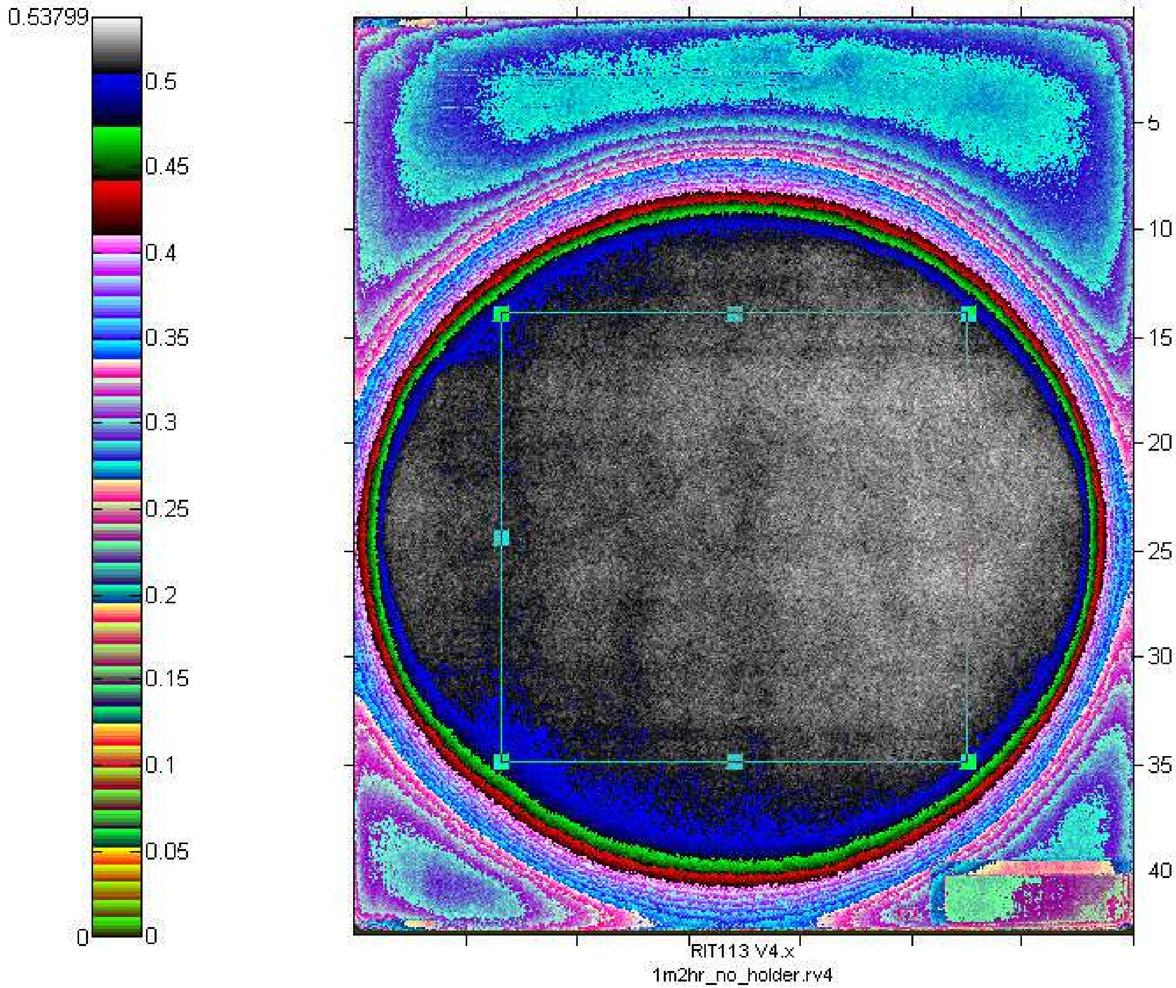
Front view of the irradiator with a dummy source.

From left to right: 4-inch lead door, collimator and Cs-137 storage safe.

Top view of the irradiator. 2 tubes of Cs-137 each of activity 290MBq (2007) are inserted into the hole. On the top, it is encapsulated by a lead cap

35cmx43cm film cassette is used to check the field uniformity.
According to ISO-4037, the variation of the air kerma rate over the useful beam area shall be less than 5%. The result is less than 2%.

