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U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology

Neutron Interactions with Biological Tissue

ACHIEVEMENTS Progress Report — 1992-1993 DOE/ER61528-1

1. 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 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

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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 have also begun 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.

2. 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, 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.

A library of y spectra as a function of neutron energy has been generated for a 1 μm cavity for energy deposition in tissue and for ionization yield for a inhomogeneous tissue-equivalent proportional counter. This library of y spectra is intended to be published as an NIST Internal Report, and will also be available on diskette. This work was set aside this year in favor of pursuing the track structure effect studies described above. We do intend to complete this work in the coming year.

3. 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".

FUTURE PLANS

1. Track Structure Effects in Nanodosimetry. In collaboration with Wilson and Paretzke the results of their proton and alpha particle track structure calculations are being used in our analytical code for neutrons especially in the site-size region of 100 to 2 nm. Both "crosser" and "passer" events are included. Some of this work has been reported in paper No. 11 listed below. We are aiming at a comprehensive paper on these results for Radiation Research.

We are planning this coming year to modify the computer program to give results in numbers of ionizations, for example, to calculate 2 or more ionizations in a 2 nm site, corresponding to double-strand breaks in DNA.

2. Libraries of Event-Size Spectra. For 1 μm cavity a complete library of the final y-spectra for all neutron energy bins has been prepared, so that the event-size spectra for any energy-distributed neutron spectrum can be calculated by adding together these y-spectra with the proper weights. Using this library of y-spectra various microdosimetric parameters are being calculated as a function of neutron energy. The parameters which will be calculated are $\bar{y}_F$, $\bar{y}_D$, y^*, and Q, using an appropriate definition for obtaining Q from an event-size spectra as a function of lineal energy. These spectra will be published as in NIST internal report (NISTIR). This work is expected to be finished in the current year.

3. Relation to Biology and Biophysical Models of Neutron Energy Deposition Calculations. As indicated earlier, the three members of this project have formed a small study group on biophysical and biochemical models of radiation action related to the neutron energy deposition problem (and also to radon carcinogenesis). We plan to continue this study of molecular biology, radiation biochemistry, neutron microdosimetry and nanodosimetry, and

biophysical models of radiation interaction. We are studying approaches to bridging the gap between the theoretical physics of energy depositions and radiation transport and the biological consequences of the irradiation. Use of our calculations as input to biophysical models such as the Katz delta-ray model, the Hofmann and Crawford-Brown effect-specific interaction model, and the Hit Size Effectiveness Function of Bond, Varma, and others all make some contribution. However, approaches on the level of molecular biology may also be needed to reach from the fundamental physics of neutron interactions to predictions of cell transformation and the problem of the induction of cancer by ionizing radiation.

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).*

2. Coyne, J. J., Caswell, R. S., Zoetelief, J., and Siebert, B.R.L., Improved Calculations of Microdosimetric Spectra for Low-Energy Neutrons, Radiat. Prot. Dosim. 31, Nos. 1-4, 217-221 (1990).

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).

4. Schuhmacher, H., Kunz, A., Menzel, H. G., Coyne, J. J., and Schwartz, R. B., "The Dose Equivalent Response of Tissue-Equivalent Proportional Counters to Low- Energy Neutrons," Radiat. Prot. Dosim. 31, Nos. 1-4, 383-387 (1990).

5. Caswell, R. S. and Coyne, J. J., "Alpha Particle Spectra and Microdosimetry of Radon Daughters", in Indoor Radon and Lung Cancer: Reality or Myth? (Battelle Press, Columbus, Richland, Washington, 1992), pp. 279-289.*

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

7. Caswell, R. S. and Lewis, V. E., "Neutron Measurement Intercomparisons Sponsored by CCEMRI Section III (Neutron Measurements)", Radiat. Prot. Dosim. 44, 105-110 (1992).

8. McDonald, J. C., Murphy, M. K., Braby, L. A., Coyne, J. J.,

Caswell, R. S. and Eisenhauer, C. M., "Comparison of Measured and Calculated Event Size Distributions for Monoenergetic Neutrons", Radiat. Prot. Dosim (in press).

9. Caswell, R. S., Karam, L. R. and Coyne, J. J., "Systematics of Alpha-Particle Energy Spectra and Lineal Energy (y) Spectra for Radon Daughters", Radiat. Prot. Dosim. (in press).*

10. Hofmann, W., Nösterer, M., Ménache, M. G., Crawford-Brown, D. G., Caswell, R. S. and Coyne, J. J., "Microdosimetry and Cellular Radiation Effects of Radon Progeny in Human Bronchial Airways", Radiat Prot. Dosim. (in press).*

11. 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).

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

RELATED ACTIVITIES

R. S. Caswell is Chairman, Science Panel, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC), Office of Science and Technology Policy; also alternate member of the main committee of CIRRPC.

S. M. Seltzer is a member of the CIRRPC Science Subpanel on the Use of Particle Fluence for Radiation Risk Assessment.

R. S. Caswell is a member and Secretary of the International Commission on Radiation Units and Measurements (ICRU).

S. M. Seltzer is a member and R. S. Caswell is a sponsor of the ICRU Committee which prepared ICRU Report 49, Stopping Power for Protons and Alpha Particles (1993).

S. M. Seltzer is a member and R. S. Caswell is a sponsor of the ICRU Committee, Beta-Ray Dosimetry for Radiation Protection.

R. S. Caswell is a sponsor of the following active ICRU committees:

Stopping Powers for Heavy Ions
Absorbed Dose Standards for Photon Irradiation and Their Dissemination

In Situ Gamma Ray Spectrometry in the Environment
Medical Applications of Beta Rays

R. S. Caswell is an honorary member of the National Council on Radiation Protection and Measurements (NCRP).

Neutron interactions with biological tissue

<950>The first area of research focuses on 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. Secondly, energy deposition spectra and their moments for fast neutrons are investigated. Using calculated charged particle initial spectra and slowing-down spectra the authors can calculate the energy deposition in spherical cavities. Lastly, an attempt was made to study the relation of neutron energy deposition calculations to biology and biophysical models.