Whack-A-Mole Model: Towards a Unified Description of Biological Effects Caused by Radiation Exposure

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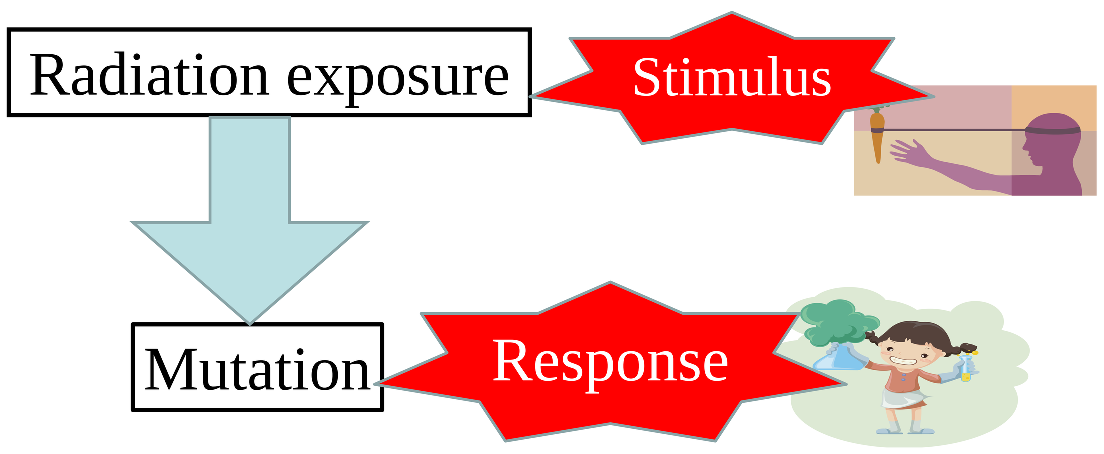
1. Introduction

