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Appendix

Appendix A. Survival Rate in the "Single-Target Single-Hit" Model

When total cell number is defined as "n", "cell survival rate with a condition of average 1-Hit per 1-Target" means "repeat an event of the probability of 1/n (1-Hit/total cell number) for n times.

$$Pk(x) = {}_nCk(1-\frac{x}{n})^{n-k}(\frac{x}{n})^k \quad \text{(A-1)}$$

Pk(x): probability of x-Hits/Target with a radiation dose that induces x-Hits per a

Target (Gy). n: total cell number.

When a dose that induces avarage 1-Hit per a Target (mean lethal dose in "1-Hit 1-Target" model) was irradiated, the survival rate (cells with 0-Hit) is described as follows;

$$S(1) = \mathrm{P0}(1) = {}_nC0(1-\frac{1}{n})^n\ (\frac{1}{n})^0 \quad \text{(A-2)}$$

S(1): cell survival rate in "1-Target 1-Hit" model with a radiation dose that induces 1-Hit per a Target (MLD: mean lethal dose)

P0(1): probability of cells with 0-Hit with a radiation dose of mean lethal dose.

n: total cell number. e: the base of natural logarithm. ln(e) = 1.

In the case of n = 100.

$$S(1) = (1-\frac{1}{100})^{100} = 0.3660\ 36.6\% \quad \text{(A-3)}$$

In the case of n = ∞.

$$S(1) = \lim_{n\to\infty}(1-\frac{1}{n})^n \text{, substitute } t = -\frac{1}{n},\ S(1) = \lim_{t\to 0}(1-t)^{-1/t},$$

$$\ln S(1) = \lim_{n\to\infty}(1-\frac{1}{n})^n = \lim_{n\to\infty}(\frac{\ln(1+t)-\ln(1)}{t})^n = -\mathrm{f}^1(1) = -1$$

$$\therefore S(1) = \mathrm{e}^{-1} = 0.3678\ (36.8\%)$$

In the case of a radiation dose that induces x-Hits per a Target is irradiated,

$$S(x) = \lim_{n\to\infty}(1-\frac{1}{n})^{nx} = \mathrm{e}^{-x} \quad \text{(A-4)}$$

S(x): cell survival rate in "1-Target 1-Hit" model with a radiation dose of x-Hits/Target.

Constant "k" is a characteristic number different according to species or cell lines.

So, survival curves of various microorganisms are described as follows;

$$S(kx) = \lim_{n\to\infty}(1-\frac{1}{n})^{nx} = e^{-kx} \quad \text{(A-5)}$$

Appendix B. Probability of k-Hits in "1-Target Multi-Hit" Model:

In the "1-Target multi-Hit" model, probability of cells with k-Hits is shown like (A-1).

In the case of n = ∞,

$$\lim_{n\to\infty} Pk(x) = \lim_{n\to\infty}\{{}_nCk\ (1-\frac{x}{n})^{n-k}\ (\frac{x}{n})^{k}\} \quad \text{(B-1)}$$

$$= \lim_{n\to\infty}\{\frac{n!}{(n-k)!*k!}\ (1-\frac{x}{n})^{n-k}\ (\frac{x}{n})^{k}\} = \lim_{n\to\infty}\{(\frac{n}{n})\ (\frac{n-1}{n})\ (\frac{n-2}{n})\ldots(\frac{n-k+1}{n})\ *\ (\frac{x^k}{k!})\ *\ (1-\frac{x}{n})^{n}\ (1-\frac{x}{n})^{-k}\}$$

When n goes to infinity,

a) converges to "1",

b) does not change,

c) converges to "e-x",

d) converges to "1".

$$\therefore\ \lim_{n\to\infty}\ \mathrm{Pk(x)} = \frac{x^k\cdot e-x}{k!} \quad \text{(B-2)}$$

The probability of k-Hits with a dose that induces average x-Hits per a Target is represented as (B-2). The probability of k-Hits in the "single-Target multi-Hit" model is given by Poisson distribution [15]

Appendix C. Fitting of Survival Curves Using the Least Squares Method:

Survival rates are plotted on log-linear scales, so square errors were calculated as follows;

$$E^2 = (\ln \mathrm{S(x)} - \ln \mathrm{Sm(x)})^2 \quad \text{(C-1)}$$

S(x): cell survival rate in "1-Target 1-Hit" model with a radiation dose of x-Hits/Target.

Sm(x): measured (actual) cell survival rate.

E: error between estimated survival rate and measured survival rate.

$$f(x) = \sum_{i=1}^{j} E^2 = \sum_{i=1}^{j}(\ln S(x) - \ln \mathrm{Sm(x)})^2$$

$$= \sum_{i=1}^{j} \{(\ln S(x))^2 - 2 * \ln Sm(x) * (\ln S(x))^2\} \quad \text{(C-2)}$$

Coefficient of (lnS(x)) is positive, so the equation (C-2) is a positive quadratic function of "x"

$\therefore$ f(x) = $\sum_{i=1}^{j} E^2$ becomes minimum when $f^1(x) = 0$

i. In the "multi-Target 1-Hit" model, sum of square errors is represented as follows;

$$g(x) = \sum_{i=1}^{j} E_{Ti^2} = \sum_{i=1}^{j} (\ln S_T(x) - \ln Sm(i))^2 = \sum_{i=1}^{j} \{\ln(1-(1-e^{-kx})^n) - \ln Sm(i)\}^2 \quad \text{(C-3)}$$

ii. In the "1-Target multi-Hit" model, sum of square errors is represented as follows;

$$h(x) = \sum_{i=1}^{j} E_{Hi^2} = \sum_{i=1}^{j} (\ln S_H(x) - \ln Sm(i))^2 = \sum_{i=1}^{j} \{\ln(\frac{kx^i \cdot e^{-kx}}{i!}) - \ln Sm(i)\}^2 \quad \text{(C-4)}$$

ST(x): estimated survival rate with a dose inducing x-Hit/Target in the "multi-Target 1-Hit" model.

SH(x): estimated survival rate with a dose inducing x-Hit/Target in the "1-Target multi-Hit" model.

Sm(x): measured cell survival rate.

ET: Error between estimated survival rate and measured survival rate in the "multi-Target 1-Hit" model.

EH: Error between estimated survival rate and measured survival rate in the "1-Target multi-Hit" model.

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Takuma Nomiya . Biomed J Sci & Tech Res

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