HelmholtzZentrum münchen
German Research Center for Environmental Health

Aircrew and Space Crew Dosimetry

EU Scientific Seminar 2021
“Advances/Innovations in Individual Dosimetry”
Luxembourg (digital)
9 November, 2021

Prof. Dr. W. Rühm
Institute for Radiation Medicine
Helmholtz Zentrum München
German Research Center for Environmental Health

HELMHOLTZ
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ICRP and Cosmic Radiation

ICRP Publication 60, 1991, Recommendations

(136) "… the Commission recommends that there should be a requirement to include exposures to natural sources as part of occupational exposure only in the following cases":

(a) … radon …

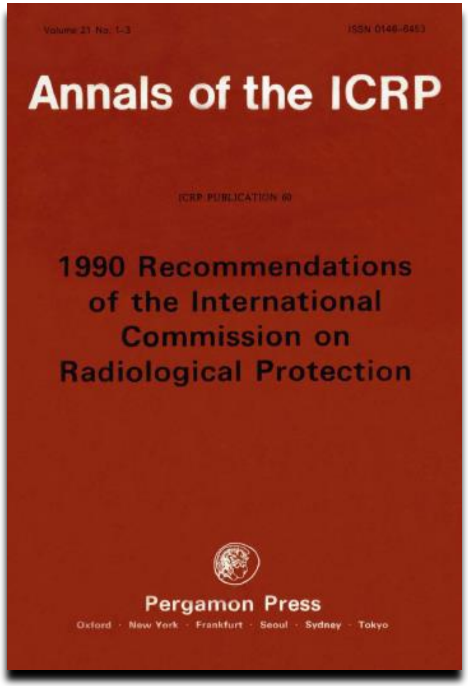
(b) **…** natural radionuclides …

(c) **Operation of jet aircraft,**

(d) **Space flight.**

„Case (c) will relate principally to the aircraft crew, but attention should also be paid to groups such as couriers who fly more often than other passengers".

"Case (d) relates to very few individuals and will not be discussed further here".



ICRP60 was a milestone, because for the first time natural exposures were explicitly addressed

Occupational exposure of pilots and cabin crew in Germany

EC-Directive 96/29 EURATOM:

Protection against significantly increased exposure by *natural* radiation

In Germany following StrlSchV 2001:

Air crew members must be monitored if

a) They are employed by an airline

b) Expected annual effective dose > 1 mSv

>> Airlines must quantify doses since August 2003

Mares V et al. Radiat. Prot. Dosim. 136, 262-266 (2009)

Mares V; Yasuda H. Radiat. Meas. 45, 1553-1556 (2010)

Chen J; Mares V. Health Phys. 98, 74-76 (2010)

Mukherjee B, …, Mares V. Radiat. Meas. 94, 65-72 (2016)

Dose quantification by computer codes

- **Example: Code developed at HMGU**

EPCARD aircrew dosimetry

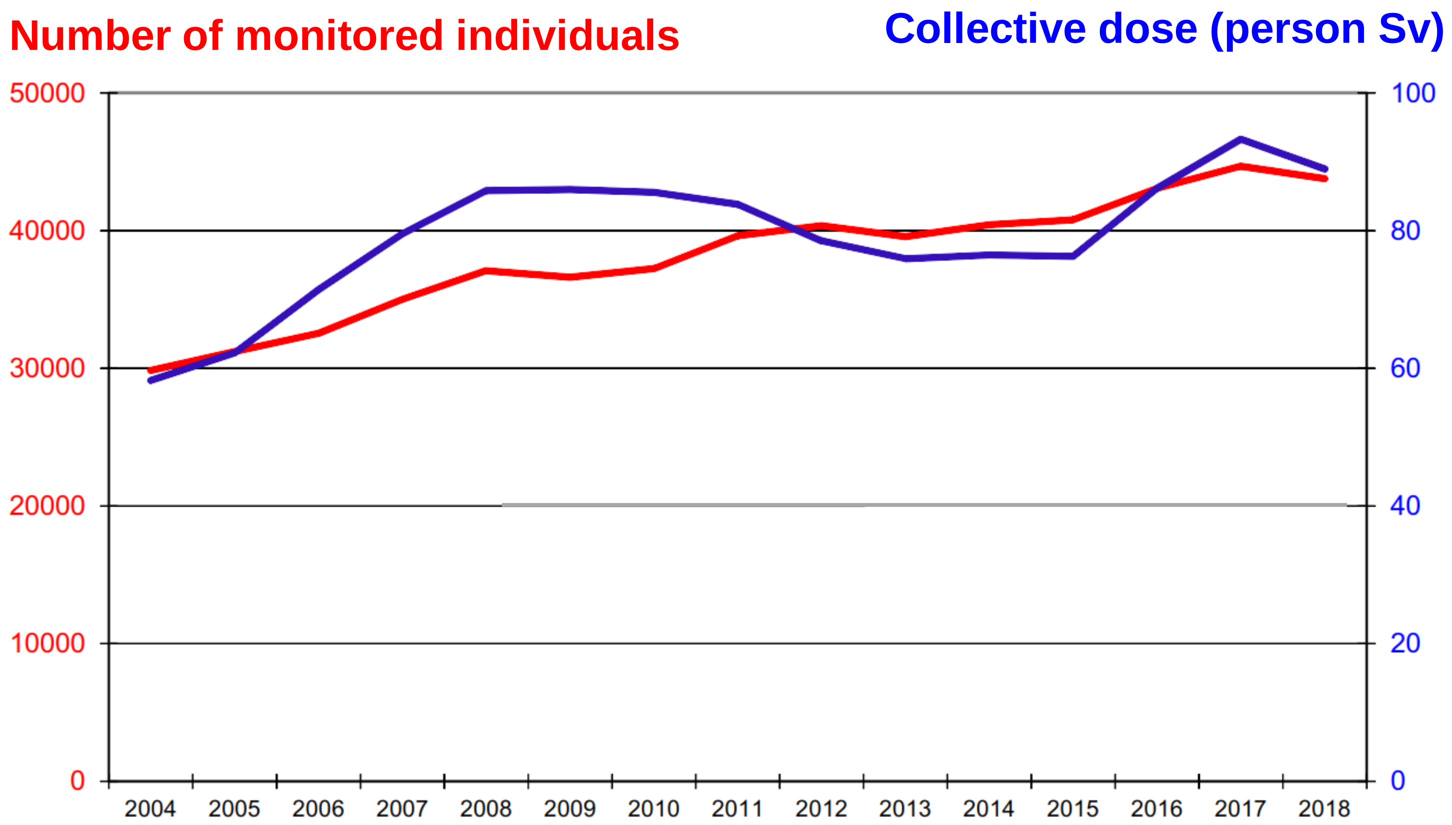
European **P**rogram Package for the **C**alculation of **A**ir **R**oute **D**oses

