Assessment of Radiation Exposures—Modelling versus Measurement and Associated Uncertainties

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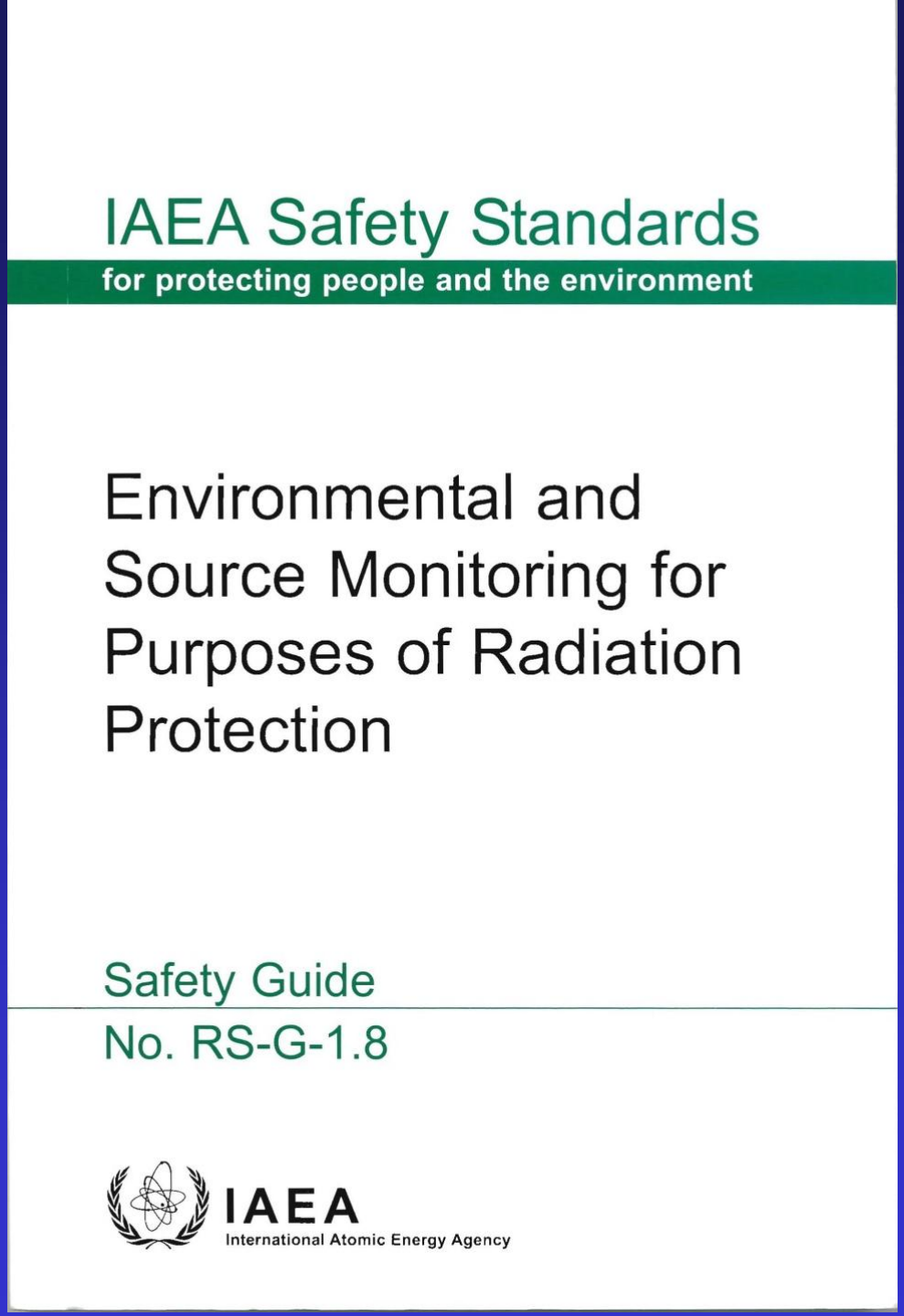
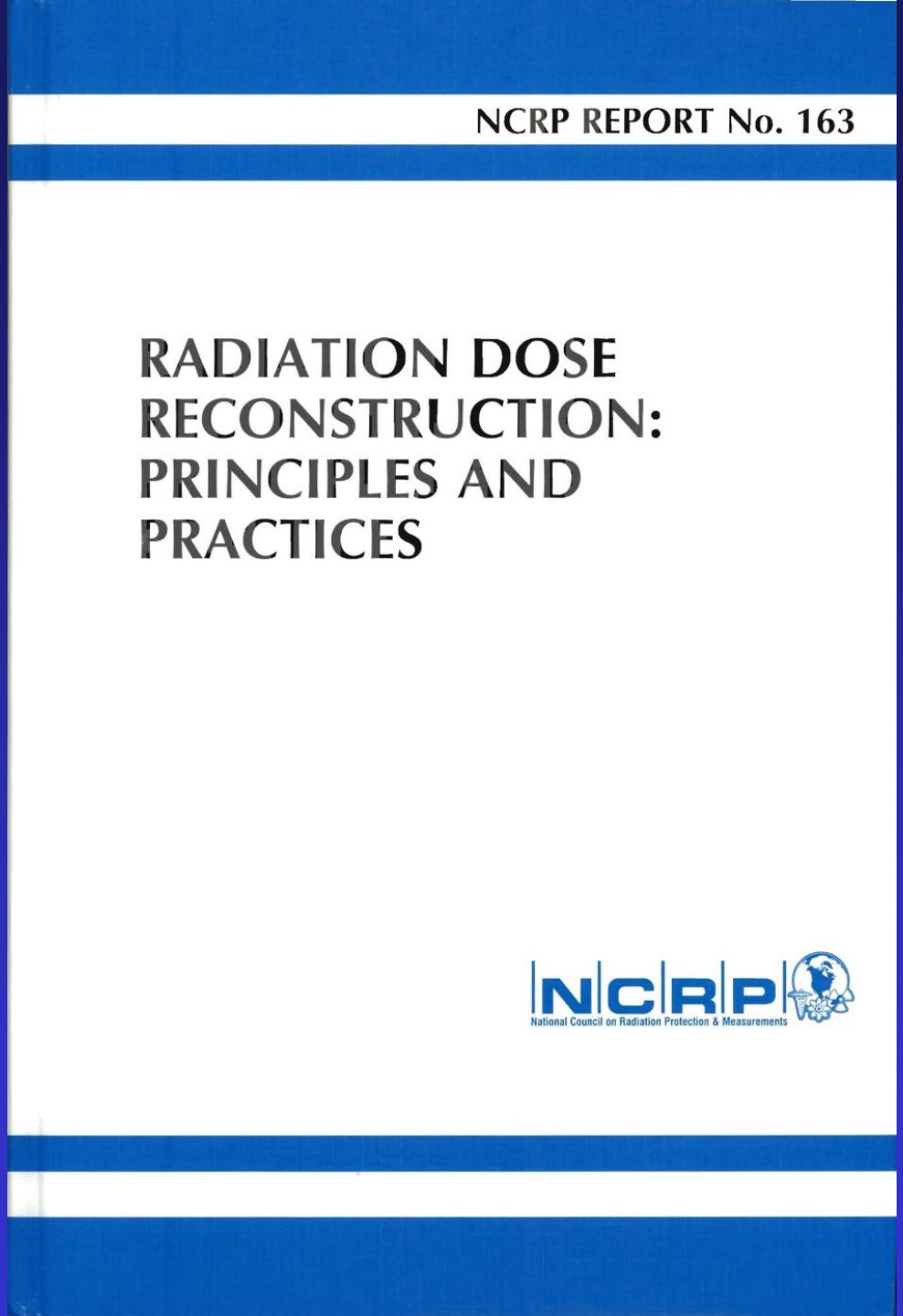


