

Assessment of Occupational Exposure due to External Radiation Sources

Set up of monitoring system

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Build-up of a dosimeter

Individual monitoring

- Goal of personal dosimetry
 - Aim to assess effective dose E and equivalent dose to tissues, H_T
- Goal is to measure the operational quantities
 - $H_p(10)$ as estimator for effective dose E
 - $H_p(3)$ as estimator for H_{lens}
 - $H_p(0,07)$ as estimator for H_{skin}
- When operational dose approaches the dose limit:
 - More detailed estimation of protection quantities (like E) might be needed
 - To avoid underestimation compared to limit
 - Take into account dosimetry characteristics compared to workplace energy and directional distribution

Individual monitoring

- In many cases, a single dosimeter worn on trunk is adequate
 - Assume whole body is uniformly exposed
- In case of inhomogeneous radiation field
 - Doses to the extremities, skin or lens of the eye?
 - Additional dosimeter might be needed: extremity dosimetry, eye lens dosimetry
 - These will be needed if these doses may approach 3/10 of the equivalent dose limits

Basic requirements for personal dosimeters



- dosimeters have to be capable of measuring the operational quantities with adequate accuracy
 - For all relevant radiation types
 - For almost all practical situations
 - Independent of type, energy and incident angle of the radiation
 - With a prescribed overall accuracy

Workplace characteristics dictate dosimetry needs



- Different dosimeter types may be needed for photons and neutrons
- Complication exists at nuclear power stations, high energy accelerators, fuel reprocessing plants, etc., where there is a mixed radiation hazard
- Beta dosimetry is difficult, particularly in mixed fields
- Directional distribution of the workplace field is important:
 - Workers at X-ray diagnostic machines are in a scattered, low photon energy, mostly non-isotropic radiation field
 - Operators of radiation sources may be exposed largely from the back: P-A exposure
 - Places where collimated beams are in operation can be characterized by a rotational geometry

Characteristics of workplace fields can help in dosimetry



- Normally, the dosimetry service has no or little information of the workplace field characteristics
- Any knowledge of workplace fields can help in better estimating dose
 - Data on energy and direction distributions, dose rates, worker orientation, environmental conditions
 - To select the appropriate types of personal dosimeter
 - To assess how well dosimeters estimate $H_p(10)$, $H_p(0.07)$ or $H_p(3)$
 - Contribute to the estimation of the overall uncertainty of measurement
 - Allow an assessment to be made of the adequacy of the use of the operational quantities as surrogates for the protection quantities
 - To optimize the design of dosimeters

Personal dosimeters fall into five classes

- Photon dosimeters only for $H_p(10)$
- Beta-photon dosimeters giving information for measuring $H_p(0.07)$ and $H_p(10)$
- Extremity dosimeters for beta-photon radiation for measuring $H_p(0.07)$
- Eye lens dosimeters for measuring $H_p(3)$
- Neutron dosimeters giving information on $H_p(10)$

Design of a personal dosimeters for photons and betas



- $H_p(10)$ can be estimated with a single detector that is tissue equivalent, and covered with material with total thickness equivalent to 10 mm of soft tissue
- Such a dosimeter should be responsive to the backscattered radiation from the body
- If such dosimeter is fulfilling the type test for mono energetic and narrow series radiation under fixed angles, it will also be measuring correctly in workplace fields

Use of algorithms

- When the detector is not acceptably tissue equivalent, multiple detectors can be used, and the result can be combined through an algorithm
- Use of algorithm: uses the signals from more than one detector to produce a measured dose value for $H_p(10)$
 - The simplest is the linear combination of the detector readings with fixed coefficients. A type test with narrow energy distributions covering the anticipated energy range is sufficient to establish whether the dosimeter is appropriate
 - Algorithms which rely on the ratio of readings from several of the detectors in the dosimeter or that use a Monte Carlo algorithm to reconstruct the radiation quality are more difficult to test, particularly those that use branching algorithms. Performance in workplace fields may be disappointing. Therefore it is important to test such dosimeters using energy and direction distributions typical of workplace fields

