

NASA Flight Surgeon Perspectives on Space Radiation Risk Communication

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Abstract

Among the various spaceflight hazards for astronauts is space radiation, which differs appreciably from typical terrestrial radiation exposures. Health effects associated with space radiation exposures include acute radiation syndrome, carcinogenesis, dysfunction of the central nervous system, and cardiovascular disease. In addition to other spaceflight hazards, NASA flight surgeons are tasked with communicating risks from space radiation exposure that may be used for flight certification or informed consent of risks. This manuscript provides an assessment of responses collected from NASA flight surgeon participants to a survey that solicited information about the primary space radiation health risk concerns and the best approaches for risk communication. Surveyed NASA flight surgeon participants expressed interest in additional measures of radiation risk to augment NASA's space radiation risk communication tools, enhanced visualization, and customizable health risk projections. They also expressed the necessity of documenting the credibility of evidence crucial for making informed medical decisions.

Introduction

NASA is engaged in space exploration beyond low-Earth orbit (LEO) with missions that aim to enable prolonged human presence on the lunar surface and Mars (www.nasa.gov/humans-in-space). As missions beyond LEO become more frequent, astronauts will face greater spaceflight hazards including distance from Earth, which may limit medical care; microgravity, which may lead to deleterious effects on bone density and muscular tissue without the intervention of medical countermeasures; and hostile environments, including confinement, and space radiation (Afshinnekoo et al., 2020). The primary health risks associated with space radiation exposure are in-flight and late central nervous system effects including changes in cognition, motor function, mood, and behavior, and neurological disorders; cardiovascular disease and other degenerative tissue effects including coronary heart disease, stroke, cataracts, diseases related to aging, endocrine system, and immune system dysfunction; acute radiation syndromes from Solar Particle Events (SPEs), which include prodromal effects (vomiting, nausea, fatigue, anorexia), depletion of the blood forming organs, and skin injury; and radiation carcinogenesis (morbidity and mortality) for a broad range of cancers (lung, breast, stomach, esophagus, liver, leukemia, ovaries, bladder, brain, skin, etc.) (Afshinnekoo et al., 2020).

The space radiation environment is composed of a complex mixture of high and low-linear energy transfer (LET) radiation that originates from galactic supernovae and solar activity. Galactic cosmic rays (GCRs) form from the shock waves of galactic supernovae (Ackermann et al., 2013) that accelerate mostly protons, and heavier nuclei, into space to relativistic speeds where energies

1 extend to hundreds of GeV/n and higher. The GCR flux is modulated inversely with the
2 approximately 11-year solar cycle, where larger GCR fluxes are observed during solar minimum,
3 and smaller GCR fluxes are seen during solar maximum (Benton & Benton, 2001). During SPEs,
4 the Sun ejects plumes of plasma into space that primarily consist of protons with energies reaching
5 hundreds of MeV and higher. Solar radiation and GCRs interact with the Earth's magnetic field
6 and atmosphere leading to a trapped particle radiation region known as the Van Allen radiation
7 belts. The inner belt is composed of protons—with energies that peak at approximately 200
8 MeV—and low energy electrons, and the outer belt is composed of relativistic electrons (Ma et
9 al., 2024). Solar activity is under constant surveillance (by the Solar Dynamics Observatory
10 (SDO), Solar and Heliospheric Observatory (SOHO), Deep Space Climate Observatory
11 DSCOVR), and others) and with sufficient warning, crew members may use existing materials on
12 the spacecraft to enter storm shelters to minimize the acute radiation risk of SPEs. However, as
13 astronauts embark on longer-duration missions beyond LEO and the protection of the geomagnetic
14 field, GCR exposure becomes a greater concern because of the difficulty of shielding crew
15 members from the deeply penetrating GCR ions.

16
17 The high LET particles in the space radiation environment engender damage at the cellular level
18 that is quite different from the damage induced by the typical low-LET radiation (gamma- and x-
19 rays) experienced on Earth (Patel et al., 2020). High-LET particles may induce clusters of single-
20 and double-strand DNA breaks that are characterized by highly ionized tracks within cellular
21 nuclei, whereas low-LET radiation is sparsely ionizing and exhibits a more uniform appearance
22 for the same radiation dose. DNA damage from radiation exposure may be so disruptive that the
23 cell undergoes apoptosis, thereby removing it from the pool of cells that can divide. Likewise,
24 radiation exposure can lead to mis-repair of DNA that may leave the cell able to divide and mutate,
25 increasing its carcinogenic potential.

26
27 Studies of astronaut cohorts have been performed to assess health risks from space radiation
28 exposure. Reynolds et al. (2017) found little evidence of space radiation induced cancers in the
29 astronaut cohort. Likewise, Elgart et al. (2018) found no evidence for excess radiation risk of
30 cardiovascular disease mortality, although the authors of both studies caution that the limited
31 statistical power constrains interpretation of the results. Charvat et al. (2022) showed that
32 cardiovascular incidence is more prevalent in an astronaut cohort than matched controls from a
33 general healthy cohort; however, the astronaut cohort is sufficiently small (approximately 300
34 astronauts) that an alternative approach is sought as a foundation for space radiation risk
35 assessment.

36
37 Instead of utilizing studies of the astronaut corps directly to assess this risk, NASA employs cancer
38 hazard rates from the Life Span Study (LSS) of the Japanese atomic bomb cohort (Preston et al.,
39 2004, 2007) and transfers the risks to the U.S. population. The Japanese atomic bomb cohort was
40 exposed to low-LET radiation consisting mostly of gamma rays that were delivered over a short
41 period of time. The high-LET space radiation risk is found by applying scaling factors that account
42 for the lower dose rates in space (as compared to the atomic bomb blast) and the radiation quality
43 factor, which is constructed from the maximum relative biological effectiveness (the ratio of the
44 doses of high-LET to low-LET radiation that gives the same biological effect) of cancer surrogate
45 endpoints.

46

1 Further, the Multi-model Ensemble Risk Assessment (MERA) cancer risk model was developed
2 by NASA to estimate the risk of exposure induced death (REID) and risk of exposure induced
3 cancer (REIC) by employing the cancer mortality and incidence rates of the average U.S.
4 population, survival curves of the average U.S. population (with never-smoker corrections), and
5 different sub-models of the low-LET excess cancer risk models from the LSS cohort, radiation
6 quality scaling factors, and dose-rate reduction factors for solid cancers (Vaeth & Pierce, 1990,
7 Thomas et al., 1992, Cucinotta et al., 2013, Simonsen & Slaba, 2021). Using concepts adapted
8 from hurricane track forecasting, the objective of MERA is to assess risk projections stochastically
9 by examining central estimates of the REID and other measures of risk. Until recently, NASA had
10 required that the career permissible exposure limits (PELs) for cancer mortality would not exceed
11 3% REID at the 95% confidence level. However, NASA changed the PEL to a whole-body
12 effective dose limit of 600 mSv, which accepts greater risk for some astronauts but remains well
13 below the 1,000 mSv limit of the Canadian Space Agency, the European Space Agency, and the
14 Russian Space Agency (NASA, 2022).

15
16 The formalism for estimating the REID has been extended to cardiovascular disease and is being
17 extended to the central nervous system effects as data become available. The REID for
18 cardiovascular disease has been estimated by implementing a relative risk model of a human cohort
19 (Little et al., 2013, 2023), but it should be noted that these data are based on gamma ray exposure;
20 models of radiation quality have yet to be developed. New evidence from the Million Person
21 Study (MPS) (Dauer et al., 2024a,b) indicates a statistically significant increase in Parkinson’s
22 disease mortality for U.S. radiation workers and veterans who were exposed to a mixed field of
23 both low- and high-LET radiation, although models of the excess risk and radiation quality have
24 not yet been developed. Unlike the LSS studies, the MPS considers protracted exposures of low-
25 LET and high-LET radiation with larger dose-rates than experienced in space, and new
26 methodologies must be developed for risk translation.

27
28 Although the MERA approach to cancer risk is the most mature model of the four major space
29 radiation health risks tracked by NASA, there remains a need to effectively communicate all major
30 space radiation hazards to NASA flight surgeons and crew members. The National Academies of
31 Sciences, Engineering and Medicine (NASEM) has made the following pertinent
32 recommendations for radiation risk communication (NASEM, 2021):

33
34 “Recommendation 2: In the near future, NASA should re-examine whether to use
35 risk of exposure-induced death (REID) or other metrics, or a combination of
36 metrics, in setting the dose-based space radiation health standard. NASA should
37 conduct an independent analysis of the validity of 3 percent REID and make explicit
38 the agency’s justification for the metrics it chooses.”

39
40 “Recommendation 3: To inform astronauts about their radiation risk, NASA should
41 provide all astronauts with an individual radiation risk assessment and revise the
42 risk communication system (...) for the updated space radiation standard....”

43
44 “Recommendation 4: NASA should communicate a comprehensive picture of an
45 individual astronaut’s cancer risks due to radiation exposure, beyond the

1 information contained in the traffic light system [a color system aimed at
2 communicating levels of risk related to effective dose estimates].”

