Moon Village Meeting
（2021年6月29日, オンライン）

Issues on radiological protection in deep space missions

深宇宙ミッションにおける宇宙放射線防護の課題

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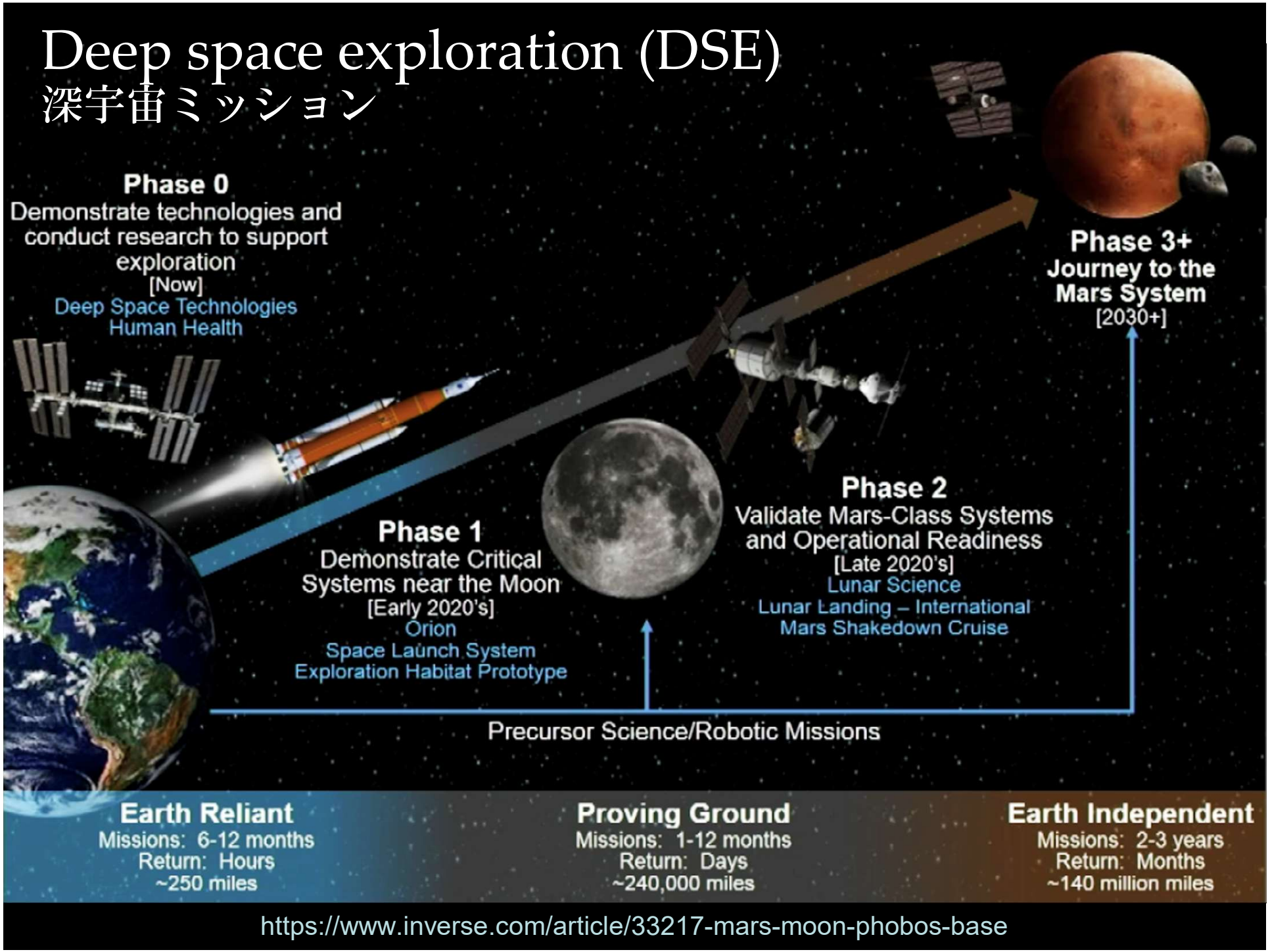
Deep space exploration (DSE)
深宇宙ミッション



https://www.inverse.com/article/33217-mars-moon-phobos-base

Mission to the moon
月へのミッション

Mars mission - it's long..
火星ミッション—これは長い..

