MINISTERIO DE EDUCACIÓN Y CIENCIA
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

CONSIDERATIONS ON UNCERTAINTIES IN DOSE ASSESSMENTS FOR NORM INDUSTRIES

Juan Carlos Mora Cañadas

EAN NORM Round Table Workshop
Dresden – november 24th 2010

Dose assessment

$$E = \sum_T w_T \sum_R w_R \cdot D_{T,R}$$

ICRP [103]

Effective dose

$D_{T,R}$ Averaged absorbed dose in the tissue T due to the radiation R

w_R Radiation weighting factor

w_T Tissue weighting factor

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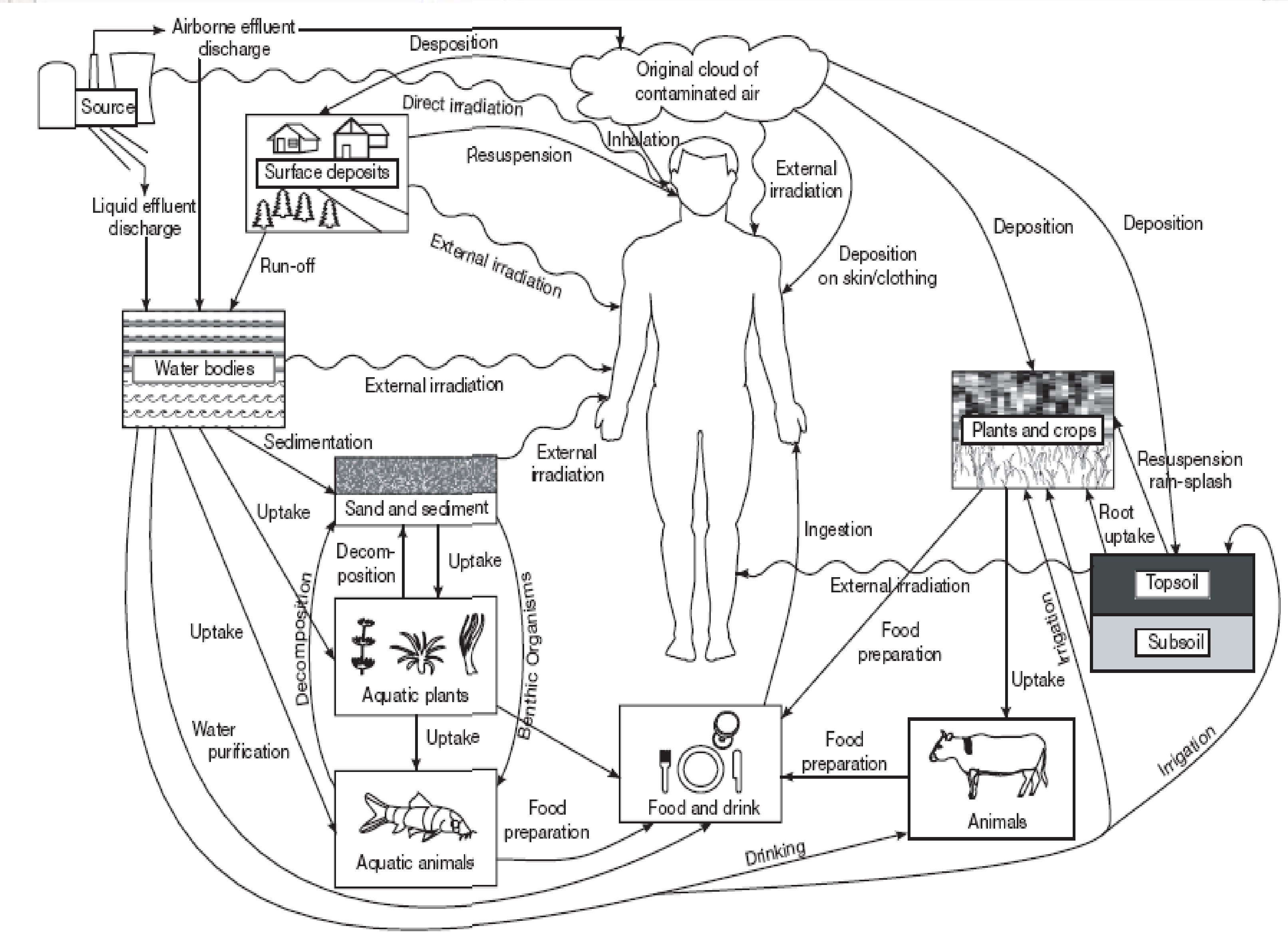
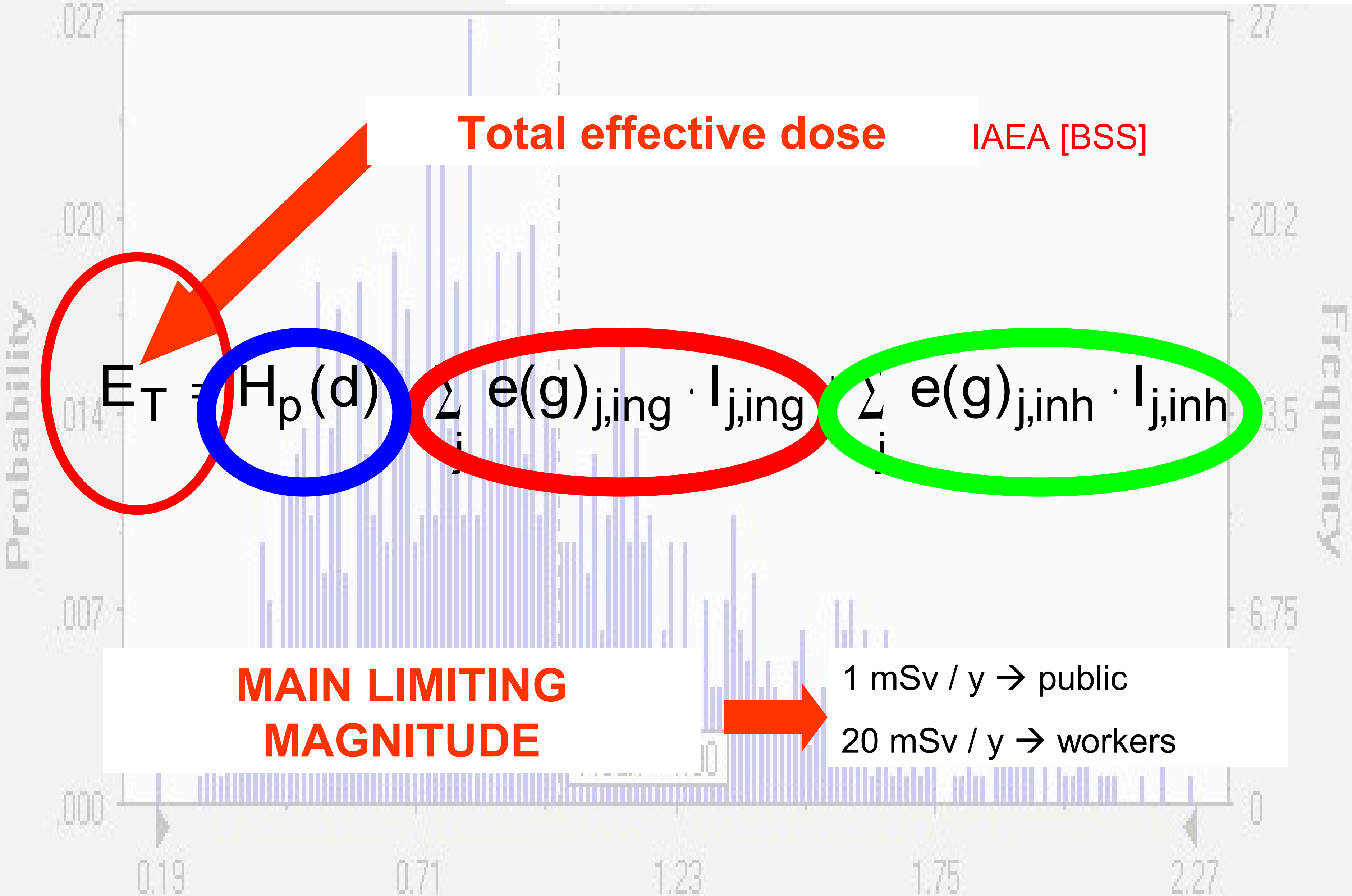
Dose assessment



Dose assessment



Total effective dose IAEA [BSS]

$$E_T = H_p(d) + \sum_j e(g)_{j,ing} \cdot I_{j,ing} + \sum_j e(g)_{j,inh} \cdot I_{j,inh}$$

