

Dose-Effect Models for Biological Risk Assessment of Exposure to Space Radiation

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The human exploration and colonization space missions in the near future

SpaceX was founded under the belief that humanity is out exploring eventually more exciting things than we are not.

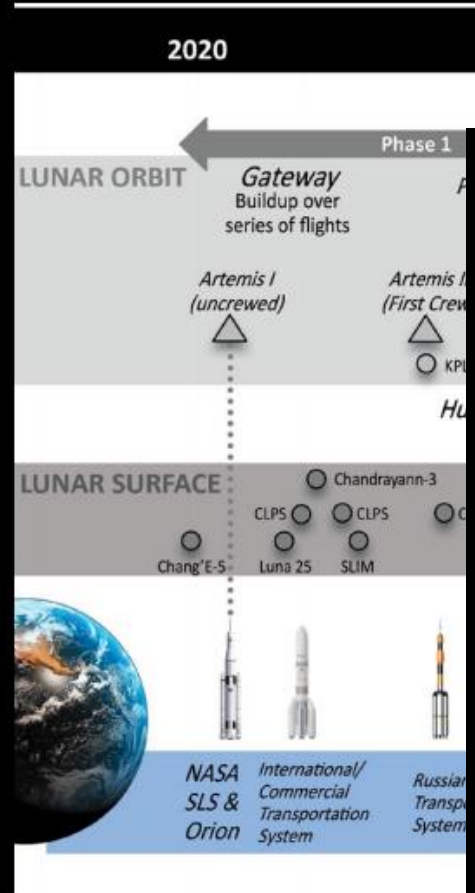


Figure 1. Updated ISECG Lunar Surface

WHAT IS THE MOON VILLAGE ASSOCIATION ?

The Moon Village Association (MVA) created in June 2017, to foster the implementation of the Moon Village.
MVA is Member of IAF and Observer in United Nations - COPUOS

A forum to advance development of the Moon Village involving Industry, government, space agencies, international organizations / NGOs, and the Public at large.

A catalyst stimulating a virtuous cycle of investments for the development of a lunar economy

> 200 INDIVIDUAL MEMBERS FROM 48 COUNTRIES



>28 INSTITUTIONAL MEMBERS FROM 10 COUNTRIES



The International Space Exploration Coordination Group to advance the Global Space Exploration Goals



MV Architecture Workshop / December 2020

John Mankins



John C. MANKINS

Vice President, Moon Village Association (MVA), President, ARTEMIS Innovation Management Solutions, United States

- A virtual event involving some 60-plus participants over three days, 5 hours each day
- Primary outcomes
 - ✓ Settlement 2045 Defined (concept, location, systems, technologies)
 - ✓ No showstoppers identified – in terms of transportation, use of local resources, energy, radiation protection, etc.
 - ✓ Significant ‘known unknowns’ to be worked – including biosphere systems, concepts of operations (CONOPS), others
 - ✓ Significant ‘unknown unknowns’ – including gravity, sources for key materials (e.g., Nitrogen, Carbon)
 - ✓ Need for better understanding of lunar topography / resources
- Other topics: will lead to updates in the study during 2021...
 - Need to incorporate installations of and operations by multiple countries and/or groups
 - Need for a ‘Metric’ to characterize ‘maturity’ to realize sustainable Lunar Operations: “**Moon Village Readiness Levels**” (MVRLs) – *now in development*

3/10/21

Expanding Humanity to the Moon: Architectural Considerations

zoom

Radiation Protection seems not to be a showstopper but for sure the characterization of the moon radiation field is crucial for a safe and healthy live at the Moon Village.

Limits and concerns

Manned spaceflight especially the one that beyond the LEO could represent a concern for the health risk assessments of astronauts.

The limit in carrying out the missions are health effects

- short-term (<hours)
- acute effects (<months)
- late effects including severe toxicity or death

Radioprotection in space is a difficult jobs due to the presence of different species of particle and nuclei that present different characteristics in penetrating the barrier and shielding

