IAEA
International Atomic Energy Agency

LECTURE 4:

BETA AND NEUTRON DOSE RATE MONITORING

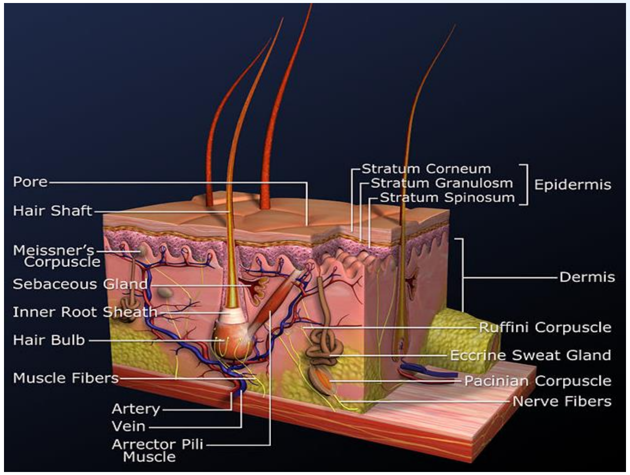
Beta Dose Rate Monitoring

- Purpose
- Technique
- Calibration and Measurement
- Practical Measurement
- Interpretation
- Instrument Characteristics

Importance of Beta Dose

Beta monitoring assumes importance due to:

- Potential for causing skin exposure at the depth of sensitive cells (0.07 mm)
- In this situation measured should be in terms of directional dose equivalent rate, H'(0.07).
- It may also contribute to exposure to the lens of the eye at the depth of 3 mm.
- This measurement should then be in terms of H'(3).
- Recent reduction in eye dose limit by ICRP and IAEA necessitates precise monitoring.



Beta Dose Rate Monitoring

Purpose:

To identify the potential areas having beta dose rates to limit the exposures.

To measure the beta dose rate, in terms of directional dose equivalent rate, H'(0.07),

In order to confirm that dose equivalent rates to the skin are acceptable.

To confirm that H’(3) to eye remains within limit.

Designing the Programme

IAEA

- Fingerprint investigations of a nuclear facility clearly reveal the possible beta emitting radionuclides.
    - In reactor environment ^{90}Sr, ^{90}Y, ^{85}Kr are predominately observed besides some beta-gamma emitters like ^{137}Cs, ^{60}Co.
    - In hospitals and research institutions P-32, Y-90 and S-35 are being used.
- Beta emitting radioactive sources, surface and air contamination with beta emitters may pose a significant external radiation hazard, especially for the skin and eye.

TECHNIQUE

Technique

1. Monitoring can be done either using instruments which indicate directly in terms of directional dose equivalent rate, H'(0.07), which are mainly
   - Thin end window detectors
   - Ionisation chambers.
   - Plastic scintillators
2. Beta counters do have lined with low Z material to ward off bremsstrahlung production.
3. Dose rates are only reliable when the detector to source distance is at least three times the maximum detector dimension.

INSTRUMENT

Instrument

IAEA

Detector choice is often more difficult than X and gamma dose rate measurement because of number of factors. These are:

Beta particles and its associated bremsstrahlung (X-radiation).

The need to make measurements relatively close to the source.

Absorption of beta by window materials.

Instrument

The complex spectrum is best handled using ionisation chamber instruments.

However the closer the approach to the source, the more the indication tends to underestimate the beta dose rate at the reference point of the chamber.

Using sliding type ionization chamber, the beta dose rate could be measure in a mixed beta, gamma field.

- This will measure the beta dose rate and the gamma/X component separately.

Instrument

A thin end window GM detector (1-3 mg/cm^2) has a reasonable beta response in terms of H′(0.07).

- Instrument is smaller and easier to position.

- Detector is normally smaller and easier to position and that the detector has basically no depth and hence is more accurate.

- The detector, however, over-responds significantly for bremsstrahlung, if the instrument is calibrated in terms of H*(10) for ^{137}Cs gamma radiation.

