Health Canada Santé Canada

Canada

Equivalent dose measurements of astronauts for ISS space missions between 2007-2016

Benjamin Puzantian, Lindsay Beaton-Green, and Ruth Wilkins

Ionizing Radiation Health Science Division, Consumer and Clinical Radiation Protection Bureau, Health Canada, ON, Canada

Department of Physics, Carleton University, ON, Canada

September 6, 2023

YOUR HEALTH AND SAFETY... OUR PRIORITY.

Outline

- Biodosimetry - Health Canada's space biodosimetry program and limitations
- Equivalent dose estimates and particle fluxes inside ISS for CSA and ESA missions from 2007 – 2016 with OLTARIS
  - GCR and TPs effects only
- Monte Carlo programs for cellular biology
- Conclusions and next steps

Biodosimetry

- **Method used to obtain dose estimates for individuals exposed to ionizing radiation based on their biological responses at the cellular level**

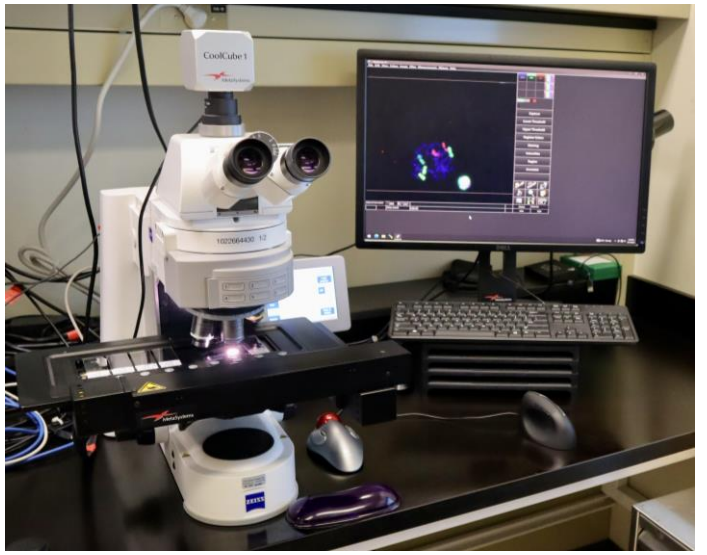
Useful in:

- Cases of accidental exposure
- When physical dosimetry is called into question or not possible
- Cases of nuclear emergencies
- Determining astronauts' exposure to space radiation

