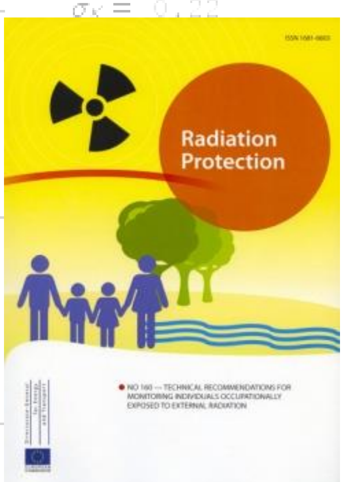
EURADOS Training course

Evaluating uncertainty

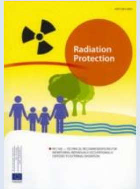


RP160 Chapter 5

Part 1

Janwillem van Dijk

Eurados Training Course
Lisbon, Portugal, 18-22 May 1015



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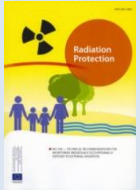
Evaluating uncertainty

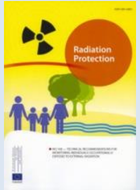
I. -Introduction to evaluating uncertainty, the GUM and its supplements,
   -The formulation stage and the GUM framework
II. - The formulation stage continued
   -The calculation stage and characteristic limits



Evaluating uncertainty

Part I

- Why it matters
- The concepts of measurement and uncertainty
- The measurement model, the measurand and input quantities



A thought experiment

A QA manager asks for 180 dosemeters

- Has them all irradiated to 1mSv randomly at various angles and energies all conform ISO 4037
- Has them evaluated and reported
- Does some statistics

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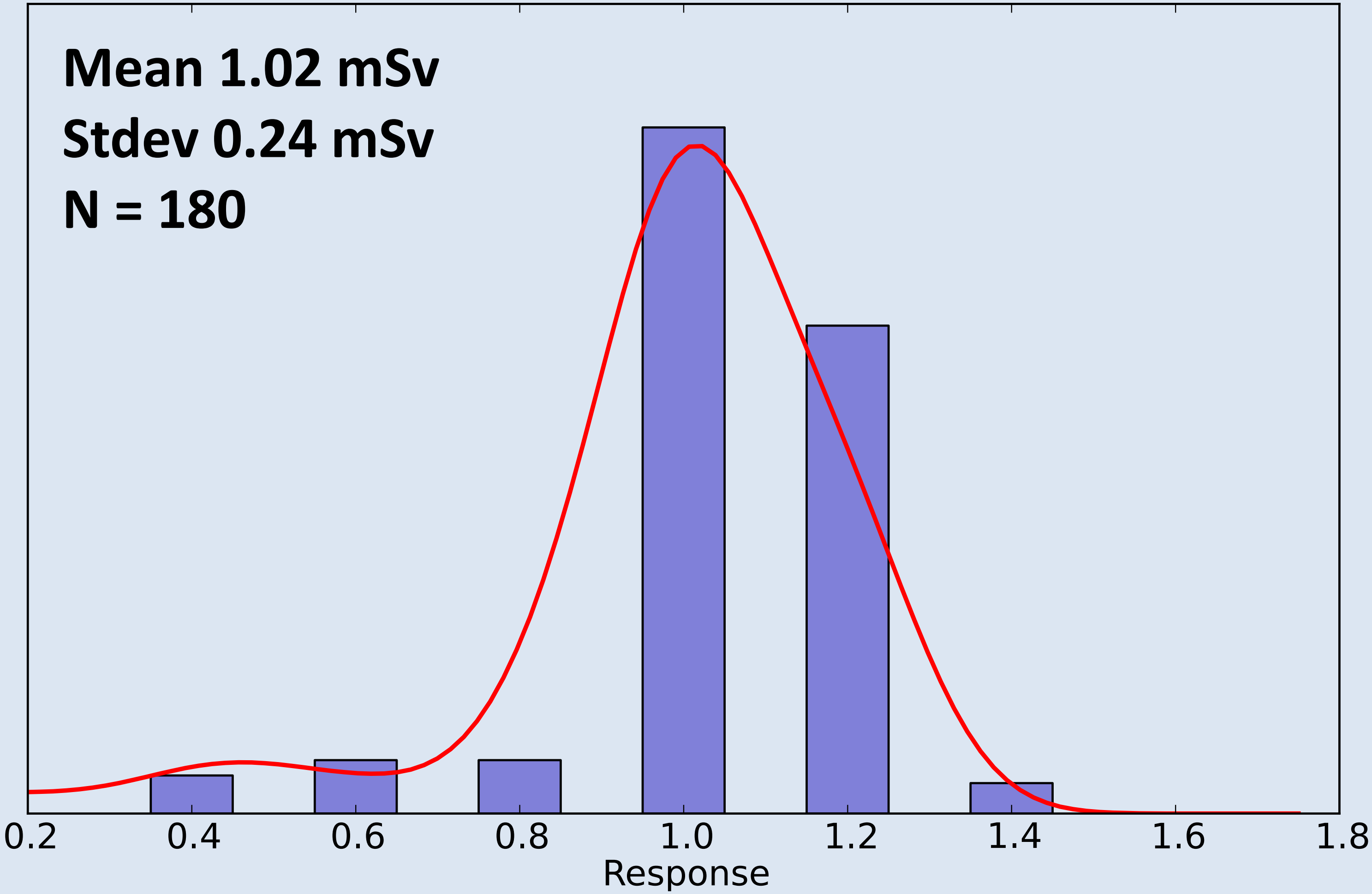
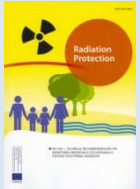
A thought experiment

