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

AMS Italy Meeting - 11/03/2021

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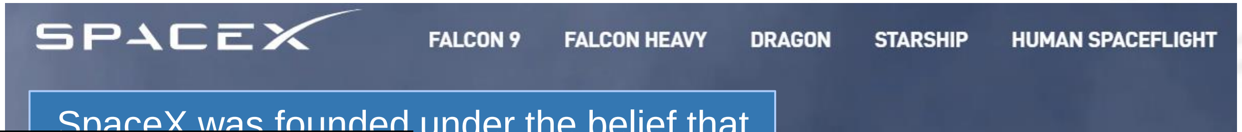
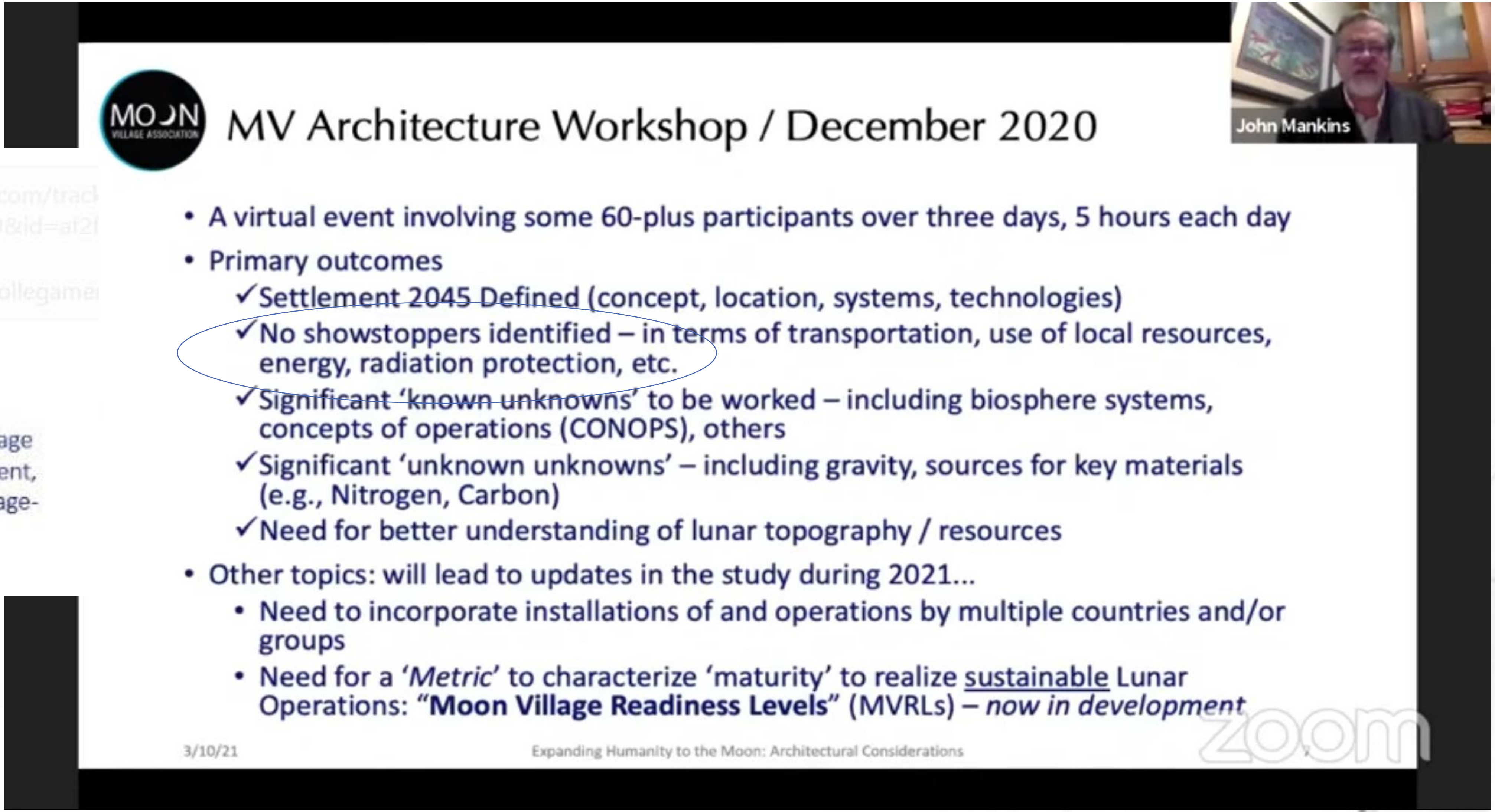
The human exploration and colonization space missions in the near future