3
4 “Recommendation 6: NASA should conduct research to develop evidence-based
5 risk communication, and the agency should develop a radiation risk communication
6 research agenda to fill knowledge gaps such as (1) what information astronauts
7 want; (2) how astronauts process risk information; and (3) who/what are the most
8 effective sources of information for astronauts. In addition, NASA should carry out
9 research to examine and improve the effectiveness of its current and proposed risk
10 communication strategies and materials.”

11
12 To address these recommendations, NASA sought to develop a tool that communicates health risks
13 from space radiation exposure. Feedback from experts on the hazards of spaceflight to crew
14 members may be used to inform such development. Input from NASA flight surgeon participants
15 was elicited via a one-on-one guided interview survey to ascertain measures of risk and other
16 factors that would be most useful and informative for risk communication. The formal guided
17 interview survey was initially designed to elicit subjective feedback from NASA medical experts
18 (such as flight surgeons about information regarded as necessary for space radiation risk
19 communications tools. The survey solicits information across a range of topics: the benefits of
20 having a tool that considers, communicates, and estimates additional measures of radiation
21 exposure risks for future crew decisions, such as short-term (10-year) and long-term (30-year)
22 risks of cancer, cardiovascular, and central nervous system (CNS) disease; alternate radiation risk
23 metrics; incorporation of the burden of disease in projection of risk with measures such as the
24 disability-adjusted life-year (DALY) (Shimada & Kai, 2015; Annand & Hansen, 1997) and
25 quality-adjusted life-year (QALY) (Weinstein et al., 2009); the potential benefits of biomedical
26 and lifestyle intervention on the mitigation of disease; general perceptions concerning current
27 methods applied to crewmember medical certification and mission assignments; types of
28 information they would like to see incorporated in the communications tool; points of reference
29 comparisons, different ways of presenting statistically relevant data; and decision-making factors.

30
31 Knowledge from the expert participants was elicited and analyzed by using a structured framework
32 known as a Cognitive Task Analysis (CTA), with the aim of generating design guidance for a risk
33 communications tool. A CTA is known for utilizing a variety of methods and techniques,
34 including interview and observation strategies, to capture the explicit and implicit knowledge used
35 by experts to make complex decisions. The methods and techniques encompassed in a CTA
36 provide researchers with the required tools to understand how people think, how they make
37 decisions and their reasoning, and how they perform under certain conditions. The premise of
38 conducting a CTA is to “capture the unobservable cognitive processes, decisions and judgments
39 of expert performance” (Yates and Feldon, 2011). Capturing the unobservable can be challenging
40 for practitioners as many experts typically make decisions unconsciously; however, through
41 applicable CTA methods and strategic interview practices, practitioners are able to obtain the
42 needed information from experts. These CTA interview methods seek to break down tasks and
43 decisions to their lowest, foundational level. Understanding how experts make decisions and the
44 rationale for those decisions are crucial components to capturing what is not directly observable.

1 Given the unique nature of any research effort, the CTA approach can be adapted based on the
2 specific goals, objectives, and research questions being explored. This methodology provides
3 practitioners with a strategic, yet flexible, path to designing user-centric systems, such as
4 workflows, user interfaces, and training in many domains ranging from aircraft flight decks to the
5 design of mission control rooms, and everything in between.
6

7 Over 100 types of CTA methods have been identified (Clark et. al., 2008), including cognitive
8 interviewing, which is a “formal technique to evaluate whether questionnaire items are
9 understandable to respondents and will be useful for making conclusions.” This cost-effective
10 method improves questionnaire-based research and “provides evidence for the content validity of
11 items” (Balza et al., 2022). Other methods include think-aloud protocols and verbal probing
12 techniques, which are sub-types of the cognitive interviewing method (Willis, 1999). The think-
13 aloud protocol encourages participants to verbalize their thoughts and decision-making process
14 while performing a task, whereas the verbal probing technique provides an avenue for the
15 investigator to ask follow-up questions that seeks more in-depth information from the participant.
16 Other methods include the critical decision method (CDM), which focuses on a specific critical
17 event in which the participant had to make important decisions. In this method, the investigator
18 develops strategic structured questions to explore the decisions made, the reasoning behind those
19 decisions, and the outcome of those decisions for that specific critical event. CDM seeks to
20 “identify the knowledge requirements, expertise and goal structures involved in performing a
21 decision-maker's work” (Wong, 2003).
22

23 Literature reviews and documentation analyses are also crucial when conducting a CTA since they
24 provide foundational context and preliminary knowledge to current procedures and processes that
25 experts follow. According to Hoffman (2005), documentation analysis is a “critically important
26 method, one that should be utilized as a matter of necessity” since it involves “specific procedures
27 that generate records or analyses of the knowledge contained in the documents.”
28

29 NASA has a history of successfully employing CTA methodologies to gather detailed information
30 from experts for the design of complex safety critical systems, including the use of Hoffman’s
31 Protocol for Cognitive Task Analysis (Daiker et al., 2018), which was chosen by the research team
32 to serve as the baseline approach for conducting the NASA flight surgeon participation survey.
33 The approach employed by Hoffman’s CTA protocol has “a proven track record of utility in
34 service of both expertise studies and the design of new technologies” (Hoffman, 2005), and it
35 provides a flexible approach that can be adapted to meet the needs of any given research.
36

37 The NASA flight surgeon participation survey was formulated, administered, and analyzed by
38 following five steps of the Hoffmann CTA protocol shown in Figure 1. The five steps include (1)
39 initial consultation with a subject matter expert (SME), (2) review and analysis of any
40 documentation provided by the SME (3) formulation of initial SME interview needed for
41 informing the NASA flight surgeon participation survey, incorporation of SME feedback, and
42 finalizing the NASA flight surgeon participation survey, (4) one-on-one formal guided interview
43 of NASA flight surgeons, and (5) analysis and interpretation of the responses.
44

45 This survey was designed with consideration of an Earth to Mars mission with a round-trip transit
46 time of 400 days and a 600 day stay on the Martian surface. Responses are subjective and based

1 on participants' experience and exposure to radiation risk related topics. Every response received
2 was taken into consideration regardless of a participant's level of experience. The questions used
3 in the NASA flight surgeon participation survey for the one-on-one guided interviews, are
4 summarized in Figure 2. NASA flight surgeon participants were asked questions regarding the
5 sufficiency of the methods applied to crewmember medical certification and assignments for future
6 missions, additional measures of radiation risk, desired tools for risk communication, preferred
7 statistical measures of radiation risk, short- and long-term estimates of health risks, and opinions
8 on the use of the mean or 95% confidence statistics for risk estimates. In addition, open ended
9 questions were asked regarding the main consideration for space exposure radiation limits for
10 future permissible exposure updates, visualization of radiation risk estimates, examples of
11 successful methods for communicating radiation risks, and other important factors for making
12 medical decisions.

13
14 The eleven questions of the flight surgeon survey required participants to respond to Likert-scale
15 ranking questions and open-ended questions that were assessed for consensus or responses that
16 provided insight into risk communication. The Likert-scale is used widely in surveys and often
17 includes a spectrum of responses (e.g., consumers could be asked to rank the quality of a vacation
18 package with the following close-ended responses: (1) terrible, (2) poor, (3) neither bad nor good,
19 (4) great, (5) perfect). The mean and standard error are then found to describe the response and
20 the degree to which the survey participants agree. Of the 30+ current NASA flight surgeons, 12
21 participated in the NASA flight surgeon participation survey. While the NASA flight surgeon
22 population sample-size limits conclusive statements representative of the entire cohort, directional
23 insights—indicators of trends without high statistical precision—from the experts can be inferred
24 and may be used to inform the development of space radiation risk communications tools. The
25 next section presents the results and discussion of the NASA flight surgeon participation survey.

26 Results and Discussion

27
28 This section describes the main findings of the NASA flight surgeon survey described above to
29 solicit information about the primary concerns associated with space radiation health risks and the
30 best approaches for risk communication.

31
32 Figure 3 shows a consensus among most respondents (n=7) that the current methods applied to
33 crewmember medical certification and mission assignments for low-Earth orbit should be updated
34 for missions to Mars (survey question #1). Although most participants agreed that the current
35 methods applied are sufficient for current-day missions to the International Space Station (ISS),
36 the radiation environment for Mars is different from what is experienced by crew members on ISS,
37 and missions will be considerably longer without the option to quickly return to Earth. Participants
38 were encouraged to provide comments regarding their chosen statement rating for context.
39 Participants suggested that information about cancer incidence and mortality should be included
40 for missions beyond low-Earth orbit.

41
42 Participants were then asked (survey question #2) about the benefits of having a tool that considers
43 and communicates additional measures of radiation exposure risks such as 10-year cardiovascular
44 disease risk, 30-year degenerative CNS disease risk, and those used by the Global Burden of
45 Disease collaboration (e.g. Years of Potential Life Lost (YPLL), Disability-Adjusted Life-Year

1 (DALY), Quality-Adjusted Life-Year (QALY)). Ten out of 12 participants agreed that having
2 such a tool would be beneficial for future crew decisions and long-term health (Figure 4). Out of
3 those ten participants, three shared that even though additional risk metrics—such as the DALY
4 and QALY—can augment risk communication, the data from which these metrics are founded
5 may limit their use for the astronaut cohort. Thus, rigorous validation of the underlying source data
6 is required.