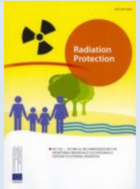




Measurement uncertainty

A single measurement is a sample from a distribution that contains the true value

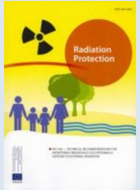
You would like to know the true value but you cannot. That is uncertainty in measurement. Lack of knowlege.



Measurement uncertainty

The task of evaluating the uncertainty in measurement is to <u>quantify</u> this lack of knowledge by finding the parameters that determine the distribution, i.e.

- **<u>mean</u> as an estimate for the true value**
- **<u>standard deviation</u> as an estimate for the <u>standard uncertainty</u>**



Uncertainty evaluation

Uncertainty evaluation involves the use of

- **Mathematics**
- **Expert knowledge**
- **Statistics**
- **Expert judgment/choices**

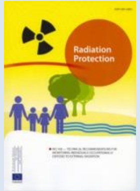
It is science but also an art

<u>Guidance is needed!</u>

Measurement uncertainty

Guidance on "how to" make choices and use standards

Joint Committee on Guides in Metrology (JCGM)



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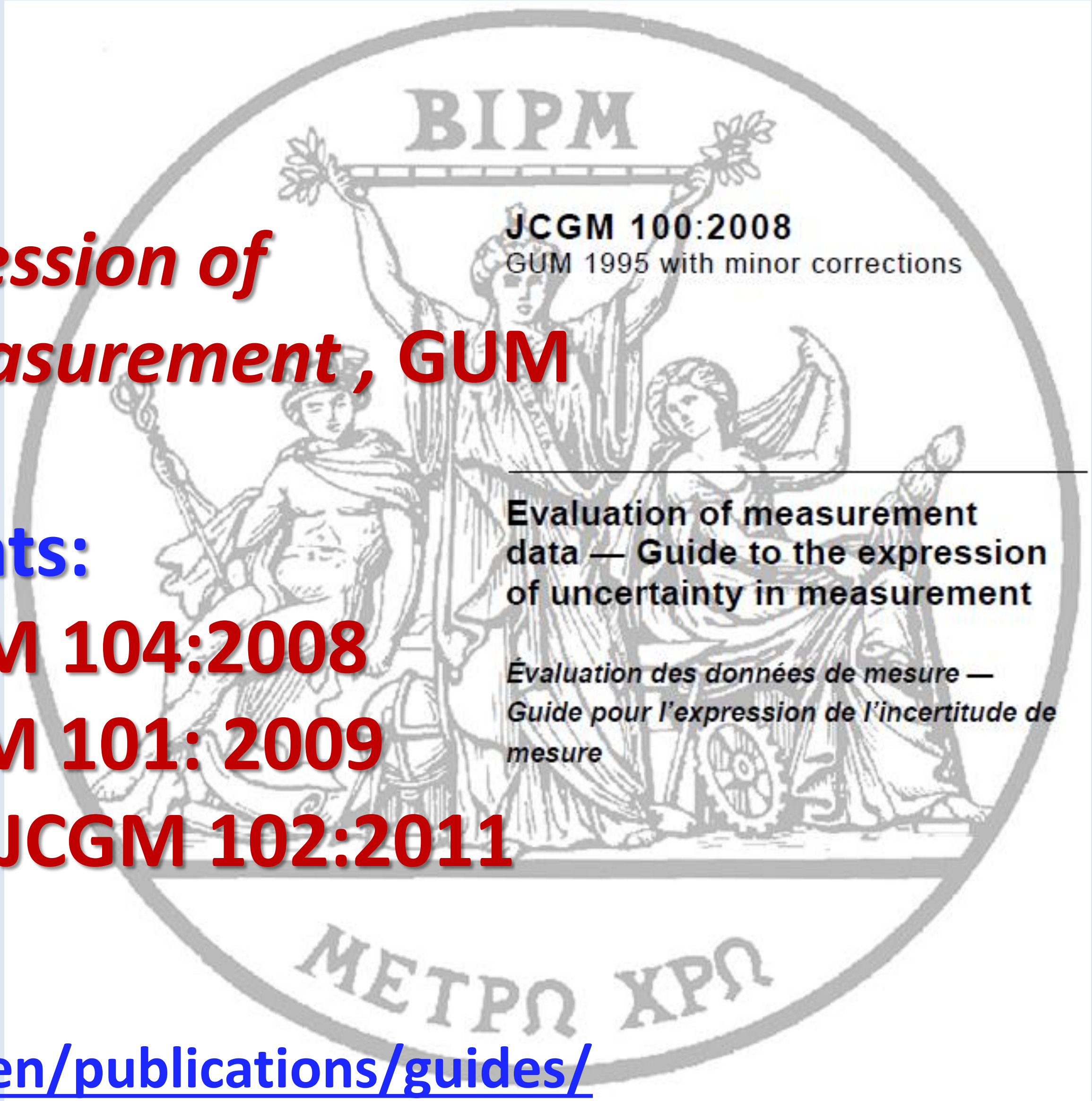


