IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Assessment of Occupational Exposure due to External Radiation Sources

Testing, Quality Control and Uncertainties

Table of content

- Different types of calibrations
- Type testing
- Quality control
- Performance testing and intercomparisons
- Uncertainties

Routine calibrations

Different types of calibrations

- Two types of routine calibration are important:
- Reference calibration in reference radiation fields, which are traceable to National Metrology Institutes (NMI)
  - To obtain an absolute reference calibration factor
  - All dosimetry systems should have periodic laboratory reference calibrations, typically at intervals of one to two years
  - Necessary to confirm the stability of the dosimetry system at more frequent intervals

Different types of calibrations

- Internal calibration to normalize the response of all the dosimeters or detectors to a reference value
  - For example using an internal ‘calibration source’ of a TLD reader
  - To allow for the variations in sensitivity of detectors within a batch, or the variation with time of a single detector
  - This procedure determines an individual normalization factor, or individual calibration factor
  - A suggested frequency is every 10 uses or every 2 years, whichever occurs first

Reference calibration factor

- For the periodic determination of the reference calibration factor radioactive sources are sufficient:
  - For example a ^{137}Cs or ^{60}Co source for photon radiation, a $^{90}Sr/^{90}Y$ source for beta radiation and/or a ^{252}Cf source for neutron radiation
- These fields must have traceability to a National Metrology Institute (NMI) or Designated Institute (DI)
- Can be provided by another laboratory, not necessarily in-house
- No need for multiple sources: this is checked in the type testing
- The measurement quantity should be the personal dose equivalent: $H_p(10)$, $H_p(0.07)$, $H_p(3)$

Individual normalisation factor

- This determination of the individual normalization factor is of internal nature of the service and should be performed under simplified conditions
- These simplified conditions could be other type of radiation and irradiation free in air instead of on phantom
- In the ideal case, the value of the individual factor is unity, in reality it scatters around 1.0 by, say, ± 0.3
- The normalization factor can be determined relative to a special batch of reference detectors reserved only for this purpose
- It is also possible to select a group of detectors, which differ in sensitivity only by a given amount, for instance 5 %, instead of using an individual normalization factor
  - Reference calibration is needed for each of these groups

Testing of personal dosimetry systems

	Test performed by	Frequency of testing
Type testing	Manufacturer or authorized type testing organization	Once, typically prior to marketing to end user
Performance testing	Authorized testing organization	Annually
Routine testing	Dosimetry service provider	Monthly
Routine testing (QA tests)	End user or dosimetry service provider	Daily/ every readout day, prior to startup of dosimeter processing

Type testing

Type testing

- Type testing of a dosimetry system: testing the performance characteristics of the system as a whole under a series of irradiation and storage conditions
  - The result of a type test is the detailed description of all the properties of a given type of dosimeter
  - Investigation of the variation of dosimeter response with the energy and the direction of incidence of the radiation
  - Also consideration of other dosimetric characteristics: e.g. linearity of response, dose range, temperature and humidity conditions, high dose rates and in pulsed radiation fields, electric and magnetic fields influence, mechanical shock and vibration
  - Includes determination of the dosimetric performance characteristics (including detection limit), tests of the system software
  - Not only dosimeter, but the whole system including any reader equipment
- As long as the type of a dosimeter, the read-out equipment and the dose calculation software is unchanged, the type test remains valid

Type testing

- Reference radiation for type testing: ISO 4037 series, 8529 series, 6980 series, see calibration module
- Further equipment is needed to test environmental influence quantities, mechanical effects, electromagnetic fields, etc.
- Test materials and conditions don't need to be available at the dosimetric service site, it is sufficient if they are available at the testing laboratory
- All the radiation fields used in type tests must be well characterized and traceable to national metrological institutes
- dosimeters should be type tested on an appropriate phantom
- Type test results give the ranges for which the dosimeter fulfils the type test criteria. Comparing these rated ranges with those required for a given workplace, the suitability of the dosimeter can be judged

Type testing: IEC 62387

- Any passive photon/beta dosimeter should fulfill the requirements of IEC 62387:
  - *Radiation protection instrumentation – Passive integrating dosimetry systems for personal and environmental monitoring of photon and beta radiation*
- Periodically publishing of new versions*:
  - Version 2012, Version 2020,…
- Scope:
  - $H_p(10)$
  - $H_p(3)$
  - $H_p(0,07)$
  - $H^*(10)$
  - $H'(0,07)$
  - The 2020 version also includes $H'(3)$
- Requirements for dosimeter, reader, dosimetry system, software