This 2005 publication contains useful information about monitoring and dose assessment under emergency conditions.



This 2009 publication is a good reference on all aspects of dose reconstruction, including evaluation of uncertainty.

Why are exposure assessments undertaken?

- Predictive—for radiation protection
- Retrospective
  - Large releases presumed to have had a biological effect
  - Revelation of formerly classified data
  - Social justice
  - Derivation of risk factors
  - Compensation programs

Exposure assessments can have very different scopes.

- Number of persons—single individual to global population
- Geography—small local area to the entire globe
- Time—forecast or years after exposure

Conclusion No. 1

It is not possible to say there is “a correct method” to assess radiation exposure.

Can radiation dose in humans be measured?

- Strictly speaking, the answer is no.
- The best that can be done is to make measurements that can be related to dose.
- It is always necessary to employ some kind of a model to convert measurements to doses.
- The uncertainty varies dramatically among the different types of models.

It is important to evaluate all pathways, and then focus on the more important.

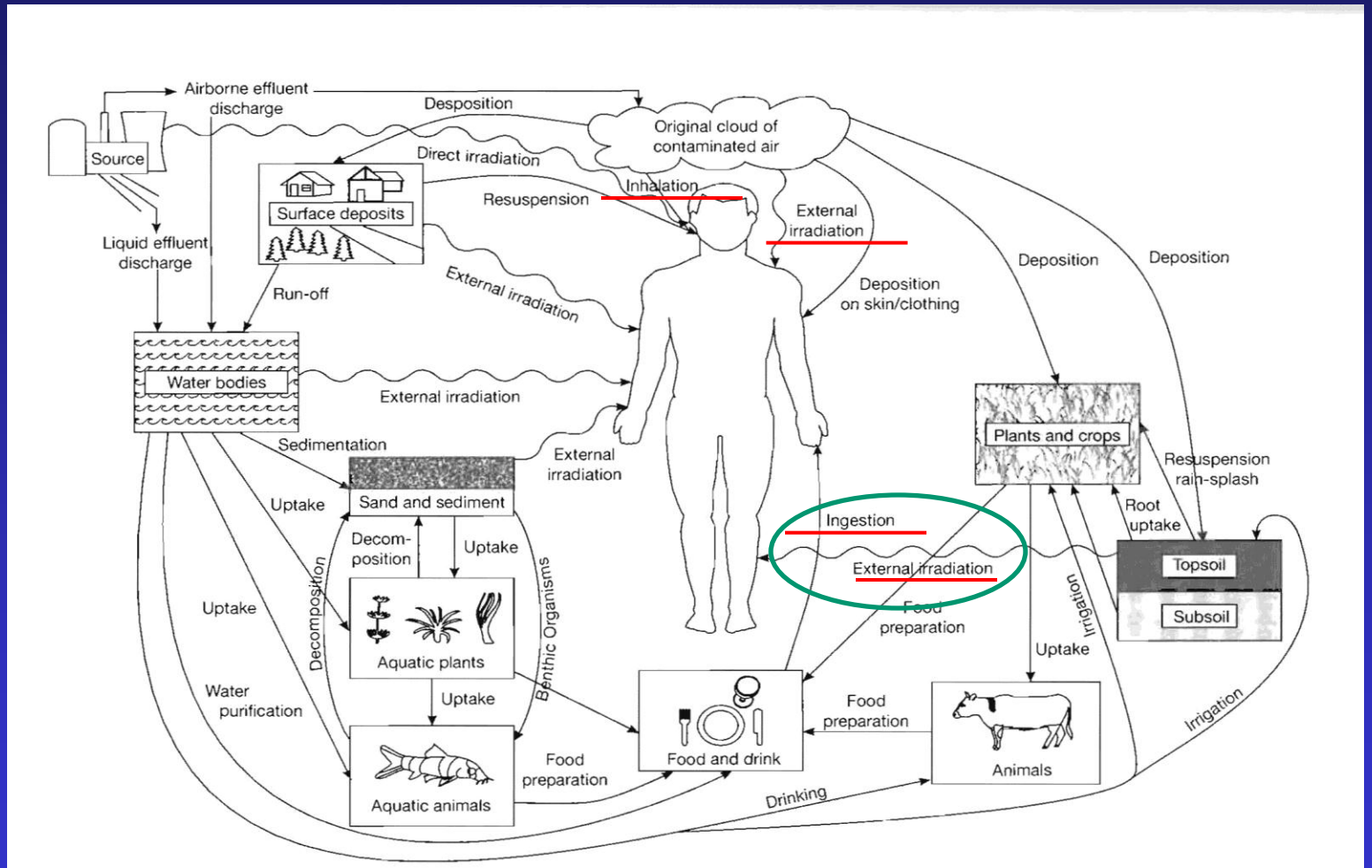


FIG. 1. The possible pathways of exposure for members of the public as a result of discharges of radioactive material to the environment.

