Modeling Acute Health Effects of Astronauts from Exposure to Large Solar Particle Events

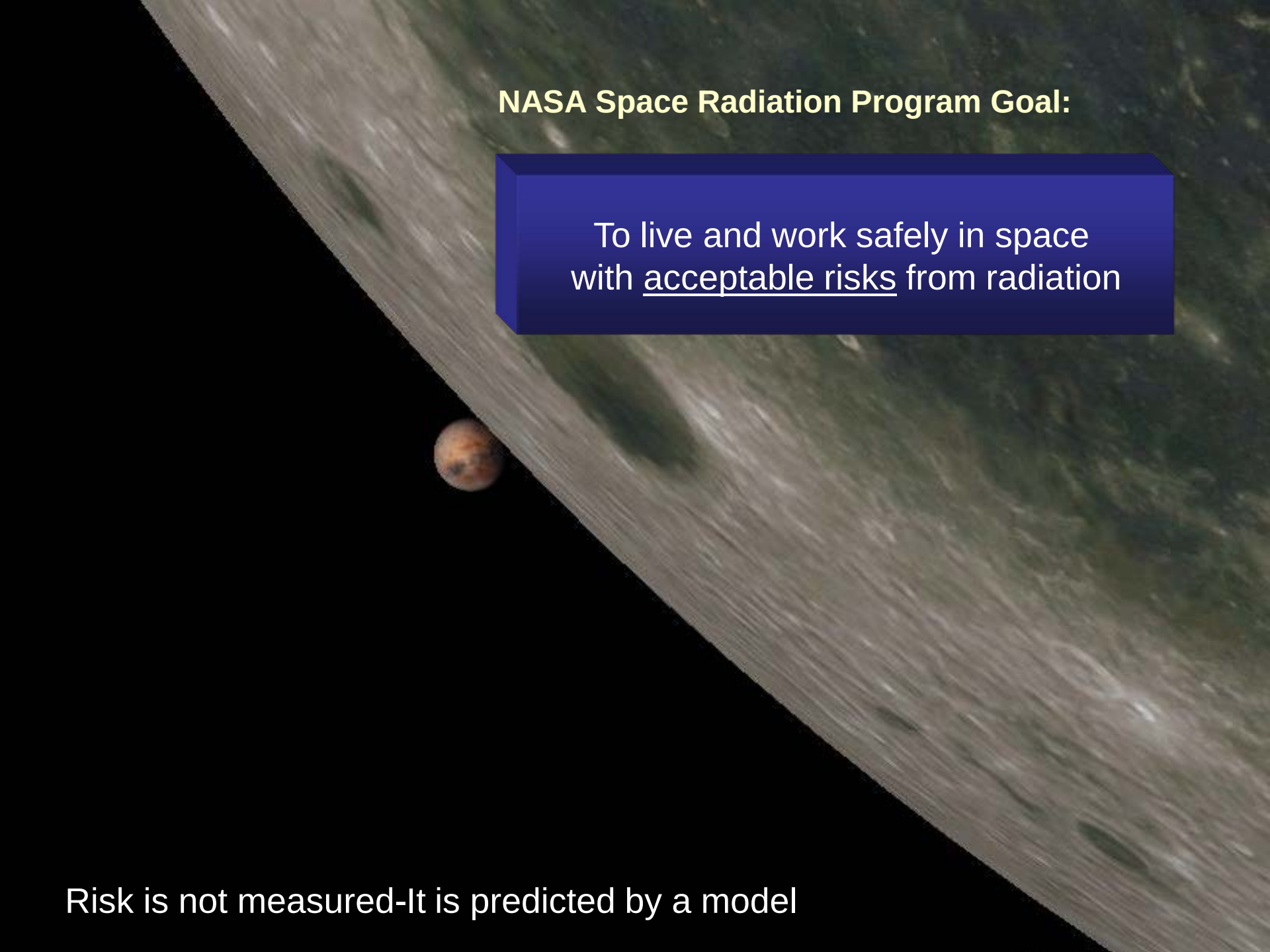
Shaowen Hu[1], Myung-Hee Y. Kim[1], and Francis A. Cucinotta[2]
[1]Universities Space Research Association, Division of Space Life Sciences, Houston, Texas 77058, USA, and
[2]NASA, Lyndon B. Johnson Space Center, 2101 NASA Parkway, Houston Texas 77058, USA

In space exploration outside the Earth's geomagnetic field, radiation exposure from solar particle events (SPE) presents a health concern for astronauts, that could impair their performance and result in possible failure of the mission. Acute risks are of special concern during extra-vehicular activities because of the rapid onset of SPE. However, most SPEs will not lead to acute risks but can lead to mission disruption if accurate projection methods are not available. Acute Radiation Sickness (ARS) is a group of clinical syndromes developing acutely (within several seconds to 3 days) after high dose whole-body or significant partial-body ionizing radiation exposures. The manifestation of these syndromes reflects the disturbance of physiological processes of various cellular groups damaged by radiation. Hematopoietic cells, skin, epithelium, intestine, and vascular endothelium are among the most sensitive tissues of human body to ionizing radiation. Most ARS symptoms are directly related to these tissues and other systems (nervous, endocrine, and cardiovascular, etc.) with coupled regulations. Here we report the progress in bio-mathematical models to describe the dose and time-dependent early human responses to ionizing radiation. The responses include lymphocyte depression, granulocyte modulation, fatigue and weakness syndrome, and upper gastrointestinal distress. The modest dose and dose-rates of SPEs are predicted to lead to large sparing of ARS, however detailed experimental data on a range of proton dose-rates for organ doses from 0.5 to 2 Gy is needed to validate the models. We also report on the ARRBOD code that integrates the BRYNTRN and SUMDOSE codes, which are used to estimate the SPE organ doses for astronauts under various space travel scenarios, with our models of ARS. The more recent effort is to provide easy web access to space radiation risk assessment using the ARRBOD code.

