Stochastic Late Effects After Partial Body Irradiation in Diagnostic Radiology: Evaluation of Approximate Data

H. Pauly

Institut für Radiologie der Universität Erlangen-Nürnberg, Krankenhausstraße 12, D-8520 Erlangen, Federal Republic of Germany

Summary. The paper describes a method to estimate the risk of inducing a malignant disease by the highly nonuniform partial body X-irradiation as performed in diagnostic radiological examinations. The cumulative probability, \( p \), for the development of a radiation-induced malignant neoplasm is obtained from the equation \( p = G_t E_s \), where \( E_s \) is the energy imparted to the soft tissues of trunk and head during a special radiological procedure. \( G_t \) is the mean integral incidence function for trunk and head, reflecting the cancer inducibility of organs and tissues in trunk and head, \( G_t \approx 0.3 \text{ kJ}^{-1} \). The value of \( G_t \) was obtained from mortality risk factors for the different tissues at risk, adopted in ICRP Publication 26, 1977.

The energy, \( E \), imparted to the body in typical radiographic procedures is in the range of 1–30 mJ, going up to about 1 J in an extensive fluoroscopic examination of the gastrointestinal tract. The corresponding values for \( p \) are about \( 10^{-6} \) to \( 10^{-5} \), in extensive examinations \( 10^{-4} \). As to a radiograph of chest, the method described in this paper yields practically the same value for \( p \) as the Monte Carlo calculation, using the MIRD phantom and the relevant mortality risk factors.

1. Introduction

The paper deals with the probability of X- or gamma-irradiation induced stochastic late effects after partial body or whole body irradiation. In this connection stochastic late effects are malignant neoplasms including neoplasms of the lymphatic and blood-forming organs. This paper is especially concerned with the late effects after highly nonuniform partial body exposures of patients in diagnostic radiology.

In Section 2 a general formalism is developed, applicable to partial and whole body irradiations as well as to short-term irradiations as done in diagnostic radiology and long-term irradiations as are characteristic for occupational exposures. The formalism is to a certain extent comparable with that of Jacobi [6].
In order to obtain values for the probability to induce a malignant neoplasm by a specific X-ray examination, data for the inducibility of a malignant disease in the organs or tissues exposed are introduced into the equations. These data are the mortality risk factors, published in Reference 5. By an averaging procedure a mean integral incidence function, \( G_t \), for trunk and head is obtained. Multiplication of this function with the energy, \( E_s \), imparted to the soft tissues of trunk and head during the X-ray examination — the energy \( E_s \), not dose, is because of the radiobiological mechanism of tumor induction (see Section 2.1) the appropriate physical quantity in this case —, results in the cumulative probability for the induction of a fatal malignant neoplasm after that specific diagnostic exposure. The values for this probability are certainly only approximate values, due to the averaging procedure used. Considering the fact, that the ICRP mortality risk factors involve a much larger biological uncertainty compared with the uncertainty in the determination of the energy imparted to the body, this averaging procedure seems to be justified. The accuracy of the data obtained is probably sufficient for risk estimations and operational optimizations in radiation protection.

Essentially the same concept was developed by Bengtsson et al. [1, 2]. These authors used the risk data in Reference 9 and 14 to evaluate — in the notation of the paper, presented here — a value for the mean integral incidence function for the total body including extremities. Considering the uncertainty of the basic risk data, they obtained a value of comparable magnitude, than the one, derived in this paper with a somewhat different procedure especially concerning the energy imparted to bones and to the extremities.

On the principle, that the cumulative probability, \( p_t \), is equal in case of an uniform and a nonuniform irradiation of the body, Jacobi [6] defined an “effective dose” by summing up weighted organ doses. This procedure was adopted and is recommended in Reference 5.

The paper, presented here, uses the extensive physical quantity “energy imparted”, because values of extensive quantities like the energy imparted to several organs can be clearly summed up without introducing a biological weighting factor into a physical quantity, where it does not belong to. Nevertheless the “effective dose” is a very useful quantity in radiation protection, especially because we are accustomed to dose values in radiation protection. The “effective dose equivalent” is identical with the “somatically significant dose” for stochastic effects, bearing formal analogy to the “genetically significant dose”.

2. Basic Equations

2.1 Cumulative Probability and Incidence Function

An organ or tissue of type \( i \) in the human body shall be exposed to X- or gamma-rays. Some years later in this organ or tissue a malignant neoplasm or another disease will arise due to the exposure with a certain, generally very small probability. The class of this induced disease will be designated by the subscript \( j \). \( p_{ij} \) shall be the cumulative probability that a person developed a radiation-induced disease of class \( j \) in the time interval between the beginning of a short-term or long-term irradiation of