**details that follow are given from the 2012 version only*

Type testing: IEC 62387

- Energy range for photons:
  - $H_p(10)$ and H*(10):
    - Mandatory: 80 keV-1,25 MeV
    - Maximum testing range: 12 keV – 10 MeV
  - $H_p(3)$:
    - Mandatory: 30 keV- 250 keV
    - Maximum testing range: 8 keV – 10 MeV
  - $H_p(0.07)$ and H'(0.07):
    - Mandatory: 30 keV- 250 keV
    - Maximum testing range: 8 keV – 10 MeV
- Mandatory range: to be in compliance with the standard

Type testing: IEC 62387

- Energy range for beta
  - $H_p(10)$ and $H^*(10)$:
    - Not applicable
  - $H_p(3)$:
    - Mandatory: E_{mean}=0.8 MeV or E_{max}=2.27 MeV
    - Maximum testing range: E_{mean}=0.7 MeV to 1.2 MeV or E_{max}=2.27 MeV – 3.54 MeV
  - $H_p(0.07)$ and $H'(0.07)$:
    - Mandatory: E_{mean}=0.8 MeV or E_{max}=2.27 MeV
    - Maximum testing range: E_{mean}=0.06 MeV to 1.2 MeV or E_{max}=0.225 MeV – 3.54 MeV
- Mandatory dose range:
  - $H_p(10)$, $H_p(3)$ and $H^*(10)$:
    - 0.1 mSv to 1 Sv
  - $H_p(0.07)$ and $H'(0.07)$:
    - 1 mSv to 10 Sv

Type testing: IEC 62387: general test procedures

- Reference conditions
  - T=20°C
  - r=65%
  - P=101.3 kPa
- Standard test conditions
  - T=15-25°C
  - r=50-75%
  - P=86-106,6 kPa
- Reference radiation: ISO 4037/6980
- Appropriate phantoms
- Details on number of dosimeters, position of dosimeters on phantom, background radiation,…
- Uncertainty on true conventional value shall be less than 8% (k=2)

Type testing: IEC 62387: $H_p(10)$ tests needed

1. Capability of dosimetry system
   - Measure range, influence quantities, model function
2. Requirements to the design of the dosimetry system
   - Information on dosimeter and reader, algorithm
3. Effects of radiation not intended to be measured
   - Thermal neutrons, Cf-252, Cf-252 (D_2O)
4. Instruction manual
   - Information on correct use
5. Software, data and interfaces
   - Authenticity of software, correctness and integrity of the data

Type testing: IEC 62387: $H_p(10)$

6. Coefficient of variation:
   - H<0.1 mSv: 15%
   - 0.1 mSv < H < 1.1mSv: (16-H/0,1)%
   - H>1.1 mSv: 5%
7. Relative response due to non-linearity
   - 0.1 mSv < H < 1 Sv: -9% to +11%
8. Overload, after-effects and re-usability
   - ten times upper limit of measurement range
9. Relative response due to mean photon radiation energy and angle of incidence
   - Range: 0° to +/- 60°
   - 12 keV <E < 33 keV: from 0.67 to 2
   - 33 keV < E < 65 keV: from 0.69 to 1.82
   - E > 65 keV: from 0.71 to 1.67

Type testing: IEC 62387: $H_p(10)$

10. Relative response to mean beta energy radiation
    - max 10% of $H_p(0,07)$
11. Points 9 and 10 but for reference direction opposite to the one used
12. Radiation incidence to the side of the dosimeter
    - 60° and 120°: less than 1.5 times of indication of front irradiation
13. Response to mixed radiation
    - Different qualities together

Type testing: IEC 62387: environmental tests

14.1: Ambient temperature and relative humidity

- -10° to +40°: from 0.83 to 1.25

14.2: light exposure

- 0 W:m² to 1000 W/m² (sunlight): from 0.91 to 1.11

14.3: Dose build up, fading, self irradiation, natural radiation

- For maximum measurement time: from 0.91 to 1.11

14.4: Sealing

14.5-8: Reader: stability, ambient temperature, light exposure, primary power supply: separate series of tests

