Generic model for population affected by chronic irradiation

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The objective of the study was development of a mathematical model,

which simulates adequately the development of radiation effects in an isolated, chronically exposed population at different dose rates.

The following umbrella endpoints were taken into consideration:

- morbidity,
- reproduction,
- decrease of the population size

The effects caused by chronic irradiation in population are considered to be a result of superposition of three major processes –

- creation of damage by radiation,
- recovery of damage by means of repairing mechanisms,
- natural growth of population

‘Repairing system’ is considered as a complex entity

(a kind of “black box”),

which repairs damage caused by ionizing radiation and other stressors.

Let us consider an **isolated generic population**,

living under **ideal conditions** (no predators, no limitation by food, optimal temperature and other environmental factors),

which is exposed to chronic ionizing radiation with a dose rate *p* (mGy/day)

We assume, that organisms composing the exposed population may be in one of the following states:

- undamaged,
- reversibly damaged,
- lethally damaged

Reversible damages are recovered by the repairing mechanisms, the repairing pool is spent for the repairing processes.

Effect on morbidity of organisms in the population depends on decrease of the repairing pool (in % from its initial value). The ionizing radiation also cause a direct damage to the repairing pool itself.

Reproduction system increases number of normal organisms in the population,

but itself is affected by the ionizing radiation

A system of differential equations describing the effects of chronic radiation exposure on fish population can be written as:

$$\frac{dx}{dt} = -\alpha p x + \kappa y R + \mu \cdot (x_{\max} - x) \cdot F$$

$$\frac{dy}{dt} = \alpha p x - \varepsilon y - \kappa y R$$

$$\frac{dR}{dt} = \mu_r \cdot R \cdot (R_{\max} - R) - \kappa_r \cdot yR - \alpha_r \cdot p \cdot R$$

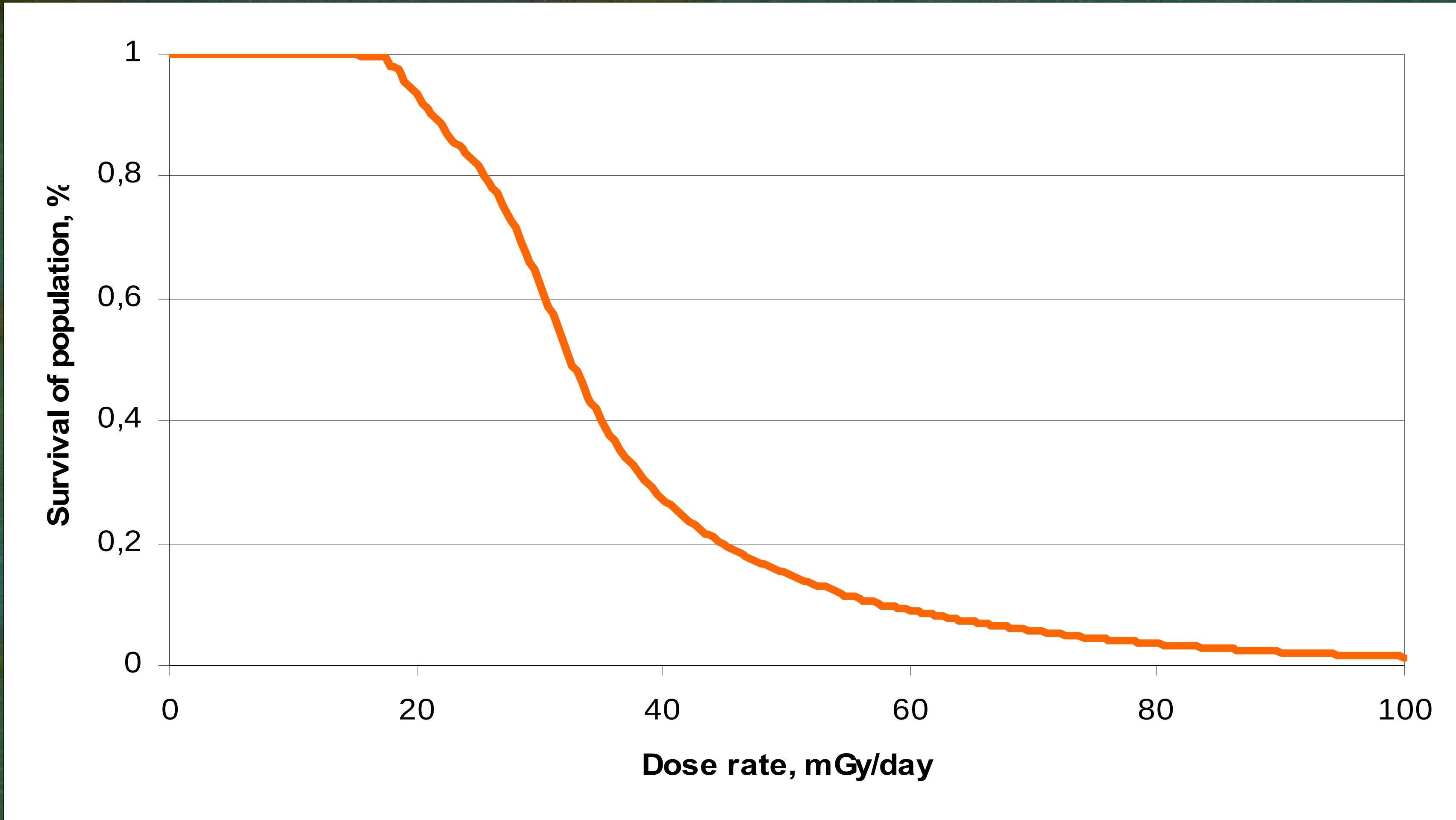
$$\frac{dF}{dt} = -\alpha_f \cdot p \cdot F - \mu \cdot F \cdot (x_{\max} - x) + \mu_f \cdot F \cdot (F_{\max} - F)$$