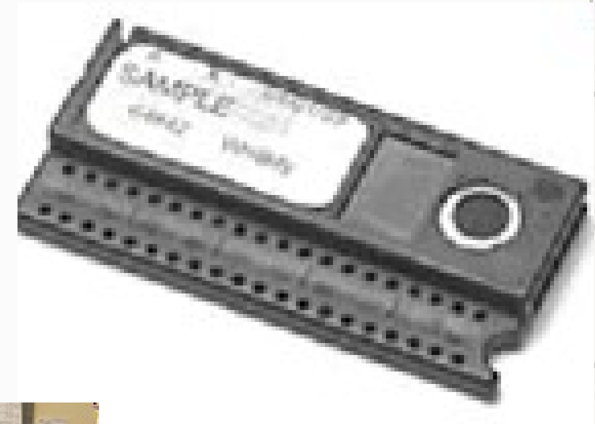
MAIN LIMITING MAGNITUDE →

1 mSv / y → public

20 mSv / y → workers

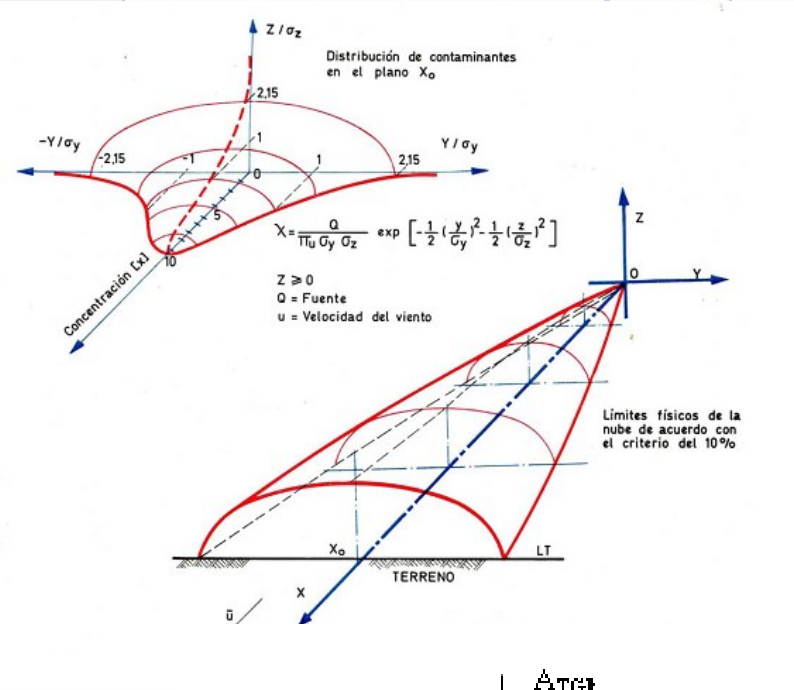
Dose assessment

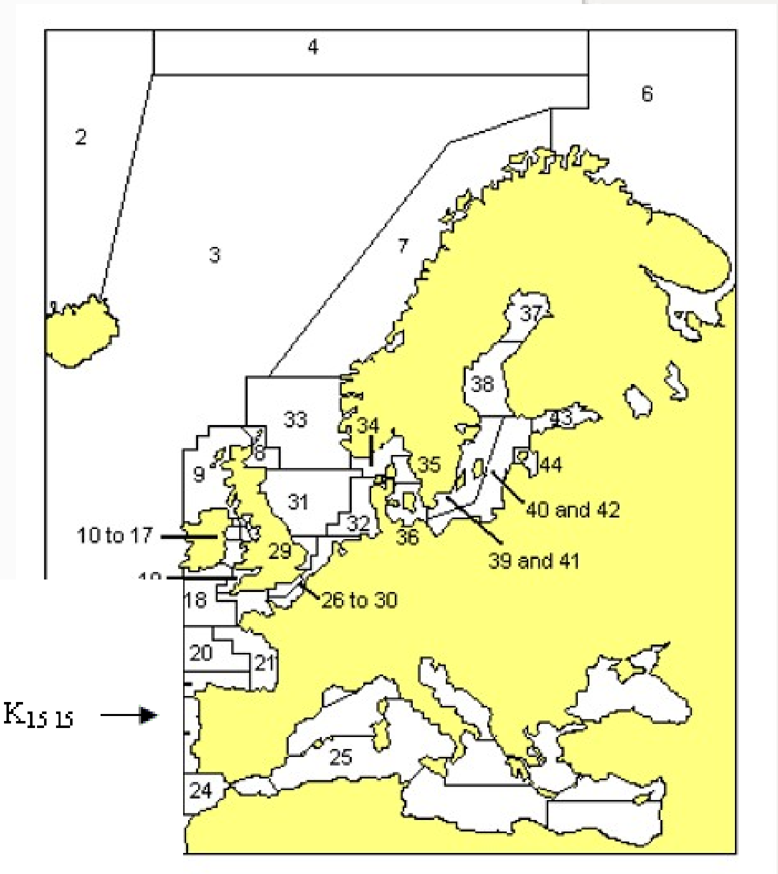
Measurements

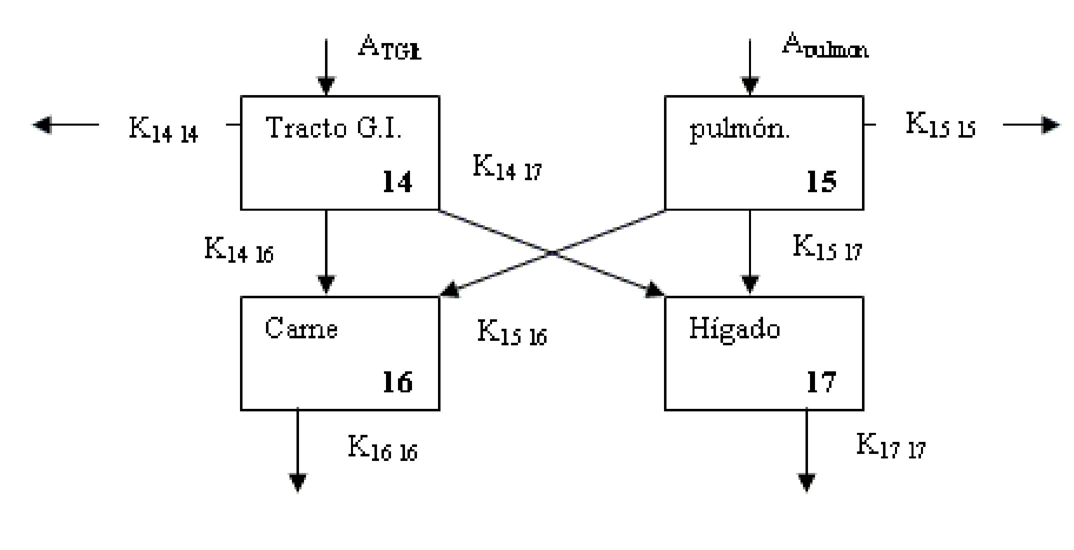


Dose assessment

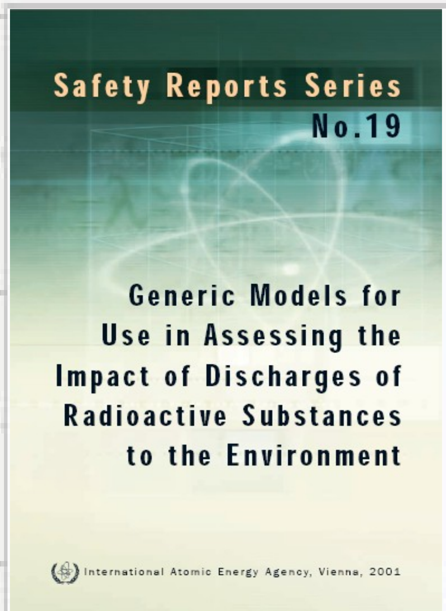
Models

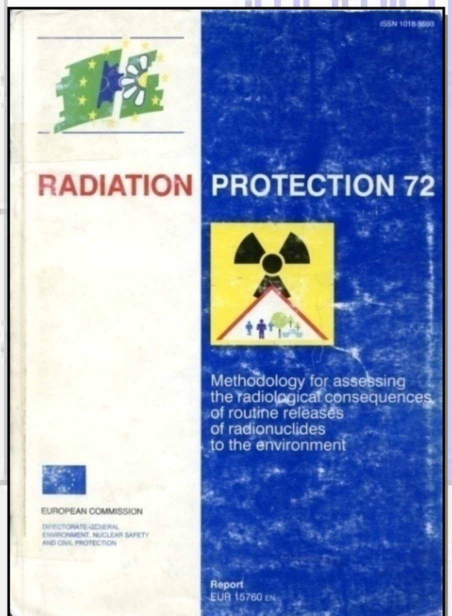


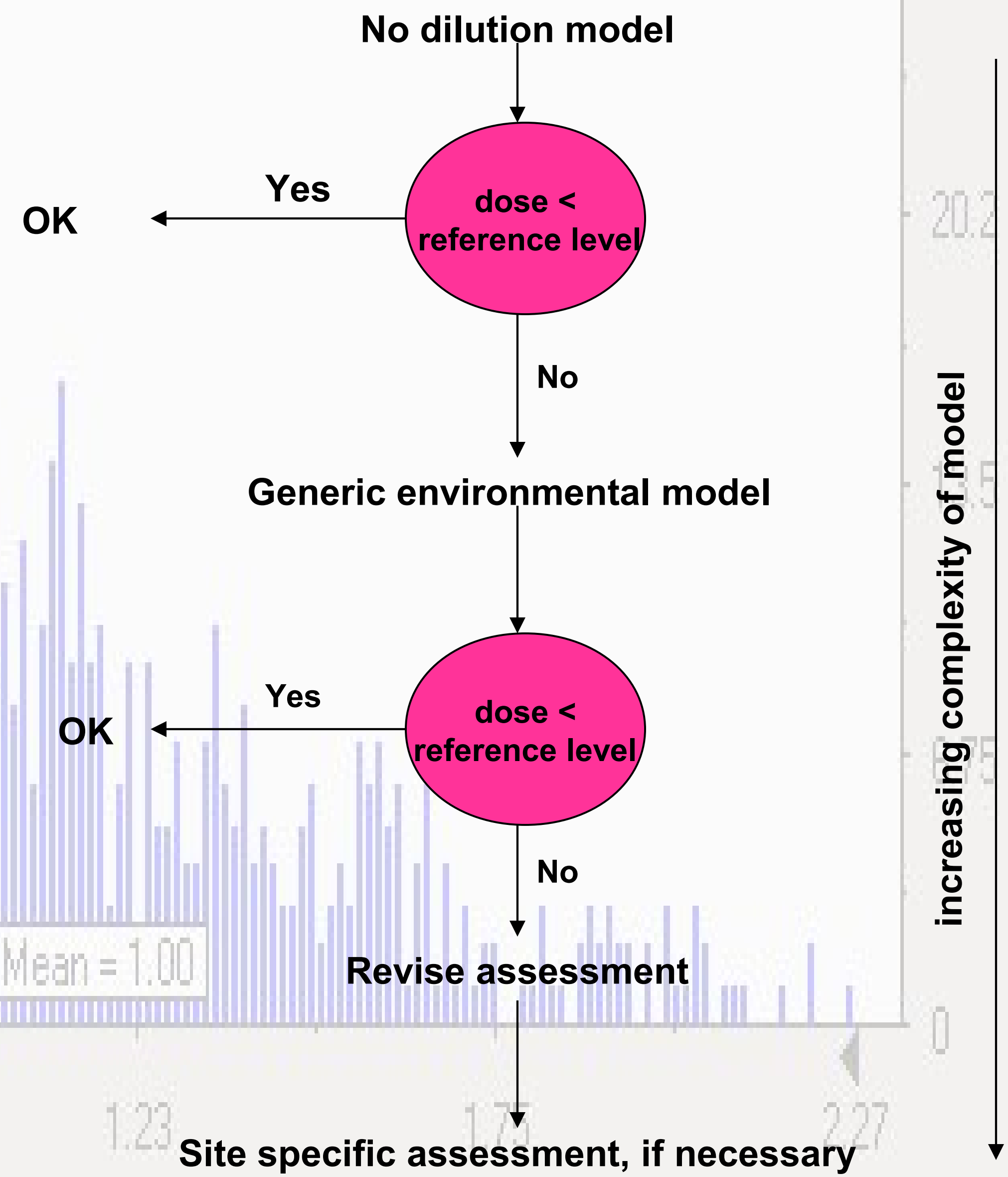




Graded approach







Graded approach

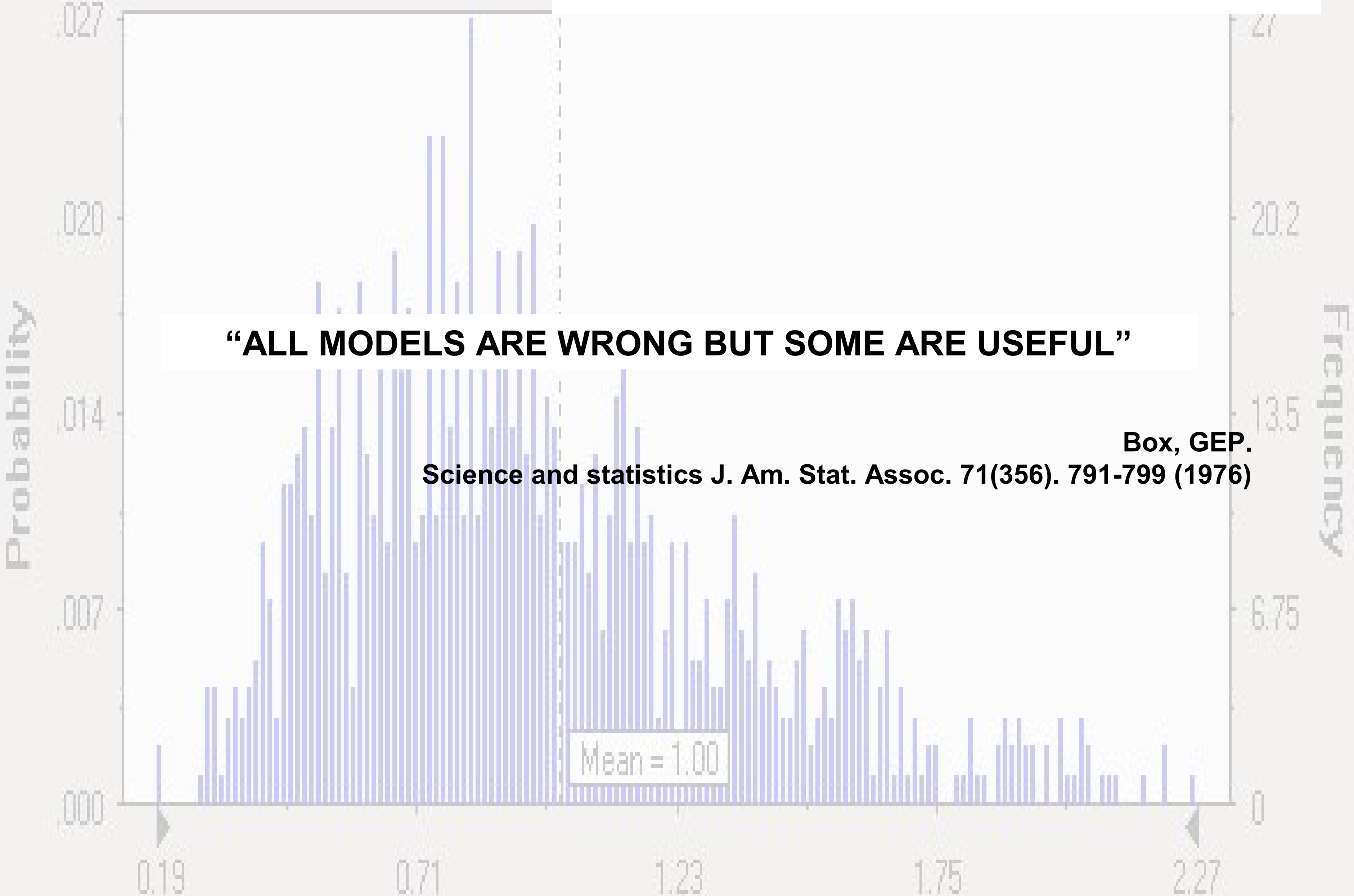
- Step by step process - model complexity increases as predicted doses increase
  - 1st step = 'most conservative'
  - 2nd step = 'generic model
  - 3rd step = 'modified generic assessment'
  - 4th step = 'site specific assessment'

Graded approach

IN BOTH DOCUMENTS:

- In a NON CONSERVATIVE assessment, uncertainty of the result (E_T) must be estimated, or at least discussed.

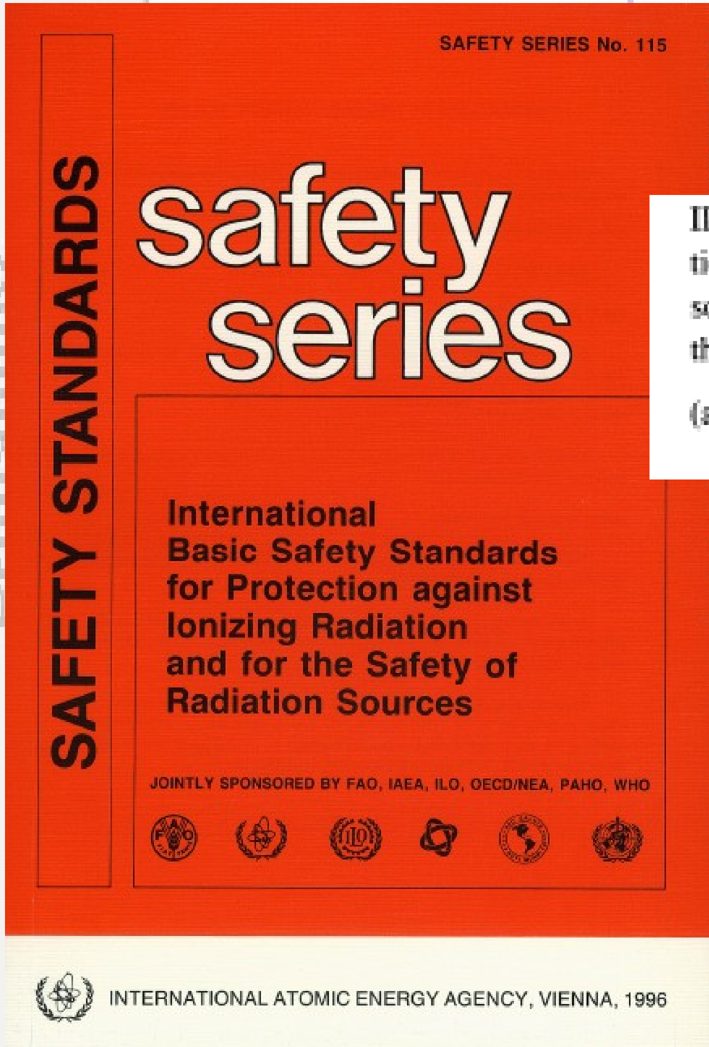
MODELS



“ALL MODELS ARE WRONG BUT SOME ARE USEFUL”

Box, GEP.
Science and statistics J. Am. Stat. Assoc. 71(356). 791-799 (1976)

Realism



1996.

