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Neutron Interactions with Biological Tissue

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PROJECT OBJECTIVES

To obtain information about the physical stage of neutron interactions with tissue through secondary charged particles. We use theoretical calculations whose input includes neutron cross section data; range, stopping power, ion yield, and straggling information; and geometrical properties. Outputs are "initial" and "slowing-down" spectra of charged particles, kerma factors, average values of quality factors, microdosimetric spectra, and integral microdosimetric parameters such as $\bar{y}_F$, $\bar{y}_D$, y^*. Since it has become apparent that nanometer site sizes are more relevant to radiobiological effects, the calculations of event size spectra and their parameters have been extended to these smaller diameters. This information is basic to radiological physics, radiation biology, radiation protection of workers, and standards for neutron dose measurement.

ACCOMPLISHMENTS

- Neutron kerma factors (energy transfer coefficients) used worldwide for neutron dosimetry
- Katz used neutron-induced secondary particle spectra to predict cellular neutron effects by delta-ray interaction model
- y spectra serve as standard for health physics analysis of radiation fields using tissue-equivalent proportional counters (state-of-the-art method)
- Neutron code led to radon code. W. Hofmann (U. of Salzburg) uses our results with his effect-specific track-length model to predict radon carcinogenesis in bronchial epithelium

Track structure effects in neutron microdosimetry and nanodosimetry. This is an investigation of the effect of proton energy-loss straggling and the associated transport of energy by secondary electrons on neutron event-size distributions in small sites. W. Wilson of Pacific Northwest Laboratory and H. Paretzke of GSF, Munich have developed an analytic model for the ionizations or energy depositions produced in nanometer-size sites for protons and alpha particles which summarizes the results of hundreds of Monte Carlo calculations. The Wilson-Paretzke modes has been used to generate event-size distributions for monoenergetic protons with a given chord length within a sphere of fixed diameter. Their

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distributions have been fitted with log normal distribution functions and the parameters of the log normal function are fitted analytically as a function of proton energy, sphere diameter, and chord length. These proton spectra are then used in a modified Caswell-Coyne code to generate event-size distributions for neutrons which include not only the effect of energy-loss straggling but also the transport of energy out of and into the cavity by the secondary delta rays. Wilson and Paretzke have also analyzed data for "touchers" or "passers" for protons and these are included in our calculations as well.

It has been clear for some time that, although the cell nucleus is of the scale of microns, say 8 µm, to understand the biological effects of ionizing radiations we need to consider as well smaller structures such as DNA (2 nm spacing between the strands) and nucleosomes (5-10 nm). For neutrons the situation is more complicated than for protons, for example, because of the many secondary particles produced by neutron interactions, the most important being p, α, C, N, and O.

Using the Wilson-Paretzke model combined with our analytic neutron code, we have calculated the spectra of neutron energy depositions in nanometer-size cavities for neutron energies from 0.5 MeV to 20 MeV. Most of our calculations are for site sizes ranging from 10 nm to 1000 nm. We are studying the question of what is the meaning of an energy deposition spectrum for site sizes as small as 2 nm. Perhaps only ionization frequency needs to be considered. Our latest work has been summarized in a paper, Randall S. Caswell and Stephen M. Seltzer, "Monte Carlo and Analytic Methods in the Transport of Electrons, Neutrons, and Alpha Particles" which is to be published in the Proceedings of the Monte Carlo Workshop, held April 27-29, 1993 in Irvine California (Plenum Press).

We are also making some comparisons of results with other calculations (Morstin and Olko) and experimental measurements (Kliauga).

The computer program is operational on both the Cray Y-MP and Convex C3820 computers at NIST, although the Cray is preferred because of the greater speed and longer word length.

Energy deposition spectra and their moments for fast neutrons. Using calculated charged particle initial spectra and slowing-down spectra we can calculate the energy deposition in spherical cavities. The spectrum obtained is sometimes called the single event spectrum or a distribution of dose versus y, the lineal energy. The frequency mean of this spectrum, $\bar{y}_F$, the dose average, $\bar{y}_D$, and the dose average including saturation correction, y^*, can then be calculated. These quantities are closely related to the Kellerer-Rossi parameters $\bar{z}_F$, ζ_s and ζ^*. We calculate these spectra and their moments for neutron energies up to 20 MeV and for cavity sizes in the range of .5 µm to 30 µm. Systematic calculations have been carried out of the energy deposition spectrum, $f_1(\epsilon)$, and the parameters $\bar{y}_F$, $\bar{y}_D$, and y^* over the range of energies and sensitive volume sizes cited using bin-averaged neutron cross sections.

Study of Relation to Biology and Biophysical Models of Neutron Energy Deposition Calculations. Stephen M. Seltzer, who is well-known in the field of radiation transport calculations, and Lisa R. Karam, who has broad experience in radiation biochemistry, and R.

S. Caswell, all participants in this project, have formed a small study group on biophysical and biochemical models of radiation interaction. Dr. Karam is teaching the two physicists molecular biology and radiation biochemistry, and Seltzer and Caswell are discussing neutron microdosimetry, neutron nanodosimetry, and biophysical models of radiation interaction. We also interact with Professor Werner Hofmann from the University of Salzburg on biophysical models of radiation carcinogenesis, which are primarily for the radon problem, but are relevant to neutron health effects. Steve Seltzer has reported on the Lethal, Potentially Lethal (LPL) model of Stan Curtis to a Science Subpanel of the Committee on Interagency Radiation Research and Policy Coordination (CIRRPC) studying Fluence-Based Risk Assessment. These discussions have been exceedingly interesting so far, and we anticipate that they will lead to significant insight into the biological effects of ionizing radiation and to new approaches to the subject of "Neutron Interactions with Biological Tissue".

RECENT PUBLICATIONS

1. Caswell, R. S. and Coyne, J. J., Microdosimetry of Radon and Radon Daughters, **Radiat. Prot. Dosim. 31**, Nos. 1-4, 395-398 (1990).*

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3. Coyne, J. J., Gerstenberg, H. M., Hansen, J., and Zoetelief, J., Calculations of the Relative Effectiveness of Alanine for Neutrons with Energies up to 17.1 MeV, **Radiat. Prot. Dosim. 31**, Nos. 1-4, 85-89 (1990).

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6. Coyne, J. J. and Caswell, R. S., "Neutron Energy Deposition on the Nanometer Scale", **Radiat. Prot. Dosim. 44**, 49-52 (1992)

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10. Caswell, R. S. and Seltzer, S. M., "Monte Carlo and Analytic Methods in the Transport of Electrons, Neutrons, and Alpha Particles", **Proceedings of the Workshop on Monte Carlo Methods in Track Structure**, Plenum Press (in press).

11. Caswell, R. S., "Neutron Dosimetry: Past and Present," Invited Refresher Course Series, **Radiation Research Society 42nd Annual Meeting**, Nashville, Tennessee, 4 May, 1994.

*These are applications of the analytic method developed for neutrons to the problem of radon.