

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

Shaowen Hu<sup>1</sup>, Myung-Hee Y. Kim<sup>1</sup>, and Francis A. Cucinotta<sup>2</sup>

<sup>1</sup>Universities Space Research Association, Division of Space Life Sciences, Houston, Texas 77058, USA, and

<sup>2</sup>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.

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The background of the slide is a photograph of Earth from space, showing a curved horizon and a mix of green land and blue oceans. A small, reddish-orange sphere, likely Mars, is visible in the blackness of space just below the Earth's horizon. A semi-transparent blue rectangular box with a 3D effect is positioned in the upper right quadrant of the image.

## NASA Space Radiation Program Goal:

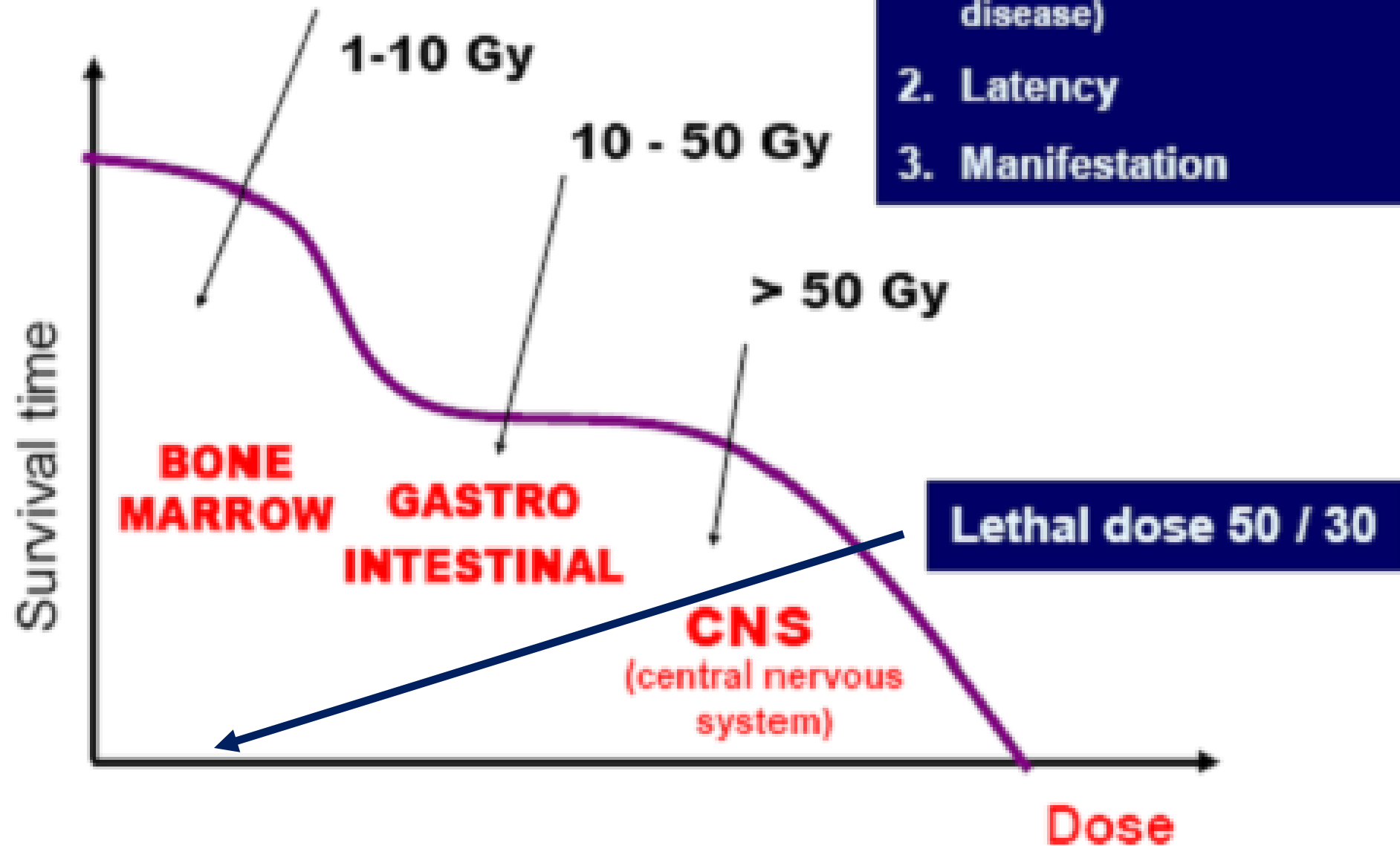
To live and work safely in space  
with acceptable risks from radiation