IAEA BSS

III.3. Registrants and licensees shall be responsible for ensuring that the optimization process for measures to control the discharge of radioactive substances from a source to the environment is subject to dose constraints established or approved by the Regulatory Authority, taking into account, as appropriate:

(a) dose contributions from other sources and practices, including realistically assessed possible future sources and practices;

Optimization process based on dose constraints, realistically assessed…

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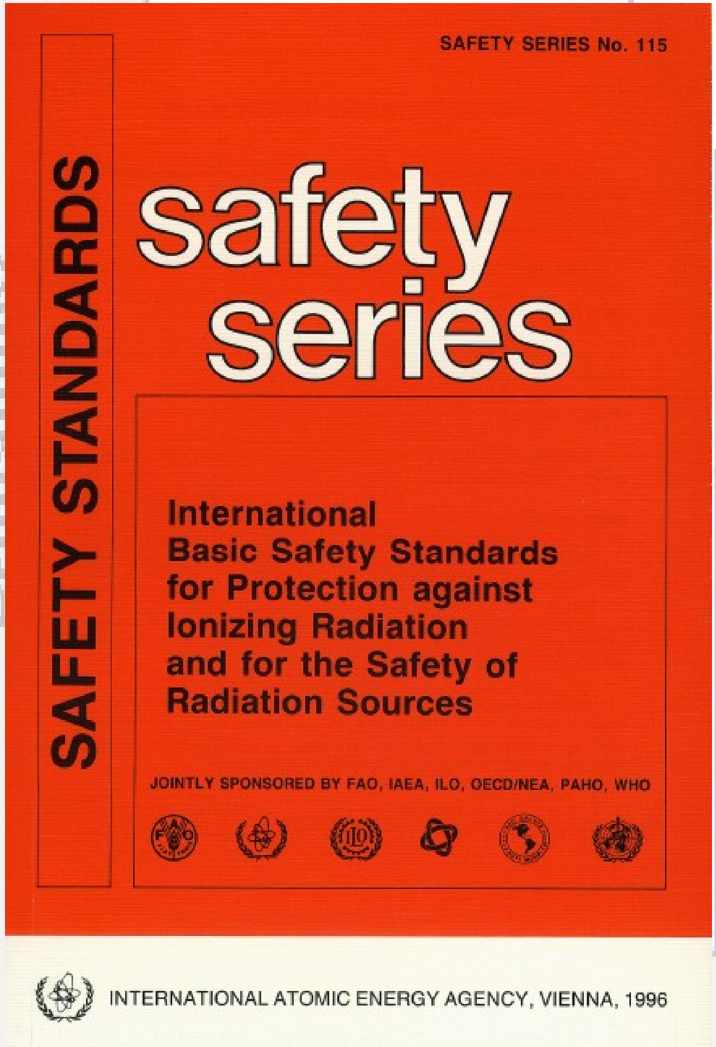
Realism



Control of discharges of radioactive substances is subject to dose constraints, taking into account any uncertainties in the assessment of exposures.

Realism

DIRECTIVA 96/29/EURATOM DEL CONSEJO DE 13 DE MAYO DE 1996 POR LA QUE SE ESTABLECEN LAS NORMAS BÁSICAS RELATIVAS A LA PROTECCIÓN SANITARIA DE LOS TRABAJADORES Y DE LA POBLACIÓN CONTRA LOS RIESGOS QUE RESULTAN DE LAS RADIACIONES IONIZANTES
DIARIO OFICIAL Nº L 159 DE 29/06/1996 P. 0001 - 0114

DIRECTIVA 96/29/EURATOM DEL CONSEJO de 13 de mayo de 1996 por la que se establecen las normas básicas relativas a la protección sanitaria de los trabajadores y de la población contra los riesgos que resultan de las radiaciones ionizantes

EL CONSEJO DE LA UNIÓN EUROPEA,

Visto el Tratado constitutivo de la Comunidad Europea de la Energía Atómica y, en particular, sus artículos 31 y 32,
Vista la propuesta de la Comisión, elaborada previo dictamen de un grupo de personas nombradas por el Comité Científico y Técnico entre expertos de los Estados miembros,
Visto el dictamen del Parlamento Europeo (1),
Visto el dictamen del Comité Económico y Social (2),

Considerando que la letra b) del artículo 2 del Tratado dispone el establecimiento de normas de seguridad uniformes para la protección sanitaria de los trabajadores y de la población;

Considerando que, de conformidad con el artículo 30 del Tratado, las normas básicas para la protección sanitaria de los trabajadores y de la población contra los riesgos que resulten de las radiaciones ionizantes se definen como:
a) las dosis máximas admisibles que sean compatibles con una seguridad adecuada;
b) los niveles de exposición y contaminación máximos admisibles;
c) los principios fundamentales de la vigilancia médica de los trabajadores;

Considerando que el artículo 33 del Tratado dispone que cada Estado miembro adoptará las disposiciones legales, reglamentarias y administrativas adecuadas para garantizar el cumplimiento de las normas básicas establecidas y tomará las medidas necesarias en lo que se refiere a la enseñanza, educación y la formación profesional;

Considerando que, para realizar su tarea, la Comunidad estableció por primera vez en 1959 las normas básicas de conformidad con lo dispuesto en el artículo 218 del Tratado mediante directivas de 2 de febrero de 1959 en las que se establecen las normas básicas para la protección sanitaria de los trabajadores y del público en general contra los riesgos que se derivan de las radiaciones ionizantes (3); que dichas directivas fueron revisadas en 1962 mediante la Directiva de 5 de marzo de 1962 (4), en 1966 mediante la Directiva 66/45/Euratom (5), en 1976 mediante la Directiva 76/579/Euratom (6), en 1979 mediante la Directiva 79/343/Euratom (7), en 1980 mediante la Directiva 80/836/Euratom (8), y en 1984 mediante la Directiva 84/467/Euratom (9);

1996.

European BSS 29/96

Article 45

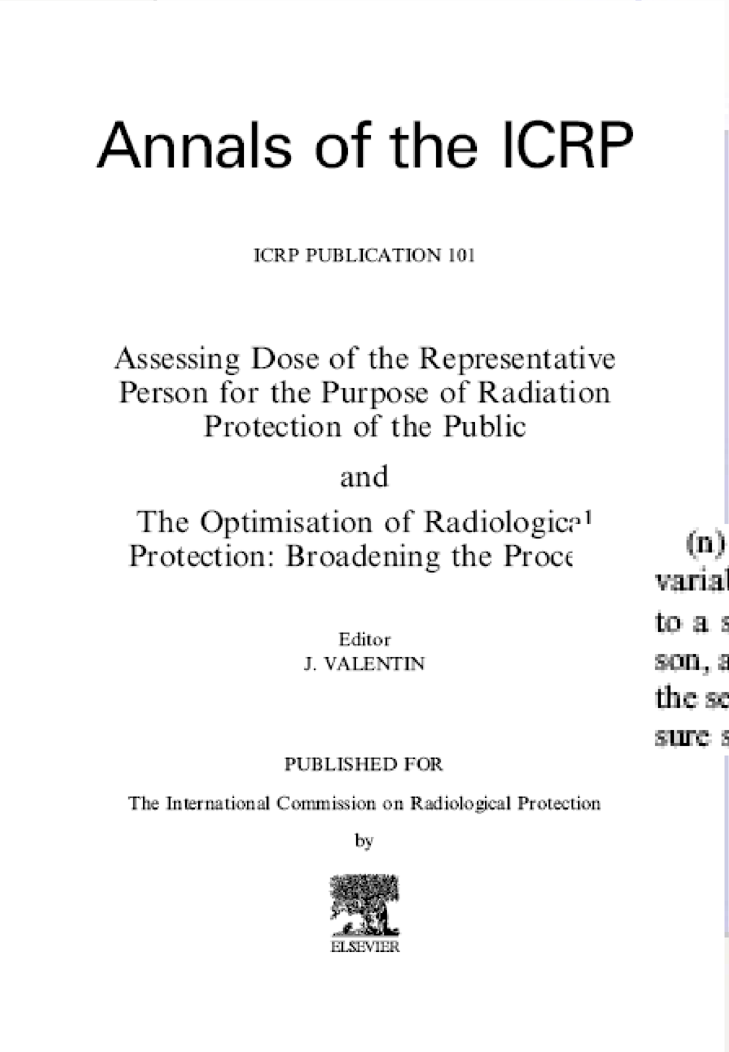
Estimates of population doses

The competent authorities shall:

(a) ensure that dose estimates from practices referred to in Article 44 are made as realistic as possible for the population as a whole and for reference groups of the population in all places where such groups may occur;

Dose estimates should be made as realistically as possible

Realism


Annals of the ICRP

ICRP PUBLICATION 101

Assessing Dose of the Representative Person for the Purpose of Radiation Protection of the Public

and

The Optimisation of Radiologica¹ Protection: Broadening the Proce

Editor
J. VALENTIN

PUBLISHED FOR
The International Commission on Radiological Protection
by
ELSEVIER

2005

ICRP 101

Representative person:

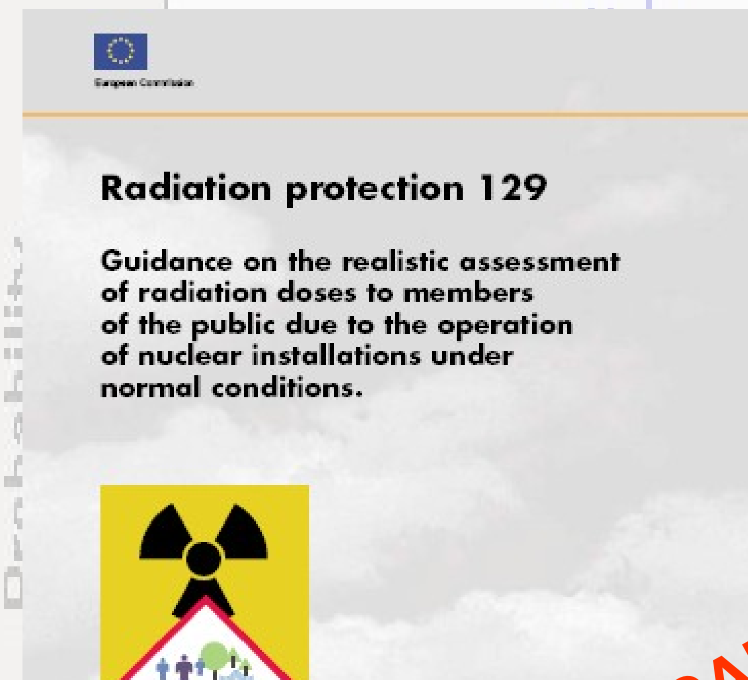
"An individual whose dose can be used for determining compliance with the relevant dose constraints".

(n) Care should be exercised to avoid selecting extreme percentile values for every variable to prevent excessive conservatism in the assessment. Such a result could lead to a significant and unrealistic overestimation of the dose to the representative person, and may unduly burden the design of medical or other facilities. Taken together, the selection of parameter values must represent a reasonable and sustainable exposure scenario.

Avoid extreme percentile values!

Prevent excessive conservatism!

Uncertainties



2002

RP 129

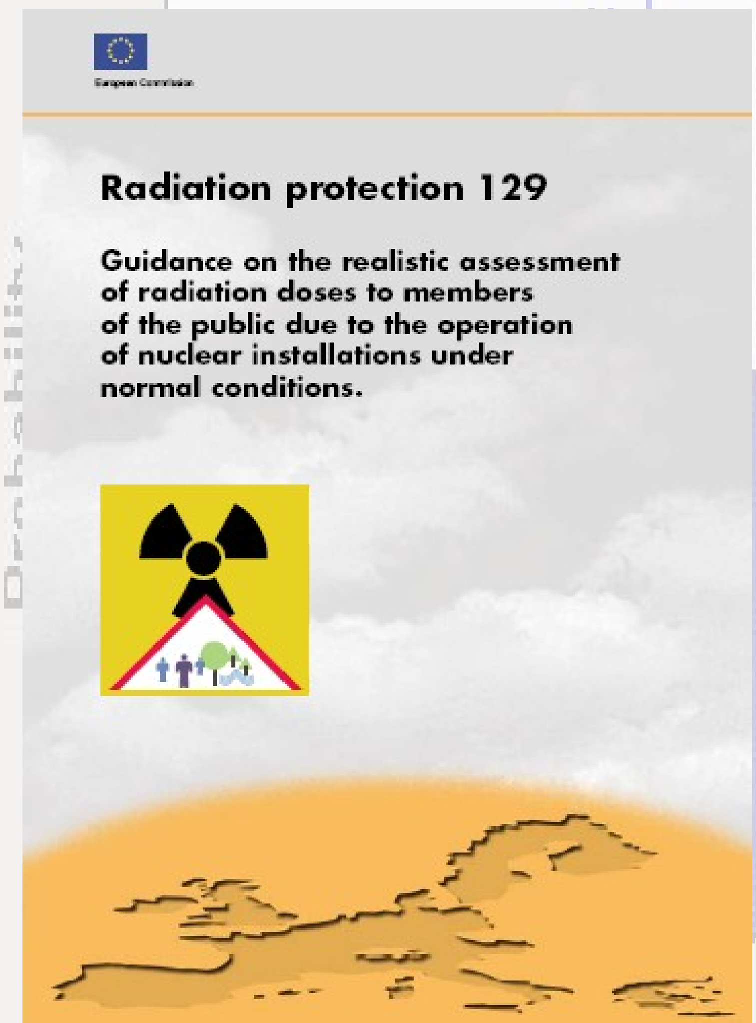
A guidance on how to perform realistic assessments for nuclear installations and under normal conditions.

Useful for other non nuclear installations

AVOID SIGNIFICANT OVER- OR UNDERSTIMATIONS

The aim of a realistic assessment is to estimate doses as closely as possible to those that would actually be received by members of the public. This is not straightforward and requires judgement but the aim is to avoid significant over- or underestimation.

Uncertainties



Europe 2002 (RP-129) – The aim of realistic assessments is to estimate doses as closely as possible to those that would actually be received by members of the public.