- Our Division focuses on all these situations

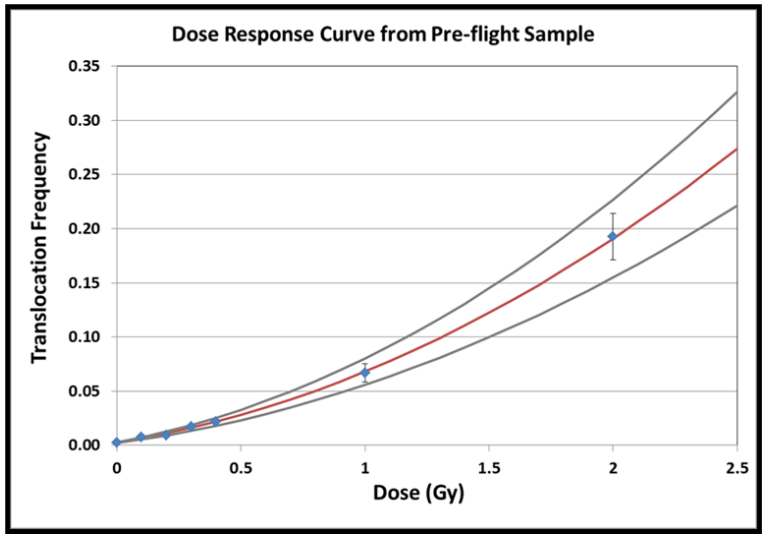
Biodosimetry

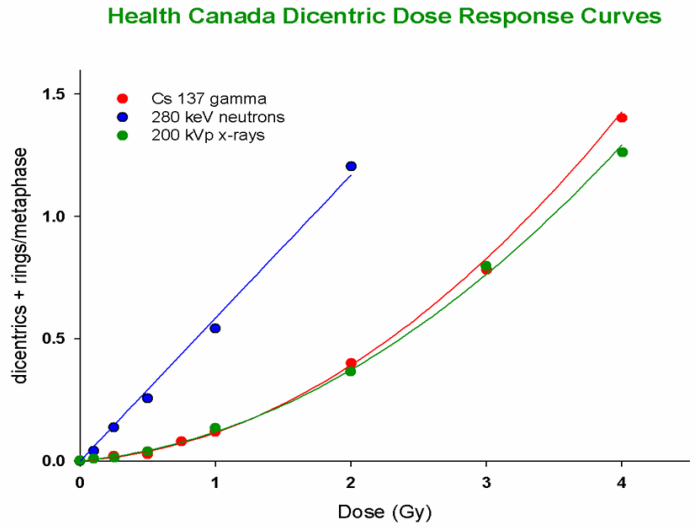
- At Health Canada, we are equipped to perform the following assays:
  - **Translocation analysis by the Fluorescence *in situ* hybridization (FISH)**
  - **Dicentric Chromosome Assay (DCA)**
  - **Cytokinesis Block Micronucleus (CBMN)**
  - **γH_2AX assay**
  - **And more …**



Biodosimetry

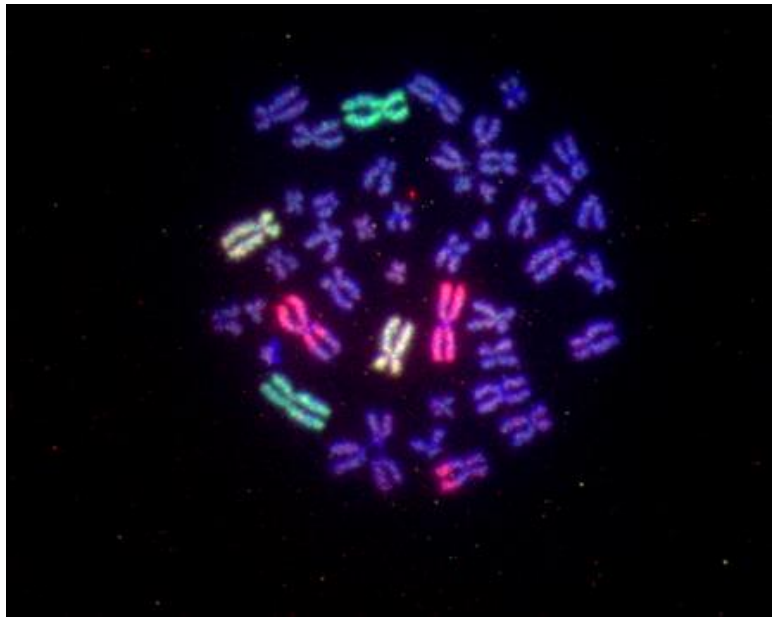
- All biodosimetry methods require the use of a **<u>calibration curve:</u>**
  - ➢ Mathematically models biological responses to irradiations at set doses
  - ➢ Used to obtain dose estimates
- Calibration curves have different shapes depending on the radiation source:
  - ➢ Linear for high LET radiation
  - ➢ Quadratic for low LET radiation
- The shape affects the accuracy of the dose estimates

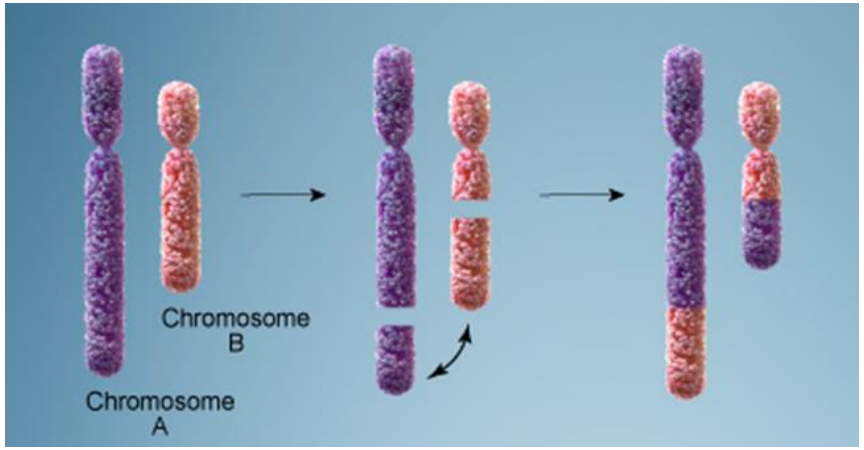




Biodosimetry

- For astronauts, translocation analysis is our go-to biodosimetry assay
  - **Measures stable translocations**
    - Occurs when chromosome segments are exchanged but no genetic information is lost
    - **Methodology** involves:
      - Irradiating blood in a 250kVp X-ray cabinet
      - Following various preparation steps, lymphocytes with painted chromosomes are scored by microscopy to measure frequency of stable translocations





