COO-1671-71

THEORY OF RBE

Progress Report

Robert Katz

University of Nebraska

Lincoln, Nebraska

1 January 1976 - 31 December 1976

PREPARED FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

UNDER CONTRACT NO. E(11-1)-1671

September 1976

DISCLAIMER

DISCLAIMER

Theory of RBE

Abstract

for

Technical Progress Report

USERDA Contract No. E(11-1)-1671

September 1976

Experimental studies of emulsion-processing combinations have demonstrated that a range of hittedness, from 1 to 8-or-more, can be achieved with specially processed nuclear research emulsions of the Ilford K series, encompassing the range of supralinear response displayed by biological cells. In analogy with the response of biological cells to high LET radiations, the processes of ion-kill and gamma-kill have been displayed for these emulsions, in that x-rays blacken emulsion in circumstances that single alpha-particles, or even single fission fragments, leave no visible track. Track structure theory, and the theory of RBE have been extended to these multi-hit detectors.

Supralinearity in thermoluminescent dosimeters has been tentatively identified as due to a population of 2-or-more hit trapping sites, coexisting with the linear 1-or-more hit sites. Inferences from this identification, that the response to high-LET radiations is linear, and that 2-hit sites must display an "RBE" greater than 1, are consistent with some experimental observations. This is a second solid state detector having the capacity to mimic the response of biological systems, identified from the theory of RBE.

Theory of RBE

Technical Progress Report

USERDA Contract No. E(11-1)1671

September 1976

1. There has been no deviation in program from that proposed in the renewal application, either in technical content or in the level of expenditure. The principal investigator has spent 0.3 time on the project during the academic year and 1.0 time on the project in June 1976.

2. Following is an index of papers and reports:

R. Katz, B. Fullerton, R. A. Roth, and S. C. Sharma, Simplified RBE-Dose Calculations for Mixed Radiation Fields, Health Physics 30, 148-150 (1976).

R. A. Roth, S. C. Sharma, and R. Katz, Systematic Evaluation of Cellular Radiosensitivity Parameters, Phys. Med. Biol. 21, 491-503 (1976).

R. Katz and F. E. Pinkerton, Response of Nuclear Emulsion to Ionizing Radiations, Nucl. Instr. and Methods 130, 105-119 (1975).

L. Larsson and R. Katz, Supralinearity of Thermoluminescent Dosimeters, Nucl. Instr. and Meth. In press.

COO-1671-65 R. A. Roth, S. C. Sharma, and R. Katz, Systematic Evaluation of Cellular Radiosensitivity Parameters, pp. 953-976 Proceedings Fifth Symposium on Microdosimetry, Euratom 1975.

COO-1671-62 R. Katz and F. E. Pinkerton, Response of Nuclear Emulsions to Ionizing Radiations, pp. 195-216, Proceedings Fifth Symposium on Microdosimetry, Euratom 1975.

COO-1671-66 R. Katz, Low Level Effects in Relation to Track Structure Theory, pp. 343-360, in Biological and Environmental Effects of Low Level Radiation, IAEA Vienna 1976.

COO-1671-67 R. Katz et F. Bermann, Un Dosimetre a Large Gamme, Peu Sensible a la Qualite du Rayonnment: L'Alanine, VIII° Congres International de la Societe Francaise de Radioprotection, Saclay, France 1976

COO-1671-68 R. Katz, Track Structure Theory in Radiobiology and in Radiation Detection, Invited Paper, 9th International Conference on Solid State Nuclear Track Detection, Neuherberg, 1976

COO-1671-69 L. Larsson, F. E. Pinkerton, R. Katz and E. V. Benton, Particle Tracks in Supralinear Nuclear Research Emulsions, 9th International Conference on Solid State Nuclear Track Detection, Neuherberg 1976.

COO-1671-70 L. Larsson, F. E. Pinkerton, and R. Katz, Supralinearity in Nuclear Research Emulsions, 9th International Conference on Solid State Nuclear Track Detection, Neuherberg 1976.

COO-1671-71 This report.

3. These continuing investigations into the Theory of RBE play on a single set of themes and variations to achieve a unified theory of track structure, a quantitative formulation of the response of different detectors to radiations of different quality. There is a continuing interplay between our understanding of the response of biological and of physical detectors through which observations and inferences first noted in one realm are extended to the other. The latest example of that interplay is the discovery of detectors having the capacity to mimic the response of biological systems to high LET radiations: first emulsion and then TLD's. From our experience with the theory of RBE in biology we have been able to write a similar theory for many-hit detectors.