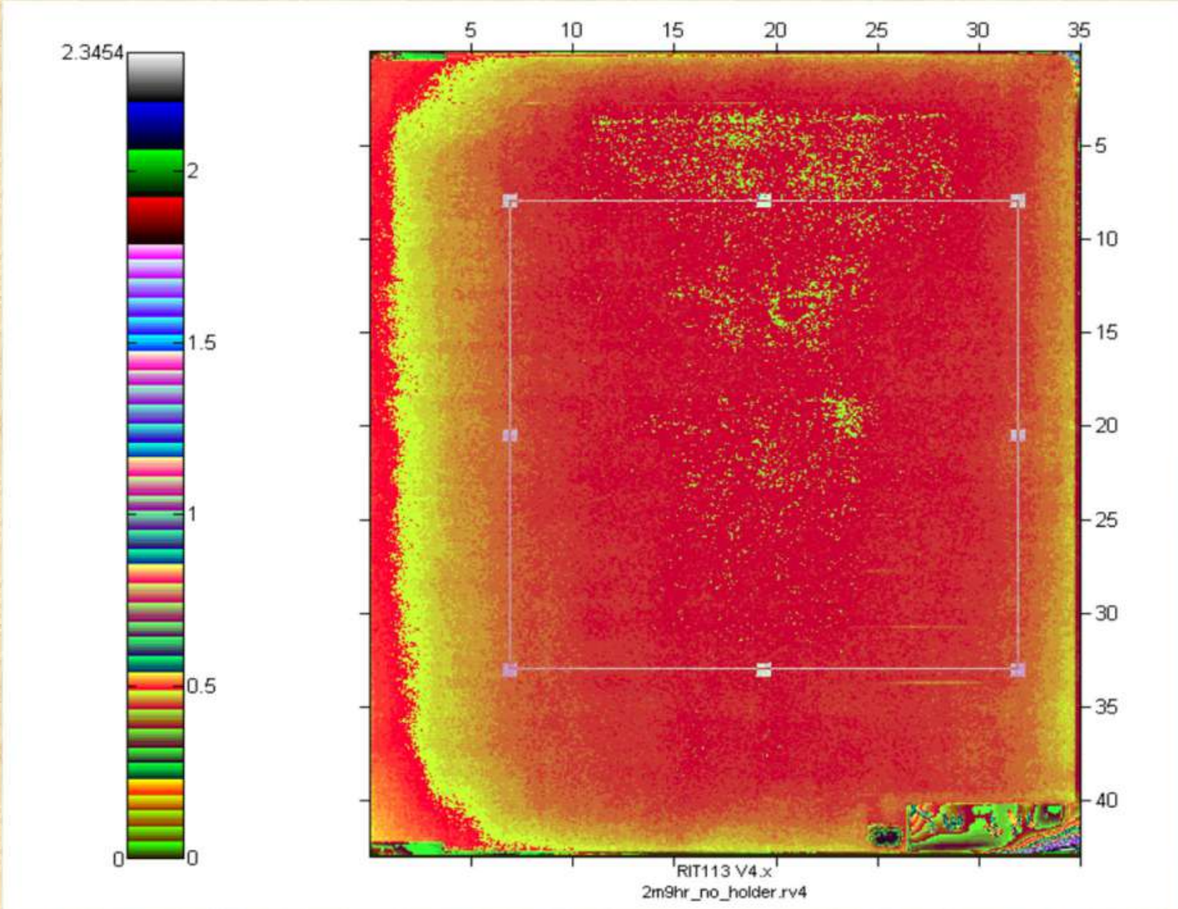
# Radiation Field Uniformity at 1m




Exposure time = 2 hrs
O.D. ≈ 0.5

At 1m, the max. variation of air kerma rate over useful beam area (21cm x 21cm) is +/-2.70%.
According to ISO-4037, it should be less than 5%.