***Guide to the expression of uncertainty in measurement* , GUM**

JCGM, 100:2008

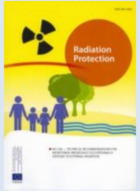
and its supplements:

Introduction, JCGM 104:2008

Monte Carlo, JCGM 101: 2009

Multiple outputs, JCGM 102:2011

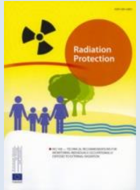
http://www.bipm.org/en/publications/guides/



Metrological terms

Components of a measurement

- **Measurand (output quantity)**
  Personal dose equivalent (mSv)
- **Input quantities**
  Radiation flux, energy and angle,
  background radiation, calibration data,
  …
- **Measurement equation**
  Formula or algorithm relating input
  quantities and measurand



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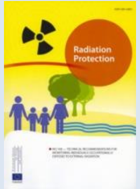
Mathematical terms

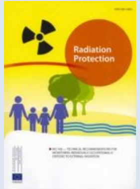
- **Expectation** is mathematical term, a parameter of a distribution function defining the central value (mean)
- **Standard deviation** is mathematical term, a parameter of a distribution function defining the dispersion



Statistical terms

- **Mean** is a measure for the central value and estimates the true value
- **Standard error** is a measure for the difference between measured value and the true value, an a–posteriori property of the measurement

True value is unknown: standard error has no meaning
(Exception: when type-testing and calibrating)



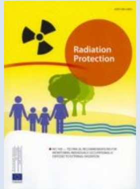
Metrological terms

- **Standard uncertainty quantifies the lack of knowledge of the true value, an <u>a-priory</u> property of the measurement system**

The standard uncertainty in the measurand has the same numerical value as The standard deviation of the distribution of the measurand

$$u_y = s_y$$

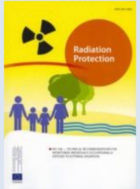
Metrological ↔ Mathematical



Evaluating uncertainty
A 2-stage process

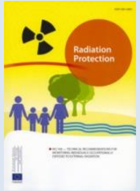
1. The formulation stage
2. The calculation stage

Metrological ↔ Mathematical



The formulation stage

- **The measurand:** Define what is to be measured
- **The input quantities:**
  - Define the signals and other inputs influence the measurand.
  - Assign a probability distribution to each input quantity
- **The measurement equation:** Determine the relation between input quantities and the measurand



Stage 1.1 Define the measurand

In individual monitoring:

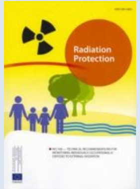
Personal dose equivalent

$H_{\mathrm{p}}(0.07)$,

$H_{\mathrm{p}}(3)$,

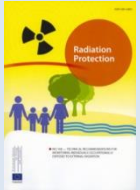
$H_{\mathrm{p}}(10)$

in sievert (Sv)



Stage 1.2 Define the input quantities

- What constitutes a dosimetry system
- What affects the measurement results
- What uncertainties are introduced



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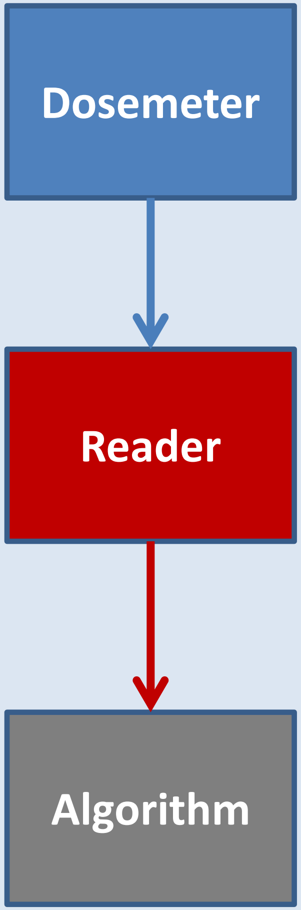
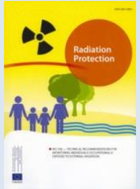
Components dosimetry system



The device send to the customer

The evaluating system, e.g.
TLD/OSL/RPL reader
Development + densitometer
Etching + track counter

Formula, series of formulas
Computer program

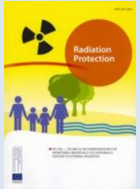


Some input quantities

Dosemeter → Reader → Algorithm → $H_p(10)$

- Radiation dose
- Radiation energy and angle of incidence
- Natural background dose
- Environmental conditions, …, …
- Blank signal
- Sensitivity of optical system
- Environmental conditions, …, …

Personal dose equivalent



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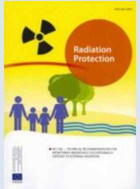
Stage 1.2 Identify input quantities