Whole body dosimeter for $H_p(10)$ and $H_p(0.07)$

- Measurement of $H_p(10)$ with whole body dosimeters is mostly sufficient to assess a worker's exposure in homogeneous fields
- However, if the radiation field contains significant amounts of weakly penetrating radiation:
 - Such as beta particles, or photons of energy below 15 keV
 - dosimeter should be capable of measuring $H_p(0.07)$
- When there is a risk of skin dose H_{skin} to reach 3/10th of the limit during whole body irradiation

Whole body dosimeter for $H_p(10)$ and $H_p(0.07)$

- For measuring $H_p(0.07)$ a simple single-element dosimeter can be sufficient
 - With a single detector that is tissue equivalent, and covered with material so that the total equivalent thickness is 0.07 mm of soft tissue
- For low energy X-rays, a larger combined thickness will be sufficient
 - No need for thin detectors, only thin filters
- Weakly penetrating beta radiation needs a thin detector
 - Total equivalent thickness needs to be 7 mg/cm²
 - For example, a measurement made using a tissue equivalent detector with an effective thickness of 3 mg/cm², beneath a tissue equivalent filter with a thickness of approximately 4 mg/cm² would suffice

Whole body dosimeter for $H_p(10)$ and $H_p(0.07)$

- Whole body dosimeter for both $H_p(10)$ and $H_p(0.07)$ mostly consists of:
 - 2 tissue equivalent elements, covered with 2 filters to yield $H_p(10)$ and $H_p(0.07)$
 - Multiple detector elements if they are not or not completely tissue equivalent with an algorithm to yield $H_p(10)$ and $H_p(0.07)$
 - Can give extra information on energy and angle of incoming radiation

Monitoring of extremity dose

- For non-uniform irradiation, additional dosimeters on other parts of the body may be necessary
- Frequently, it is necessary to wear an additional suitable dosimeter on the hands or fingers (or even feet)
- The dosimeter should be worn on the extremity where the dose is expected to have its highest value
 - Often the location of the maximum dose is not known in advance, or it is not practicable to wear a dosimeter at these locations.
- The skin of the extremity is the limiting organ, so an extremity dosimeter should measure $H_p(0.07)$

Extremity dosimeter

- A simple, one element tissue equivalent detector will be sufficient
 - Filtered by a tissue equivalent material so that the dose at a nominal depth of 7 mg/cm² can be assessed
 - Range 5 to 10 mg/cm² would mostly suffice
- Should be responsive to backscatter
- Multiple element detectors very difficult to implement in extremity dosimeters
 - In practice limited to tissue equivalent detectors

Eye lens dosimetry

- For non-uniform irradiation, additional eye lens dosimeters may be necessary
- Particularly relevant for some workers in medical sector and in some nuclear facilities
- Need to assess personal dose equivalent $H_p(3)$
- The eye lens dosimeter should always be located near the eyes, if possible in contact with the skin and facing towards the radiation source