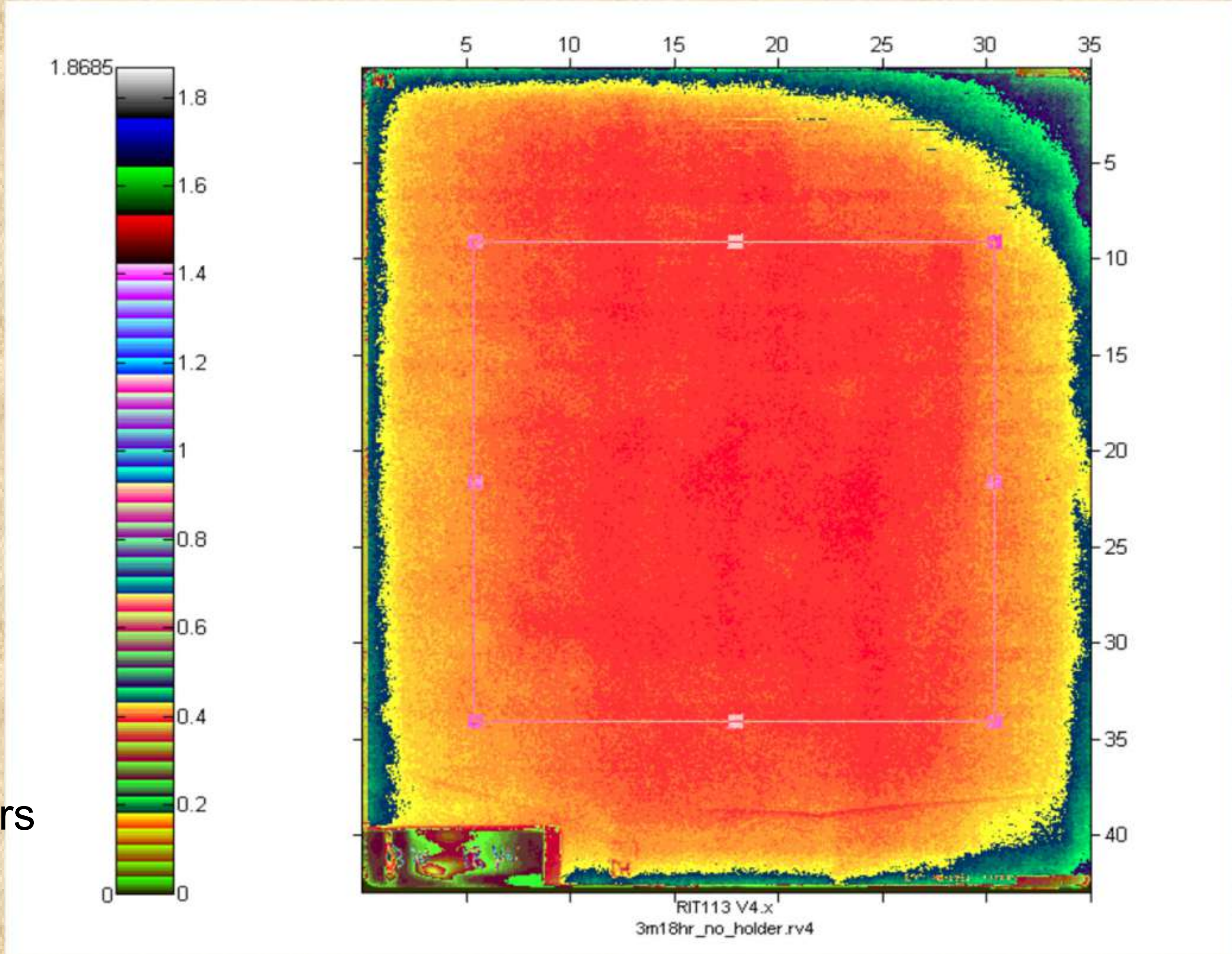
# Radiation Field Uniformity at 2m




Exposure time = 8 hrs
O.D. ≈ 0.5

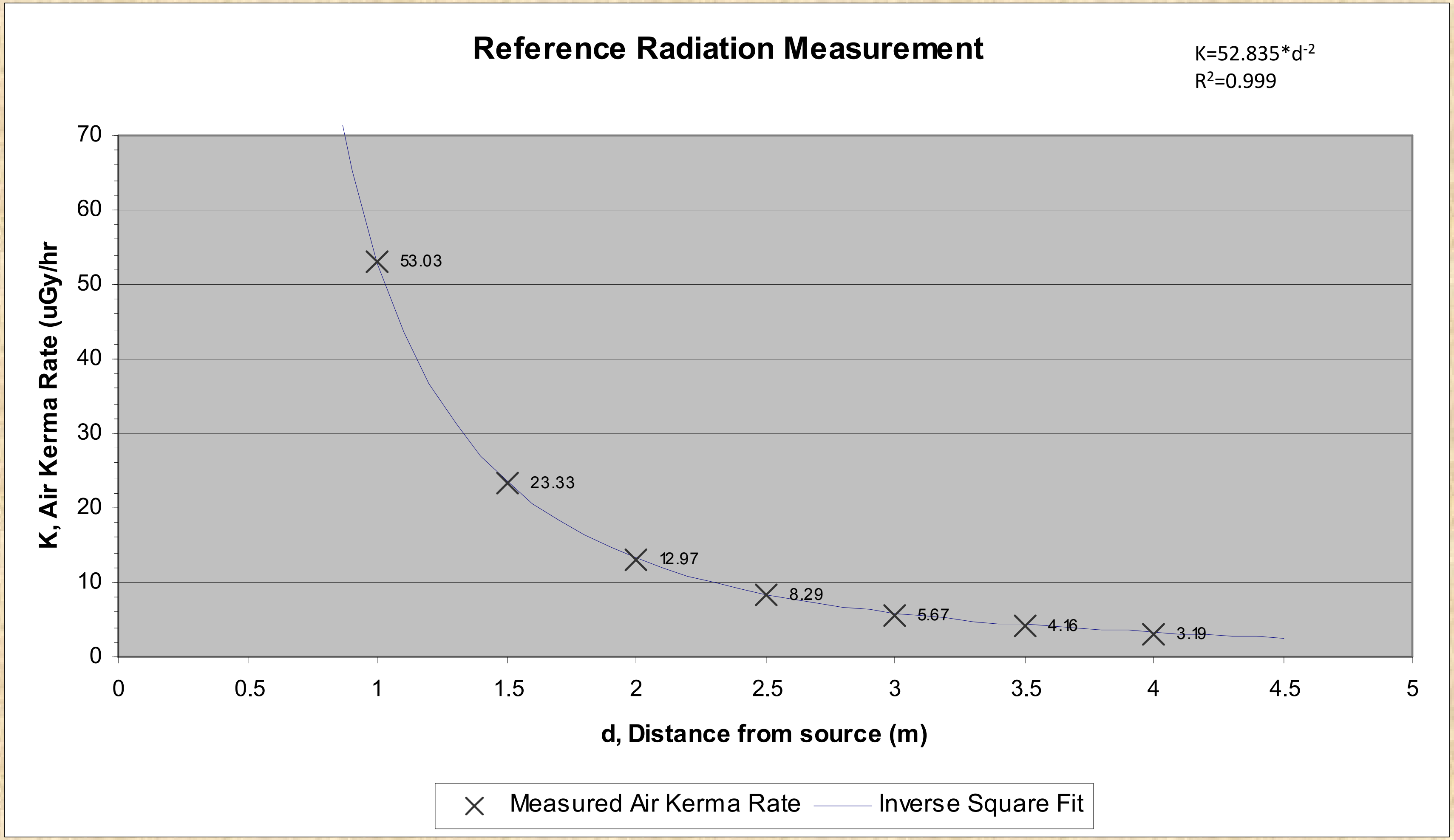
At 2m, the max. variation of air kerma rate over useful beam area (25cm x 25cm) is +/-2.65%. According to ISO-4037, it should be less than 5%.