Source: U.S. National Library of Medicine

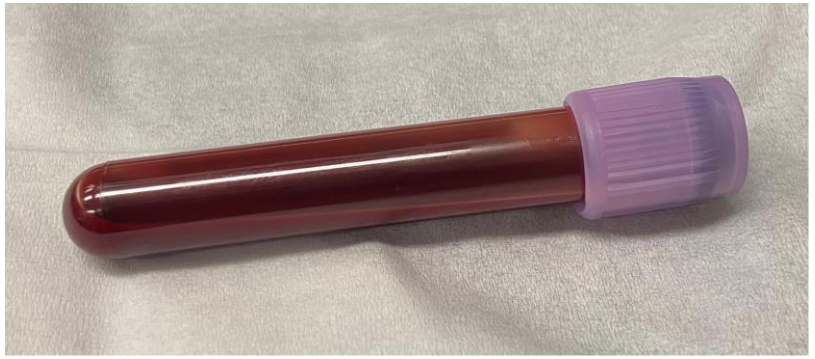
Health Canada's space biodosimetry program

- Biodosimetry is currently a medical requirement for astronauts as specified in the ISS MED Vol. B Appendix A for CSA
- Career radiation dose limit for CSA astronauts is 1Sv
- Health Canada conducts biodosimetry analysis for CSA astronauts after every space flight
  - We produce personalized calibration curves for each astronaut
  - Our translocation analysis scoring system has been harmonized with NASA to ensure comparability of data
  - ESA analysis was also done by HC from 2007 until 2016 but has since been discontinued
- Overall, program has completed dose assessments on 11 astronauts

Beaton-Green et al. Toxicology and Environmental Mutagenesis, 793, 101-106. (2015)

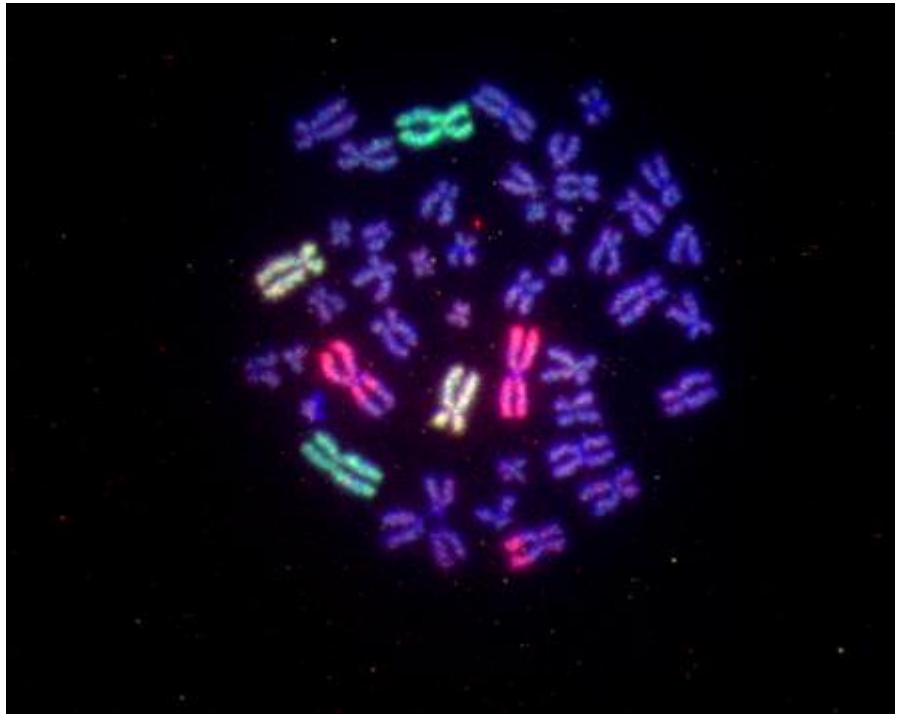
FISH procedure for astronauts

- ✓ Blood samples collected under the supervision of the flight surgeon pre- and post-flight
  - ❑ Pre-flight sample is used to establish a baseline
    - 34 mL of blood drawn 35-90 days before flight
  - ❑ Post-flight sample drawn immediately after flight and 6 months after
    - 17 mL of blood drawn 7-14 days post-flight
    - 17 mL blood drawn 6-18 months post-flight
- ✓ Samples are delivered within 24-48 hours after collection
- ✓ Dose estimates provided approximately 1 month after receiving the blood