7
8 In Figure 5, participants were asked to rank (survey question #3) the types of information they
9 would like to see incorporated into a prospective communications tool from the following list:
10 permissible mission duration; MST - risk of mortality from all causes (i.e., cancer and other
11 causes); MLT - risk of mortality from all causes (i.e., cancer and other causes); IST -
12 cardiovascular disease risk; ILT - cardiovascular disease risk; MST - cardiovascular disease risk;
13 MLT - cardiovascular disease risk; IST - central nervous system (CNS) degenerative disease risk;
14 ILT - central nervous system (CNS) degenerative disease risk; IST - cancer risk; MST - cancer
15 risk; MLT - cancer risk; future quality of life indicator; and pure exposure information (as opposed
16 to risk). MST is mortality-short term (10 years), MLT is mortality-long term (30 years or more),
17 IST is incidence-short term (10 years), and ILT is incidence-long term (30 years or more). Each
18 category was accompanied by a Likert-scale with ratings from 0 to 5, where 0 = “no opinion,” 1 =
19 “not important,” 2 = “slightly important,” 3 = “moderately important,” 4 = “important,” and 5 =
20 “very important.” The average rating for each category was calculated by taking the sum of all
21 responses in that specific category and dividing it by the number of responses received. A response
22 of “0” was not included in the average rating and was treated as “missing data” due to a
23 participant’s inability or unwillingness to evaluate that specific category. Responses were not
24 weighted based on participants’ years of experience.

25
26 Most categories were deemed by the NASA flight surgeons to be moderately important; however,
27 “pure exposure information (as opposed to risk),” “MLT cancer risk,” and “MLT-risk of mortality
28 from all causes” were valued as more important. Participants were encouraged during the
29 interview process to provide an explanation of their chosen Likert-scale ratings. The observed
30 themes and trends from those explanations showed that participants believed that having as much
31 information as possible is important, but with the caveat that the data, and sources of information
32 from which the models are founded, are reliable and fully validated, when possible.

33
34 Participants were asked about information they would like to be incorporated into a risk
35 communications tool (survey question #4): “potential effects of biomedical interventions on risk,”
36 “potential effects of lifestyle interventions on risks,” and “points of reference comparison with
37 other life-threatening risks”. Likert-scale ratings were assessed as they were for survey question
38 #3—ratings from 0 to 5, where 0 = “no opinion,” 1 = “not important,” 2 = “slightly important,” 3
39 = “moderately important,” 4 = “important,” and 5 = “very important”. There was moderate support
40 for information regarding the potential impact of biomedical interventions or how changes in
41 lifestyle factors might change risks. Participants stated that analogous types of risk for points of
42 reference are desirable (Figure 6); however, any analogies used would need to be appropriate and
43 representative of the astronaut crew to effectively communicate space radiation risks. For instance,
44 the example of equivalent cigarettes smoked was viewed unfavorably by all participants since
45 astronauts are monolithically non-smokers, while an example of equivalent number of diagnostic
46 x-rays was generally preferred.

1
2 Overall, participants agreed that having a customizable visualization tool of features with
3 radiation-related risk data would provide improvements in data interpretation when asked for
4 further information on questions 3 and 4. Although participants believed that more information is
5 better, they did not want to be overloaded with excessive information. They would prefer a tool
6 that has copious information but is customizable to their needs and specific mission/astronaut
7 portfolio. Visual data was also preferred over tables of data; however, NASA flight surgeon
8 participants noted that they would prefer the option to have both.
9

10 Participants were also asked to rank other ways of presenting statistically relevant data (survey
11 question #5). Eight out of 12 participants chose "Mean" as the most important way of presenting
12 statistically relevant data. A Confidence Level (CL) of 95% was the second most important as
13 participants consider these as the most relevant metrics. Three participants also provided other
14 suggestions, such as having a curve with skew information, P-values, relative risk, absolute risk,
15 and range deviations. These results indicate a reasonable, actionable outcome would be to ensure
16 the radiation risk tool presents the risk as a mean value with 95% CL, and the more sophisticated
17 statistical measures could be provided as additional options for interested parties.
18

19 Open-ended survey question #6 focused on the importance of near term and long term outcomes.
20 Five of the 12 NASA flight surgeons interviewed stated that near term outcomes factor more into
21 their decision making, compared to two of the 12 NASA flight surgeons interviewed who favored
22 long term outcomes. Three of the 12 NASA flight surgeons interviewed stated that both near term
23 and long-term outcomes factor into their decision making. Two of the 12 NASA flight surgeons
24 stated that they do not take either near- or long-term outcomes into consideration when making
25 decisions and focus on crew members' current health status instead.
26

27 When asked how the credibility of evidence factored into their decision making (survey question
28 #6A), nine of the 12 NASA flight surgeons believed the credibility of evidence is important for
29 their decision making. Two of the 12 NASA flight surgeons interviewed provided varying
30 responses which did not directly address the credibility of evidence. One of the 12 participants
31 stated that the credibility of the evidence may not matter given other health risks that the flight
32 crew may encounter.
33

34 NASA flight surgeon participants were asked to rate how they would describe the numerical 3-
35 percent cutoff and 95-percent CL cutoff limits for REID (survey questions #7 and 7-A) (Figures 7
36 and 8). Likert-scale ratings were assessed from 0 to 5, where 0 = "no opinion," 1 = "too
37 conservative," 2 = "somewhat conservative," 3 = "just right," 4 = "somewhat risky," and 5 = "too
38 risky". The frequencies of the responses were tallied in Figures 7 and 8. Most participants (n=8)
39 believed the 3-percent cutoff was either "too conservative" or "somewhat conservative." The
40 reasons for why they believed this was varied; however, some noted that astronaut crew already
41 know that space travel is risky, while others noted that there is room for error based on the
42 assumptions made and factors considered for REID. The ratings provided by participants for the
43 95-percent CL cutoff leaned more towards "conservative" (n=7); however, four participants
44 believed this cutoff was "just right." Among the explanations for these ratings, concerns were
45 expressed for the constraints that the cutoff limits place on female astronauts. Participants also
46 noted that these cutoff limits are based on low-Earth orbit and need to be reinterpreted for missions

1 to Mars. Since these interviews were conducted over a span of time in which the Space Permissible
2 Exposure Limits (SPELs) were updated (NASA, 2023), there may be differentially affected
3 responses.

4
5 Several open-ended questions (survey questions #8-11) were also asked about what the main
6 considerations should be if SPELs are updated in the future, in addition to questions about
7 visualization preferences of radiation-risk data, previous experience with successful methods of
8 communicating space radiation risk, and other factors important for NASA flight surgeons when
9 making medical-based decisions.

10
11 Three of the 12 participants identified the need for more emphasis on the credibility of evidence
12 when updating the SPELs. Moreover, another three of the 12 participants stated that additional
13 training for crew members and NASA flight surgeons would be beneficial when updating the
14 SPELs (survey question #8).

15
16 When asked how visualization of radiation-related risk data could be improved (survey question
17 #9), eight of the 12 participants stated that there needs to be more data visualization instead of
18 numerical values while three of the 12 participants emphasized that customizability of features
19 within radiation-related risk data would provide improvements in data interpretation.

20
21 Participants who had previous experience with successful methods of communication (survey
22 question #10) stated that comparisons of radiation effective dose values (reference tables provided
23 in the Supplemental Information section) would be an effective means of communicating radiation
24 risk data. Participants (n=2) also stated that past exposure information along with expected
25 exposure for an upcoming mission would be effective for the communication of radiation risks.
26 One participant stated that Permissible Mission Days (PMD) would be a successful method of
27 communicating radiation risks, while another participant stated that a tool like the one being
28 discussed in the NASA flight surgeon participation survey would be beneficial for communicating
29 radiation risks. PMD for ionizing radiation is the number of days an astronaut may spend in space
30 and not exceed an effective dose limit of 600 mSv. For example, if the dose rate is 1 mSv/day in
31 deep space, an astronaut would have a PMD of 600 days, assuming no prior radiation exposure.

32
33 Among the responses about other factors that are considered important for decision-making
34 (survey question #11), participants (n=2) noted radiation dose rate with more objective/absolute
35 data is better along with how the numbers are calculated/estimated. Two out of 12 participants
36 stated that genetics testing (if allowed) for predisposition to radiation exposure related problems
37 would be important for medical decision making. Individual risk tolerance of the crew members
38 and policy makers were also identified by participants (n=2) along with graphical representations
39 of radiation exposure risks. These results provided the research team with information needed to
40 pursue additional research and next steps.

41
42 Overall, three principal insights were observed based on common trends among the participants
43 interviewed that received high consensus ranking among the NASA flight surgeons: a radiation
44 risk tool that can be customized to NASA flight surgeon needs, with the ability to adapt to specific
45 missions and astronaut portfolios, would help facilitate better risk communication; adding new
46 training material that focuses on the unique challenges of Mars missions was considered important,

1 including training on a future customizable risk communications tool; and, lastly, documenting
2 and emphasizing both the credibility of evidence and reliability of data were considered crucial to
3 decision making.