- **Codes accredited in Germany:** PANDOCA, EPCARD, PCAIRE

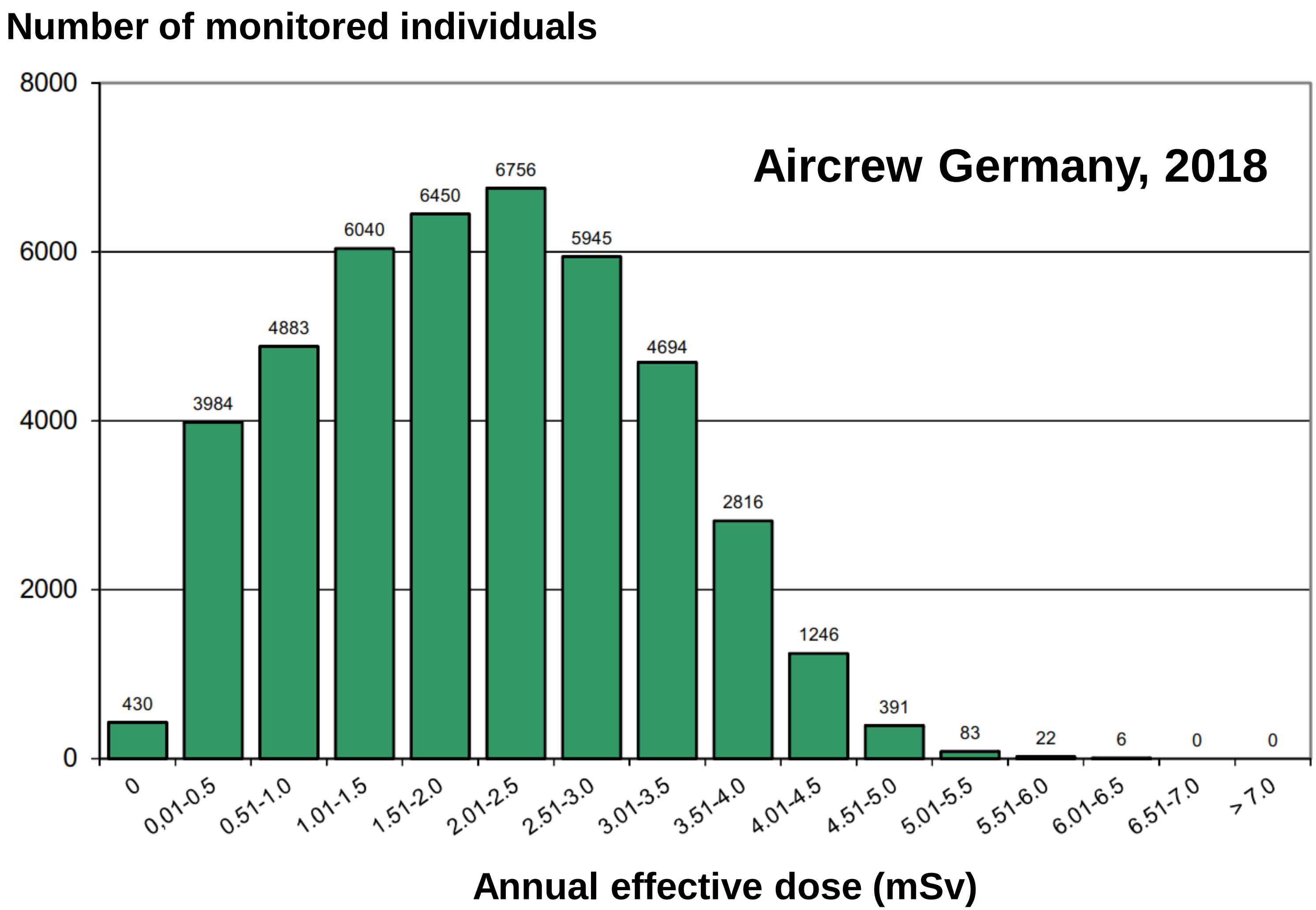
In Germany, aircrew are among the occupations with highest annual effective dose and collective effective dose

- Annual effective dose, 2018: **2.0 mSv**
- Annual collective dose, 2018: **89 person Sv**

Germany, 2018

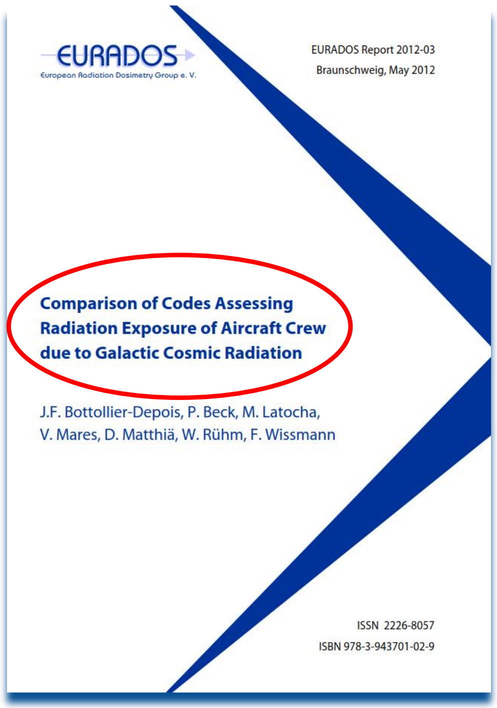


(Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2019) Environmental Radioactivity and Radiation Exposure – Annual Report 2018)



(Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2019)
Environmental Radioactivity and Radiation Exposure – Annual Report 2018)

Exposure to *Galactic* Cosmic Radiation: WG11 EURADOS Study 2012


EURADOS
European Radiation Dosimetry Group e. V.