Experimental studies of emulsion response have encompassed the full range of the Ilford K series of nuclear emulsions, exposed to heavy ion beams at Berkeley for track studies in emulsions processed according to the customary wet hot-stage Bristol formula, and exposed to x-rays and ^{252}Cf at Lincoln, and processed there by several schemes intended for particle discrimination and fog suppression. We have demonstrated a range of supralinear response in emulsion, to 8-or-more hit, in both processing conditions. In the Lincoln work we have been able to demonstrate gamma-kill, in that emulsion-developer combinations in which the tracks of individual alpha-particles, and even fission fragments are not exhibited can be made to blacken with x-rays. Where single alpha particles from an ^{241}Am source (5.5 MeV) do not leave a developed grain, long exposures to the source blacken the emulsion, presumably where different alpha particle paths intersect in a single grain, and this repeated many times in the exposed region. In this emulsion-developer combination single fission fragment tracks are visible. Thus we have achieved a range of hittedness encompassing biological systems, we have demonstrated the validity of the concepts of ion-kill and gamma-kill in emulsions, concepts first evolved for biology. We have found an emulsion-processing combination whose hittedness and radiosensitivity are within a range resembling the parameters of bacterial spores. We must still find the range of parameter values which can be attained in this system, and the extent to which we can approach the response of mammalian cells to particulate radiations.

Along with our experimental work for emulsions we have extended the theory of particle tracks to multi-hit detectors, and have extended the theory of cellular survival (RBE) in arbitrary radiation environments in the same way. With the growth in intensity and reliability of Bevalac beams, it is intended to test this theory for emulsions in experiments analogous to the radiobiological submarine experiments.

There are other interesting aspects in these sensitometric measurements of emulsions exposed to x-rays and developed with different developers. We have observed disjoint sensitometric curves, that are clear mixtures of response with different hittedness. These may be of fundamental interest in the study of the photographic process. We have found that we can change the shapes of these curves by changes in developer or in development time. Changes not unlike these, in the survival curves of bacteria exposed to x-rays, have been associated with post irradiation culture conditions. From our studies of these disjoint sensitometric curves, we have been stimulated to examine the supralinearity of thermoluminescent dosimeters, whose dose-response curves exhibited similar shapes. In short, we have found that we can decompose the dose-response curves of thermoluminescent dosimeters into a mixture of 1-or-more hit and 2-or-more hit responses, and have been led to suggest that there are separate trap populations, of which the 2-hit traps are responsible for supralinearity. There are supporting observations, similar to radiobiological results, that the supralinearity in the high temperature peaks tends to become linear when the irradiation is with alpha particles instead of beta particles, in a way which is reminiscent of the disappearance of the shoulder of the cellular survival curve when irradiated with high LET radiations. We strongly infer that we have now found a second detector, the supralinear TLD, having the capacity to mimic the response of biological cells to high LET radiations.

Our ability to mimic the response of mammalian cells with multi hit detectors is somewhat constrained by their lack of tissue equivalence. At the moment we are fixing our attention on the response to particulate radiations, especially high LET radiations. In order to extract radiosensitivity parameters most simply from the observations of particle tracks, we are building a track atlas, from computer simulations, where parameters may be identified by recognition, visually. We are attempting to construct a simulation of tracks in a detector made up of bacterial spores. Here certain assumptions about the size and number of sensitive sites must be made, and it remains to be seen whether we can extract some additional information about the radiosensitivity sites in spores from the insights gained from these simulations.

We continue to attempt to apply track theory to new data, and to improve our model, and our computer programs for their reapplication and refinement in relation to older data. Our programs are being streamlined, and improved conceptually. They are being reapplied to 1-hit detectors, especially solid organic scintillators for which new data is becoming available. By comparing theoretical calculations of detector response to data we hope to ascertain limits of validity of the present calculations and to find the directions in which it will be most profitable to move to improve the theory.

Finally, we note that the theory of cellular survival has now been incorporated into computer codes at Oak Ridge, Los Alamos, and Stuttgart for use in cancer therapy, and the associated radiobiological investigations, with fast neutrons, negative pions, and energetic heavy ions.