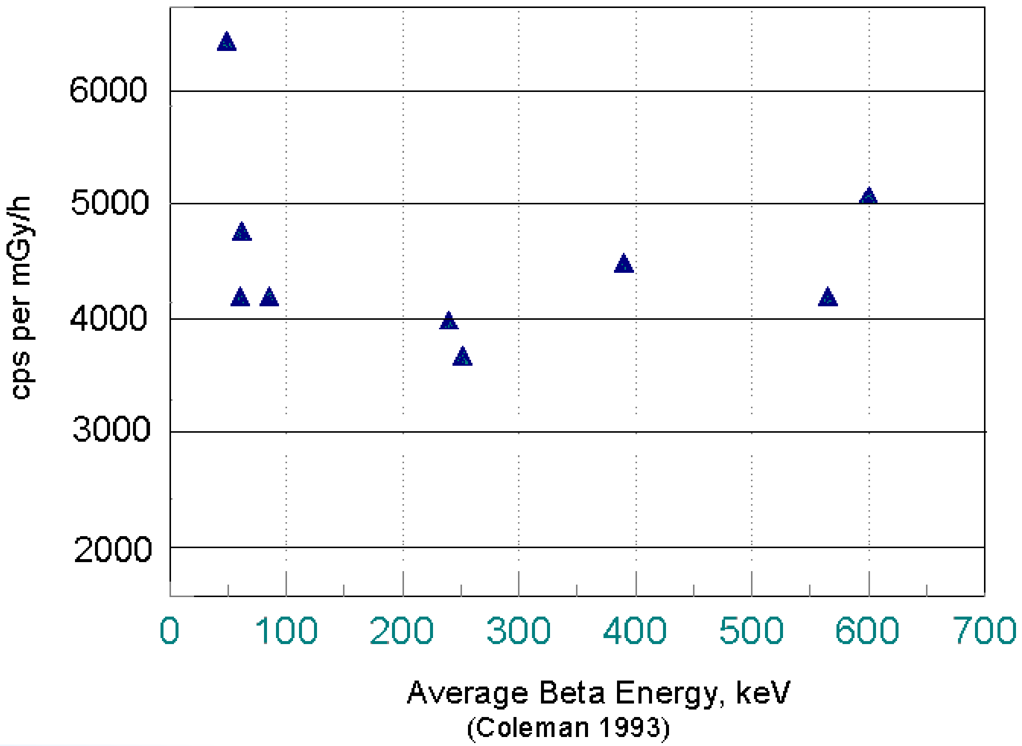
A pancake GM will give a very good indication of dose rate to the skin averaged over 1 square centimetre.

Instrument

The "pancake" detectors have an entrance window area of about 15 cm^2.

Estimates of dose rate can be made by using the detector efficiency and with published conversion factors.

Instrument



The graph summarizes the expected count rate (counts/minute) per dose rate (mGy/h) as a function of average beta energy for a GM pancake detector with a typical operational configuration.

The full irradiation of the probe active surface area (15 cm^2) and an equal amount of exposed tissue area is assumed.

http://homer.ornl.gov/coleman/public/HPInfo/Beta-Dose-Conversion.htm

TYPE TESTING AND CALIBRATION

Type Testing and Calibration

Type testing involves calibrating a dosimetry system under a series of beta dose rate sources and filters.

When selecting an instrument for beta measurement applications, your procurement specifications should include requirements that the instrument comply to recognized industry standards, such as IEC 60846, IEC 60325, ANSI N323, etc.

For example, for end window GM types, IEC 60325 is the base document but requires the addition of beta dose rate response measurements.

If the monitors are also used to measure the photon dose rate then it must also be calibrated against H*(10).

PRACTICAL MEASUREMENT

Practical Measurement

- The detector has to be placed with its reference point (for an ion chamber) or its window centre (for an end window GM tube) at the point of interest.
  - Points of interest for beta radiation are position of the hands and position of the eyes, especially when the head is more exposed than the body
- The detector must then be aligned to maximise the indication, as the indication may depend significantly on how the detector is aligned to the radiation beam.

Practical Measurement

- In many cases, even when an ionisation chamber is used for the final measurement, a search with a thin end window GM detector will identify areas of significant dose rate quickly and efficiently, generally by using the audio output. The application of this technique may be limited in high noise background areas or areas with high gamma radiation.