Monitoring the lens of the eye

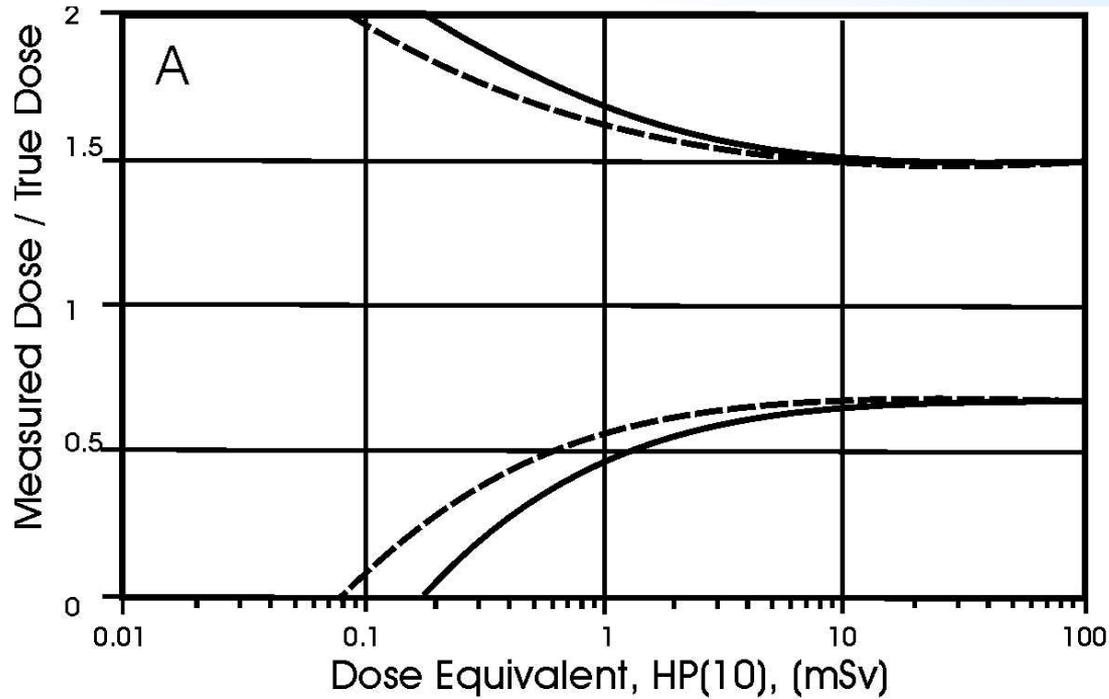
- dosimeters designed specifically for $H_p(3)$ not yet widely available
 - Measurement of $H_p(0.07)$ or sometimes $H_p(10)$ may provide estimate
- A simple, one element tissue equivalent detector will be sufficient
 - Filtered by a tissue equivalent material so that the dose at a nominal depth of 300 mg/cm^2 can be assessed
- Should be responsive to backscatter
- Multiple element detectors very difficult to implement in eye lens dosimeters
 - In practice limited to tissue equivalent detectors

Accuracy and detection levels

Required accuracy according ICRP

- ICRP Publication No. 75: accuracy in making measurements with individual dosimeters in the workplace :
 - In good laboratory conditions: it is possible to achieve an accuracy of about 10% ($k=2$)
 - In the workplace: the uncertainties will be significantly greater
 - The energy spectrum and orientation of the radiation field are generally not well known
 - The overall uncertainty around the relevant dose limit may well be a factor of 1.5 in either direction for photons= +50% and -33%
 - May be substantially greater for neutrons of uncertain energy and for electrons
 - Greater uncertainties are also inevitable at low levels of effective dose for all qualities of radiation: factor 2

