Application of the BIANCA biophysical model to space radiation research: latest updates

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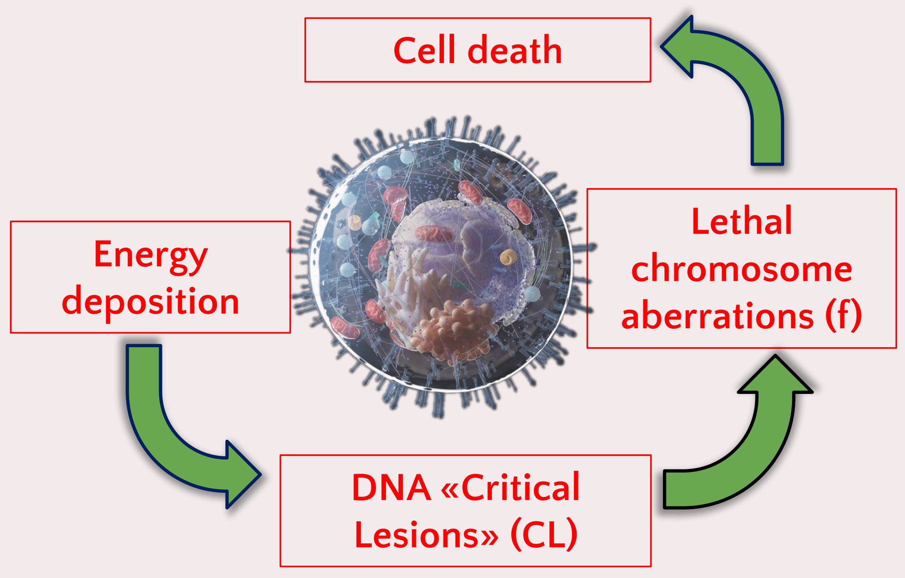
1 Introduction: Space radiation

Future space missions to the Moon and Mars
Main radiation sources in free space

Source	Dose Rate	Particles
Galactic Cosmic Rays (GCR)	0.5 mGy/day (max)	Protons, He-ions and Heavy-ions
Solar Particle Events (SPE)	Gy/event	

Biological response strongly depends not only on dose and radiation quality, but also on dose rate.

BIANCA model developed in Pavia



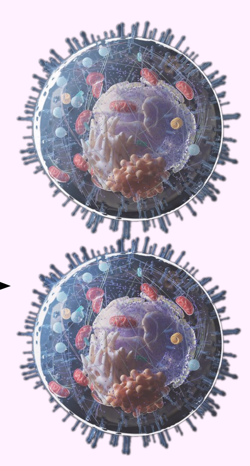
Main assumption: DNA "critical lesions" lead to chromosome aberrations, and some chromosome aberrations lead to cell death

2 Materials and Methods: space radiation calculations

Calculate the **RBE** depending on LET, particle, dose and dose rate

Relative **B**iological **E**ffectiveness

$$\mathbf{RBE} = \frac{\text{Dose}_{\text{photons}}}{\text{Dose}_{\text{space radiation}}}$$



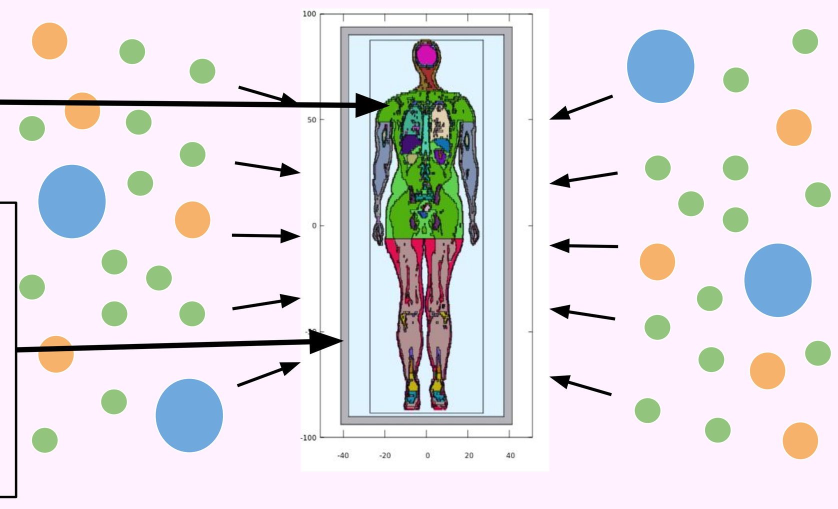
Same biological effect

In this work, two radiobiological databases have been generated by BIANCA for ions up to iron: Human skin fibroblasts cell survival and lymphocyte dicentric aberrations *[1]*

BIANCA + FLUKA → Dose calculation for comparison with space agency limits

Male and female ICRP phantoms

Cylindrical Al shielding (r=38cm, h=180cm) Variable thickness (from 0 to 30 g/cm2)



GCR,SPE sources

3 Results

Galactic Cosmic Rays

Dose in a Mars Mission (650 days, solar minimum) [2].