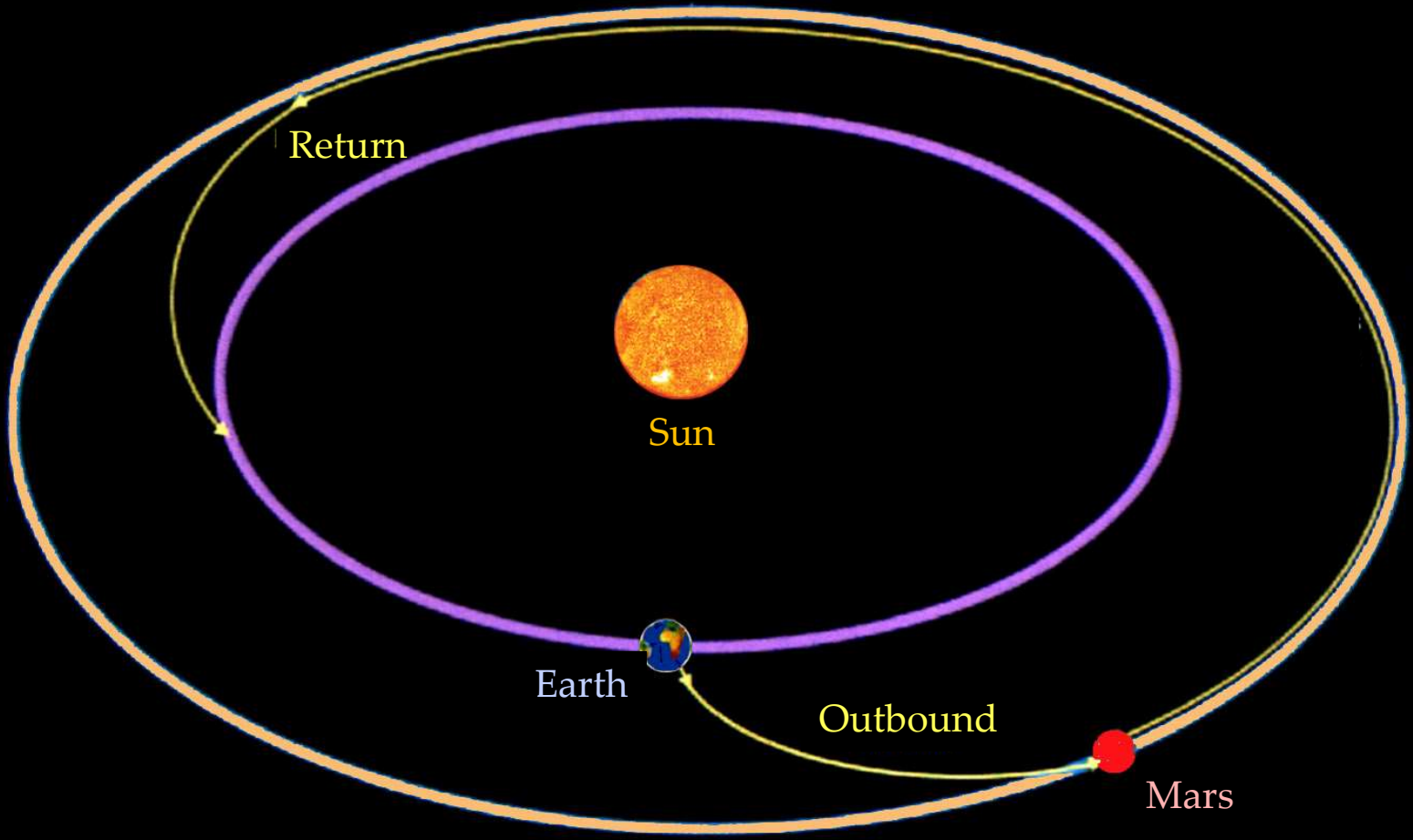