LEO-ISS



X150-200

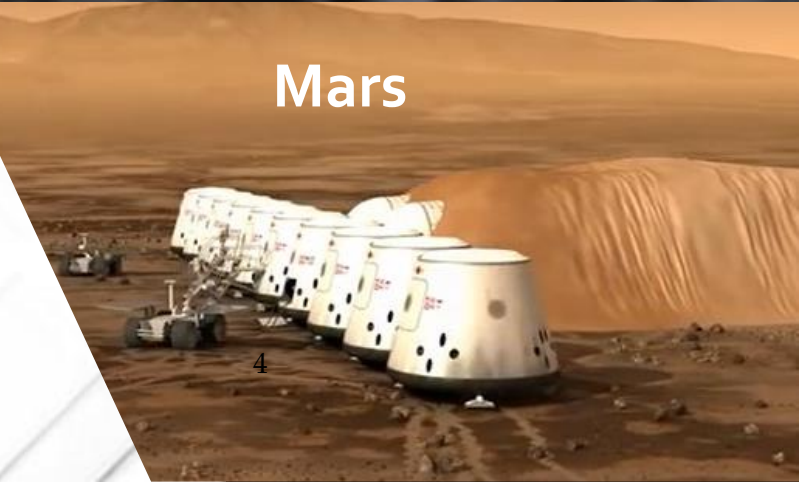
Moon



X300-400

Mars

X250 (X750)



Space Radiobiology

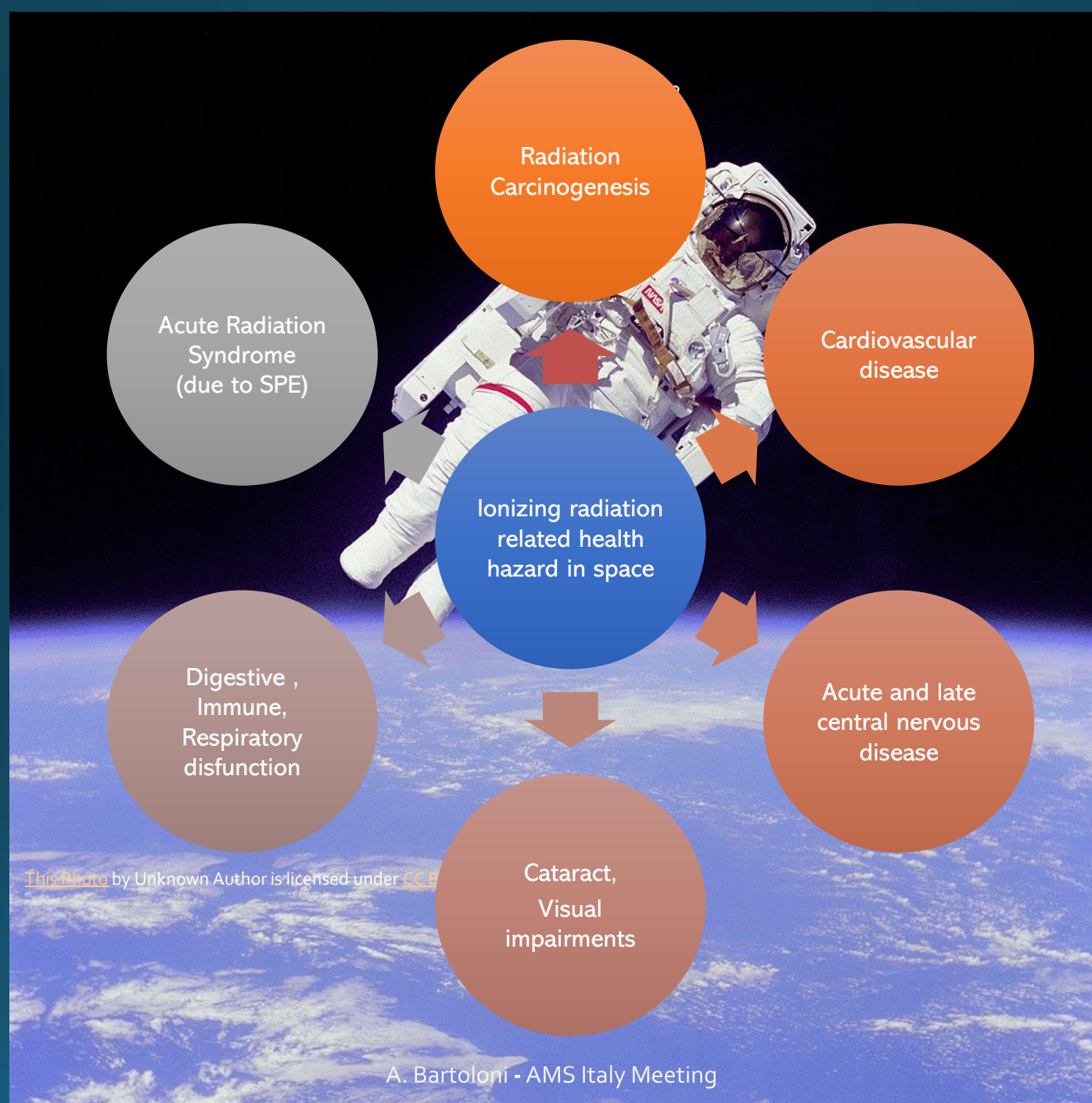
- Growing interest in recent years due to the increased human capability to realize manned **space missions**
- Space Radiation Environment is a complex mixture of radiation species
 - SUN originated (SPE, CME)
 - Trapped in the Earth Magnetic Field
 - Galactic Cosmic Ray
- In space both deterministic than stochastic effects are present
- In addition the presence of shielding on space stations or starship modifies the incident spectrum and exposure due to particle production by spallation with such structure
- Usual technical solution used on the Earth to protect workers do not apply for astronauts/space-worker (e.g. distance)