IAEA Safety Guide No. RS-G-1.8 (2005)

Measurements are of high priority.

- ***If,*** **they are appropriate to support a dose reconstruction for the population of interest.**
- ***If,*** **they are of sufficient coverage for the area of interest.**

It is almost always the case that one or more models must be used to transform measurements into estimates of dose.

Some useful thoughts from George E.P. Box about models

- **Essentially, all models are wrong, but some are useful.**
- **Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful.**
- **Since all models are wrong the scientist cannot obtain a "correct" one by excessive elaboration…overelaboration and overparameterisation is often the mark of mediocrity.**

(http://en.wikiquote.org/wiki/George_E._P._Box)

Hierarchy of methods of dose reconstruction

- Individual biologic analysis
- Dosimetry of materials in homes—like thermal or optical luminescence of quartz extracted from bricks or porcelain
- Analysis of environmental residues
- Reconstruction of releases, plus atmospheric transport models
- Rule of thumb factors

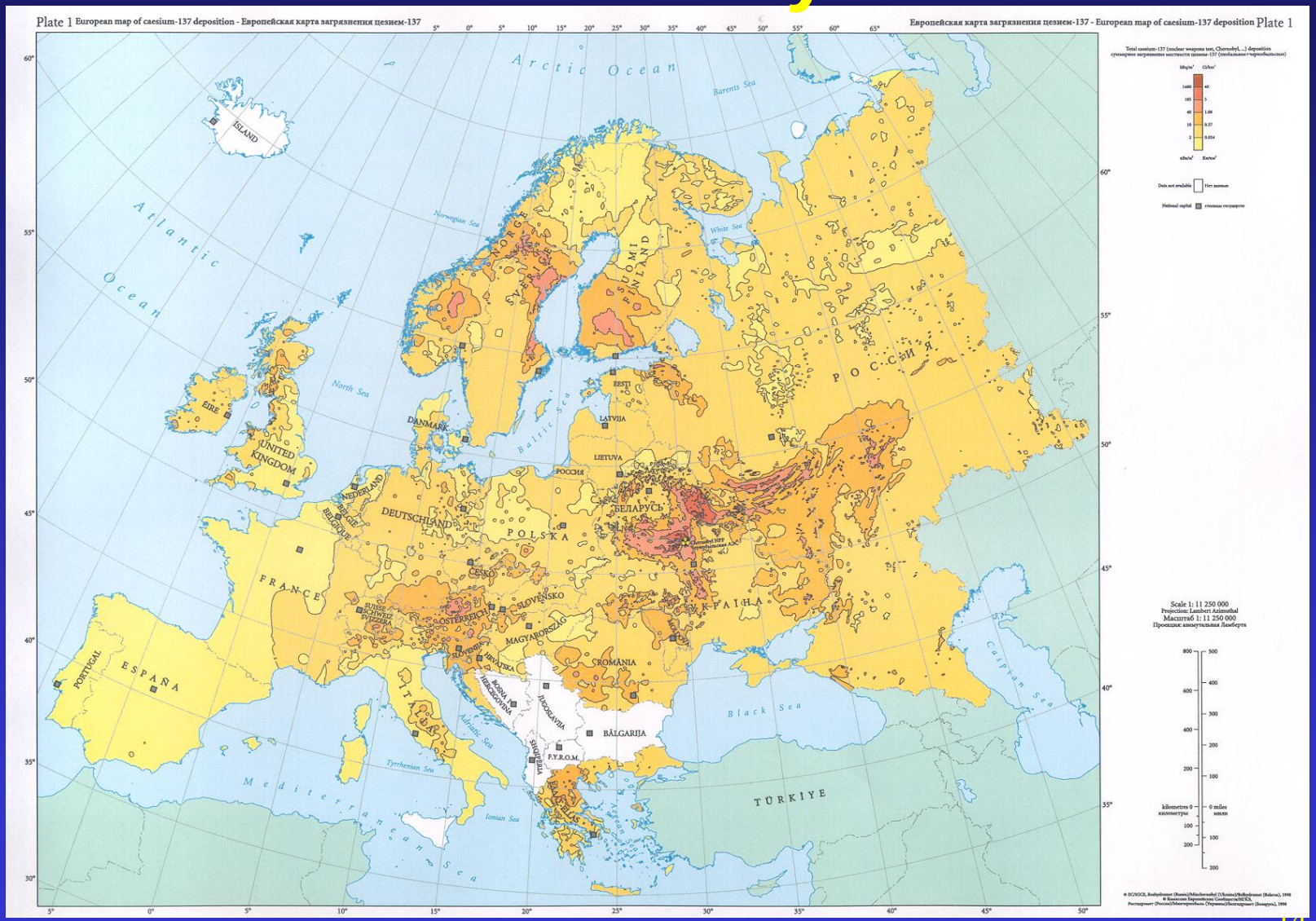
Individual biologic analysis

- Differential blood counts
- Chromosome analysis (dicentric or transformation) of circulating lymphocytes
- Electron paramagnetic resonance of teeth
- Measurement of dose rate over the thyroid
- Whole body counting for some materials that remain in the body for a long time
- Analysis of tissues collected at autopsy or exhumation