EURADOS Report 2012-03
Braunschweig, May 2012

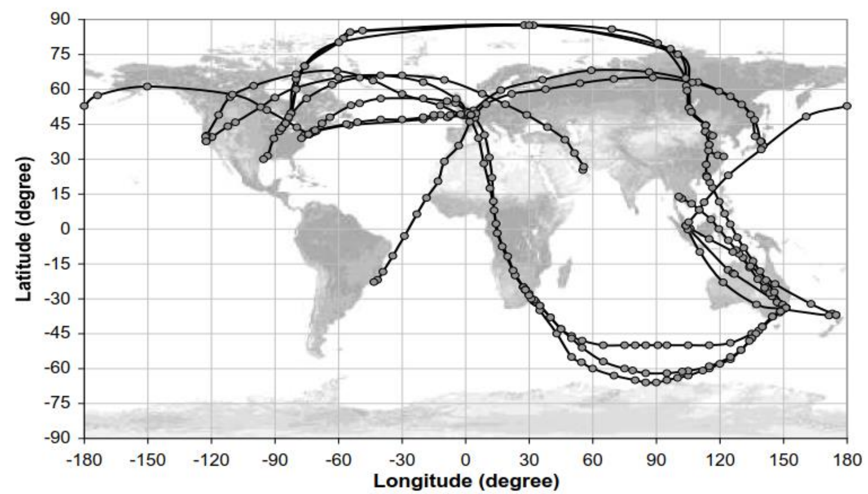
Comparison of Codes Assessing Radiation Exposure of Aircraft Crew due to Galactic Cosmic Radiation

J.F. Bottollier-Depois, P. Beck, M. Latocha, V. Mares, D. Matthiä, W. Rühm, F. Wissmann

ISSN 2226-8057
ISBN 978-3-943701-02-9

1. Eleven codes (Europe, US, Canada, Japan)

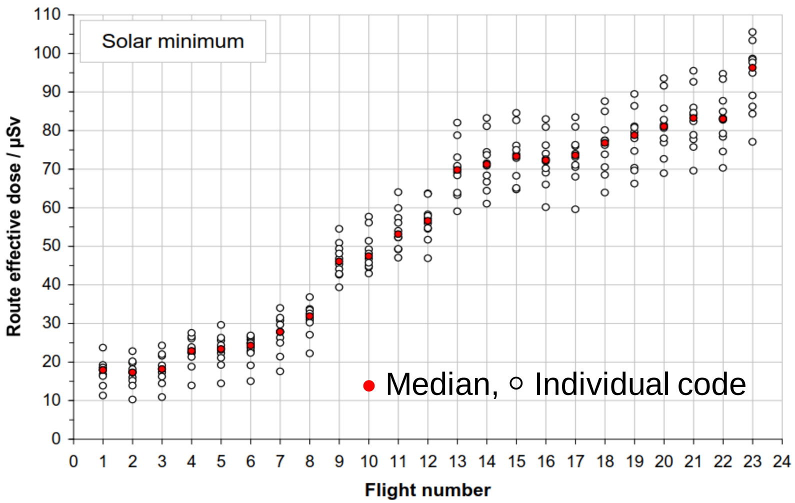
2. Twenty-three flight routes selected

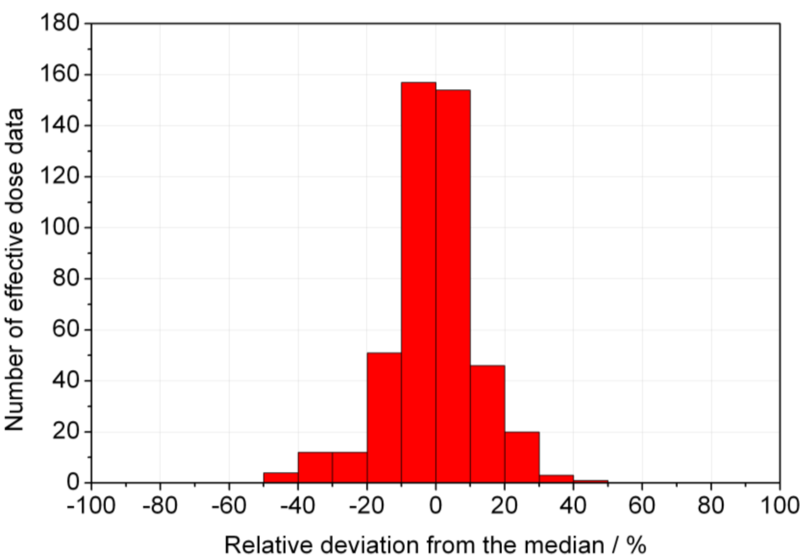


3. Two departure times during Cycle 23

August 2000 (close to solar maximum)

September 2007 (close to solar minimum)

