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The Concept of Equivalent Dose and Dose Limits - Urgent Improvements

Abstract

The relative biological effectiveness (RBE) of photon radiation differs in a range of about one order of magnitude depending of her energy. The recommendation of a weighting factor radiation of one for this radiation must be updated. The dose limits must be decreased a) 4times because of the energy difference of A-bomb radiation in relation to X-rays; b) 2times because of the linearity of the dose response curve (no DDREF); c) 4times in case of an occupational exposure because of improvement of conventional working conditions; d) 3times in case of low dose and low dose rate neutrons because of enhanced RBE; d) 7.5times in case of an exposure to Radon because of new epidemiological findings; e) 1.4times because of the underreporting of cancer risk in the mortality statistics of A-bomb survivors; f) 1.4times because of the higher cancer risk of the European population. In summary the dose limit must be reduced at least by a factor of 50-60. For occupational exposure the dose limit must be reduced from 50 mSv/y to 1 mSv/y, for public exposure from 1 mSv/y to 0.02 mSv/y. The weighting factor radiation for low dose and low dose rate neutrons must be set to 75. For occupational exposure to Radon the dose limit must be decreased from 4 WLM/y to 0.5 WLM/y. A limitation of collective dose in public exposure is necessary.

Introduction

The various kinds of ionising radiation show remarkable differences of their biological effectiveness. To avoid own dose limits for every kind of radiation the concept of equivalent dose was recommended: For all kinds of radiation such a uniform dose limit can be used expressed in units of the equivalent dose. The physical dose of the different kinds of radiation must be weighted with a weighting factor radiation w_R. This presentation deals with the difference between the weighting factors radiation recommended by ICRP and the actual effectiveness and the consequences of this difference for the dose limits. In addition necessary adaptations of dose limits are discussed.

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Relative Biological Effectiveness of Photon Radiation

The relative biological effectiveness (RBE) of photon radiation is dependent on her energy (cf. fig. 1). Tested on the production of dicentric chromosomal aberrations the difference for stochastic effects covers a range of about one order of magnitude. This fact is masked by the recommendation of a weighting factor radiation w_R of one for all kinds of photon radiation regardless of her energy. In so far this recommendation has an immediate consequence for setting the dose limits because of the difference of energy between photon radiation from important sources and the gamma radiation of the atomic bombs. Initially the gamma radiation of the atomic bombs was considered as equivalent to the gamma radiation of ^{60}Co. But according to newer findings an energy of 3-4 MeV must be assumed [**3**]. Calculated as biologically equivalent radiation one unit of the dose of the atomic bomb radiation has only approximately a quarter of the RBE of the same physical dose of X-rays and a half of the RBE of the same physical dose of the gamma radiation from usual sources in medicine and industry.