Analysis of environmental residues

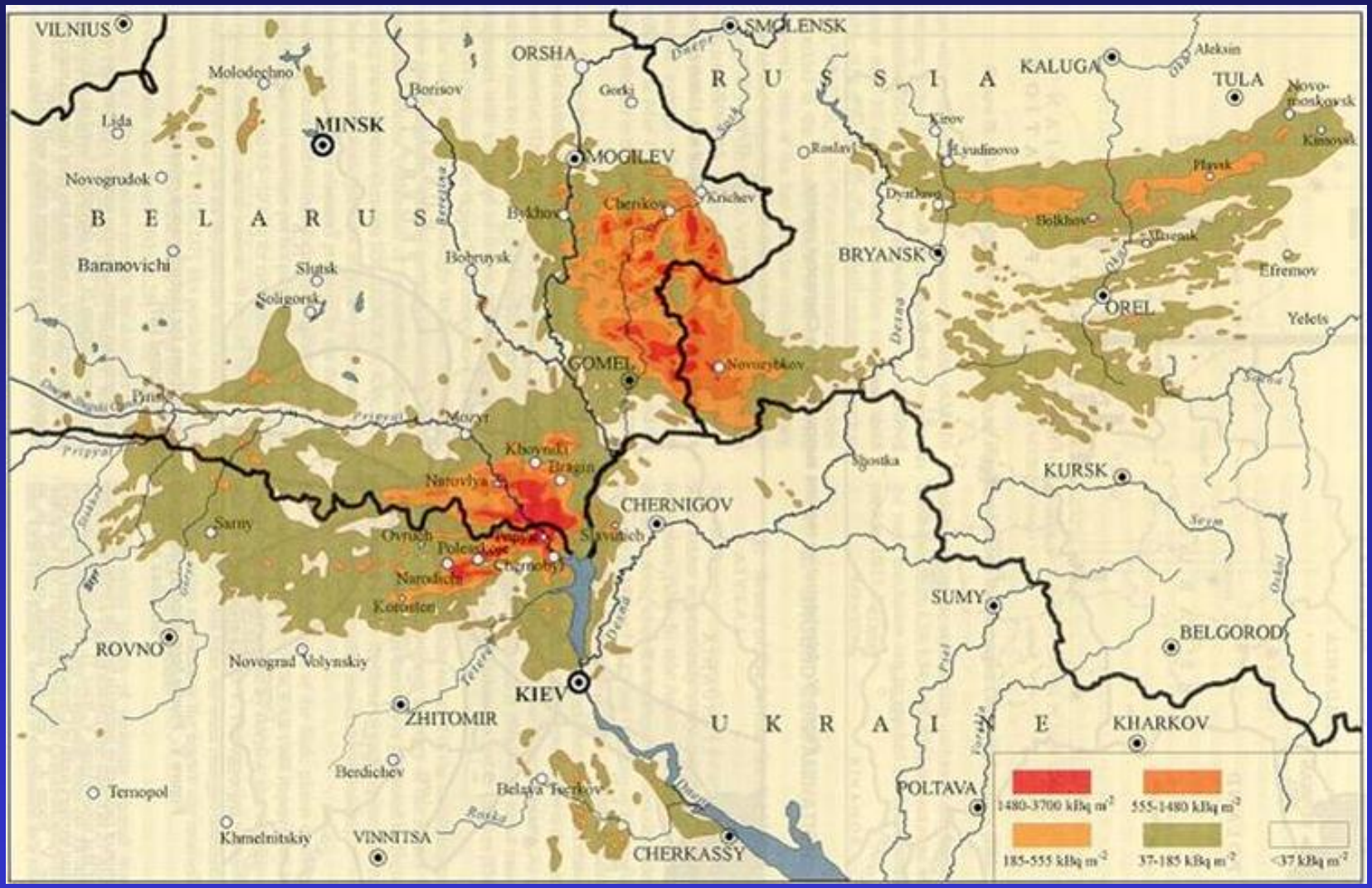
- Current or historical measurements of external gamma-exposure rate
- Deposition densities, historical or current data
  - Short-lived radionuclides (may be historical only)
  - ^{90}Sr
  - ^{129}I—Very long lived, measure by accelerator mass spectrometry
  - ^{137}Cs
  - $^{239+240}Pu$, plus the ratio of ^{240}Pu-to-^{239}Pu

Ground deposition of ^{137}Cs from Chernobyl



De Cort et al. (1998)

Close-in ground deposition of ^{137}Cs



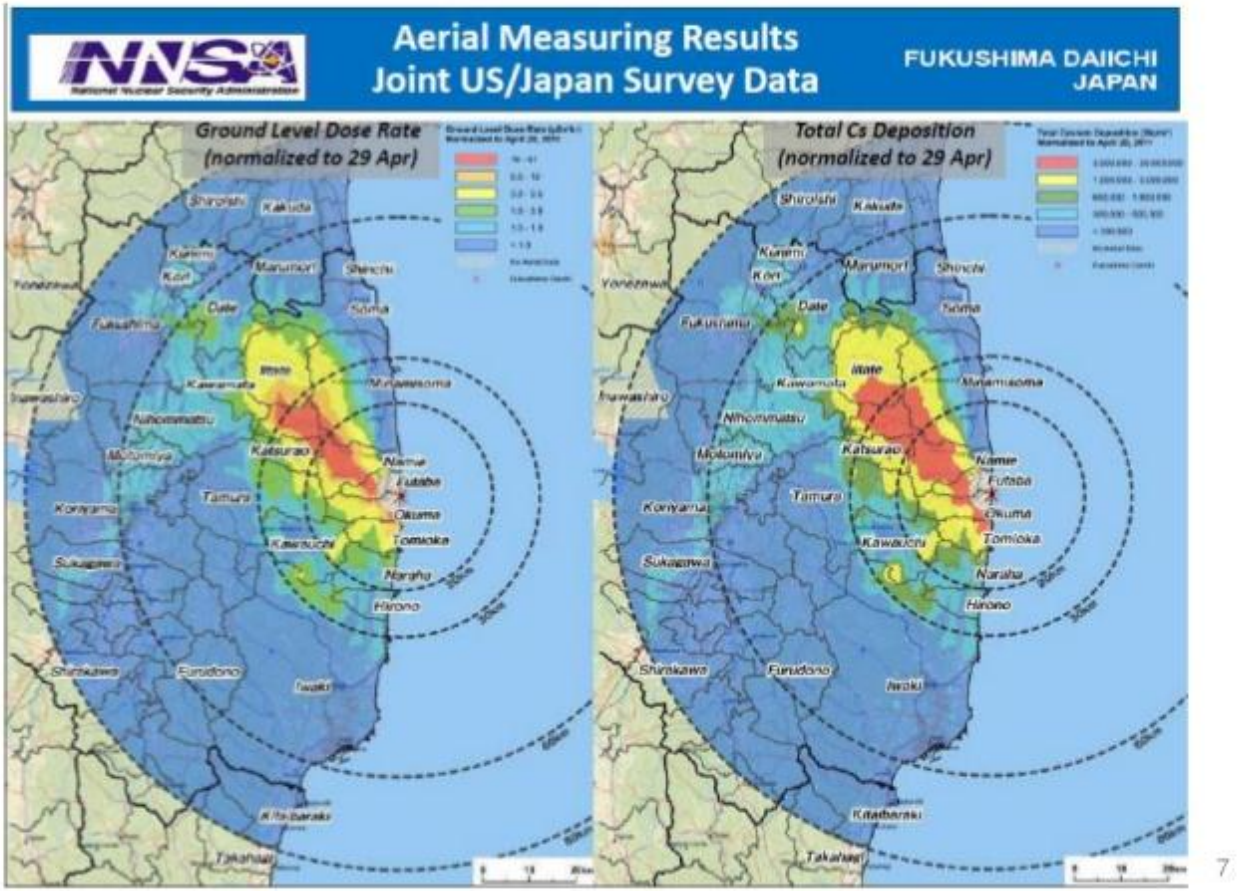
International Chernobyl Advisory Committee (IAEA 1991) based on Izrael (1990)