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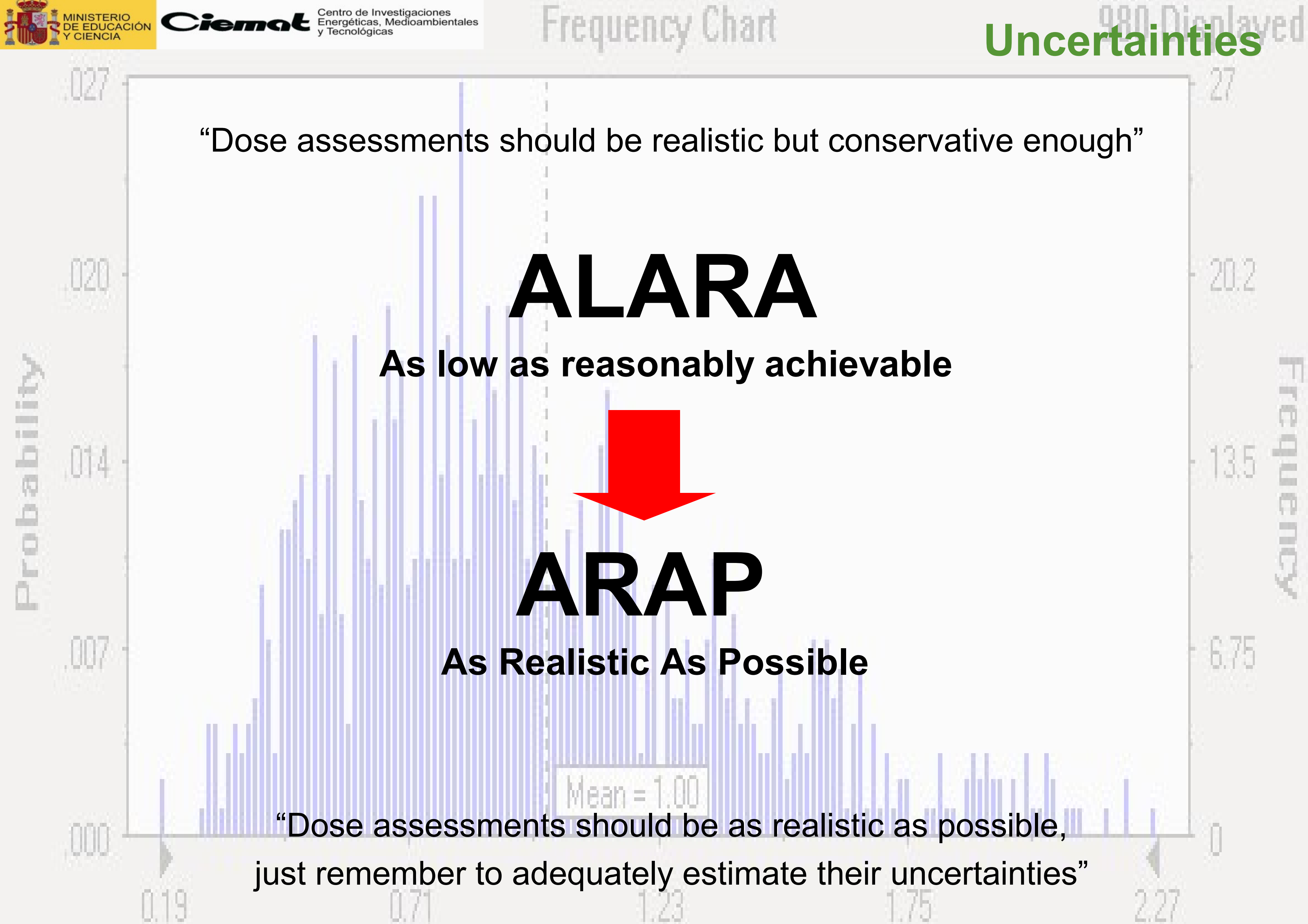
Uncertainties



"Dose assessments should be realistic but conservative enough"

ALARA

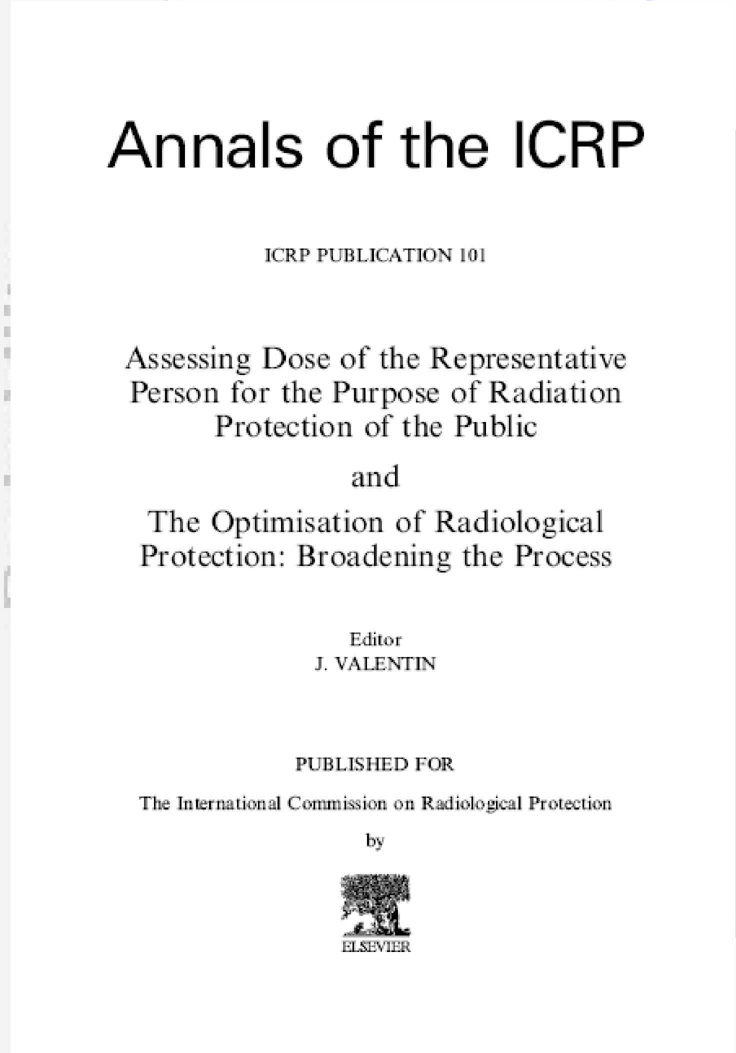
As low as reasonably achievable

ARAP

As Realistic As Possible

"Dose assessments should be as realistic as possible,
just remember to adequately estimate their uncertainties"

Realism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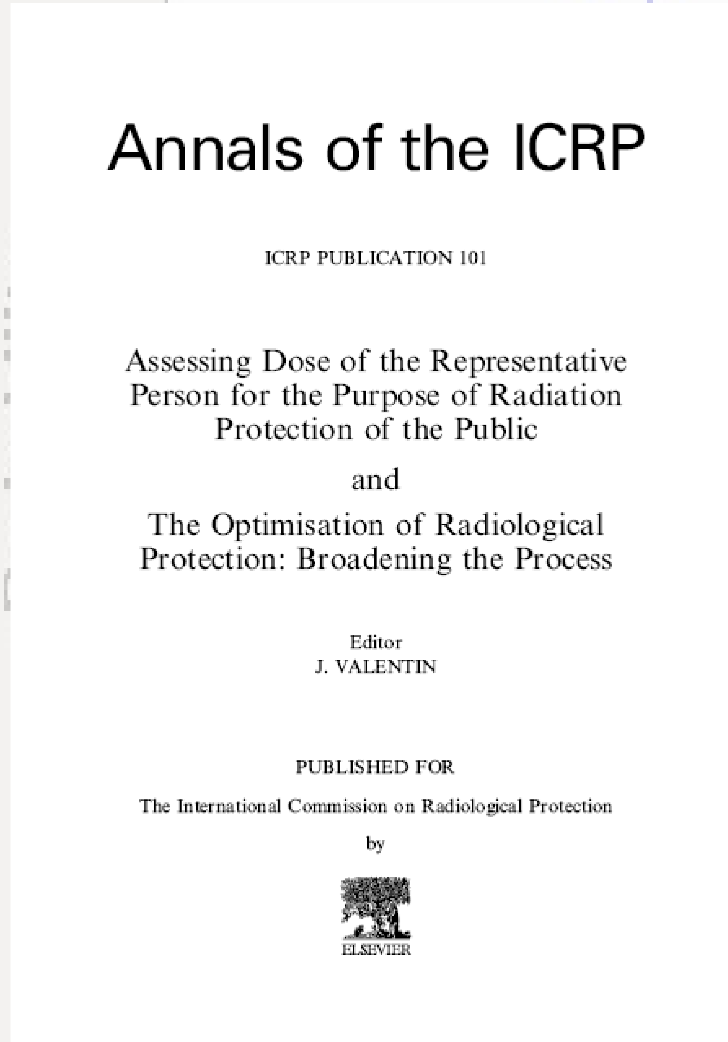
ICRP 101

Variability and uncertainty (V&U) are inherent in any process of estimating doses. In doses estimated using measurements or models, V&U contribute to a distribution of possible values.

Realism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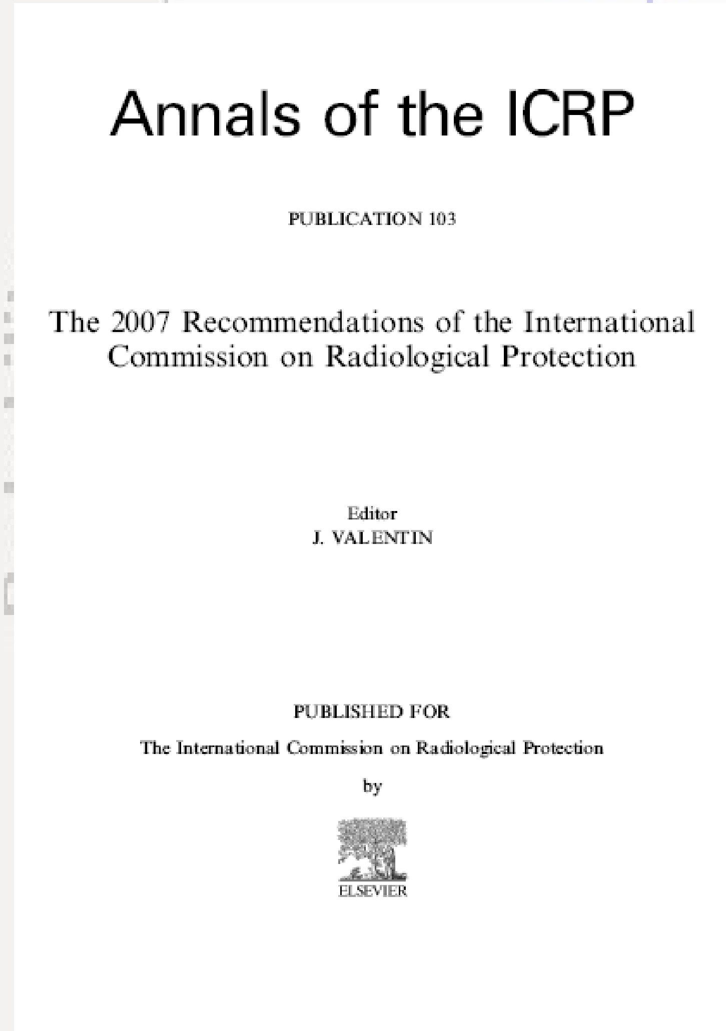
ICRP 101

- **The variability and uncertainty contribute to a distribution of possible values.**

- **The degree of variability and uncertainty is represented by the shape and extent of that distribution**

Uncertainties



Annals of the ICRP

PUBLICATION 103

The 2007 Recommendations of the International Commission on Radiological Protection

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J. VALENTIN

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by
ELSEVIER

2007

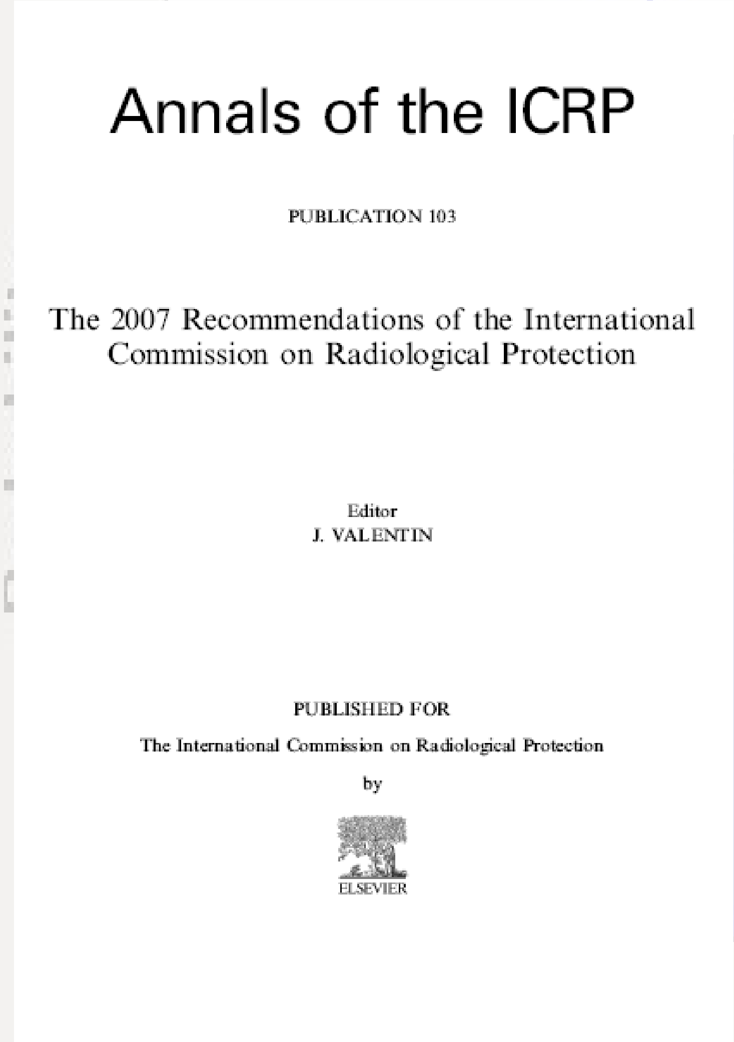
ICRP 103

(320) The measurement or assessment of radiation doses is fundamental to the practice of radiological protection. Neither the equivalent dose in an organ nor the effective dose can be measured directly. Values of these quantities must be inferred with the aid of models, usually involving environmental, metabolic, and dosimetric components. Ideally, these models and the values chosen for their parameters should be realistic, so that the results they give can be described as 'best estimates'. Where practicable, estimates and discussion should be made of the uncertainties inherent in these results (see Section 4.4).