- Reader sensitivity
- Blank signal
- Detector sensitivity
- Angle and energy dependant response
- Detector signal
- Background dose
- Fading
- Environmental conditions, …, …

IEC International Electrotechnical Commission

For a list of 20 input quantities see
IEC TR 62461, *Determination of uncertainty in measurement*, Annex B



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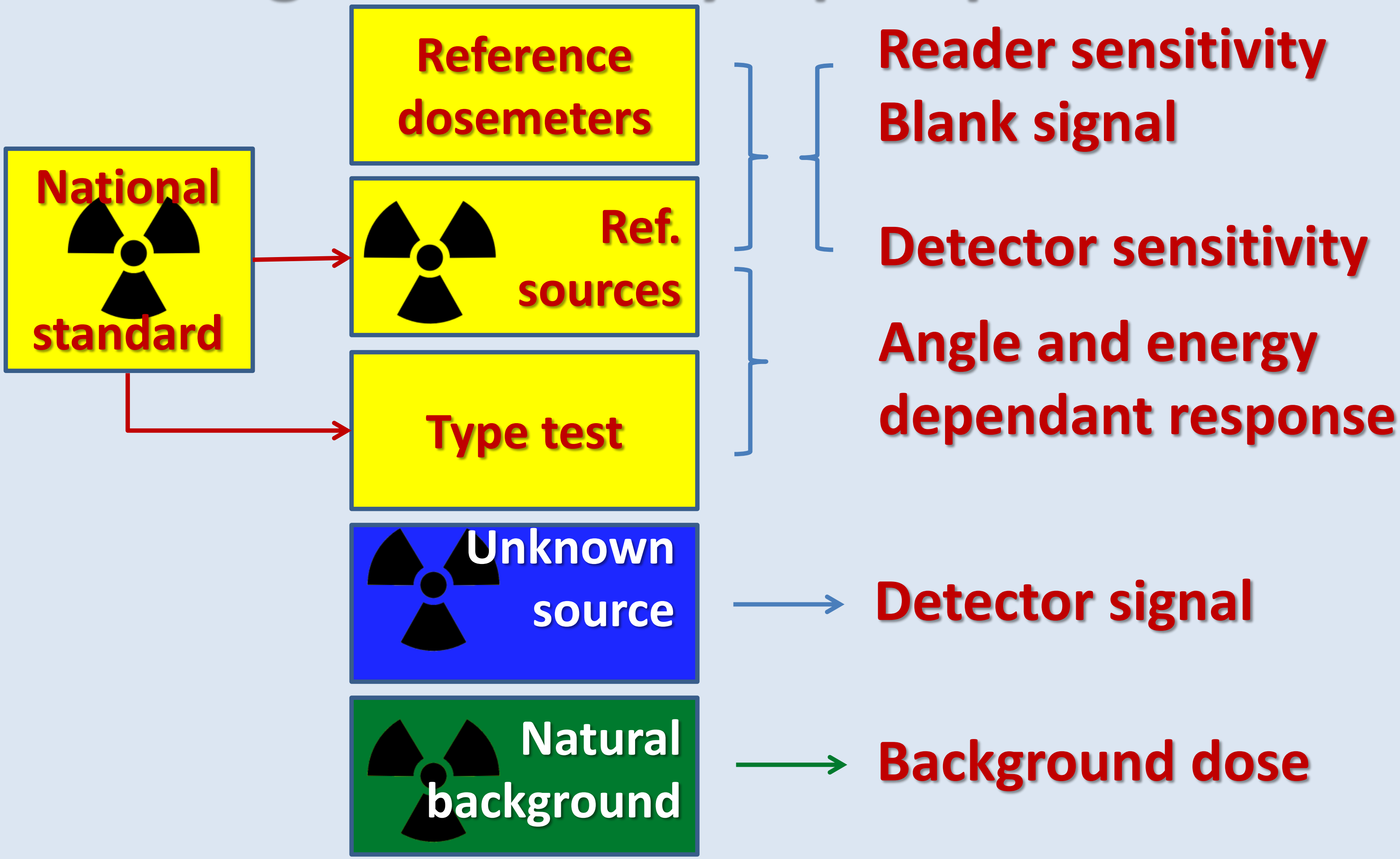
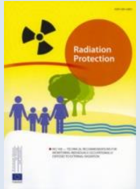
Stage 1.2 Identify input quantities

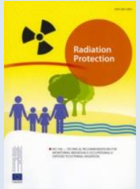




Stage 1.3 Identify probability densities

Probability distributions,

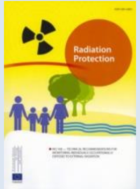
some concepts



Probability distribution

The cumulative distribution function (CDF), gives the probability that the random variable X is no larger than a given value

The probability density function (PDF), is a function that describes the relative likelihood for the random variable X to take on a given value