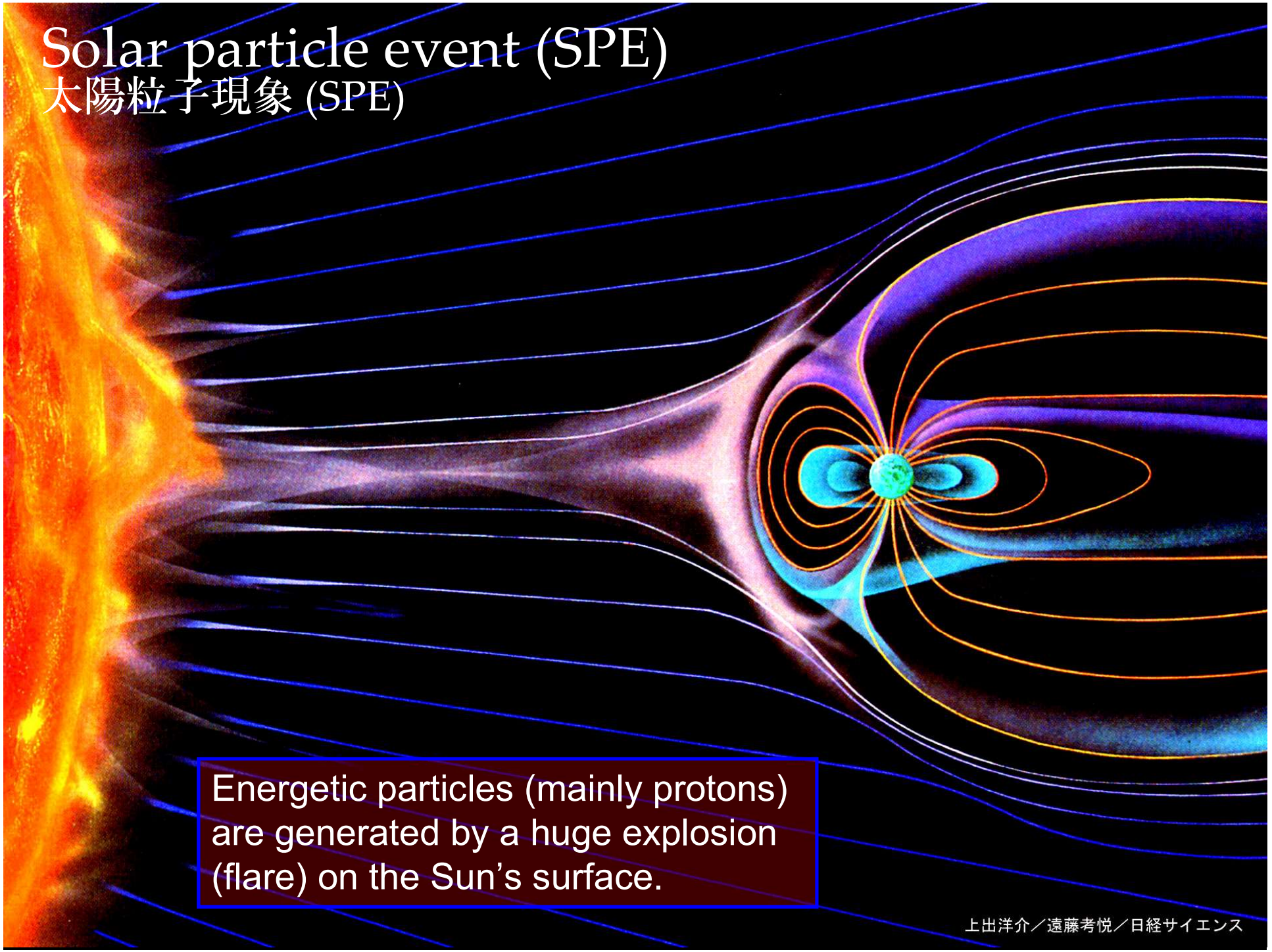