John C. MANKINS
Vice President, Moon Village Association (MVA), President, ARTEMIS Innovation Management Solutions, United States



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.

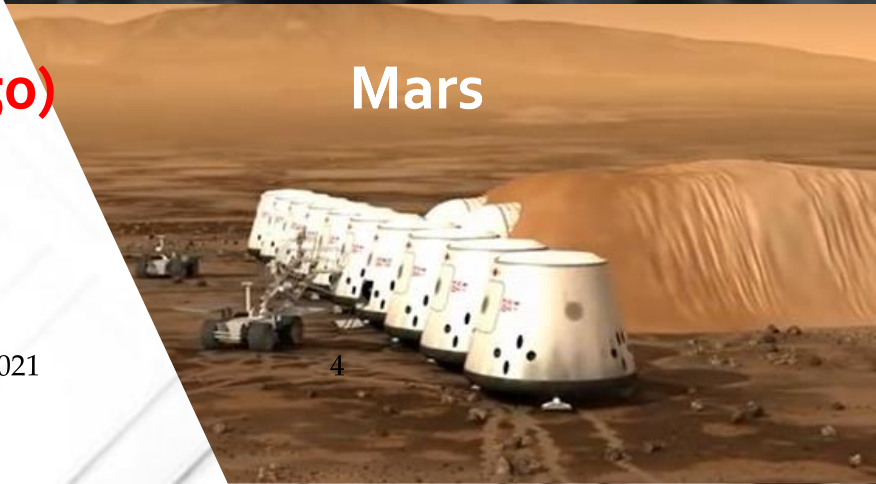
The limit in carrying out the missions are health effects

- 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

x150-200

x300-400



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 sthocastic 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)