15: Mechanical disturbances of reader

16: Mechanical performance test: drop test dosimeter

Type testing: IEC 62387: statistical aspects

- Confidence interval
  - $x_l < \overline{x} \pm U_m < x_u$
  - $U_m = \frac{t_{n-1}}{\sqrt{n}} . s$
- x_l and x_u: lower and upper limits
- U_m: confidence interval of the mean
- t: student's t-value
- s: standard deviation
- n: number of measurements

Type testing: IEC 62387: example: non-linearity test

$$0.91 - U_{C,com} \leq \left(\frac{\bar{G}_i}{\bar{G}_{r,0}} \pm U_{com}\right)\frac{C_{r,0}}{C_i} < 1.11 + U_{C,com}$$

- $U_{C,com}$: uncertainty on reference radiation
- $C_{r,0}$: reference dose
- Gi: average result

- In principle to be done at 3 dose levels in each decade: total w dose points
- Depending on number of dosimeters used, and number if dose levels, a certain c_1 and c_2 value can be found in IEC 62387 (in this example: 1.2 and 1.8)
- w-2 values need to be within limits times c_1
- 2 remaining values need to be within limits times c_2

Type testing: IEC 62387: example: non-linearity for TL system: pass

C(mSv)	E_{avg}(count)	n	Stdev	$t_{n-1}/\sqrt{n}$	U_m	Cr,o/Ci	(Ei/Er,o + Ucom)*Cr,o/Ci	(Ei/Er,o - Ucom)*Cr,o/Ci	Uc,com	1.11+Uc,com	0.91-Uc,com
0,1	1161	5	44	1,24	55	30	1,10	0,99	0,042	1,15	0,87
0,3	3411	5	57	1,24	70	10	1,06	0,99	0,042	1,15	0,87
1	10954	5	538	1,24	668	3	1,05	0,92	0,042	1,15	0,87
3	33246	5	726	1,24	900	1	1,04	0,96	0,042	1,15	0,87
10	107833	5	2258	1,24	2800	0,3	1,01	0,94	0,042	1,15	0,87
30	283197	5	10546	1,24	13076	0,1	0,90	0,81	0,067	1,18	0,84
100	902751	5	41674	1,24	51676	0,03	0,87	0,76	0,067	1,18	0,84
300	2965735	5	87312	1,24	108267	0,01	0,93	0,85	0,067	1,18	0,84
1000	10394942	5	747923	1,24	927424	0,003	1,03	0,85	0,067	1,18	0,84
3000	30227858	5	431265	1,24	534768	0,001	0,94	0,88	0,067	1,18	0,84
10000	115708580	5	5779932	1,24	7167116	0,0003	1,11	0,97	0,067	1,18	0,84

Type testing: IEC 62387: general uncertainty

- If the dosimetry service fulfills all requirements of IEC 62387
- In addition if for all environmental tests

$$\sqrt{\sum\left(\frac{1}{r_q}-1\right)^2} < 20\%$$

- The total uncertainty of the dosimetry system will fulfill the ICRP requirement of a factor 1.5 (trumpet curve)

Type testing: IEC 62387: 2020 version

- Small new changes in 2020 version
- Including H'(3) quantity
- Minor changes in energy/angular dependence tolerance levels
- Mandatory mean energy range for beta's for $H_p(0.07)$ includes 0.24 MeV
- Update of conversion coefficients
- Distinguish for workplace monitoring and environmental monitoring for H*(10)
  - Different angular and environmental test ranges
- Maximum overload dose to 20 Sv
- Simplify radio-frequency immunity test

Quality Control

QC routine testing

- It is necessary to demonstrate that the standard of performance is maintained continuously
- Internal system to assure quality
- QC tests to monitor specific aspects of system performance are generally performed daily
- Results of internal performance tests should be followed up closely, e.g. by the use of control charts, where warning and action levels are defined to trigger necessary actions by the service
- Warning level often taken as 2 standard deviations, action level as 3 standard deviations
  - One time out of action or two consecutive times outside warning levels require action