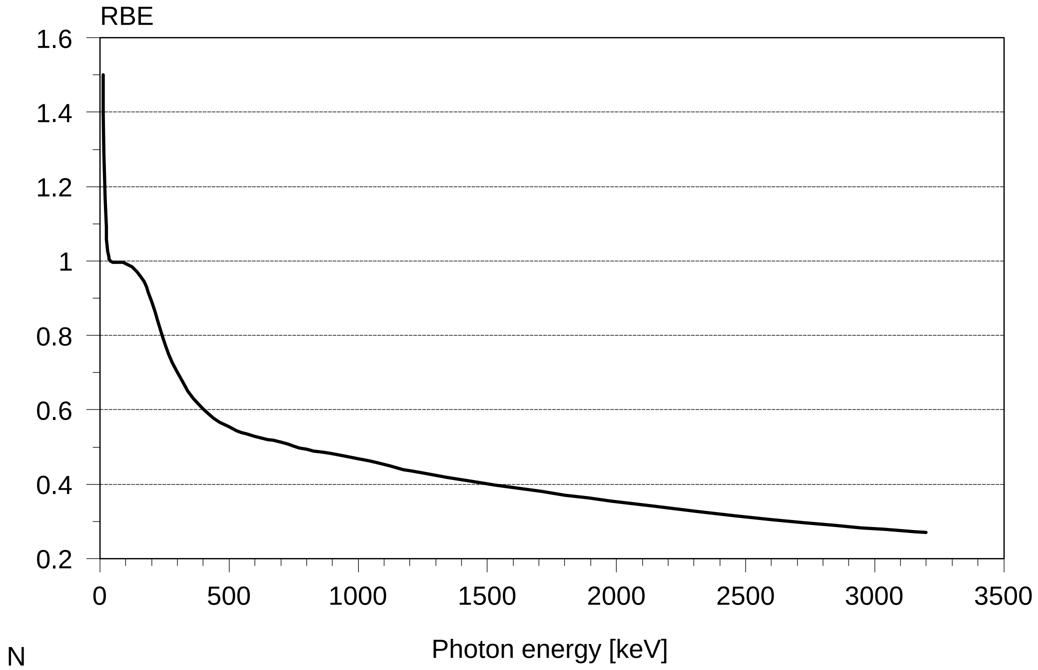

Fig. 1: Relative biologic effectiveness of photon radiation for stochastic effects (e.g. carcinogenesis) depending on energy. Curve after ICRU 40 [**2**] extrapolated after data of the production of dicentric chromosomal aberrations [**3**]. Values standardised for 250 kVp X-rays.

Vice versa X-rays are about four times more biologically effective as the radiation of the atomic bombs. The dose limits of X-rays must be reduced by a factor of four. As a quality factor with reference to X-rays is being used this is also true for densely ionising radiation.

Linearity of Dose Response Curve

The probability coefficients for stochastic effects (e.g. carcinogenesis) used by the ICRP 60 to justify the dose limits were derived from the mortality statistics of the atomic bomb survivors after the dose revision DS86. ICRP assumes a dose-response curve with a linear-quadratic shape. The used hypothesis interprets the carcinogenic effects of an exposure to high doses in the range of one Sievert and more as the consequence of multiple hits of photons. In the low dose range, say below 200 mSv, or in case of low dose rates less than 100 mSv per hour, the hypothesis supposes an additional recovery with the result of a decreased probability coefficient. ICRP postulates a dose and dose rate effectiveness factor (DDREF) of two (cf. 2). A figure like this is missed in ICRP 60. Quite obviously the observations support a linear relationship more strongly than a linear-quadratic one. Beyond that, in the lowest dose groups a significantly higher excess relative risk per dose was observed as claimed by Köhnlein and Nußbaum [5] and as confirmed in the recent update of the mortality data by RERF [6].