Ionization chambers

Thermoscientific SmartIon

Pancake GM detectors

RadEye Pancake GM detector used to measure H’(0.07) from beta radiation

INTERPRETATION

Interpretation

Interpretation is generally more difficult for beta than for X or gamma radiation.

The instrument responses in terms of H'(0.07) tend to be more energy dependent.

Typical ionisation chamber instruments have responses for H'(0.07) within the ranges below, when correctly calibrated for ^{137}Cs gamma radiation in terms of H*(10).

Interpretation

Response of typical ionisation chamber

Nuclide	E_{max} (MeV)	Response
$^{90}Sr + ^{90}Y$	0.54 + 2.27	0.9 - 1.1
^{85}Kr	0.69	0.5 – 0.7
^{204}Tl	0.76	0.5 - 0.7
^{147}Pm	0.227	0.5 - 1.2

Interpretation

Response of typical end window GM detectors

Nuclide	Emax (MeV)	Response
$^{90}Sr + ^{90}Y$	0.54 + 2.27	1.0
^{85}Kr	0.69	0.7
^{204}Tl	0.76	0.7
^{147}Pm	0.227	0.7

Interpretation

However, for end window GM detectors, the response to bremsstrahlung tends to increase as the X-ray energy drops, at least down to 80 keV, and then falls slowly.

The typical maximum over-response is within the range 4 to 8 in terms of directional dose equivalent rate. The uncertainty could be up to an order of magnitude.

A partial solution to this problem is to identify the beta and bremsstrahlung components separately.

- Make two measurements in any position, one with the window open and another with the window covered by about 12 mm of plastic.
- The difference between the two values will be the beta component
- Result with the window covered is the bremsstrahlung contribution.

Interpretation

Dominating interpretation challenges is the effect of distance to detector, especially for ion chambers

If the detector is less than three times the maximum detector dimension, to assess dose rate to 1 cm^2 of skin:

Multiply dose rate by 5 for a large area contamination.

Multiply by 100 for a point source.

Interpretation

IAEA

- When estimating the dose rate to skin (based on the most exposed skin area) using an end window pancake GM detector (only), the response, in counts per second per microSv per hour, H'(0.07), from widespread activity is approximately 1.5 times the response to ^{137}Cs gamma radiation in terms of H*(10).

- The response to a point source is the number calculated above multiplied by the area of the detector in cm^2.

- These distance/depth corrections are the most significant.

Interpretation

- True beta dose rate is rather to difficult to measure due to large variations in short range of beta.

- True beta dose rate is measured by:
  - Using a TLD for direct measurement
  - Correcting the dose rate using the inverse square law
  - Comparison of the dose rate with a calculation of the beta dose rate

- It is as important, if not more important to avoid and shield beta dose rates as it is to measure them.

Beta dose rate monitoring challenge

- True beta dose rate is difficult to measure with monitoring instruments
  - Measurement distance is small and therefore distance is a major factor due to rapid absorption in air
  - The need to make measurements relatively close to the source
  - True beta dose rate is measured by direct measurement using TLD
- High dose rate compared to gamma (per disintegration)
- A complex spectrum, often a mixture of beta radiation and bremsstrahlung (X-radiation).
  - Using ionization chamber with a cap, the beta dose rate could be measure in a mixed beta/gamma field.

Therefore…

A general advice for WPM at in NPPs is

To use beta dose rate monitors for identification of beta radiation but not for quantification.

To protect against the beta radiation rather than measure.

Reducing the beta hazards

For sources, beta shielding can be used to reduce beta exposure

- 0.4cm of metal will absorb all betas
- Betas within closed system will typically be absorbed
- Higher energy beta emitters should be stored in low Z materials to reduce bremsstrahlung production.

Distance can also be used to reduce exposure, for example, use source at end of rod or handle debris using tongs.

NEUTRON DOSE RATE MONITORING

Reducing the beta hazards

- Purpose
- Designing the Programme
- Technique
- Instruments
- Practical Measurement
- Calibration and Testing
- Interpretation

PURPOSE OF NEUTRON MONITORING

Neutron Monitoring - Purpose

1

Neutron monitoring in workplace helps us to control the exposures and improve the individual monitoring.