4
5 In addition to the three principal insights, there are three actionable findings identified from the
6 results. The NASA flight surgeon participants identified the desire to have as much reliable and
7 validated information as possible. As a result, an actionable finding is to ensure well-documented
8 references and quantifiable validation results are included in the documentation that accompanies
9 any tool developed. Additionally, the idea of equivalent risk comparisons was well liked by the
10 cohort interviewed with the caveat that the analogous risk must be relevant to the astronaut crew
11 members. An example of a poor fit was equivalent cigarettes smoked as the astronaut corps is
12 monolithically non-smokers, while a good comparison brought up during the interviews was
13 equivalent diagnostic x-rays. Finally, a few NASA flight surgeons expressed the desire for an
14 option to explore more advanced statistical measures of the REID.

15
16 Twelve out of 30+ flight surgeons (approximately 40% of the NASA flight surgeon cadre) have
17 participated in this survey. Complete consensus of the 12 NASA flight surgeon participants should
18 be interpreted with caution as the NASA flight surgeon sample-size limits conclusive statements
19 representative of the entire cohort; confidence intervals in the statistical assessment are large. The
20 results reported in this manuscript should be deemed as exploratory and descriptive, which are
21 characteristics of pilot studies. Future follow-up studies with larger sample sizes may provide
22 greater statistical power and confidence of results. Nonetheless, directional insights from the
23 experts presented herein may be used to inform the development of space radiation risk
24 communications tools.

25 Methods

26
27 A review of multiple Cognitive Task Analysis (CTA) techniques (Crandall, et al., 2008) was
28 performed, and the Hoffman CTA protocol was selected for eliciting knowledge from subject
29 matter experts (SMEs) (Daiker, et al. 2018) using formal guided interviewing methods. This
30 section describes the Hoffman CTA protocol (Figure 1) as adapted for the NASA flight surgeon
31 participation survey. Steps 1-3 provide a high-level description of initial consultation with a
32 subject matter expert (SME), literature review and analysis of any documentation provided by the
33 SME, formulation of initial SME interview needed for informing the NASA flight surgeon
34 participation survey, administration of the SME interview, and design of the NASA flight surgeon
35 participation survey. In Step 4, data is collected through one-on-one guided formal interviews
36 with NASA flight surgeon participants. The data analysis techniques are described in Step 5.

37
38 During Step 1, the research team met with the SME to establish a relationship, to discuss the best
39 method to elicit data from NASA flight surgeon participants (e.g., does the Hoffman CTA Protocol
40 need to be modified for this study), and to gather background information regarding the overall
41 role and responsibilities of a NASA flight surgeon, including what types of decisions they make,
42 the purpose of those decisions, how they are made and why, and an introduction to any
43 procedures/protocols they follow when making those decisions. For Step 2, documentation from
44 the NASA flight surgeon SME was analyzed in a process known as “documentation analysis” and
45 used to help formulate the initial NASA flight surgeon SME interview. For Step 3, an initial

1 interview with the NASA flight surgeon SME was conducted for two reasons: to take a deeper
2 inspection of the daily responsibilities of NASA flight surgeons, the techniques they use to
3 communicate risk to crew members and how they communicate that information to crew members,
4 and to ensure that the NASA flight surgeon participation survey is cohesive and comprehensible.
5 The one-on-one formal guided interview was administered in Step 4, which included career
6 interviews of the flight surgeon participants—information such as medical expertise and years of
7 experience—and responses to NASA flight surgeon participation survey.
8

9 Step 5 entails analyzing and interpreting the responses from the NASA flight surgeon participation
10 survey. Likert-scale questions used ratings that ranged from 0 to 5, with a “no opinion” rating
11 option provided (rating of “0”). Depending on the question being asked, a rating of 1 was
12 categorized as either “not important” or “too conservative,” and a rating of 5 was defined as either
13 “very important” or “too risky.” Likert-scale ratings use a “range of answer options ranging from
14 one extreme attitude to another, sometimes including a moderate or neutral option”
15 (SurveyMonkey Inc., n.d.). Subjective questions are quantitatively assessed by the Likert-scale
16 and measure the opinions, attitudes, and motivations of participants. Responses from the Likert-
17 scale questions were assessed with basic descriptive statistical analyses, including means and
18 standard errors.
19

20 Responses to open-ended questions, which encourage additional feedback and comments from
21 participants and are used to supplement the Likert-scale ratings by providing additional insight
22 into how the participant perceived a particular topic area, were analyzed by identifying common
23 themes and trends using a technique called binning (also referred to as discretization or bucketing),
24 which groups similar responses into identified categories (e.g., current communications methods
25 and tools; credibility of near-term and long-term data; future communications tool: desirable
26 features, customizability, and data representation; lifestyle interventions; medical decision making
27 factors, numerical limits for REID, radiation risk and exposure thresholds; terrestrial data; and,
28 training requirements). This process simplifies the analysis of large sets of non-numerical,
29 qualitative data by converting them into categorical data. These binning categories can be pre-
30 determined by the research team prior to data collection (deductive coding) or after the data has
31 been collected from participants using a data analysis process approach known as inductive coding.
32

33 All open-ended and follow-up questions were categorized using inductive coding; a bottom-up,
34 qualitative data analysis approach that allows the research team to develop categories based on
35 themes and trend categories (or codes) derived from the raw data collected. In this process, the
36 raw data from general comments and open-ended questions are thoroughly examined to identify
37 common patterns. This data-driven approach provides the research team with the opportunity to
38 explore new insights and develop theories based on the raw data collected that were not previously
39 evident during the preceding steps. This approach also provides flexibility since the coded
40 categories can be refined throughout the analysis process. Categorical data is evaluated alongside
41 the responses from the Likert-scale questions to reveal insights into the respondent’s experience
42 and opinions that would otherwise not be known from stand-alone closed-ended questions (e.g.,
43 Likert-scales). The information obtained from these results will be used to help guide potential,
44 future research and risk communication tool development.
45

1 Ethics Statement

2 The study was approved by NASA’s Institutional Review Board (IRB) (study electronic IRB
3 number: STUDY00000239) as an expedited review under Category 7 in accordance with the IRB’s
4 Code of Federal Regulations (14CFR1230) and NASA’s policies and guidelines (NPR 7100.8,
5 NPR 7100.1) (reference: <https://www.nasa.gov/irb-overview/>). The NASA IRB protocol reviews
6 each research effort to ensure the ethical, safe, and equitable treatment of subjects per regulatory
7 guidance and U.S. Federal regulations. The recruitment method was designed in this manner to
8 provide prospective participants with upfront information about the study, encouraging them to
9 address any questions or concerns prior to participation. Informed consent was obtained from each
10 participant prior to their one-on-one formal interview. As part of the informed consent process,
11 participants were informed about their privacy and the method in which their data were to be stored
12 and shared. NASA flight surgeons participated voluntarily and were able to end their participation
13 at any time, if desired.

15 Participant Selection and Recruitment

16 Flight surgeons from NASA Johnson Space Center (JSC) were recruited for participation.
17 Multiple phases of recruitment occurred between June 2020 and May 2024. The research team
18 collaborated with a flight surgeon SME from JSC and forged a partnership with the University of
19 Texas Medical Branch (UTMB) to offer an educational project focused on data acquisition for the
20 NASA flight surgeon survey. A UTMB aerospace medicine resident working on-site at JSC
21 administered the NASA flight surgeon participation survey to members of the flight surgeon cadre
22 under the direction of the on-site NASA flight surgeon SME who is affiliated with the project and
23 who served as a mentor to the UTMB resident. With the guidance of the on-site NASA flight
24 surgeon mentor, the UTMB resident invited the entire NASA flight surgeon cadre (n=30+) to
25 participate in the NASA flight surgeon participation survey. The research team did not set any
26 minimum level of experience as all levels of experience were sought, allowing for data that
27 encompasses broad perspectives and opinions; however, NASA flight surgeon participants were
28 required to have completed their Mission Control console training.

29
30 Due to the COVID-19 pandemic, the initial recruitment process was conducted via weekly virtual
31 meetings and email. The UTMB resident participated in this role for the entirety of the residency
32 program, which occurred over a period of approximately two years. Afterwards, the primary
33 research team continued the recruitment process by visiting NASA JSC and scheduling both in-
34 person and virtual one-on-one guided interviews.

35
36 In total, 12 NASA flight surgeons participated in this study. Basic demographics data, known as
37 the career interview under Hoffman’s CTA protocol, was collected from each NASA flight
38 surgeon participant. Five participants had been practicing medicine for more than 15 years, while
39 the remaining seven participants had practiced medicine for less than 15 years. Areas of medical
40 specialization for participants included aerospace medicine, emergency medicine, family
41 medicine, and occupational medicine. Four of the 12 participants reported having some level of
42 previous radiation/oncology experience or training. When asked about their current field of
43 medicine, six participants described their field as “Operational”, one as “Clinical”, four as both
44 “Operational and Clinical”, and one as a mix between “Clinical and other.” The demographic data
45 collected was used to provide additional context to the responses gathered from the NASA flight
46 surgeon participation survey.