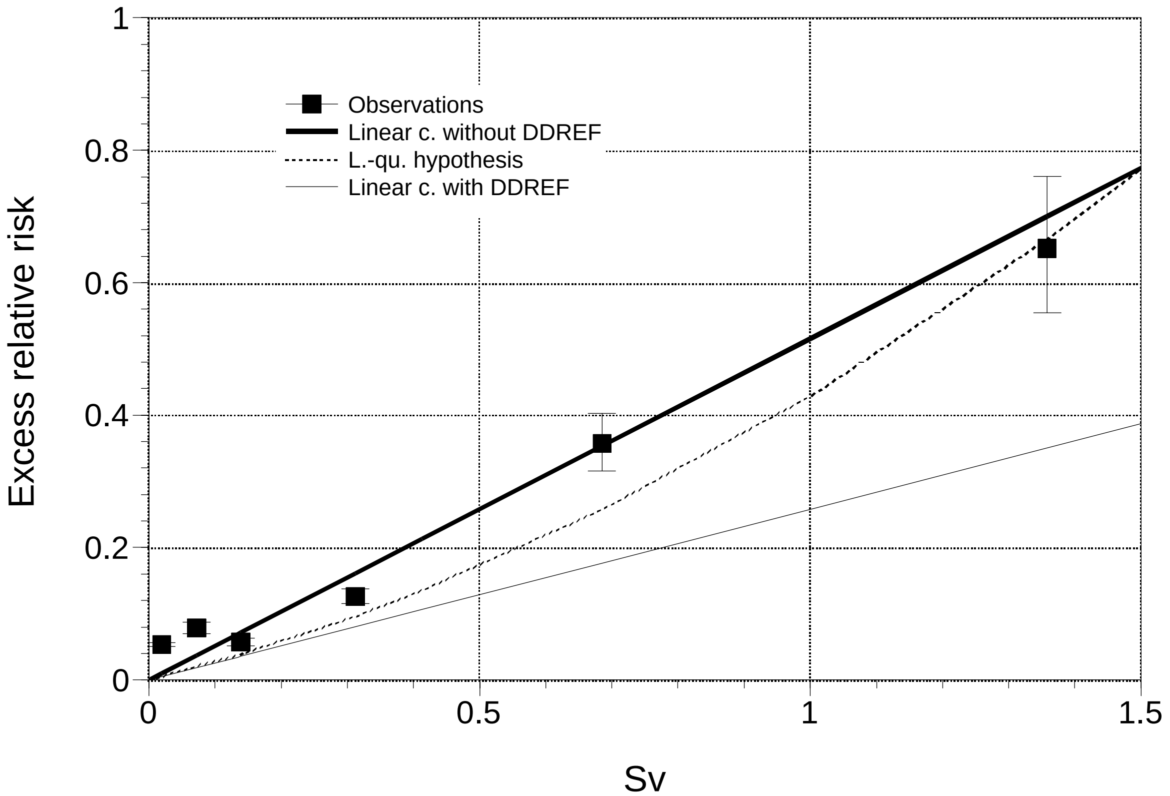

Fig. 2: Relationship of excess relative risk for mortality from solid tumours (all cancer except leukaemia) and dose.
Colon dose representing the mean dose of all tissues. The correlation of the excess relative risk and the probability coefficient of ICRP 60 is valid for a mean relative cancer mortality of 19%. Mean values and 95% confidence intervals of observations after [4]

The defenders of the linear-quadratic hypothesis and of a DDREF claim that in the dose range less than 200 mSv the difference between the two curves cannot be distinguished significantly. Not to mention that this uncertainty should be a good reason for caution, the difference between the various shapes of the dose-relationship can also be discriminated in the high dose range up to four Sievert (cf. 3). Again the hypothesis of a linear dose-response relationship is supported more strongly than the linear-quadratic one.