FISH scoring methodology

- We score 10,000 cells in metaphase pre-flight at 0 Gy to determine the background damage, then between 500 (high doses) – 4000 (low doses) to produce the calibration curve.
- 1,000 cells are scored in both post-flight draws.
  - Use our own damage scoring system that has been harmonized with NASA
  - Score different types of simple DNA damage including Apparently Stable Translocations (AST)
  - Also, take note of but not include complex damage (3 or more cuts in 2 or more chromosomes).



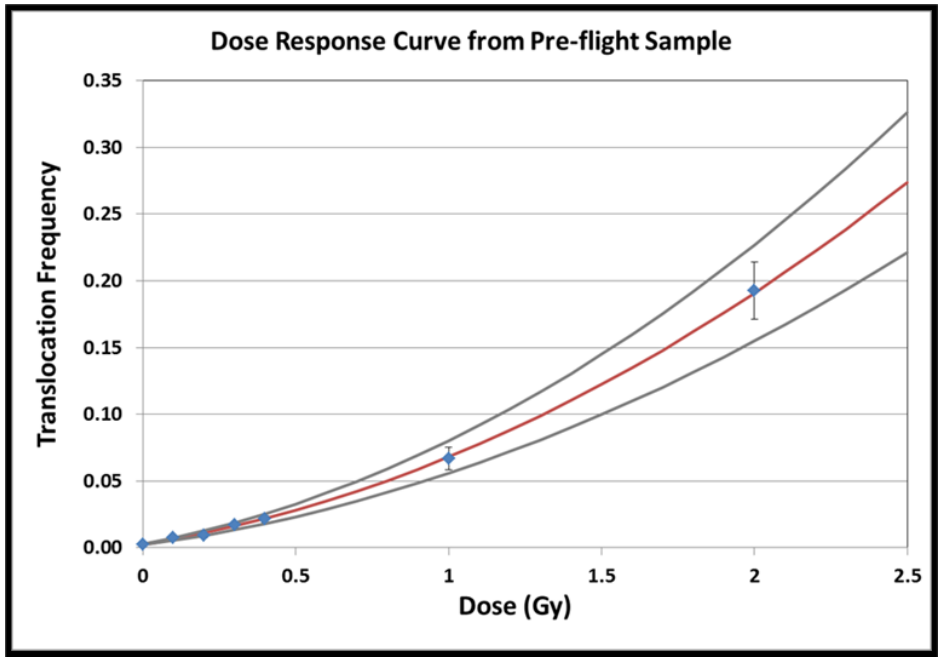
Slide quality: _____ Case or Folder name: _____ Slide ID: _____ Page #: ___ of ___

Date: _____ Date FISH done: _____ Scorer: _____ Microscope, objective: _____ DCheck: _____