An example of more recent airborne survey results

U.S. DEPARTMENT OF ENERGY

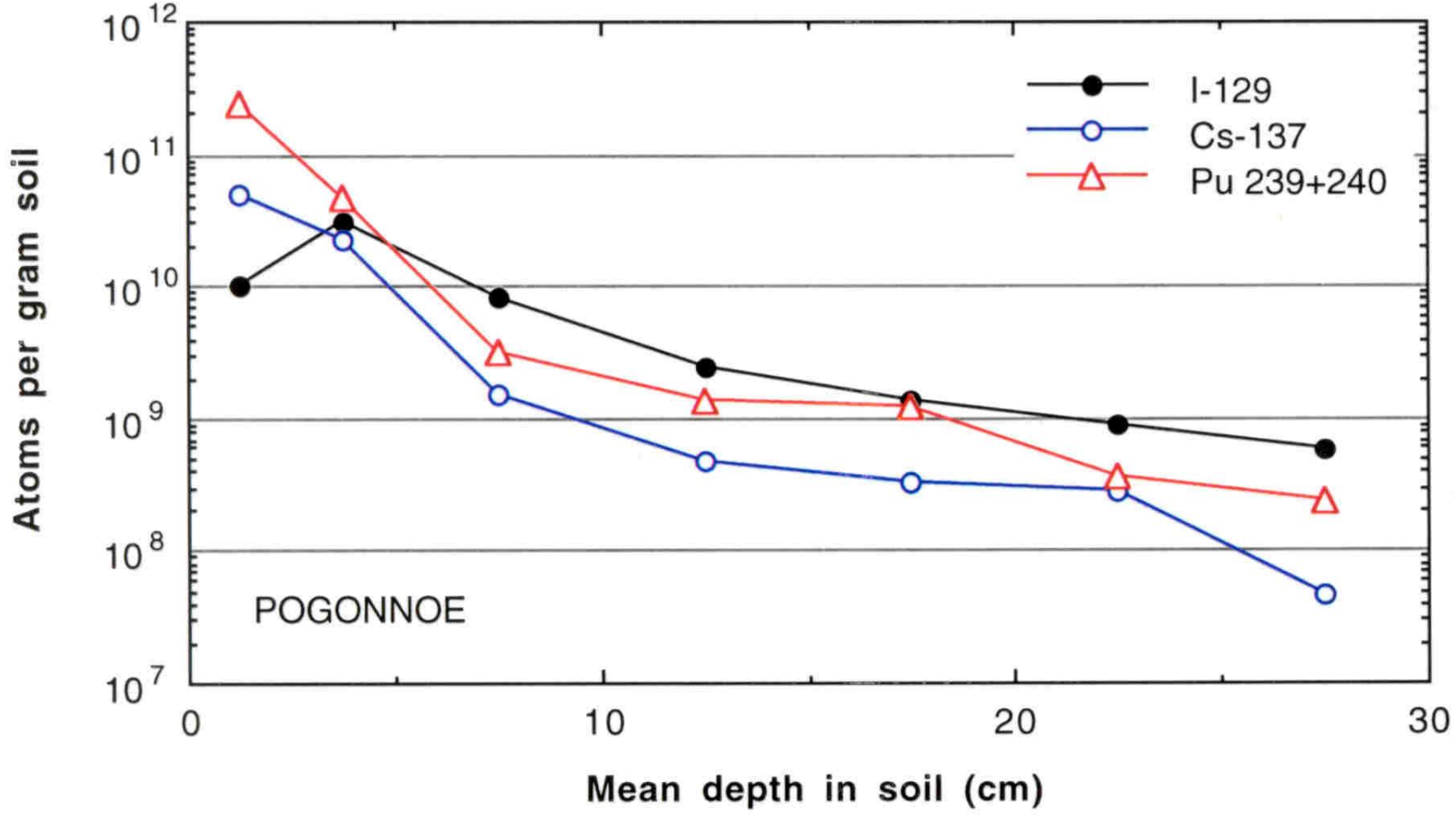
NNSA

Joint US-Japan AMS Data



http://energy.gov/situation-japan-updated-12513

An example of the analysis of environmental residues



From Straume et al. *Stem Cells* 15(Suppl):183-193; 1997.

Behaviour of deposited radionuclides

- Radionuclides deposited on virgin land or lawns will stay there, but will migrate slowly into deeper layers of soil.
- Radionuclides deposited on other surfaces (roofs, asphalt, trees, bushes, etc.) tend to weather away. A large fraction of deposited radionuclides in urban areas ends up in storm drains.

The important pathway for radioiodines is

- Direct deposition on food to be consumed by milk-producing animals or by humans.
- The half lives of radioiodines are too short for uptake from soil to plants to occur in a significant way. Radioiodines are a major concern only during early periods.
- Milk-producing animals concentrate radioiodines in milk and humans concentrate radioiodines in the thyroid.

