

Know Less and Understand More

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Theme

***“Where is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?”***

T. S. Eliot 1888-1965.

Outline

- **Introduction - A Winter of Discontent?**
- **Radiological Protection (RP) – the first 100 years**
- **Hypotheses, theories, laws and models**
- **The limitations of statistical and epidemiological analysis**
- **Needs for Radiological Protection in the future**
- **Conclusion and Suggestions**

Introduction - A Winter of Discontent?

- **Previous speakers at the Stannard lecture series (and elsewhere) have noted ‘a slowing of progress’ in radiological protection over the past 50 years**
- **At first sight this is surprising in view of the large quantity of detailed information now available to many disciplines e.g. radiobiology, dosimetry, human metabolism of radionuclides, phantom modeling, radiation-transport codes etc.**

Introduction - A Winter of Discontent? (2)

- **BUT this wealth of information has not yet brought sufficient fundamental understanding necessary to provide a truly scientific basis for radiological protection**
- **Thus, at the present time, radiological protection continues to be constrained to being an empirical discipline, dependent upon judgment rather than scientific certainty**
- **Is any expressed “discontent” perhaps an expression of some impatience with the difficulty of, and time necessary for, the full understanding of the complexity of the fundamental mechanisms of radio-carcinogenesis in humans?**

Radiological Protection – the first 50 years

- **1895–mid 1930s: Scheme of radiological protection developed by empirical methods (*c.f.* toxicology)**
- **1920-1950: protection standards for external exposure fell about 50-fold**
- **By 1936, for external radiation exposures, the NCRP recommended maximum permissible level for radiation workers was 0.3 R per day.**
- **This NCRP limit for external photon-exposure (with an RBE of 10 for neutron exposure incorporated) and a body burden equivalent to 0.1 μ Ci radium were the protection standards in effect throughout the Manhattan project.**

Radiological Protection – the second 50 years

By the late 1950s the fundamental questions had been framed including:

- Dose and dose-rate dependence?**
- Thresholds or hormesis?**
- LET dependence?**
- Extrapolation from cellular and animal studies to humans? (NCRP 150)**

These questions are still open...

Radiological Protection – the second 50 years

- **1956 - Last significant change in protection standards based on theoretical grounds was made by ICRP in [Predicted genetic effects. Now believed to be unfounded.]**
- **Subsequent emphasis on carcinogenesis**
- **Introduction of many modified-absorbed dose quantities**
- **Many details worked out based on models representing judgments by ICRP, NCRP *et al.* are now available**

Hypotheses, theories, laws and models

“Theories are nets cast to catch what we call ‘the world’: to rationalize, to explain and to master it. We endeavor to make the mesh ever finer and finer.” Popper (1959)

- **The physical sciences and now, increasingly, the biological sciences progress in three stages:**

Hypothesis < Theory < Law

- **These concepts are often confused in both lay- and scientific-discourse**
- **In the absence of either theory or law we are forced to create models**

The limitations of models, statistical and epidemiological analysis

- Remember “GIGO” when using models. Naturally, calculations made with models incorporate the uncertainties intrinsic to those models
- At the present time statistical and epidemiological analyses of data are necessary to efficiently extract all the intrinsic information. Both are fraught with traps for the unwary
- *“There are three kinds of lies: lies, damned lies and statistics.” Benjamin D’Israeli (1804-1881)*
- **Caveat: best left to professionals! Amateurs beware**

Some common deductive flaws (naiveté) using statistical analysis

“He uses statistics as a drunken man uses lamp posts-for support rather than illumination.” Andrew Lang 1844-1912.

- **Small sample size requires special statistical techniques**
- **Good correlation does not validate causation**
- **Application of the Method of Least Squares to data that are not randomly distributed may lead to incorrect assessment of errors**
- **Observed experimental data should not be compared with flawed estimates of “expected data”**

Some limitations of epidemiological analysis

- The power of epidemiological studies is typically low
- Pochin (1988) gives a simple expression:

$$PY \geq 4M. (KD)^{-2}$$

P = number of people exposed

Y = years of exposure (y)

M = annual risk of death from cancer (y^{-1})

D = annual excess dose rate ($Sv.y^{-1}$)

K = estimated risk of radiation-induced cancer (Sv)⁻¹

Epidemiology II

- A sample calculation with:

$$M = 3.5 \times 10^{-3} \text{ y}^{-1}$$

$$K = 5 \times 10^{-2} \text{ Sv}^{-1}$$

yields:

$$PY \geq 5.6 \times D^{-2}$$

$$= 5.6 \times 10^6 \text{ person years @ } 10^{-3} \text{ Sv.y}^{-1}$$

- Thus a study lasting 40 years would require about 140,000 persons
- Need to resort to more subtle techniques

Childhood Leukæmia as an example of the pitfalls inherent in epidemiological analysis

- The observation of 4 deaths (less than 1 expected) from childhood leukæmia during 1963-1980 at Seascale led to intense activity in the UK and the publication of many papers
- Example of one hastily conceived paper was by Barton *et al.* “*Childhood Leukæmia in West Berkshire,*” *Lancet*, 30 November 1985, which reported from 1972-1984: 45 cases of children diagnosed with acute leukæmia. (33.3 cases expected $p= 0.06$)