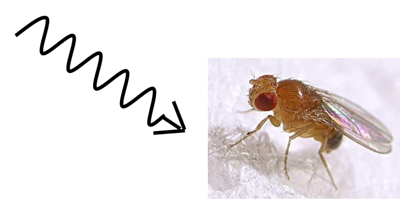
Process of mutation

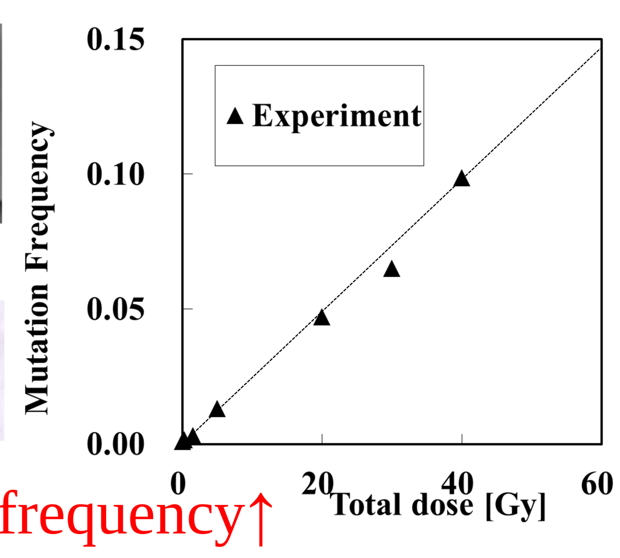


Drosophila experiment of Muller

Science, Vol. 66, p. 84, 1927

X-ray



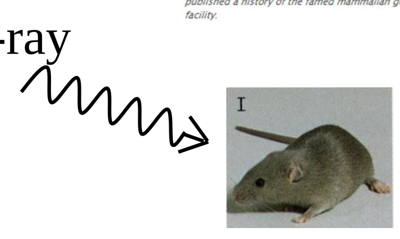


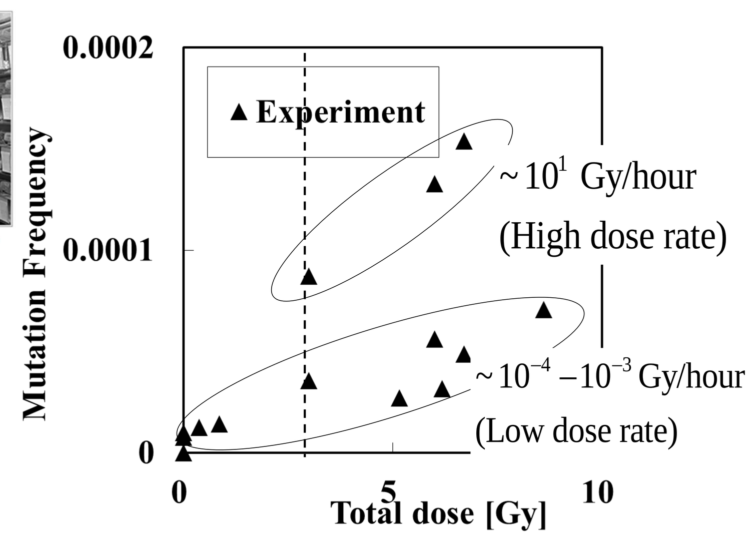
Total dose↑⇒Mutation frequency↑
= LNT（Linear non-threshold）