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Data Acquisition

At the start of each one-on-one guided interview, and after informed consent was acquired, NASA flight surgeons who volunteered to participate were asked questions about their background experience (i.e., Hoffman’s CTA protocol career interview). Following the career interview, guided interviews, referred to as “client interviews” in Hoffman’s CTA protocol, were approximately 45-minutes to one-hour long and consisted of multiple primary questions and were supplemented with follow-on questions based on the NASA flight surgeon participant’s responses. The NASA flight surgeon participation survey was shared on the screen throughout the duration of the virtual interview (or via a paper copy if the interview was conducted in-person). These questions were designed to elicit respondents’ general medical experience with radiation risks and how this relates to clinical practice. This information will be used to provide better radiation risk models for the purposes of long-term health and to better communicate radiation exposure risks to stakeholders. The NASA flight surgeon participation survey gathered respondents’ subjective feedback concerning the importance of several types of information needed to properly communicate radiation exposure risks with focused consideration of an Earth to Mars mission, including a round-trip transit time of 400 days and a 600 day stay on the Martian surface. The data collected from these one-on-one guided interviews can be used to form the basis of a user information requirements analysis and synthesis.

Data Availability

Due to privacy and ethical considerations, raw data from the surveys, including the initial NASA flight surgeon SME interview and the NASA flight surgeon participation interviews, cannot be disclosed to the public. Open-ended responses from the NASA flight surgeon participation survey have been summarized in the manuscript; however, direct quotes are withheld to protect anonymity.

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30 provide valuable knowledge to this research effort.

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38 Ethics Declarations

39 The authors declare no conflicts of interest.

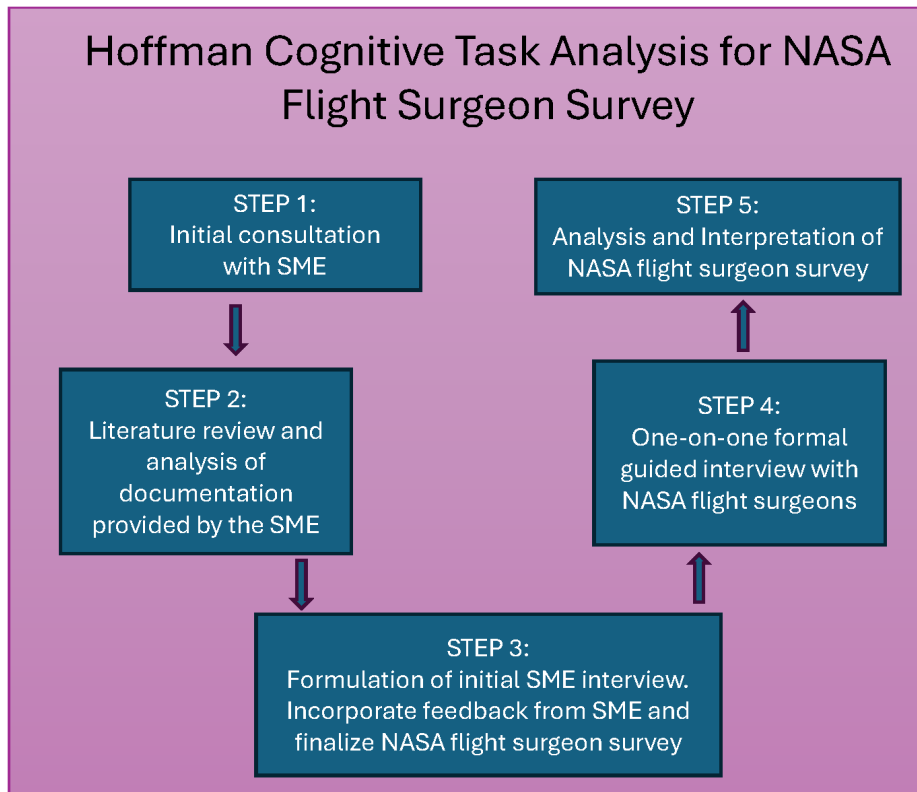
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Figures



7
8 Figure 1: The five steps of the Hoffmann Cognitive Protocol Analysis used for development, one-
9 on-one formal guided interviews, and analysis of the NASA Flight Surgeon Survey. SME
10 represents Subject Matter Expert.

Summary of NASA Flight Surgeon Survey Questions

1. With regard to communicating radiation exposure risks, are the methods currently applied to crewmember medical certification and mission assignments sufficient for future missions?

2. Would a tool, which takes into account and communicates additional measures of radiation exposure risk, be beneficial for future crew decisions and long-term care?

3. What kind of information would you like to see incorporated into this tool? (permissible mission duration, risks of mortality from all causes, cardiovascular disease risk, central nervous system degenerative disease risk, cancer risk, future quality of life, pure exposure information)

4. What kind of information would you like to see incorporated into this tool? (points of reference comparison to other common life-threatening risks, potential effects of lifestyle interventions on risks, potential effects of biomedical interventions on risks)

5. What other ways of presenting statistically relevant data do you consider important when making a decision? (mean, median, 95% CL, 66% CL, other)

6. How does a near term outcome vs. a longer-term outcome (e.g., 10-year risk vs. lifetime) factor into your decision making?

6-A. How does the credibility of evidence factor into your decision making (e.g., you may have better data on 10-year risk)?

7. How would you describe the current numerical, 3-percent cutoff, limits for REID?

7-A. How would you describe the current numerical, 95-percent confidence level, cutoff limits for REID?

8. What should be the main considerations if Space Permissible Exposure Limits (SPELs) are updated in the future? (open-ended response)

9. How could the visualization of radiation-related risk data be improved? (open-ended response)

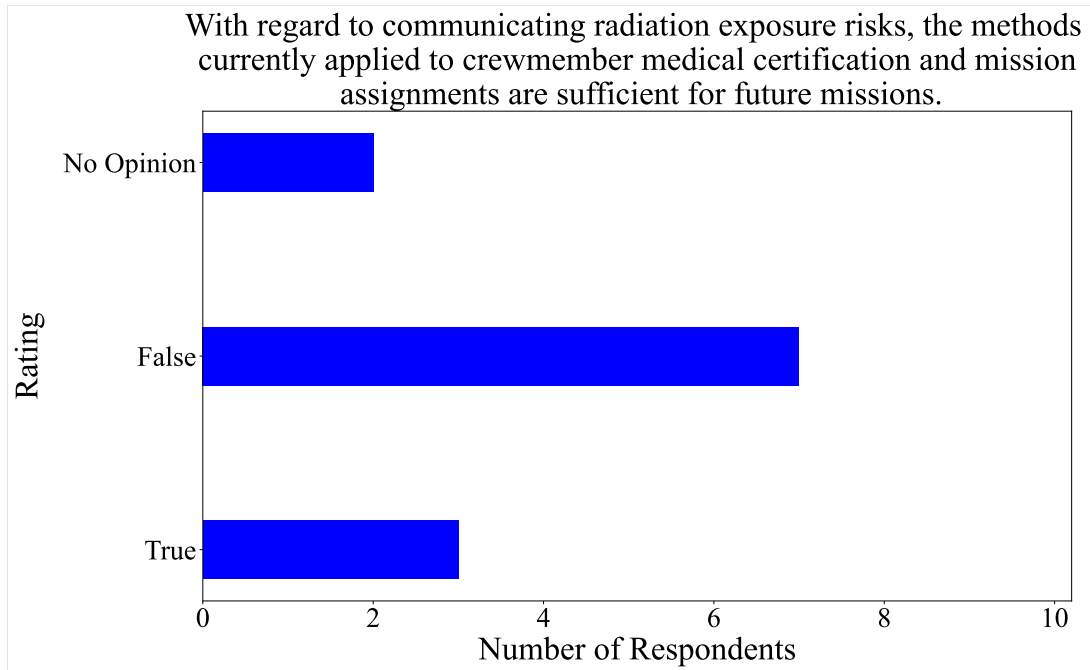
10. If applicable, can you list other examples of successful methods for communicating radiation risks, which have been proven effective? (open-ended response)

11. With regard to radiation exposure risks, what other factors are important for medical decision making? (open-ended response)

1
2 Figure 2: Summary of flight surgeon survey questions that result from step 4 of the Hoffmann
3 Cognitive Task Assessment Protocol.

