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Thindown in Biological 1-Hit Detectors: *E. Coli* B/r and Bs-1*

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Thindown in biological 1-hit detectors: *E. Coli* B/r and Bs-1*

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According to the theory of Butts and Katz[1] and the new radial dose distribution of Zhang *et al.*[2], we have calculated inactivation cross sections for the heavy ion bombardment of *E. Coli* B/r and Bs-1 which was in agreement with the measurements of Schäfer *et al.*[3], made with ions from O to U at energies from 1.5 to 19.5 MeV/u. The data display "thindown", and the decrease in cross section with an increase in stopping power is accompanied by a decrease in energy of a bombarding ion. Following an earlier analysis of heavy ion bombardments of these *E. Coli* mutants with low atomic number ions at energies neighboring 10 MeV/u by Katz and Zachariah[4], it can be seen that these bacteria act as 1-hit detectors on the response of these bacteria to ions of lower atomic number and LET where thindown is not exhibited. The analysis of thindown in these bacteria is much clearer than that in the case of mammalian cells because of the relative simplicity of the structure of these bacteria as compared to the complexity of mammalian cell structure. The significance of studying the thindown of *E. Coli* is to get further understanding of the radiation action in biology.

1 Theory

The theory of the 1-hit detector has been described by Butts and Katz[1]. As all of the track theory, we take it that dose is an appropriate quantity for the description of effects produced in bulk matter by γ rays and by the effects produced by δ rays in the region about an ion's path. When we speak of the dose of δ rays surrounding an ion's path we image that we study the energy deposited in nests of coaxial cylindrical shells surrounded by many ions. Thus the dose of δ rays within a shell is an average quantity, over a synthetic large volume made up of equivalent shells about many ions. We use the effect produced in a macroscopic large volume by a dose of γ rays to estimate the effect

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produced in the shell about our typical averaged ion. That effect is the probability of activating a target as a function of the macroscopic dose. By combining the dose-effect relationship for γ rays and the radial distribution of dose we find the radial distribution of inactivation probability. Since the radial distribution of dose falls off nearly quadratically with radial distance, we compensate for the difference in dose on opposite sides of a target by finding the average dose experienced by a hypothetical target, taken for convenience in calculation to be a short cylinder whose radius is a_0, and whose axis is parallel to the ion's path. Because of the gradient in radial dose the average energy deposited in a target must be calculated to estimate the inactivation probability as a function of distance from the ion's path, called an "extended target" calculation. The probability for inactivation cross section being such an extended target is integrated radially, to find the theoretical value of inactivation cross section, σ. While a_0 is expected to lie in the neighborhood of the actual target size we do not expect that it is a precise representation of the size of an actual target[5,6]. In many cases it is possible to calculate the cross section from the point distribution of dose, especially at larger distances the difference in dose across the target may be neglected. In concept our present calculations do not differ from many earlier presentations for 1-hit detectors. The central difference is the use of a new calculation for the radial distribution of dose by Zhang *et al.*[2]. A logarithmic polynomial is used to describe the range-energy relationship for electrons. The δ rays are taken to be ejected according to an angular distribution given by classical collision kinematics, and thenceforth move in straight lines, with scattering neglected. Calculation then proceeds by numerical integration. The results of these calculations in general do not differ greatly from the results of an earlier calculation by Zhang *et al.*[7] though it is a significant improvement in the calculation that a single formulation applies to ions of all energies. These are somewhat in better agreement with the measurement of the radial dose distribution. The central difference in the results arises from the incorporation of an angular distribution for the ejected δ rays resulting in a reduction of the cutoff radial distance for energy deposition by factors 3 to 5, depending on the incident energy of the particle. This is of greatest significance for calculations of cross sections in the thindown region, which is the focus of the present work.

2 Results and discussion

As in the work of Katz and Zachariah[4] we have taken the target size parameter a_0 to be 0.5 μm. In that work the D-37 doses for γ rays were taken from measurements of Takahashi *et al.*[8] to be 36.5 Gy for B/r and 12.6 Gy for Bs-1. These values differ from those reported by Schäfer *et al.*, which are 47.6 and 12.6 Gy, respectively. We have no explanation for this discrepancy. In the present work in which we calculate cross sections for comparison with the measurements of Schäfer *et al.* we have chosen to base our calculations on their measured D-37 doses. For best visual agreement with the reported

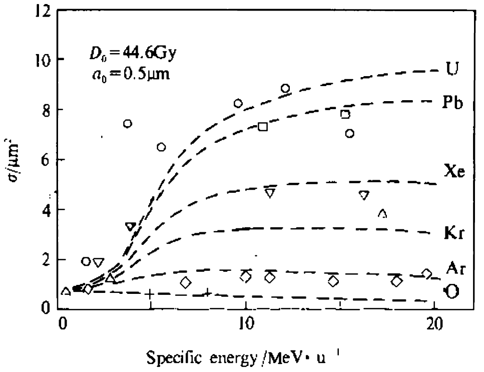

Fig. 1. Inactivation cross section vs. incident energy for *E. Coli* B/r. Experimental data are plotted as points while theory is plotted as curves.