Fig. A typical route of Mars Mission planned by NASA.

Solar particle event (SPE)
太陽粒子現象 (SPE)



Energetic particles (mainly protons) are generated by a huge explosion (flare) on the Sun's surface.

上出洋介／遠藤考悦／日経サイエンス

Predicted dose from SPE
SPEによる予測線量

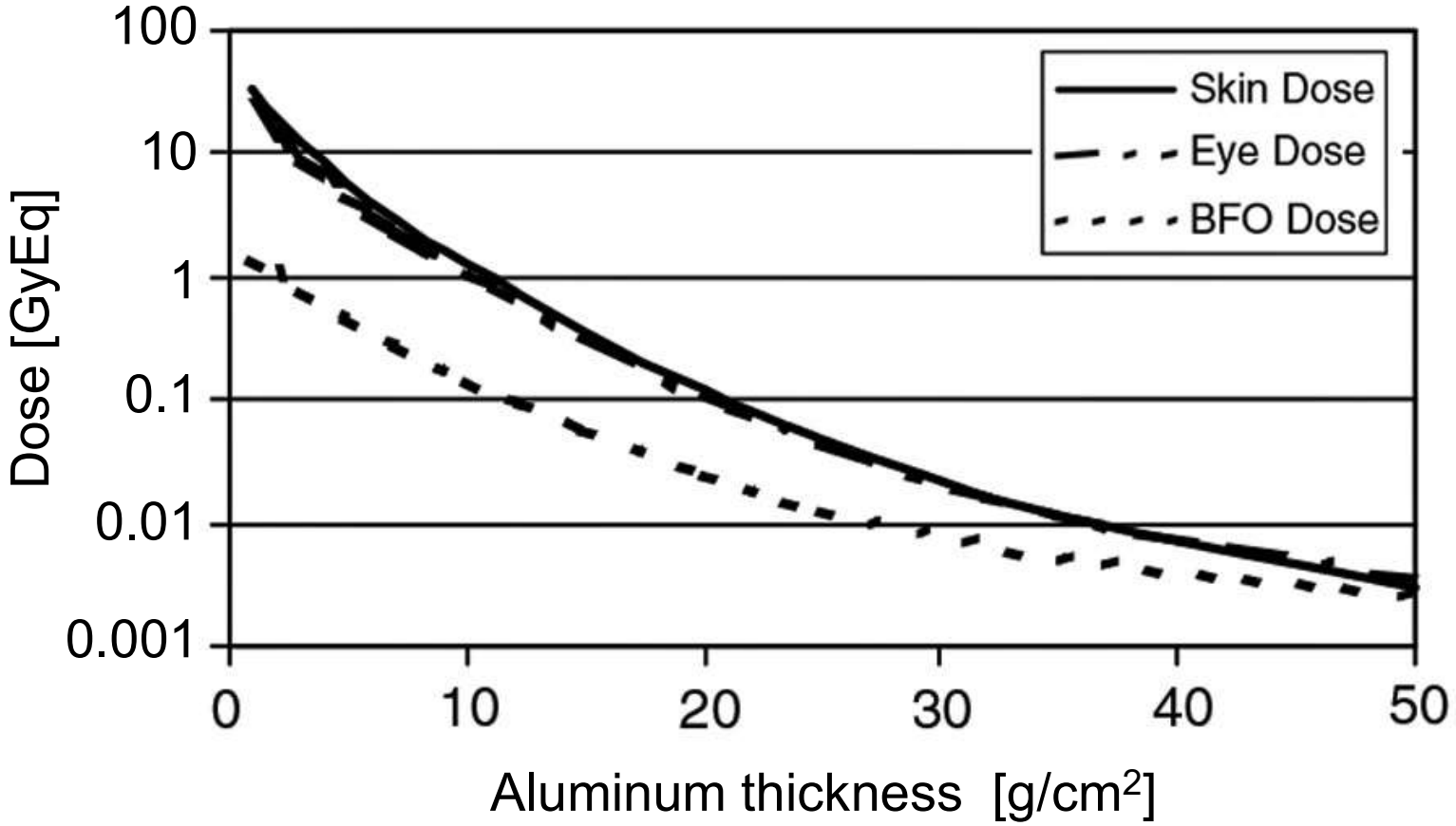


Fig. Predicted doses of selected organs as functions of the thickness of aluminum shielding for the hypothetical largest SPE (comparable to the Carrington event) with RBE=1.5 [Townsend et al., 2006].

確定的影響のしきい値
Threshold doses of selected deterministic effects

表. 主な確定的影響とそのしきい線量および潜伏期 [ICRP, 2007等].

組織／臓器	症状	しきい線量	潜伏期
骨髄	造血機能障害	～0.5 Gy	3～7日
精巣	一時的不妊（男性）	～0.15 Gy	3～9週
	永久不妊（男性）	3～6 Gy	～3週
卵巣	一時的不妊（女性）	～1.5 Gy	～1週
	永久不妊（女性）	2～7 Gy	～1週
皮膚	一時的脱毛	3 Gy	2～3週
	皮膚紅斑	2～6 Gy	1～4週
	皮膚熱傷	5～10 Gy	2～3週
腸	下痢、下血	6～20 Gy	数日
	死亡（100%）		1～2週
中枢神経	痙攣、麻痺等	20 Gy~	直後
	死亡（100%）		数日以内

Organ dose limits for LEO astronauts (NASA)
低軌道宇宙飛行士のための組織線量限度 (NASA)

Table. Recommended RBE-weighted dose limits regarding the deterministic effects for LEO astronauts [NCRP, 2000].

Period	RBE-weighted dose limit [GyEq]		
	Bone marrow	Lens of the eye	Skin
Career	-	4.0	6.0
1 year	0.50	2.0	3.0
30 days	0.25	1.0	1.5

* These limits are applied to all ages. The career effective-dose limits for stochastic effects are given separately.

Effects of space radiation exposures on the reproductive potentials of astronauts have not yet been considered...

