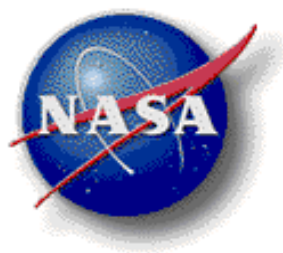




2021 Annual Report

January 2022



National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

The Health Risks of Extraterrestrial Environments (THREE)
2021 Annual Report

Submitted by:

Walter Schimmerling, PhD
THREE Chief Editor

Nicholas Meyer
THREE Page Editor

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1 EXECUTIVE SUMMARY

The Health Risks of Extraterrestrial Environments (THREE) website completed another successful year in 2021 following a significant upgrade. The main features of the upgrade were significantly increased functionality in the Search function and a new graphic interface.

A plan for THREE evolution was developed in order to expand participation, and increase the value of THREE to the space radiation research community.

THREE served over 13,382 distinct users in 2020, with over 1,697,490 webpages displayed and 34,282 files downloaded. Unfortunately, flaws in the analytics software did not allow a full accounting of the users.

New content added to the website in 2021 included three new articles, 57 citations, as well as multiple general news items and additional archive contents.

The 2021 death of Laurence (Larry) R. Young, Apollo program professor emeritus of astronautics from the Massachusetts Institute of Technology was noted and an obituary was added to the In Memoriam section of the Archive page.

THREE continued to be a valued resource in the space radiation community in 2021.

2 INTRODUCTION

THREE is an encyclopedic website (<http://three.jsc.nasa.gov>) about the space radiation environment and its health risks to humans. The goals for the site are:

1. to serve as a starting point for researchers new to either space, radiation, or both;
2. to serve as a source of useful information for established investigators;
3. to serve as a teaching tool for students; and,
4. to serve as a NASA reference source on all scientific aspects of space radiation and health.

THREE is funded by the Space Radiation (SR) Element within NASA's Human Research Program (HRP). The THREE Editorial Board is responsible for oversight of the content and policies for the website. The website is hosted by the NASA Johnson Space Center.

3 ORGANIZATION

The THREE Editorial Board is led by a Chief Editor appointed by the NASA SR Chief Scientist. In addition, up to 10 Associate Editors may serve as volunteer members of the Editorial Board at the invitation of the NASA SR Chief Scientist, upon recommendation of the Chief Editor, for nominally three-year terms.

In 2021 there were seven Associate Editors on the THREE Editorial Board. Two terms set to expire at the end of 2020 were renewed and extended to 2023 at the recommendation of the Chief Editor and by invitation of the SR Chief Scientist.

One of the Associate Editors, Professor Michael Weil, stepped down after many years of meritorious service. We are grateful for his support and his good counsel during his service on the Board. He is succeeded by Albert J. Fornace Jr., M.D. Dr. Fornace is a professor in the departments of Oncology, Biochemistry and Molecular & Cellular Biology, and Radiation Medicine of Georgetown University, as well as Chair of Molecular Cancer Research at the Lombardi Comprehensive Cancer Center and Director of the Waters Center of Innovation for Metabolomics at the Georgetown University Medical Center. THREE is fortunate to count him among its Associate Editors.

The current membership of the Editorial Board is as follows:

- Chief Editor: Walter Schimmerling
- Associate Editors:
 - Stanley Curtis (term expires 2022)
 - William Dynan (term expires 2024)
 - Amelia Eisch (term expires 2023)
 - Dudley Goodhead (term expires 2022)
 - Derek Lowenstein (term expires 2022)
 - Marianne Sowa (term expires 2023)
 - Albert Fornace (term expires 2024)

The THREE Editorial Board met monthly via Teams teleconference in 2021 (nominally on the first Wednesday of each month) to manage the development of new THREE content. The January meeting that was held in-person at the HRP Investigators' Workshop in the past was held as a virtual meeting in 2021 in order to conform to covid-19 precautions and will continue to be a virtual meeting in 2022.

In addition to the Editorial Board, a Page Editor and a NASA IT specialist supported the development and implementation of THREE website content. The Chief Editor and Page Editor held weekly teleconference meetings in 2021 to create and track needed update requests and manage activities for the Editorial Board. The Page Editor served as the primary interface to NASA IT for executing THREE website content updates (nominally on a monthly basis using a newly created template file) and receiving monthly website usage statistics. The Page Editor maintained the distribution list (through the NASA HQ "Mailman" application) for the remittance of THREE monthly website usage information – there are currently 782 members of this distribution list, which is modified to include new THREE authors by default and to add or remove persons as explicitly requested.

The authors appreciate the contributions made by Lisa Stephenson, Science Integrator, for many important contributions to the operation of THREE and this report.

