Overview of International Space Agencies Assessment of Dose and Risk for Astronauts

ICRP TG115 –NAS Committee on space radiation exposure

Joint Meeting

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Risk assessment for astronauts by different space agencies

Recommendations for deterministic effects

- Used to limit acute exposures
- Organ based
- Similar values for all agencies based on ICRP Pub. 41 or NCRP rep. 142

Stochastic effects: career limits

- Some agencies base their recommendations on ICRP Pub. 60 (ESA, CSA, ISA), which returns age- and sex-independent fixed values (based on risk/Sv)
- Other agencies use risk-based models (NASA, RSA, JAXA)

ICRP-60 based limits

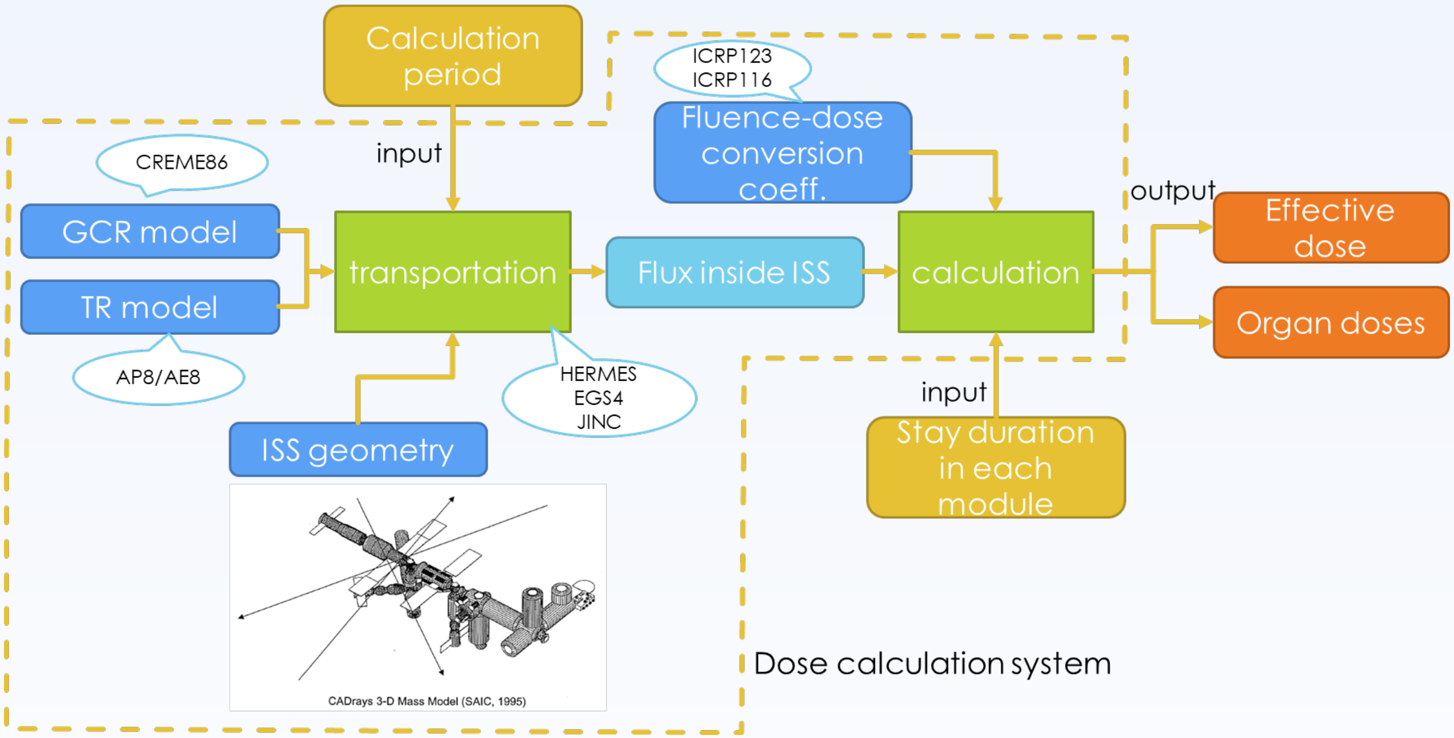
Limit	Value	Comment
Career	1 Sv. (1000 mSv)	ICRP—no age or gender dependence
Blood Forming Organs (BFO)	0.25 Sv. for 30 d 0.5 Sv. for annually	ISS consensus limits
Eye	0.5 Sv. for 30 d 1.0 Sv. for annually	
Skin	1.5 Sv. for 30 d 4.0 Sv. for annually	