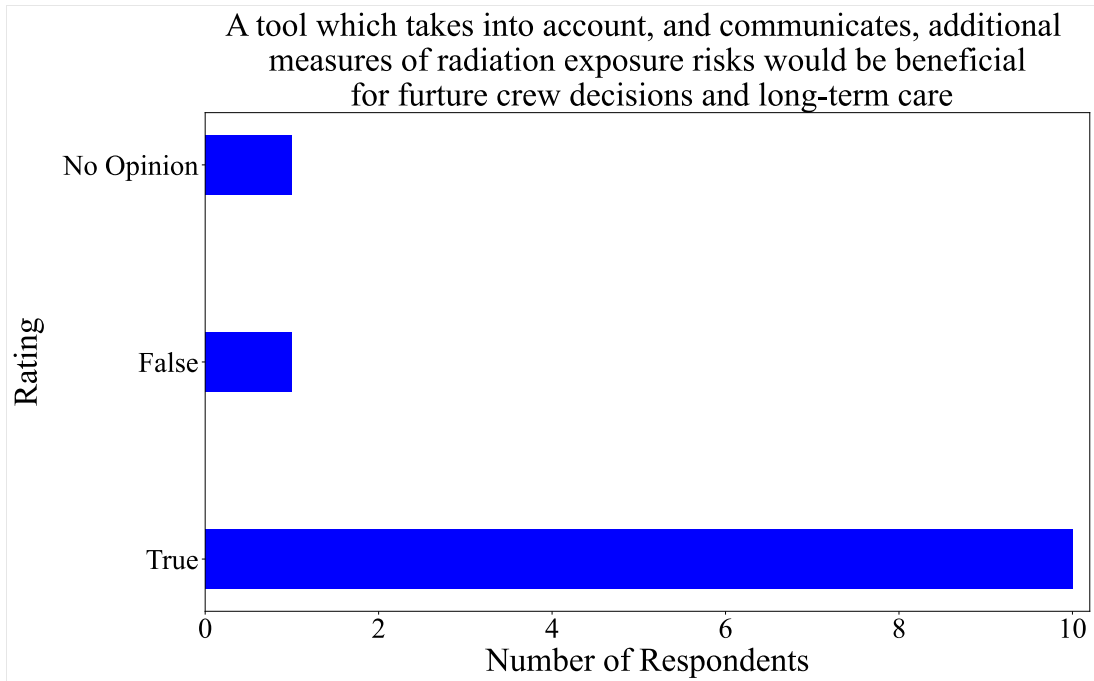
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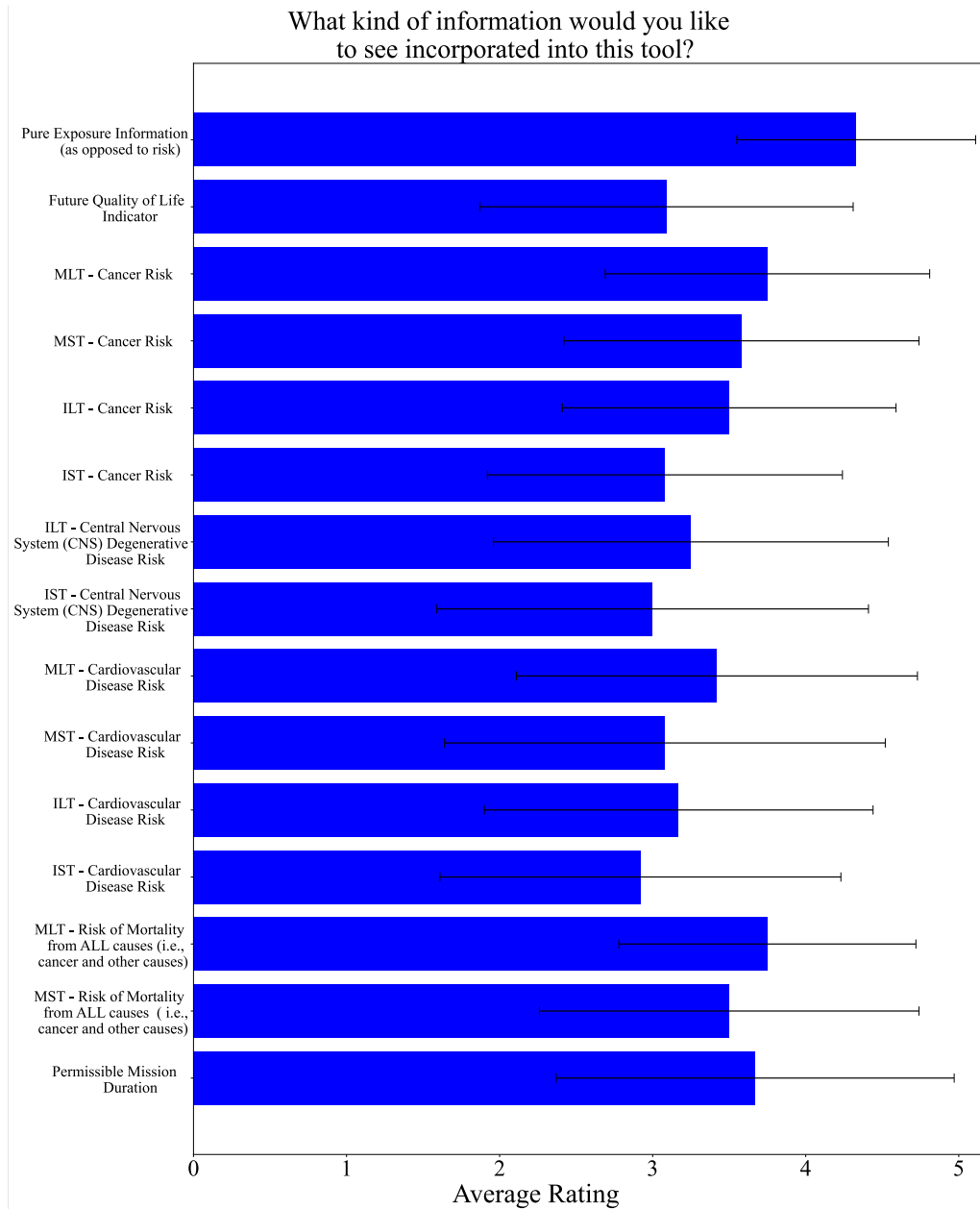


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5 Figure 3: NASA flight surgeon responses to space radiation health risk survey assessing the
6 sufficiency of the methods currently applied to crewmember medical certification and mission
7 assignments for future missions.

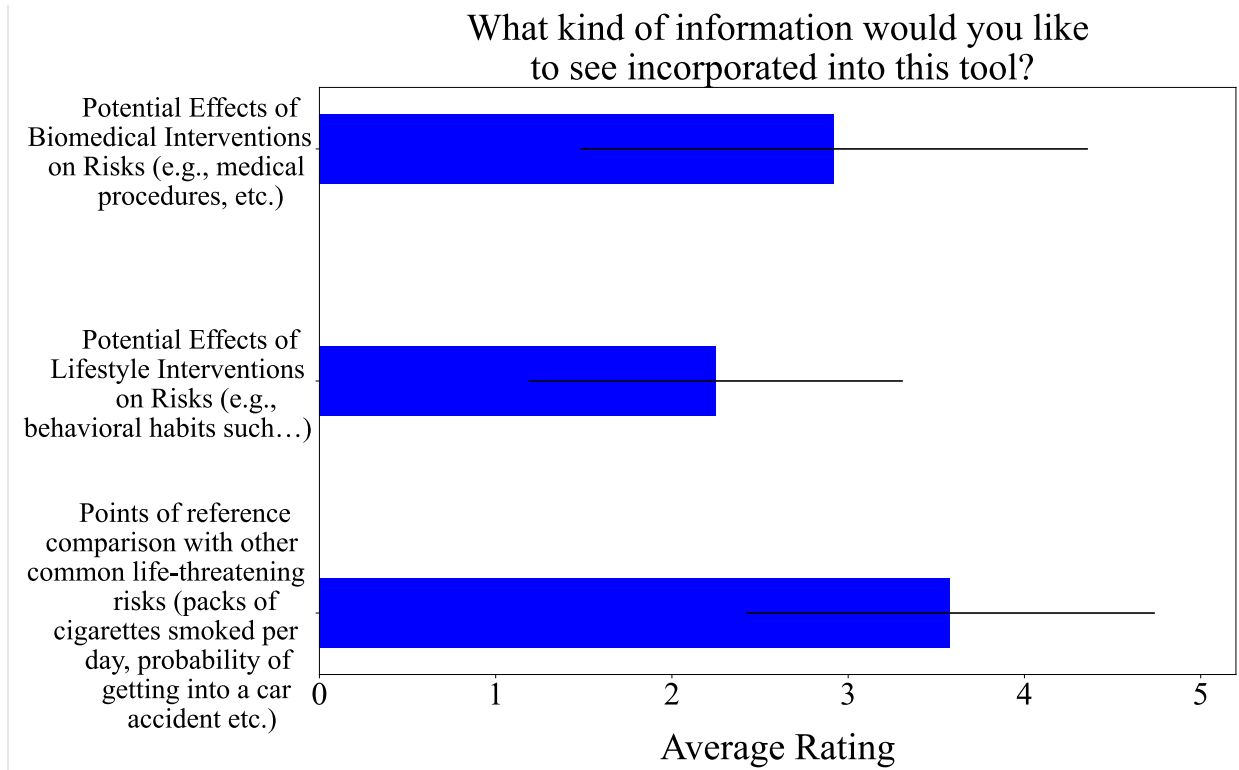
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2 Figure 4: NASA flight surgeon responses to space radiation health risk survey assessing if tools
3 that communicate additional measures of radiation risks would be beneficial for future crew
4 decisions and long-term health care.