The pathways of radiocaesiums are more complicated.

- Direct deposition on forage to be consumed by milk- or meat-producing animals is important, as for radioiodines.
- The uptake by plants from soil is also important. This leads to long-term contamination of
  - Plants,
  - Milk, and
  - Meat

Forest ecosystems are unique.

- Radionuclide cycling is rather different.
- Some trees are about as sensitive to the lethal effects of radiation as are humans. (The Red Forest, for example.)
- Some plants (e.g., mushrooms and berries) are very efficient at uptake of ^{137}Cs, and this varies with season and weather.
- Animals that eat such plants can accumulate substantial amounts of ^{137}Cs.
- Wood ash can have elevated levels.

Two types of measurements are required for environmental dose reconstruction.

- The relative amounts of radionuclides released.
- and
- One of the following:
  - Normalized external gamma exposure rate, or
  - The deposition density of any one radionuclide.

The additional knowledge required is the relationship between exposure rate above ground surface for each radionuclide in the release.

Three comprehensive tabulations exist

- Beck, EML-378 (1980),
- Jacob et al., GSF-Bericht 12-90 (1990), and
- Eckerman and Ryman, EPA 402-R-93-081 (1993).

Uncertainty in dose assessment

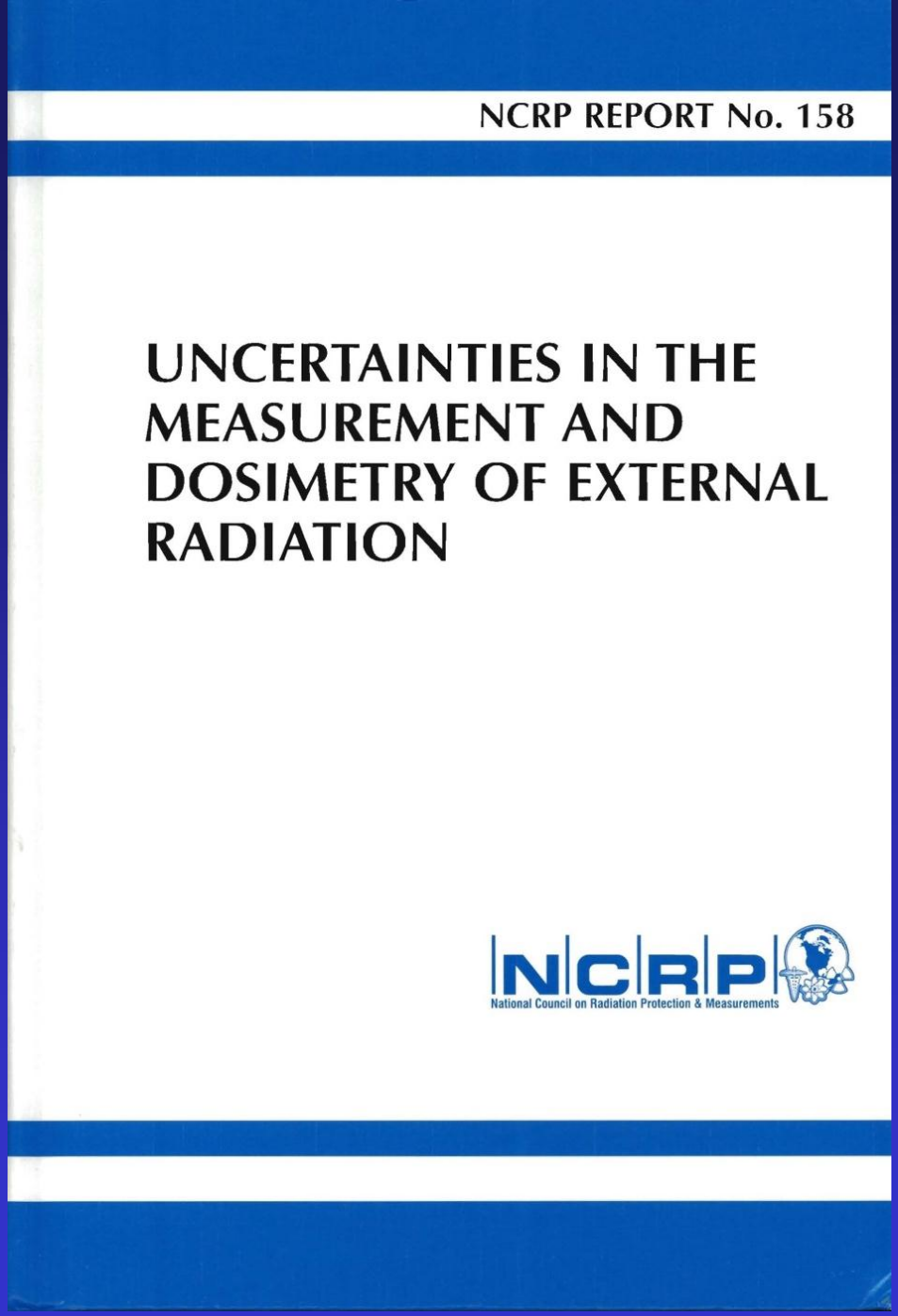
- Years ago it was common to calculate maximum doses.
- With evaluation of uncertainty, it is possible to provide a best estimate with associated levels of confidence.
- Two major types of uncertainty are
  - Systematic errors in models, and
  - Variability of various parameters.

In general uncertainty increases going down the previously indicated hierarchy.