Synergy Source

(Space) Radiobiology

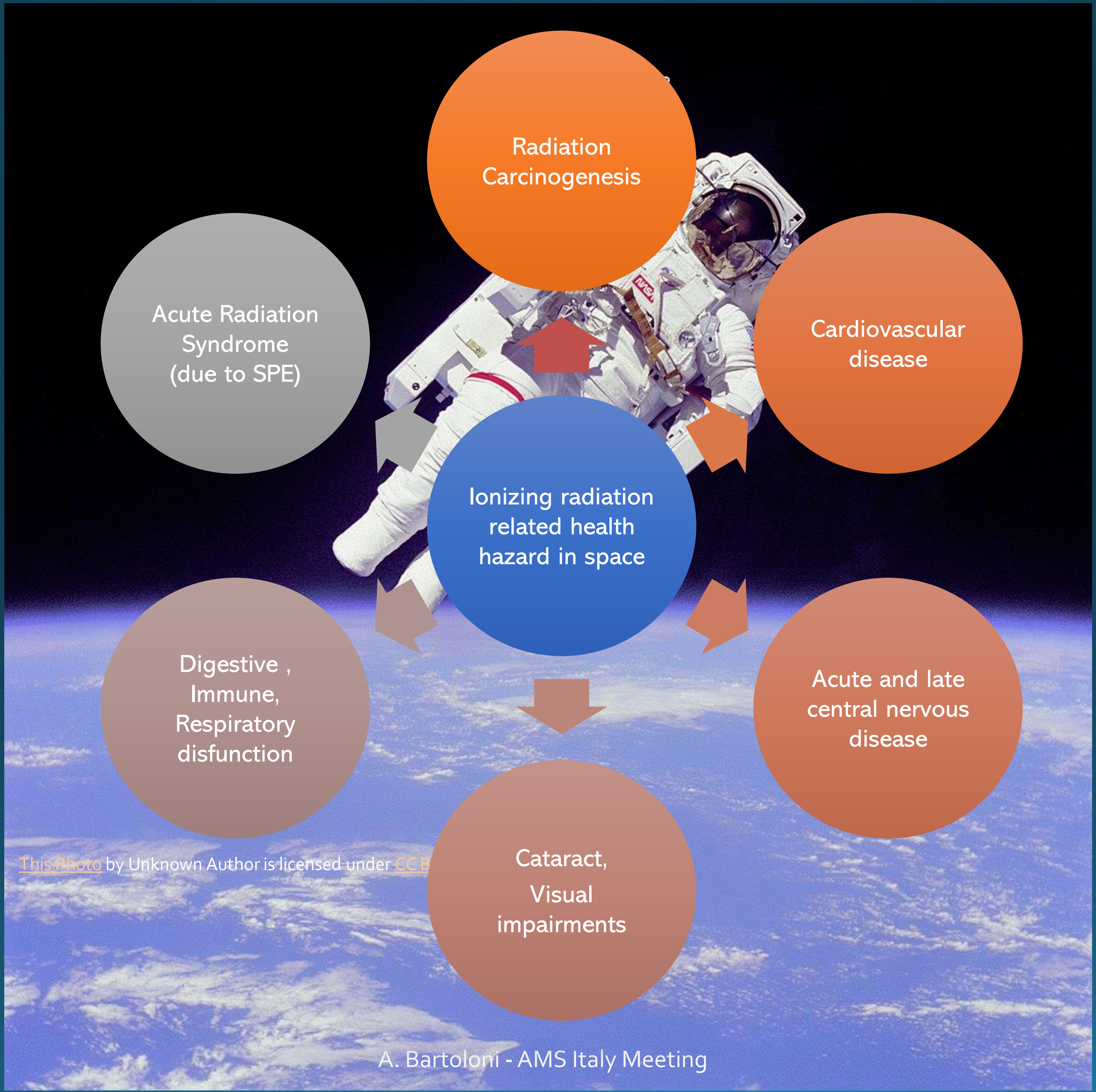
- Molecular and cellular level

- 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

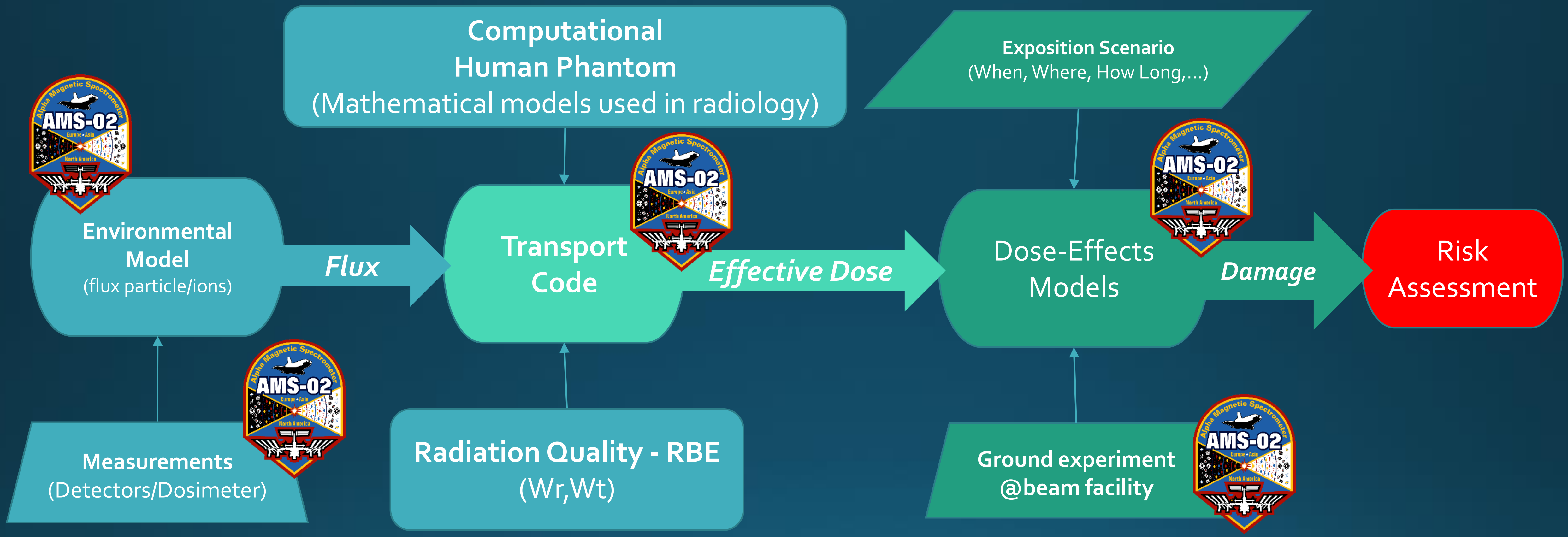
Ionizing radiation exposures is one of the main concern for astronaut's health involved in exploratory missions to the Moon and Mars due to the high doses of radiation expected during the flight and on the surface