Mega-mouse experiment of Russell

Pnas, Vol. 79(2), 542-544, 1982

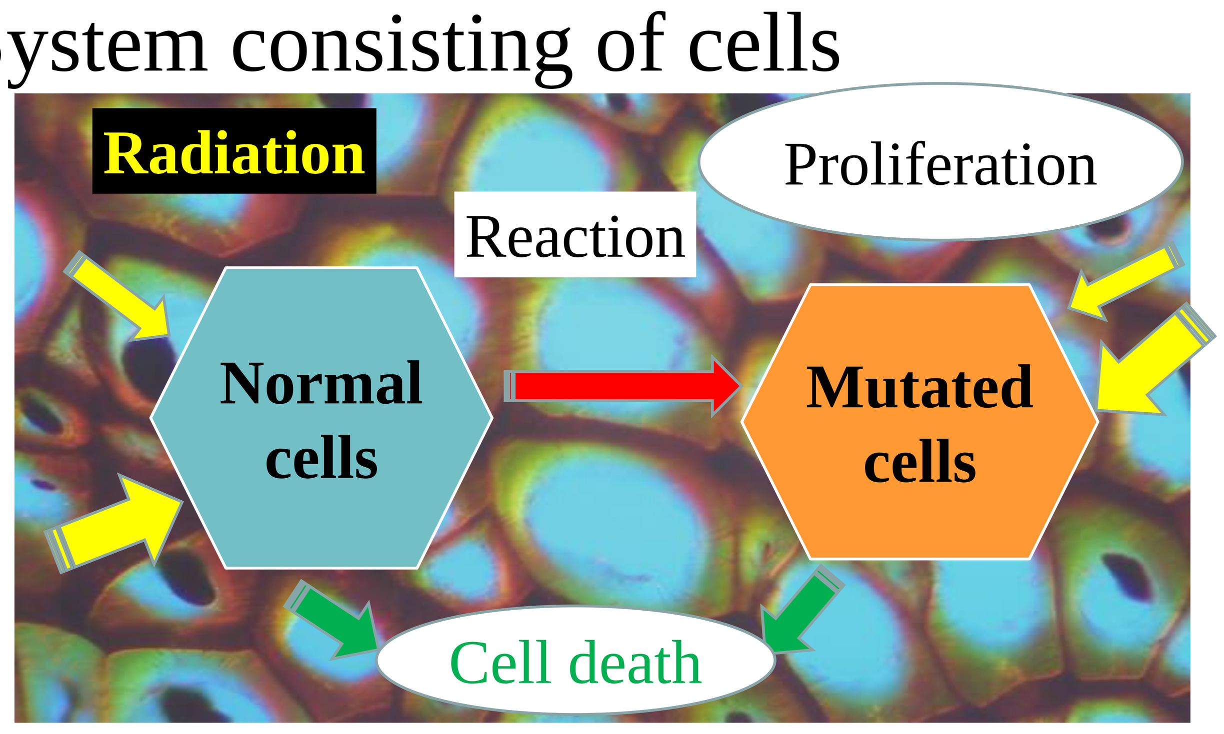
X-ray, γ-ray





Dose-rate↑⇒Mutation frequency↑

System consisting of cells



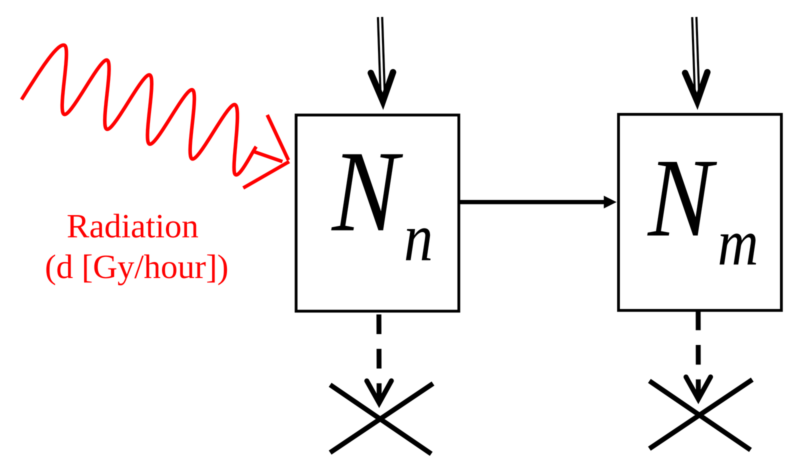
A variety of mechanisms works

We need a mathematical model considering dose rate dependence and a variety of mechanisms at cell level

2. Mathematical formula

Whack-A-Mole (WAM) Model

1. Important variable is dose-rate
2. Transition between Normal cell and mutated cell
3. Proliferation, cell death, recovery effect



N_n :number of normal cell

N_m :number of mutated cell

Basic equation: $\frac{dN_n}{dt} = T_{nn}N_n + T_{nm}N_m,$

$$\frac{dN_m}{dt} = T_{mn}N_n + T_{mm}N_m$$

Applied to mutation frequency F

$$F \equiv \frac{N_m}{N_0}, T_{mn} \equiv a_0 + a_1 d, T_{mm} \equiv -(b_0 + b_1 d)$$

Equation for mutation frequency

Preventative effects :
Mutation frequency is expressed as a differential equation with respect to time.

$$\frac{d}{dt}F(t) = (a_0 + a_1 d) - (b_0 + b_1 d)F(t)$$

$$\frac{dF}{dD} = c\frac{F_0}{D_0}$$

F:mutation frequency

d: Dose rate [Gy/hour]

D:Total dose [Gy]