# Radiation Field Uniformity at 3m




Exposure time = 18 hrs
O.D. ≈ 0.4

At 3m, the max. variation of air kerma rate over useful beam area (25cm x 25cm) is +/-4.20%.
According to ISO-4037, it should be less than 5%.

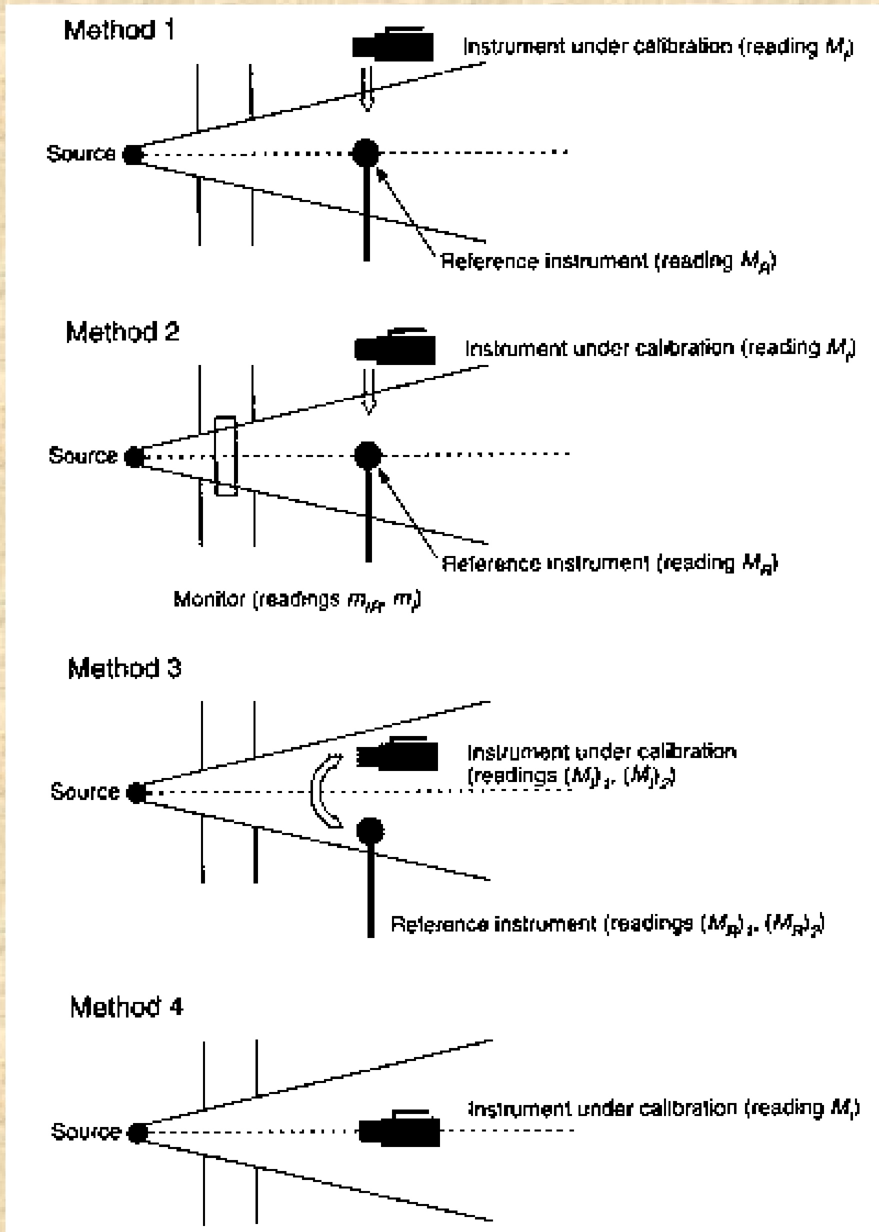



Calibration range: 1m to 3m ➔ ~ 50 to 5 uSv/hr

# Method of calibration

X-ray shadow free Chamber (monitor)

1-litre Ionization Chamber (reference)




1. *Calibration with a reference instrument without any monitor.*
   *(measure reference instrument and then instrument under calibration)*
2. *Calibration with a reference instrument and with a monitor.*
   *(e.g. x-ray unit with variable air kerma)*
3. *Calibration by simultaneous irradiation of reference instrument and instrument under calibration.*
   (either meter not influenced by presence of other one to an extent exceeding 2%)
4. *Calibration in a known radiation field.*