Effective dose limit for career is based on 20 mSv/year limit averaged over 5 years, and corresponds to 5% risk of cancer mortality + hereditary effects as also confirmed by ICRP-103 (2007)

Risk-model based limits

- **NASA career limits according to NSCR-12 are based on age- and sex-dependent *risk of exposure-induced death* (REID) calculation with a career limit at 3% within 95% CI**
- **JAXA accepts around 3% *lifetime attributed cancer mortality* (LCM) and sets dose limits based on the accepted LCM.**
- **RSA has developed an independent model since the 60's, the only one including noncancer risk factors and the full space environment. However, they have agreed to follow the 1 Sv effective dose recommended by ICRP**
- **Several changes are ongoing, including a model based on *radiation-attributed decrease of survival* (RADS) in Europe**

JAXA



$$LCM = \int_{A_0}^{\infty} \prod_{i=A_0}^{a-1} \{1 - p_0(i) - p_{D,A_0}(i)\} \times p_{D,A_0}(a)\, da$$

$$p_{D,A_0}(a) = \{p_{D,A_0}^{ERR}(a) + p_{D,A_0}^{EAR}(a)\} \times \frac{1}{2}$$

Probabilities are calculating based on the Japanese baseline cancer mortality, ICRP-103 coefficients, and for solid cancer a latency of 5 years and DDREF=2

JAXA vs. NASA dose limits

Agency	Personal traits				
	Gender	Age of the First Space Flight			
		30	40	50	60
NASA	M	0.78	0.88	1.00	1.17
	F	0.60	0.70	0.82	0.98
JAXA	M	0.60	0.80	1.00	1.00
	F	0.50	0.65	0.80	0.80

Limit values are estimated not to exceed a 3% Risk of Exposure Induced Death (REID) from fatal cancers at a 95% confidence level [42].
Dose limits are expressed in units of Sv.

RSA model

- **Effective dose is replaced by the "generalized dose"**

$$H[Sv] = \sum_{i=1} (\overline{D_i}[Gy] \cdot QF_i \cdot TF_i \cdot SF_i) \cdot MF$$

- $\overline{D}$ is mean tissue absorbed dose
- QF is quality factor of radiation, where biological effectiveness of cosmic rays and HZE particles are accounted for
- TF is a temporal non-uniformity coefficient of irradiation, temporal dose distribution and influence of dose rate accounted for, converting the effects that are induced by fractional and persistent irradiation to a single acute exposure
- SF is representing the coefficient of spatial non-uniformity of irradiation, to convert the nonuniform irradiation effects to a uniform exposure where the character of body dose distribution is accounted for

where i indicates the i-th source of radiation hazard and MF is a modification coefficient for non-radiation factors of space flight.