Risk is not measured-It is predicted by a model

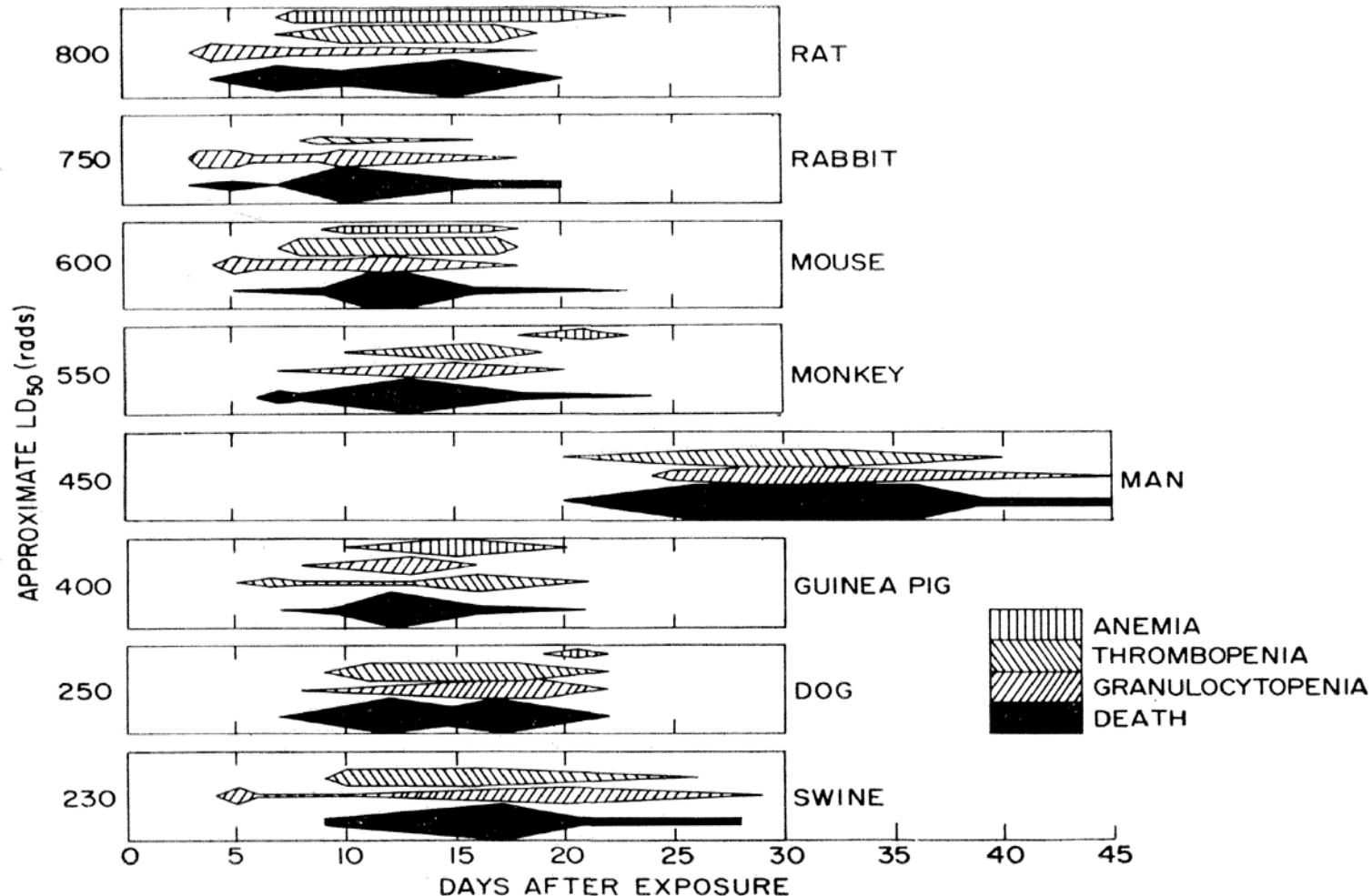
# Acute irradiation syndrome

## Steps:

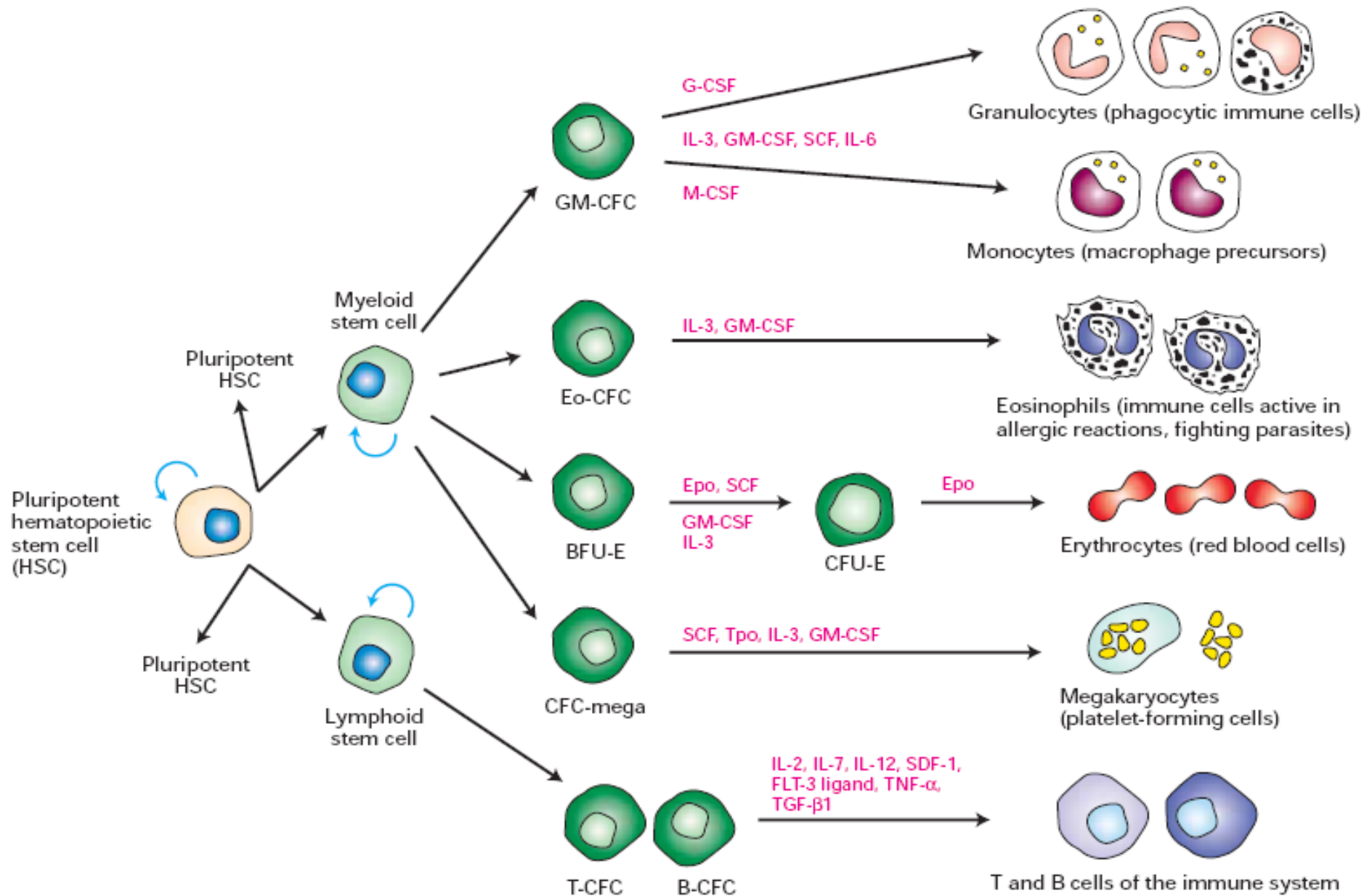