Estimates and discussion should be made of the uncertainties inherent in the results

Models and parameters should be realistic.

Uncertainties


Annals of the ICRP

PUBLICATION 103

The 2007 Recommendations of the International Commission on Radiological Protection

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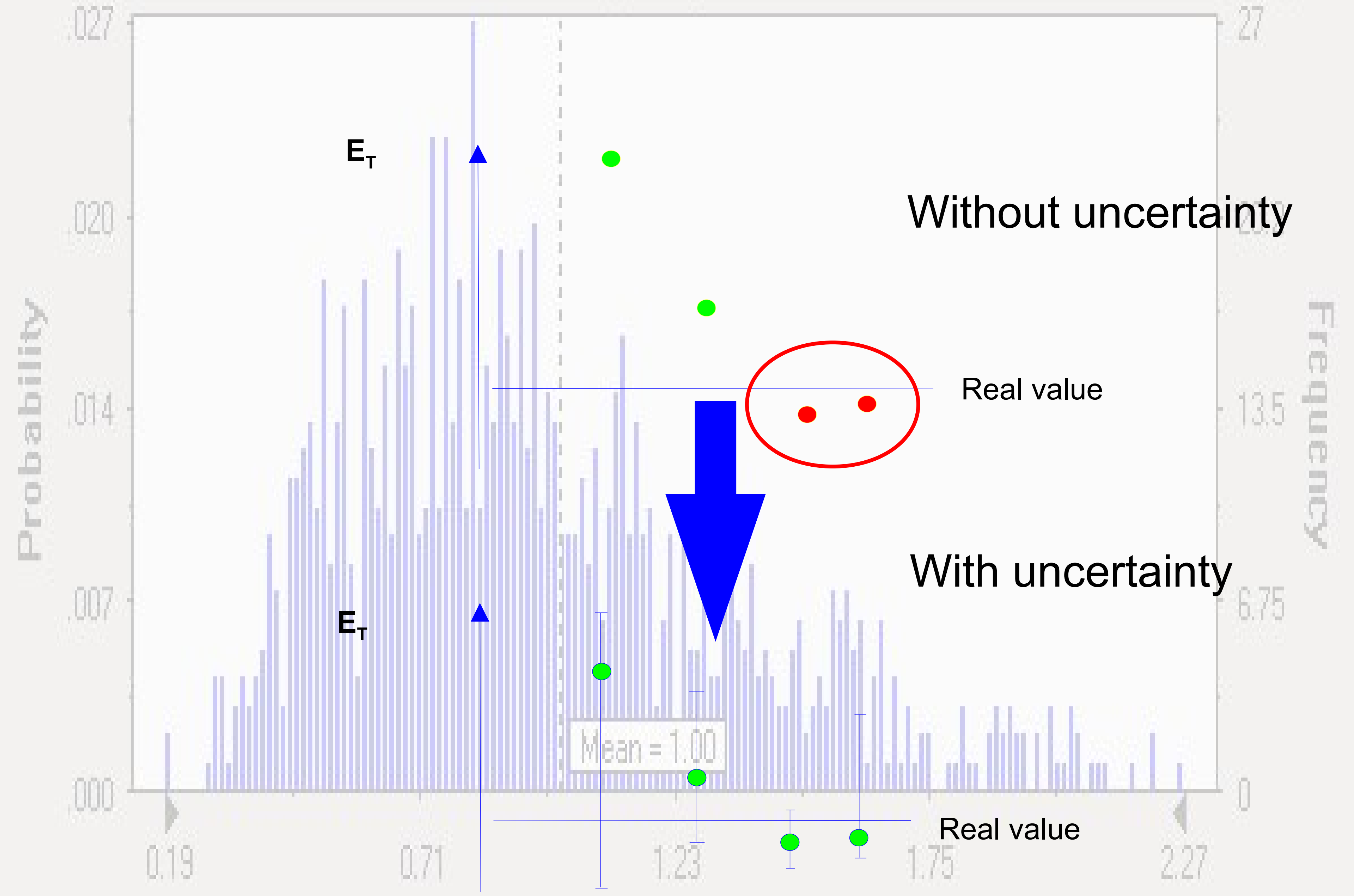
ELSEVIER

Effective dose cannot be measured directly, but it must be inferred with the aid of models. Ideally these models and the parameters should be realistic. Where practicable, estimates and discussion should be made of the uncertainties of the results.

Uncertainties



Uncertainties

IAEA

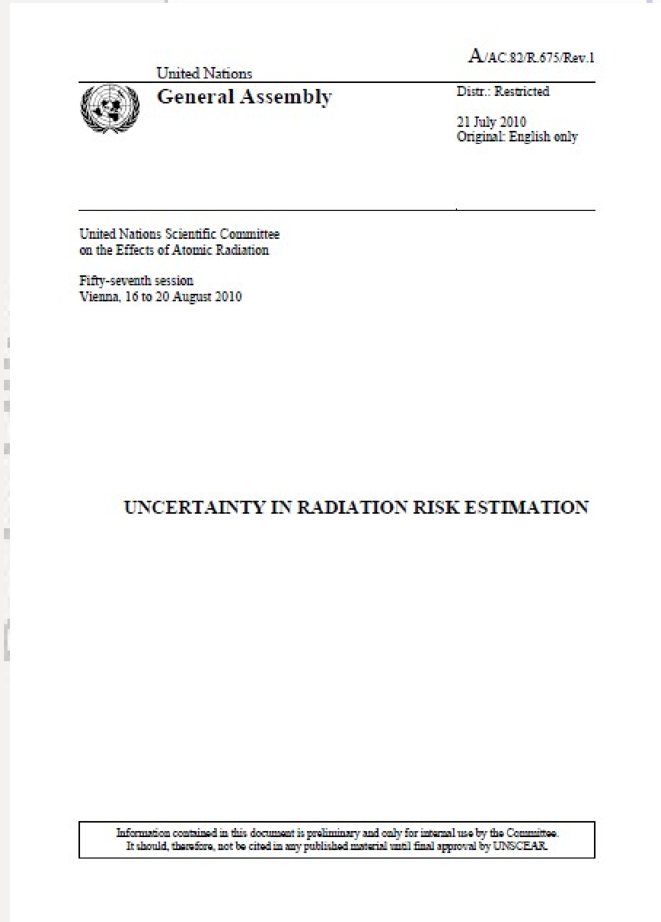
Safety Series 100 (1989)

Evaluating the Reliability of Predictions Made Using Environmental Transfer Models

Supplements the guidance on modelling methods by describing the available approaches to establishing the uncertainty in model predictions

Uncertainties

UNSCEAR DRAFT (march 2010)


A/AC.82/R.675/Rev.1

United Nations
General Assembly

Distr.: Restricted

21 July 2010
Original: English only

United Nations Scientific Committee
on the Effects of Atomic Radiation

Fifty-seventh session
Vienna, 16 to 20 August 2010

UNCERTAINTY IN RADIATION RISK ESTIMATION

Information contained in this document is preliminary and only for internal use by the Committee. It should, therefore, not be cited in any published material until final approval by UNSCEAR.

Uncertainty In Radiation Risk Estimation

“The committee recommends that uncertainty in the measurements, variables, and models that are used to estimate exposures, doses and risks – both for specific individuals and for groups – be defined as probability distributions that represent the state of the knowledge about true but imperfectly known quantities”.

Uncertainties

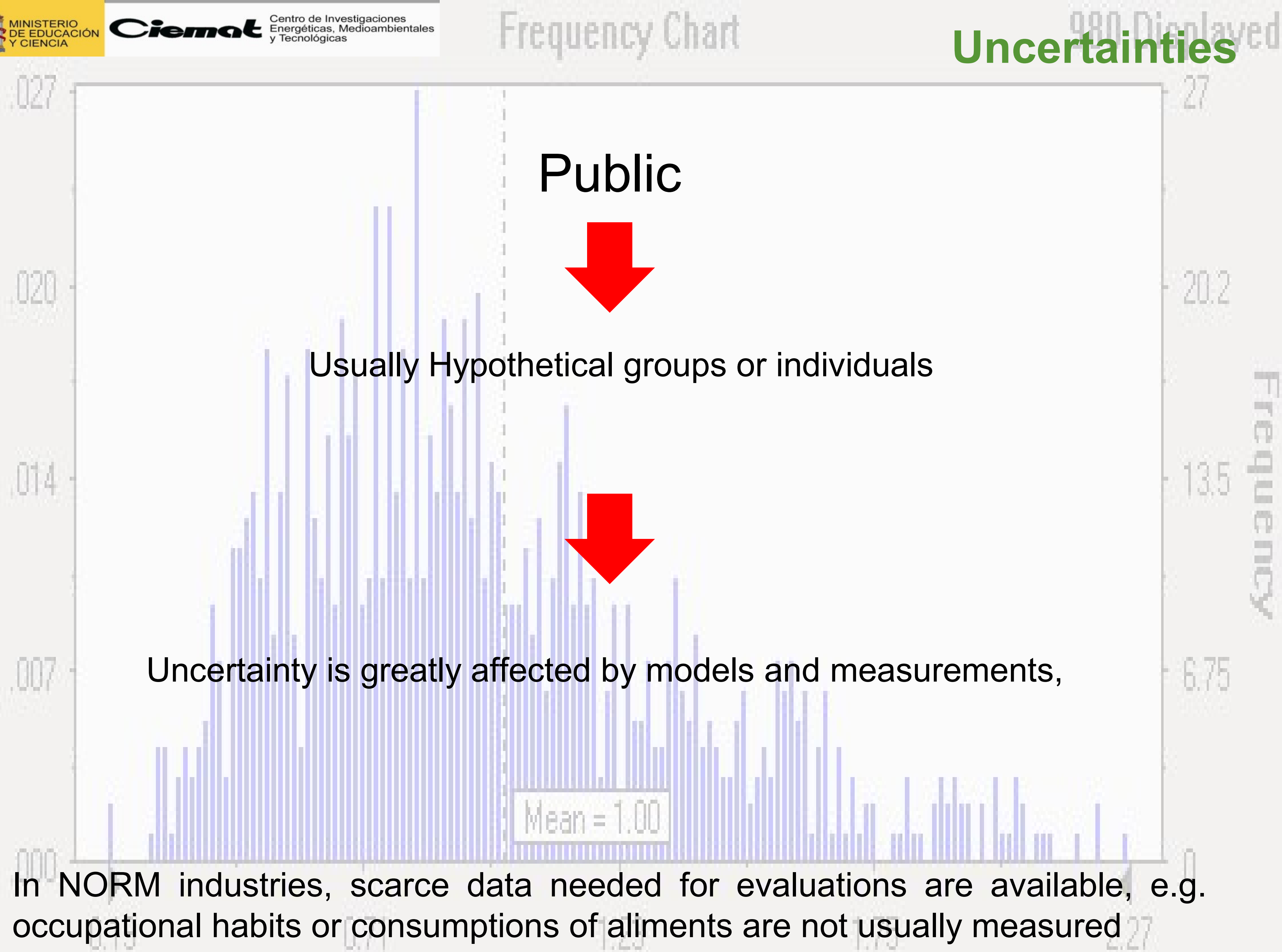
Workers

Controlled one by one
internal and external dosimetry

Uncertainty mostly from measurements, including technique, calibration of the instruments, variabilities, and even dose conversion factors

In NORM industries, individual dosimetry is not usual, so the model contribution is greater in this case.

Uncertainties



Public

Usually Hypothetical groups or individuals

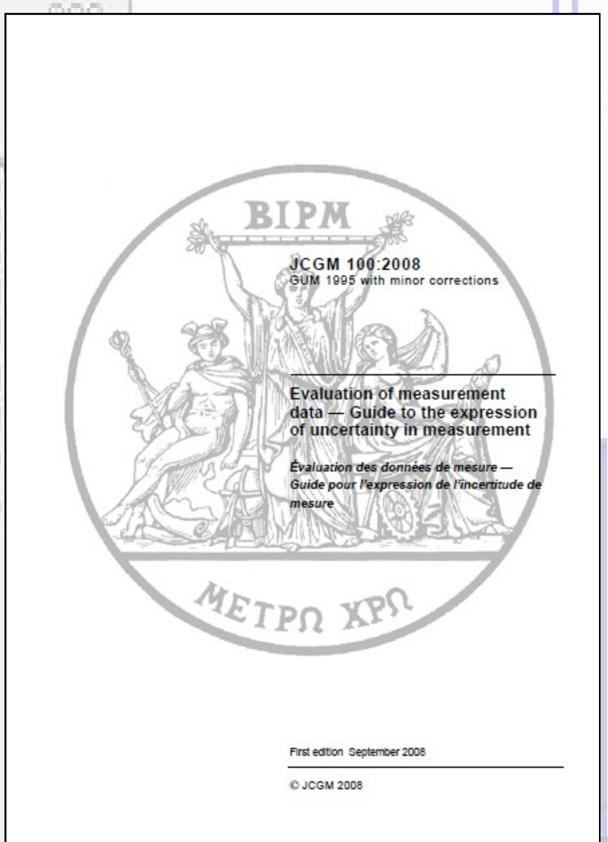
Uncertainty is greatly affected by models and measurements,

In NORM industries, scarce data needed for evaluations are available, e.g. occupational habits or consumptions of aliments are not usually measured

Uncertainties

MEASUREMENTS

Representativity of the temporal and spatial variability


JCGM 100:2008
GUM 1995 with minor corrections

Evaluation of measurement data — Guide to the expression of uncertainty in measurement

Évaluation des données de mesure — Guide pour l'expression de l'incertitude de mesure

First edition September 2008

© JCGM 2008

• Evaluation of measurement data – Guide to the expression of uncertainty in measurement – ISO; Joint Committee for Guides in Metrology (JCGM: BIPM, IUPAC, IUPAP, …) – 1995 (→ 2008 minor corrections).

