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GUEST EDITORIAL

Linear, no threshold model in radiation protection and safety: standards thrive on 'assumptions' and not on science-based evidence

Lauriston Taylor in his 1980 Sievert Lecture (*Health Phys.*, 1980, **39**, 851–874) stated that 'some non-scientific influences prevail over scientific facts on radiation protection standards and practice'. This trend continues despite many low dose radiobiological data negating the linear, no threshold (LNT) hypothesis. More recently, Anthony D. Wrixon, a consultant to the Nuclear Energy Agency of OECD, IAEA, UNSCEAR wrote, 'Radiation protection is not "pure science"; it is based on science but also relies on assumptions that are necessary to the application of scientific knowledge to real life issues' (*Radiat. Protect. Environ.*, 2016, **39**, 117–121).

The indisputable fact is that the LNT model was an ideological creation by H. J. Muller in his Nobel Lecture delivered on 12 December 1946 (Calabrese, E. J., *Arch. Toxicol.*, 2011, **85**, 1495–1498). In the Guest Editorial (*Curr. Sci.*, 2014, **106**, 7–8) and the review paper following it (*Curr. Sci.*, 2014, **107**, 46–53), this author has brought out that LNT hypothesis did not have scientific evidence when Muller proposed it in 1946, and the growing volume of scientific literature on low dose radiobiology since then, has unequivocally invalidated LNT. Notably, LNT then rested on assumptions such as (i) all doses of ionizing radiation are harmful, (ii) doses are cumulative and (iii) the radiobiological damage is irreversible. These assumptions have all been proven scientifically wrong following the findings of radiation hormesis (Luckey, T. D., *Radiation Hormesis*, CRC Press, USA, 1992) and low dose radioadaptive response (Wolff, S., *Environ. Health Prospect.*, 1998, **106**, 277–283). That there is indeed a 'threshold dose' for radiation-induced mutations has been clearly demonstrated by Koana, T. *et al.* (*Radiat. Res.*, 2007, **167**, 217–221).

Several research papers have also revealed that there is a *dose-dependent* activation or suppression of the gene expression (reviewed by Kesavan, P. C., *Curr. Sci.*, 2014, **107**, 46–53). It is therefore obvious that the quality of the gene products induced at low and high doses is *qualitatively different* and hence, it is absurd to draw a linear line from low to high doses or make backward extrapolation of genetic damage from high to low doses.

The assumptions-based LNT has already done considerable damage to both the radiation industry and the general public. Because of the use of the LNT model, most of the general public have developed 'radiophobia' and unfounded 'fear psychosis' whenever there has been a radiation 'incident' or 'accident' at the nuclear sites. Further, the LNT is used in conjunction with an absurd hypothetical approach of making calculation of 'collective dose'. The United States Nuclear Regulatory Commission (USNRC) has defined it as the sum of the individual doses received in a given period by a specified population from exposure to a specified source of radiation. What it simply means is that the total outcome of adverse health effects would be the same whether 100 persons swallow an aspirin each, or one person swallows 100 aspirins! Worse of all, LNT is used as the basis for estimating the number of people who would develop cancer, because of their exposure to varying doses of radiation. The exposed survivors are haunted by the fear of cancer death.

The prevalent policies and practices of the radiation protection and safety agencies seem to accept that exposure to radiation is the major cause of increasing cancer incidence, leaving aside exposure from chemical industries, pesticides, electronic and nano-waste. On the other hand, the Royal Society, London has noted a few years ago, that nuclear fuels are vastly safer than fossil fuels as these do not emit greenhouse gases, and the much needed energy in the future should be generated from nuclear fuels. Today, the major threat to the planet Earth and humanity is climate change racing towards the 'tipping point'.