2

It also helps us to reduce the intensity of dose rate by augmenting appropriate shielding.

Neutron Fields

- Neutrons are emitted from radionuclides via (α,n) and (γ,n).
- Neutrons from nuclear reactors (prompt and delayed fission neutrons)
- Neutron beams produced in research reactors
- Spontaneous fission from spent fuels (^{242}Cm, ^{244}Cm and ^{238}Pu to ^{242}Pu).
- Neutrons produced from ion beam accelerators.
- Neutrons sources used for calibration purpose and in industrial gauging such as ^{241}Am-Be, ^{252}Cf.

DESIGNING THE PROGRAMME

Designing the Programme (1)

IAEA

Mapping of neutron field by measurements considering the spectrum of neutrons

For sealed sources, locations are evident and energies are tabulated

For other fields, locations should be identified and energies may need to be assessed

IAEA has published a compendium of neutron spectra in the workplace (technical report series-403).

Scatter causes a wide range of neutron energies.

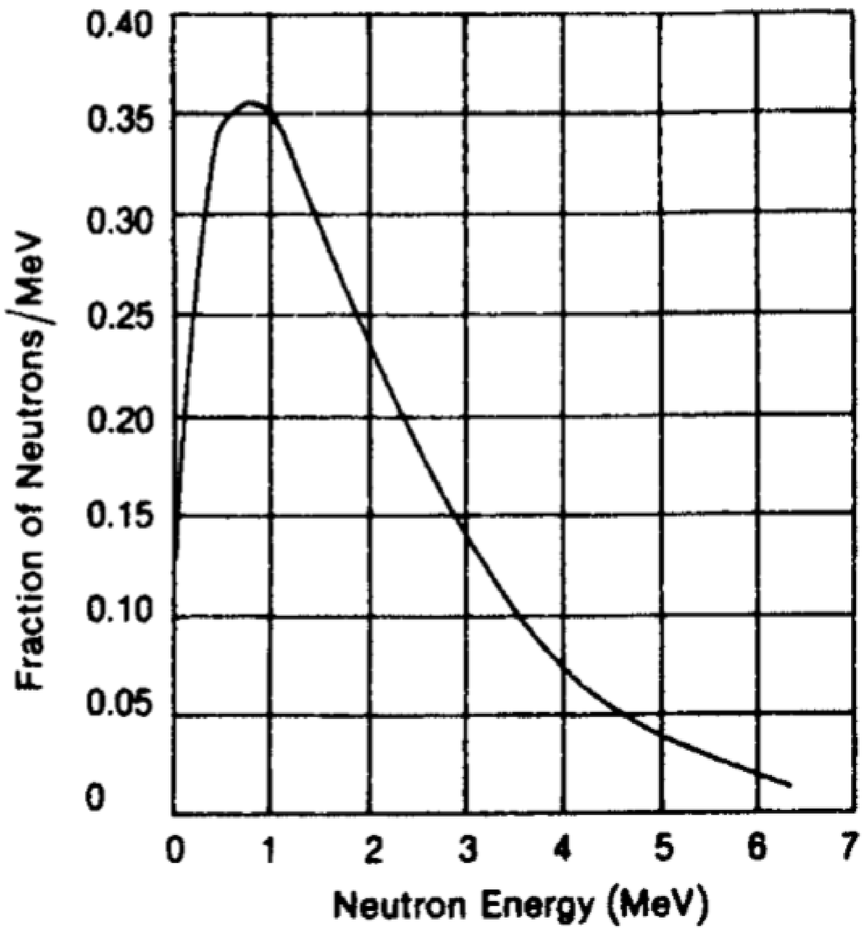
Designing the Programme (2)

Considerations of mixed field (neutron and gamma).

Typical locations may be boundaries of source stores, outside of fuel transport containers, areas where neutrons generated, etc.

H*(10) used to measure ambient dose equivalent rate due to neutrons.