Required accuracy follows the trumpet curve



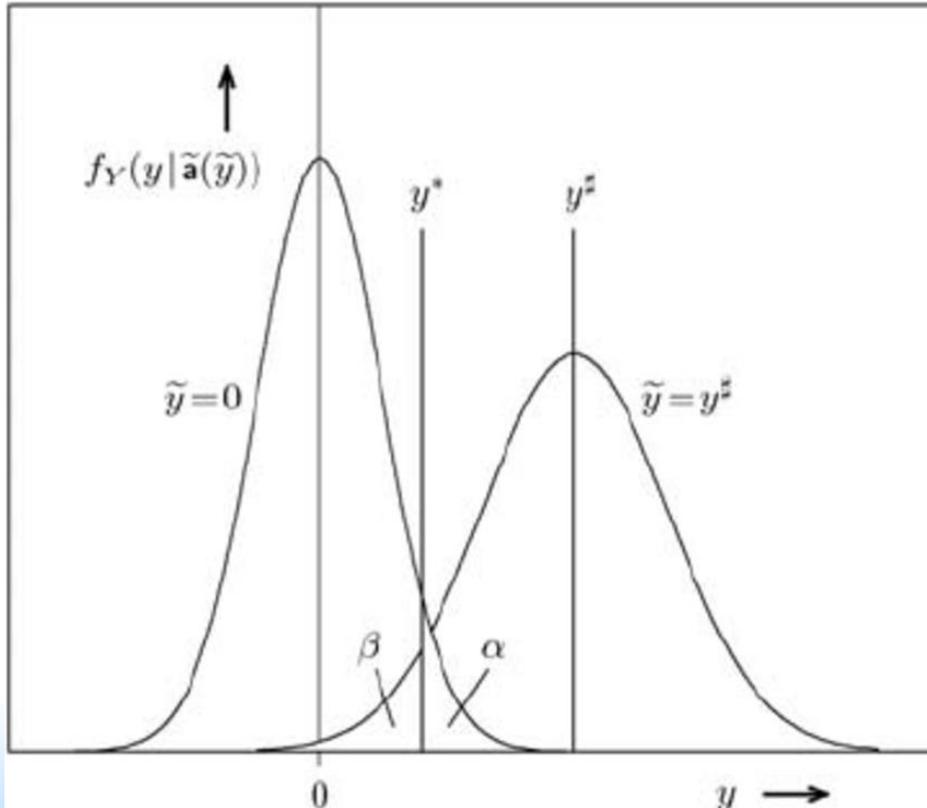
Minimal value of recording level

- The ICRP has also prescribed a minimum value for the recording level, i.e. the dose above which recording of the doses should be required. It is stated that:
 - “The Commission considers that the recording level for individual monitoring should be derived from the duration of the monitoring period and an annual effective dose of no lower than 1 mSv or an annual equivalent dose of about 10% of the relevant dose limit.”
 - For $H_p(10)$ and $H_p(3)$
 - For monthly exchange: $1 \text{ mSv}/12 = 83 \text{ } \mu\text{Sv}$
 - For three monthly exchange: $1 \text{ mSv}/4 = 250 \text{ } \mu\text{Sv}$
 - For APD (daily)
 - $1 \text{ mSv}/240 = 4.2 \text{ } \mu\text{Sv}$
 - For skin dose $H_p(0.07)$
 - For monthly exchange: $50 \text{ mSv}/12 = 4.2 \text{ mSv}$

Decision threshold vs Detection limit

- Decision threshold: is a fixed value of the dose, which if exceeded by the result of an actual measurement, is taken to indicate that a dose has been received, and that the probability for a false positive is no more than some given probability α (often 5%)
- Detection limit: measured quantity value for which the probability of a false negative is β (often 5%), given a probability α of falsely claiming its presence
 - It is the smallest true value of the measurand (dose) that ensures a specified probability of being detected by the measurement method
- The difference in application is that measured values are to be compared with the decision threshold, whereas the detection limit of a measuring system is to be compared with a guideline value

Decision threshold vs Detection limit



Background probability distribution \tilde{y}

Decision threshold y^*

Probability distribution around the detection limit $y^\#$

Decision threshold and detection limits

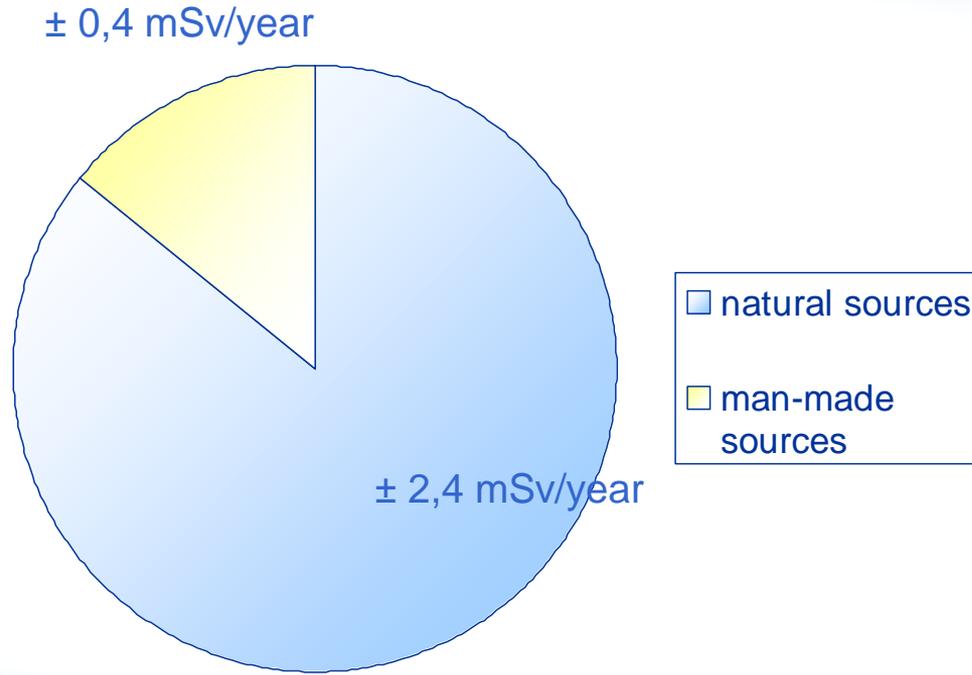
- Approximations that can serve as a rule of thumb are
- Decision threshold $\approx 1.7u(0)$
- Detection limit $\approx 3.3u(0)$
 - Where $u(0)$ is the uncertainty at zero dose.
- They assume that the blank indication (zero dose indication) and the subtracted natural background are well known and that $u(y)$ is more or less constant below the detection limit