Solution for mutation frequency

$$F(t) = F(\infty)\left(1 - e^{-(b_0+b_1 d)t}\right) + F(0)e^{-(b_0+b_1 d)t}$$

$$F(\infty) = \frac{(a_0 + a_1 d)}{(b_0 + b_1 d)}$$

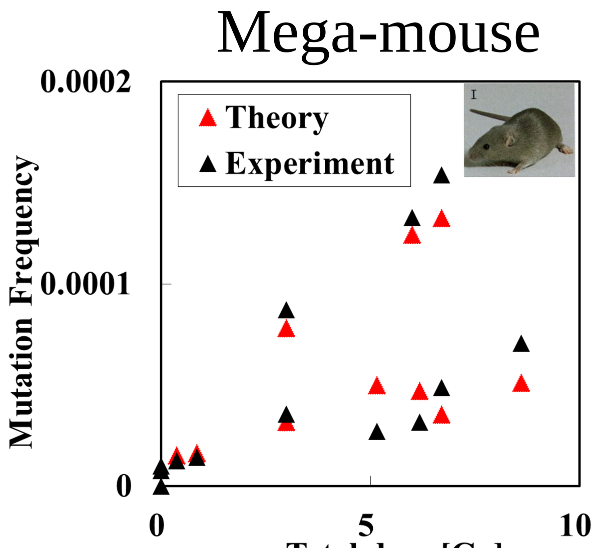
a_0, a_1, b_0, b_1

4 parameters

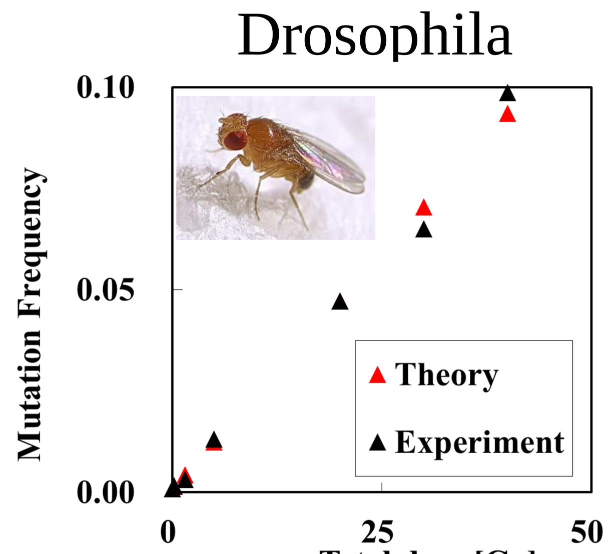
We determine four parameters by χ fit

3. Results

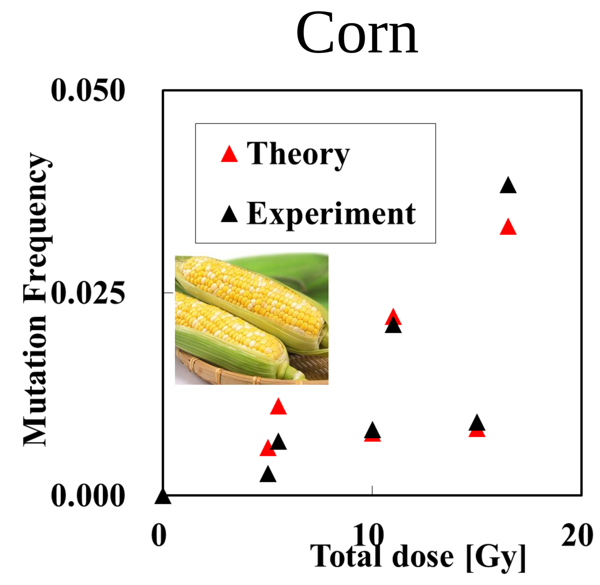
Mega-mouse



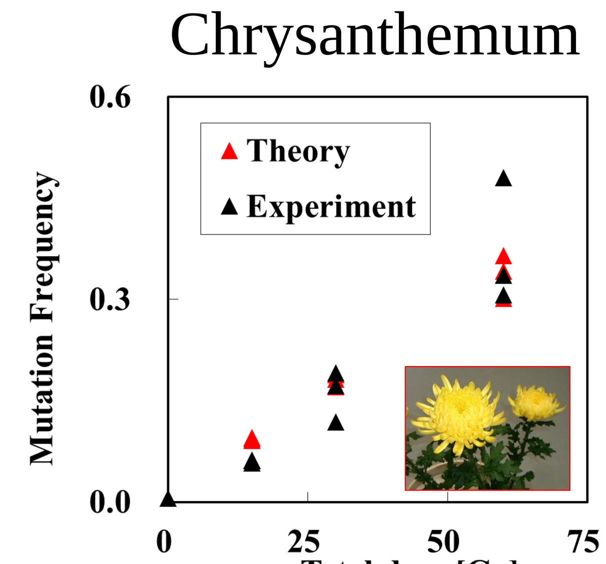
Drosophila



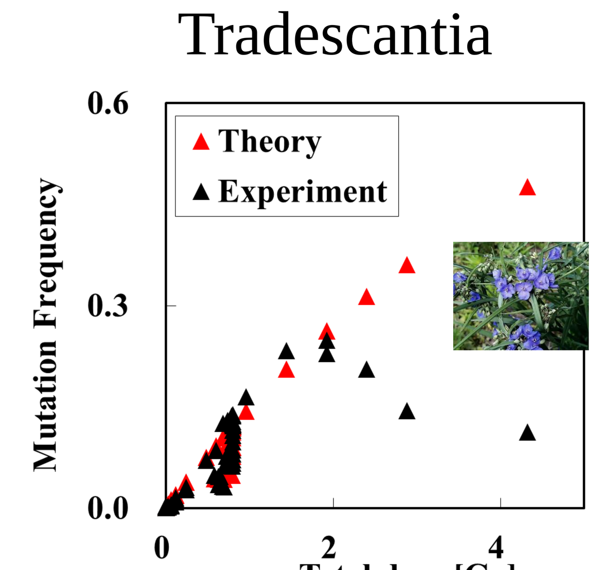
Corn



Chrysanthemum



Tradescantia



4. Conclusion

1. We have analyzed the experimental data of five living organisms;
   mouse, drosophila, chrysanthemum, maize, and tradescantia.
2. Despite the difference between animal and plant, all these data reasonably fall on our predicted value.
3. We can apply this model to the scheduling of cancer therapy and radiation protection of nuclear plant workers.