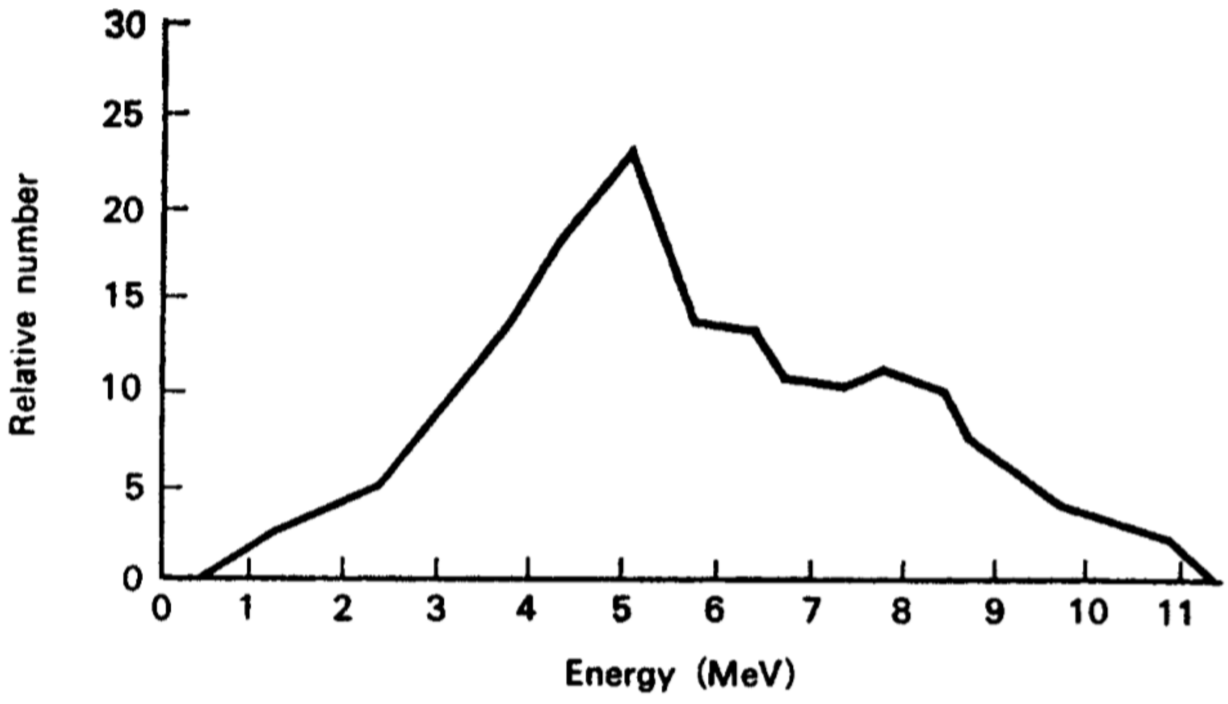
Neutron Spectrum from Fission of U235



- Fission neutrons have a wide range of energies. The distribution peaks at 0.7 MeV and has a mean value of 2 MeV.
- ^{252}Cf undergoes spontaneous fission with a wide range of neutron energies. The most probable energy is 1 MeV with an average energy of 2.3 MeV.

Neutron Spectrum from ^{241}Am-Be

- Neutrons depending on nuclear reactions are high energy with average energy of Am-Be at 4.2 MeV.



Neutron spectrum

Classification of Neutrons

- Neutrons are classified according to their energy:

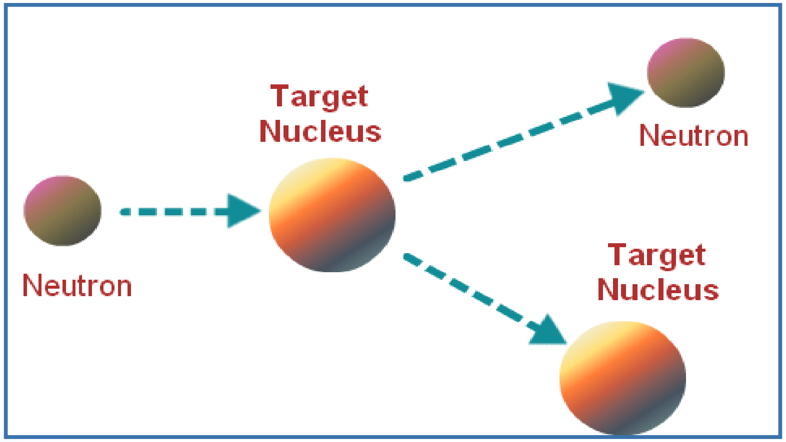
  - High Energy > 100 keV — Fast
  - 0.025 eV- 100 keV — Intermediate
  - 0.025 eV — Thermal

- Neutrons lose energy through interactions in their environment.