1
 2 Figure 5: NASA flight surgeon responses to space radiation health risk survey assessing what
 3 information would be useful for informing space radiation risk projection tools. Each category was
 4 accompanied by a Likert-scale with ratings from 0 to 5, where 0 = “no opinion,” 1 = “not
 5 important”, 2 = “slightly important”, 3 = “moderately important”, 4 = important”, and 5 = “very
 6 important.” The average rating for each category was calculated by taking the sum of all responses
 7 in that specific category and dividing it by the number of responses received. A response of “0”
 8 was not included in the average rating and was treated as “missing data” due to a participant’s
 9 inability or unwillingness to evaluate that specific category. Responses were not weighted based
 10 on participants’ years of experience, which resulted in a variation of responses. This variation is
 11 represented by the standard error bars. MST is mortality-short term (10 years), MLT is mortality-
 12 long term (30 years or more), IST is incidence-short term (10 years), ILT is incidence-long term
 13 (30 years or more).

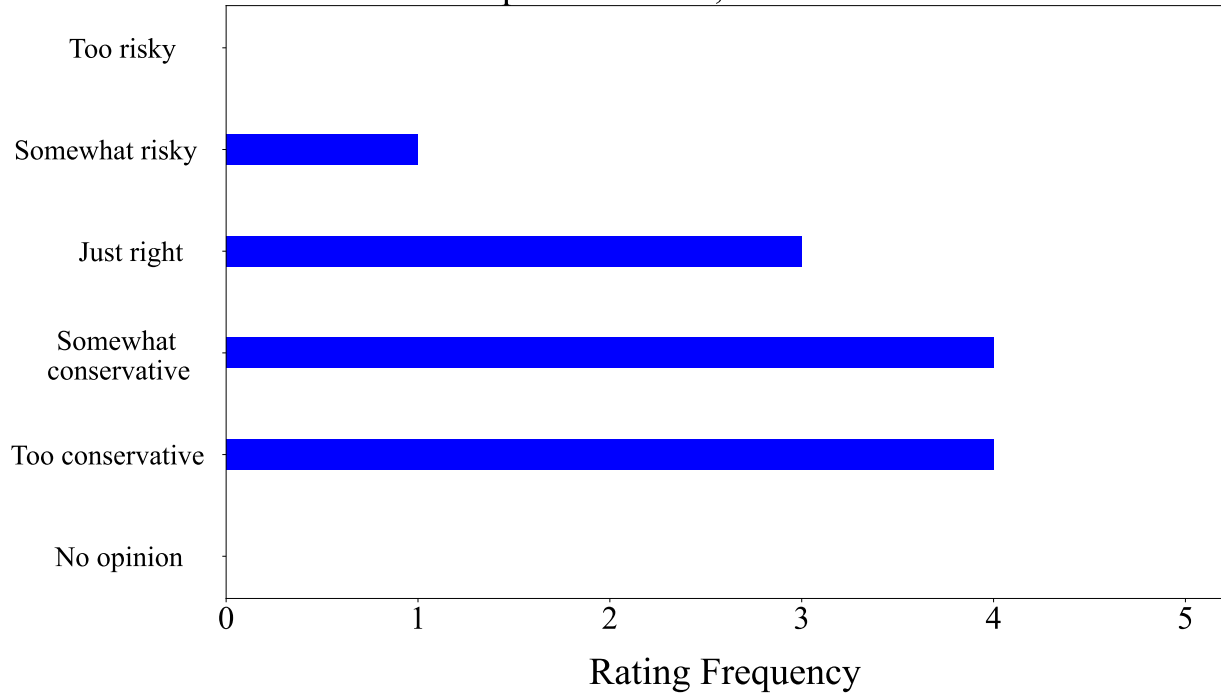


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 2 Figure 6: NASA flight surgeon responses to space radiation health risk survey assessing what
 3 information would be useful for informing space radiation risk projection tools. Each category was
 4 accompanied by a Likert-scale with ratings from 0 to 5, where 0 = “no opinion,” 1 = “not
 5 important”, 2 = “slightly important”, 3 = “moderately important”, 4 = “important”, and 5 = “very
 6 important”. The average rating for each category was calculated by taking the sum of all responses
 7 in that specific category and dividing it by the number of responses received. A response of “0”
 8 was not included in the average rating and was treated as “missing data” due to a participant’s
 9 inability or unwillingness to evaluate that specific category. Responses were not weighted based
 10 on participants’ years of experience, which resulted in a variation of responses. This variation is
 11 represented by the standard error bars.

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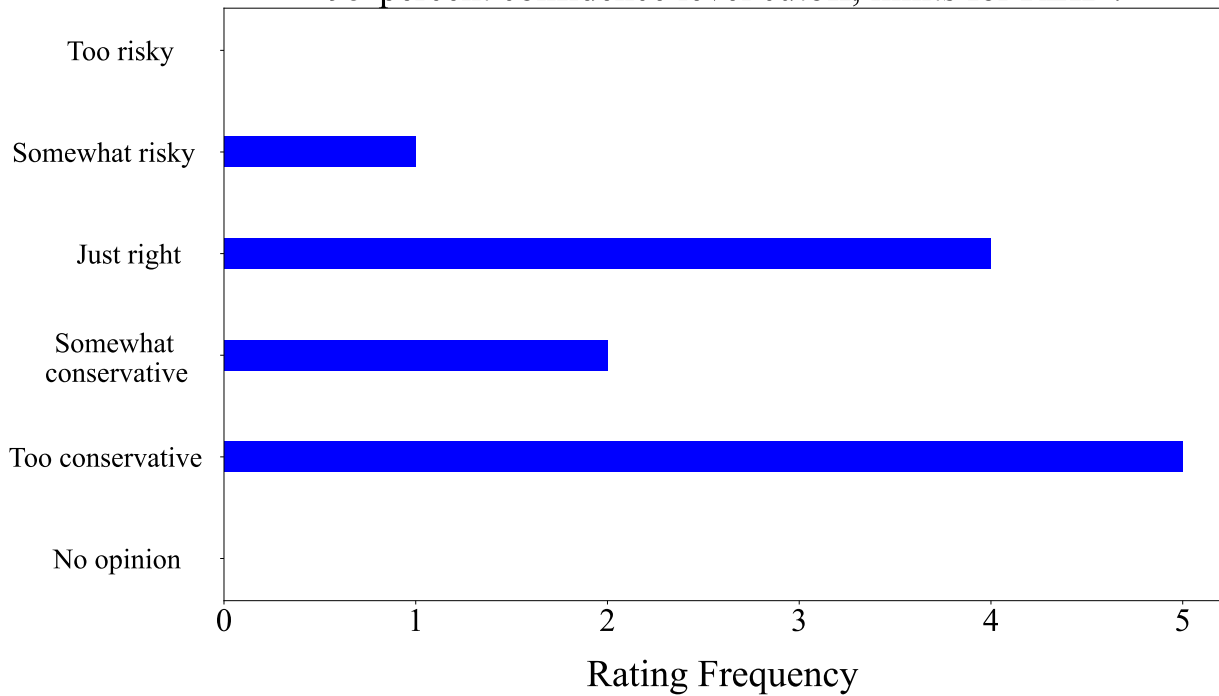
Question #7: How would you describe the current numerical, 3-percent cutoff, limits for REID?



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Figure 7: NASA flight surgeon responses to a space radiation health risk survey concerning risk assessment with a 3% limit for the REID. Likert-scale ratings ranged from 0 to 5, where 0 = “no opinion”, 1 = “too conservative”, 2 = “somewhat conservative”, 3 = “just right”, 4 = “somewhat risky”, and 5 = “too risky”. The rating frequency is obtained by summing the NASA flight surgeon participant responses to question 7.

Question #7-A: How would you describe the current numerical, 95-percent confidence level cutoff, limits for REID?



1
2 Figure 8: NASA flight surgeon responses to a space radiation health risk survey concerning the
3 assessment of risks with the 95% confidence level of the REID. Likert-scale ratings ranged from
4 0 to 5, where 0 = “no opinion”, 1 = “too conservative”, 2 = “somewhat conservative”, 3 = “just
5 right”, 4 = “somewhat risky, and 5 = “too risky. The rating frequency is obtained by summing the
6 NASA flight surgeon participant responses to question 7-A.

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1 Supplementary Information

2 Space Radiation Risk Assessment – Flight Surgeon Questionnaire

4 **Background:**

6 The MERA (Multi-model Ensemble Risk Assessment) project seeks to effectively communicate
7 ensemble-model-based radiation risk information to multiple stakeholders, and to communicate
8 forecast uncertainty associated with multiple probabilistic distributions, in a way that is
9 understandable to both experts and lay persons.

11 NASA Technical Standard 3001 F.8.2 states, “Career exposure to radiation is limited to not exceed
12 3 percent REID for fatal cancer. NASA assures that this risk limit is not exceeded at a 95 percent
13 confidence level *using a statistical assessment of the uncertainties* in the risk projection
14 calculations.”