Is SPE predictable? – Not yet.
SPEを予測できるか? – まだできない

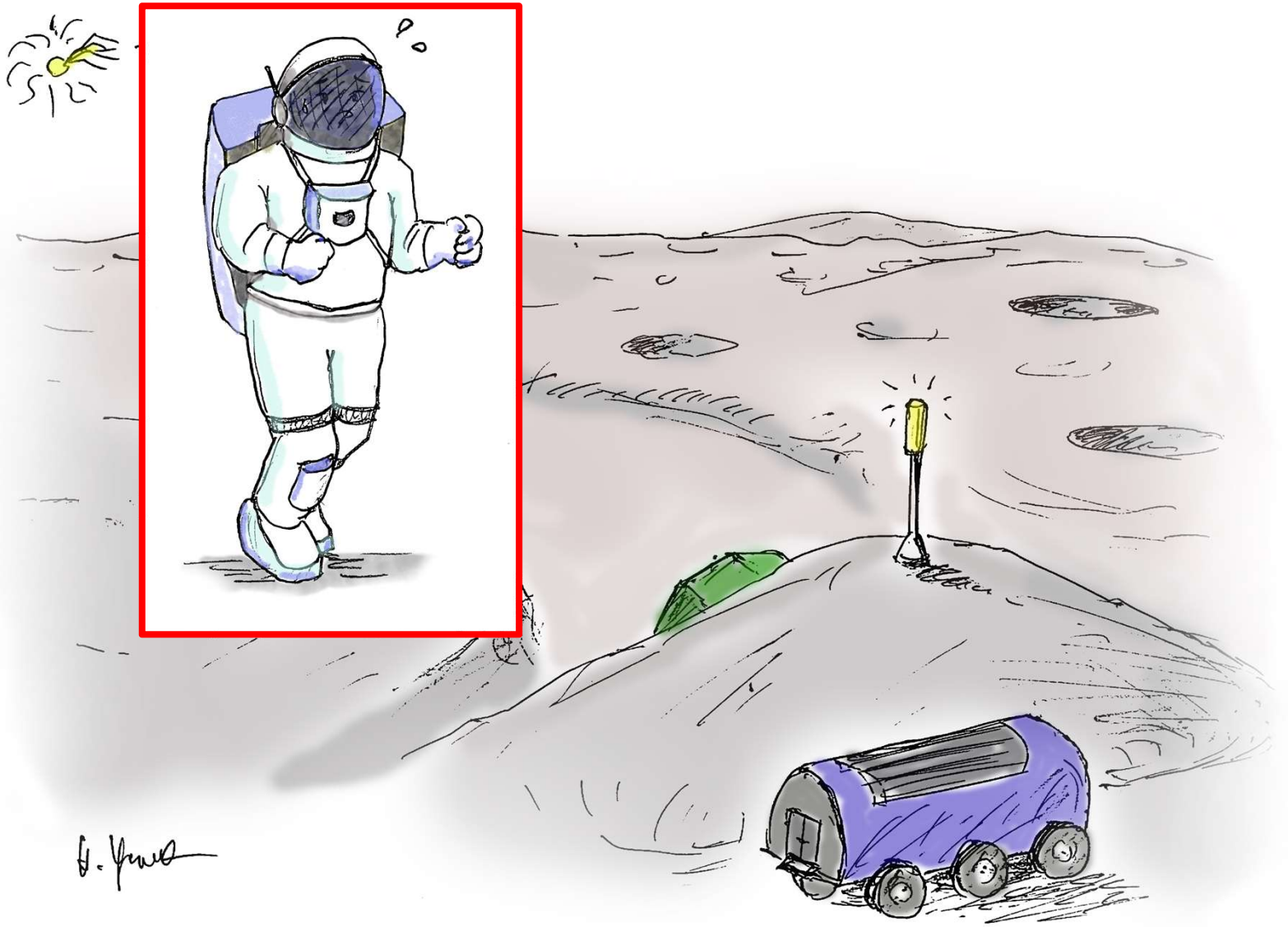


Fig. Image of an astronaut hurrying to return to the moon base.

Exposure to SPE is hard to avert
SPEによる被ばくを回避するのは難しい

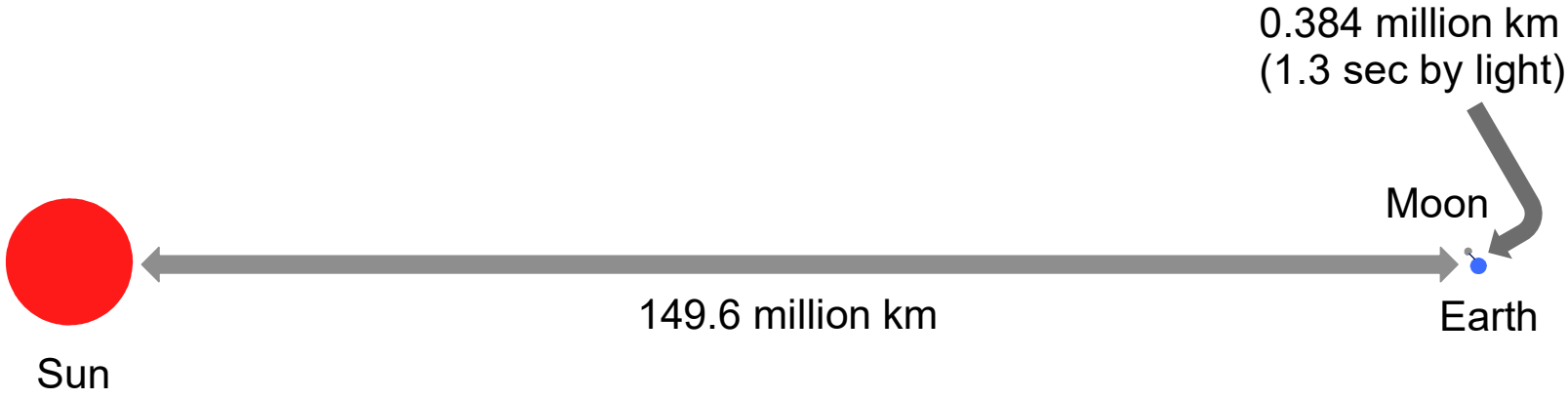


Table Estimates of the time for averting the exposure.