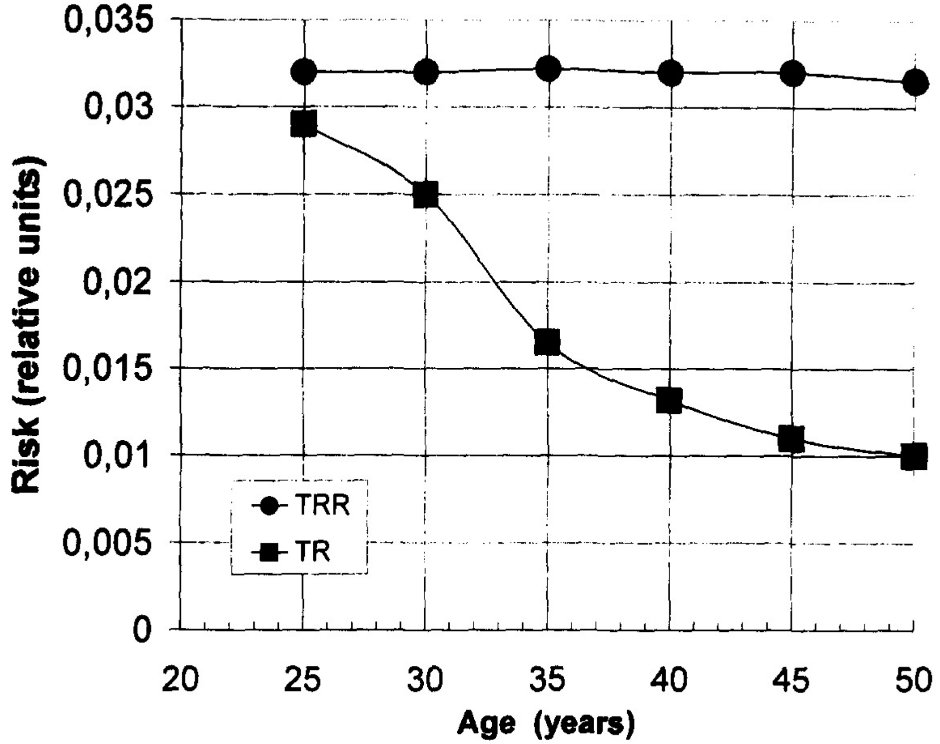
RSA risk

TRR= $TR_{cancer} + R_{other\ radiation\ induced\ effects}$

$$R^{rad}(T) = V(T) - V^{rad}(T)$$

$$V(T) = exp[-\int_{t_0}^{T} \mu(t)dt]$$

$$V^{rad}(T) = exp[-\int_{t_0}^{T} \mu^{rad}(t)dt].$$



RSA risk

Calculated values	Age of cosmonaut [y]	Mean tissue equivalent dose [cSv]		
		100	125	150
Generalized dose [cSv]	-	53.8	65.6	100
Total radiation risk [%]	-	7.00	8.53	12.0
Radiation risk of cancer [%]	30	3.60	4.50	5.40
	40	2.36	2.95	3.54
	50	1.83	2.29	2.74
Mean lifetime reduction [y]	30	2.42	2.95	3.49
	40	2.16	2.63	3.10
	50	1.89	2.30	2.71

For the generalized dose, the GCR contribution was 30% of total dose, and preflight medical procedures contributions were taken to be 25 cSv.

1 Sv ～12% risk

New approach in preparation for ESA

RADS= radiation-attributed decrease of survival= cumulative decrease in the unknown survival curve at a certain attained age, due to the radiation exposure at an earlier age

$$RADS(a|e,D,RBE) = 1 - \exp(-H_c(a|e,D,RBE)) \qquad H_s(a|e,D,RBE) = \int_{e+l}^{a} h_s(u,e,D_c,RBE)du$$

$$h_S(a,e,D_c,RBE) = \frac{wERR_S(D_c,a,e,RBE)m_S(a)+(1-w)EAR_S(D_c,a,e,RBE)/10{,}000}{DDREF}$$

which accounts for a Dose and Dose Rate Effectiveness Factor (DDREF) and population age and sex specific cancer incidence rates ms(a). The factor w is applied to weight the relative contributions by the ERR and EAR models.

Dc=colon dose
e=age at exposure – a=attained age
l=latency time
s=solid cancers
H=radiation-attributed hazard function

Other possible innovations and preliminary estimates based on RADS

- **Use of all solid cancers to reduce the uncertainty and some major organ model**
- **Use of a LSS neutron dose-dependent neutron RBE>10**
- **Using a DDREF<2**
- **Using incidence rather than mortality risk to account for the increasing cure rates**

Table 3: Cancer incidence risks, in percent, for different cancer sites for different missions. The risks are calculated for an age at exposure of 40 years, an attained age of 65 years using a mixed ERR and EAR model. The weights, w, for the mixed ERR and EAR (ERR:EAR) are: all solid cancer (0.5: 0.5), leukemia (0.5: 0.5), all solid cancer plus leukemia (0.5: 0.5) lung and lung adjusted for non-smoking (NS)(0.3: 0.7), breast (0:1).