Minimal recorded level

- No dose report should contain values lower than detection limit
 - Monthly reported dose of e.g. 15 μSv or 22.5 μSv are nonsense
- Three possibilities to report values below DL
 - Zero value
 - “<DL”
 - DL
- Reporting of values below DL can be dependent on national regulations

Background subtraction

Average radiation exposure worldwide (UNSCEAR 2000)



Man-made sources of radiation

Type of exposure	Effective dose (mSv/year) - UNSCEAR 2000	
	Mean (worldwide)	Typical range or trends
Medical exposures	0,4	Industrialised countries: 1 à 2 mSv/ year
Atmospheric nuclear testing	0,005	Maximum (0,15 mSv) in 1963
Chernobyl accident	0,002	Maximum (0,04 mSv) in 1986 - average in northern hemisphere
Nuclear power production	0,0002	Increased with expansion of programme but decreased with improved practice
Total	± 0,4	

Exposures from natural radiation sources

Type of exposure	Effective dose (mSv/year) - UNSCEAR 2000	
	Mean (worldwide)	Typical range
Cosmic radiation	0,4	0,3 - 1,0
External terrestrial radiation	0,5	0,3 - 0,6
Ingestion exposure	0,3	0,2 - 0,8
Inhalation exposure (mainly radon)	1,2	0,2 - 10
Total	± 2,4	1 - 10

Background radiation is visible on your personal dosimeter



- Lifetime dose of the average Belgian
 - Man: 354 mSv
 - Woman: 382 mSv
- Monthly dose from natural radiation in Belgium (not including medical exposures) = 208 μ Sv/month
 - 119 μ Sv from Radon/Thoron
 - 23 μ Sv from internal (K-40)
 - 35 μ Sv terrestrial
 - 31 μ Sv cosmic
 - 0,04 μ Sv/h on ground (3-5 μ Sv/h in airplane)
 - 4 μ Sv man-made
- From external radiation sources: around 70 μ Sv, or 2.3 μ Sv/day
- This 70 μ Sv is what your dosimeter sees every month, even if it is not used...

Background subtraction is needed

- The dose limits count for occupational exposures
- The personal dosimeter will include a contribution from the natural (radiation) background in addition to any dose from the worker's occupational radiation field
- The zero dose indication and the natural background dose need to be subtracted
- The zero dose indication (background or blank indication) of a dosimetry system comprises the readout system background plus the detector intrinsic background
- Estimates of the associated uncertainties should be included in the overall uncertainty assessment

Zero value subtraction

- The determination of the intrinsic detector background and readout system background is straightforward for reusable passive detectors
 - Intrinsic detector background can be determined for individual detectors or for batches
 - In the latter case the uncertainty contribution to a single result will be larger
 - In both approaches, the determination should be repeated at the same frequency as the determination of individual or batch calibration factors/coefficients