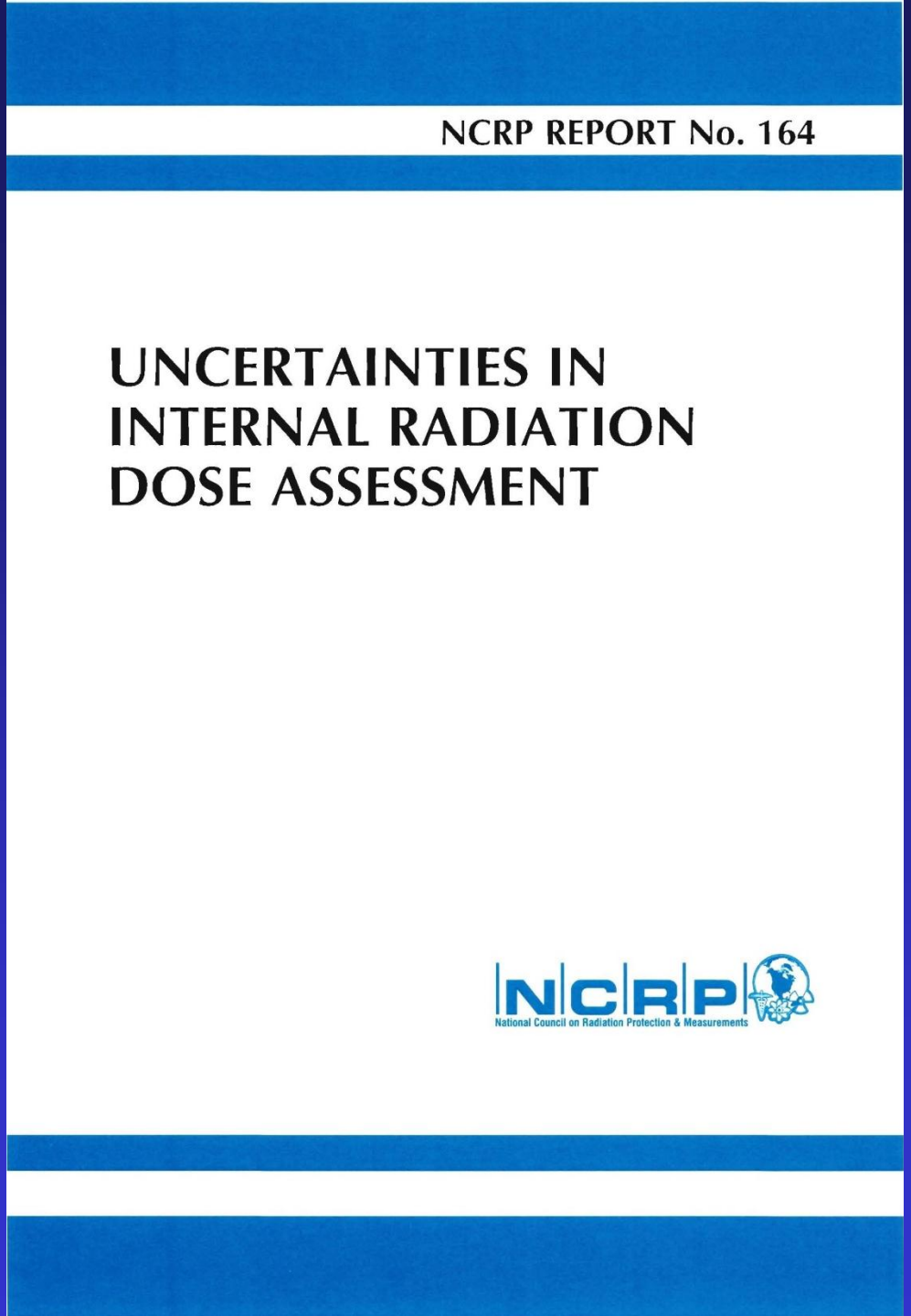
- Uncertainty can be small if based upon measurements in humans.
- Uncertainty is rarely less than a factor of two, if based upon environmental measurements.
- Uncertainty can be very large (>10), if based upon atmospheric dispersion. In this case uncertainty decreases with the length of time of release.

Evaluation of uncertainty can be very complex.

- Analytical propagation of variability is too complex, if parameters have several different types of distributions.
- A Monte Carlo simulation is usually employed to sample various distributions and combine the results into a best estimate with confidence limits.