Childhood Leukæmia problems with interpretation of Barton *et al.*

- **Geographical variation of incidence rates**
 - South to North England: 4 to $8 \cdot 10^{-5}$ per year
 - In Berkshire gradient from urban (low) to rural areas
- **Incomplete Cancer registry (estimated ~ 20%)**
- **Leukæmia distribution may not be Poissonian (credibility of testing?)**
- **Authors honestly self-impeached by their own paper (expectations; nuclear installations; forthcoming TV exposé)**

Fatal malignant disease in British radiation workers

- Source UKAE (5 sites)
- Number in Study 23,000 males
- Mean Follow up time: 16 years
- Mean accumulated dose: $3.2 \cdot 10^{-2}$ Gy
- $PY = 3.7 \cdot 10^5 < 4M.(KD)^{-2} = 1.4 \cdot 10^6$

Standardized Mortality Ratios for Malignant Disease	
All Cancer	75 (p<1%)
Lung	69 (p<1%)
Stomach	79
Bladder	79
Leukæmia	110
Multiple Myeloma	60
Prostate	115

Studies of Leukæmia near British nuclear sites

- Forman, D. *et al.* “*Cancer near Nuclear Installations.*” *Nature* 39, 499-500 (1987).

“There has been no general increase in cancer mortality near nuclear installations in England and Wales during the period 1959-1980. Leukæmia in young people may be an exception, though reasons remain unclear.”

- Bithell, J. F. *et al.* “*Leukæmias and non-Hodgkin's lymphomas near nuclear installations in England and Wales.*” *British Medical Journal* 309, 501-505 (1994).

“There is no evidence of a general increase of childhood leukæmia or non-Hodgkin's lymphoma around nuclear installations. Apart from Sellafield, the evidence for distance related risk is very weak.”

Conclusions

- **The current practice of radiological protection is pragmatic and quasi-scientific in character.**
- **Answering the remaining questions that will place radiological protection on a firm scientific basis will be arduous. Epidemiology and animal data are of limited help. A general theory of radiocarcinogenesis will be necessary.**
- **The “winter of discontent debate” is driven by differing emphases, generally pragmatic and philosophical in character.**

Conclusions

- **Pragmatists hold that, in the absence of demonstrated deleterious health effects in humans, the status quo seems acceptable.**
- **Philosophers: agree pragmatism has served well in the past but suggest a new approach will be needed to meet the challenges of the future.**
- **There is concern that the supporting structure of current practice is inadequate to meet the challenges of the future. The existing structure is ambiguous, lacking in rigor and has produced costly muddle. It must be reformed to adequately include external exposure to high-LET radiations.**

Conclusions

- **The world energy situation behooves the RP profession perhaps to assess its needs for the next 25 years.**
- **Priority should be given to anticipating technological developments, particularly in the field of energy-production, which will almost certainly lead to larger numbers of people being exposed high-LET radiations (neutrons).**
- **If the radiological protection profession is not to stand in the way of progress it must be prepared for the future.**

Suggestions

1. For the “discontented”

- **Patience is a virtue.** A firm scientific basis for our discipline is much to be desired but its construction will take a little more time.
- **The record of safety provided by the RP profession is seen to excellent, even if dependent on empirical methods.**
- **Wisdom will be found in making judgments not from the detailed information obtained from models but from a comprehensive understanding both of the certainty and uncertainty in the fundamental data now being developed.**

Suggestions

2. For Model-makers

- **KISS! Develop simple, internally consistent models. Avoid unjustified complexity in models when (as is often the case) the fundamental data are uncertain.**
- **Ensure that models are consistent with the laws of physics, mathematical logic and with the recommendations of advisory bodies.**
- **The frequency with which changes in models are made should be minimized and changes made only if serious errors are to be corrected.**

Suggestions

3. For Advisory bodies

- **Avoid changes in nomenclature. (In the past this has caused some confusion.)**
- **Avoid changes in recommendations unless either required by practice or significant error is determined. (“Significant” is interpreted to imply “comparable with the estimated uncertainty in the basic data.”)**
- **Establish a system to review new publications to ensure that they are in full concordance with existing policies of the organization.**

Suggestions

3. For Advisory bodies (continued)

- **Make serious attempts to inform educated lay-people. Prepare intelligible documents to that avoid professional jargon. These documents should clearly & consistently reflect the uncertainty underlying any judgments, the impact of these uncertainties and how judgments are made that safeguard the general public and workers. Explain what new knowledge is needed to confirm the validity of our judgments. There is no shame in admitting that we do not yet understand everything.**

Suggestions

3. For Advisory bodies (continued)

- **Address recommendations for neutron (and other high-LET radiation) dosimetry with the rigor it merits.**
- **Form a “Blue Ribbon Panel” to review the needs of Radiological Protection for next 25 years and develop an action plan.**

Suggestions

4. For all of us

- **Encourage Congress to provide adequate financial support for NCRP to make it truly independent of and insulated from external pressures.**
- **Better understand the basic concepts of the development of science and the system of radiological protection.**
- **Discriminate between “hypothesis,” “theory” and “scientific law.”**
- **Understand the difference between a “quantity” in science, its “unit” and its “special name” if it has one.**