4 THREE UPGRADE

The major redesign to modernize and improve the ease of using the THREE website that was initiated in 2020 was completed by the Human Health and Performance Contract Information Technology team led by Judith Peace. A detailed list of requirements, developed with assistance of Linda Reyna, is shown in Appendix A. The main features accomplished were:

- **Redesign and modernize home page to be more intuitive**
- **Update search capability.**

- Support display of pdf files and presentations with animations to replace the Flash software for which support has ceased.

The project was completed by IT. After extensive testing it was considered by the THREE Editorial Board for approval and released for public access.

5 UPGRADED WEBSITE STRUCTURE

5.1 HOME PAGE

Figure 1 shows the new home page of THREE in the full screen view, with section tabs above the main page tile. These tabs disappear when the home page window size is reduced, in order to accommodate its use on other devices (Figure 2). In that case, the triple bar (“hamburger”) in the upper right hand corner can be clicked to show a list of the various sections, as shown in Figure 3.

The left-hand navigation menu on the Home Page is shown in Figure 4.

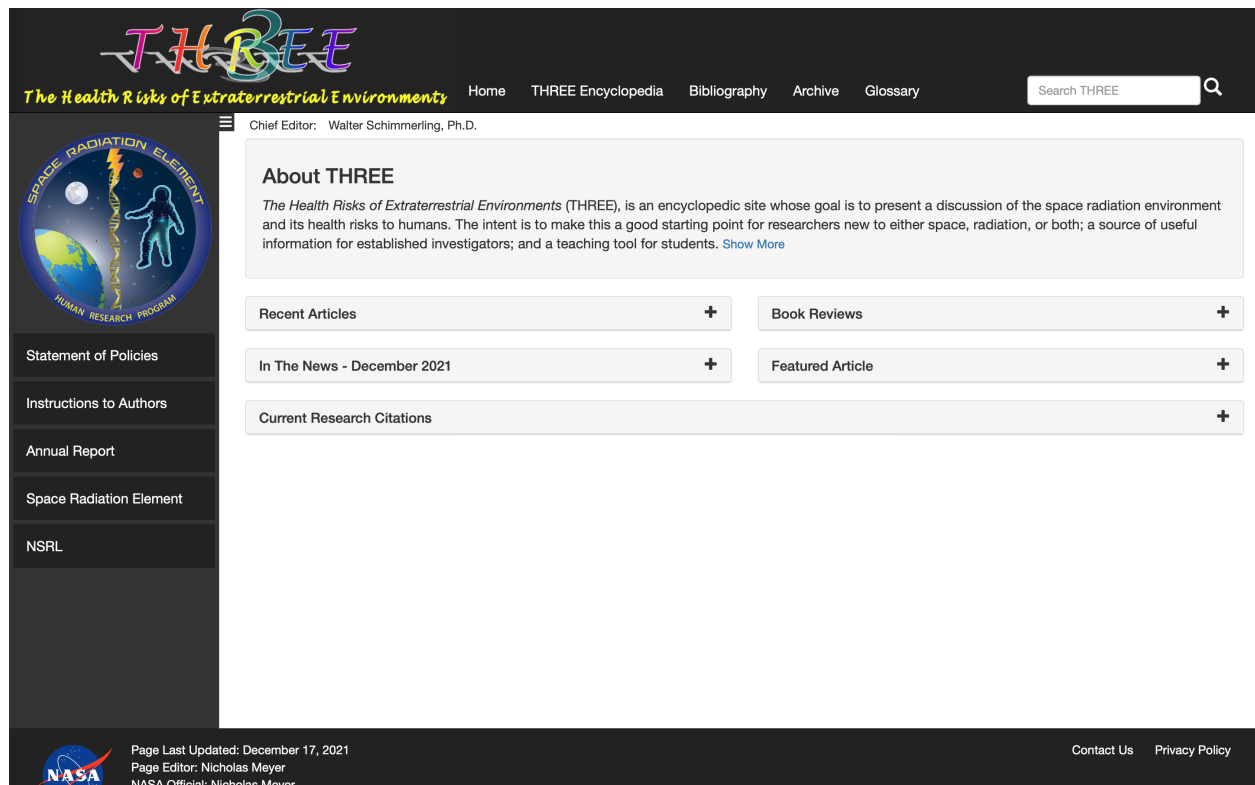


Figure 1. THREE Home Page – full screen

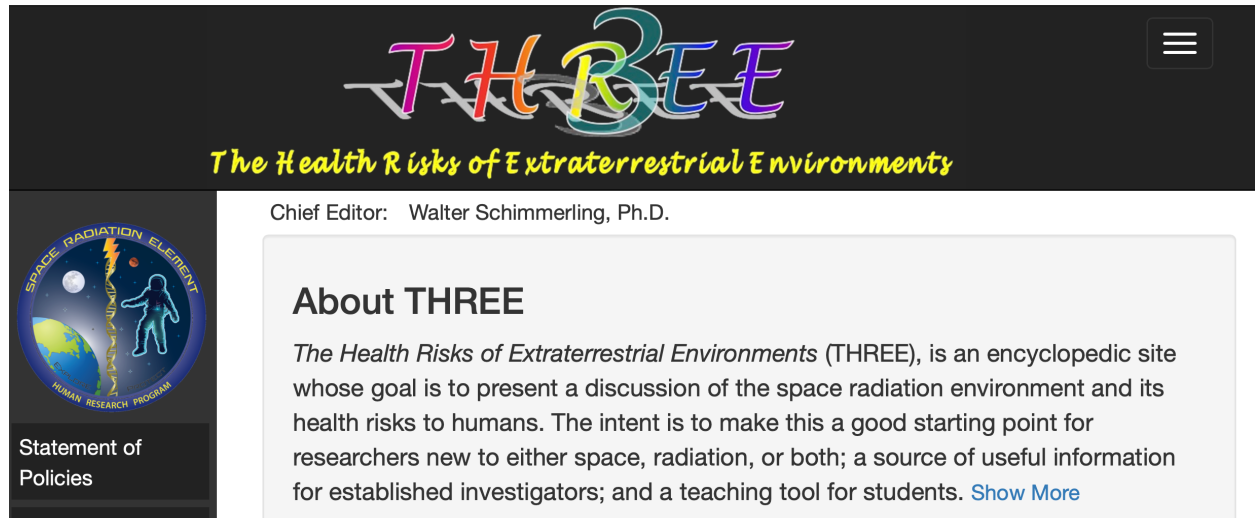


Figure 2. THREE Home Page – reduced window size with triple bar button displayed.

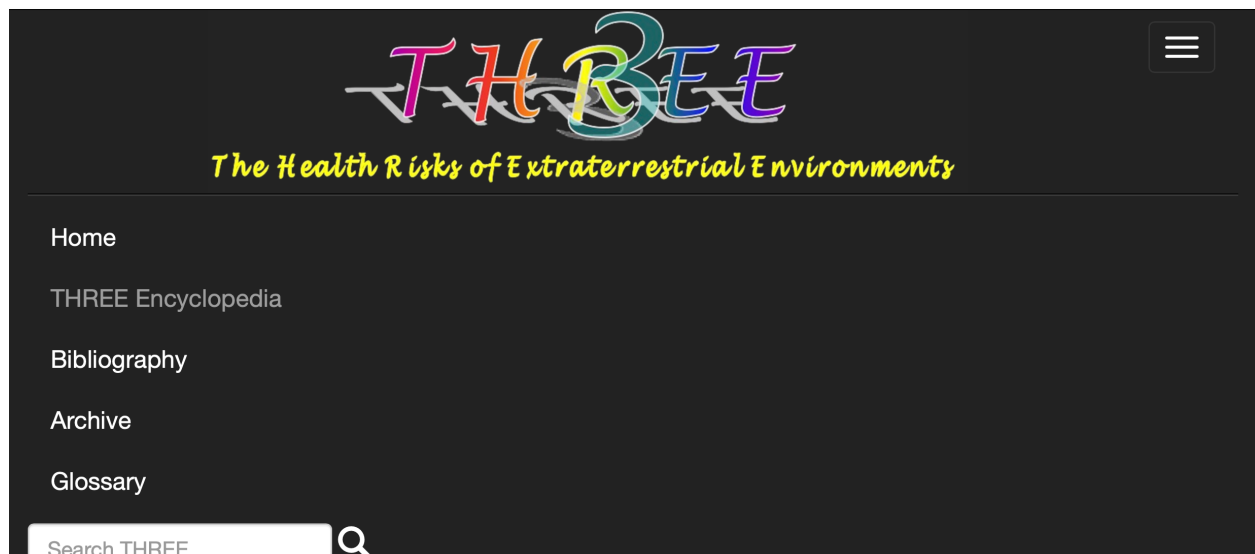


Figure 3. THREE Home Page – reduced window size with triple bar button activated



Figure 4. THREE Home Page – Navigation Menu.