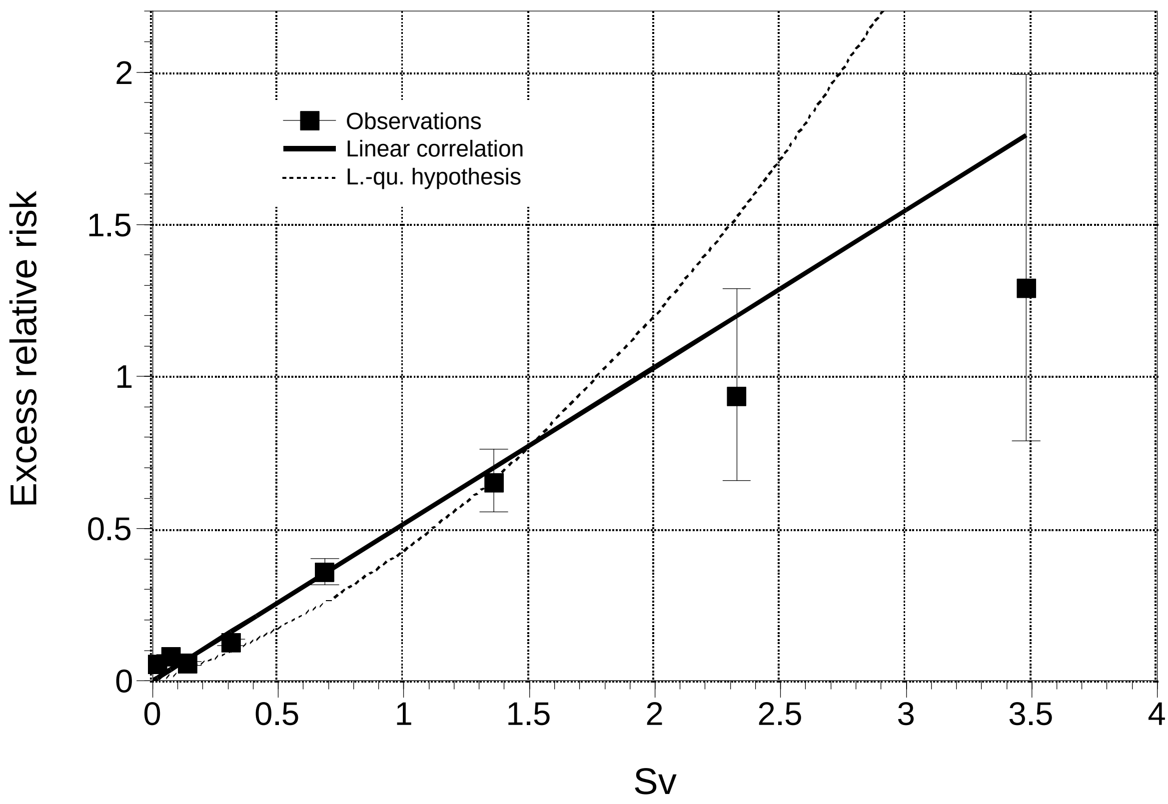

Fig. 3: Comparison of the linear and linear-quadratic hypothesis with the observations in the dose range up to 4 Sv. Mean values and 95% confidence intervals of observations after [4]

Summing up important human data about the induction of solid tumours a DDREF of two isn't justified. Solid tumours are responsible for about 90% of the additional mortality after an exposure to ionising radiation as well as for more than 95% of the additional incidence of malignant tumours. Therefore the dose limits recommended by ICRP must be corrected for the DDREF and therefore decreased by a factor of two.

Underreporting of Radiation Induced Cancer Mortality

The ICRP calculations of cancer risk base on the data of mortality registers. But more recent results of RERF using incidence data show an underreporting of the cancer risk described by the mortality data. Thereby follows a 40% increase of the gradient of dose-relationship [7]. Again the linear dose-relationship is supported strongly [8] (cf. fig. 4).

The underreporting of mortality data must be considered by a decrease of the dose limits by a factor of 1.4.