Fortunately, there is a growing demand the world over to reject LNT and make a science-based model for radiation protection and safety policies and practice. In fact, the US-based SARI (Scientists for Accurate Radiation Information) formed about five years ago, has several leading radiation researchers, radiation medical experts, radiobiologists and also policy-oriented thinkers from most parts of the world. Through emails, the members exchange views on the subject and explore the best ways and means to put the radiation protection policies on science-based facts and discard the ideology-based LNT. J. M. Cuttler (*Health Phys.*, 2016; doi:10.1097/HP.00000-00000000383) points out how the recommended radiation dose limit (i.e. 'tolerance dose') of 0.2 R per day, which implied a safe threshold was used until 1950s for radiation protection of radiation workers. Multiplying this dose limit per day by the number of working (i.e. exposure) days in a year (i.e. 0.2 R × 8 h per day × 5 working days × 52 weeks) corresponds to about 400 mGy. The upper limit could be 500 mGy per year. Lauriston Taylor then a leading personality in National Council on Radiation Protection (NCRP) and, who was also a founding member of the International Commission of Radiological Protection (ICRP) made an apt statement in his Sievert Lecture (*Health Phys.*, 1980, **39**, 851–874): 'No one has been identifiably injured by radiation while working within the first numerical standards (0.2 R/day) set by the NCRP and then by the ICRP in 1934'. It works out to about 680 mGy/year at the maximum. He also vehemently opposed the prediction of cancer risk rate and cancer mortality risk rate based on LNT and 'collective dose' following radiation exposures in varying circumstances. He said: 'An equally mischievous use of the numbers game is that of calculating the number of people who will die as a result of having been subjected to diagnostic X-ray procedures. An example of such calculations are those based on a literal application of the linear, non-threshold, dose–effect relationship, treating a concept as a fact rather than a theory… . These are deeply immoral uses of our scientific knowledge.'

Yet another serious disagreement with the present day regulatory policies and practice is regarding the dose and dose-rate effectiveness factor following exposures at high (acute) and very low (chronic) dose-rates. What it means is that if a total dose of 10 Gy is delivered in 10 min (i.e. dose-rate of 1 Gy/min) or in 100,000 min (i.e. 0.0001 Gy/min), the magnitude of radiobiological effects would be quite significantly reduced in the latter. Hiroshi Tanooka has shown (*Int. J. Radiat. Biol*., 2011, **87**, 645–652) that quantitative analysis of cancer risk of ionizing radiation is a function of dose-rate. Employing what he refers to as 'non-tumour dose, D_{nt}, defined as the higher dose of radiation at which no statistically significant tumour increase is observed above the control (spontaneous) level, he found an inverse correlation between D_{nt} and dose-rate of the radiation. The D_{nt} increases 20-fold with decreasing dose-rate from 1 Gy to 10^{-8} Gy/min for whole body irradiation with low linear energy transfer (LET) radiation'. He concludes that the cancer risk of ionizing radiation varies 1000-fold depending on the dose-rate of radiation and exposure conditions. He has also estimated the dose-rate effectiveness factor to extrapolate the A-bomb data to cancer risk of environmental radiation as 16.5; presently the dose and dose-rate effectiveness factor (DDREF) for cancer risk to extrapolate from A-bomb survivors data is just 2 (set by BEIR, UNSCEAR , ICRP, etc.).

From the foregoing review, it is evident that highly rigorous but largely unscientific standards for radiation exposures are set for radiation workers and the general public. These lead to at least two major adverse consequences. One is the throttling of the uses of nuclear energy in the fields of power generation, medical diagnosis and treatment of cancer and induction of useful mutations, radiation preservation of readily perishable fish, fruits and vegetables, etc.; the other is that by putting all the blame on the environmentally realistic radiation exposures for increasing incidence of cancer, the really dangerous genotoxins associated with pesticides, nanoparticles and electronic waste are let to accumulate freely in the human environment.

Several parts of the world including India and China have high level natural background radiation areas (HLNBRAs) and the density of population living there is also high. Cytogenetic and epidemiological studies with special reference to cancer risk incidence and cancer risk mortality have been systematically carried out by scientists of both the countries. Japanese scientists have also been involved in some of these studies, because of their expertise in genetic and carcinogenic risk assessment of the A-bomb survivors and their descendants. Voluminous data of high quality derived from these studies reveal that there are neither cytogenetic aberrations, nor cancer mortality positively correlated with dose-rates and elevated levels of natural background radiation (Dobrzynski, L. *et al*., *Dose–Response*, 2015; https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4674188/).

On the basis of the ICRP's current maximum permissible doses of 1 $mSvy^{-1}$ for a member of the public and of 20 $mSvy^{-1}$ for the occupational radiation worker, the entire population of Chavara in Kerala would have to be evacuated! HLNBRAs of Chavara have up to 45 mGy^{-1}. Yet, the fact is that people have been living there for at least 40 generations. Science explains why there are no deleterious effects on people living in HLNBRAs of the world, but those relying on the LNT seem to be wondering as to why these people do not have the expected increase in the incidence of cancer and cancer mortality.

Extensive studies over the past seven decades on the cancer rate incidence and cancer mortality rate in the A-bomb survivors from both leukaemia and solid tumours do not support the LNT model. On the contrary, an unmistakable hormesis below certain low exposure levels and a definitive threshold dose for the induction of leukaemia and solid tumours have been presented by several authors, which are reviewed by T. D. Luckey (*Int. J. Nuclear Law*, 2008, 33–65).

Time has come for a paradigm shift.

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