Reflections
(thoughts and considerations)

on the risks associated to radiation exposure

(Attribution of effects vis-à-vis Inference of risks)

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1. The Meaning of ‘Risk’
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   (i.e., there are plausible risks of effects, even if they are not attributable)
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1.
The meaning of ‘Risk’
In radio-epidemiology

Risk ~ rate of disease

- **Excess absolute risk** = the rate of disease in an exposed population minus the rate of disease in an unexposed population.

- **Excess relative risk** = the rate of disease in an exposed population divided by the rate of disease in an unexposed population minus one
In the IAEA safety standards

- **Set of triplets**, \( R=\{(S_i/p_i/X_i)\} \), where \( S_i \) is an identification or description of a scenario \( i \), \( p_i \) is the probability of that scenario and \( X_i \) is a measure of the consequence of the scenario.

- **Mathematical mean (expectation value)** of an appropriate measure of a specified (usually unwelcome) consequence, \( R = \sum_i p_i C_i \), where \( p_i \) is the probability of occurrence of scenario or event sequence \( i \) and \( C_i \) is a measure of the consequence of that scenario or event sequence.

- **Probability** of a specified health effect occurring in a person or group as a result of exposure to radiation, commonly expressed as the product of the probability that exposure will occur and the probability that the exposure, assuming that it occurs, will cause the specified health effect.
In life

- possibility,
- chance,
- plausibility,
- likelihood,
- prospect,
- hazard,
- imperilling,
- jeopardizing,
- gambling,
- betting,
- wagering,
- venturing,
- danger,
- peril,
- threat,
- menace,
- fear,
- endangering
In the context of radiation-related health effects, **risk** refers to the probability that an **onset of cancer will occur** during a given time period (e.g. the rest of life following an exposure).

I.e. it is prospective notion!
For UNSCEAR

- Risks can be estimated using **objective evidence** of from epidemiological investigations of frequencies of disease rates in previously exposed populations (i.e. based on objective observations of past frequencies).

- Risk can be estimated using **subjective inference**, based on such retrospective analyses, ...... ......and judging that the same ‘risk’ is valid for other exposure situations for which direct epidemiological data are not available.
2. The risk-dose relationship
Dose (Sv)

Likelihood of health effects

100% (certainty)

Approx. lower bound of pathological knowledge

~ 0.1

Approx. lower bound of epidemiological knowledge

~ 1

~ 10%

~ 5% (UNSCEAR estimate)

~ 1%

Estimated likelihood of cancer

~ 0.1

~ 1

~ 10

Radiation syndromes and death
Dose (Sv) vs. Likelihood of health effects

- Approx. lower bound of epidemiological knowledge: ~0.1
- Approx. lower bound of pathological knowledge: ~1

- Typical dose: ~5% (UNSCEAR estimate)
- Estimated likelihood of cancer: ~1% (UNSCEAR estimate)

Increased syndromes and death:
Dose (Gy)

Likelihood of health effects

100% (certainty)

Approx. lower bound of pathological knowledge

5% (UNSCEAR estimate)

Approx. lower bound of epidemiological knowledge

10% ~ 1%

Typical Background

Region of individual attribution of effects

Region of inference of radiation risks

Region of collective attribution of effects
Total background incidence of effects

Postulated likelihood of health effects

Incremental dose

Nominal Risk %/mSv

Nominal incremental likelihood of health effects

Background annual dose (average 2.4, typical 10 mSv y⁻¹)
... above the prevalent **background dose**, for an **increment in dose** it is assumed (for radiation protection purposes) a **proportional increment** in the **subjective probability of stochastic effects** of

\[ \approx 0.005\% \text{ per mSv} \]
Should we consider the influence of dose-protraction over time?
Postulated risk

Risk = \frac{\Delta p}{\Delta D}

Nominal Risk

Dose Increment

Dosis

time
What happens with changes in the dose rate?; specifically, what implications does variations in the second derivative of dose have?
Should adaptive response be real, and its dynamic varies with dose rate,.....

... Would $\frac{\delta D^2}{\delta t^2}$ influence the nominal risk, $\frac{\Delta p}{\Delta D}$?
Hiroshima & Nagasaki

Typical exposure situations
Nominal risk $\Delta \rho / \Delta D = 5 \% / \text{Sv}$,

Derived from high $\delta D^2 / \delta t^2$

Should it be different for very low $\delta D^2 / \delta t^2$?
Cytogenetic Damage in Cells Exposed to Ionizing Radiation under Conditions of a Changing Dose Rate

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3. Attribution

vis-à-vis

Inference
Attribution

The ascribing of a health effect to radiation exposure

It requires:

- **Provability**
- **Demonstrability**
- **Attestability**

In our context, *attributability* refers to the ability of ascribing to a radiation exposure a manifest health effect in an individual or a manifest change in frequency of health effects in a population.
Inference

The process of drawing conclusions from scientific observations, evidence and reasoning in the presence of uncertainty requires judgment on plausibility and probability.