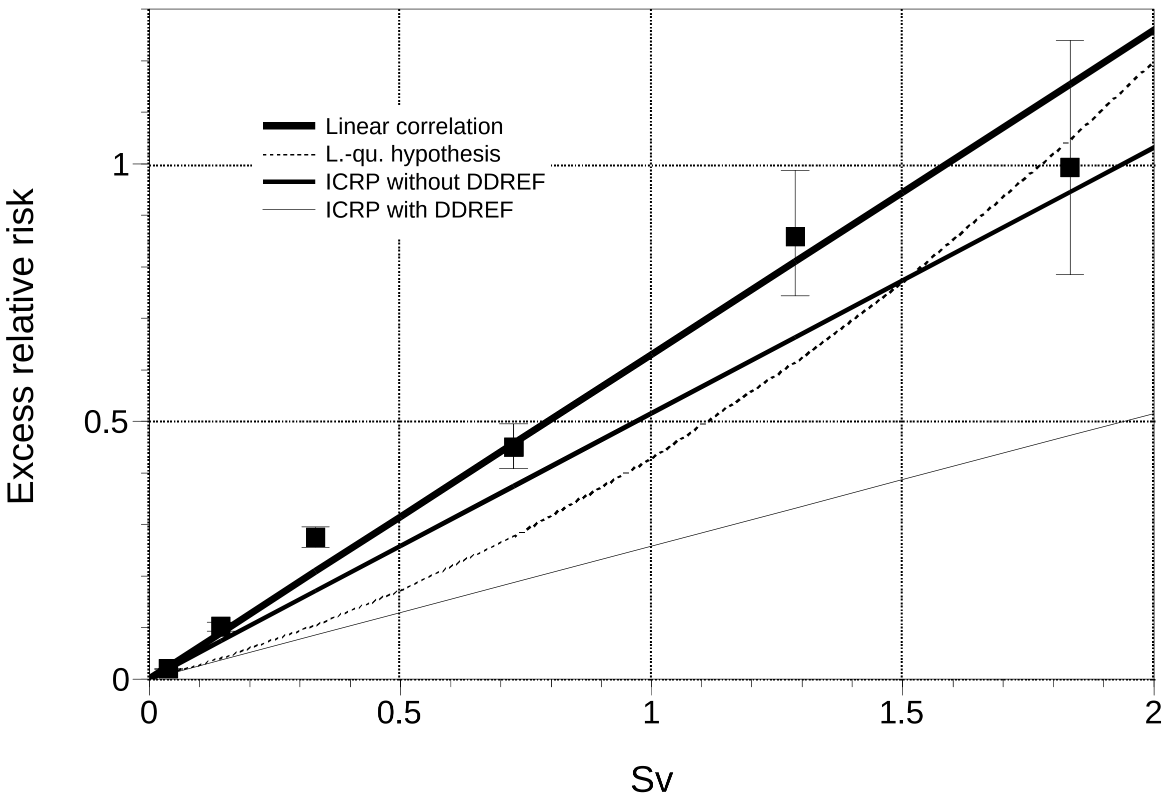

Fig. 4: As fig. 2, but for incidence data and with the linear relationship between incidence and dose. Mean values and 95% confidence intervals of observations after [8]

Improvement of Conventional Working Conditions

The dose limits of ICRP for radiation workers are justified by the comparison with the risk of fatal industrial accidents. But the refined reference value is not a constant. In all industrial countries a long-term decreasing trend of about 3% per year can be observed. E.g. in FRG the figure drops about to a quarter during three decades (cf. fig. 5).

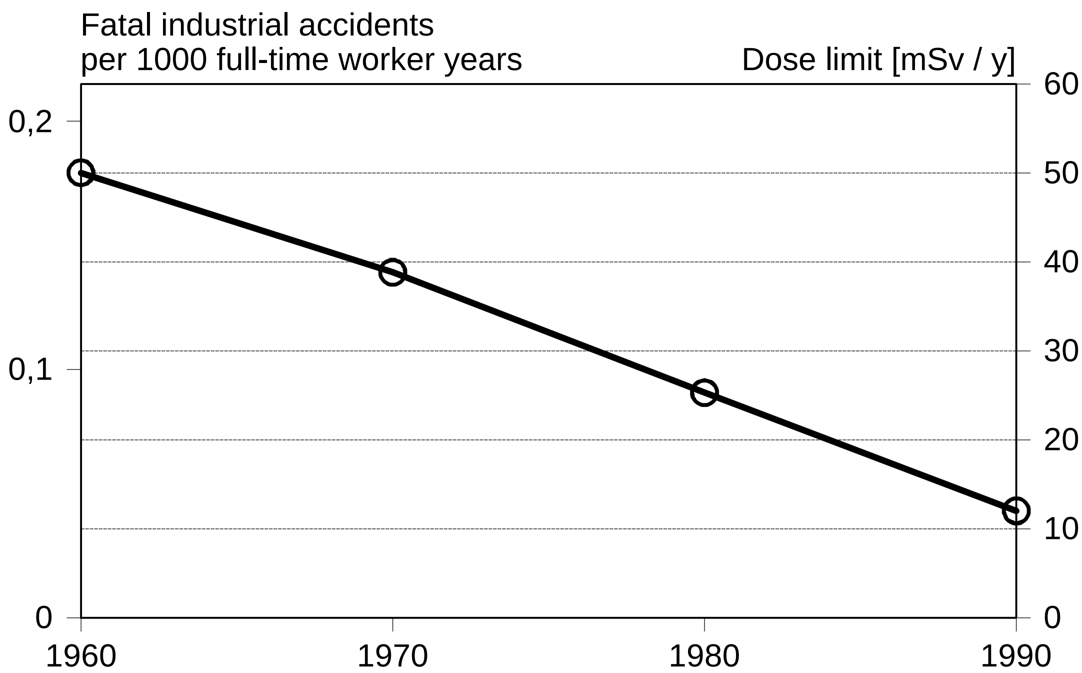

Fig. 5: Revision of dose limits necessary to follow the increasing standard of industrial safety.
Demonstrated by the comparison with the number of fatal industrial accidents per 1000 full-time worker years in the FRG. Mean of all branches without road accidents.
Data: [**9**]

Independently of the new scientific results described above the dose limit must be lowered by a factor of four.