1. Prodromic (onset of disease)
2. Latency
3. Manifestation



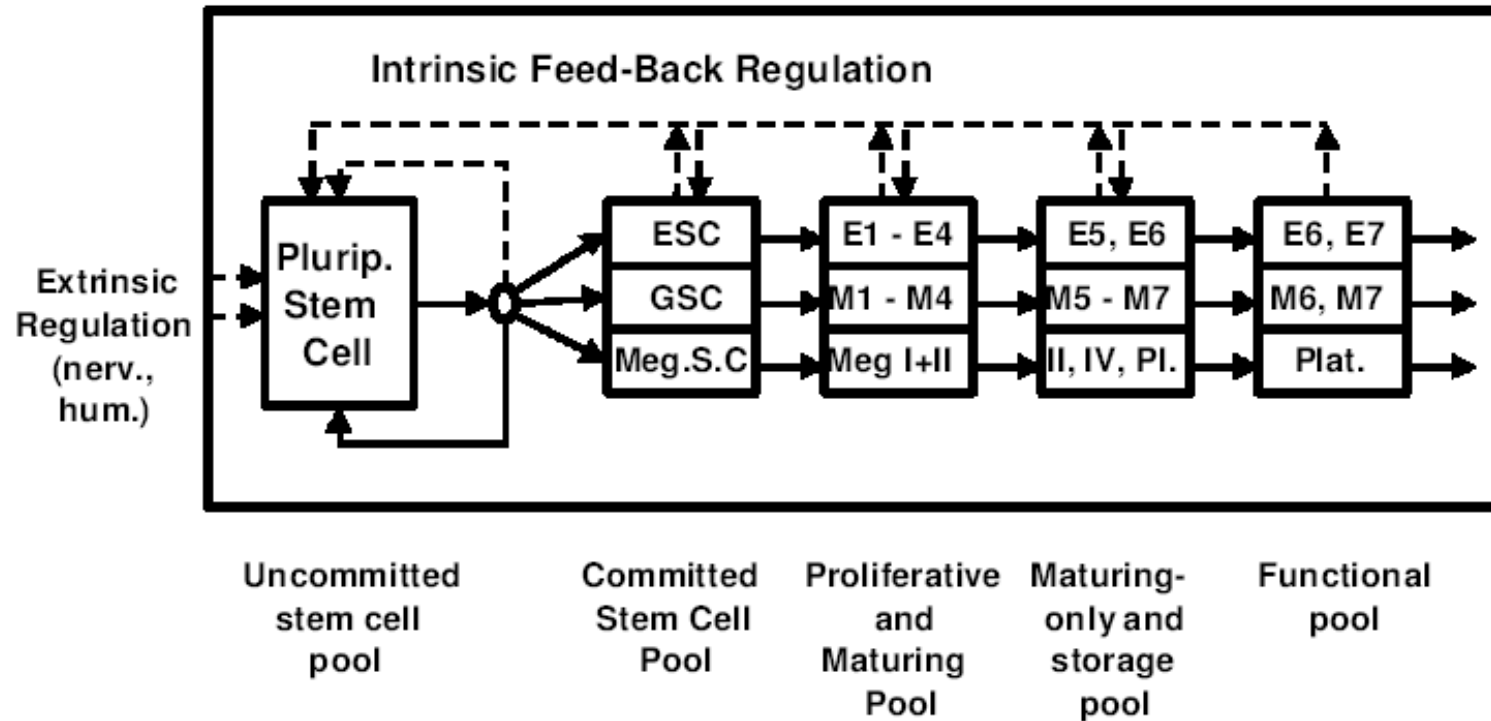
# Correlation of time of death with irradiation anemia of different species