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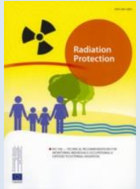
Probability distribution

$$F\left(a\right)=P\left[x\leq a\right]$$ **CDF**

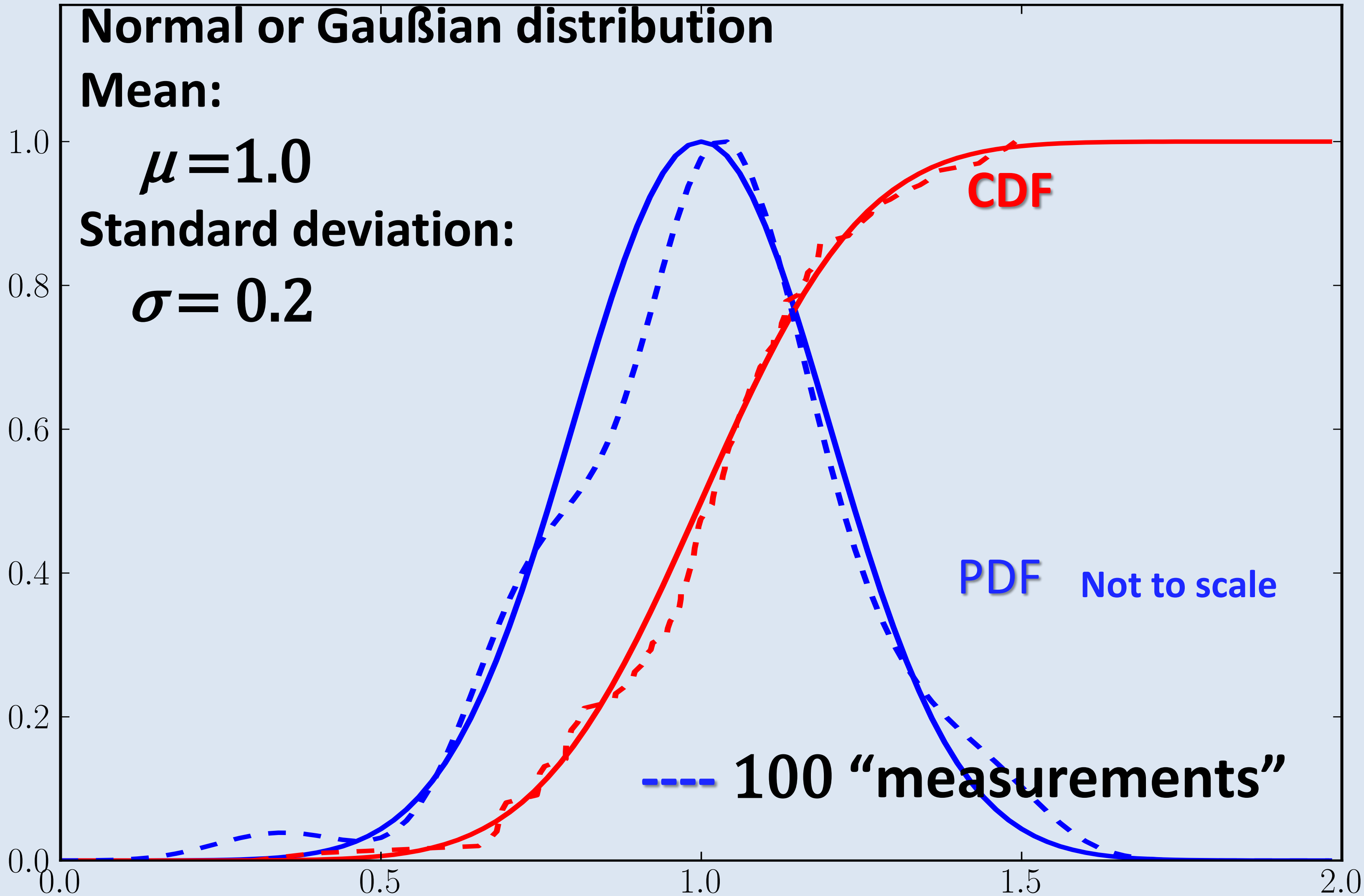
$$f\left(x\right)=\frac{dF\left(x\right)}{dx}$$ **PDF**

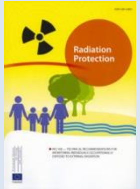
$$F\left(x\right)=\int_{-\infty}^{u=x}f\left(u\right)du$$ **CDF**

$$F\left(\infty\right)=\int_{-\infty}^{\infty}f\left(u\right)du=1$$



Evaluating uncertainty





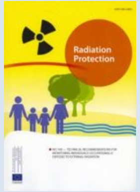
Assigning probability distributions

What do we know?