The Demographic Influence

The longer the observation of the atomic bomb survivors can be extended, the more clearly the multiplicative model can be confirmed. This means, that in a population with a higher spontaneous incidence of cancer, the number of excess tumours after an exposure to ionising radiation increases proportionally. In the European countries with long life expectancy the probability of fatal cancer is about 20% higher than in Japan, as demonstrated for the example of Great Britain. The ICRP has determined the probability coefficient for a special „world population“, a mean of China, Great Britain, Japan, Puerto Rico and USA, with reduced life expectancy. The lower result is used to justify the recommended dose limit (cf. fig. 6). On the contrary respecting the demographic situation in European countries with high life expectancy the dose limit must be reduced by a factor of 1.4.

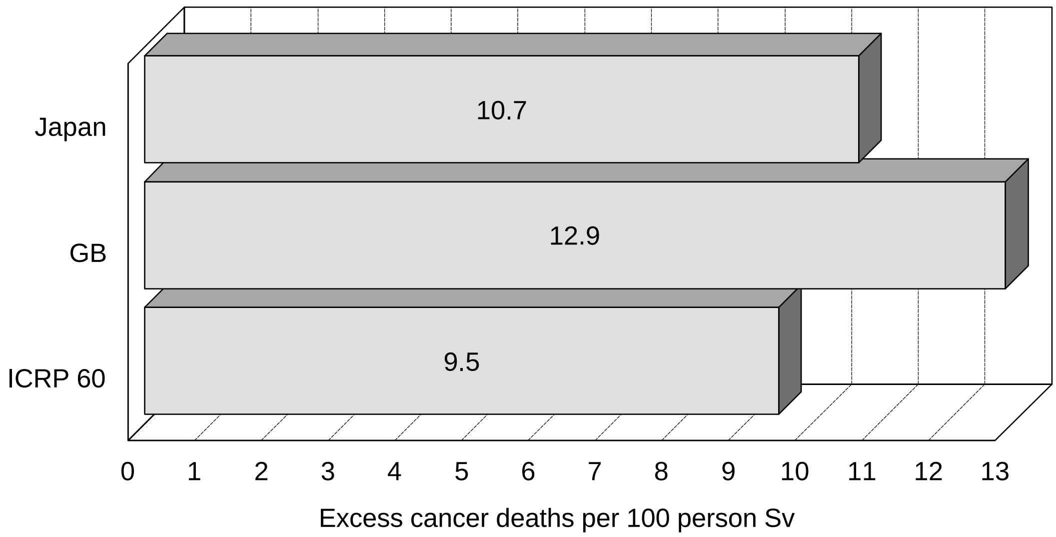

Fig. 6: Probability coefficients for fatal cancer as estimated in the population of Japan, extrapolated into the population of Great Britain using the multiplicative model and stated for „world population“ by ICRP 60.

Densely Ionising Radiation

Assessing neutrons in the concept of equivalent dose the ICRP 60 recommends higher values of weighting factor radiation than the old quality factor, e.g. for neutrons with unknown energy 20 instead of 10. Depending from neutron energy lower values are recommended, too. Many higher results of RBE research are not considered [10]. Especially in the range of low doses and/or low dose rates an enhancement factor of at least three must be taken into account.

Most of the results were taken from experiments with animals and cell cultures. But now first experience with human data from flight personnel, occupationally exposed to low dose rate neutrons can be used proving the following thesis [11]: Taking the recommendation of a quality factor of 25 by ICRU 40 as a basis a RBE of 75 must be expected.

Following this thesis, the observed cancer risk must be higher than a factor of 20 than the values expected using the dose equivalent after ICRP 60 (RBE X-rays vs. gammarays of atomic bombs: 4, factor of inverse dose rate of neutrons: 3, w_R ICRP 60 vs. Q ICRU 40: 1.25; 4∗3∗1.25=16). The observed multiples with factors between 16 and 25 support my thesis (cf. fig. 7).