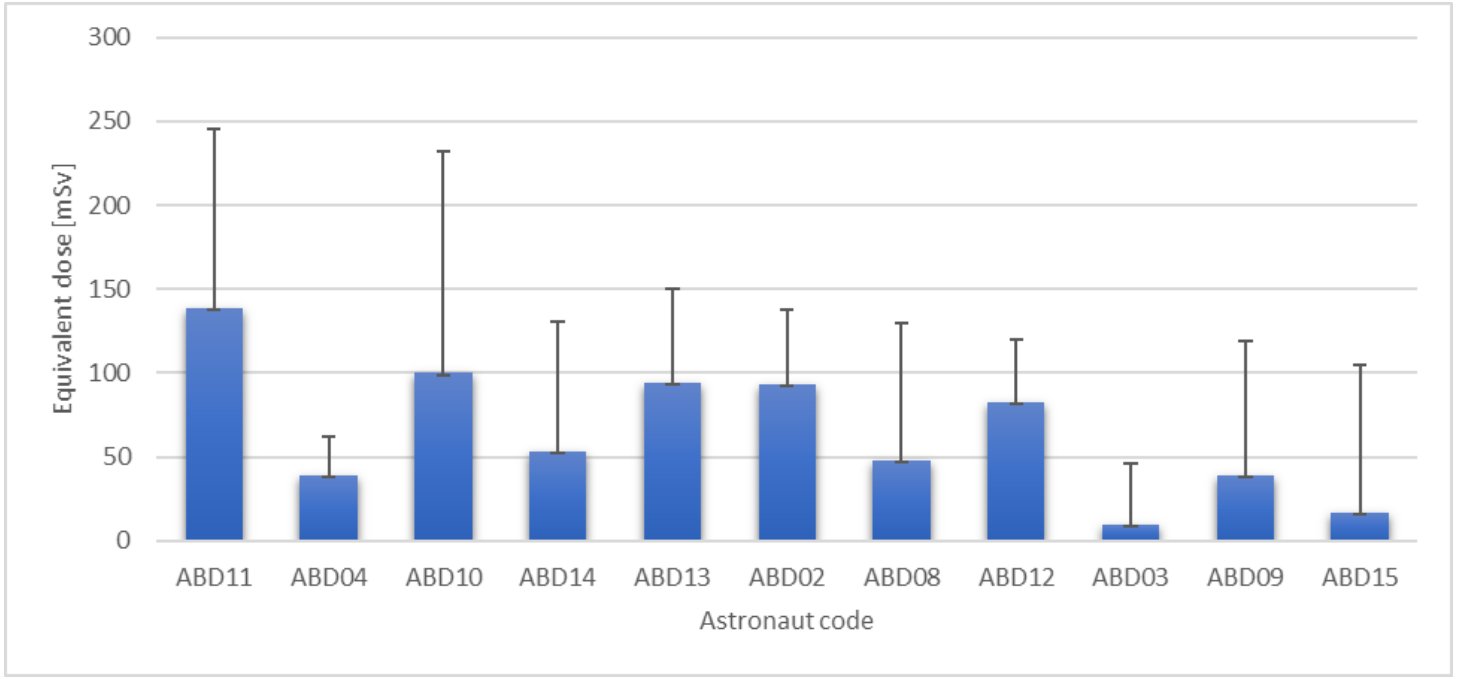
Pic No	Cell No	Normal	PAINT Score (damage + comments)	Type of damage							Simple			Complex		Chroms			Stable Cell
				CJ	Del	Inv	Ins	Dic	R	Ace	AST	PIT	TIT	SC	Unst	R	G	Y	

FISH

- At HC we build personalized astronaut calibration curves by finding the translocation frequency (translocations/cells scored) for different doses
    - Post-flight (immediately and 6 months), translocation frequencies measured in blood samples and matched to these calibration curves to obtain dose estimates



Health Canada's space biodosimetry program: at a glance



Total: 11 individuals over 10 years

Mostly 6-month missions

Health Canada's space biodosimetry program: limitations

- Our calibration curves are limited to X-ray sources (due to laboratory restrictions)
  - ➢ To address this issue, we are exploring the use of Monte-Carlo based methods to create mixed source calibration curves that more accurately reflect space radiation environments
  - ➢ With these calibration curves, we seek to determine a correction factor to apply to our current assay

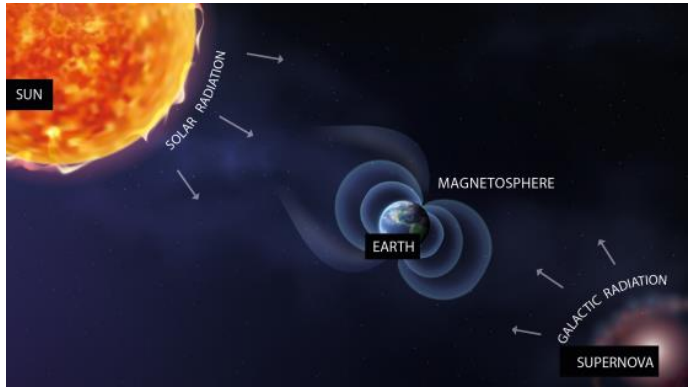
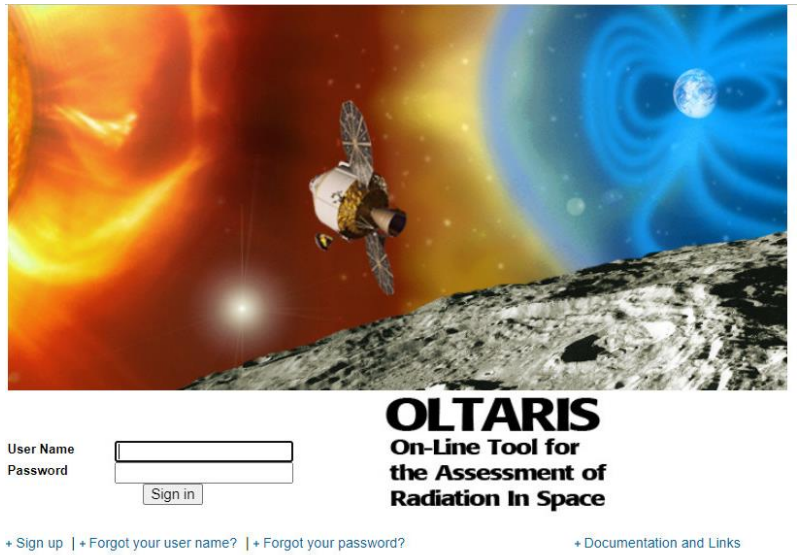