$$x(0) = x_{\max}; y(0) = 0; R(0) = R_{\max}; F(0) = F_{\max}$$

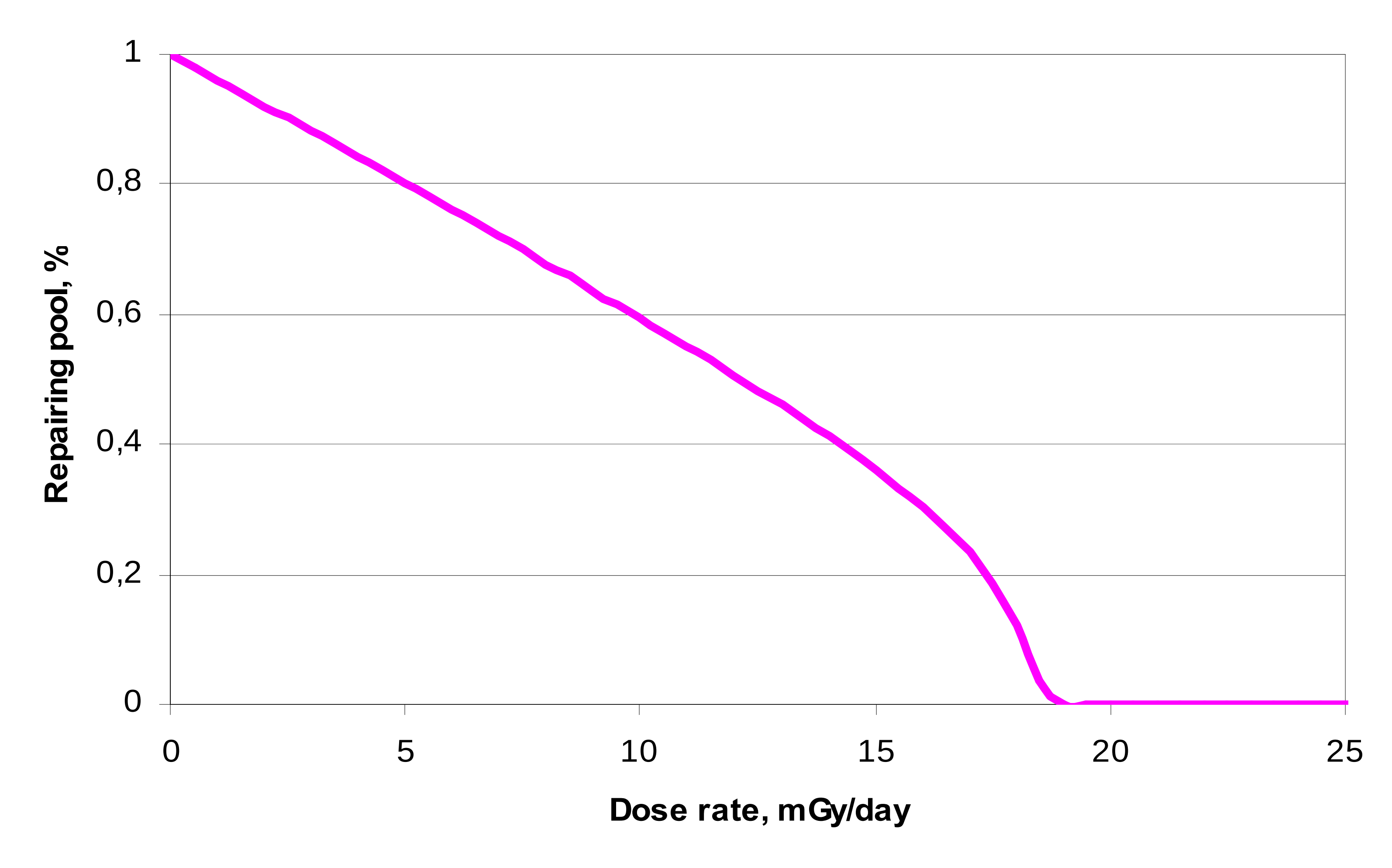
Effect of the chronic radiation exposure on the survival was estimated using the ratio X/X_{max}.