# Calibration of Personal Dosimeters

TABLE XVII. RADIONUCLIDE SOURCES AND HIGH ENERGY PHOTON RADIATIONS

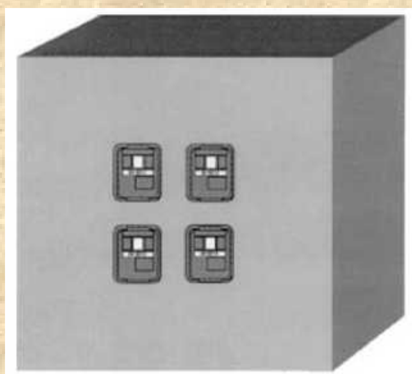
| Radiation quality | Energy of radiation (MeV) | Half-life (d) | Air kerma rate constant[a] ($\mu Gy \cdot h^{-1} \cdot m^2 \cdot MBq^{-1}$) | Conversion coefficient for normal incidence | | Conversion coefficient for the slab phantom (normal incidence) | | Conversion coefficient $H_p(0.07)/K_a$ ($Sv \cdot Gy^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $Hc(0.07)/K_a$ ($Sv \cdot Gy^{-1}$) | $H^*(10)/K_A$ ($Sv \cdot Gy^{-1}$) | $H_p(0.07)/K_a$ ($Sv \cdot Gy^{-1}$) | $H_p(10)/K_a$ ($Sv \cdot Gy^{-1}$) | Pillar phantom | Rod phantom |
| S-Co | 1.1733<br>1.3325 | 1 925.5 | 0.31 | | 1.16 | | 1.15 | | |
| S-Cs | 0.6616 | 11 050 | 0.079 | | 1.20 | 1.25 | 1.21 | | |
| S-Am | 0.05954 | 157 788 | 0.003 | 1.59 | 1.74 | | 1.89 | 1.39 | 1.14 |
| R-$^{12}$C | 4.44 | | | | 1.12 | | 1.11 | | |
| R-$^{19}$F | 6.13–7.12 | | | | 1.11 | | 1.12 | | |
| R-Ti(n,K) | 5.14 | | | | 1.11 | | 1.11 | | |
| R-Ni(n,K) | 6.26 | | | | 1.11 | | 1.11 | | |
| R-$^{16}$O | 6.13–7.12 | | | | 1.11 | | 1.12 | | |

[a] The value of the air kerma rate constant is only valid for an unshielded point radionuclide source. It is given only as a guide. Air kerma rates at the exposure positions should be measured by using a secondary ionization chamber.

Safety Reports Series No .16. Calibration of Radiation Protection Monitoring Instruments. International Atomic Energy Agency (IAEA). Vienna; 2000.

Personal Dosimeter

For dosimeter worn on body to measure $H_p(10)$, a phantom of outer dimensions of 30cmx30cmx15cm with PMMA walls filled with water and termed ISO water slab phantom. When using radiation with energy equal or greater than Cs-137, a solid PMMA phantom of same dimension may be used.



Calibration of pocket dosimeters

**Table 14 — Conversion coefficient $h^*_K(10;S)$ and $h^*_K(10;R)$ from air kerma, $K_a$, to ambient dose equivalent $H^*(10)$ for radiation qualities given in ISO 4037-1 (expanded and aligned field) and the ICRU sphere for collimated beams, reference distance 2 m.**

| Radiation quality | Irradiation distance<br>m | Build-up layer thickness<br>mm | $k_{PMMA}$ | $h^*_K(10;S)$<br>$h^*_K(10;R)$<br>Sv/Gy |
|---|---|---|---|---|
| S-Am | 1,0 - 2,0 | -- | --- | 1,74 |
| S-Cs | 1,0 - 3,0 | 2 | 1,00 | 1,20 |
| S-Co | 1,0 - 3,0 | 4 | 1,00 | 1,16 |
| R-C | 1,0 - 3,0 | 25 | 0,94 | 1,12 |
| R-F | 1,0 - 3,0 | 25 | 0,94 | 1,11 |
| R-Ti | 1,0 - 3,0 | 25 | 0,94 | 1,11 |
| R-Ni | 1,0 - 3,0 | 25 | 0,94 | 1,11 |
| R-O | 1,0 - 3,0 | 25 | 0,94 | 1,11 |

Dosimeter for area monitoring shall be irradiated in free air (without phantom). For the ISO reference condition, conversion coefficient h from air kerma to ambient dose equivalent can be found from tables.

# Wipe Test / Leakage Test

The surface contamination in Bq/cm$^2$ :

$$\frac{(C_s - C_b)*10}{(A*\varepsilon_i)*f_{absorb}}$$

where $\varepsilon_i$ is the detection efficiency for the isotope i,
A is the swab area (e.g. wiping a bench) in cm$^2$.
$f_{absorb}$ is the fractional attenuation caused by absorption of the swab and ethanol.

For Beta or Gamma, $f_{absorb}=1$
For alpha, $f_{absorb}=0.5$

Leakage test of sealed source in Bq:

$$\frac{(C_s - C_b)}{\varepsilon_i * f_{absorb}}$$

< 200 Bq (ISO 9978)
➔ Leak free

- For strong source, e.g. Co-60 machine, blood irradiator, only accessible surface close to source are wiped.

# Contamination Test of Working Area for Unsealed Radioactive Sources

**Table A5.1 Derived limits/or surface contamination**

| Category | Surface | Levels of contamination that should not be exceeded (Bq $cm^{-2}$) | | |
|---|---|---|---|---|
| A | Surface of the interiors contents of glove boxes and fume cupboard | The minimum reasonably achievable | | |
| B | Surfaces in controlled areas including any equipment therein (other than those in Category A) | Class III<br>30 | Class IV<br>300 | Class V<br>3000 |
| C | Surfaces of the body | 3* | 30 | 300 |
| D | Supervised and public areas | 3 | 30 | 300 |

Derived levels for Class I and Class II radionuclides may be taken as $10^{-2}$ and $10^{-1}$ respectively of the Class III levels.