Uncertainty propagation using differential equations

USEFUL FOR SINGLE SAMPLES AND SYMMETRICAL DISTRIBUTIONS

Uncertainty propagation

If $f = f(x_1, x_2, \ldots, x_n)$

$$u^2(f) = \left(\frac{\partial f}{\partial x_1}\right)^2 \cdot u^2(x_1) + \left(\frac{\partial f}{\partial x_2}\right)^2 \cdot u^2(x_2) + \ldots + \left(\frac{\partial f}{\partial x_n}\right)^2 \cdot u^2(x_n)$$

$$f(x,y) = x + y \quad \Rightarrow \quad u(f) = \sqrt{u^2(x) + u^2(y)}$$

$$g(x,y) = x \cdot y \quad \Rightarrow \quad u(g) = g \cdot \sqrt{\frac{u^2(x)}{x^2} + \frac{u^2(y)}{y^2}}$$

$$h(x,y) = \frac{x}{y} \quad \Rightarrow \quad u(h) = h \cdot \sqrt{\frac{u^2(x)}{x^2} + \frac{u^2(y)}{y^2}}$$

Error and Uncertainty

Error: difference between the measurements or estimators and the real value.

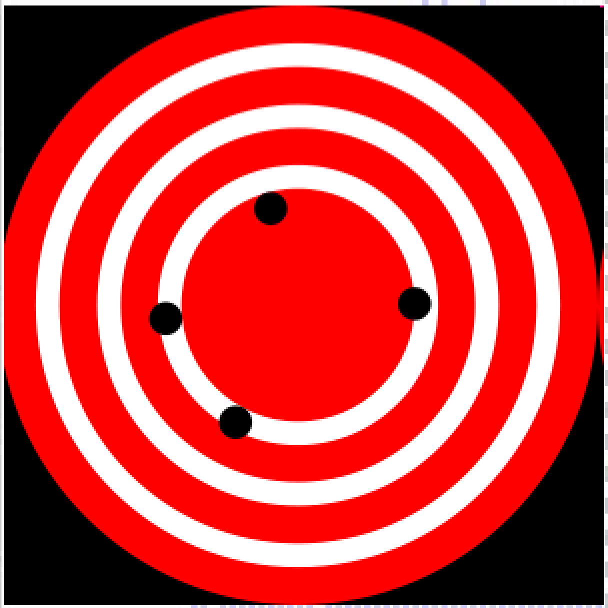
Uncertainty: degree of doubt that the measurement is equal to the real value

Uncertainties

Accuracy and precision

High Accuracy

Low Precision

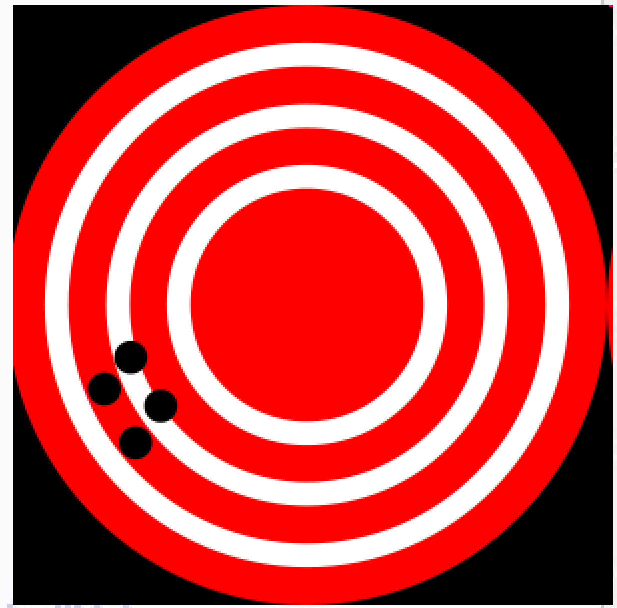


High uncertainty

No systematic errors

Low Accuracy

High Precision



Low uncertainty

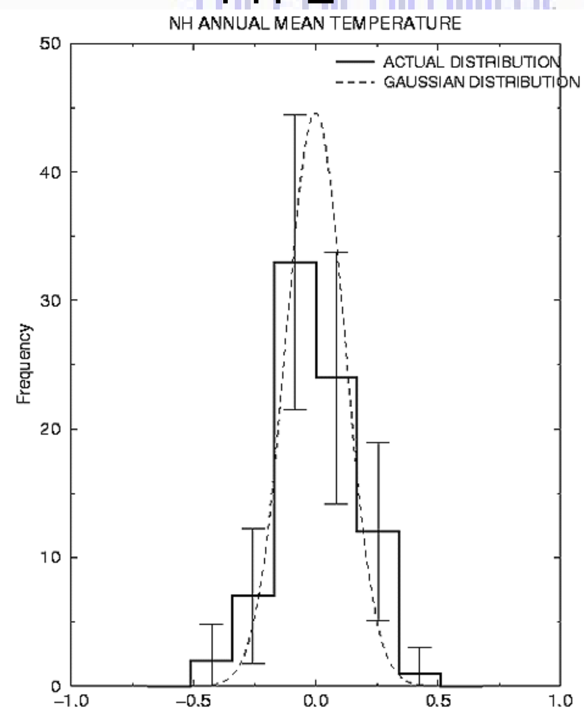
Systematic errors

Uncertainties

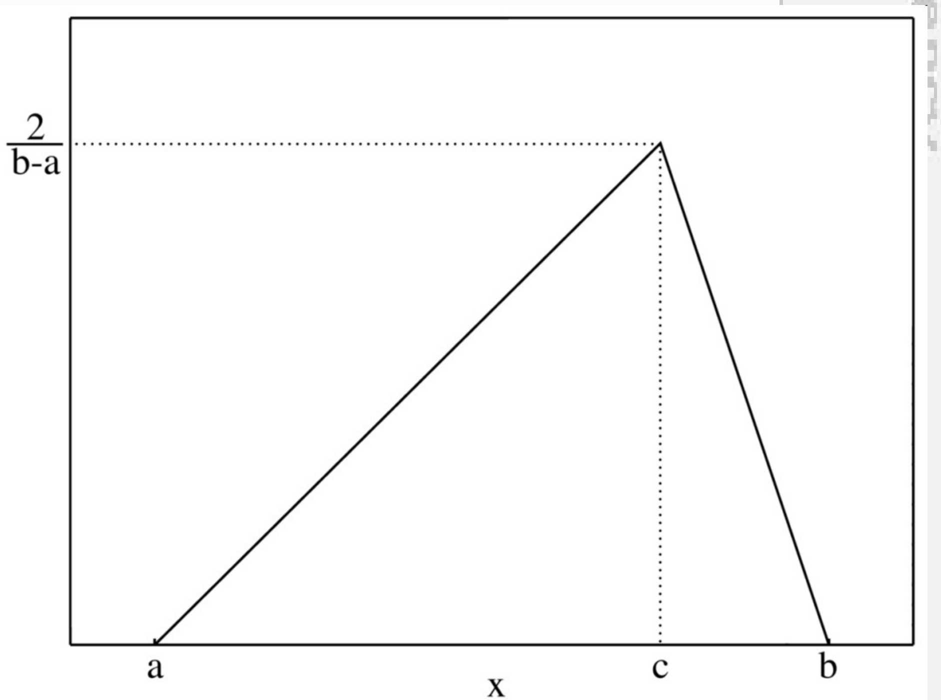
TYPE A: "[…] probability distribution function derived from an observed frecuency […]"

TYPE B: "[…] probability distribution function assumed[…]". Usually based in a set of reliable informations.

TYPE



TYPE B



Components of the uncertainty

- Measurements
- Models (approach, simplification of the reality)
  - Specification of the problem and definition of the scenario
  - Formulation of the conceptual model
  - Formulation of the mathematical model
  - Estimation of parameter values
  - Formulation of the computer code
- Modeller
- Parameters

Natural background - must be considered in NORM

METHODS

Uncertainty propagation

Fuzzy logic

Bayessian

Montecarlo

...

Should incorporate every component

Usually is possible to incorporate spatial and temporal variability

MONTECARLO

The method is based in the random generation of numbers under a preknown probability density function (pdf).

The basis for the pdf generation is the uniform U(0,1) pdf

$$U(x) = 0 \qquad \text{if } \; x < 0$$

$$U(x) = \frac{1}{1-0} \qquad \text{if } \; 0 \le x \le 1$$

$$U(x) = 0 \qquad \text{if } \; x > 1$$

MONTECARLO

There exists multiple routines for U(0,1) generation. Ex:

J. Carlson

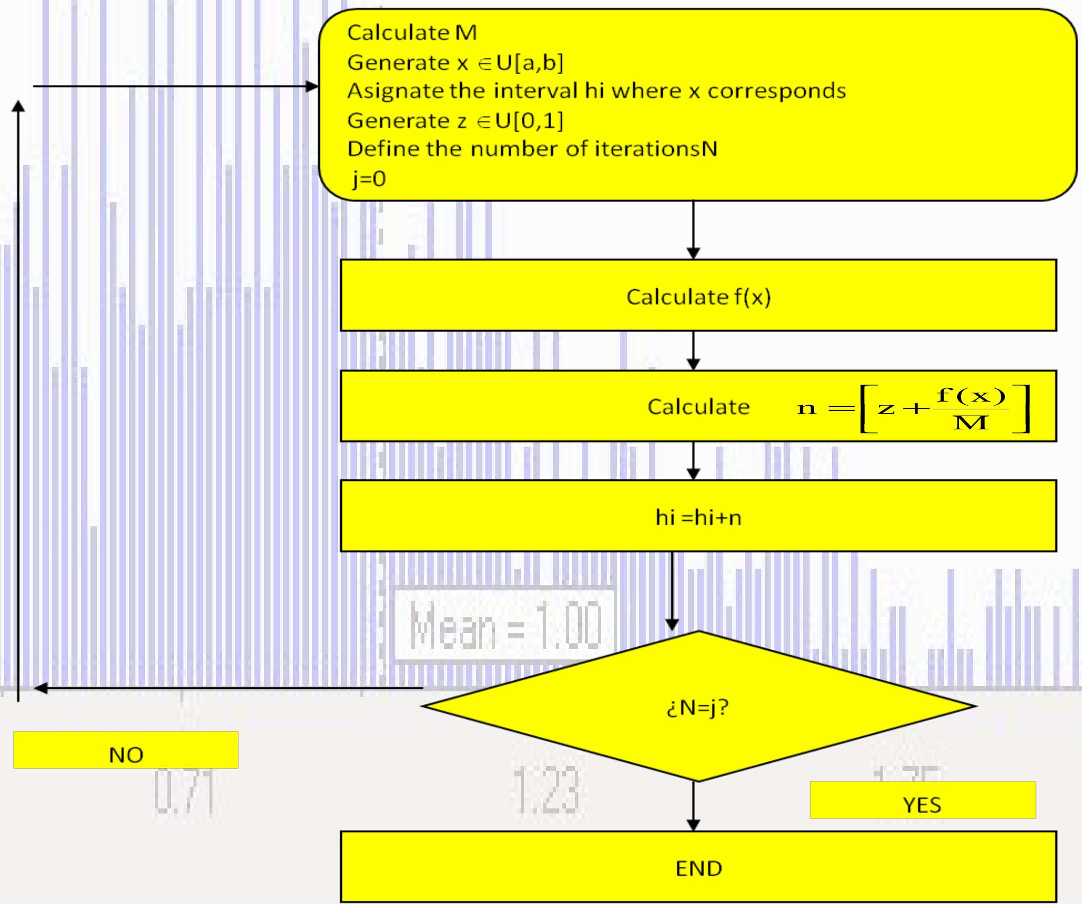
$$y_k \leftarrow (y_k + y_{k+31}) \bmod 2^{47}$$

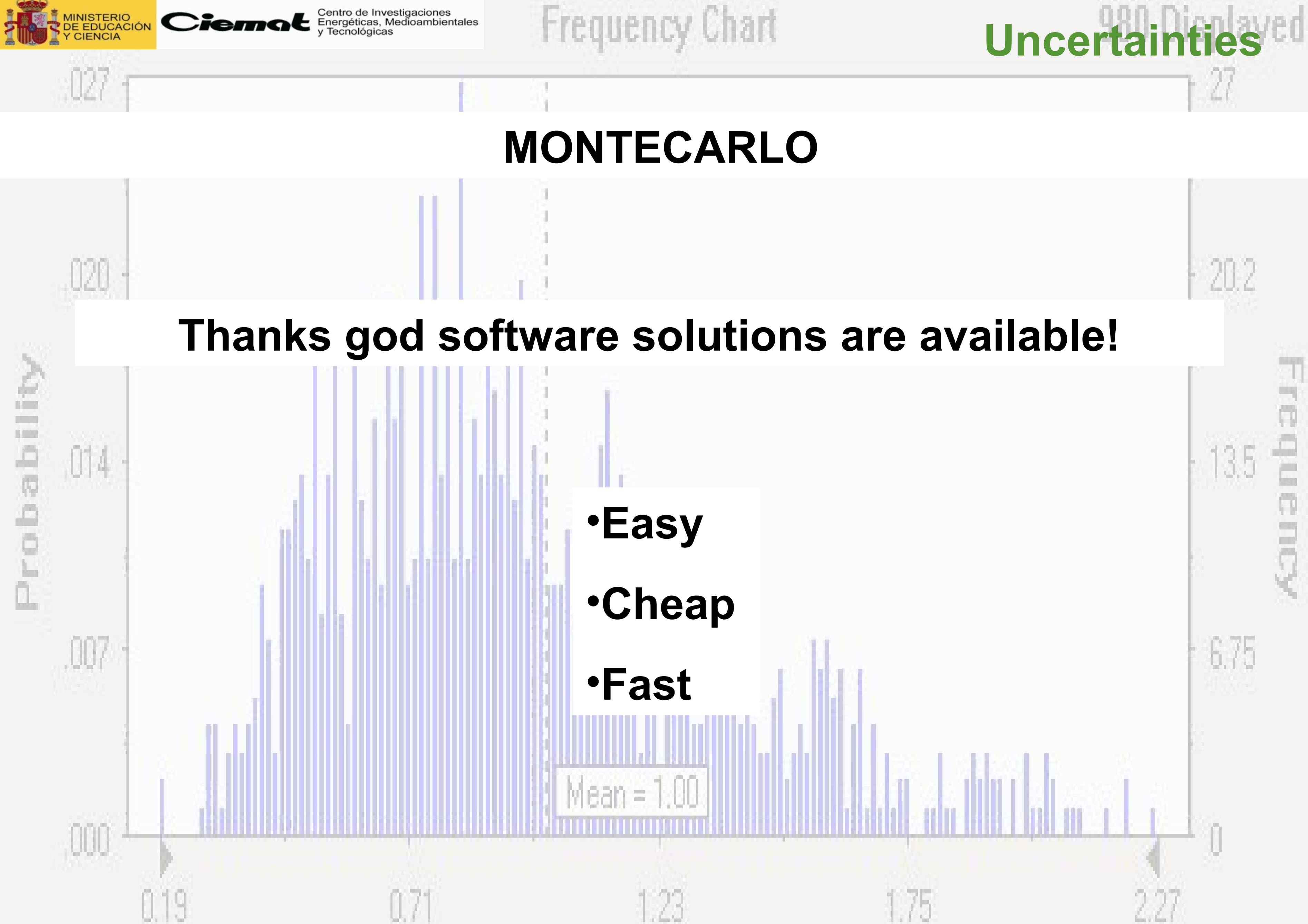
$$y_k = 16805 \cdot y_{k-1} \bmod 2^{23}$$