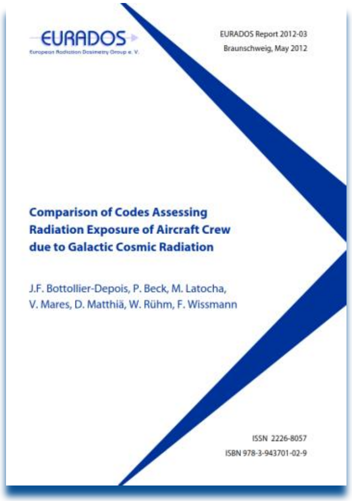




Conclusions

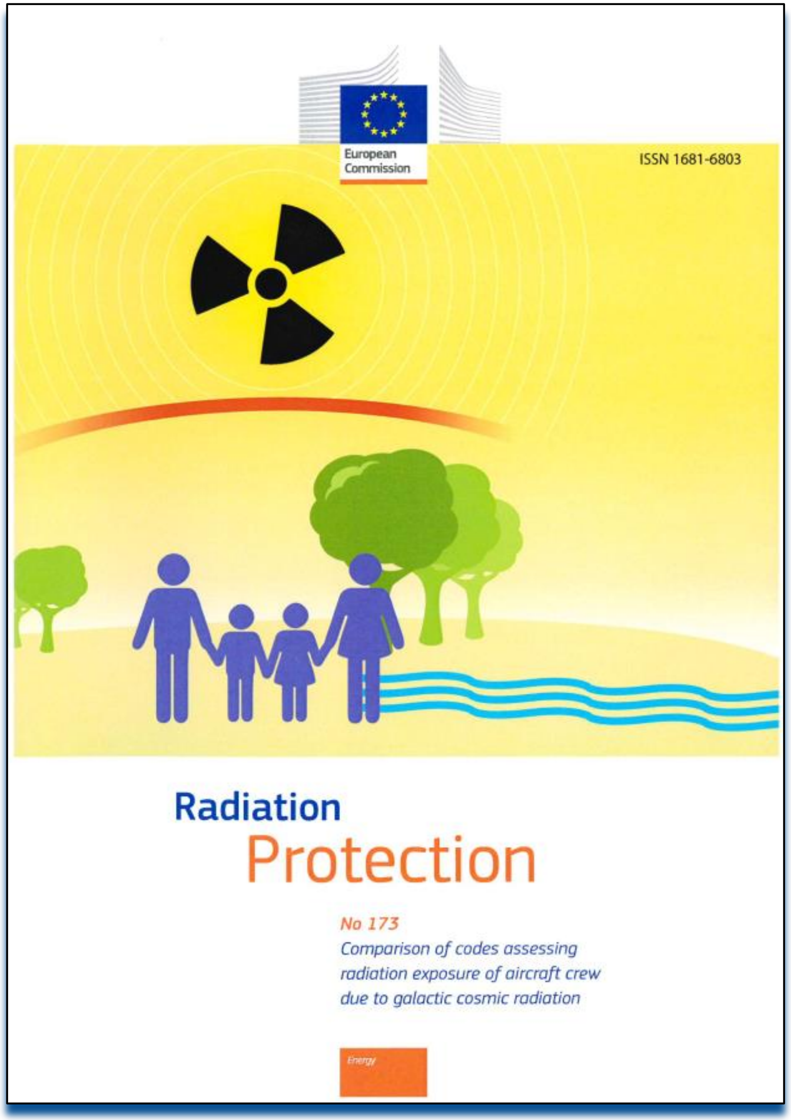
- One code provided systematically lower dose and dose rate values (up to – 40%)
- Another code showed a few dose and dose rate values that were higher by some +30%.
- The overall agreement between codes was better than ±20% from the median
- Most of the codes had been validated by measurements before with an agreement between measured and calucated doses better than ±20% (Lindborg 2004)

J.F. Bottolier-Depois, P. Beck, M. Latocha, V. Mares, D. Matthiä, W. Rühm, F. Wissmann. Comparison of Codes Assessing Radiation Exposure of Aircraft Crew due to Galactic Cosmic Radiation. EURADOS Report 2012-03, ISSN 2226-8057, ISBN 978-3-943701-02-9, 2012.



- This study was supported by DG Energy (Stefan Mundigl)

- Results were also published as EC report (Radiation Protection No 173)

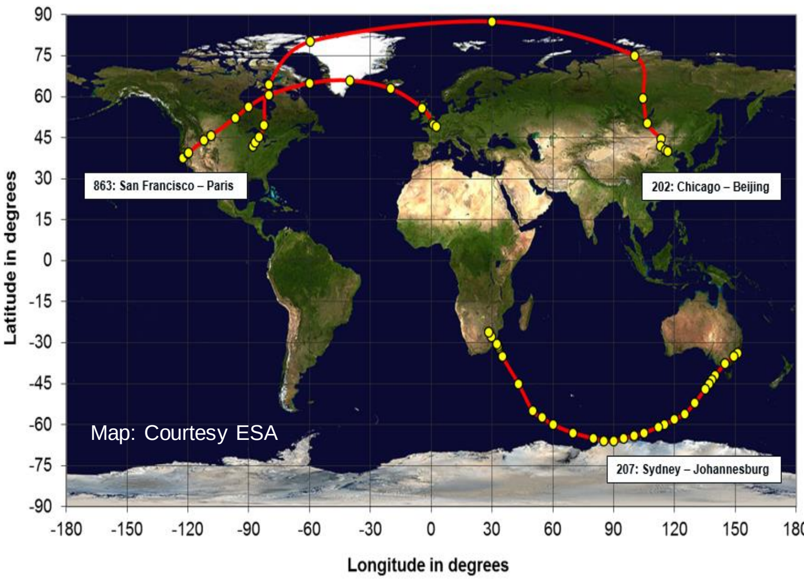


Exposure to *Solar Particle Events*: WG11 EURADOS Study 2021

Nine codes (Europe, Canada, Japan)

AVIDOS, EPCARD, FDOScalc, JISCARD EX7WASAVIES/, PANDOCA, PCAIRE PLANETOCOSMICS (Bern code), and QARM; SIEVERT/SiGLE

Three flight routes selected



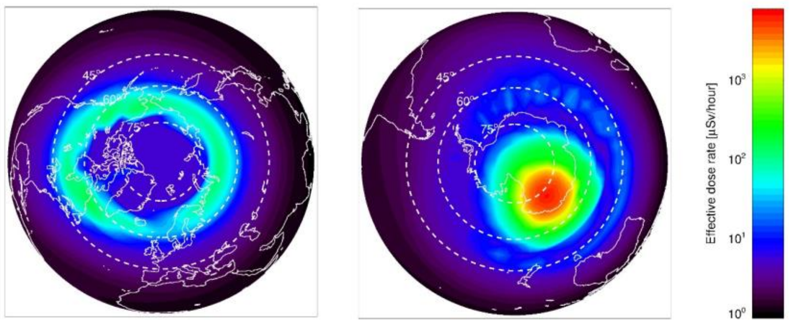
Exercise 1

- Simplified GLE 42 (September 29 1989)
- Primary solar particle spectrum given (based on Smart et al. 1991)

Exercise 2

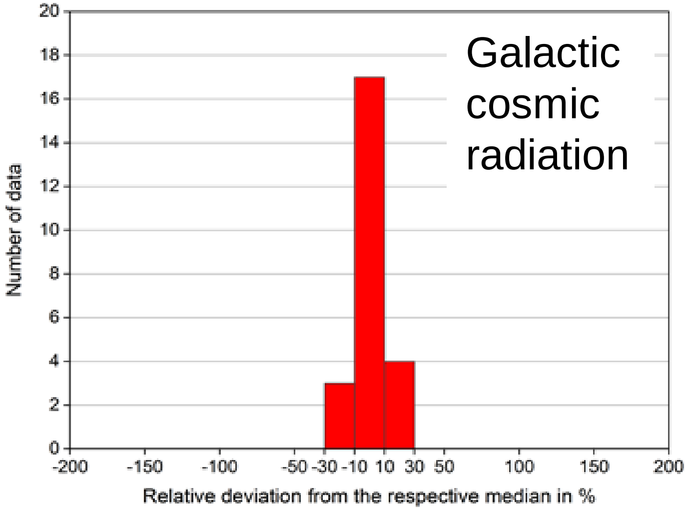
- GLE 69 (January 20 2005)
- Publications on this GLE were distributed Difficulty: anisotropy!