* For alpha emitters use one-tenth of this value.

Code of Practice on Radiation Safety. Hospital Authority, 2011.

**Table A5.2 Classification of radionuclides for the control of surface contamination**

| Class | Radionuclide |
|---|---|
| I | $^{227}$Ac, $^{228}$Th, $^{230}$Th, $^{232}$Th, Th-nat, $^{231}$Pa, $^{232}$U, $^{233}$U, $^{234}$U, $^{236}$U, alpha emitters with Z>92 |
| II | $^{147}$Sm, $^{210}$Pb, $^{227}$Th, $^{235}$U, $^{238}$U, U-depl, U-nat, U-enr, $^{241}$Pu |
| III | All nuclides which are not in the other classes |
| IV | $^{14}$C, $^{35}$S, $^{54}$Mn, $^{57}$Co, $^{65}$Zn, $^{67}$Ga, $^{75}$Se, $^{77}$Br, $^{85}$Sr, $^{99m}$Tc, $^{109}$Cd, $^{123}$I, $^{125}$I, $^{129}$Cs, $^{197}$Hg, $^{201}$Tl |
| V | $^{3}$H, $^{51}$Cr, $^{55}$Fe, $^{63}$Ni, $^{131}$Cs |

# Calibration of surface contamination monitor

Jigs are used to maintain a reproducible separation between planar source & meter (3mm)

Detection Efficiency ε is calculated as follows:

$$\varepsilon = \frac{\left(N - N_{bkg}\right)}{A} \times 100\%$$

# Lessons learned from Fukushima

- Initially, 13k cpm (217 cps) of GM counter, criteria for decon
- Eventually, count of 100k cpm (1667 cps) was used due to:

  ~ Disrupted water supply

  ~ Very low temperature

  ~ Thousands of evacuees

- 1500 patients within 20-km zone required to evacuate, 21 erderly patients died from hypothermia & dehydration
- Stay indoor already provide a good shelter for external contamination