$k \in [1,55]$

MONTECARLO

Several numerical techniques allows the creation of a lot of other pdf. Modified Von neumann method:



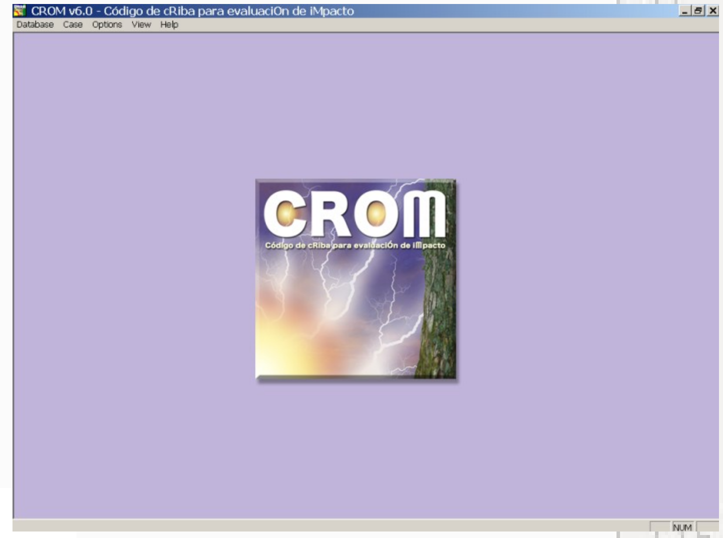


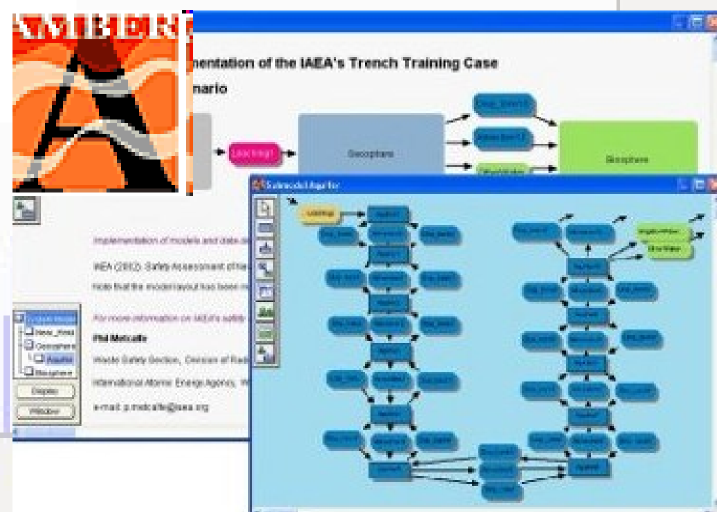
MONTECARLO

Thanks god software solutions are available!

- Easy
- Cheap
- Fast

Uncertainties





Uncertainties in NORM

Example of uncertainties in NORM:

Coal-fired power plants

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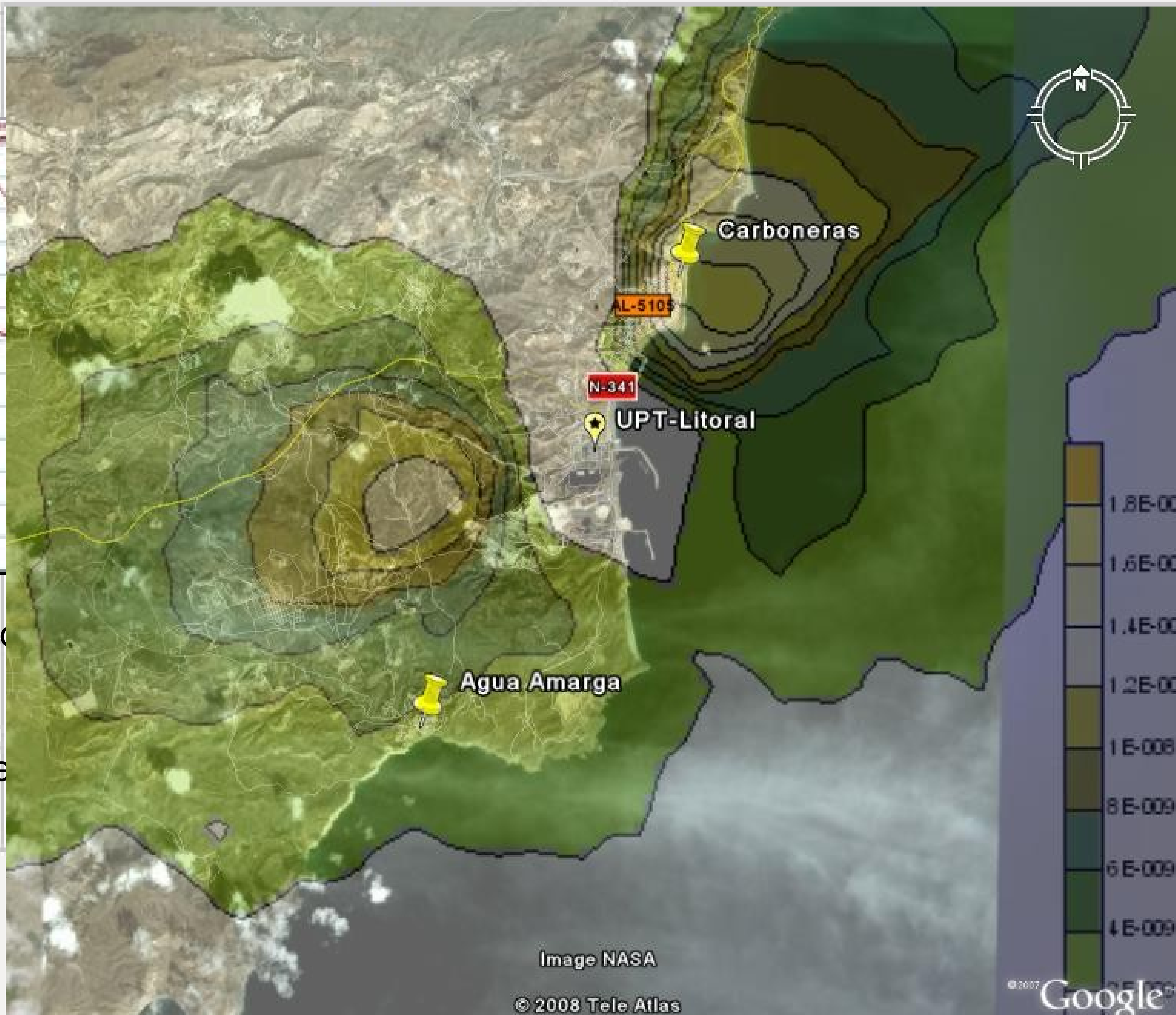
Uncertainties in NORM

Frequency Chart 980 Displayed

Continu

Validity:

Possible



(x, − y,z)

(x, − y,0)

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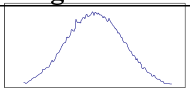
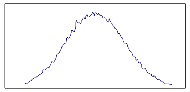
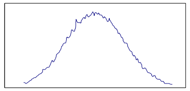
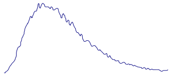
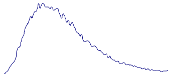
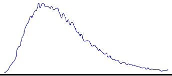
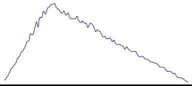
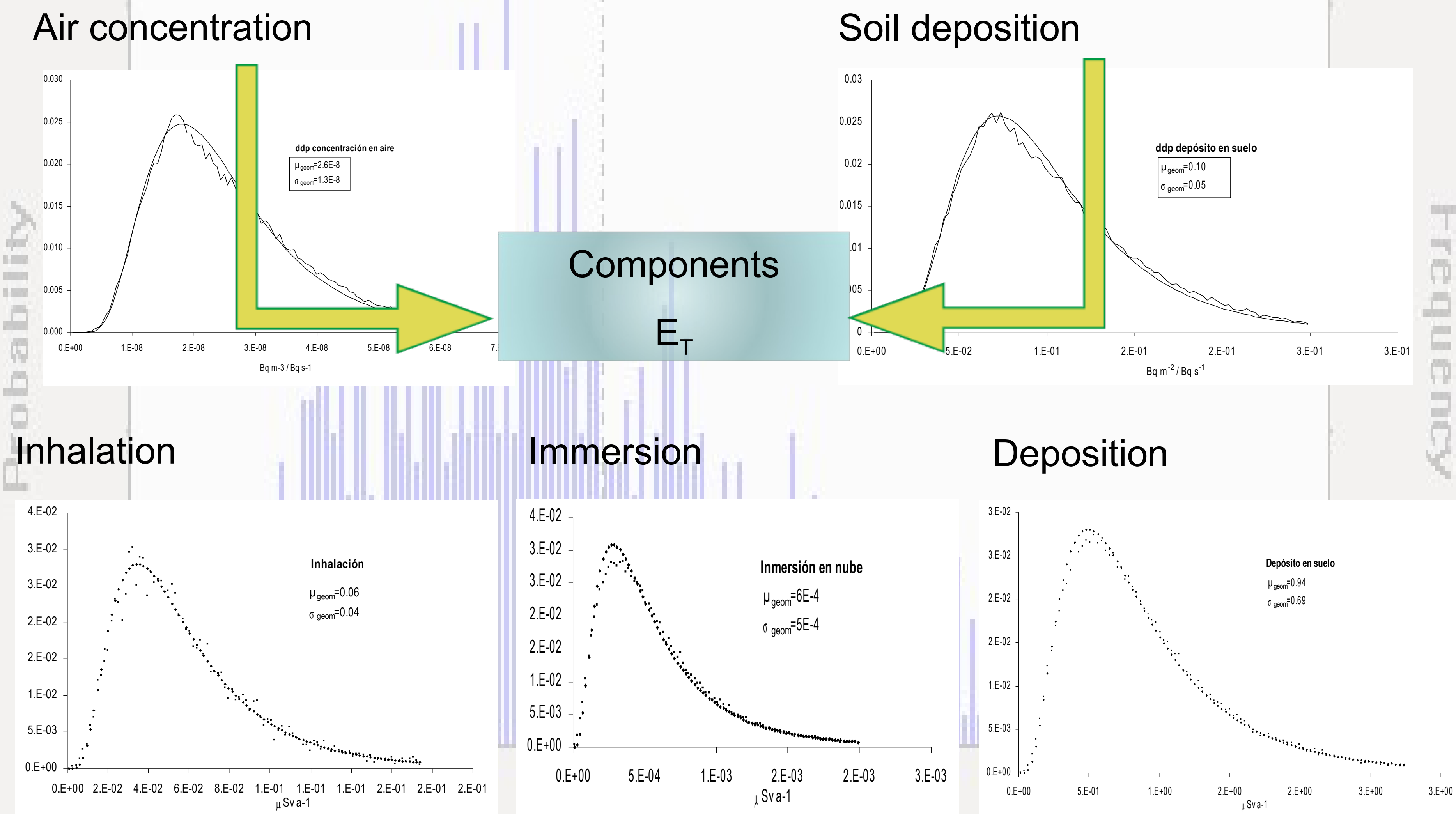
Uncertainties in NORM

Parámetro (unidad)	Distribución típica	Representación gráfica	Media (μ)	Desv. Est. (σ)	
Altura física de la chimenea (m)	Normal		200	$7 \cdot 10^{-2}$	
Diámetro de la chimenea en su salida (m)	Normal		9.4	$3 \cdot 10^{-3}$	
Tiempo de exposición del individuo (h)	Normal		7300	1800	
			Media geom. μ_{geom}	**desv. est. g.(σ_{geom})**	
Temperatura ambiente (K)	Lognormal		287	10	
Velocidad promedio del viento ($m\ s^{-1}$)	Lognormal		9	5	
Concentración vertida por radioisótopo ($Bq\ s^{-1}$)	Lognormal		Datos en tabla 1		
			Lim. Inf.	**Lim. Sup.**	
Distancia de la chimenea al individuo (m)	Uniforme		4650	5250	
			Lim. Inf.	**moda**	**Lim. Sup.**
Tasa de inhalación ($m^3\ a^{-1}$)	Triangular		2600	8300	20000
Sin variaciones					
Temperatura de salida del gas (K)			360		
Probabilidad de que el viento sople en la dirección del individuo			0.16		
Velocidad de depósito ($m\ s^{-1}$)			0.012		
Velocidad de salida del gas ($m\ s^{-1}$)			2.3		
Factores de conversión a dosis ($Sv\ Bq^{-1}$, $Sv\ m^3\ Bq^{-1}$, $Sv\ m^2\ Bq^{-1}$)			Datos en tabla 1		