Energy	Velocity [km s^{-1}]	Time [min]
1 GeV	2.63 10^5	10
100 MeV	1.28 10^5	20
10 MeV	0.43 10^5	58

Male reproductive organ – Testis –
男性の生殖器 —精巣—

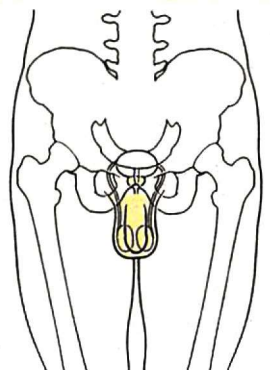


Table. The RBE values of neutrons and selected heavy ions for spermatogorium killing in mice [Wang and Yasuda, 2020].

Particle	Energy or source	RBE value	Reference
Carbon	400-670 MeV/u	< 3	Alpen et al. (1981)
Oxygen	400-670 MeV/u	< 3	Alpen et al. (1981)
Neon	400-670 MeV/u	< 3	Alpen et al. (1981)
Argon	400-670 MeV/u	< 3	Alpen et al. (1981)
Neutron	1 MeV	5.7	Gasinska et al. (1985)
Neutron	5.5 MeV	4.6	Gasinska (1985)

Courtesy of Dr. Bing Wang (QST)

Female reproductive organ – Ovary –
女性の生殖器 —卵巣—

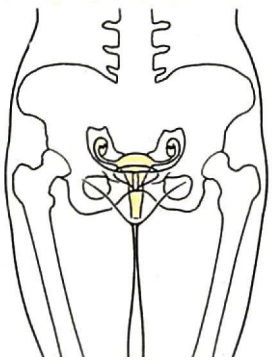


Table. The RBE values of neutrons and selected heavy ions for oocyte killing in mice [Wang and Yasuda, 2020].

Particle	Energy or source	RBE value	Reference
Carbon	80 MeV/u	1.3－1.5	Zhang et al. (2006)
Neon	450 MeV/u	0.4－0.6	ICRP (1989)
Silicon	670 MeV/u	0.4－3.0	ICRP (1989)
Argon	570 MeV/u	0.4－2.2	ICRP (1989)
Neutron	0.43 MeV	1.7	Straume et al. (1987)
Neutron	from ^{252}Cf	1.6 – 3.5	Satow et al. (1989)

Courtesy of Dr. Bing Wang (QST)