Males	**Lunar mission 0.17 Sv**	**Mars swing-by 1.03 Sv**	**Mars exploration 1.07 Sv**
All solid cancer	0.53 (0.42;0.67)	3.20 (2.53;3.99)	3.32 (2.62;4.14)
Leukemia	0.13 (0.02;0.26)	0.81 (0.13;1.56)	0.84 (0.14;1.62)
All solid cancer plus leukemia	0.67 (0.51;0.85)	4.00 (3.05;5.11)	4.16 (3.16;5.30)
Lung	0.08 (0.04;0.13)	0.47 (0.25;0.77)	0.48 (0.26;0.79)
Lung adjusted (NS)	0.04 (0.02;0.08)	0.26 (0.12;0.49)	0.27 (0.12;0.51)
Females	**Lunar mission 0.17 Sv**	**Mars swing-by 1.03 Sv**	**Mars exploration 1.07 Sv**
All solid cancer	0.85 (0.70; 1.03)	5.06 (4.18; 6.07)	5.25 (4.34; 6.30)
Leukemia	0.09 (0.01; 0.18)	0.54 (0.08; 1.08)	0.56 (0.08; 1.12)
All solid cancer plus leukemia	0.94 (0.77; 1.14)	5.59 (4.57; 6.75)	5.80 (4.75; 7.00)
Lung	0.14 (0.09; 0.22)	0.85 (0.56; 1.32)	0.88 (0.58; 1.37)
Lung adjusted (NS)	0.06 (0.04; 0.09)	0.37 (0.24; 0.56)	0.38 (0.25; 0.59)
Breast	0.08 (0.05; 0.13)	0.49 (0.29; 0.79)	0.51 (0.30; 0.82)

Main references

- ICRP TG115, *Risk and Dose Assessment for Radiological Protection of Astronauts*. Draft, March 2021
- ESA, *European Radiation Facility Network (ERFNet) project, Deliverable 6a: State of the art of the risk modelling*. ESA-EAC, February 2019
- IAA Cosmic Study Group SG 3.19/1.10, Feasibility study of astronaut standardized career dose limits in LEO and the outlook for BLEO. *Acta Astronautica*, **104** (2015) 565-573.
- IBMP, Lifetime total radiation risk of cosmonauts for orbital and interplanetary flights. *Advances in Space Research* **30** (2002) 999-1003.
- ESA Topical Team in Space Radiation Research, Research plans in Europe for radiation health hazard assessment in exploratory space missions. *Life Sciences in Space Research*, **21** (2019) 73-82
- ESA, A bespoke health risk assessment methodology for the radiation protection of astronauts. *Radiation and Environmental Biophysics*, 2021 (in press).

NAS questions -1

- When were these standards developed? *Different times, starting from the 60's*
- Is there a publicly available report that describes the standard? *Reference list gives general publications, more specific papers are available*
- Is the standard risk or dose-based and what is the dose or risk value. If risk-based, is it based on cancer risk or on other end points as well? Is it based on disease incidence or mortality? *Most models use cancer mortality, but the Russian model includes noncancer mortality risks*
- What epidemiological health data are part of the risk model that the standard is based on? For example A-bomb survivor data or other occupational studies? *Essentially all use A-bomb data, in the versions provided by ICRP or NCRP. The data of the South Ural nuclear plant accident were used by RSA*
- Do the different space agencies have separate standards depending on sex, age, or other factors of crew members? *Presently only NASA and JAXA*

NAS questions -2

- How do the other agencies model the risk? What terms are in their risk models? *See previous slides*
- How do the other agencies model the uncertainty in the risk? How large are their estimates of the uncertainties and what does their distribution look like? *Uncertainties are, as yet, only included in dose limits by NASA*
- Do the other agencies base their standard on the mean risk, the median risk, or some upper percentile of the estimated risk? *NASA only uses upper 95% limit, others use the mean risk (including ICRP based fixed models)*
- Are space agencies considering re-evaluating their standard and if yes, for what reasons? *Yes, for many reasons e.g. the simple ICRP model is considered a large over-simplification and different Agencies feel the urge to agreeing on common standard*
- Do space agencies use genetics or other factors to assess and provide astronauts' personal risk from radiation? If yes, how are genetics or other factors used for risk assessment. If not, why? *Nobody does it so far, and neither it is applied as yet in radiation oncology, pending the results of e.g. Radiogenomics Consortium.*