Modeling Acute Health Effects of Astronauts from Exposure to Large Solar Particle Events

Shaowen Hu[1] , Myung-Hee Y. Kim[1], and Francis A. Cucinotta[2]

[1]Universities Space Research Association, Division of Space Life Sciences, Houston, Texas 77058, USA,
[2]NASA, Lyndon B. Johnson Space Center, Houston, Texas 77058, USA

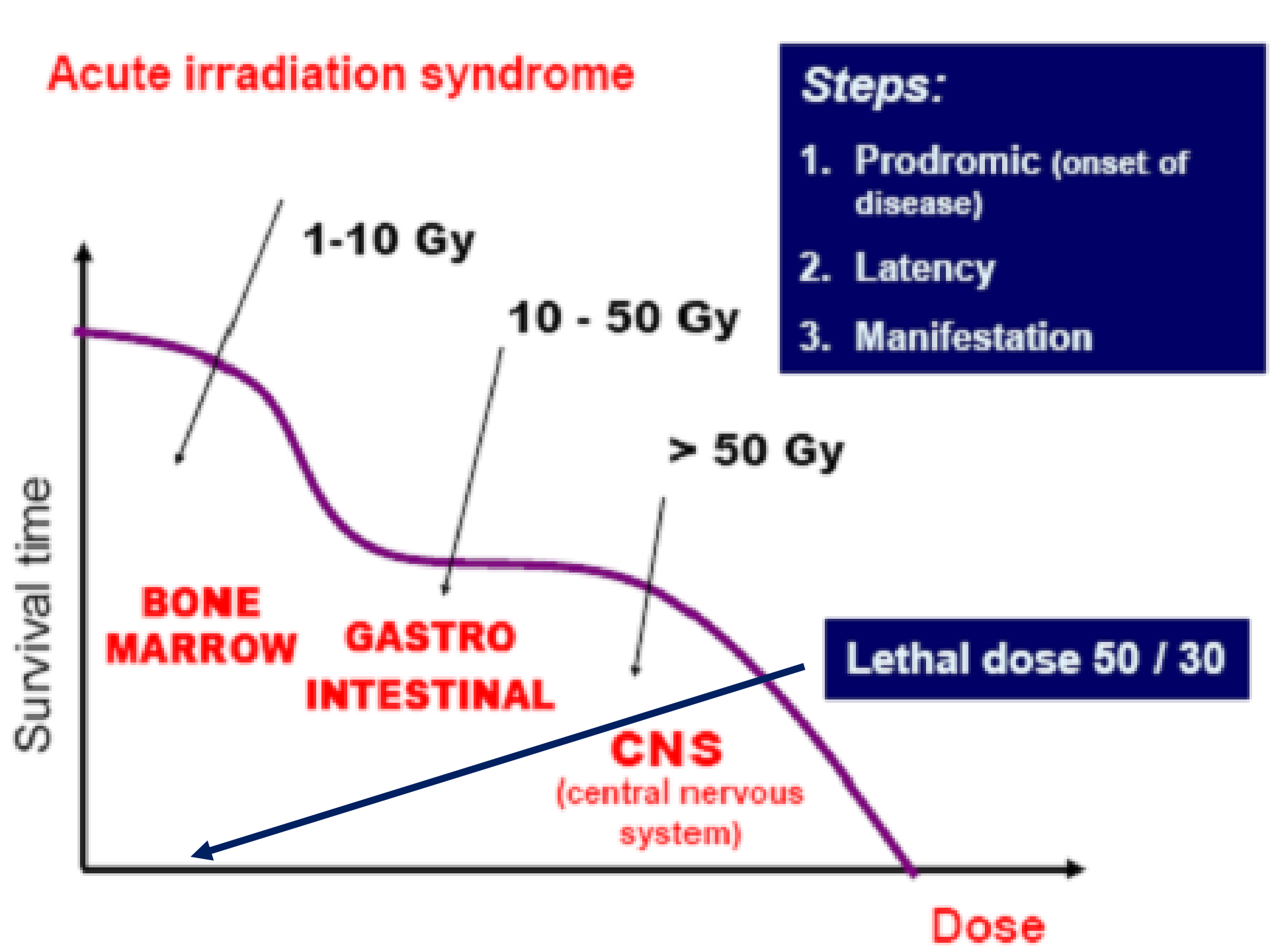


NASA Space Radiation Program Goal:

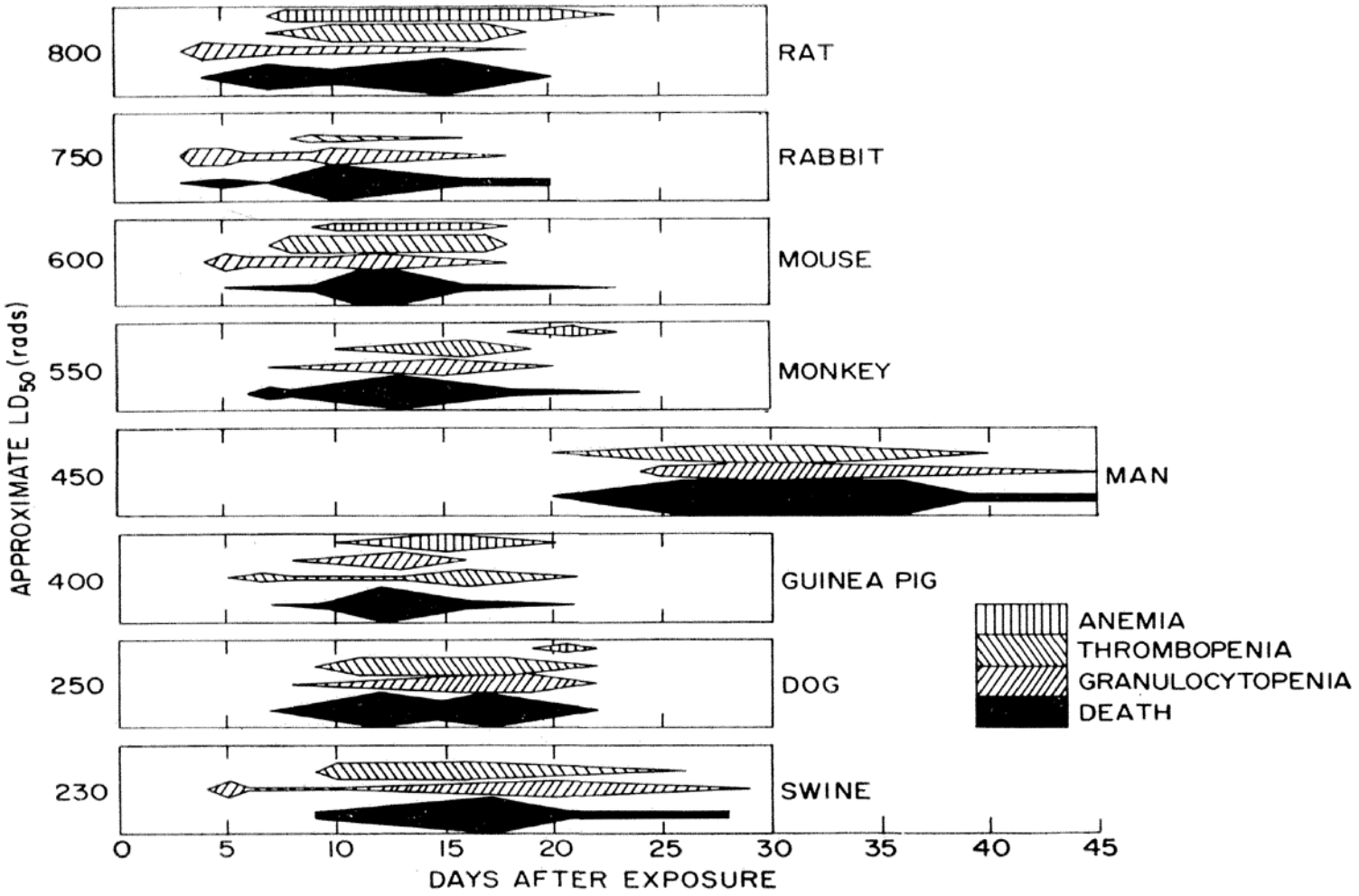
To live and work safely in space
with acceptable risks from radiation