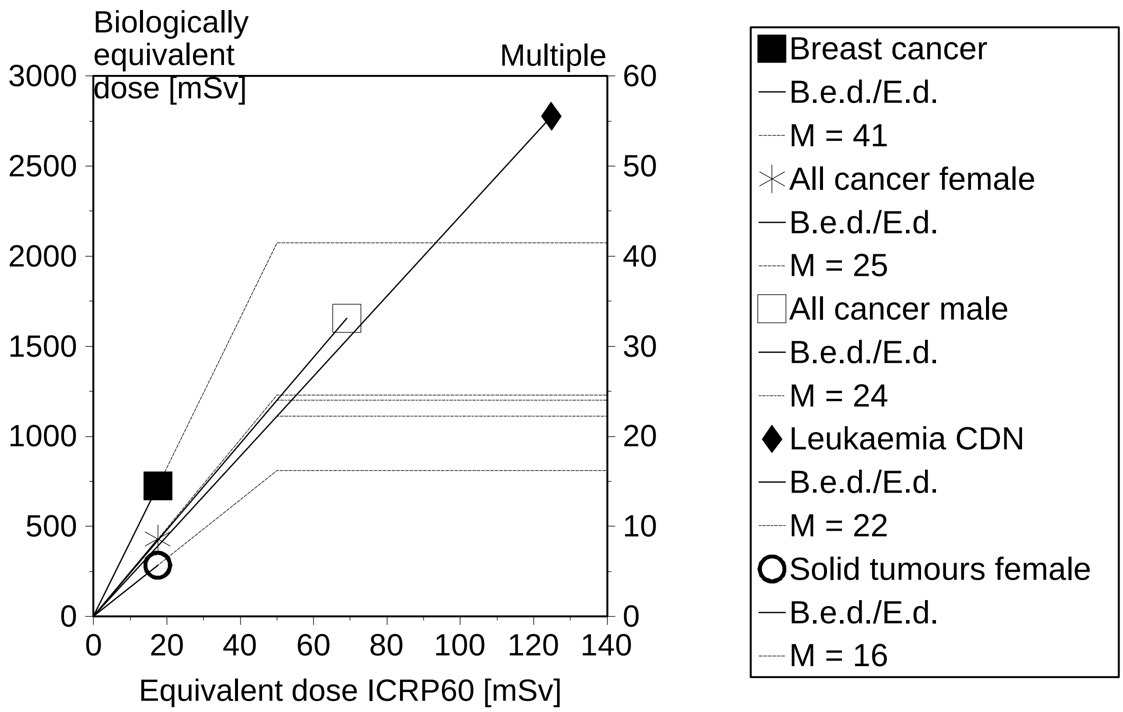

Fig. 7: Comparison of the equivalent dose of occupational exposure of various groups of flight personnel calculated using the weighting factors radiation of ICRP 60 with the biologically equivalent dose necessary explaining the observed increase of cancer risk (left scale). The multiple, biologically equivalent dose divided by equivalent dose ICRP 60, is shown at the right scale.
Data on breast cancer, all cancers female and solid tumours female after [12], on all cancers male after [13], on leukaemia after [14].

However, the observed risk of breast cancer exceeds the value expected according to ICRP nearly forty times and the value calculated according to my thesis nearly two times. Regarding this also a specially high sensitivity of breast tissue to neutrons as seen also in animal experiments should be discussed [15].

In the special case of an occupational exposure to Radon new epidemiological findings support an inverse dose rate effect. Considering this the interpretation of the differences between the lung cancer risk in various populations exposed to very different dose rates has the result of higher risk values per dose than assumed before. A more detailed discussion in not possible without extension of the given time frame. Very briefly it must suffice that a reduction of the dose limit is necessary by a factor of 7.5 [16].

Conclusions

The interference of all these corrections necessary to establish appropriate safety standard in European countries is multiplicative. The deviation of the parameters chosen by the ICRP from the mean of observations is unidirectional. Therefore the complete correction factor is the result of a chain multiplication, which I hardly dare to present. In the case of X-rays: $4*2*1.4*4*1.4 = 63$. This means a reduction of the permissible occupational dose for radiation workers from 50 mSv/y to 1 mSv/y, at least. Using this improved dose limit for neutrons a weighting factor radiation of at least 75 must be recommended. The dose limit for an occupational exposure to Radon must be reduced from 4 WLM/y to 0.5 WLM/y.

Again I hardly dare to present the conclusions that must be claimed for public radiation protection: To provide an adequate safety standard the dose limit of 1 mSv/y have to be reduced to 0.02 mSv/y or 20 µSv/y.

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