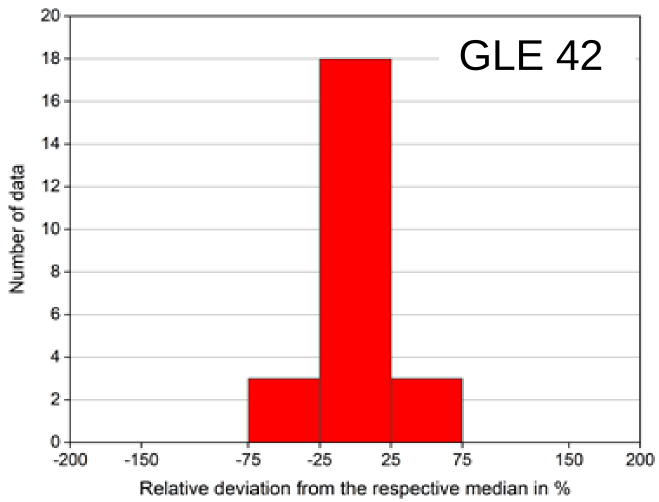
Effective dose rate, 10.5 km, max. phase



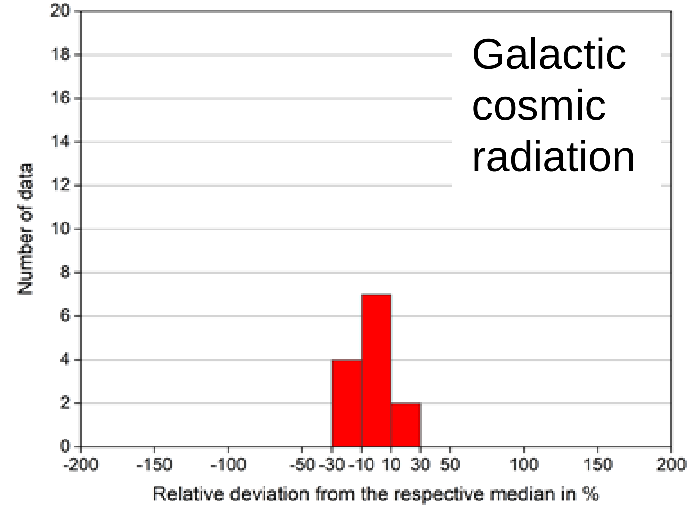
Northern hemisphere Southern hemisphere (Bütikofer, 2007; Bütikofer 2008)

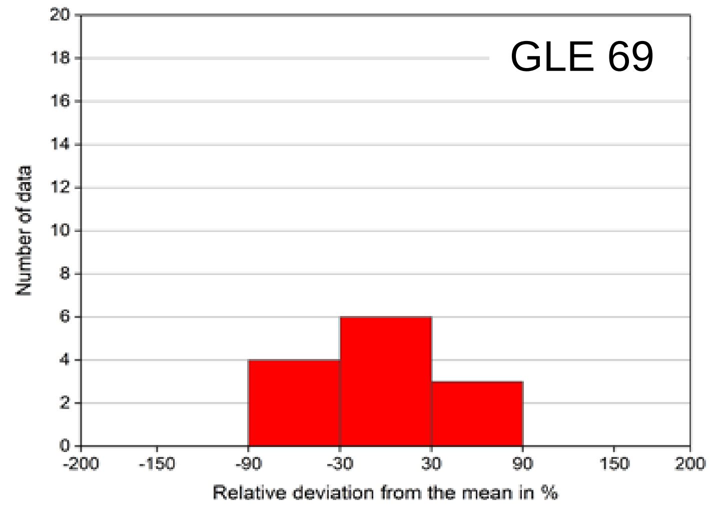
Exercise 1 – H*(10) Route Doses





Exercise 2 – H*(10) Route Doses

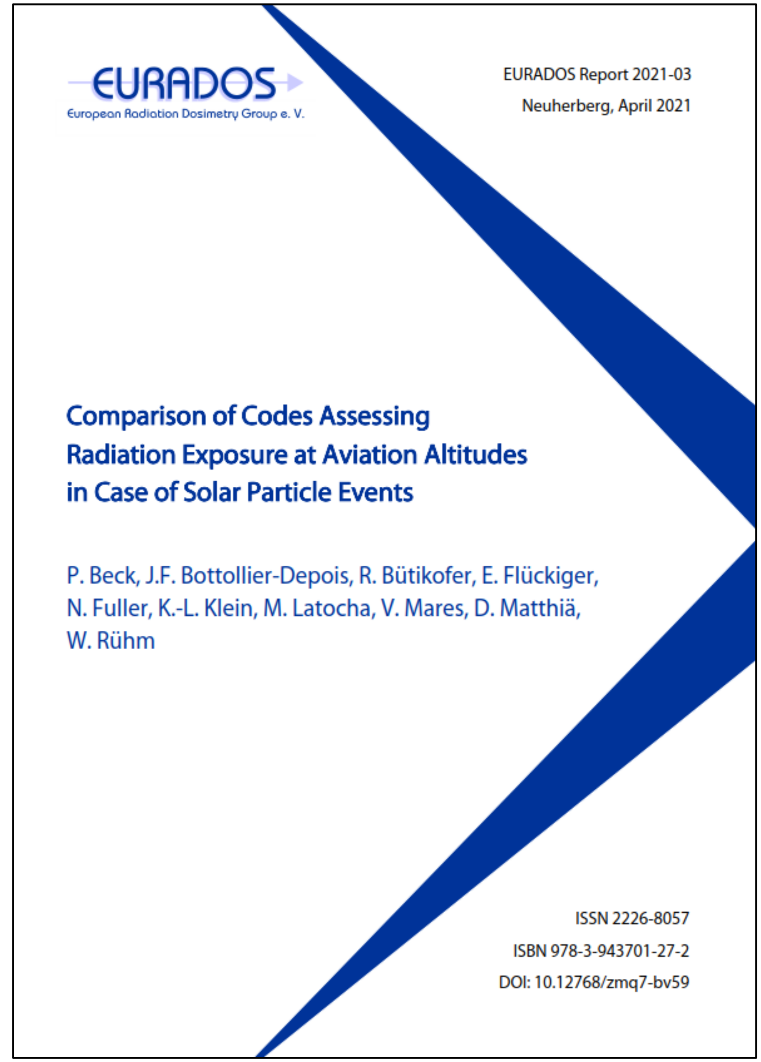




Conclusions

- As expected, the GCR dose data agree quite well
- Dose comparisons for GLE42 and GLE 69 show larger dose differences than for GCR.
- There is obviously a significant spread in the doses for the SCR but not for GCR.
- “Therefore, we conclude that one of the major reason for the different results of both investigations is the different treatment of the SCR characteristics in the different codes”

P. Beck, J.F. Bottolier-Depois, R, Bütikofer, E. Flückiger, N. Fuller, K.-L. Klein, M. Latocha, V. Mares, D. Matthiä, W. Rühm. Comparison of Codes Assessing Radiation Exposure at Aviation Altitutdes in Case of Solar Particle Events. EURADOS Report 2021-03


EURADOS
European Radiation Dosimetry Group e. V.