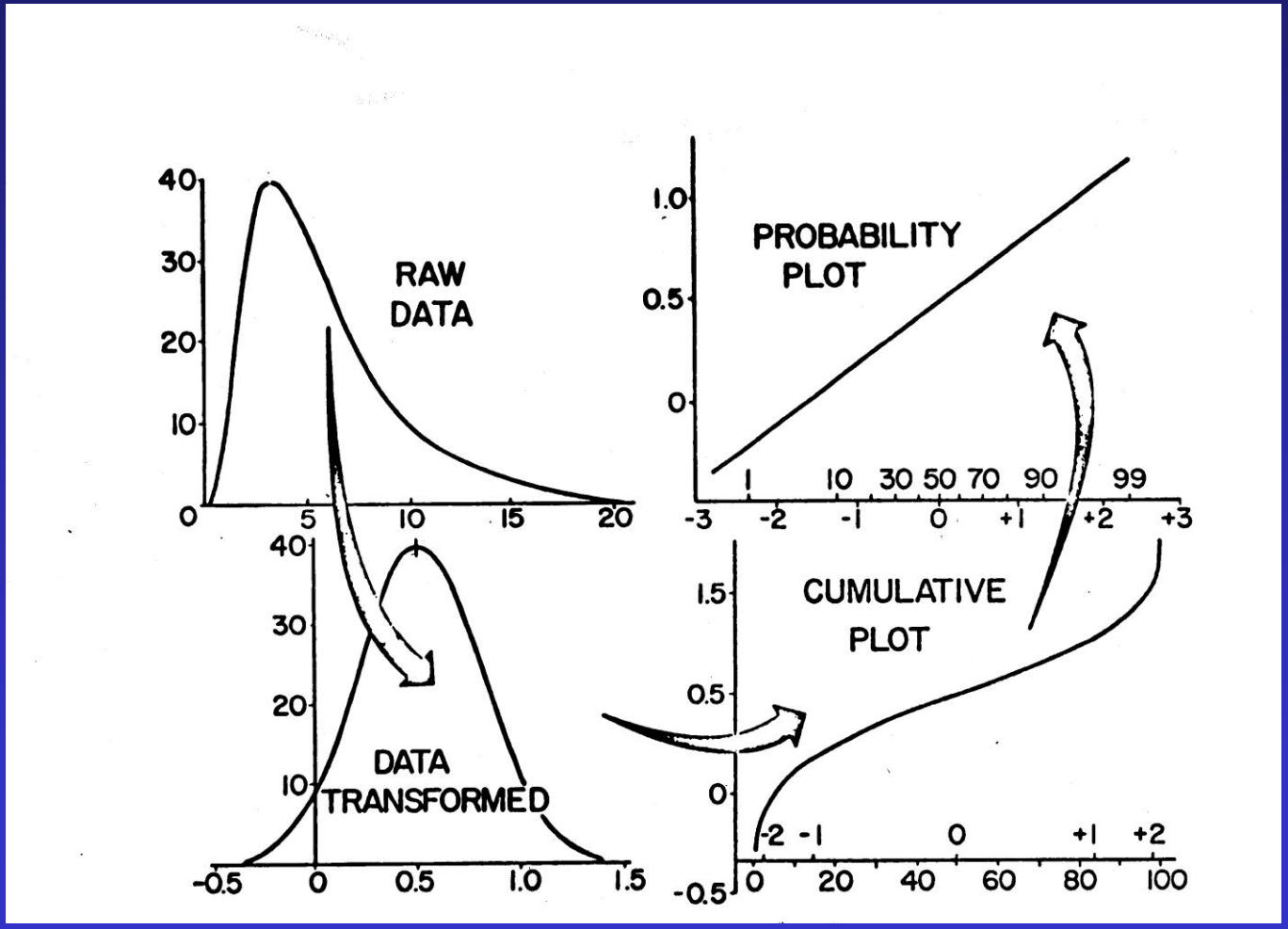


A specialized publication on uncertainty in the calculation of external dose.



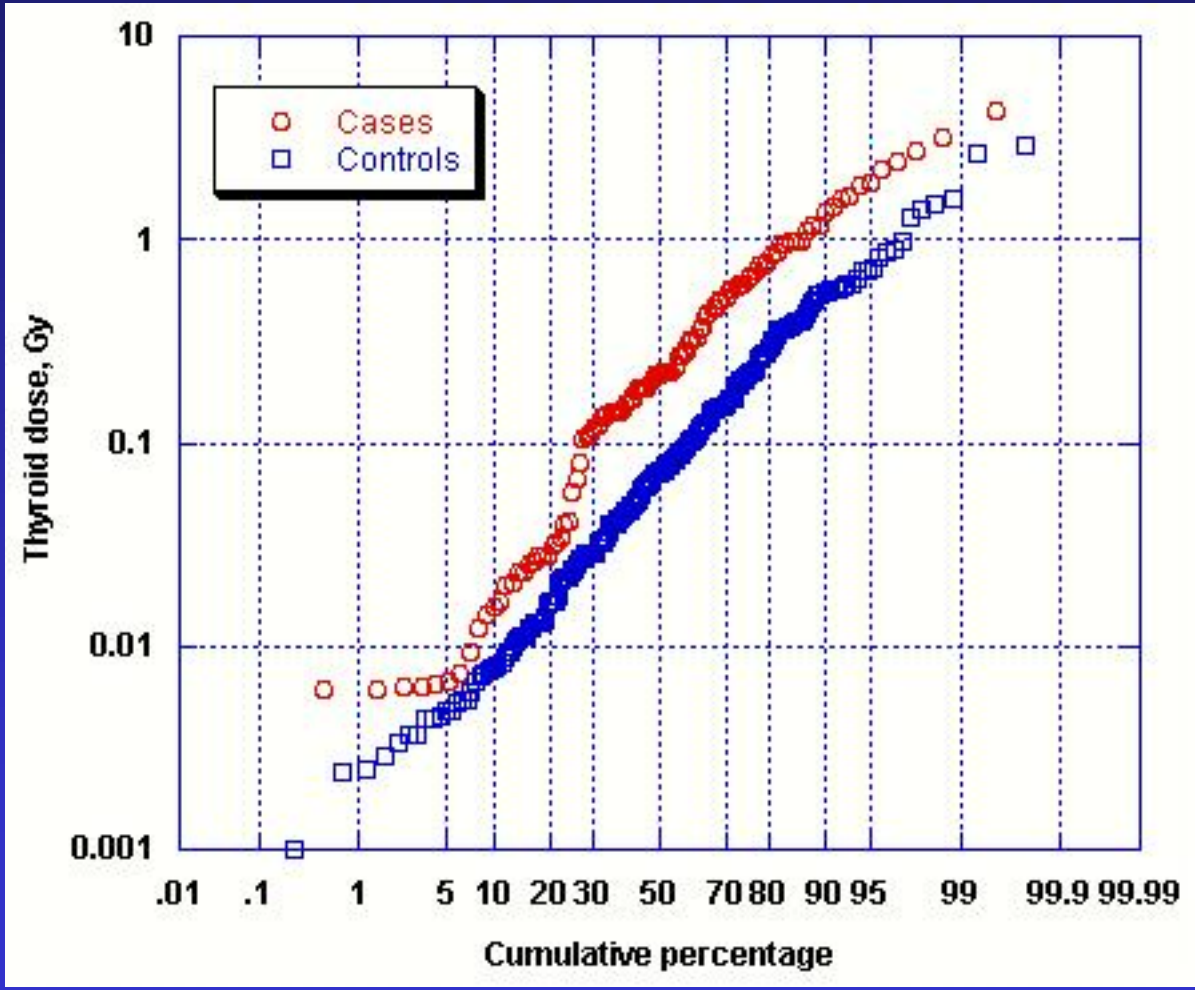
A specialized publication on the assessment of the uncertainty in the calculation of internal dose.

Many variables can be described by lognormal distributions.



From D. Michaels, Rocky Flats Plant

Case-control study of childhood-thyroid cancer in Belarus



Astakhova et al. *Radiat. Res.* 150:349-356; 1998.

Summary

- There is no single correct method to perform exposure assessment.
- Data are preferred, but they must be appropriate.
- Models are always necessary to interpret data.
- Models used without supporting data tend to produce highly uncertain results.
- It is important to provide the best estimate of dose with corresponding confidence intervals.

Thank you for your attention!

Photo courtesy of National Nuclear Security Administration / Nevada Site Office