Al thickness (g/cm^2)	Equivalent Dose Q-value (mSv)	Equivalent Dose (mGy.RBE)
0	986.7	809.8
0.3	904.5	774.3
1	812.1	693.5
2	770.4	669.3
5	729.0	658.9
10	681.6	652.2
20	708.5	680.9

Stochastic effects (lymphocyte dicentric aberrations)
< 1 Sv career (ESA limit), but > 600 mSv (NASA limit)

Solar Particle Events

Spe of August 1972 [3,4].

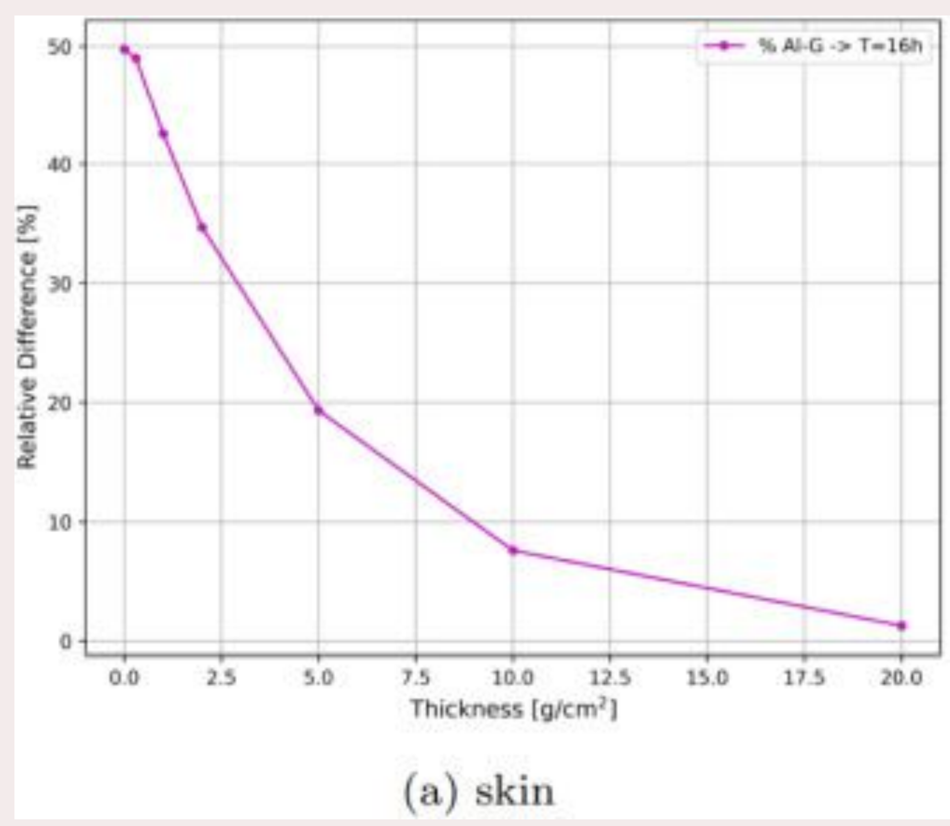
Al thickness (g/cm^2)	Equivalent Dose MALE (Gy.RBE)		Equivalent Dose FEMALE (Gy.RBE)	
	Skin	BFO	Skin	BFO
0.3	18.37	1.66	19.27	1.71
1	10.18	1.29	10.62	1.34
2	5.95	0.96	6.19	1.03
5	2.06	0.47	2.16	0.50
10	0.62	0.19	0.65	0.20
20	0.12	0.05	0.13	0.06

Deterministic effects
NASA and ESA limits (30-day limit)
Skin = 1.5 Gy-Eq
Blood Forming Organs (BFO) = 0.25 Gy-Eq

Dose rate *[5]*

Introduction of the **G** correction factor in the Lea Catcheside model to account for the repair of sublethal damage during prolonged or fractionated irradiations [5].

Fig. 1: Acute vs 16-h irradiation



Relative differences in the RBE-weighted dose reach up to 50% at low shielding thicknesses.

4 Conclusions & impact

- **BIANCA + radiation transport** enabled prediction of RBE for cell killing (deterministic effects) and chromosome aberrations (stochastic effects).
- **Mission timing and shielding are critical:** to respect NASA limits, a 650-day Mars mission should be performed during solar maximum; ~5 g/cm^2 Al is required for the October 2003 SPE and ~10 g/cm^2 for the August 1972 SPE.
- **Dose rate strongly impacts risk:** organ RBE-weighted doses for the August 1972 SPE differed by up to ~50% between acute and prolonged irradiation, confirming that RBE depends on LET, dose, and dose rate.
- **Comprehensive RBE modelling:** BIANCA accounts for RBE variations with particle type, LET, absorbed dose, and dose rate.
- **Dose-rate matters:** Biological effectiveness changes significantly with dose rate and must be included in space radiation risk assessment.

References

1. Ricardo L Ramos et al 2022 J. Radiol. Prot. 42 021523
2. Ricardo L Ramos et al 2023 Int. J. Mol. Sci. 24(3), 2328
3. Ricardo L Ramos et al 2024 J. Radiol. Prot. 44 041502
4. Ricardo L Ramos et al 2024 L. Sci. Space Res. 41 210 217
5. Ezequiel I Canay et al 2025 Life Sci. Space Res. In Press.

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