THE INFLUENCE OF DOSE DISTRIBUTIONS ON THE RESULT OF UV-BIODOSIMETRY

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INTRODUCTION

Disinfection of drinking water with ultraviolet radiation has become a common method in Austria and in many other countries. The water usually is disinfected in flow through systems with low pressure mercury lamps as UV source, which emit predominantly UV radiation with wavelength 253.7 nm. Because of varying residence times of microorganisms and the spacial distribution of fluence rate in the irradiation volume, caused by different distances from the radiation source, by absorption of radiation in the water and by reflexion at the walls of the reactor, the microorganisms passing through in a turbulent flow, receive different fluences. In Austria UV-disinfection plants for drinking water must deliver a minimal dose of 400 Jm^{-2} for radiation of wavelength 253.7 nm (1,2). The fulfillment of this demand is proved during type testing. As dosimeter suspensions of bacterial spores are used whose UV-susceptibility has to be measured in a laboratory irradiation device. The dose, determined in this way, is called Reduction Equivalent Dose (3).

THEORY

If UV-inactivation of microorganisms used as biodosimeter follow first order kinetics their survival rate depends on dose in the following way:

$$\frac{N}{N_0} = e^{-a \cdot D} = 10^{-h \cdot D} \quad (a > 0, h > 0)$$

(N: Number of microorganisms after irradiation, N_0: Number of microorganisms before irradiation, a: UV-susceptibility of microorganisms (base e), h: UV-susceptibility of microorganisms (base 10), D: dose). The Reduction Equivalent Dose (RED) then can be calculated as:

$$RED(f(D),a) = -\frac{1}{a} \cdot \ln\left(\frac{\int_0^\infty e^{-a \cdot D} \cdot f(D) \cdot dD}{\int_0^\infty f(D) \cdot dD}\right),$$

where f(D) is the probability density of the dose distribution. If f(D) is distributed symmetrically, then the expectation value of dose E(D) is equal to the mean value μ of the distribution: $E(D) = \mu$. The expectation value of survival $E(\frac{N}{N_0})$ is:

$$E(\frac{N}{N_0}) = \int_{\mu-k}^{\mu+k} e^{-a \cdot D} \cdot f(D) \cdot dD = e^{-a \cdot \mu} \cdot \int_{-k}^{k} e^{-a \cdot u} \cdot f(u+\mu) \cdot du$$

or, for ξ between 0 and a:

$$E(\frac{N}{N_0}) = e^{-a \cdot \mu} \cdot 2 \cdot \int_0^k \cosh(a \cdot u) \cdot f(u+\mu) \cdot du = e^{-a \cdot \mu} \cdot \cosh(a \cdot \xi)$$

Because of $\cosh \geq 1$ follows:

$$E(\frac{N}{N_0}) \geq e^{-a\cdot\mu} \quad \text{and} \quad \mu \geq RED.$$

If the probability distribution of UV-dose is symmetric, the RED measured with microorganisms with exponential survival rate in general is smaller than the arithmetic mean of the dose distribution.

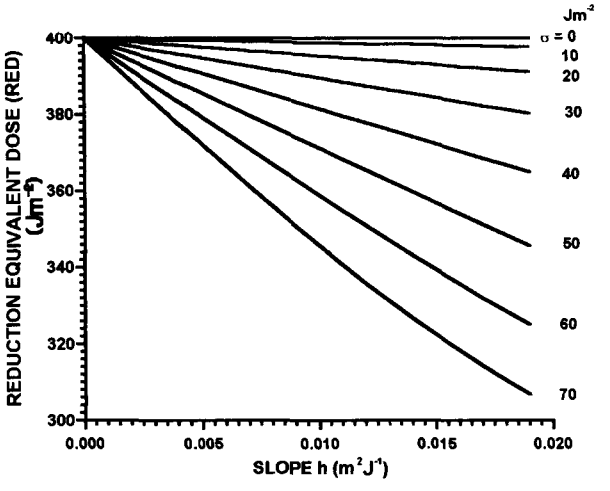

Figure 1. Dependence of RED from UV-susceptibility h of the biodosimeter (shoulder broadness = 200 Jm^{-2}) and from the standard deviation σ of the dose distribution (normal distribution, μ = 400 Jm^{-2}).

MODEL CALCULATIONS

The true shape of the dose distribution among the microorganisms passing a flow through UV-disinfection plant is unknown. Therefore we assumed the presence of normally distributed doses, from which follows:

$$RED_{norm}(h,\mu,\sigma) = -\frac{1}{h}\cdot\lg\left(\frac{\int_0^\infty e^{\frac{-h\cdot D}{\lg e}-\frac{(D-\mu)^2}{2\sigma^2}}\cdot dD}{\int_0^\infty e^{-\frac{(D-\mu)^2}{2\sigma^2}}\cdot dD}\right)$$

Integration was performed by numerical methods and in using survival curves with shoulder. We found a decrease of RED for incresing σ, that is for broader dose distributions and for more susceptible biodosimeters (increasing h). If the dose distribution is very narrow (σ very small) no difference exists between the Reduction Equivalent Dose and the arithmetic mean of of the dose distribution. These results are given in Fig. 1.

MODEL EXPERIMENT

In order to prove these theoretical considerations with an experiment we produced suspensions of spores of *Bacillus subtilis* ATCC 6633 with known dose distributions. The spores were cultivated with two different methods (4) resulting in different UV-susceptibilities

h of the microorganisms. The spores were irradiated in a laboratory irradiation device with doses from 200 to 600 Jm^{-2} and with an increment of 50 Jm^{-2}. Distinct volumina of these suspensions were mixed in order to get suspensions with known and symmetric dose distributions. The resulting discrete dose distribution is shown in Fig. 2.

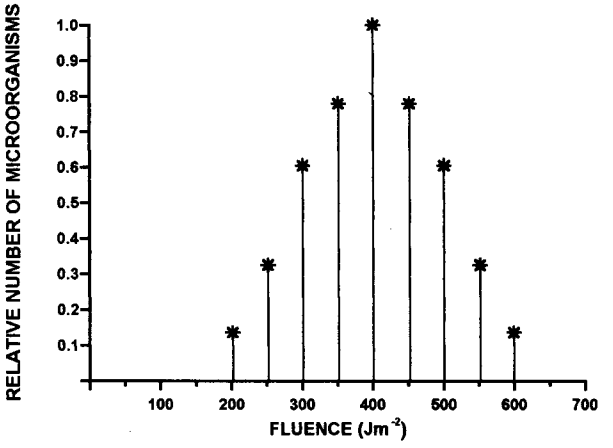

Figure 2. Experimentally produced discrete dose distribution with arithmetic mean $\mu = 400\ Jm^{-2}$.

The REDs following from the survival rate in the experiment were determined and compared with theoretical values. The results are given in Tab. 1. Within the accuracy of the method experimental and theoretical values showed good agreement.

slope h (m^2J^{-1})	μ (Jm^{-2})	RED (calculated) (Jm^{-2})	RED (experiment) (Jm^{-2})
0.0134	401	296	308
0.00687	402	339	337

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