Two types of evaluation:

Type A: Based on statistical data,
e.g. repeated measurements

Type B: Based on all other knowledge



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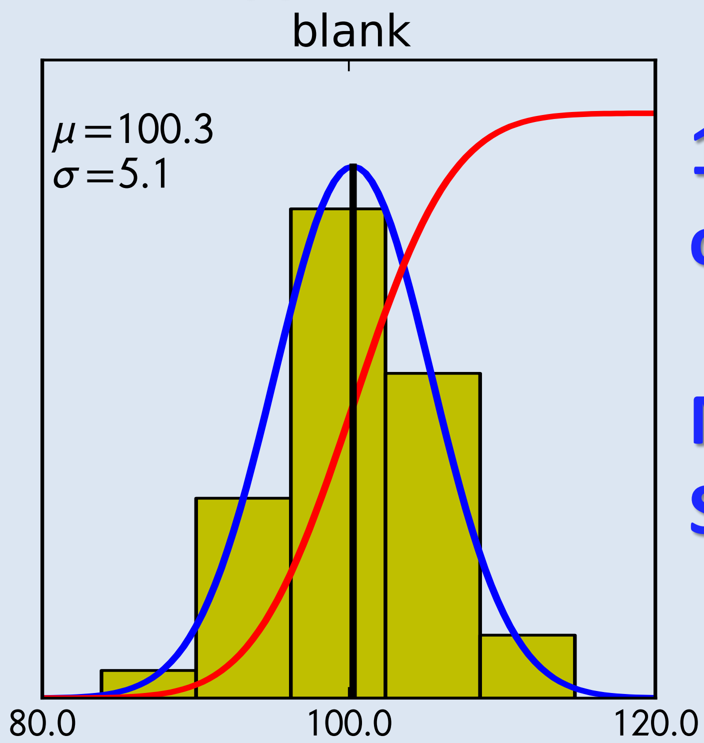
Assigning probability distributions

Type A evaluation

98.8	85.5
97.1	85.5
100.5	85.6
96.6	87.1
105.7	87.2
99.2	87.3
113.8	87.7
101.4	87.7
…	…
…	…
96.9	114.9
102.6	115.4
102.2	115.7



1000 measurements of blank signal, z

Mean $z = 100.3$

Stdev $u_z = \sigma_z = 5.1$

Assigning probability distributions

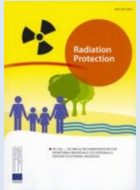
Symmetrical distributions characterized by mean and standard deviation

$$\mu = \int_{-\infty}^{\infty} x f(x)\, dx$$

$$\sigma = \sqrt{\int_{-\infty}^{\infty} (x-\mu)^2 f(x)\, dx}$$

E.g. the normal or Gaußian distribution

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$



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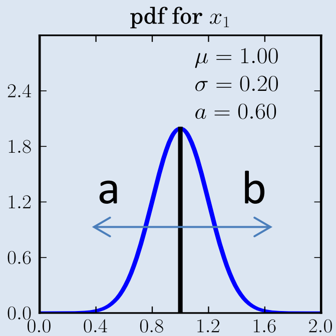
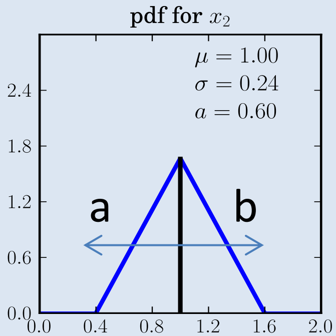
Assigning distributions: Type B evaluation



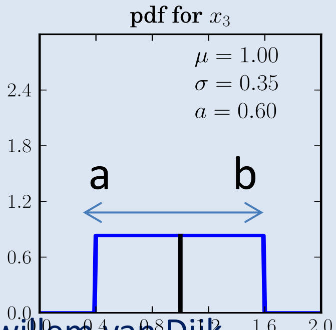
We know:

1. 99% of data between ***a*** and ***b*** and
2. central values most likely and
3. extremes very unlikely.



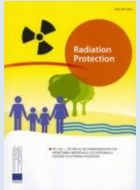
We know:

1. all data between ***a*** and ***b*** and
2. central values more likely.

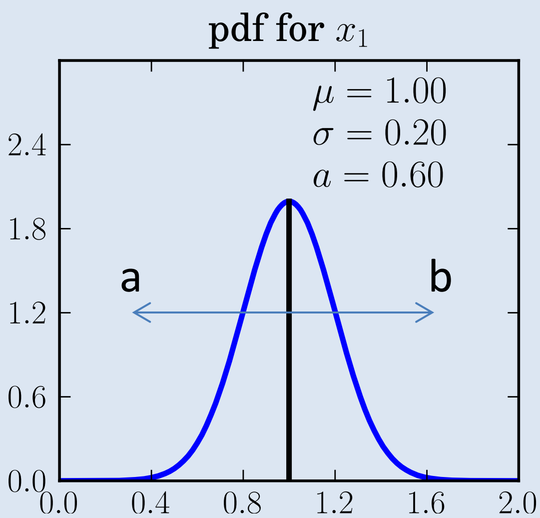


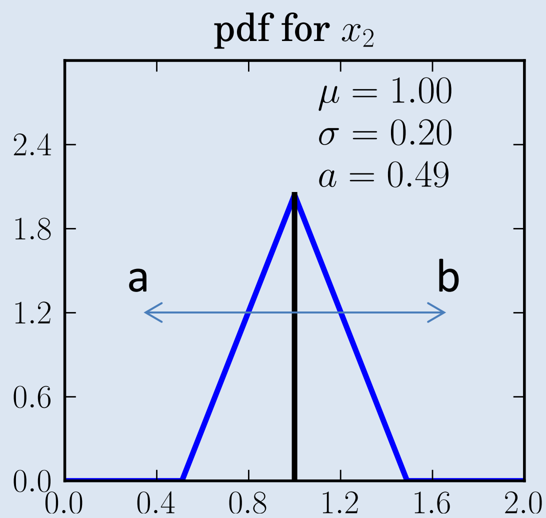
We know:

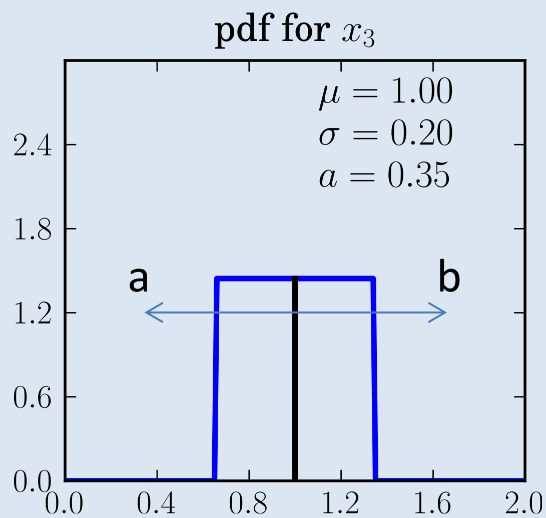
1. all data between ***a*** and ***b***



Assigning distributions: Type B evaluation







$$\mu = (a+b)/2 \qquad \sigma = (b-a)/6$$

Range/6

$$\mu = (a+b)/2 \qquad \sigma = (b-a)/2\sqrt{6}$$

Range/4.9

$$\mu = (a+b)/2 \qquad \sigma = (b-a)/2\sqrt{3}$$

Range/3.5

Stage 1.3 The measurement equation

In mathematical terms:

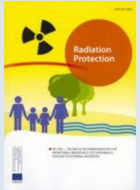
A function of the input quantities.

$$x_1, x_2, \ldots\ldots, x_N = X$$
$$y = f\,(X)$$

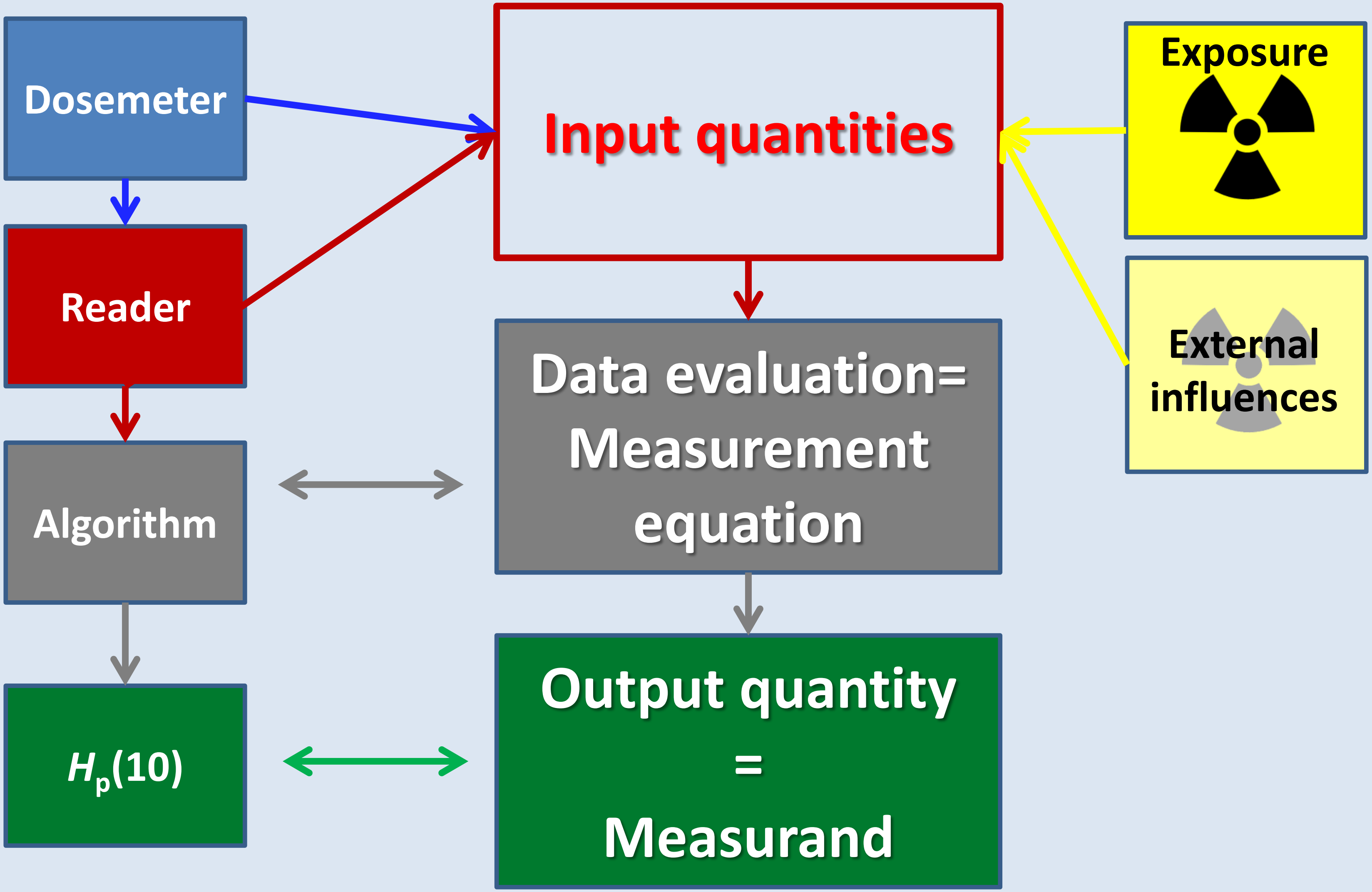
In practical terms:

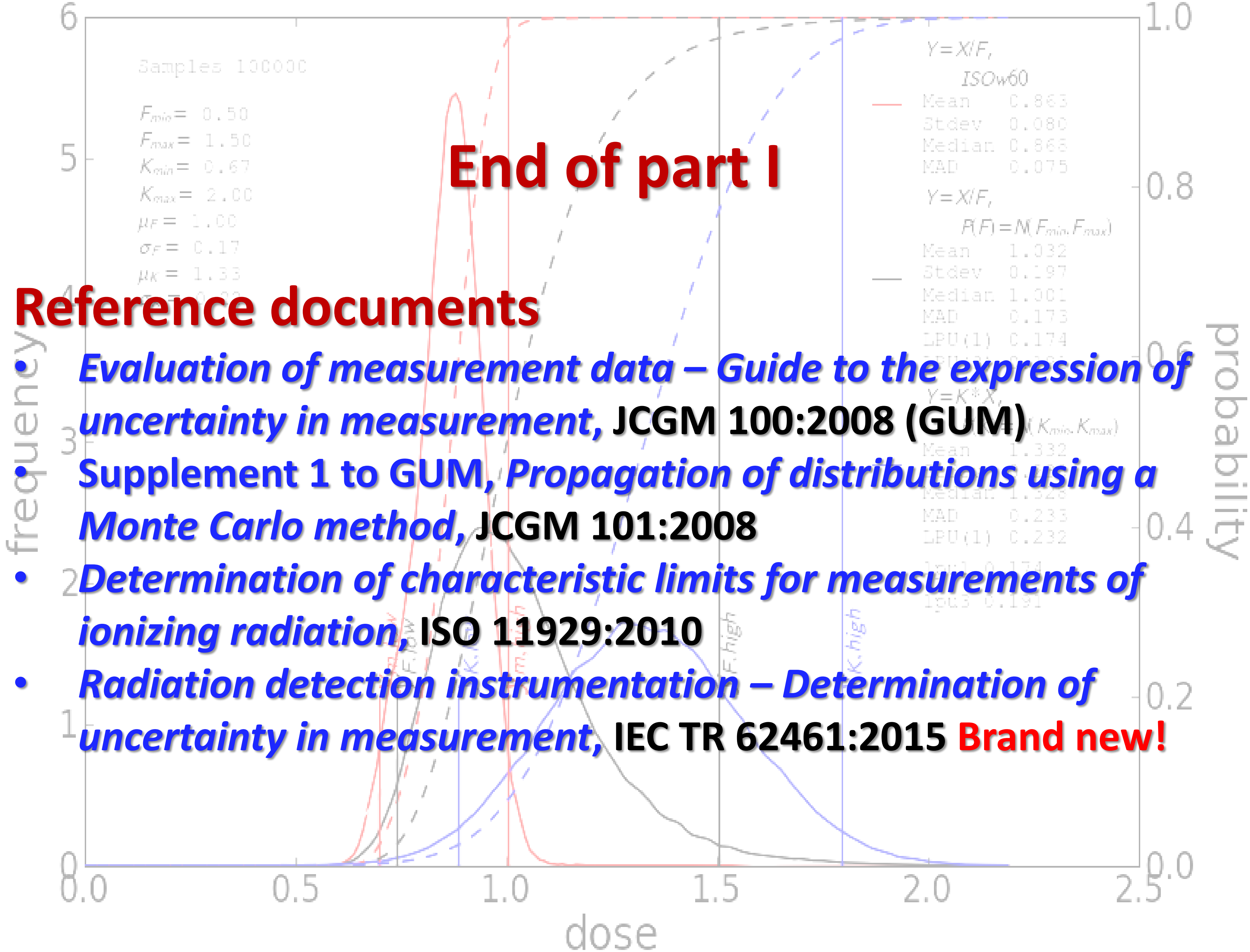
A number of formulas used to calculate the dose.

Usually implemented in software.



Evaluating uncertainty





End of part I

Reference documents

- ***Evaluation of measurement data – Guide to the expression of uncertainty in measurement,*** **JCGM 100:2008 (GUM)**
- **Supplement 1 to GUM, *Propagation of distributions using a Monte Carlo method,*** **JCGM 101:2008**
- ***Determination of characteristic limits for measurements of ionizing radiation,*** **ISO 11929:2010**
- ***Radiation detection instrumentation – Determination of uncertainty in measurement,*** **IEC TR 62461:2015 Brand new!**