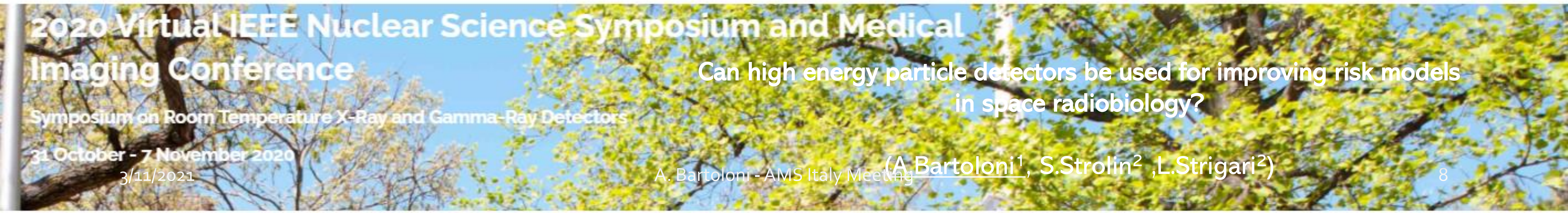


The radiation health hazard assessments in exploratory space missions requires the evaluation of the dose effects models in order to quantify the expected damage in the forecast astronaut's exposition scenario.

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

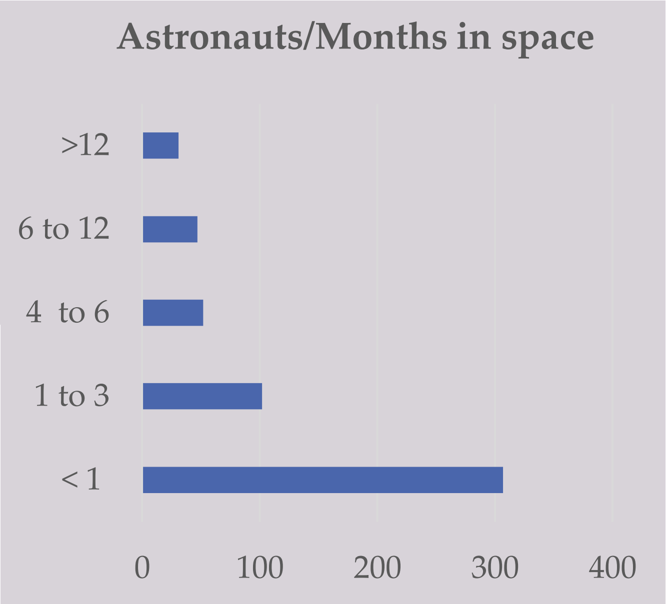




Dose-Effects Relationship

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)