Risk is not measured-It is predicted by a model

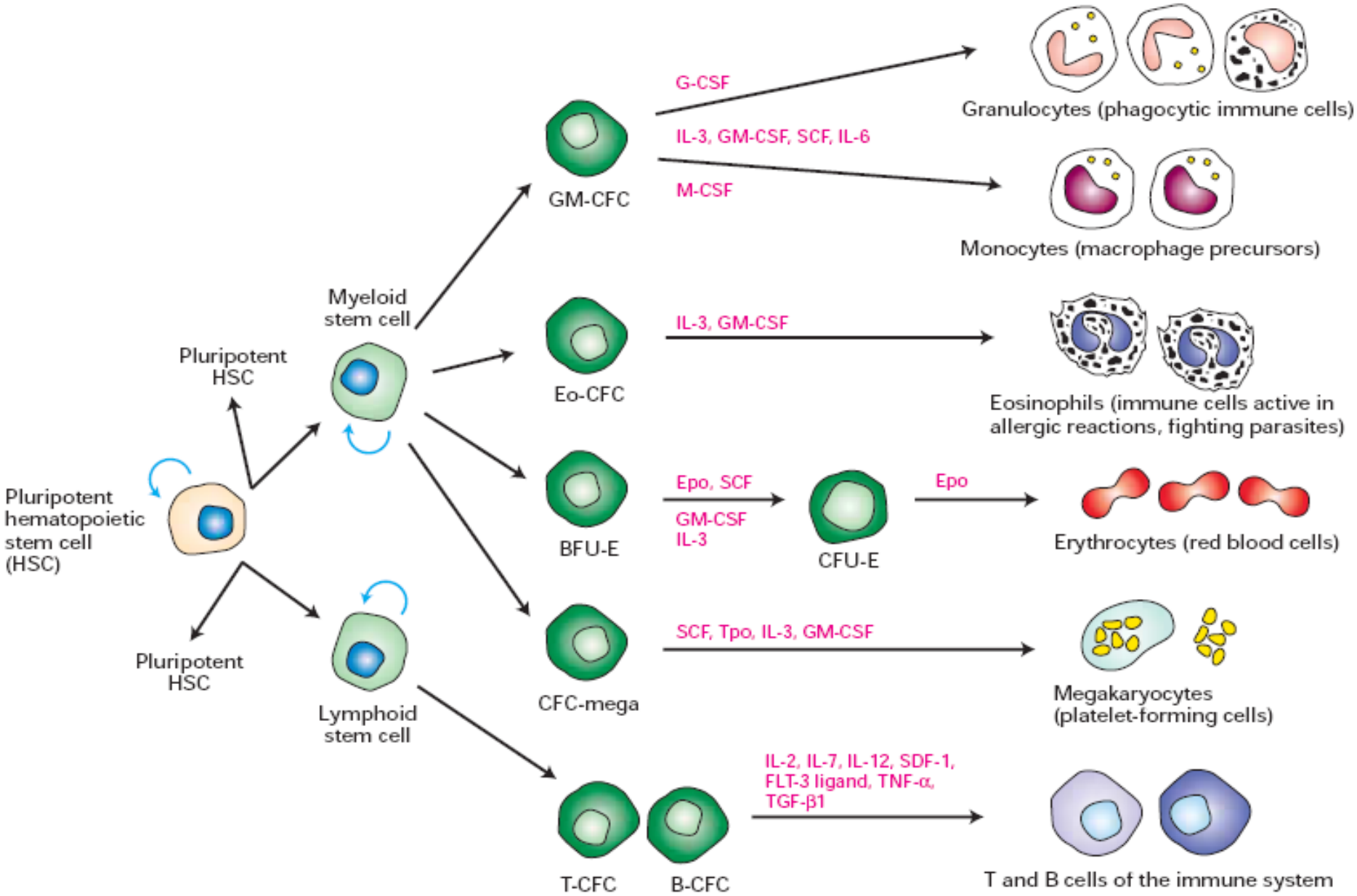
Acute irradiation syndrome



Correlation of time of death with irradiation anemia of different species



Hematopoiesis in human



Basis of mathematical modeling: regulation mechanism

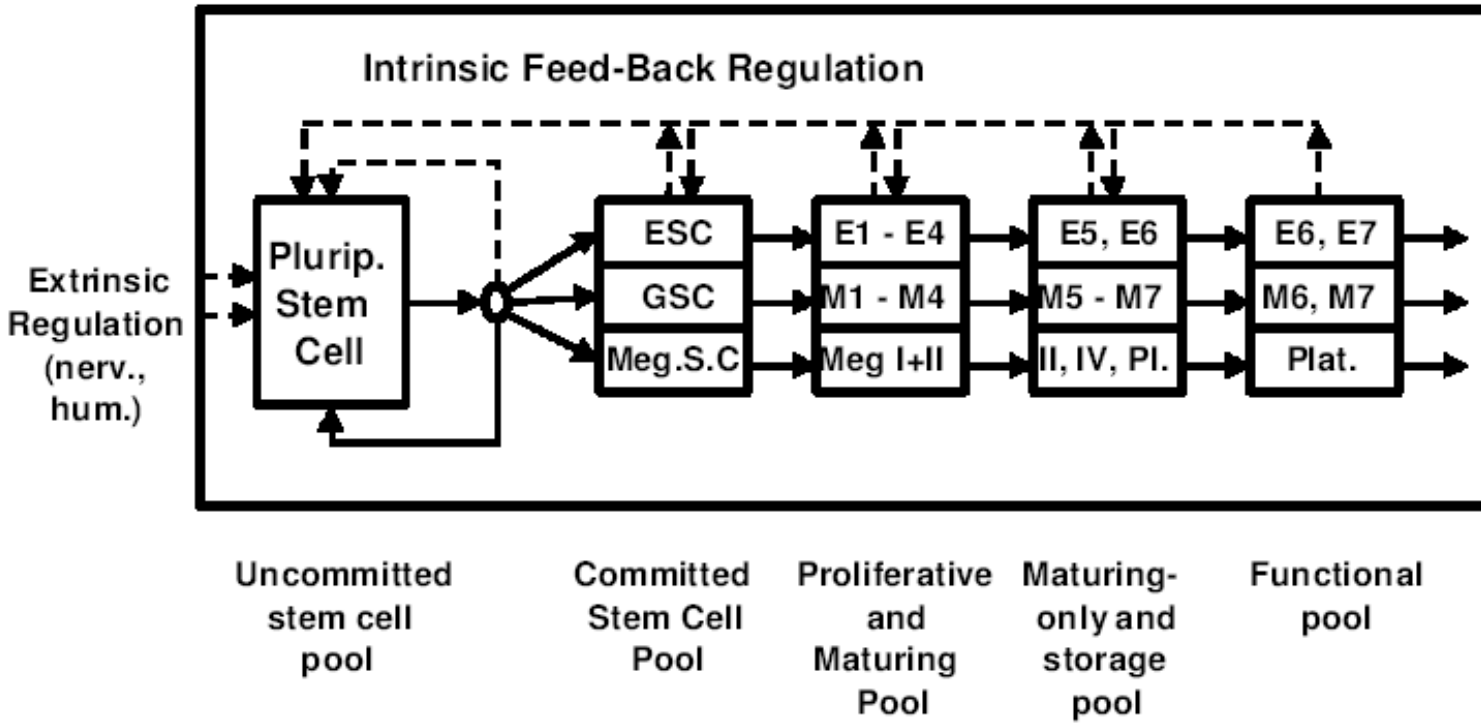


Figure 2. Schematic representation of the hemopoietic cell renewal systems (E = Erythropoiesis; G = Granulopoiesis; Meg = Megakaryocytopoiesis) all fed by the pluripotent hematopoietic stem cell pool.

Fliedner et al. Exp. Hematol. (2007)

Smirnova's model

- Three compartments:
  - X_1: bone marrow precursor cells
  - X_2: nondividing maturing bone marrow cells
  - X_3: mature blood cells
- Feed-back regulator I: dependent on the concentration of X_1, X_2, and X_3 cells

Model equations:

$$\frac{dx_1}{dt} = Bx_1 - Cx_1,$$

$$\frac{dx_2}{dt} = Cx_1 - Fx_2,$$

$$\frac{dx_3}{dt} = Fx_2 - Ex_3,$$

$$\frac{dI}{dt} = G(x_1 + \theta_2 x_2 + \theta_3 x_3) - HI.$$

Granulocytopoiesis

$$\frac{dx_1}{dt} = \frac{\alpha x_1}{1 + \beta (x_1 + \theta_2 x_2 + \theta_4 x_4 + \theta_5 x_5)} - \gamma x_1,$$

$$\frac{dx_2}{dt} = \gamma x_1 - \delta \frac{1 + M x_4^2}{1 + L x_4^2} x_2,$$

Reserve pool in bone marrow

$$\frac{dx_4}{dt} = \delta \frac{1 + M x_4^2}{1 + L x_4^2} x_2 - \kappa x_4,$$

$$\frac{dx_5}{dt} = \kappa x_4 - \psi x_5.$$

Tissue pool

Lymphopoiesis model

$$\frac{dx_1}{dt} = Bx_1 - \gamma x_1 - \frac{N}{D_c} x_1,$$

$$\frac{dx_{wd1}}{dt} = \left(\frac{N}{D_c} - \frac{N}{D_1} \right) x_1 + Bx_{wd1} - \gamma x_{wd1},$$