EURADOS Report 2021-03
Neuherberg, April 2021

Comparison of Codes Assessing Radiation Exposure at Aviation Altitudes in Case of Solar Particle Events

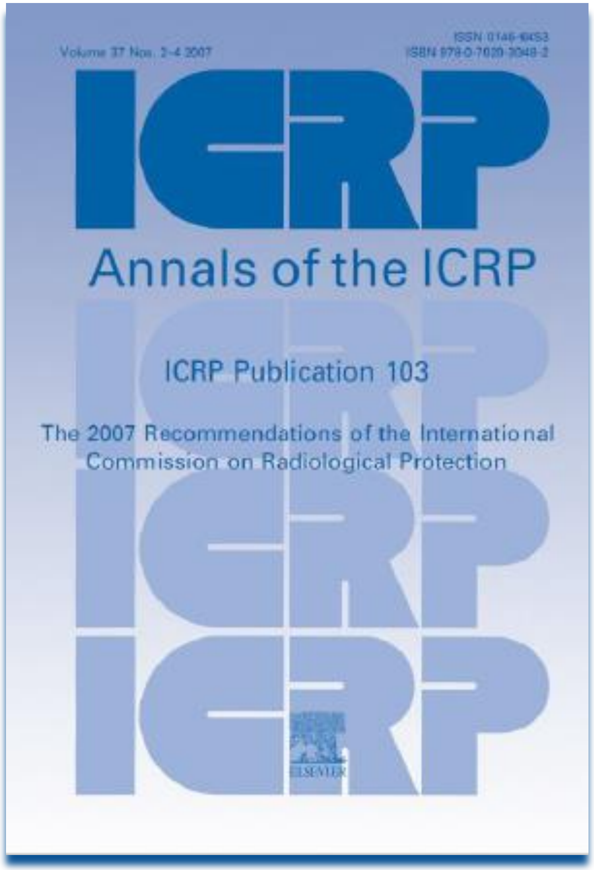
P. Beck, J.F. Bottollier-Depois, R. Bütikofer, E. Flückiger, N. Fuller, K.-L. Klein, M. Latocha, V. Mares, D. Matthiä, W. Rühm

ISSN 2226-8057
ISBN 978-3-943701-27-2
DOI: 10.12768/zmq7-bv59

ICRP Publication 103, 2007, General Recommendations

On exposures in space

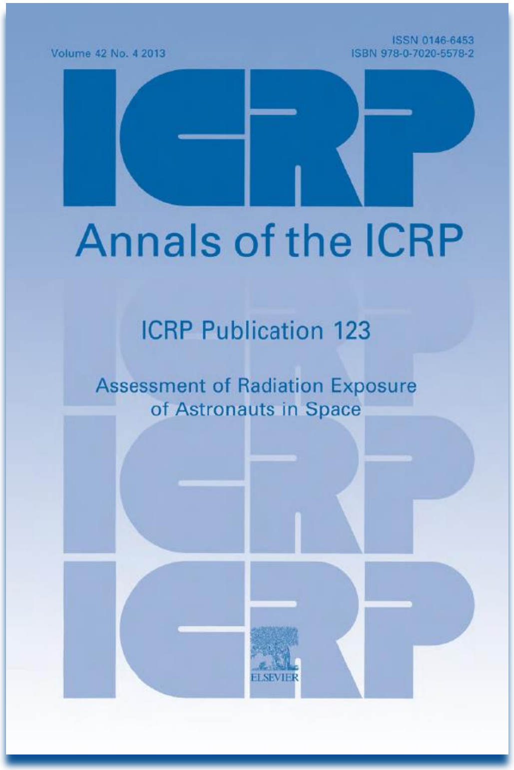
(190) Exceptional cases of cosmic radiation exposures, such as **exposure in space travel**, where doses may be significant and some type of control warranted, **should be dealt with separately, taking into account the special type of situations that can give rise to this type of exposure**.



ICRP Publication 123, 2013, Assessment of Radiation Exposure of Astronauts in Space

Authors on behalf of ICRP
G. Dietze, D.T. Bartlett, D.A. Cool, F.A. Cucinotta, X. Jia, I.R. McAulay, M. Pelliccioni, V. Petrov, G. Reitz, T. Sato

- ICRP 123 focusses on astronaut exposure
- The different – **more risk-related** – concept of exposure assessment described in this report is clearly restricted to the special situation in space, and should not be applied to any other exposure situation on Earth or for aircraft crews.
- Due to the specifics of the radiation field in space, not all concepts of quantities defined for radiological protection applications on Earth are appropriate for applications in space missions, especially **when risk assessment is an important task**.



In Feb 2018, the International Systems Maturation Team (ISMT-Radiation) asked ICRP

- To provide expert opinion/guidance on radiation effects to the CNS during spaceflight based upon a review of available evidence base.
- To provide recommendations on inclusion of cardiovascular disease as a health outcome
- To provide recommendations on the occurrence and latency of lens opacification during a long duration exploration-class mission
- To evaluate results from a selection of space agency-provided risk models for designed reference missions
- To provide recommendations on both a common risk assessment framework and recommendations on exposure limits for cancer risks for exploration-class human spaceflight missions.