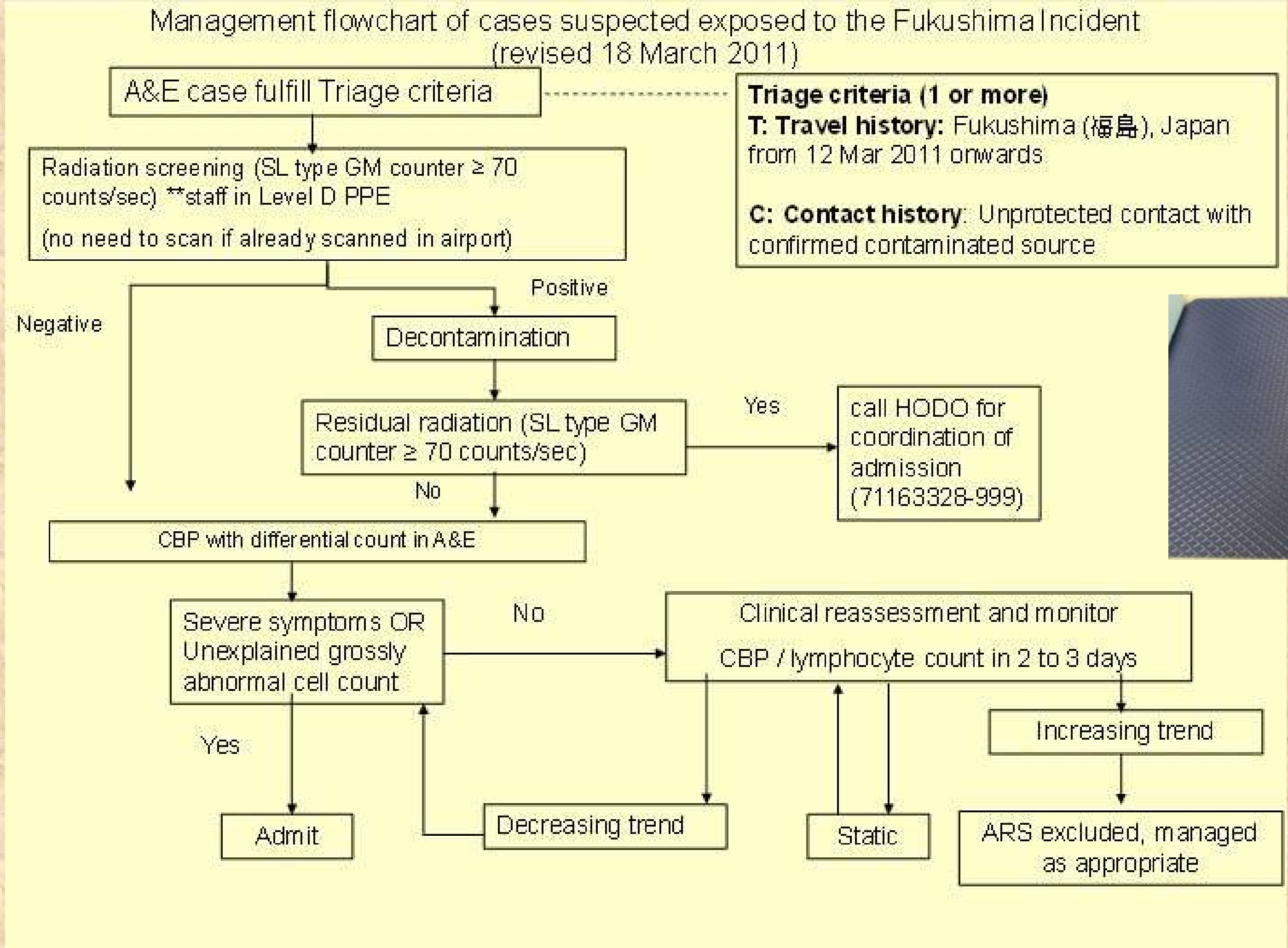
# 中國核電站分布圖


資料來源：互動百科

# Daya Bay Contingency Plan (DBCP) Meter for A&E


Screening criteria: 1000 cps
(corresponds to 30 $Bq/cm^2$ of Sr-90)

## Side-windowed GM counter in A&E (old model)




Screening criteria: 70 cps
(corresponds to 30 $Bq/cm^2$ of Sr-90)

# Radiation Security & Safety

Access card control

Alarm

Calibration Lab. (Rm 615)

Micro-switch

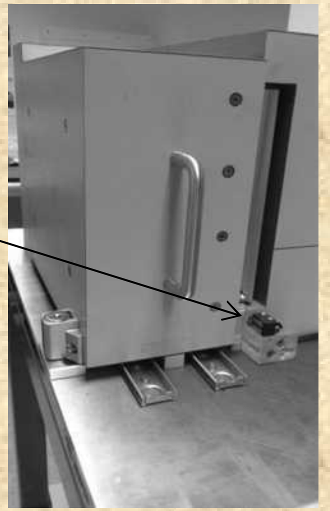


Figure: Alarm is triggered by the micro-switch installed on lead door of irradiator

# Radiation Security & Safety

Beam on, stay behind yellow line!
Background radiation level behind the yellow line.

Always good to have audible sound when radiation is on!

# Neutron Detector Calibration in HK?

~ scattering issue, radiation protection issue, low utilization rate ………….

Constancy check at 1m:

| | | LB123 | 451P |
|---|---|---|---|
| Date | FS | Neutron (mSv/hr) | Gamma (mSv/hr) |
| 22/9/2015 | 40x40 | 14.2 | 74 |
| LA4 | 20x20 | 15.51 | 60 |
| 15X | 10x10 | 15.91 | 26 |
| 400MU/min. | 0.5x0.5 | 15.43 | 4.8 |

Neutron source:

(1) Cf-252 (spontaneous fission source)

| | |
|---|---|
| Half-life | 2.645 years |
| Specific activity | 536.3 Ci/g |
| Decay mode | α (96.908 %), SF (3.092 %) |
| Neutron multiplicity | 3.768 n/fission |
| Mean fission neutron spectrum energy | 2.13–2.15 MeV |
| Prompt γ-ray multiplicity (mean) | ~10/fission |
| Average prompt γ-ray energy | 0.7–0.9 MeV |

(2) Am-Be (Alpha neutron source)

- AmBe (“ambee”) sources are a mix of Am-241 and Be-9.
- Half-life: 432.2 years
- Average neutron energy: 4.2 MeV

# Off-site Calibration


Very sensitive radiation detector at entrance

Clinical Waste Treatment Centre at Tsing Yi

Refer to manual or calibration certificate for testing

# Specifications

**Sensitivity**: The Model 375P incorporates very sensitive detectors and sensitivity sophisticated electronics. The following tests were performed at Ludlum Measurements, Inc., and the results of these tests should be considered typical of the Model 375P.

**Dynamic Sensitivity Test**: The dynamic sensitivity test was conducted with the detectors mounted on either side of a 1.5 meter (5-foot) hallway, with a 5 µCi $^{137}$Cs source passed down the center of the hallway at approximately 3 mph. The results were as follows:

| SYSTEM | ALARMPT | SOURCE DETECTED |
|---|---|---|
| 375P-336 | 6 Sigma | 5 out of 5 passes |
| 375P-1000 | 6 Sigma | 5 out of 5 passes |
| 375P-3500 | 6 Sigma | 5 out of 5 passes |

**Static Sensitivity Test**: The following test was conducted by making a slow approach towards a single detector. Distance stated is measured from source to detector at time of alarm.

| SYSTEM | SOURCE | ALARMPT | DISTANCE |
|---|---|---|---|
| 375P-336 | 84 µCi $^{241}$Am | 6 Sigma | 1.63 m (5.3 ft) |
| 375P-1000 | 84 µCi $^{241}$Am | 6 Sigma | 3.4 m (11 ft) |
| | | (18.3 m [60 ft] w/o PVC enclosure) | |
| 375P-3500 | 84 µCi $^{241}$Am | 6 Sigma | 9.1 m (30 ft) |
| 375P-336 | 5 µCi $^{137}$Cs | 6 Sigma | 1.5 m (60 in.) |
| 375P-1000 | 5 µCi $^{137}$Cs | 6 Sigma | 1.8 m (72 in.) |
| 375P-3500 | 5 µCi $^{137}$Cs | 6 Sigma | 3 m (118 in.) |