Effects on reproduction were described by the ratio F/F_{max}.

Effects on morbidity were described by the ratio R/R_{max}.



Decrease of population size with the increase of dose rate



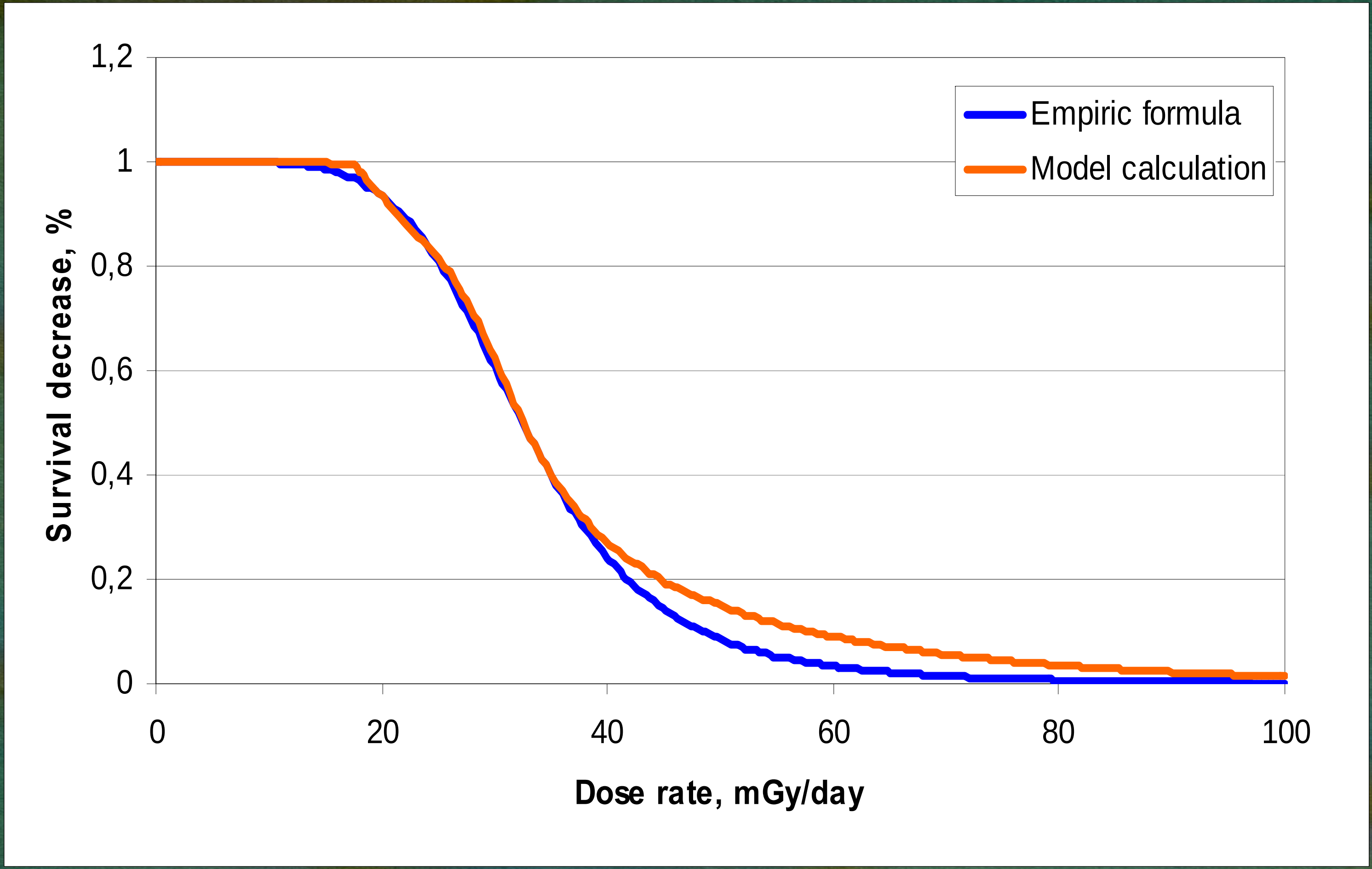
Decrease of repairing capacity with the increase of dose rate

Dose rate – effect curve in general form:

$$X(P) = \frac{1}{1 + (P / P_{50})^{\alpha}}$$

In our model:

P_{50}=32.5 mGy/day; α=5.5



Dose-effect curves obtained from the general empiric formula and from the dynamic population model

Conclusions

Generic population model with repairing of radiation damage can adequately describe the observed dose-effect relationship;

Considerable radiation effects on the survival of an isolated population are predicted to be at dose rates higher than 20 mGy/day