Image from: https://www.iaea.org/newscenter/news/cosmic-radiation-why-we-should-not-be-worried

Modelling equivalent doses and particle fluxes inside the ISS with OLTARIS

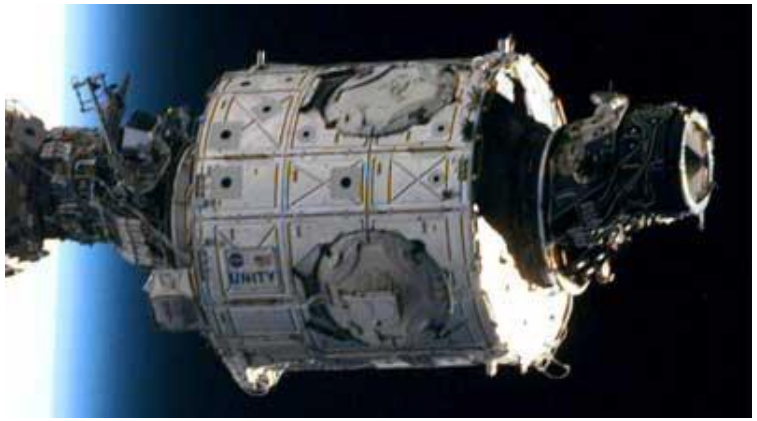
- On-Line Tool for the Assessment of Radiation in Space (OLTARIS) is an internet-based tool to assess the risk of radiation on astronauts or equipment in ISS or in spaceship
- Runs on NASA's High Charge(Z) and Energy TRaNsport (HZETRN) deterministic code



Thickness distributions

Built-in ISS components:

- US LAB
- Node 1
- Cupola
- Service module

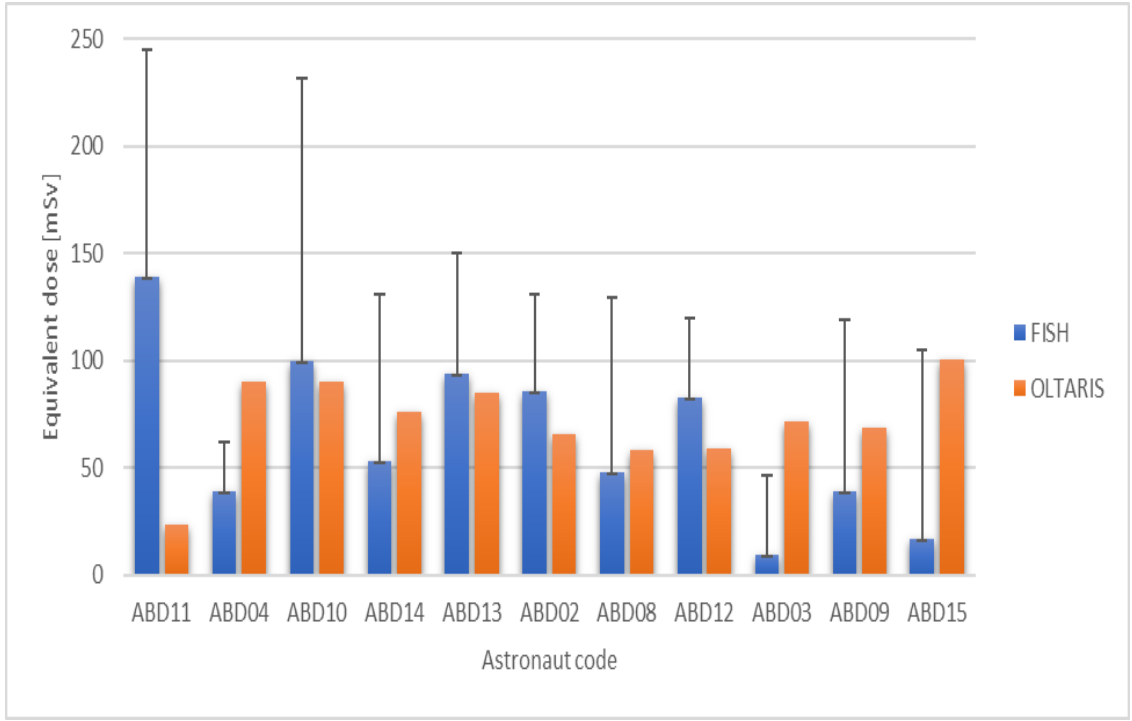


Simulation parameters

Parameter	Feature Used
Environment	Circular Earth Orbit
Altitude	400 km
Inclination	51.6 degrees
GCR model	Badhwar-O’Neil 2020
Trapped particle model	AP8
Dose equivalent quality factor	ICRP60

Comparison of OLTARIS and HC biodosimetry dose estimates

- Dose estimates from biodosimetry are usually higher then OLTARIS
  - Possibly due to using low LET calibration curves to model predominately high LET radiation.
- With permission and consent from CSA, ESA, and NASA medical boards and individuals, HC would like to benchmark these results with physical dosimetry

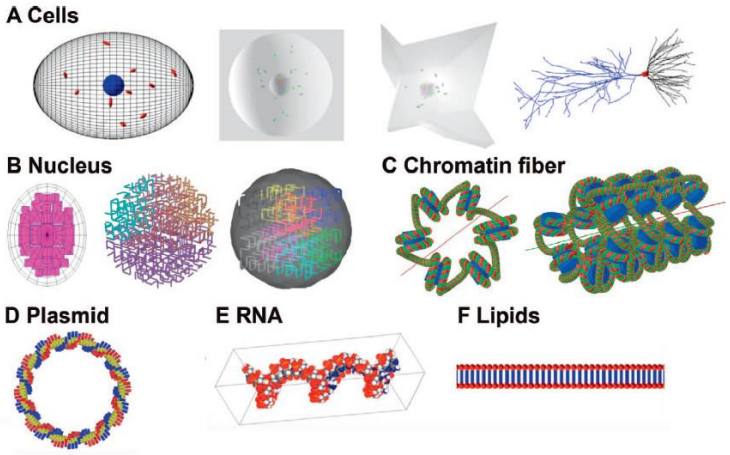


Code	Dose Rates OLTARIS [mSv/day]
ABD11	0.47
ABD04, ABD10	0.48
ABD14	0.47
ABD13	0.44
ABD02	0.38
ABD08	0.35
ABD12	0.35
ABD03	0.36
ABD09	0.37
ABD15	0.49