(Space) Radiobiology

- Molecular and cellular level
- Stochastic effects
 - Hereditary effects
 - Cancer
- Deterministic effects

Time	Event
10-18 s	Absorption of Ionising Radiation
10-16 s	Physical Events
	Ionization
10-12 s	Physicochemical Events
	Free radical formation
	Breakage of chemical bonds
10-12 – 10-6 s	Chemical Events
	Reactions of radicals
Minutes to hours	Biochemical/Cellular Processes
	Repair
	Division delay
	Chromosome damage
	Loss of reproductive capacity
Days to months	Tissue Damage
	Central Nervous System, Gastro-Intestinal, Bone marrow syndromes
	Late tissue damage
	Birth defects from in utero exposure
Years	Late Somatic Effects
	Cataracts
	Carcinogenesis
Generations	Genetic Effects

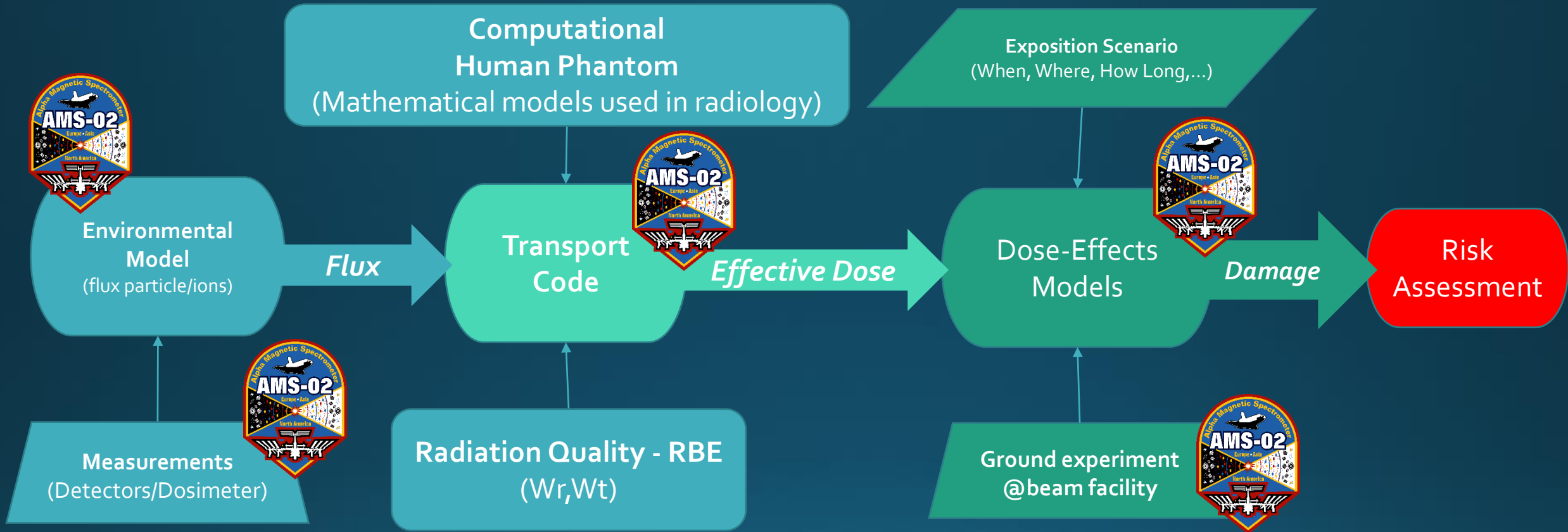
Ionizing radiation exposures is one of the main concern for astronaut's health involved in exploratory missions to the Moon and Mars due to the high doses of radiation expected during the flight and on the surface



The radiation health hazard assessments in exploratory space missions requires the evaluation of the dose effects models in order to quantify the expected damage in the forecast astronaut's exposition scenario.