# 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.

# 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:

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

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

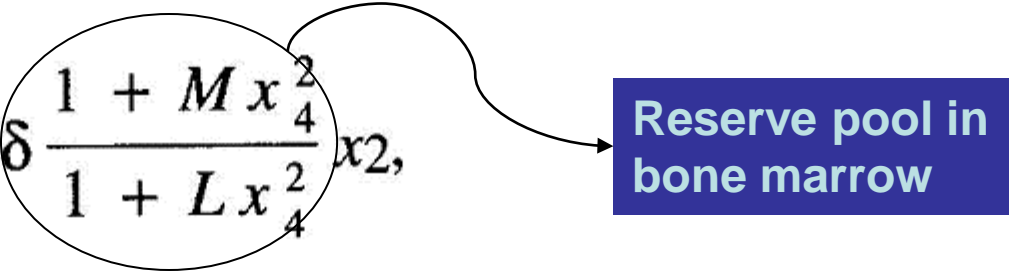
$$\frac{dx_3}{dt} = Fx_2 - Ex_3,$$

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



# 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

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

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

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

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

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

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

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

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

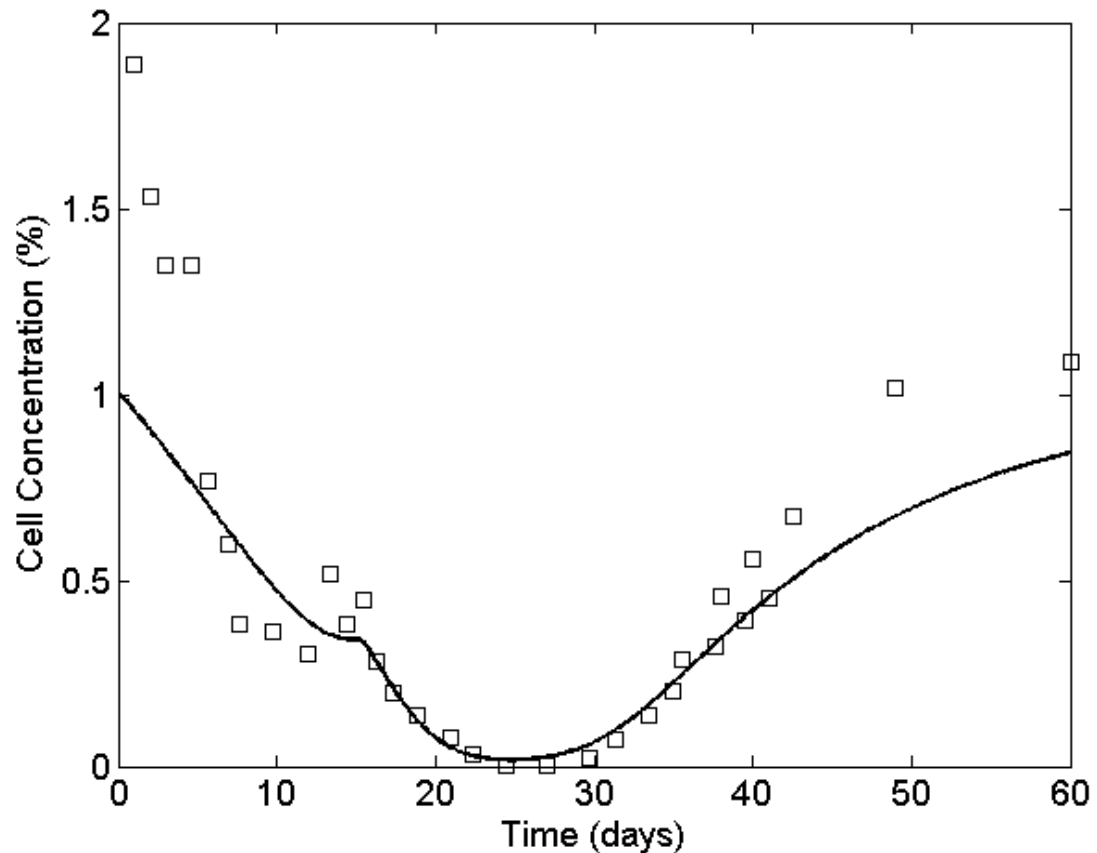
$$\frac{dx_2}{dt} = \gamma x_1 - \delta x_2 - \frac{N}{D_2} x_2,$$