TECHNIQUE

Neutron Moderation

- Moderation is usually done by surrounding the detector and/or by hydrogen-rich material (moderator) such as high density polyethylene.
- Due to the presence of moderator the weight of detector assembly is increased.



Technique (1)

- Most instruments based on thermal neutron detection with moderator (polyethylene) to reduce higher energy neutrons and allow detection. (Moved from instruments).
- Techniques involves neutron sensitive elements converting neutron into measurable radiation, such as ^{6}Li, ^{3}He and ^{10}B.
- A neutron monitor should be designed to have a tissue equivalent response over a broad energy range.
- Problem is the lower sensitivity of neutron detectors compared to X, gamma and beta detectors.

Technique (2)

Ensure the instrument used responds adequately over the neutron energy response spectrum encountered in the workplace.

- Additional spectral measurements are sometimes undertaken to justify the assumption that the instrument is measuring the incident spectrum, but, in practice, the majority of fields encountered do not pose problems.

Monitoring generally employs instruments capable of measuring ambient dose equivalent H*(10).

- Sensitivity is low and need long integrating times.
- Instruments usually range from 10 μSv/h to 50 mSv/h, from neutron energies from 0.025 eV to about 10 MeV.

Technique (3)

Place the instrument with the centre of the moderator at the point of interest and average over a sufficient time to get good precision

Note holding the monitor close to body can impact results, therefore use a stand and leave the instrument for measurement

Neutrons often accompanied by gamma radiation which also has to be measured

INSTRUMENT

Instrument for Neutron Monitoring

Choice of instruments:

Flat response over full energy range is not possible – usually over-estimate intermediate energies

Practical factors such as the weight of the instrument and coexistence of gamma field along with neutron is also to be considered.

Adequate gamma rejection is desirable, but contributes to lower neutron sensitivity.

Instrument for Neutron Monitoring

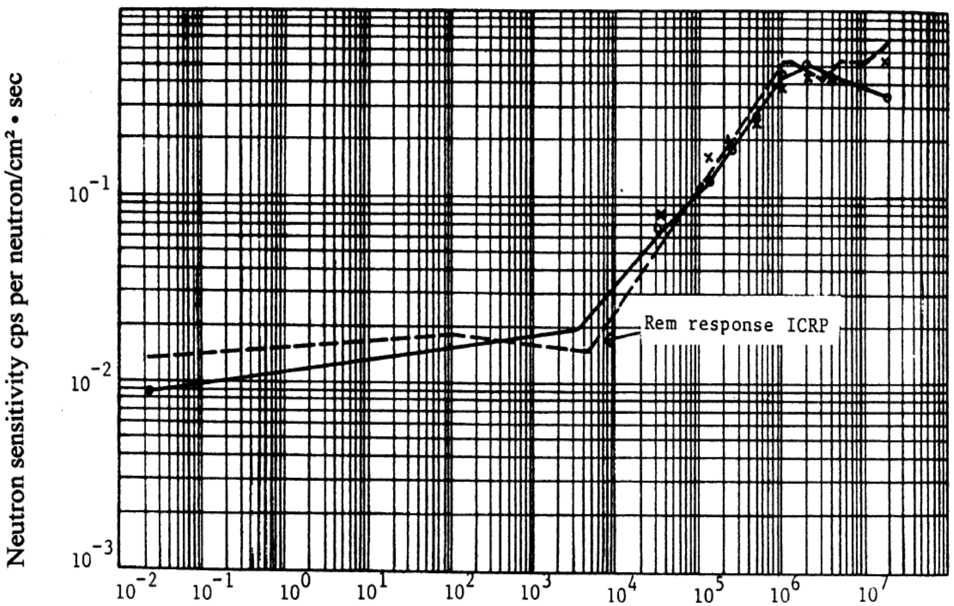
Proportional counters:

- This is widely employed.
- This method make use one of the reactions namely, $^{10}B(n, \alpha)^{7}Li$, $^{3}He\,(n,p)\,^{3}H$, $^{6}Li(n,^{3}H)^{4}He$. conductors.
- Alpha and triton can be easily distinguishable and hence gamma rejection is high.
- This counter can be designed to provide dose equivalent response.
- Pulse height is proportional to the number of ions resulting from a charged particle interaction.
- Pulse height discriminator rejects ionization caused by photons which enables the neutron dose rate monitor to be relatively insensitive to photon fields.
- High energy neutron needs to be slowed down using moderator.

PRACTICAL MEASUREMENT

Practical Measurement -1

^{3}He counter
Courtesy:Digipig



Measurement range: 0.1μSv/h to 999.9mSv/h
Measured quantity: H*(10)
Energy dependence: ±20% between 0.025eV-17MeV

Practical Measurement -2

BF_3 counter

Neutron monitor	BF_3 Tube
Energy Range	Thermal to 10MeV
Sensitivity	Thermal to 10MeV
Measurement range	10 µSv/h to 100mSv/h
Gamma rejection	1Sv/hr

Caution: Gas filled neutron counters are likely to loose pressure of gas and hence periodic testing is mandatory.

Neutron Scintillator

IAEA

- Europium-activated lithium iodide is a scintillator useful for neutron counting.

- It contains ^{6}Li component (96%) through $^{1}n + {}^{6}Li$ $^{4}He + {}^{3}H + 4.78$ MeV.

- It detects thermal neutrons.

- Fast neutrons are detected by organic scintillators.

Practical Measurement

The error caused by influence of the operator´s body this can be reduced by mounting the instrument on a stand to support it at the desired height, if possible.

This will also allow counting over a longer period and is the preferred method in lower dose rates and for investigation or identification of the hazard.

In practice these doses may be estimated from gamma and previous surveys.

CALIBRATION AND TESTING

Type Test

- Type test data should be based on IEC Publication 61005.
- Very limited range of neutron energies available, even for well equipped laboratories.
- Statistical modelling (e.g. MNCP) used in the design of monitoring equipment and prediction of its response, supported by practical measurement.
- The neutron response of the measuring instrument should be tested in presence of both ^{241}Am–Be neutron source and a ^{137}Cs source simultaneously. Neutron response should not change by 10% in presence of gamma field.

Calibration and Functional Tests

1. Calibration is essentially a process of comparing an Instrument indication with the conventionally true value of the quantity of interest.
2. Each workplace monitoring instrument is required to have a valid calibration before operational use.
3. Isotopic sources provide the most convenient neutron fields for calibration purposes.
4. Neutrons produced by spontaneous fission (^{252}Cf) or by (α, n) reactions (^{241}Am–Be, ^{241}Am–B, ^{239}Pu–Be, etc.) are recommended by IEC standard (Publication number:1005).

Calibration

- Calibration and testing should be performed in conformance with national regulations. IAEA Safety Report Series No. 16 gives clear guidance on the calibration procedures.
- For neutron calibration the quantity fluence should be used and conversion coefficient for fluence to ambient dose equivalent H*(10) is given.
- Calibration of neutron survey meter is performed in air.
- New standard ISO 12789-1 using realistic fields.

Function Tests

Tests are intended to confirm that an instrument is functioning correctly.

This includes, check on battery performance, background indication, zero setting, display condition and responding to a check source, e.g. ^{252}Cf or ^{241}Am-Be.

INTERPRETATION

Interpretation

1. Instruments tend to over-respond to intermediate energy neutrons.

2. Interpretation requires making allowance for this weakness and deciding if a correction factor is required

3. Uncertainties are dominated by a lack of knowledge of the energy spectrum.

4. At working dose rates, a few μSv/h, there is statistical uncertainty.