Formal Establish-ment of Task Group

ICRP NEWS WORK ORGANISATION SUPPORT ICRPAEDIA

ICRP (ORGANISATION)

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

A Task Group under Committee 1

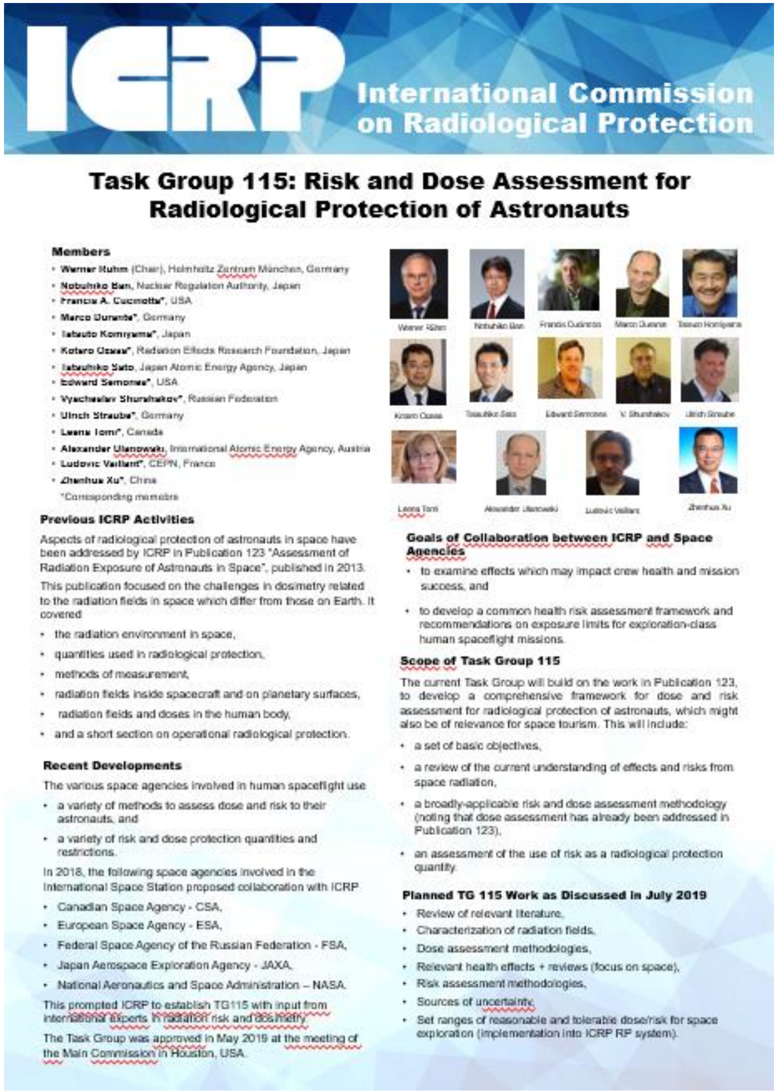
Terms of Reference

- Will build on the work in Publication 123
- To develop a comprehensive framework for risk and dose assessment for radiological protection of astronauts, including
  - a set of basic objectives
  - a review of the current understanding of effects and risks from space radiation
  - a broadly-applicable risk and dose assessment methodology
  - an assessment of the use of risk as a radiological protection quantity.

TG115 Kick-Off Meeting

November 20, 2019
Adelaide, Australia

In conjunction with the 5th ICRP Symposium



ICRP International Commission on Radiological Protection

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

Members

- **Werner Ruhm** (Chair), Helmholtz Zentrum München, Germany
- **Nobuhiko Ban**, Nuclear Regulation Authority, Japan
- **Francis A. Cucinotta***, USA
- **Marco Durante***, Germany
- **Tatsuto Komiyama***, Japan
- **Kotaro Ozasa***, Radiation Effects Research Foundation, Japan
- **Tatsuhiko Sato**, Japan Atomic Energy Agency, Japan
- **Edward Semones***, USA
- **Vyacheslav Shurshakov***, Russian Federation
- **Ulrich Straube***, Germany
- **Leena Tomi***, Canada
- **Alexander Ulanowski**, International Atomic Energy Agency, Austria
- **Ludovic Vaillant***, CEPN, France
- **Zhenhua Xu***, China

*Corresponding members

Previous ICRP Activities

Aspects of radiological protection of astronauts in space have been addressed by ICRP in Publication 123 "Assessment of Radiation Exposure of Astronauts in Space", published in 2013.

This publication focused on the challenges in dosimetry related to the radiation fields in space which differ from those on Earth. It covered

- the radiation environment in space,
- quantities used in radiological protection,
- methods of measurement,
- radiation fields inside spacecraft and on planetary surfaces,
- radiation fields and doses in the human body,
- and a short section on operational radiological protection.

Recent Developments

The various space agencies involved in human spaceflight use

- a variety of methods to assess dose and risk to their astronauts, and
- a variety of risk and dose protection quantities and restrictions.

In 2018, the following space agencies involved in the International Space Station proposed collaboration with ICRP

- Canadian Space Agency - CSA,
- European Space Agency - ESA,
- Federal Space Agency of the Russian Federation - FSA,
- Japan Aerospace Exploration Agency - JAXA,
- National Aeronautics and Space Administration – NASA.

This prompted ICRP to establish TG115 with input from international experts in radiation risk and dosimetry.

The Task Group was approved in May 2019 at the meeting of the Main Commission in Houston, USA.

Goals of Collaboration between ICRP and Space Agencies

- to examine effects which may impact crew health and mission success, and
- to develop a common health risk assessment framework and recommendations on exposure limits for exploration-class human spaceflight missions.

Scope of Task Group 115

The current Task Group will build on the work in Publication 123, to develop a comprehensive framework for dose and risk assessment for radiological protection of astronauts, which might also be of relevance for space tourism. This will include:

- a set of basic objectives,
- a review of the current understanding of effects and risks from space radiation,
- a broadly-applicable risk and dose assessment methodology (noting that dose assessment has already been addressed in Publication 123),
- an assessment of the use of risk as a radiological protection quantity.

Planned TG 115 Work as Discussed in July 2019

- Review of relevant literature,
- Characterization of radiation fields,
- Dose assessment methodologies,
- Relevant health effects + reviews (focus on space),
- Risk assessment methodologies,
- Sources of uncertainty,
- Set ranges of reasonable and tolerable dose/risk for space exploration (implementation into ICRP RP system).