NAS questions - 3

- Do they typically provide individual risk assessments? If yes, what factors (age, sex, other) goes in the risk assessments? As noted previously, only NASA and JAXA are currently age- and sex-dependent, the others only dose-dependent.
- In your view, what are some of the challenges with existing standards as space missions become of longer duration? *The basics remain the same, but BLEO can increase the importance of noncancer effects and impact of the environment (microgravity) on the expression of radiation damage, due to longer time in space and different radiation spectrum compared to LEO*
- In your view what are the reasons that are driving the need for harmonization of standards? *Ethical and practical, in relation to the international exploration missions*
- Please provide any additional information that the committee did not ask but you think is relevant to this committee's task. *We feel that NAS and ICRP should work in close contact to ensure that a uniform recommendation is given to all space agencies for future exploratory-class missions.*

NAS questions -4

- How do the other agencies communicate the risk to their astronauts and how do they communicate the uncertainty in their risk estimates? JAXA tells individual doses and risks to their astronauts when they are assigned to a specific mission, after they return to the earth and annually. But JAXA can not tell the specific uncertainty.
- ***New!*** Do they typically provide both dose and risk estimates? In what format(s)? JAXA; yes. But only Japanese.
- How do the agencies deal with crew members who are likely to exceed the standard? For example, is there a waiver process and if yes, what is the threshold for requiring that waiver (in terms of exceeding dose or risk)? JAXA can not assign the crew members who are likely to exceed the dose limit to a coming mission.
- ***New!*** How do space agencies typically communicate with astronauts about various assessments of risk from radiation? JAXA tells individual LCM and that organ doses do not exceed the dose limits (=threshold values).
- ***New!*** How, if at all, do space agencies evaluate the effects/effectiveness of their radiation risk communications with astronauts? JAXA confirms that their astronauts understand the risk. Especially, JAXA gets signature from astronaut for risk communication when he/she is assigned to a specific mission.
- ***New!*** Are any reports available from space agencies about the communication of risks to astronauts from radiation, or about how astronauts perceive their risks from radiation? JAXA can provide a blank sample but only in Japanese.

NAS questions - 4

- How do the other agencies communicate the risk to their astronauts and how do they communicate the uncertainty in their risk estimates?

  Basic Training, mission specific briefings, in-inflight support, post flight debriefing

- ***New!*** Do they typically provide both dose and risk estimates? In what format(s)?

  Depends both or dose only

- ***New!*** How do the agencies deal with crew members who are likely to exceed the standard? For example, is there a waiver process and if yes, what is the threshold for requiring that waiver (in terms of exceeding dose or risk)?

  For ESA this hasn't happened

- ***New!*** How do space agencies typically communicate with astronauts about various assessments of risk from radiation?

  As above

- ***New!*** How, if at all, do space agencies evaluate the effects/effectiveness of their radiation risk communications with astronauts?

  Astronaut feedback

- ***New!*** Are any reports available from space agencies about the communication of risks to astronauts from radiation, or about how astronauts perceive their risks from radiation?

  No

NAS questions -4

- How do the other agencies communicate the risk to their astronauts and how do they communicate the uncertainty in their risk estimates? RSA informs the crewmembers on the expected doses for the assigned mission and on the years of life lost (YLL) due to the space radiation exposure for the career period
- ***New!*** Do they typically provide both dose and risk estimates? In what format(s)? RSA, yes, but mostly the dose and YLL rather than the total radiation risk values are provided.
- How do the agencies deal with crew members who are likely to exceed the standard? For example, is there a waiver process and if yes, what is the threshold for requiring that waiver (in terms of exceeding dose or risk)? RSA has never applied any waver process.
- ***New!*** How do space agencies typically communicate with astronauts about various assessments of risk from radiation?
- ***New!*** How, if at all, do space agencies evaluate the effects/effectiveness of their radiation risk communications with astronauts? RSA considers the radiation risk communication with the crewmembers as an important part of the crew training that help them to fulfil all the flight program in future.
- ***New!*** Are any reports available from space agencies about the communication of risks to astronauts from radiation, or about how astronauts perceive their risks from radiation? The RSA cosmonauts perceive the radiation risk communication different way for different individuals. Only private experience from the crew training has been available.

Thank you very much!

International Commission on Radiological Protection

Task Group 115: Risk and Dose Assessment for Radiological Protection of Astronauts

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- **Alexander Ulanowski**, International Atomic Energy Agency, Austria
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Previous ICRP Activities

Members at the 2019 kick-off