Routine QC testing

- Carried out
  - At one radiation energy, mostly ^{137}Cs or ^{60}Co for photon dosimeters
  - Under a given set of repeatable irradiation conditions
  - Does not always need a phantom
  - To normalize or standardize the sensitivity of the system
  - Mostly in-house
- Tests the accuracy and precision of the dosimetry system for measurement of doses
- Should be repeated by the service, at regular intervals
  - Depending on number of read outs
  - If daily read out: at least daily QC
  - Should be done for each reader separately
  - If done less frequently: evaluate risk of deviations

Quality control on calibration factors

- It is necessary to guarantee the stability of the reference calibration factor in between reference calibrations
- This can be done by readout of periodic control dosimeters on a daily basis before starting with the routine dosimeters
- Irradiation of the periodic control dosimeters does require use of a stable irradiation source, not necessarily traceable

- Also QC follow up on internal calibration factor can be useful (for re-use type of dosimeters), e.g. on random part of the dosimeters

Dummy customer

- One extra way of internal QC testing is a dummy customer
- dosimeters from such a dummy customer undergo the same treatment as the normal routine dosimeters, but a known dose is given to them every period
- dosimeters exposed to known doses either in the laboratory or by some external test facility
- Measured values are compared with conventional true values and results interpreted using prescribed methods (action levels/warning levels)
- Following up the reported doses from this dummy customer gives a good idea of the evolution of the overall performance of the dosimetry system

Extra QC measures

- Other QC measures are possible, some examples:
  - Follow up of ratios of different elements in dosimeter
  - Follow up of ratio $H_p(10)/H_p(0.07)$
  - Follow up of percentage of dosimeters above LLD
  - Other performance indicators, like number of failed reads, number of badges read per day,….

Performance testing

External performance testing

- To check the dosimetry reliability and consistency
- The results obtained should meet specific performance criteria
- External performance tests serve a different objective to type-tests
- Can be used to obtain a ‘snapshot’ of the overall accuracy of a dosimetry service, and may involve attempts to replicate workplace radiation fields
- Performance tests may separately assess components of accuracy as the bias and statistical uncertainty

Performance test for personal dosimetry

- Blind test: the dosimetry service provider is not aware of the tests and cannot use selected dosimeters or special evaluation procedures for the tests.
- Surprise test: the dosimetry service provider is aware of the tests but does not know the actual test date in advance. It is possible to use selected dosimeters but not to use special evaluation procedures.
- Announced test: the dosimetry service provider is aware of the tests and may use selected dosimeters and special evaluation procedures. An intercomparison exercise among dosimetry service providers can be regarded as an announced performance test.

Intercomparisons for dosimetry services

- Intercomparisons are most used performance test
  - Required for ISO17025
  - Sometimes required for approval by competent authority
- Different types
  - Sometimes organised by competent authority (national)
  - Can be organised regional (like IAEA)
  - EURADOS intercomparison: self sustainable systematic series
  - Can be organised by institutes themselves (like bilateral intercomparisons)
- Participation needed in regular intervals: if possible every 1 to 2 years
- Certificates needed

ISO standard on how to organise intercomparisons

- ISO 14146: Criteria and performance limits for the periodic evaluation of dosimetry services

- The quantities which may influence the result, such as ambient temperature, relative humidity, background radiation and contamination by radioactive elements, shall conform to the standard test conditions
- The dosimeters, including the control dosimeters, shall be stored in environmental conditions that do not affect the measurement results obtained from the dosimeters
- The background radiation shall be as small as possible

ISO 14146

- The choice of radiation qualities and doses should be guided by the following considerations:
  - Attempts should be made to vary the radiation qualities used for repeated performance evaluations while one radiation quality should be left unchanged from evaluation to evaluation to assess the calibration control
  - The radiation qualities and the doses should be selected from the range of energies, angles of incidence and doses for which the dosimetry system has been approved
  - The majority of irradiated doses, radiation qualities and angles of incidence should be similar to the conditions found in routine radiation surveillance
  - Mixtures of two or more radiation qualities may be appropriate in order to mimic workplace fields
  - Should be chosen from relevant ISO standards
  - The uncertainty of the irradiated dose shall be less than 10 % (k=2), in simulated workplace fields the uncertainty can be higher