To complete this task the charged particle data taken by the high energy particle experiments can be useful to increase knowledge in many part of the risk assessment phases

Radiation health hazard assessment in exploratory space missions



2020 Virtual IEEE Nuclear Science Symposium and Medical Imaging Conference

Symposium on Room Temperature X-Ray and Gamma-Ray Detectors

31 October - 7 November 2020

3/11/2021

Can high energy particle detectors be used for improving risk models in space radiobiology?

A. Bartoloni¹, S. Strolin², L. Strigari²

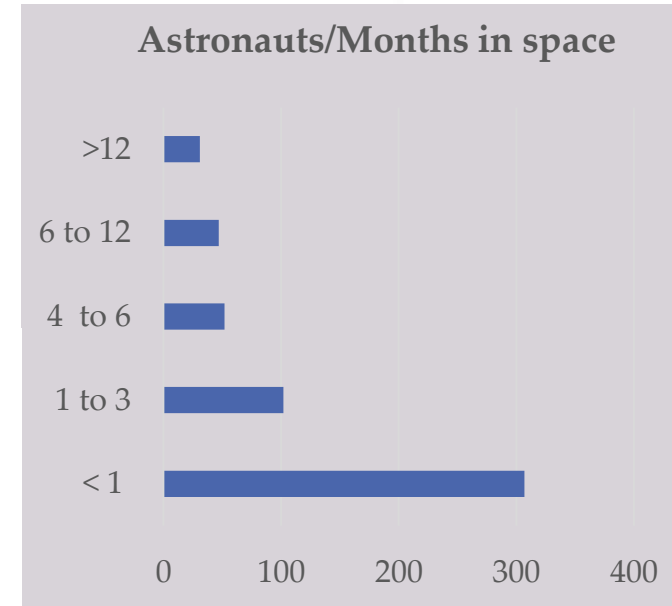
A. Bartoloni - AMS Italy Meeting

Dose-Effects Relationship

The known dose-effect relationships are based on a limited number of astronauts (hundreds)

Total Space Radiation Dose (mGy)	<0.2	0.2-1.99	2-3.99	4-10.99	≥11	Total
# Astronauts	14	19	11	15	14	73
# Cancer Deaths	2	2	1	0	2	7
# Cardiovascular Disease Deaths	1	4	1	1	0	7
# Accident Deaths	6	5	0	0	1	12
# Other Deaths	1	0	1	0	1	3
# Unknown Deaths	1	0	0	3	1	5
Mean Medical Dose (SD)	2.4 (6.4)	27.7 (13.6)	34.4 (20.8)	29.1 (15.6)	32.5 (21.7)	25.1 (19.4)
Mean Year at Birth (SD)	1932.6 (4.1)	1931.7 (5.2)	1931.6 (2.5)	1932.2 (4.4)	1931.5 (3.3)	1931.9 (4.1)
Mean Age at Entry into Astronaut Corps (SD)	31.6 (2.7)	32.2 (3.4)	33.0 (2.5)	31.8 (2.8)	32.5 (2.2)	32.2 (2.8)
Mean Follow up Time (SD)	29.3 (23.6)	40.3 (15.0)	46.4 (12.9)	50.7 (7.8)	48.1 (7.5)	42.8 (16.1)
Total Group Person Years	409.9	766.5	510.1	760.8	673.4	3120.8
Mean Age at Death (SD)	57.7 (23.8)	65.7 (15.9)	64.5 (14.9)	78.2 (19.9)	74.9 (10.2)	65.2 (19.1)
Mean Current Age of Living Astronauts (SD)	79.9 (2.9)	82.1 (3.9)	84.9 (3.1)	83.6 (3.6)	83.8 (2.3)	83.4 (3.4)

Table 1. Early astronaut cohort demographics binned by total space radiation dose category. SD = standard deviation.