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

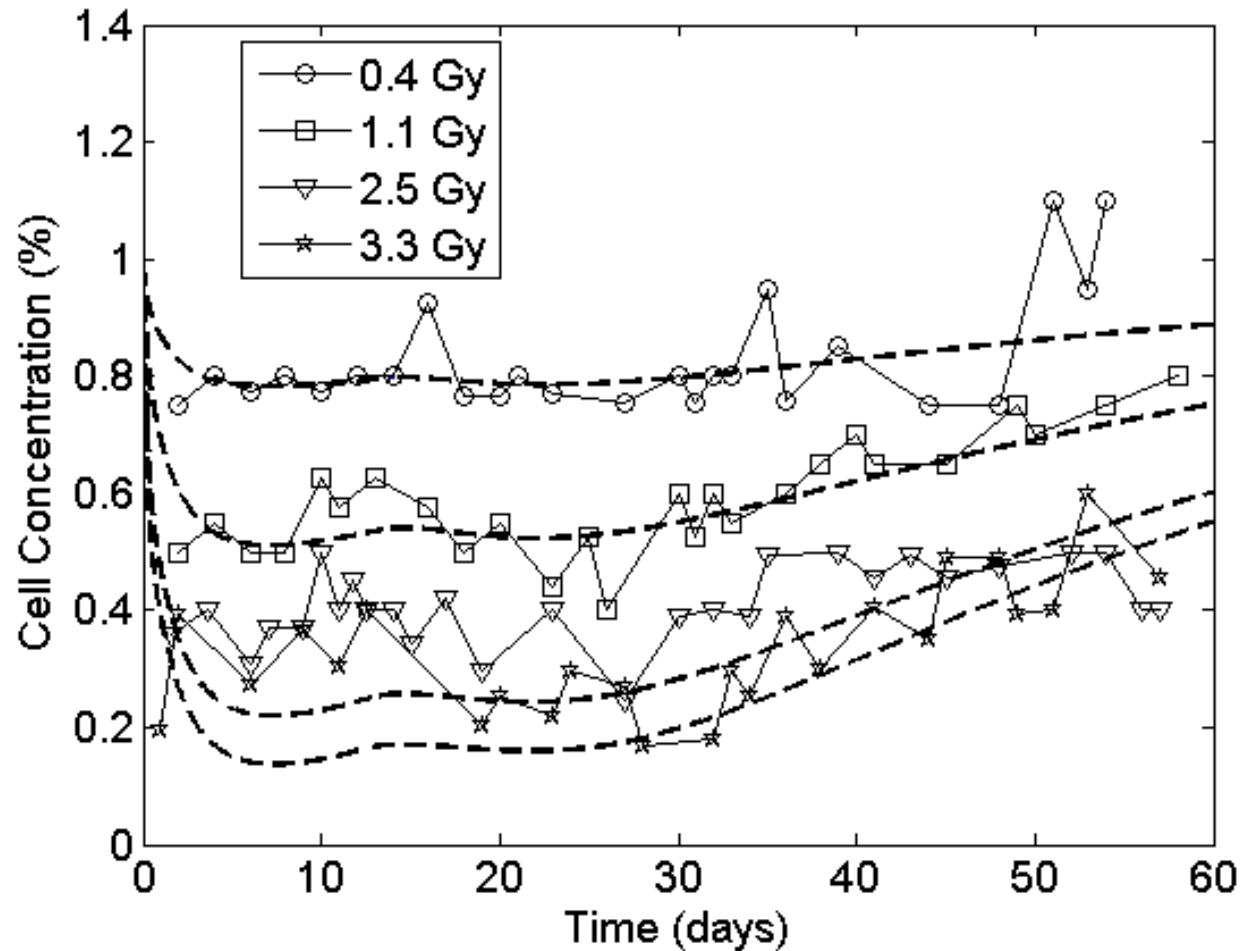
# Acute irradiation of human: data of 11 Chernobyl patients and model simulation

Exposure  
range from  
2.6 to 7.1 Sv.

Assuming an  
average 5.9  
Sv exposure.