Uncertainties in NORM



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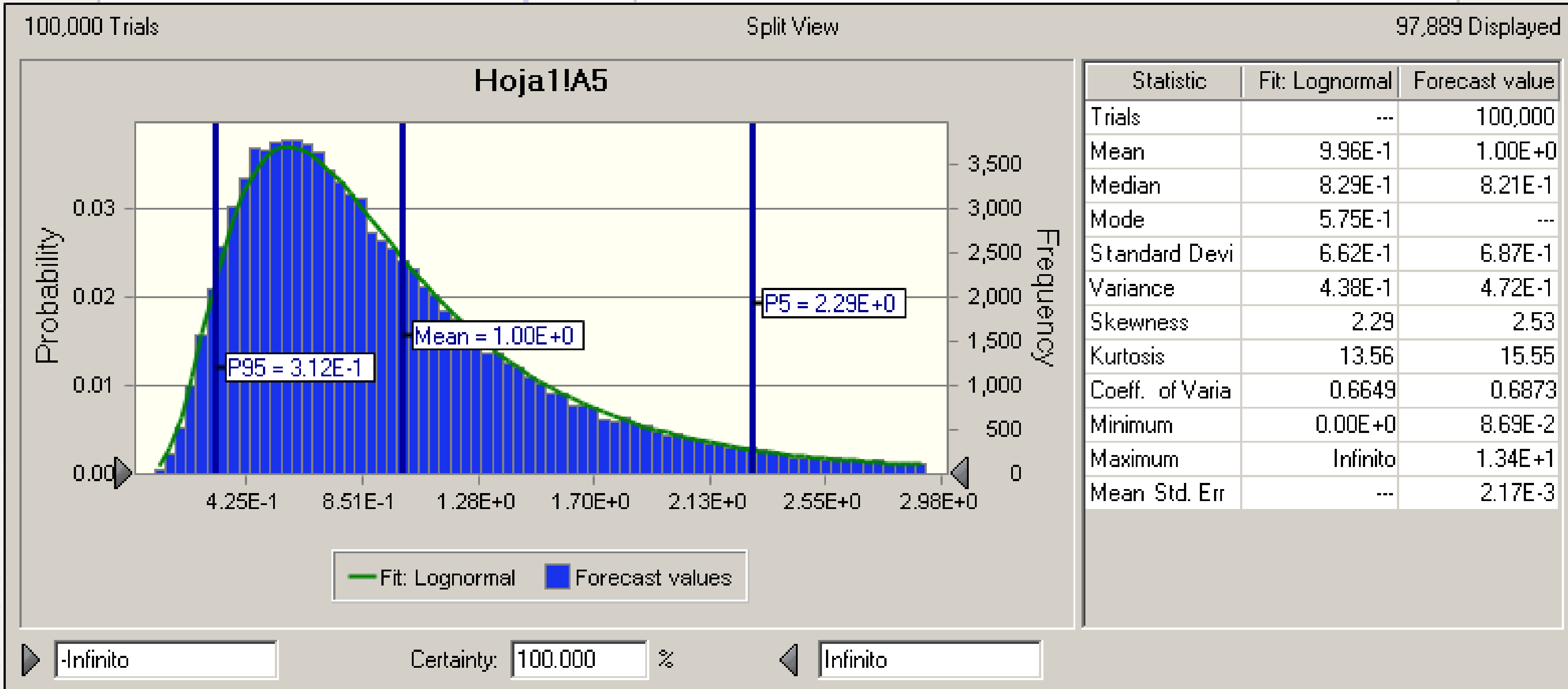
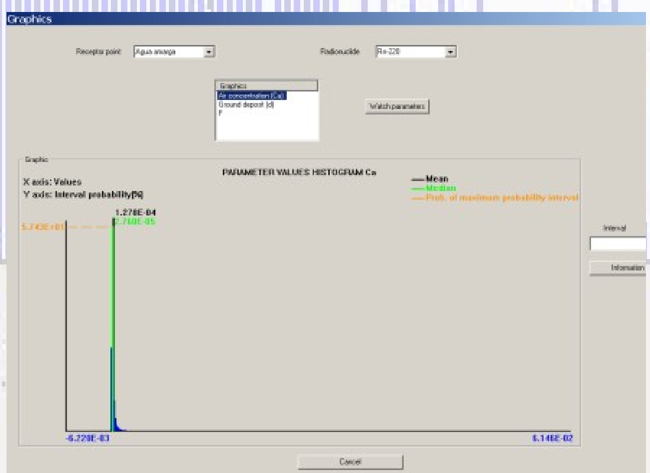
Uncertainties in NORM





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Other NORM industries

One of the main problems in NORM are the big amount of residues that are produced.

The main pathways in those cases are:

- **External exposure due to the materials**
- **Internal due to the inhalation of the resuspended material**
- **Inhalation of radon**

Other NORM industries

And so the main uncertainties will come from:

- Time of exposure
- Resuspension factor (mass loading factor)
- Ingested amount
- Radon exhalation rate
- Spatial and temporal variability

Other NORM industries

The uncertainty due to the model can be estimated as the difference of results from different models.

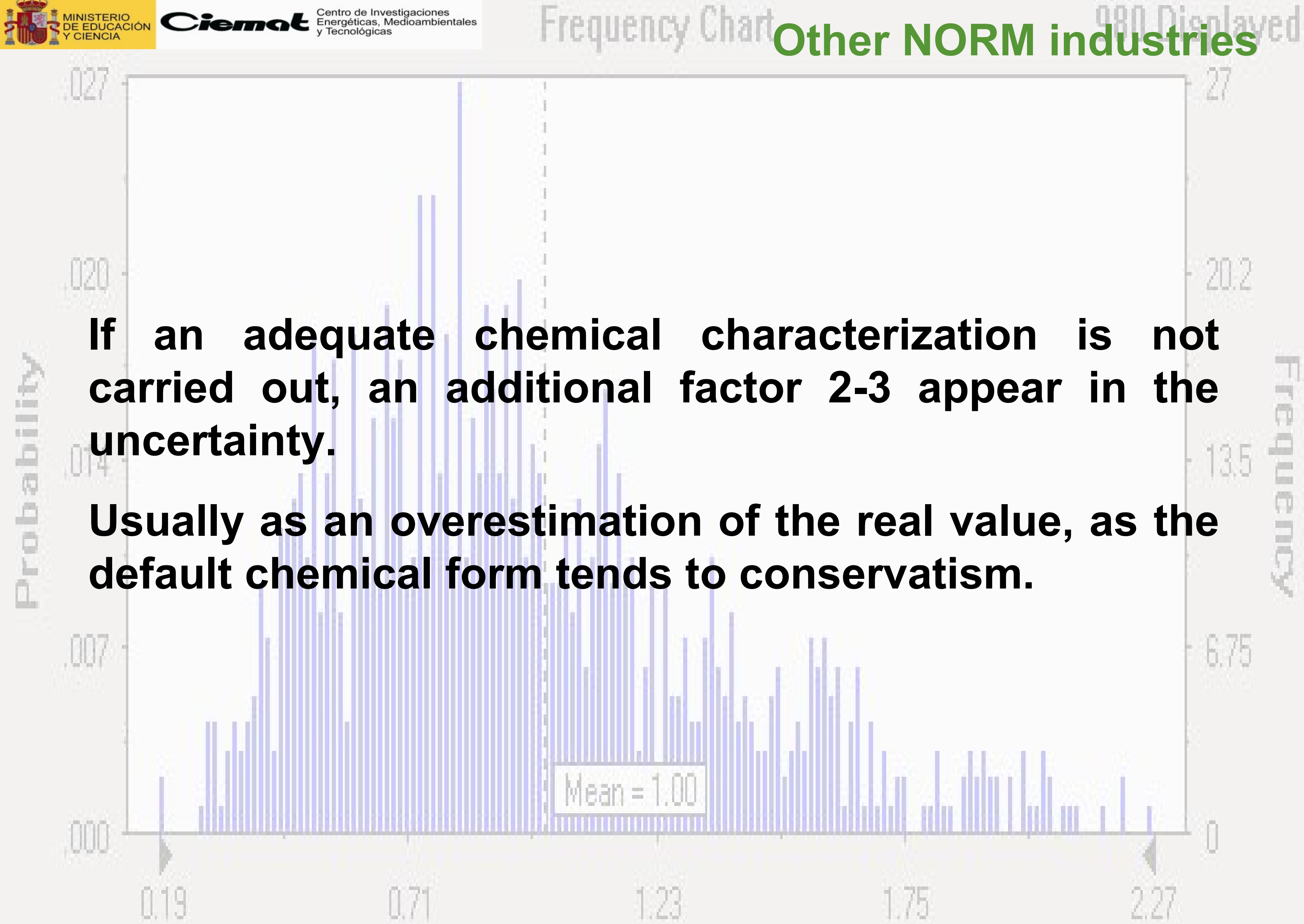
That value should be incorporated to the final uncertainty

Other NORM industries

The use of materials from different locations will appear as a temporal variability in the activity concentration of the raw materials.

This component can represent several orders of magnitude.

Other NORM industries



If an adequate chemical characterization is not carried out, an additional factor 2-3 appear in the uncertainty.

Usually as an overestimation of the real value, as the default chemical form tends to conservatism.

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Conclusions

- Too conservative assessments in NORM industries might produce more harm than benefits to the society
- Comparisons between different assessments are more understandable, both for the modeller and the regulator, using uncertainties analysis

Conclusions

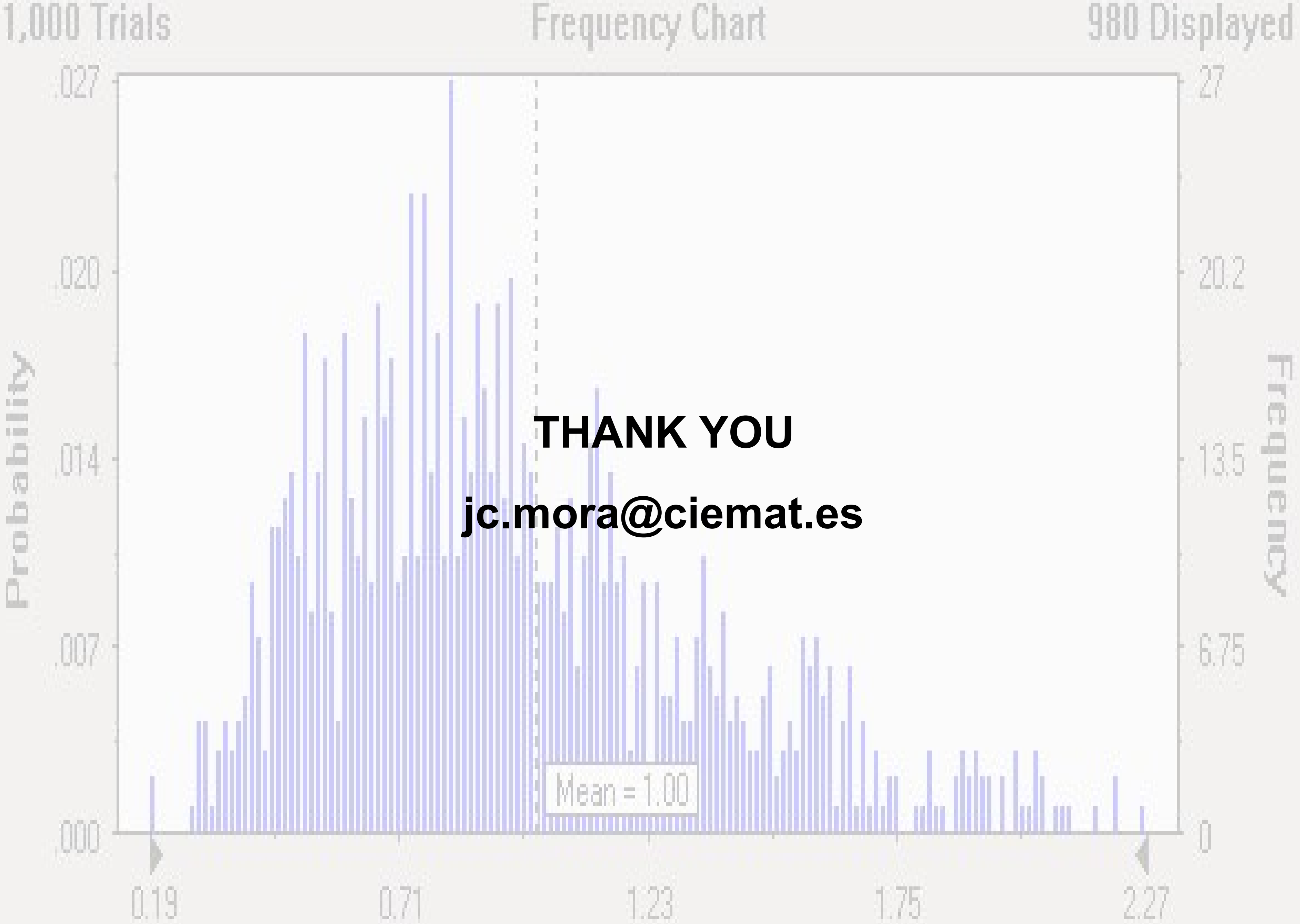
- Basic Regulations on Radiation Protection which regulate nuclear installations will also regulate NORM industries.
- Confidence levels for the results must be a-priori defined (95%, 99%?) by the regulatory authority
- New results will assure that dose constraints are not surpassed within the confidence level

Conclusions

- The uncertainties of some parameters usually not considered can be easily implemented:
  - Ocupancy times
  - Different places for occupancy
  - Consumption habits
  - Inhalation rates

Conclusions

- ➢ Some uncertainties that has never been faced, are now been under consideration:
  - ➢ Epidemiological studies
  - ➢ LNT model
  - ➢ Dose Conversion Factors (variability in persons)
  - ➢ Weighting factors
- ➢ New results will assure that dose constraints are not



THANK YOU

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