Modelling biodosimetry with Monte Carlo programs

Modelling biodosimetry: TOPAS-nBio

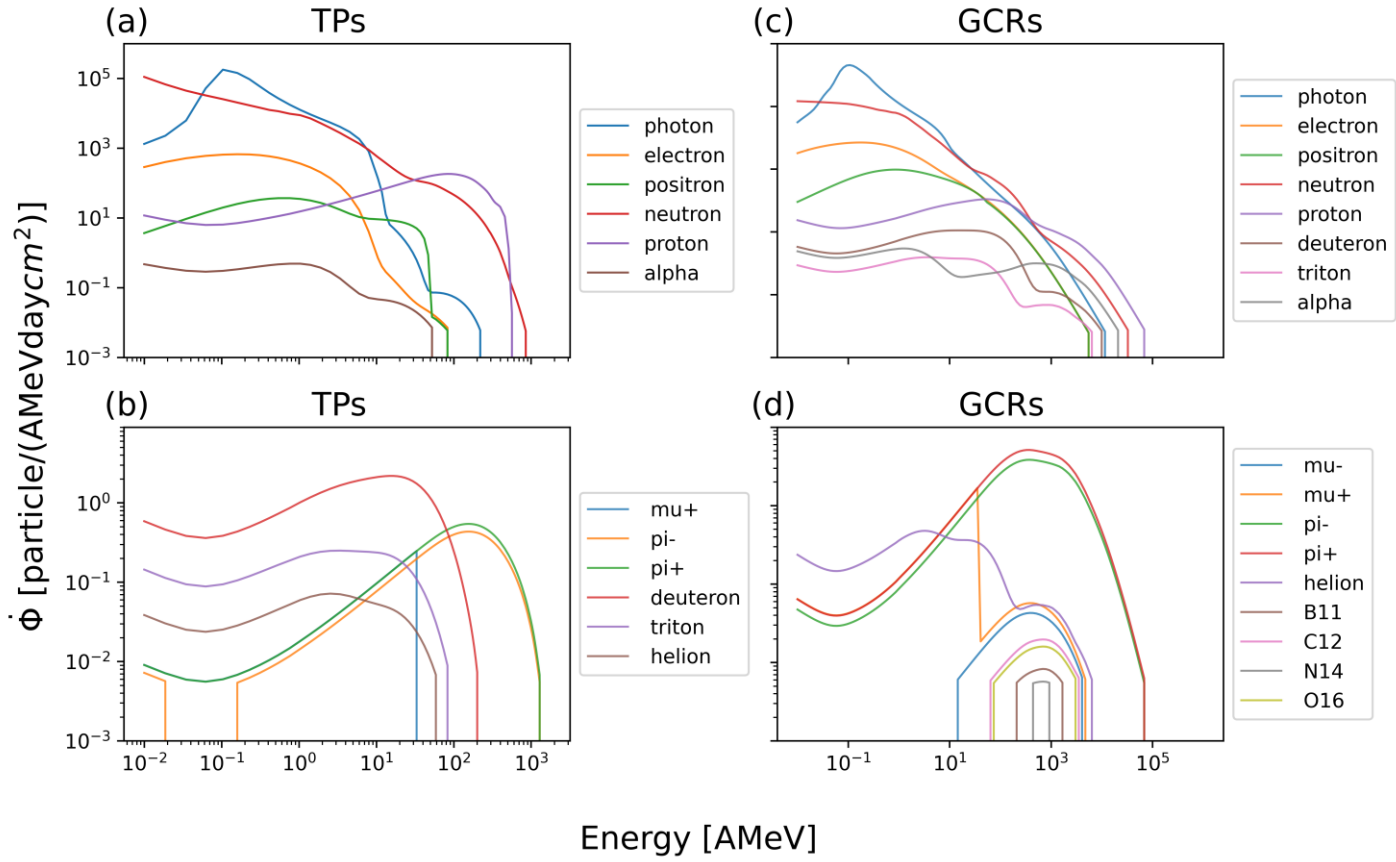
- TOPAS-nBio is Monte Carlo tool package that is built off and extends Geant4-DNA
  - Focusses on biological responses to radiation damage down to the DNA level
  - Can implement different cell types and geometries
  - Capable of outputting scored DNA damage in the standard DNA damage format



Schumann et al. RADIATION RESEARCH 191, 125–138 (2019)

Modelling biodosimetry: mixed beam calibration curves

- Produced particle fluxes as function of energy for TPs and GCRs for 2015 mission in Cupola component
  - Tune these particle fluxes and use as source inputs (e.g. to irradiate a tissue equivalent phantom) in Monte Carlo programs to produce mixed beam calibration curves
  - With these simulated mixed beam calibration curves, we will determine a correction factor
  - Correction factor will help improve the accuracy of our current assay



Conclusions

- ✓ Discussed and presented current state of Health Canada's space biodosimetry programme
- ✓ Simulated astronaut missions from the programme with NASA's OLTARIS to obtain equivalent dose estimates and particle fluxes
- ✓ Equivalent dose estimates from OLTARIS are generally lower than those obtained by HC's biodosimetry

Next steps

- Perform these mission simulations with ESA's SPENVIS program to validate the particle flux results from OLTARIS
- Work is underway to build mixed radiation beams with Monte Carlo programs (TOPAS-nBio or other …) to obtain mixed radiation calibration curves
- Benchmark mixed radiation calibration curves against experimental ones

Acknowledgements

Lindsay Beaton-Green[1]
Ruth Wilkins[1]
Samy El-Jaby[2]
Chris Sandridge[3]
Leena Tomi[4]

Thank you for your time and attention!

[1] Ionizing Radiation Health Science Division, Health Canada, Government of Canada
[2] Canadian Nuclear Safety Commission, Government of Canada
[3] NASA Langley Research Center
[4] Canadian Space Agency, Government of Canada

Funding: Support from NSERC grant number RGPIN-2022-0431 is greatly appreciated.