Needs of an improvements

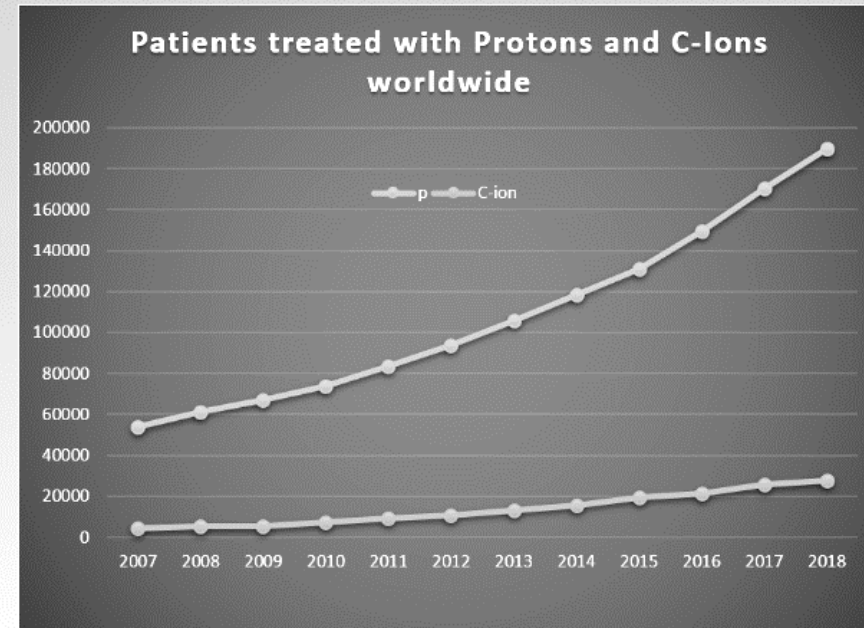
Dose-Effects Relationship – How improve ?

The optimization of the radiation shielding/layout is based on the improvement of the dose-effect relationships.

This approach allows a balance between shielding thickness and sanitary aspects.

This is what is done in the healthcare, both in diagnosis than in treatment (almost the entire population for hundred years)

Statistics of patients treated in particle therapy facilities worldwide:



You have to register and/or to login as PTCOG Member to get access to the PTCOG Patient Treatment Statistics.

Investigated models for predicting dose effect relationship in humans involved in space missions (August 2020)

Effects/Model (number of studies)	Dose Range or LET
Chromosomal Aberrations (7)	5 : 150 mGy
Cataract Risk (7)	8 mSv
Central Nervous System Risk (2)	100-200 mGy
Oral Mucositis (2)	2000 mGy
Cardiovascular Disease (4)	1000 mGy
Eye Flashes (4)	LET>5-10 KV/um
Cancer (6)	<100mGy

Only Targeted Effects (TE) are represented

Targeted Effects vs Non targeted Effects

Target Effects (TE) will regards the IR damage due to the irradiated tissue or organs

Non Target Effects instead will refers to the damage generated in tissue not directly irradiated

Usual linear model used in radioprotection do not take in account the NTE effects

“The scarcity of data with animal models for tissues that dominate human radiation cancer risk, including lung, colon, breast, liver and stomach , suggest that **studies of NTEs in other tissues are urgently needed** prior to long-term space missions outside the protection of the Earth’s geomagnetic sphere”

“Non Targeted Effects Models Predict Significantly Higher Mars Mission cancer Risk than Targeted Effects Models” - F.Cucinotta et al. 12/05/2017

Individual radiosensitivity

- Individual radiosensitivity will refer to the different way in which each person reacts to the ionizing radiation exposure. In the space colonization scenario, it will be crucial to identify the limits on this feature.
- It is present in both deterministic (e.g. erythema, ...) than stochastic (e.g. cancer, ..) effects .
- Individual radiosensitivity has been reported in the experience from the clinical fields and the origin comes from by genetic susceptibility. (DNA repairs capability)
- The International Commission of Radiobiological Protection (ICRP) did in 2007 an estimation that between 5% to 15% of population may be carriers of genetic mutations conferring more radiosensitivity.
- Methods that can measure or predict the individual radiosensitivity and the identifications of predictive biomarker would be of great value for both astronauts screening and for a precision radiotherapy treatments plan
- Same problems are present for cancer patients treated with radiotherapy to implement a precision medicine treatment

Summary

- In the coming years there will be a great interest for space human mission non only to explore but also for a permanent presence of humans outside the geomagnetosphere
- Space Radiation is a main concern and the first one showstopper in many human exploration scenarios.
- Dose-Effects models knowledge should be improved and a synergy with the experience from the clinical field is crucial to perform this task
- Other important topics needs to be faced (Non-Targeted Effects, Individual Radiosensitivity,...)
- AMS02 detector is a principal, and also unique, source of information to perform this investigations

THANKS for the attention !!!

References

- «Global Exploration Roadmap – Lunar Surface Exploration Scenario – update August 2020» ISECG
- “Radiation Exposure and Mortality from Cardiovascular Disease and Cancer in Early NASA Astronauts» S.Robin et Al - 2018
- «Research plans in Europe for radiation health hazard assessment in exploratory space missions” L.Walsh et Al. -2019
- “Non-Targeted Effects Models Predict Significantly Higher Mars Mission cancer Risk than Targeted Effects Models” - F.Cucinotta et al. 12/05/2017
- “Assessment of Radiosensitivity and Biomonitoring of Exposure to Space Radiation” – R. Quintens, S. Baatout, M.Morels – 2020