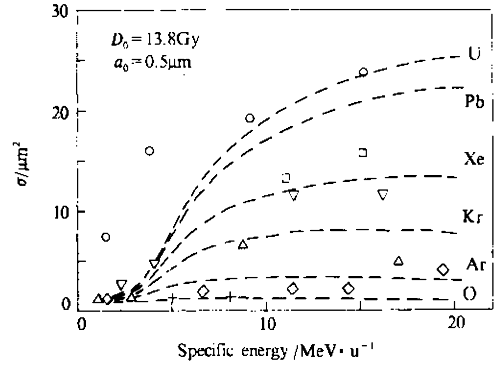

Fig. 2. Inactivation cross section vs. incident energy for *E. Coli* Bs-1.

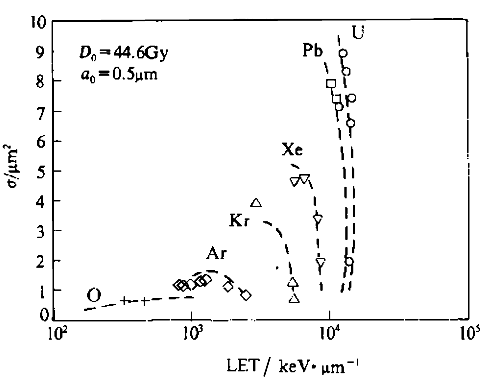

Fig. 3. Inactivation cross section vs. LET for *E. Coli* B/r.

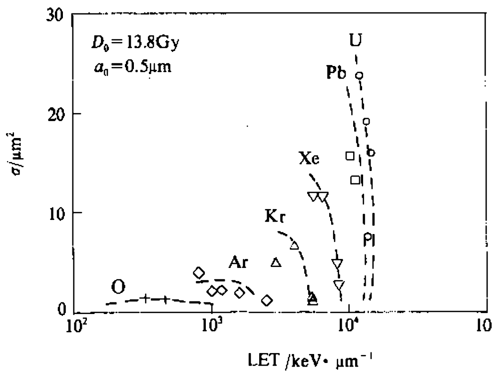

Fig. 4. Inactivation cross section vs. LET for *E. Coli* Bs-1.

cross sections we have chosen adjusted values of 44.6 and 13.8 Gy respectively, about 8% less than the measured values of these authors.

Both measured and calculated values are shown in figs. 1 and 2 where σ is plotted against specific energy of the bombarding ion, as plotted by the original authors, and in figs. 3 and 4 where σ is plotted against LET to display thindown in a customary setting. While there are a number of discrepancies between experimental values plotted as points, and theoretical calculations plotted as curves, the overall agreement between theory and experiment is gratifying. It is reasonable to claim that the theory is generally in agreement with the experiment.

References

1 Butts, J. J., Katz, R., Theory of RBE for heavy ion bombardment of dry enzymes and viruses, *Radiat. Res.*, 1967, 30(4): 855.

2 Zhang Chunxiang, Liu Xiaowei, Li Mianfeng *et al.*, Numerical calculation of the radial distribution of dose around the path of a heavy ion, *Radiat. Prot. Dosim.*, 1994, 52(1— 4): 93.

3 Schäfer, M., Facius, R., Bücker, H., Inactivation of *E. Coli* cells by heavy ions with different radiosensitivities, *GSI Scientific Report*, 1986, GSI 87-1 March 1987. ED. U. Grundinger, Gesellscharft für Schwerionenforschung mbH,

6100 Darmstadt.
4 Katz, R., Zachariah, R., Experimental and theoretical cross sections for *Escherichia Coli* mutants B, B/r, and Bs-1 after heavy-ion irradiation, *Radiat. Res.*, 1993, 134(3): 261.
5 Waligorski, M. P. R., Kim Sun Loh, Katz, R., Inactivation of dry enzymes and viruses by energetic heavy ions, *Radiat. Phys. Chem.*, 1987, 30(3): 201.
6 Katz, R., Dunn, D. E., Sinclair, G. L., Thindown in radiobiology, *Radiat. Prot. Dosim.*, 1985, 13(1—4):281.
7 Zhang Chunxiang, Dunn, D. E., Katz, R., Radial distribution of dose and cross-sections for the inactivation of dry enzymes and viruses, *Radiat. Prot. Dosi.*, 1985, 13(1—4): 215.
8 Takahashi, T., Yatagai, F., Konno, S., Microdosimetric considerations of effects of heavy ions on microorganisms, *Adv. Space Res.*, 1986, 6(11): 117.