Lifestyle on the moon or Mars
月や火星での生活様式

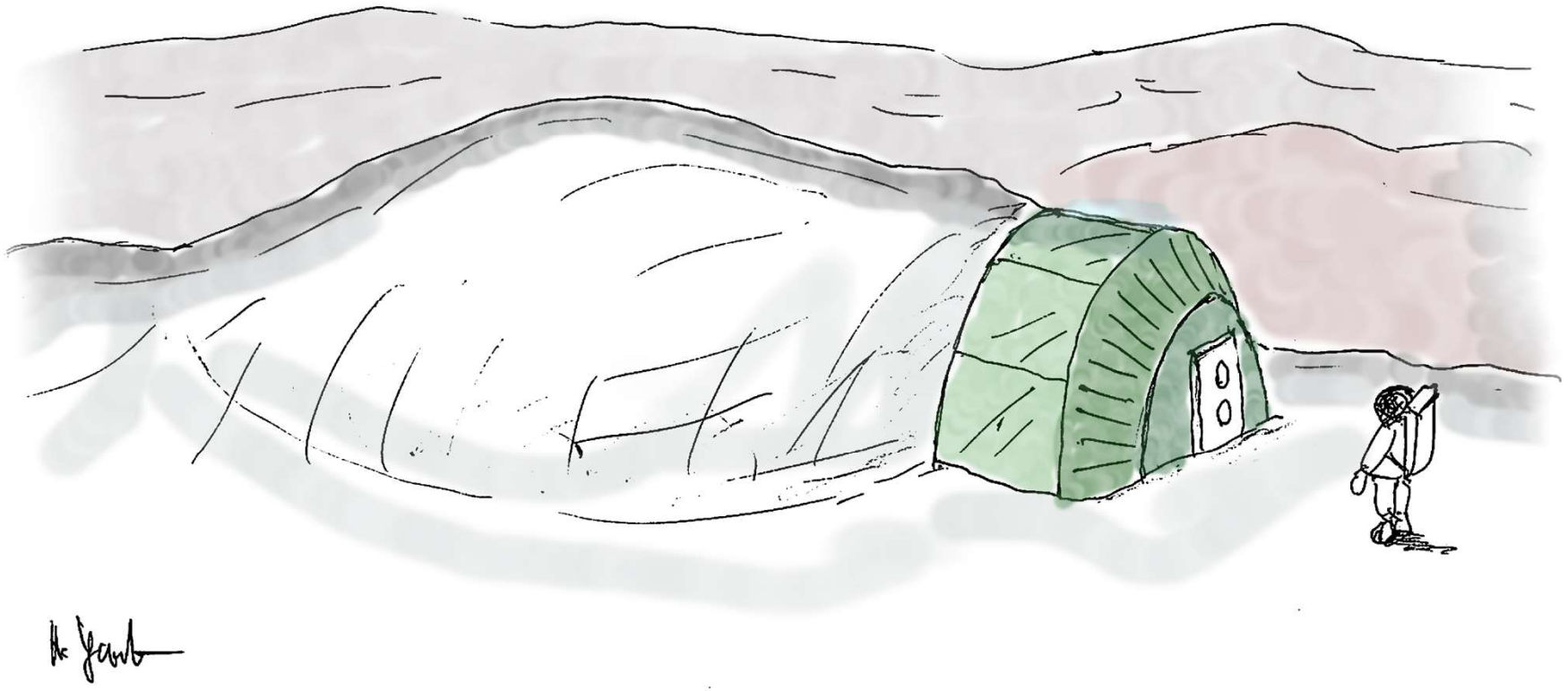
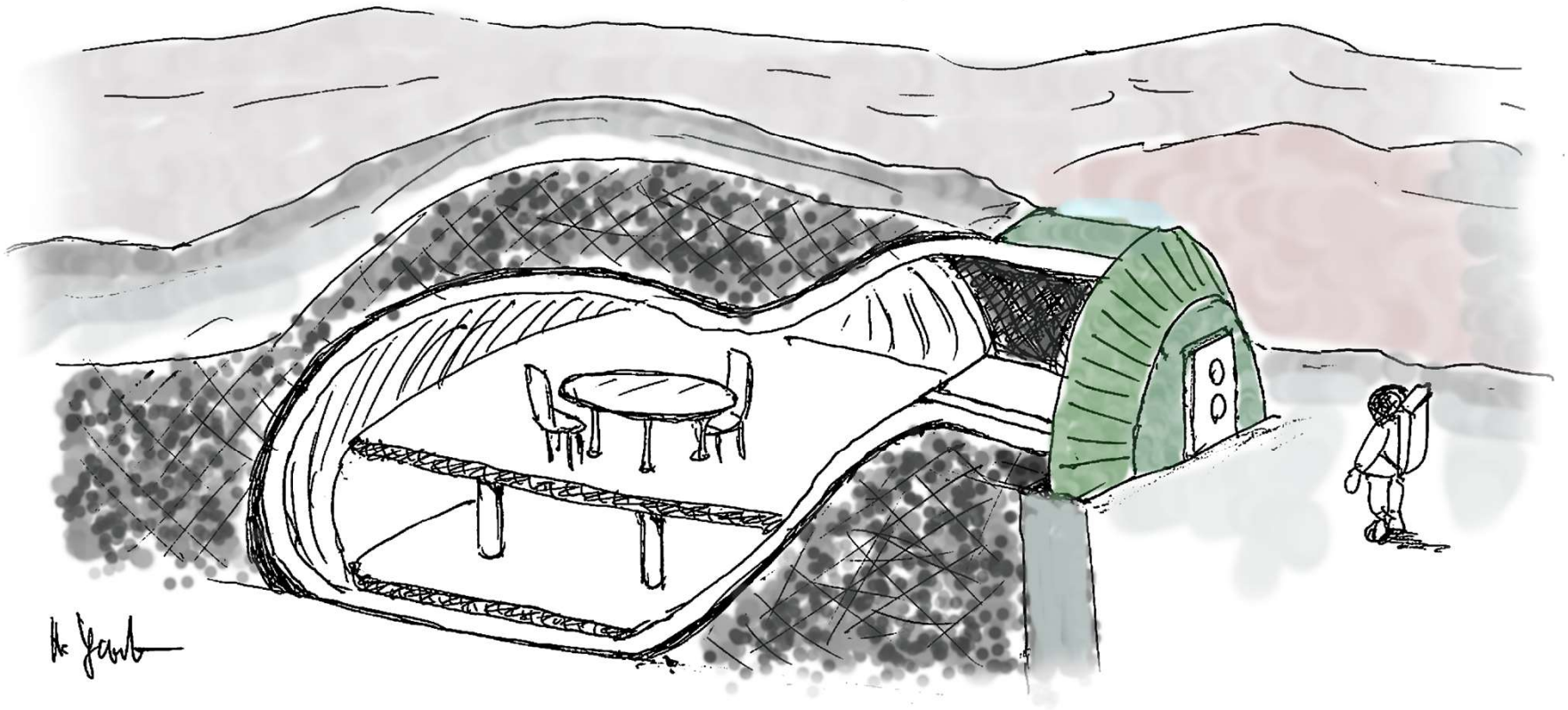


Fig. Illustration of a possible lunar base in near future.