Current Membership – www.icrp.org

Werner Rühm (Chair), Helmholtz Zentrum München, Germany

Chunsheng Li (Secretary), Health Canada, CANADA

Nobuhiko Ban (Member), Nuclear Regulation Authority, Japan

Marco Durante (Member), Germany

Tatsuto Komiyama (Member), Japan

Kotaro Ozasa (Member), Radiation Effects Research Foundation, Japan

Tatsuhiko Sato (Member), Japan Atomic Energy Agency (JAEA), Japan

Edward Semones (Member), USA

Vyacheslav Shurshakov (Member), USSR/Russian Federation

Ulrich Straube (Member), European Space Agency , Germany

Leena Tomi (Member), Canadian Space Agency , Canada

Alexander Ulanowski (Member), International Atomic Energy Agency, Austria

Ludovic Vaillant (Member), CEPN, France

Zhenhua Xu (Member), China

Short-term Goal

Preparation of report to answer ISMT-Rad request including

- Setting the scene
- Describing the methods used for dose and risk assessment by space agencies involved in ISS (CSA, ESA, JAXA, NASA, RSA)
- Defining two example missions
  - Cislunar mission and lunar surface mission
  - Exposures from galactic cosmic radiation and from a solar particle event
  - Doses and risks calculated following space agency procedures
- Reviewing relevant tissue reactions (anything new since ICRP Publ. 118?)
- Reviewing relevant stochastic effects and associated risk metrics
- Reviewing issues related to RBE and radiation quality factors

Radiation Protection and Cosmic Radiation is a Hot Topic!

- **NCRP Annual Meeting 2021**

- Flight Environments and Combined Stressors
- Cancer Risks
- Noncancer Risks
- Biomarkers and Countermeasures
- Conclusions

Radiation Dose & Risks to Flight Crews: The European Perspective
Werner Rühm
German Research Center for Environmental Health, Munich

NASA and the US National Academy of Sciences

Previous NASA approach

- Career exposure should not exceed 3% risk of exposure-induced death (REID), at a 95% confidence level

After a 320 d first mission at age 44 y, permissible duration of a second mission:
- Male astronaut on ISS: 211 d
- Female astronaut on ISS: 43 d

New NASA approach

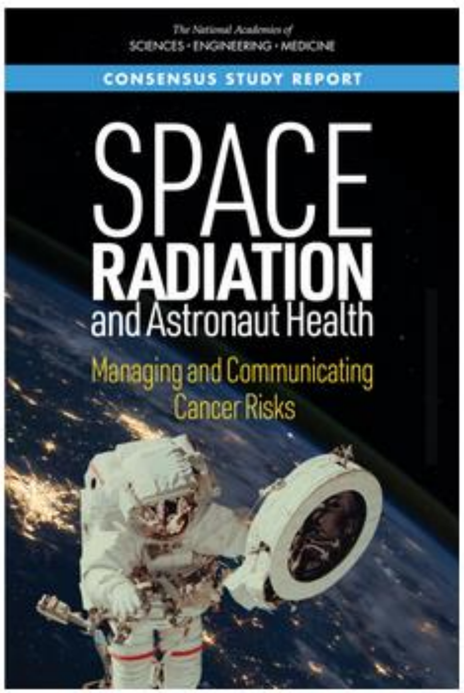
- Focus on most susceptible individual (35 y female) and calculate mean 3% REID
- **This corresponds to 600 mSv effective dose for all**

Consequences

- Overall, higher allowable exposures for a subset (primarily females), limiting exposures below otherwise acceptable doses for others (primarily older male astronauts)

The NAS consensus study report

- NAS Committee on "Assessment of Strategies for Managing Cancer Risks Associated with Radiation Exposure During Crewed Space Missions"
- ICRP TG115 was invited to join a NAS meeting on April 14, 2021, on this issue



Comments on updated health standards proposed by NASA

- Would provide equality of opportunity
- Choice of 35 y female most protective approach
- Results in a higher dose limit … which conflicts with an ethics commitment to protection from harm, minimization of risk, and NASA's principal of keeping exposures as low as reasonably achievable.

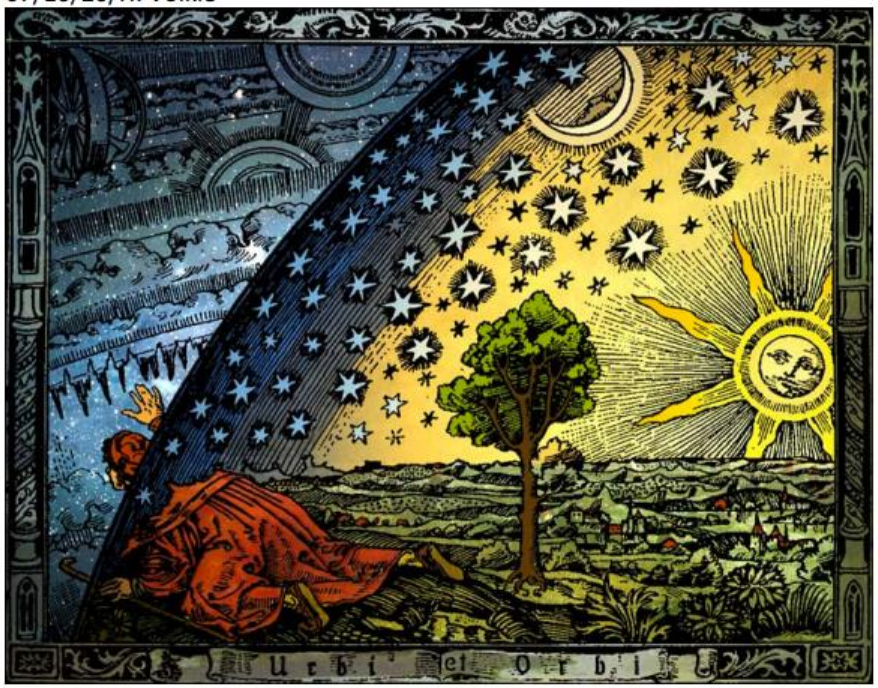
NAS conclusions and recommendations

- that NASA proceed with the proposed approaches
- that NASA should utilize the mean value of the risk distribution based on a 3 % REID
- that NASA provide all astronauts with an individual risk assessment
- that NASA communicate a comprehensive picture of an individual astronaut’s cancer risks
- that NASA develop a radiation risk communication research agenda
- that astronauts who travel on long-duration spaceflight missions are likely to be exposed to radiation levels that exceed the proposed standard
- that NASA (in those cases) develop a protocol for waiver of the proposed space radiation standard that is judicious, transparent, and informed by ethics.

- **Special Issue of the German Radiation Protection Association**

4/2021 Herausforderungen für den Strahlenschutz in der Raumfahrt – Challenges for RP in Space

07/10/20/H. Völkle



THANK YOU!