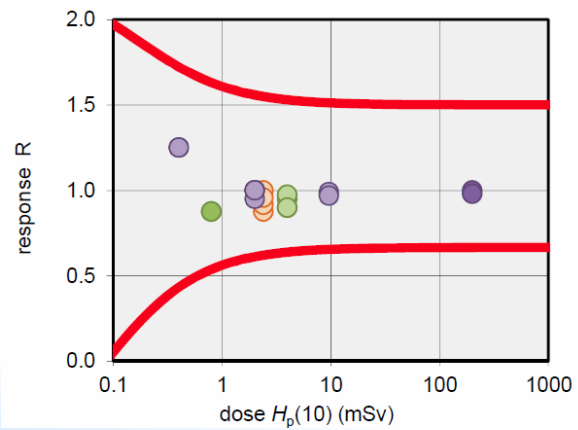
ISO 14146: evaluation of intercomparison results

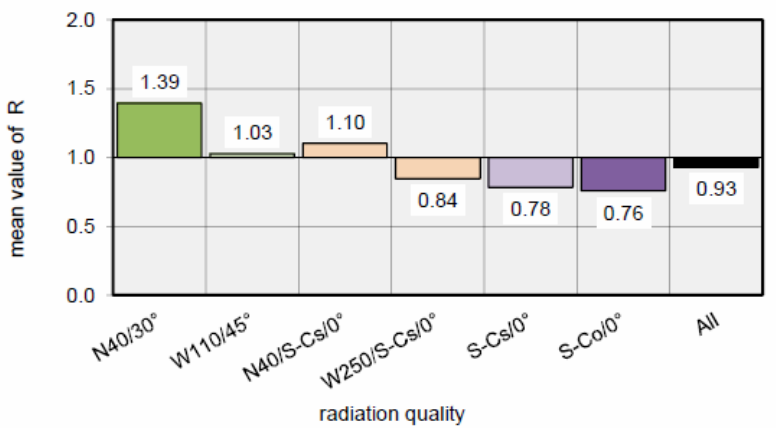
- The dosimetry service shall certify that the dosimeters submitted for evaluation are representative of those supplied routinely to users.
- The dosimetry service processes the dosimeters using normal practices and reports the measured doses and associated uncertainties to the evaluating organization
- The dose shall be reported with enough significant digits in order to rule out rounding effects
- The measured (e.g. by control dosimeters) or calculated transport or background dose will be subtracted by the dosimetry service or by the evaluating organization
- Evaluation will be done relative to accuracy requirements: trumpet curve
- 10% of outliers are allowed

Example of EURADOS intercomparison result

radiation quality	number of values	median (R)	mean (R)	maximum (R)	minimum (R)	coefficient of variation (R)
N40/30°	2	1.39	1.39	1.48	1.30	9%
W110/45°	4	1.03	1.03	1.06	0.98	3%
N40/S-Cs/0°	2	1.10	1.10	1.12	1.08	3%
W250/S-Cs/0°	2	0.84	0.84	0.85	0.84	1%
S-Cs/0°	8	0.78	0.78	0.85	0.68	7%
S-Co/0°	2	0.76	0.76	0.78	0.74	4%
All	**20**	**0.85**	**0.93**	**1.48**	**0.68**	**22%**

outliers: 0 of 20 **Fraction of outliers: 0%**





According to ISO 14146 max. 10 % of outliers are allowed

Analyses of intercomparisons results

- Accredited labs will have to prove that the results of an intercomparison are consistent with the measurement uncertainty from the method.
- They will have to do an analyses of the results, not only compared to the trumpet curve
- One way to check results from an intercomparison is by calculating the E_n values (u are given for 95% interval)

$$E_n = \frac{(X_{lab} - X_{ref})}{\left(\sqrt{u^2{}_{ref} + u^2{}_{lab}}\right)}$$

$| E_n | \leq 1$: acceptable
$1 < | E_n | \leq 1{,}5$: further investigations are needed and maybe corrective actions
$| E_n | > 1{,}5$: further research and corrective action is needed

