DOE/ER/61022--T1

Nanodosimetry and nanodosimetric-based models of radiation action
for radon alpha particles

U.S. Department of Energy Grant DE-FG02-90ER61022

Final Performance Technical Report

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The goal of this project was to develop theoretical/computational tools for evaluating the risks incurred by populations exposed to radon alpha particles. The results obtained in the course of this study have been reported in the articles listed below. For each article we give a brief summary of the main findings:

Compound Dual Radiation Action
I. General Aspects

Harald H. Rossi and Marco Zaider

Radiat. Res. 132:178-183, 1992

The theory of dual radiation action (A. M. Kellerer and H. H. Rossi, Curr. Top. Radiat. Res. Q. 8:85-158, 1972) has attributed the effects of ionizing radiation on eukaryotes to the production of molecular changes (sublesions) that combine pairwise to produce injury (lesions) responsible for radiation effects. If the yield of sublesions is independent of radiation quality (as is currently assumed), dual radiation action results in the well-known proportionality between the average yield of lesions and $\alpha D + \beta D^2$, where β is a radiation-independent quantity. It has, however, been observed that β changes with radiation type. In this paper we propose an explanation of this discrepancy. Specifically, we suggest that dual radiation action-type processes where β is variable are the result of a mechanism - termed compound dual radiation action - which consists of a sequence of simple dual radiation action processes, each process being the causative agent for the next one. The sequence, single-strand DNA breaks, double-strand DNA breaks (chromosome breaks), and exchange-type chromosomal aberrations, is one such example examined in the paper.

**A Mathematical Formalism Describing the Yield of
Radiation-Induced Single- and Double-Strand DNA Breaks,
and Its Dependence on Radiation Quality**

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MASTER

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Radiat. Res. 134:1-8, 1993

The purpose of this paper is to describe mathematically the observed dependence of the number of DNA single-strand breaks (SSBs) per unit dose on radiation quality (e.g., LET) by invoking the concept of matrix saturation (i.e., the fact that a nucleotide can be the site of one SSB only and therefore further local energy deposition is wasted), and to show that, based on this, one obtains a characteristic variation of the yield of DNA double-strand breaks with variation of LET, in qualitative agreement with certain experimental determinations. The formalism developed here makes use of methodology from the field of integral geometry, introduced by Kellerer (Radiat. Prot. Dosim. 31:9-16, 1990) in microdosimetry.

A Study of the Excited States in Cytosine and Guanine Stacks in the Hartree-Fock and Exciton Approximations

Marjan Grobelsek-Vracko and Marco Zaider

Radiat. Res. 138:18-25, 1994

We report calculated exciton energies for the cytosine and guanine stacks obtained in the *ab initio* Hartree-Fock crystal orbital and exciton approximation, which includes the excited electron-hole interaction. This interaction plays an important role in description of excited electron spectra in the low-energy region. The stacks were chosen as examples of polymers with helical symmetry.

Nanodosimetry of Radon Alpha Particles

M. Zaider and Matesh N. Varma

Indoor Radon and Lung Cancer: Reality or Myth?
In 29th Hanford Symposium on Health and the Environment
October 15-19, 1990
Part 1
(Frederick T. Cross [Ed.])

It is currently accepted that energy deposition at the nanometer level (rather than conventional microdosimetry) determines the biological effects of ionizing radiation. Many previously established experimental techniques (e.g., the Rossi proportional counter) or theoretical methods (e.g., simplified calculations using the continuous slowing-down approximation (CSDA) are inapplicable to the study of nanodosimetry. The peculiarities of the geometry of exposure to radon progeny further complicate the

problem. This is because the conditions under which several "classical" models of radiation action are obtained (e.g., the alpha-beta formulation of the Theory of Dual Radiation Action, which is built on microdosimetry) are no longer valid. It thus becomes clear that not only new techniques but new concepts are required to describe the effects of radon alpha particles.

In this paper we discuss a number of computational aspects specific to radon nanodosimetry. In particular, we describe the novel concept of "associated surface" (AS) which is necessary for efficiently converting Monte-Carlo-generated particle tracks to nanodosimetric spectra. The AS is the analog of Lea's associated volume, applied to radiation sources subject to the geometrical restrictions or internal exposure.

We systematically analyze factors affecting the nanodosimetry of radon progeny, such as the distance between the radioactive source and the sensitive volume, the size of the sensitive volume, and CSDA versus full Monte-Carlo track generation.

Application of the HSEF to Assessing Radiation Risks in the Practice of Radiation Protection

V. P. Bond, M. Varma, L. E. Feinendegen, C. S. Wu, M. Zaider

Health Phys. 68(5):627-631, 1995

The primary risk coefficients upon which exposure limits for radiation purposes are currently based are derived almost exclusively from cancer-induction data obtained from human populations exposed to radiation of low linear energy transfer. The question of higher linear energy transfer radiations is handled by means of quality factors derived from values for relative biological effectiveness obtained from animal data. However, the advent of microdosimetry has made it possible to establish hit size effectiveness functions from single-cell systems, both *in vitro* and *in vivo*. This type of function can substitute complete for the concept of relative biological effectiveness, Q and equivalent dose. A common basis for risk coefficients and the hit size effectiveness function lies in the fact that human cancers are monoclonal and thus single cell in origin. The present communication utilized this common base as a means of extending the present low-linear energy transfer based risk coefficients to include carcinogenic responses from exposure in radiation fields of any one or mixed qualities, extending from the smallest to the largest linear energy transfers of practical consequence. In doing so, risks from ionizing radiations of any linear energy transfer may be predicted more accurately than at present.

Carcinogenic Risk Coefficients at Environmental Levels of Radon Exposures: A Microdosimetric Approach

Marco Zaider and Matesh N. Varma

Health Phys 70(6):837-844, 1996

We report a microdosimetric-based evaluation of the effects of domestic exposure to radon. The risk coefficients obtained here are based on the microdosimetry of radon progeny alpha particles, on a function $q(y)$ for *in vivo* radiogenic neoplasia, and on scaling A-bomb results (epidemiology + microdosimetry) to radon exposure. We do not use miner data, nor do we invoke such notions as quality factors, dose equivalent or equivalent dose. With basal cells as targets our estimated risk coefficients are in good agreement with the miner data, and thus a quality factor of about 20 (as suggested by ICRP 60) is not unreasonable. However, if we take as targets the secretory cells our risk coefficients are twice as large as those reported by BEIR-IV. The main uncertainty in these estimates remains the dosimetric model.

Hit-Size Effectiveness Approach in Radiation Protection

M. N. Varma, V. P. Bond, L. A. Braby, L. Feinendegen and M. Zaider

J. Radiol. Prot. 13(4):243-258, 1993

This paper is a review of the hit-size effectiveness (HSE) approach as applied to radiation protection. Topics discussed include: the rationale for the HSE method, the mathematical description of the formalism, biological end points relevant for the application of HSE in radiation protection, and theoretical and experimental methods for obtaining microdosimetric spectra. The application of HSE requires a mathematical unfolding algorithm. Of several methods proposed we have selected a technique based on Bayesian and maximum entropy methodology; this bias-free approach is described. By way of illustration we present a catalogue of currently available HSE functions for different end points: cellular reproductive inactivation, mutation, chromosome aberrations and neoplastic cellular transformation. In each case, we indicate the sensitivity of the result to the selected size of the sensitive volume, taken for simplicity as spherical. From this analysis we conclude that the site size plays only a minor role in selecting the appropriate HSE function; it follows that practical means (e.g., microdosimetric proportional counters) are already at hand to implement the HSE formalism in radiation protection and health physics.