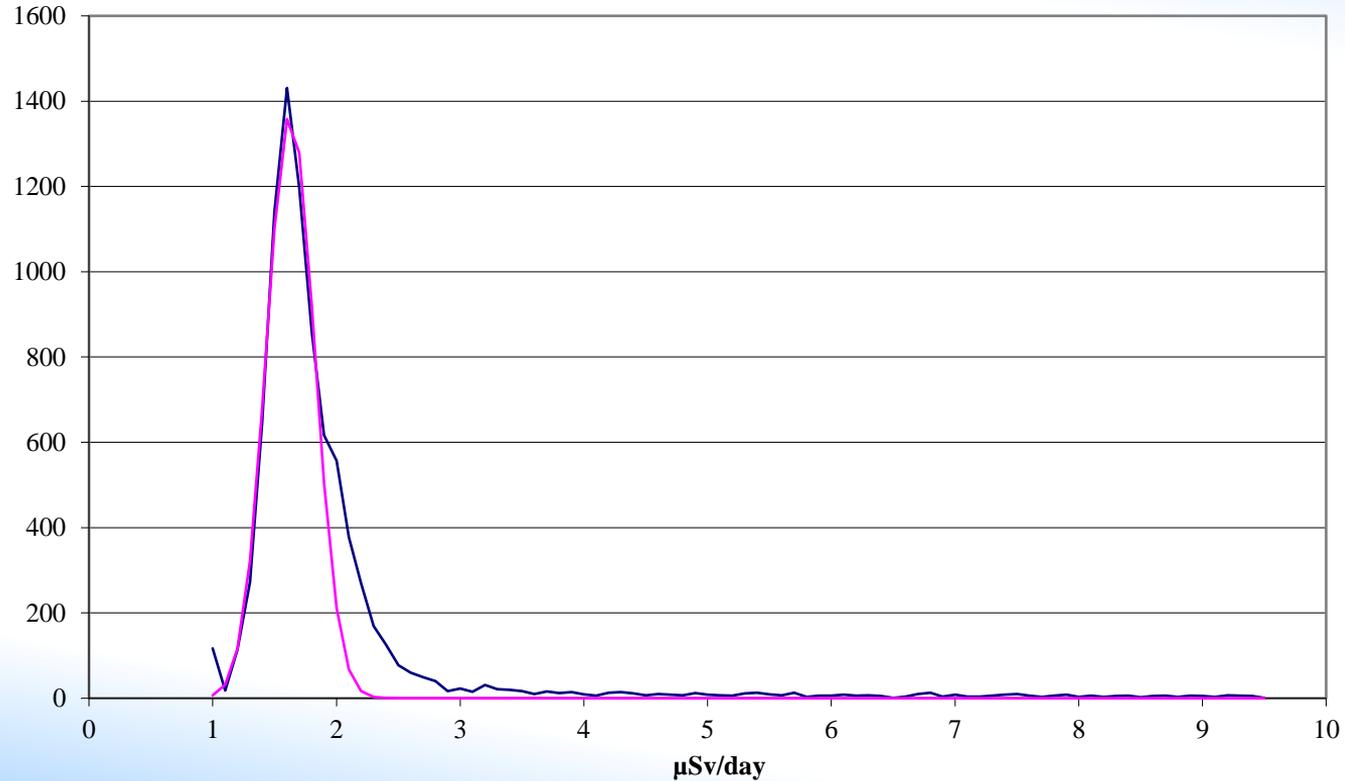
Methods of background subtraction

- The methods of natural background subtraction are to use either an average value based on customer geographic spread (usually a national average) or specific customer or location values
 - The use of a geographic spread average background will add to the total uncertainty of dose assessment
 - For many services this will still enable the recommended accuracy requirement to be met
 - If the difference between a local and the geographic spread average natural background radiation dose is no greater than about 100 μSv per year, it would seem to be acceptable to simply use the average value.

Methods of background subtraction

- If the local background differs from the average natural background, local natural background dose rate will need be taken into account.
 - Local background variation can be taken into account by the use of control dosimeters which are supplied by an ADS to a customer, and stored at the location where workers' dosimeters are kept when not being used
 - In some cases, subtraction of transit doses may be done
 - Use of statistical methods based on the assumption that the majority of issued dosimeters are only exposed to natural background radiation. Mean values and standard deviations can then be derived from an examination of the relationships of dose and number of days of exposure using regression analysis

Statistical method for background correction



Background subtraction for passive dosimeters: example



- Monthly exchange of passive dosimeter:
 - Read out of dosimeters every two month
 - Background subtraction of 60 days needed
 - Suppose local background varies between 1,5 and 3,0 $\mu\text{Sv}/\text{day}$ for different customers
- Between 90 and 180 μSv to be subtracted
- If one average is taken (like 130 μSv)
- Doses can not be determined better than 50 $\mu\text{Sv}/\text{month}$
 - Any value between 0 and 50 μSv can be caused by background radiation
- Determination of background per customer
 - Even like this, the DL is between 30-50 $\mu\text{Sv}/\text{month}$
- Without background per customer
 - DL will be between 60-70 $\mu\text{Sv}/\text{month}$