In our context, *inferability* refers to the ability to judge the plausibility of prospective health effect in individuals or change in frequency of health effects in populations, due to a radiation exposure situation.
4. Provability

vis-à-vis

Probability
Actual effects are akin to **provability**

i.e., to the ability to attribute by *evidence*

the *true existence* of health effects

Risk is akin to **probability**

i.e., to the ability to infer by *judgment*

the *plausibility* of health effects
5. Objective Probability 

\textit{vis-à-vis} 

Subjective Probability
Objectivism: Frequentist probability

- Frequentist probability of a health effect is the limit of relative frequency of the effect occurring in a large number of cases.
Subjectivism: Bayesian probability

- Bayesian probability of a health effect is a quantification of a reasonable expectation of the effect occurring, representing a state of knowledge and personal belief or subjective judgement, instead of the frequency or propensity of the effect.
6.

UNSCEAR in a Picture
Statistically observable in populations (epidemiology)

Biologically plausible

Increasing risk of cancer about 5% per Sv

Burns, radiation sickness and death

Clinically observable in individuals

Natural background, occupational doses

Chernobyl child thyroid doses

Chernobyl firemen
Subjective conjectures | Objective facts

- Biologically plausible
- Statistically observable in populations (epidemiology)
- Increasing risk of cancer about 5% per Sv
- Statistical limitations
- Burns, radiation sickness and death
- Clinically observable in individuals

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- Occupational doses
- Thyroid doses
- Firemen
Subjective conjectures

Objective facts

Subjective inferences of risk

Objective attribution of effects

Biologically plausible

Statistical limitations

Increasing risk of cancer about 5% per Sv

Burns, radiation sickness and death

Occupational doses

Thyroid doses

Firemen
Relationship of radiation doses and health effects

Subjective inferences of risk

Objective attribution of effects

Collective attribution

Individual attribution

Subjective conjectures

Objective facts

Statistically observable in populations (epidemiology)

Biologically plausible

Statistical limitations

Moderate

High

Radiation

Clinically observable in individuals
Health effects are not individually attributable but collectively attributable to occupational doses.

Health effects are not attributable but risks are inferable to thyroid doses.

Health effects are individually attributable to firemen.
The basic question is: Shall the IAEA safety standards treat these situations indistinctly?
7. ICRP Inference: No Dose-threshold (i.e., there are plausible risks of effects, even if the effects are not attributable)
Postulated likelihood of health effects

Background annual dose (average 2.4, typical 10 mSv y⁻¹)

Postulated likelihood of health effects

Nominal incremental likelihood of health effects

Nominal Risk %/mSv
Quantitative uncertainty analysis (QUA)

- Decision theoretic framework involving the application of Bayesian probability methods to estimates and decision rules based on uncertain statistical and subjective information.
**Reductio ad absurdum**
(reduction to absurdity)

- Method formalized and used by Aristotle.
- The opposite hypothesis to that tried as true is assumed to be valid.
- From it and through valid logical deductions an absurd result is obtained.
- It is concluded that the starting hypothesis (the negation of the original) must be false, so the original is true.
Reductio ad absurdum
(reduction to absurdity)

- Disprove the possibility of a threshold dose by showing it inevitably leads to an impractical conclusion.
Nominal statistical uncertainty distribution for excess lifetime risk of solid cancer mortality among atomic-bomb survivors
Uncertainty distribution for excess lifetime risk
(taking into account extrapolation to another population)

Approximately log-normal.

Risk (%)/Sv
Cumulative probability
95% upper limit
5%

Risk per Sv, in percent
Assuming a 20% probability of threshold

Risk (%)/Sv

Cumulative probability

95% upper limit

8.8%/Sv

5%
Assuming a 50% probability of threshold
Assuming a 80% probability of threshold
Mean and upper 95% probability limit for ERR per Gy as functions of threshold probability.
Degrees of belief (or disbelief) on a risk threshold

Assuming 'degrees of disbelief' of 20%, 50%, and 80%.

Nominal risk (%)/Sv

Cumulative plausibility
Thus

ICRP assumed a *nominal radiation risk* at low doses and recommended to restrain it with radiation protection measures.
**Ignoratio elenchi**
(Ignoring refutation or missing the point)

- Is the conclusion in ICRP99 relevant?
- Is it relevant that the distribution, on which the reasoning is based, be a distribution of data at high dose and high dose rate?
8. Cruciality of the Issue
Miscalculations
Collective Dose \times \text{Nominal Risk Coefficient} = \text{Nominal Deaths}

X \quad \text{5%/Sv} \quad =

Collective Dose \times \text{Nominal Risk Coefficient} = \text{Nominal Deaths}
Annals of the New York Academy of Sciences

It concluded that some 985,000 people died of cancer attributable to the Chernobyl accident!
Legality
Imputation

(charge someone with something bad)
Attribution is different than Imputation!
Radio-pathologists
Radio-epidemiologists

Lawyers

Attribute

Impute
Attributability
(scientific ability to attribute)

Future

Imputability
(legal ability to impute)

Done
By
UNSCEAR

Still a challenge
Thank you!

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