16 A goal of the MERA project is to improve communication, and thus understanding, regarding
17 probabilistic REID (Risk of Exposure Induced Death) model projections and the underlying
18 statistical assessments through reporting and data visualization techniques. Your feedback
19 (provided via this questionnaire) will help researchers better understand key information that
20 stakeholders need in order to make decisions regarding radiation exposure risks.

22 This questionnaire has been created with particular consideration of an Earth to Mars mission
23 with 400 days transit time and a 600 day stay on the Martian surface. NASA estimates that the
24 average mission radiation effective dose will be approximately 1,000 mSv (Solar minimum, 5
25 g/cm² Aluminum). The information gathered will be used to develop capability for more general
26 mission scenarios as well.

28 The TREAT Astronauts Act (signed into law on March 21, 2017) authorizes occupationally related
29 medical monitoring, diagnosis, and treatment for medical and psychological conditions
30 associated with human spaceflight. This law brings forth a renewed emphasis on the long-term
31 care implications associated with radiation exposure risks and the importance of clearly
32 communicating these risks to key stakeholders.

34 This survey is intended to gather information about respondents’ general medical experience
35 with radiation risks and how this relates to clinical practice. This information will be used to
36 provide better radiation risk models for the purposes of long-term care and to better
37 communicate radiation exposure risks to stakeholders. Within the context of the information
38 provided above, please answer the following questions.

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1 *True or False Instructions: Please indicate whether the following statements are "True" or "False,"*
2 *and provide any additional comments after making your selection.*

- 3
4 1. With regard to communicating radiation exposure risks, the methods currently applied to
5 crewmember medical certification and mission assignments are sufficient for future
6 missions.

7
8 _____ TRUE

9
10 _____ FALSE

11
12 _____ NO OPINION

13
14 Comments:

15
16 _____
17
18 _____
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20 _____

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22
23 2. A tool which takes into account, and communicates, additional measures of radiation
24 exposure risks (10-year cardiovascular disease risk, 30-year degenerative CNS disease risk,
25 those used by the global burden of disease collaboration (e.g. Years of Potential Life Lost
26 (YPLL), disability-adjusted life-year (DALY), quality-adjusted life-year (QALY)) would be
27 beneficial for future crew decisions and long-term care.

28
29 *Note:* You will have the opportunity to provide further comments on these additional
30 measures later in the questionnaire.

31
32 _____ TRUE

33
34 _____ FALSE

35
36 _____ NO OPINION

37
38 Comments:

39
40 _____
41
42 _____
43
44 _____

1 3. What kind of information would you like to see incorporated into this tool? Probabilistic
 2 risks are typically used, but not readily understood by many people.
 3 Please rate below (where 0 = No Opinion, 1 = Not Important, 5 = Very Important) and list
 4 your preferred quantities of measure where applicable.
 5

6 3-A. Permissible Mission Duration (PMD)
 7

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

8
 9 3-A Comments:

10 _____
 11 _____
 12 _____
 13 _____
 14 _____
 15 _____
 16 _____
 17 _____
 18 _____

19 3-B. Risk of Mortality from **ALL causes** (i.e., cancer and other causes)
 20

21 **Mortality: Short-term (10 years)**

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

22
 23
 24 **Mortality: Long-term (30 years or Lifetime)**

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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3-B Comments:

10 3-C. Cardiovascular Disease Risk

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Incidence: Short-term (10 years)

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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Incidence: Long-term (30 years or Lifetime)

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

16
17
18

Mortality: Short-term (10 years)

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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21

Mortality: Long-term (30 years or Lifetime)

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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3-C Comments:

3-D. Central Nervous System (CNS) Degenerative Disease Risk

Incidence of Degenerative CNS Diseases: Short-term (10 years)

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

Incidence of Degenerative CNS Diseases: Long-term (30 years or Lifetime)

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

3-D Comments:

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3-E. Cancer Risk

Incidence: Short-term (10 years)

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

Incidence: Long-term (30 years or Lifetime)

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

Mortality: Short-term (10 years)

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

Mortality: Long-term (30 years or Lifetime)

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

3-E Comments:

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3-F. Future Quality of Life Indicator

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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3-F Comments:

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3-G. Pure Exposure Information (as opposed to "risk")

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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Preferred Quantities of Measure (*if applicable*):
(Examples: Dose or Effective Dose)

Quantity 1: _____

Quantity 2: _____

Other: _____

3-G Comments:

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3-H. Other: _____

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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Preferred Quantities of Measure (*if applicable*):

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Quantity 1: _____

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Quantity 2: _____

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Other: _____

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3-H Comments:

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3-I. Other: _____

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No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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Preferred Quantities of Measure (*if applicable*):

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Quantity 1: _____

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Quantity 2: _____

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Other: _____

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3-I Comments:

3-J. Other: _____

No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

Preferred Quantities (*if applicable*):

Quantity 1: _____

Quantity 2: _____

Other: _____

3-J Comments:

1 4. Similar to number 3 above, what kind of information would you like to see incorporated
2 into this tool? Probabilistic risks are typically used, but not readily understood by many
3 people. *Please rate below (where 0 = No Opinion, 1 = Not Important, 5 = Very Important)*
4 *and list your preferred quantities where applicable.*

5
6 4-A. Points of reference comparison with other common life-threatening risks (packs of
7 cigarettes smoked per day, probability of getting into a car accident etc.)
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No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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10 Preferred Quantities of Measure (if applicable):

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12 Quantity 1: _____

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14 Quantity 2: _____

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16 Other: _____

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19 4-A Comments:
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1 4-B. Potential Effects of **Lifestyle Interventions** on Risks (e.g., behavioral habits such as
2 smoking, exercising, diet, etc.)
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No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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4-B Comments:

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4-C. Potential Effects of **Biomedical Interventions** on Risks (e.g., medical procedures (such
17 as receiving a stent), pharmaceuticals, and their possible side effects)
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No Opinion	Not Important	Slightly Important	Moderately Important	Important	Very Important
0	1	2	3	4	5

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4-C Comments:

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5. What other ways of presenting statistically relevant data do you consider important when making a decision? *Please rank each item below on a scale of 1 to 7 (where 1 = Most Important, 7 = Least Important)*

Choices	Rank Order
▪ Mean	1. _____
▪ Median	2. _____
▪ 95% CL	3. _____
▪ 66% CL	4. _____
▪ Other: _____	5. _____
▪ Other: _____	6. _____
▪ Other: _____	7. _____ (Least Important)

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Comments:

6. How does a near term outcome vs. a longer term one (e.g., 10-year risk vs. lifetime) factor into your decision making?

1 6-A. How does the credibility of evidence factor into your decision making (e.g., you may
2 have better data on the 10-year risk)?

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11 7. How would you describe the current numerical, 3-percent cutoff, limits for REID?
12 *Please rate below (where 0 = No Opinion, 1 = Too Conservative, 5 = Too Risky)*

13

No Opinion	Too Conservative	Somewhat Conservative	Just Right	Somewhat Risky	Too Risky
0	1	2	3	4	5

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15 Comments:
16 _____
17 _____
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19 _____
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23 7-A. How would you describe the current numerical, 95-percent confidence level cutoff,
24 limits for REID?

25
26 *Please rate below (where 0 = No Opinion, 1 = Too Conservative, 5 = Too Risky)*

27

No Opinion	Too Conservative	Somewhat Conservative	Just Right	Somewhat Risky	Too Risky
0	1	2	3	4	5

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29 Why did you choose those ratings?
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8. What should be the main considerations if Space Permissible Exposure Limits (SPELs) are updated in the future?

9. How could the visualization of radiation-related risk data be improved?

10. If applicable, can you list other examples of successful methods for communicating radiation risks, which have been proven effective?

11. With regard to radiation exposure risks, what other factors are important for medical decision making?

1 *Reference Tables:*

2 Table 1. Radiation Units of Measure

System of Units	Absorbed Dose	Equivalent Dose	Effective Dose	Radio-Activity
SI:	Gray (Gy)	Sievert (Sv)	Sievert (Sv)	Bequerel (Bq)
Traditional:	rad	rem	rem	Curie (Ci)

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5 Table 2. Conversion factors

1 Gy = 1 J/kg
1 Gy = 100 rads
1 rad = 0.01 Gy
1 Sv = 1 J/kg
1 Sv = 100 rems
1 rem = 0.01 Sv

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8 Table 3. Comparison of Radiation Effective Dose Values

Procedure:	Effective Dose Values (mSv):
Max allowable Occupational Dose US Radiation Workers (Annual)	50
Coronary CT Angiogram	16
Myocardial Perfusion Imaging	14
Barium Enema XR	8
Abdomen CT	8
Fluoroscopic Coronary Angiogram	7
Chest CT	7
Bone Scan	4
Head CT	2
Lumbar Spine XR	1.5
Cosmic Radiation Living in Denver (Annual)	0.8
Mammogram	0.4
Smoking 20 cigarettes/day	0.36
Cosmic Radiation Living at Sea Level (Annual)	0.3

Chest XR	0.02
3-Hour Jet Plan Ride	0.01
Living Near a Nuclear Power Station (Annual)	<0.01
Dental Bitewing XR	<0.01

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