$$\frac{dx_{d1}}{dt} = \frac{N}{D_1} \frac{1}{1+\rho_1} x_1 - \nu_1 x_{d1},$$

$$\frac{dx_{hd1}}{dt} = \frac{N}{D_1} \frac{\rho_1}{1+\rho_1} x_1 - \nu_2 x_{hd1},$$

$$\frac{dx_2}{dt} = \gamma x_1 - \delta x_2 - \frac{N}{D_2} x_2,$$

$$\frac{dx_{d2}}{dt} = \frac{N}{D_2} \frac{1}{1+\rho_2} x_2 - \nu_1 x_{d2},$$

$$\frac{dx_{hd2}}{dt} = \frac{N}{D_2} \frac{\rho_2}{1+\rho_2} x_1 - \nu_2 x_{hd2}$$

$$\frac{dx_3}{dt} = \delta x_2 - \psi x_3 - \frac{N}{D_3} x_3,$$

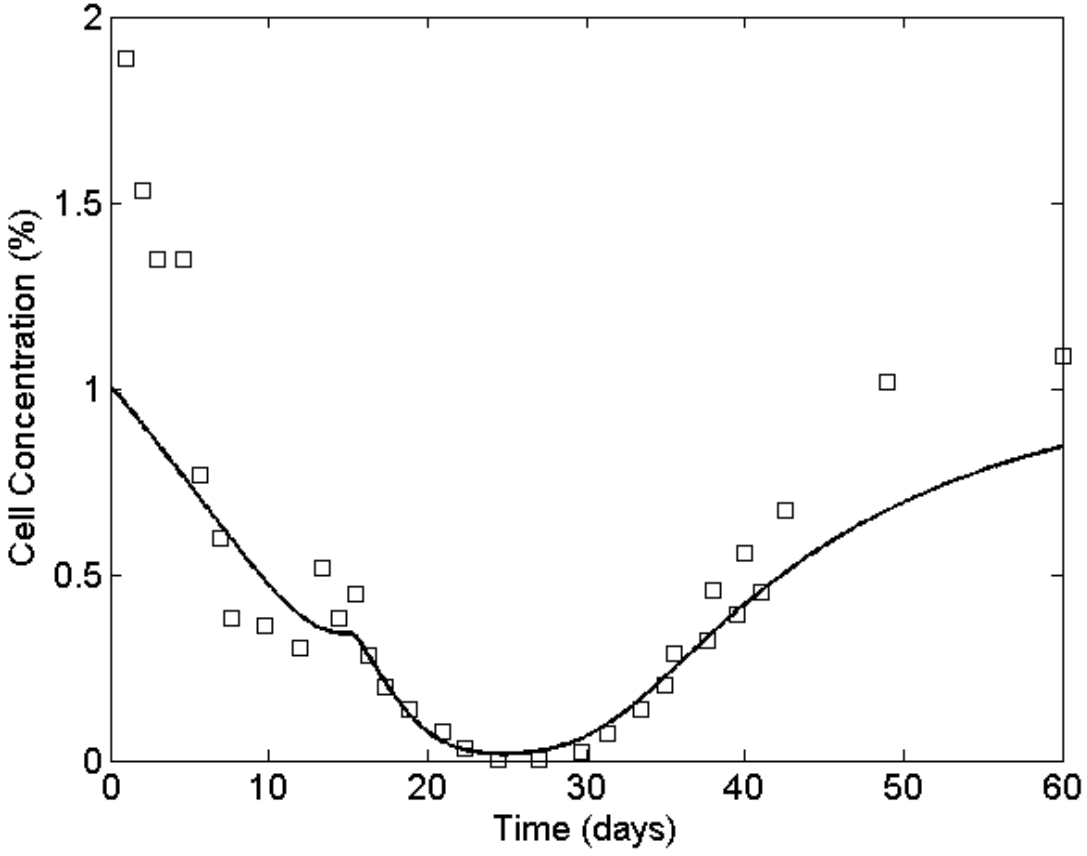
$$\frac{dx_{d3}}{dt} = \frac{N}{D_3} \frac{1}{1+\rho_3} x_3 - \nu_1 x_{d3},$$

$$\frac{dx_{hd3}}{dt} = \frac{N}{D_3} \frac{\rho_3}{1+\rho_3} x_3 - \nu_2 x_{hd3}$$