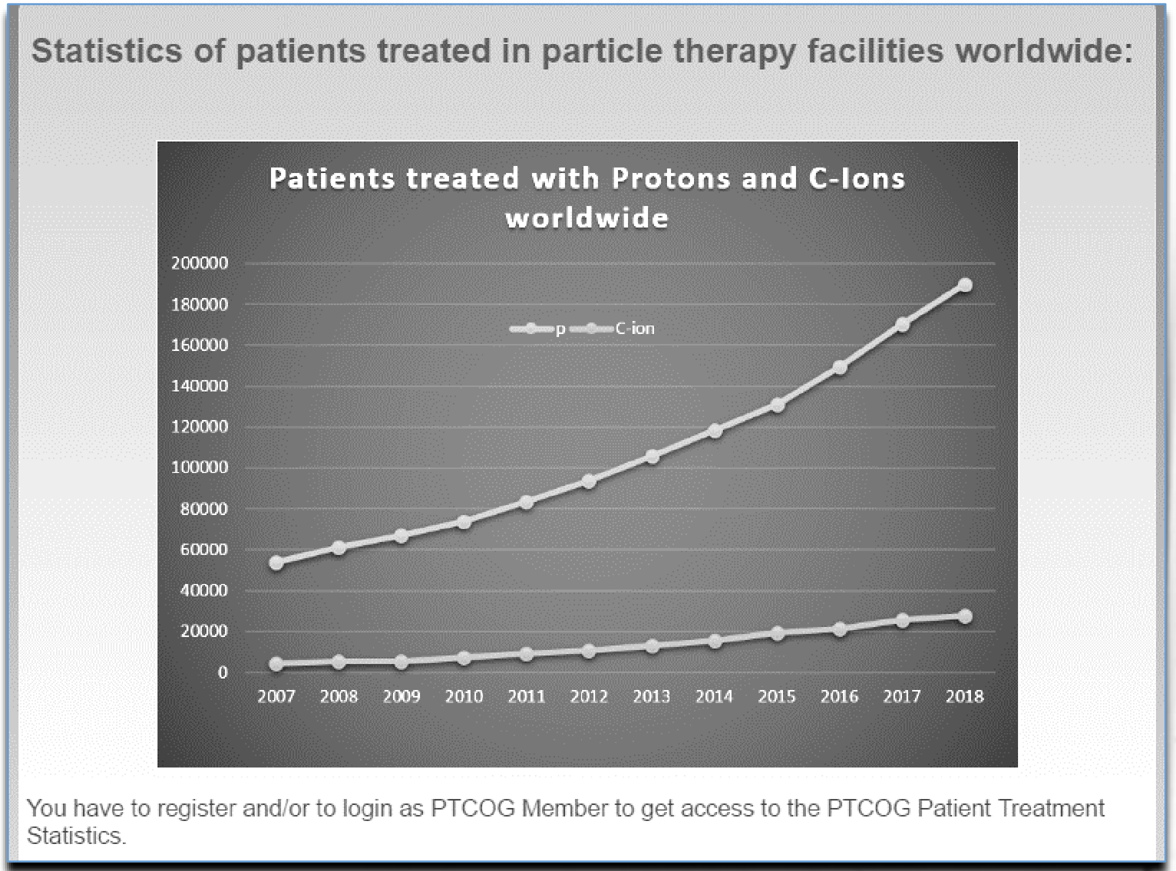
Table 1. Early astronaut cohort demographics binned by total space radiation dose category. SD = standard deviation.

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 appraoch 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)



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 refers to the different way in which each persons react 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 carries 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 explorate 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

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