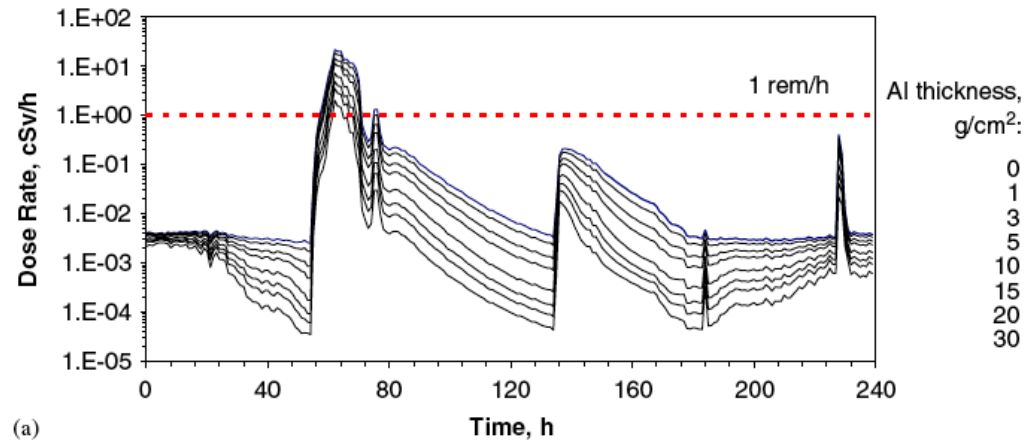
# Chernobyl accident



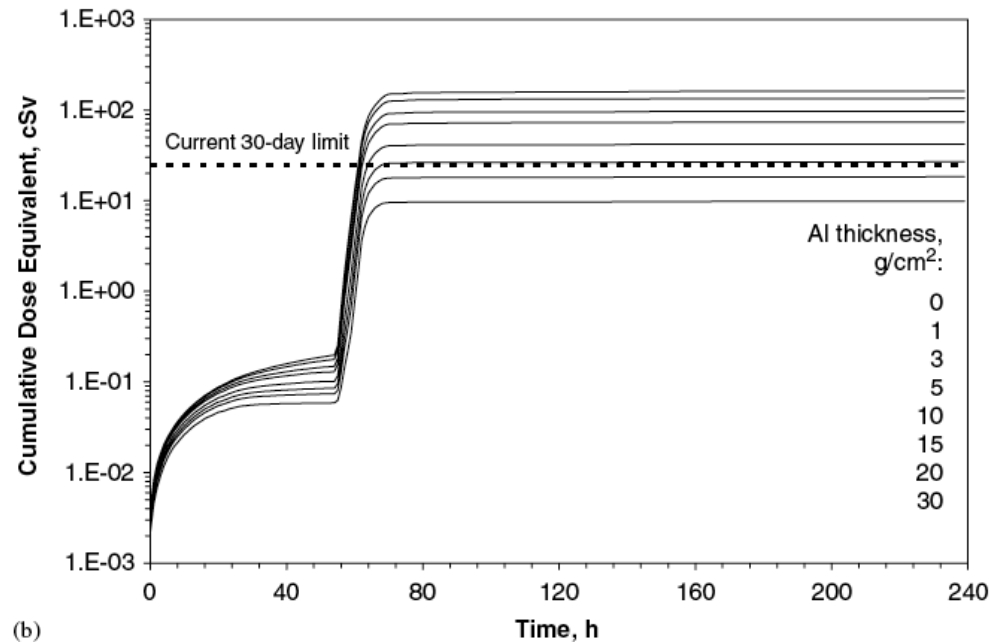
Guskova et al, 2001

# Radiation Exposure from Large SPE Events

BFO dose rate  