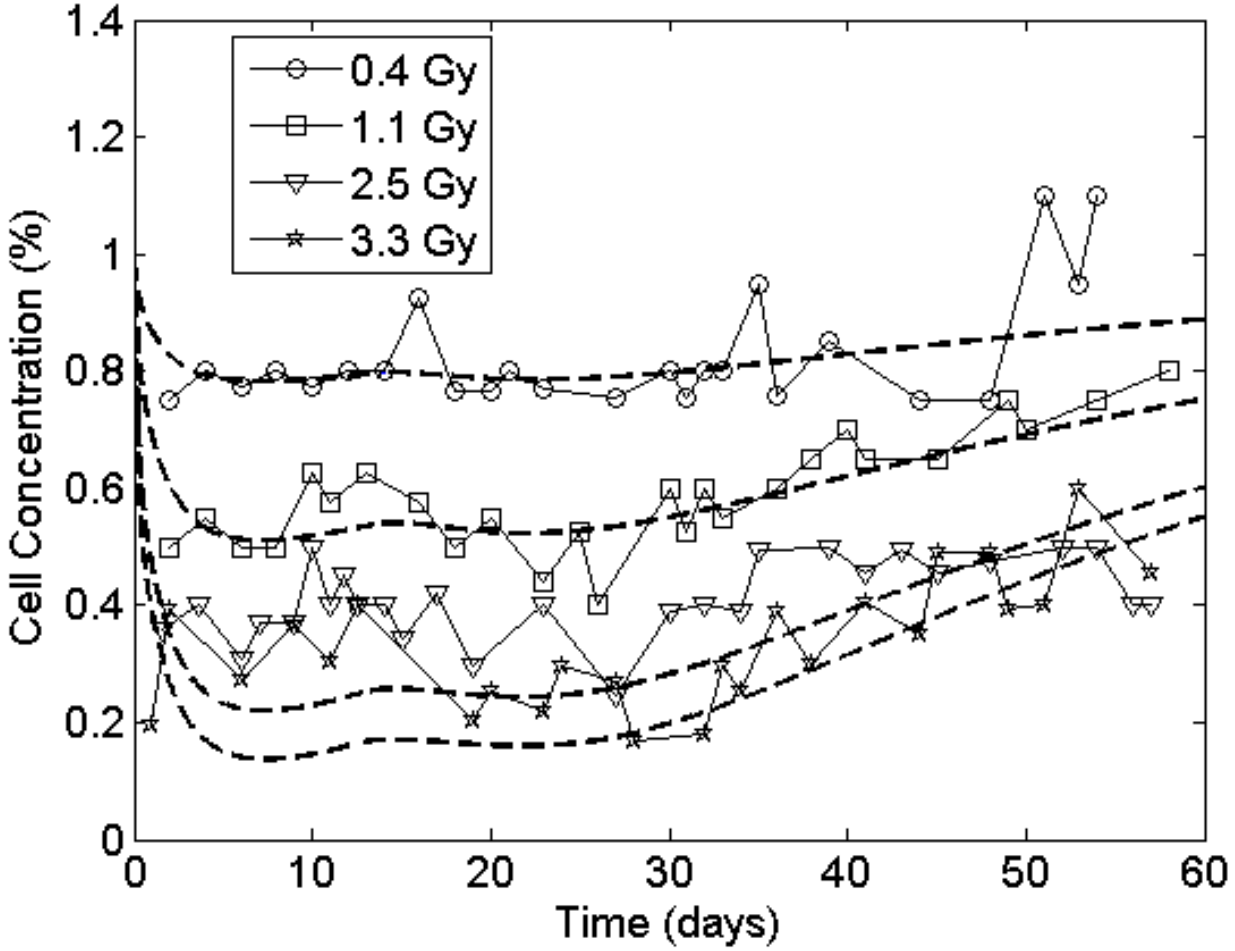
Acute irradiation of human: data of 11 Chernobyl patients and model simulation

Exposure range from 2.6 to 7.1 Sv.

Assuming an average 5.9 Sv exposure.