**Theoretical Sensitivity**: Given the following typical data:

| SYSTEM | BKGND | $^{137}$Cs Sensitivity |
|---|---|---|
| 375P-336 | 0.8 kcps | 0.2 kcps per µR/hr |
| 375P-1000 | 2.0 kcps | 0.4 kcps per µR/hr |
| 375P-3500 | 5.0 kcps | 2.0 kcps per µR/hr |

# Propagation of Uncertainty

The uncertainties are based on an estimated level of confidence of 95%.
Suppose that $z=f(x_1,x_2,x_2, \ldots)$ where $x_1$, $x_2$, $x_3$, ….. are all independent variables.
The uncertainty in z, $\Delta z$, is calculated according to propagation of errors:

$$\Delta Z^2 = \left(\frac{\partial f}{\partial x_1}\right)^2 \Delta x_1{}^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 \Delta x_2{}^2 + \left(\frac{\partial f}{\partial x_3}\right)^2 \Delta x_3{}^2 + \cdots\cdots\cdots$$

$$F = \frac{M \times R \times f \times U \times \left(\frac{1}{d^2}\right) \times \frac{273 + T}{293} \times \frac{1013}{P}}{I} = \frac{\text{Reference Reading}}{\text{Instrument Reading}}$$

$$\frac{\Delta F}{F} = \pm\sqrt{\left(\frac{\Delta M}{M}\right)^2 + \left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta f}{f}\right)^2 + \left(\frac{\Delta U}{U}\right)^2 + \left(\frac{2\Delta d}{d}\right)^2 + \left(\frac{\Delta T}{273 + T}\right)^2 + \left(\frac{\Delta P}{P}\right)^2 + \left(\frac{\Delta I}{I}\right)^2}$$

$$= \pm 5\%$$

Where F is the calibration factor for the instrument being calibrated;

M is the dosimeter reading in nC; $\frac{\Delta M}{M} \approx \pm 0.8\%$

R is energy response of the 1-litre chamber in the range of Cs-137 to Co-60*; $\frac{\Delta R}{R} \approx \pm 1\%$

f is the calibration factor of the 1-litre chamber in Gy/C*; $\frac{\Delta f}{f} \approx \pm 2.5\%$

U is the uniformity of the field with ±1cm displacement; $\frac{\Delta U}{U} \approx \pm 1\%$

d is the distance from source to detector; $\frac{2\Delta d}{d} \approx \pm 0.4\%$

T is the temperature measured in laboratory; $\frac{\Delta T}{273 + T} \approx \pm 0.5\%$

P is the pressure measured in laboratory; $\frac{\Delta P}{P} \approx \pm 0.5\%$

I is the instrument reading being calibrated; $\frac{\Delta I}{I} \approx \pm 4\%$

Therefore, Uncertainty of instrument reading at 95% Confidence Level: ±10%

(The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of 95%)

* The 1-litre ionization chamber is calibrated using Co-60 in PTW but we are using it to calibrate Cs-137 source.

# ISO method of uncertainty assessment

Type A evaluations: uncertainty estimates using statistics (usually from repeated
(random) readings)

Type B evaluations: uncertainty estimates from other information, e.g. calibration
(systematic) certificates, manufacturer's spec, published information, etc.

| Quantity | Standard Deviation (%) | Type of Uncertainty | Degree of Freedom |
|---|---|---|---|
| Dosimeter Reading M | 0.8 | A | 9 |
| Energy Response R | 1 | B | - |
| Calibration factor f | 2.5 | B | - |
| Field Uniformity U | 1 | B | - |
| Distance d | 0.4 | B | - |
| Temperature T | 0.5 | B | - |
| Pressure P | 0.5 | B | - |
| Instrument Reading I | 4 | A | 9 |
| Combined Uncertainty | 5 | (Assume Normal Distribution) | |
| Expanded Uncertainty | 10 | Coverage Factor (k=2) | |

Reference:


1. International Atomic Energy Agency,
   IAEA Safety Reports Series No. 16 – Calibration of Radiation Protection Monitoring Instruments
   http://www-pub.iaea.org/MTCD/publications/publications.asp
2. National Council for Radiation Protection and Measurements,
   NCRP Report No. 112 – Calibration of Survey Instruments used in Radiation Protection for the Assessment of Ionizing Radiation Fields and Radioactive Contamination
   http://www.ncrppublications.org/
3. National Physical Laboratory,
   NPL GPG (Good Practice Guide) No. 14, No. 30, and No. 49
   http://www.npl.co.uk/publications/
4. National Physical Laboratory,
   NPL Report CIRM (Centre for Ionising Radiation Metrology) No. 55
   http://www.npl.co.uk/publications/
5. International Organization for Standardization,
   ISO 9978 (Radiation protection - Sealed radioactive sources - Leakage test methods)
6. National Institute of Standards and Technology,
   NIST Technical Note 1297 – Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results
   http://physics.nist.gov/Pubs/pdf.html
7. International Organization for Standardization,
   Guide to the Expression of Uncertainty in Measurement (ISBN 92-67-10188-9)


Worst case scenario:

Meter is still "working",
but you didn't know that it shows no response to any radiation!

Thank you!