during Aug.  
1972 SPE  
Event

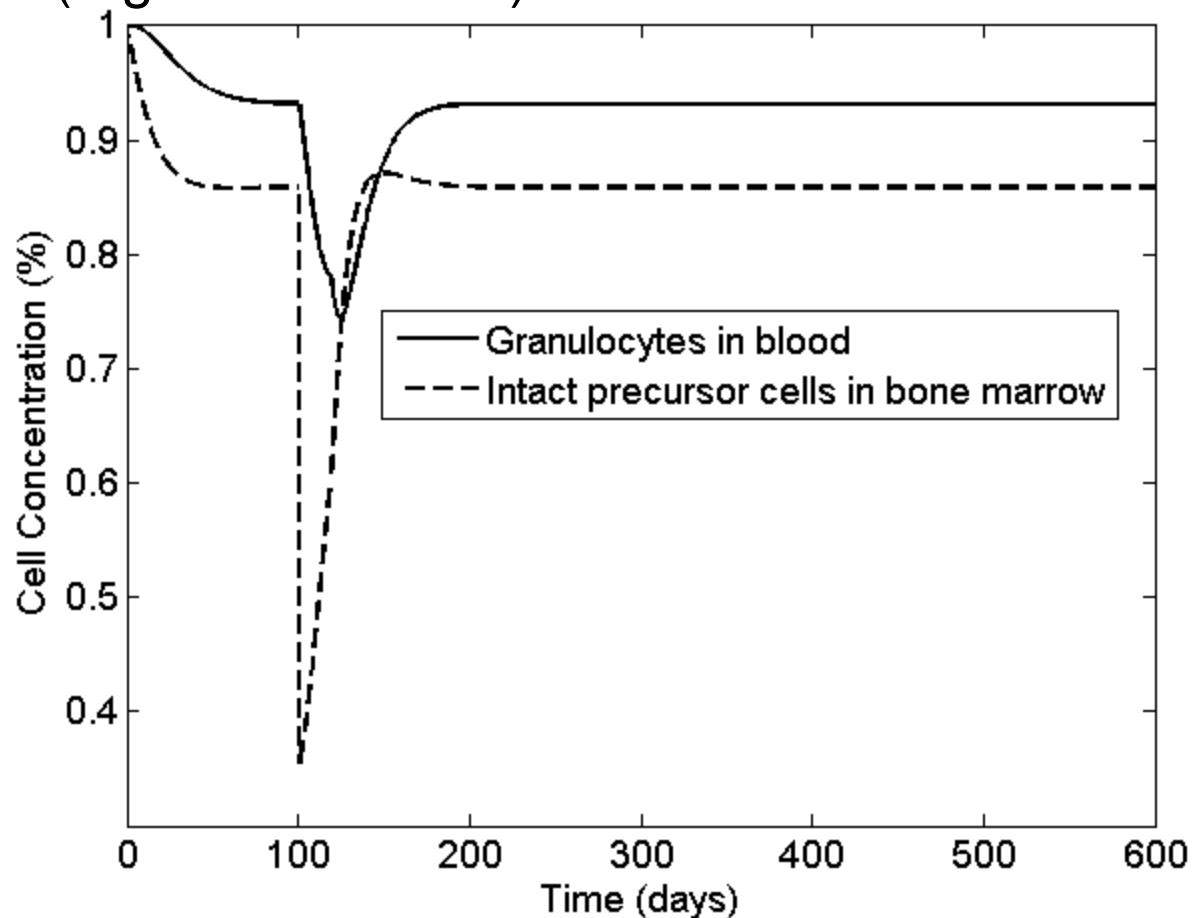


Cumulative  
dose



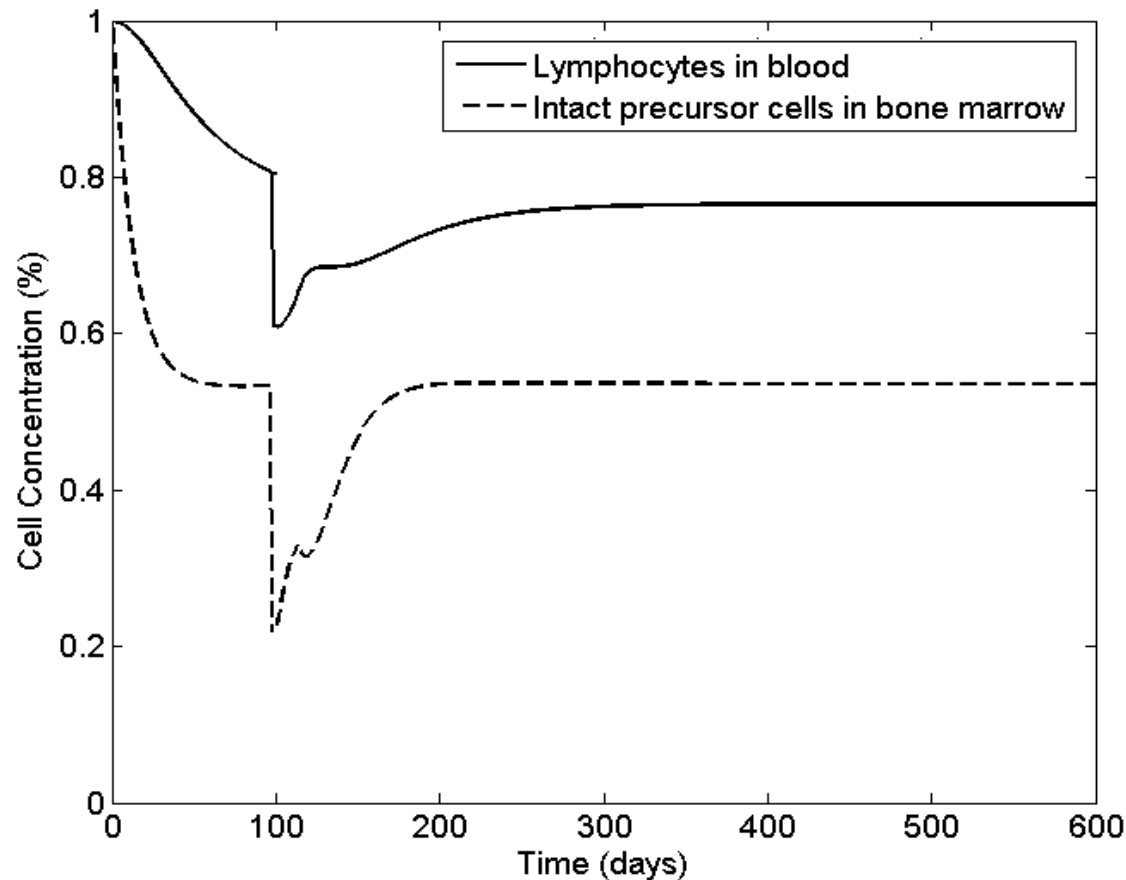
# Modeling the granulopoiesis response to the 1972 SPE