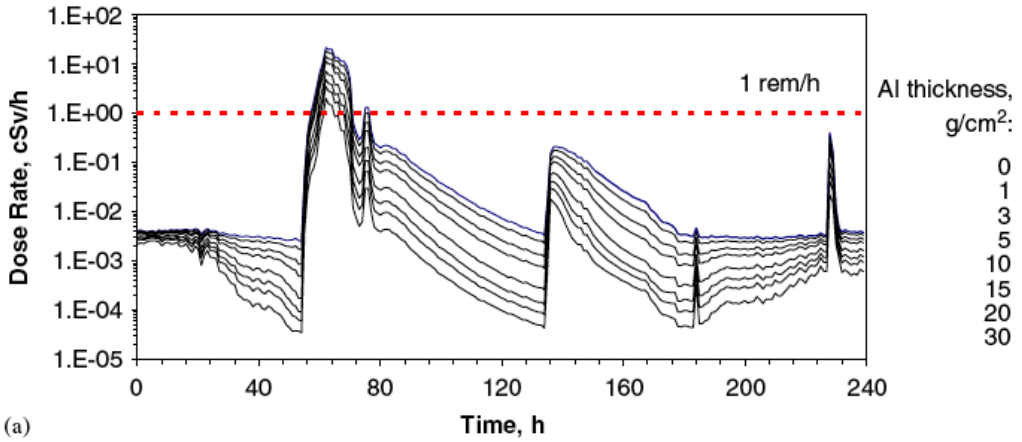
Chernobyl accident



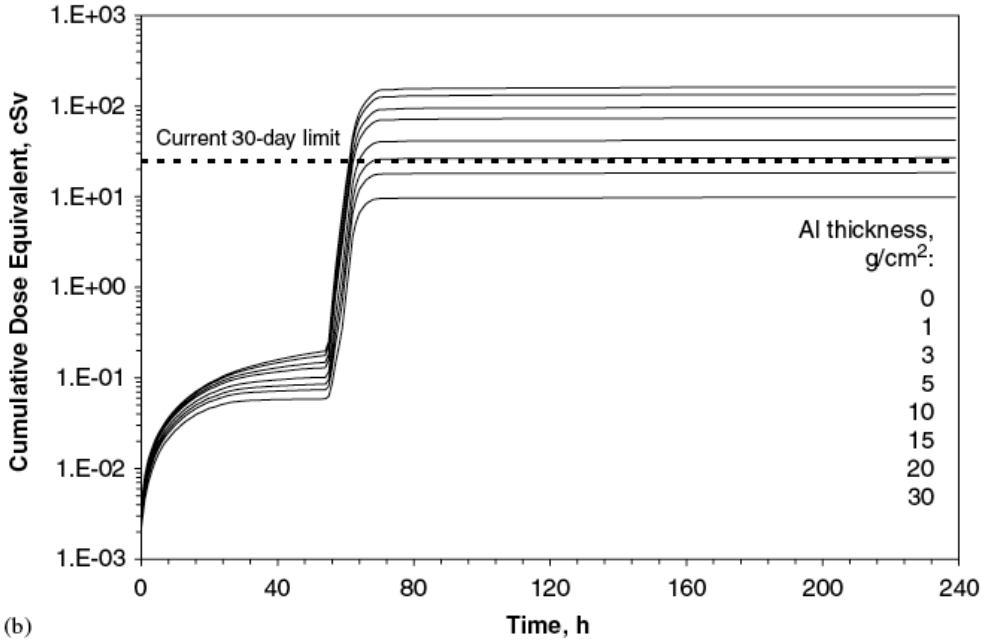
Guskova et al, 2001

Radiation Exposure from Large SPE Events

BFO dose rate during Aug. 1972 SPE Event



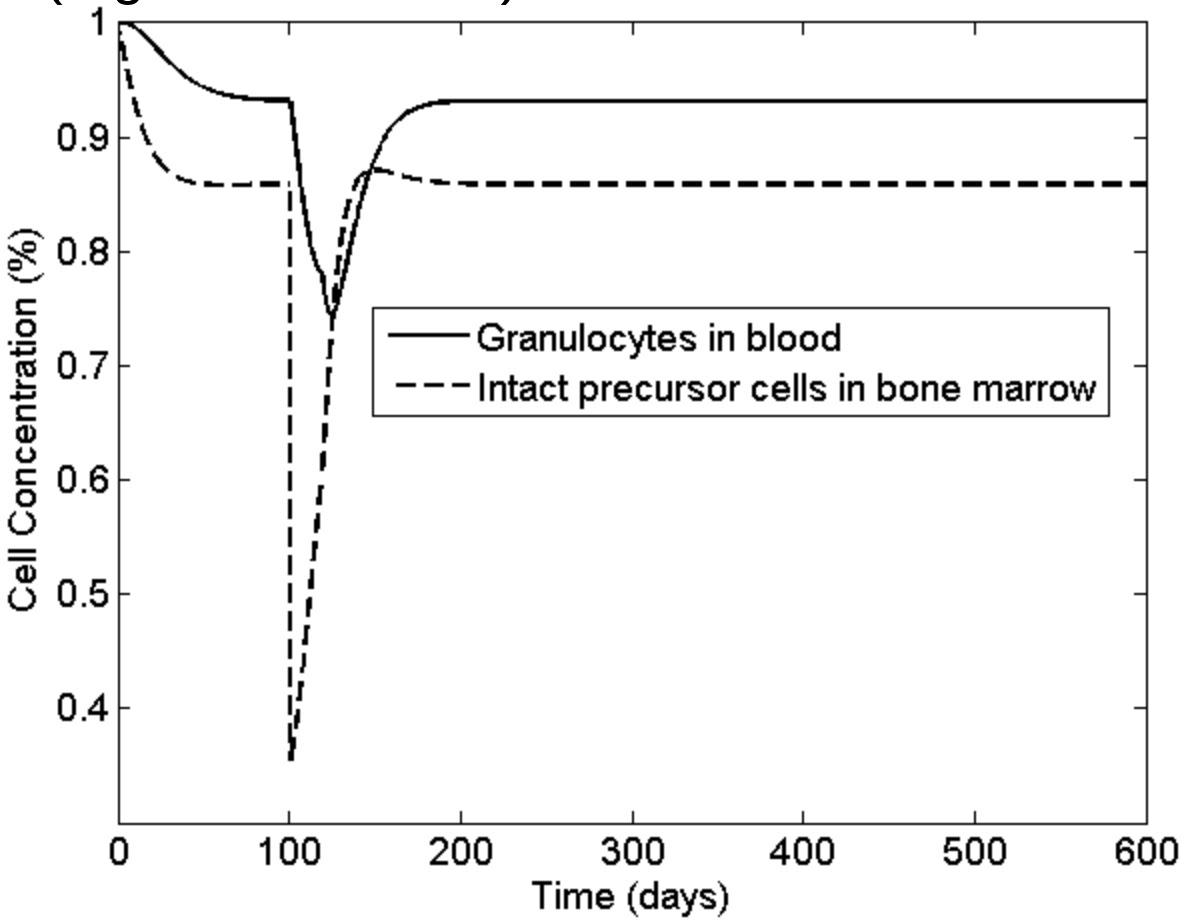
Cumulative dose



Kim et al., 2006

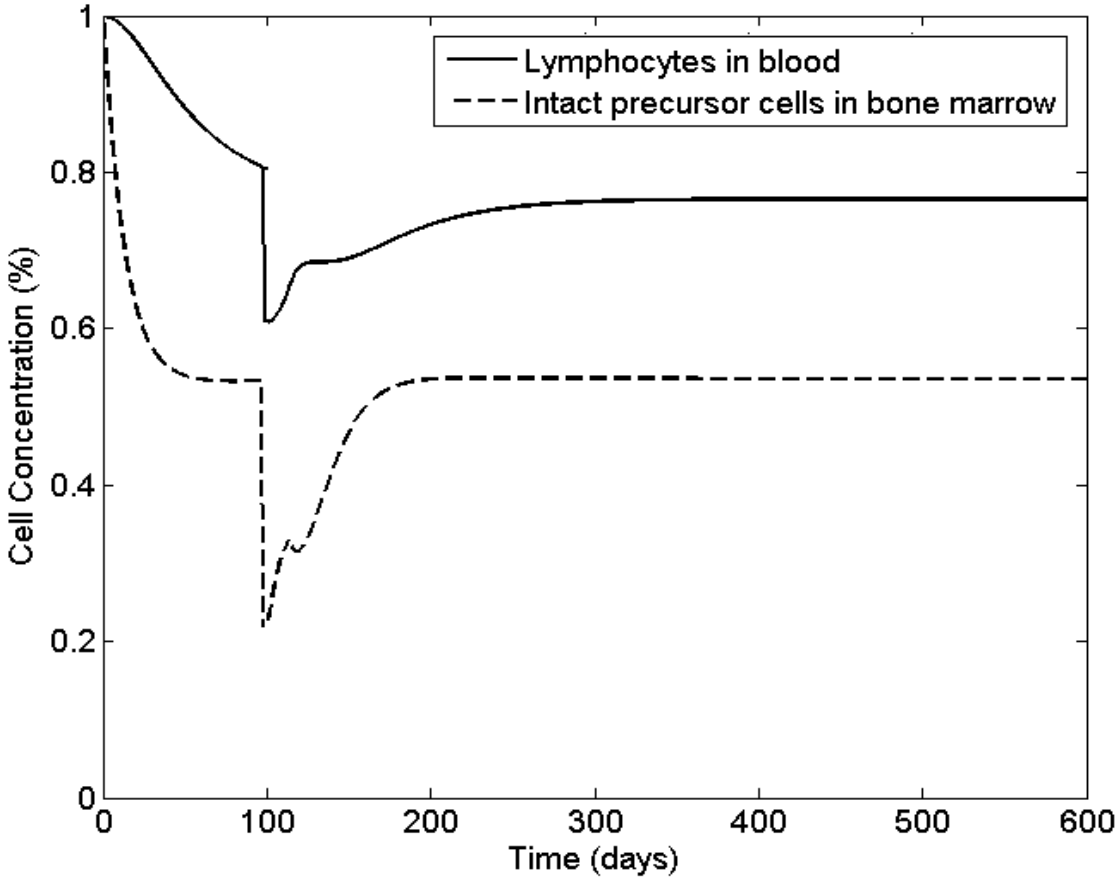
Modeling the granulopoiesis response to the 1972 SPE