Lifestyle on the moon or Mars
月や火星での生活様式



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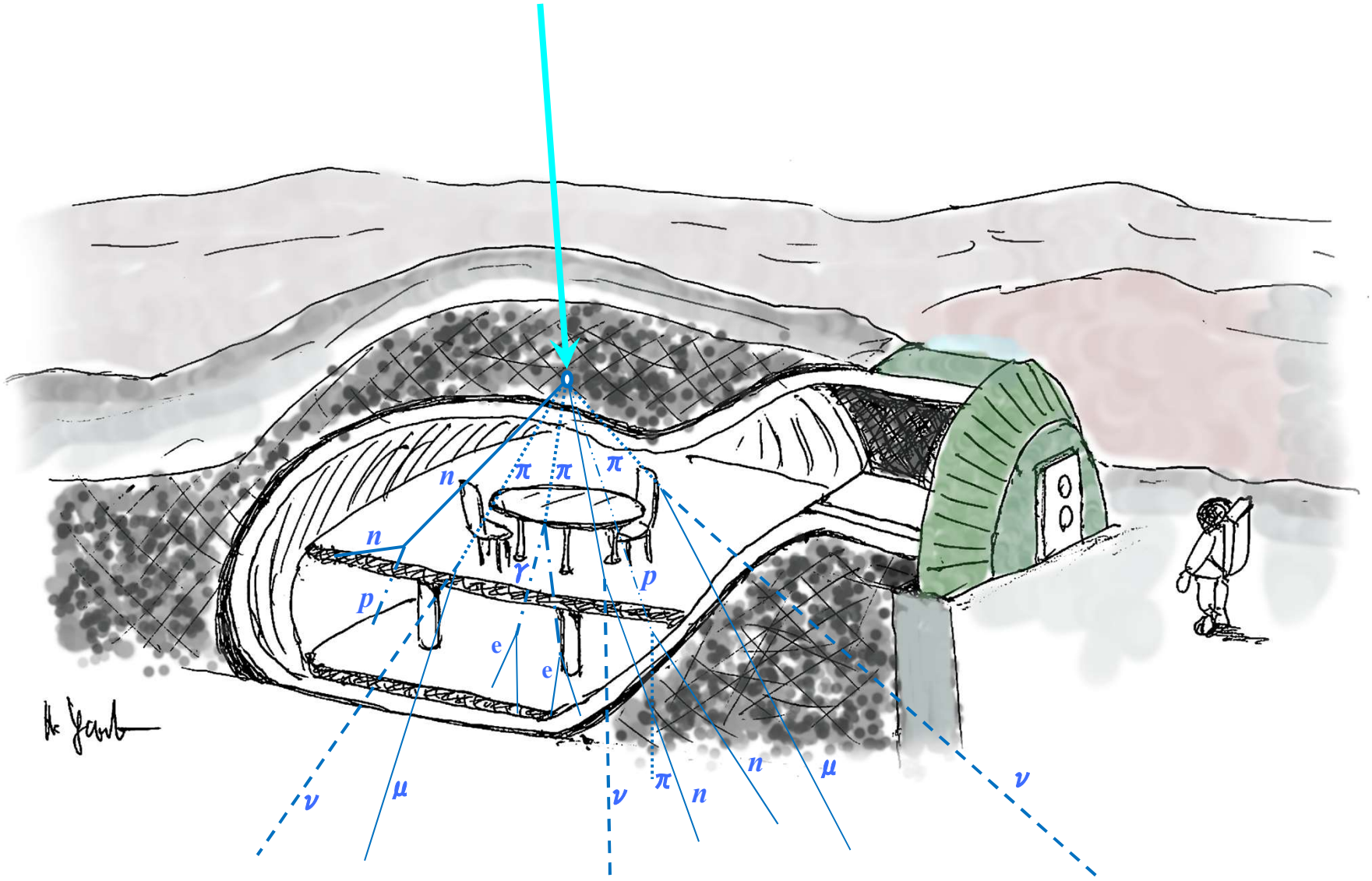

Fig. Illustration of a possible lunar base in near future.

Summary
まとめ

- One of the most serious concerns in future interplanetary missions is potential exposures to SPE particles that would threaten the lives of astronauts.
- To avoid a high-dose exposure during the long mission, the reliability and precision of the space weather forecast system regarding the SPE occurrence will be desirably improved.
- In parallel, intensive studies on the biological effects of high-LET particles (protons, heavy ions, neutrons and pions) are needed for protecting the health of astronauts.

Thank you for your attention.

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