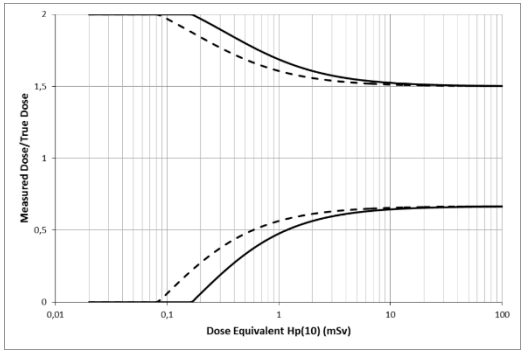
Example intercomparison analyses

Quality	Measured value [mSv]	Reference value [mSv]	Ratio	Within trumpet curve	Ref unc [mSv]	service unc [mSv]	En-score
S-Cs 0°	5.71	6.50	0.88	Y	0.46	1.48	**0.51**
S-Cs 0°	5.81	6.50	0.89	Y	0.46	1.50	**0.44**
S-Cs 0°	5.78	6.50	0.89	Y	0.46	1.50	**0.46**
S-Cs 0°	5.83	6.50	0.90	Y	0.46	1.51	**0.42**
S-Co 0°	4.16	4.79	0.87	Y	0.34	1.08	**0.56**
S-Co 0°	4.12	4.79	0.86	Y	0.34	1.07	**0.60**
S-Co 0°	6.15	7.01	0.88	Y	0.49	1.59	**0.52**
S-Co 0°	5.78	7.01	0.82	Y	0.49	1.50	**0.78**
S-Co 0°	39.65	46.00	0.86	Y	3.22	10.27	**0.59**
S-Co 0°	39.72	46.00	0.86	Y	3.22	10.29	**0.58**
S-Co 0°	447.88	500.00	0.90	Y	35.00	116	**0.43**
S-Co 0°	440.24	500.00	0.88	Y	35.00	114	**0.50**
N-60 0°	6.75	5.70	1.18	Y	0.40	1.75	**0.59**
N-60 0°	6.48	5.70	1.14	Y	0.40	1.68	**0.45**
N-60 60°	7.83	6.00	1.31	Y	0.42	2.03	**0.88**
N-60 60°	7.65	6.00	1.28	Y	0.42	1.98	**0.81**
S-Cs/N-150 45°	5.53	6.00	0.92	Y	0.42	1.43	**0.31**
S-Cs/N-150 45°	5.36	6.00	0.89	Y	0.42	1.39	**0.44**

Estimation of Uncertainties

Large uncertainties allowed in personal dosimetry

- Uncertainty allowed: ICRP 75: factor 1.5 at high doses, factor 2 at lower doses
  - Not very strict…
  - Is uncertainty on operational quantities
- Why are such large uncertainties allowed?
  - Other uncertainties involved to get to risk assessment…
- $H_p(10)$ is only estimation of E: large uncertainty
  - System of operational quantities as estimation for limiting quantities
- From E to risk: even larger uncertainties (Hiroshima/Nagasaki data)
  - And not personalized!



Uncertainty sources

- No dosimeter is perfect for $H_p(10)$
  - Energy and angle of incident radiation
    - In workplace, mostly E and angle is not known
  - Fading, environmental characteristics, individual sensitivity, non-linearity…
  - Also calibration uncertainties should be added
- IEC 62387 lays down requirements for type testing: they give upper limits of uncertainties

- Uncertainty estimation is required by ISO 17025

Guidance on uncertainty estimation: GUM

- The fundamental reference document is the *Guide to the Expression of Uncertainty in Measurement* (GUM):JCGM 100:2008
- A series of documents to accompany the GUM is developed: gives practical examples, also for radiation protection

Recommendations for uncertainty determination

- In the **formulation stage**:
  - All input/influence quantities that may contribute to the uncertainty should be identified
  - All model input/influence quantities should be characterized by a best estimate and either a probability density function (PDF) or a (combined) standard uncertainty
- In the **calculation stage**:
  - The GUM framework is based on the law of propagation of uncertainties (LPU) and the central limit theorem (CLT)
  - Monte Carlo methods can also be used
- Many methods for calculating the output PDF involve mathematical or statistical assumptions or approximations. This means that the results are subjected to an appraisal
- The amount of effort put into the uncertainty assessment should be realistic in view of its purpose in radiation protection

Formulation stage

- The assigning of PDFs to some of the input quantities can be based on statistical analysis: type A evaluation
  - Examples are the signal measured by light detection system of a TL-reader and the blank (zero signal) of the reader system
- For many of the other input quantities an educated guess is the best available: type B evaluation
  - Examples are the characteristics of the fields to which the dosimeter wearer was exposed but also fading parameters such as temperature and time and durations of exposures
  - Such distributions can e.g. be rectangular (uniform) distribution or triangular distribution