Recorded worst SPE: 44.3 mSv/h for 10 hours inside a typical spacecraft (5 g/cm thickness) .

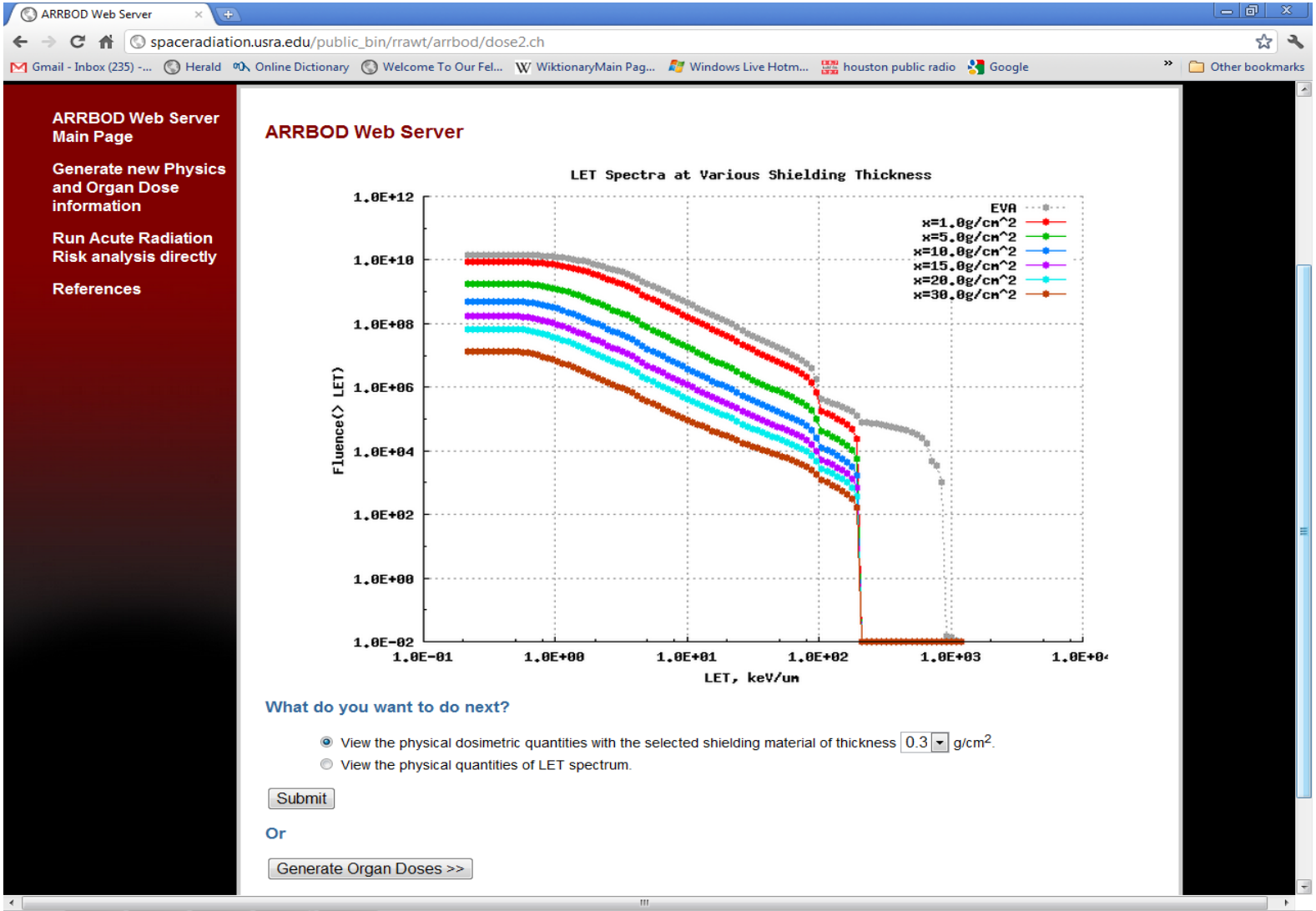


Modeling the lymphopoiesis response to the 1972 SPE

Recorded worst SPE: 44.3 mSv/h for 10 hours inside a typical spacecraft (5 g/cm thickness) .



ARRBOD Web Server



http://spaceradiation.usra.edu/irModels
It is not ready for public use yet.

Acknowledgements

- Dr. Olga Smirnova