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

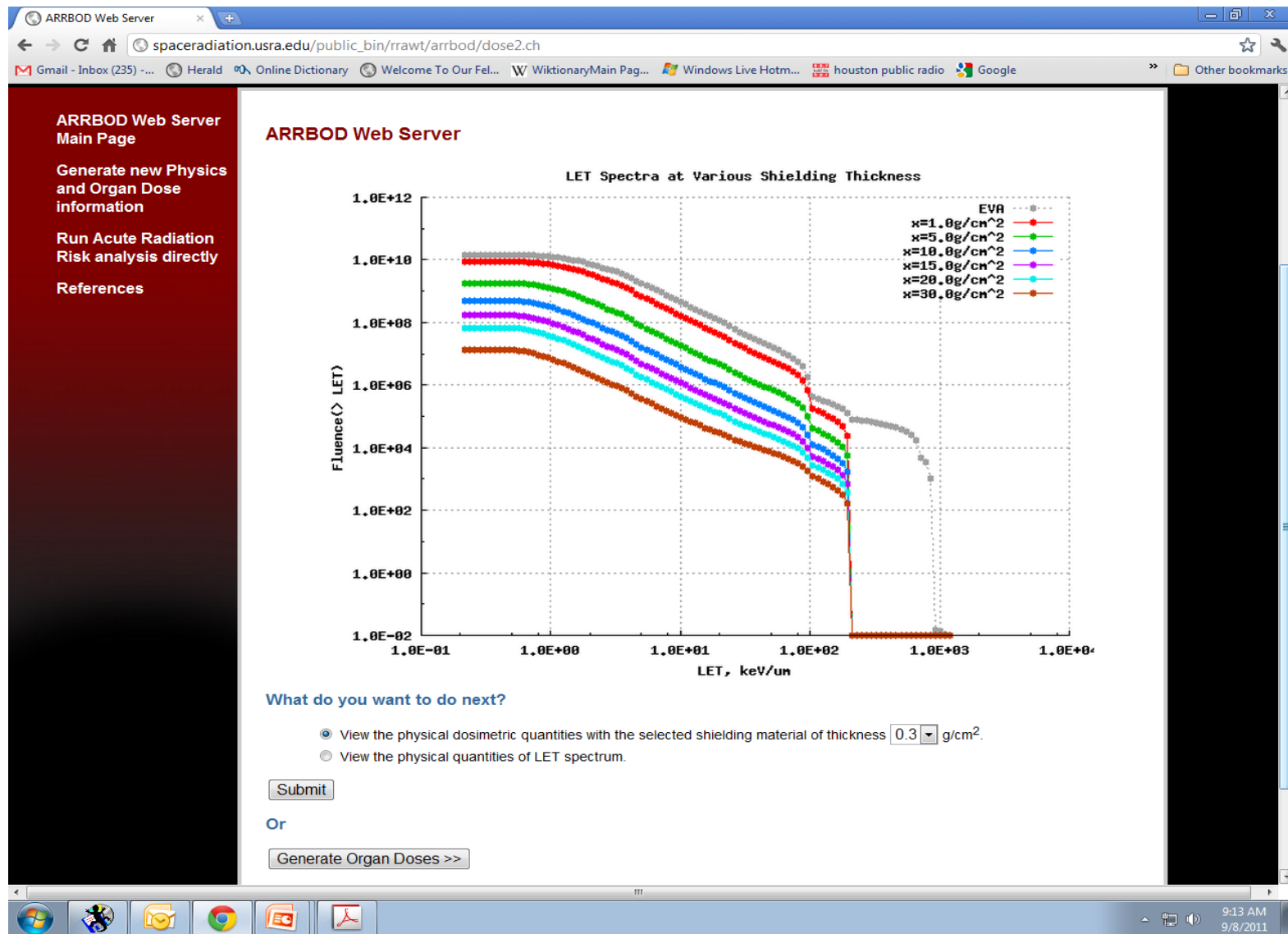


# Modeling the lymphopoiesis response to the 1972 SPE

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.

ARRBOD Web Server

spaceradiation.usra.edu/rrawt/rrawt1.html

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# NASA SPACE RADIATION PROGRAM

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**ARRBOD Web Server Main Page**

**ARR Web Tools Main Page**

**Lymphocytes Depression**

**Granulocytes Modulation**

**Fatigue and Weakness Syndrome**

**Upper Gastrointestinal Distress**

**References**

## Acute Radiation Risk Assessment Web Tools

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. 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 syndromes are directly related to these tissues, as well as the coupled regulation and adaptation systems (nervous, endocrine, cardiovascular systems). There are three phases in the development of ARS: the prodromal phase, the latent phase, and the manifest phase. The severity and duration of each of these phases are dependent on the dose and dose rate. The prodromal phase refers to the first 48 hours after exposure, but may persist up to 6 days. The syndromes are dose-dependent and include hematopoietic depression, gastrointestinal distress (nausea, vomiting and/or diarrhea), and neurological symptoms (including fatigability, weakness, headache, impaired cognition, disorientation, ataxia, seizures and hypotension). The latent phase lasts about 2 to 20 days with a seeming improvement of most syndromes (except cytopenia), with duration correlating inversely with the absorbed dose. The manifest phase lasts from 2 to 60 days, with signs and symptoms expressed by various organs, and profound immune suppression predisposing the body to infection and sepsis. This phase is critical for radiation injury. Most patients surviving this phase will recover, but are still at risk for intermediate effects such as pneumonitis and late effects.

We have developed/adapted four biomathematical models to quantitatively characterize the degrees of ARS under various radiation conditions. The two hematopoietic models can also be used as tools to estimate the exposed dose or dose rate based on the depressed level of cells in peripheral blood.

- [Lymphocytes Depression](#)
- [Granulocytes Modulation](#)
- [Fatigue and Weakness Syndrome](#)
- [Upper Gastrointestinal Distress](#)

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