Calculation stage

- The calculation stage consists of propagating the PDFs of the inputs with the measurement model Y = f(X)

- From this resulting PDF the following summarizing quantities must be calculated:
  - The expectation, the central value of the PDF that is taken as the estimate y of Y for the dose
  - The standard deviation that is taken to be the combined standard uncertainty $u_C(y)$ of the dose
  - A coverage interval that contains Y with a specified probability, the coverage probability which is often taken as 95%

Examples of uncertainties for the determination of $H_p(10)$

- the standard uncertainty of Type A:
  - Measurement of light detection system of a TL reader
  - Blank signal of the reader system
  - Sensitivity of the individual detectors
- type B uncertainties
  - Characteristics of field to which the dosimeters were exposed
  - Energy and angular dependence of the dosimeter
  - Non-linearity of the response
  - Fading, dependence on ambient temperature and humidity
  - Effects due to exposure to light
  - Effects due to exposure to types of ionizing radiation that are not intended to be measured by the dosimeter
  - Effects from mechanical shock
  - Calibration uncertainty
  - Variation in local natural background

Model function

- $M = \frac{N_0}{\prod_{q=1}^{m} r_q}\left(G - \sum_{p=1}^{l} D_p\right)$

- M = Dose
- G = Indication of dosimeter
- N_0 = Reference calibration factor
- r_q= Influence factor (e.g. fading, individual calibration factor)
- D_p= Deviation (e.g. background, zero,…)

Combined Uncertainty: U_C

- For each influence quantity, the probability density function needs to be estimated by measurements, best estimates or Monte Carlo methods
- The combined uncertainty is calculated via the law of propagation of uncertainties with the model function
- For simple multiplicative influence factors, the combined uncertainty is:

$$U_C = \sqrt{\sum U_{type\ A}^2 + \sum U_{type\ B}^2}$$

Energy and angular uncertainties

- Effects from all other uncertainty components may be small compared with those due to the energy and angular dependence
- Example how to estimate energy and angular uncertainty:
  - Use of type test data: response at different energies and angles
    - Assume all energies and angles in range from type test as equally probable in workplace: rectangular PDF
    - Use workplace data (e.g. spectra or energy ranges): more realistic PDF
      - Also possible to use specifically determined response functions, like workplace test results
    - Use Monte Carlo methods to sample workplace energies and angles
      - PDF can be asymmetric

Examples of other uncertainties

- Calibration:
  - From calibration certificate
- Individual correction factors
  - From repeated measurements
- Blanco value
  - From repeated 2nd reading for TLD
- Temperature, non-linearity, fading
  - From type test results
- Background
  - From estimation, national data, measurements, …..

Example of total uncertainty budget

	Best estimate	Type uncertainty	Standard uncertainty (k=2)	Sensitivity coefficient	Contribution to total uncertainty [mSv]
Measurand G	12622 cts	A	4.9%	$9\ 10^{-5}$	**0.056**
Energy/angle	1	B	22%	1.15	**0.252**
Zero	170 cts	A	68	$-9\ 10^{-5}$	**-0.006**
Calibration factor CF	11000 cts/mSv	B	5.3%	$-1\ 10^{-4}$	**-0.060**
Ind. Factor IF	1.00	A	1.6%	-1.13	**-0.018**
Background	0.132 mSv	A	5.2%	-1	**-0.007**
Dose	**1.00 mSv**				**0.27**

Example of combined uncertainty

- Dependent on dose level
- For other dose levels (k=2):
  50 µSv : 90%
  100 µSv: 44%
  300 µSv: 29%
  500 µSv: 28%
  1 mSv: 27%

- Please remember this when looking at the dose reports…..

Reporting of Uncertainties

- Conform the requirements in ISO 17025, the uncertainty in measurement should be reported
- Few dosimetry services report the uncertainty for each measured dose in the dose report
- It is sufficient if general info is available to customers
  - The detection limit
  - Relative standard uncertainty for certain doses
- Uncertainties are in general not reported to more than two significant digits.
- The doses of systems with a standard uncertainty in low doses of less than 0.1 mSv can be reported in multiples of 0.01 mSv and with a higher standard uncertainty in steps of 0.1 mSv:

1.3 mSv instead of 1.345 mSv
0.26 mSv instead of 0.258 mSv
0.07 mSv instead of 69 µSv