5.2 ARTICLES

THREE articles are original reports contributed by NASA internal or external authors on topics relevant to THREE. In 2021, three new articles were posted to THREE. The last was initially posted as Featured Articles:

- Radiation Chemistry and DNA Damage (Peter O'Neill) Posted October 05, 2021
- PolyFit: A C++ code for polynomial curve fit with calculation of error bars (Ianik Plante) Posted May 28, 2021
- **Microglia Cells, The Brain Innate Immune System: Friend or Foe? (Xi Feng, Karen Krukowski, Susanna Rosi, Maria Serena Paladini) Posted February 24, 2021**

The full list of all 98 articles currently contained in the THREE Encyclopedia is included in Appendix B.

5.3 NEWS ITEMS

THREE news items are topics/events of interest to the general space radiation investigator community that are contributed by NASA internal or external authors, Multiple news items were posted to THREE in 2021.

5.4 CITATIONS

57 new citations were added to the THREE Bibliography in 2021, under the topical headings shown in Table I.

Table I. THREE Citations Posted in 2021

NASA and exploration	1
Basic Concepts of Space Radiation	4
<i>The Space Radiation Environment</i>	2
<i>Track Structure</i>	
<i>Interactions of Radiation with Matter</i>	2
<i>Shielding</i>	
Proton and HZE Accelerator Sources	1
Radiation Measurements	4
Radiation Chemistry	-
System Biology	1
Cell Damage and Repair	8
Tissue Biology and Pathology	20
<i>Models</i>	1
<i>CNS Effects</i>	10
<i>Degenerative Effects</i>	3
<i>Solid Cancers</i>	6
<i>Leukemia</i>	-
Health Effects	8
Radiation Therapy	2
Non-Radiation Risks	-
Radiation Risk Management	8
<i>NASA Program Documents</i>	-
<i>Reports</i>	-
<i>Articles</i>	8
Computer Tools	-
Total Citations added in 2021	57

Since Citations are directly related to the body of work published in scientific journals, they also reflect current emphases in research funding and progress. The most active heading in 2021 continued to be Tissue Biology and Pathology, which itself is a broad category, and within that, CNS Effects, which reflects the generation and publishing of results primarily from recent NASA-funded research efforts. As NASA research focus areas change going forward, so will the resulting citation areas.

5.5 ARCHIVE

The THREE Archive page features historical content. Work to complete posting available information on the annual investigator workshops was interrupted by covid-19 work limitations and will be resumed when possible.

In the future, recordings of webinars organized by the Space Radiation Element are planned to be archived with links on this page. It is not clear at this time whether this material will appear in the Multimedia section or will be given a separate tab.

Also under consideration is archiving Annual Reports on this page.

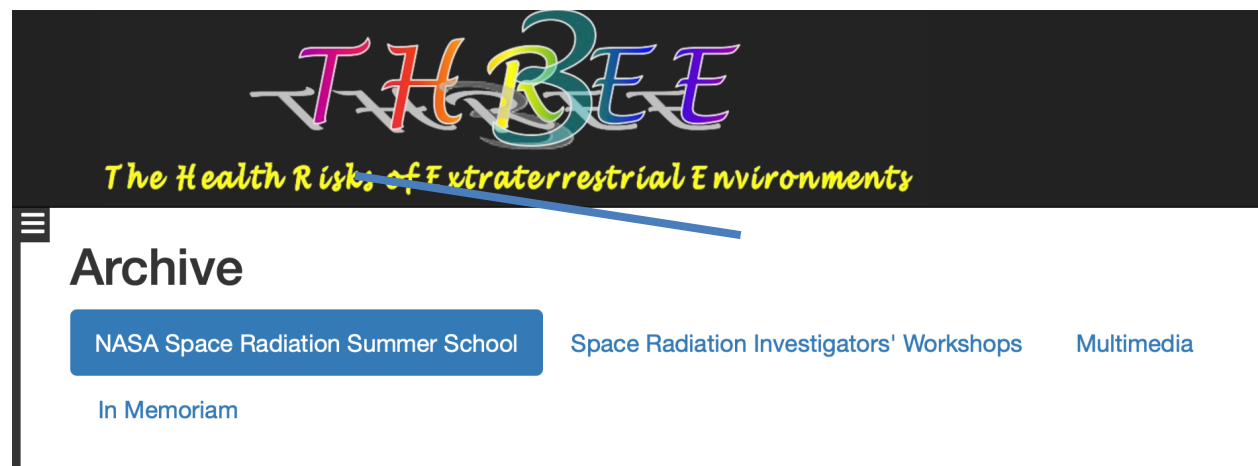


Figure 5. THREE Archive.

5.6 SEARCH

Implementation of a search capability was one of the major goals of the THREE upgrade. It now is possible to enter one or more search terms and obtain information on where it occurs, by

page and section, by author and title of the entry, and by the text in which it is mentioned. Figure 6 shows, as an example, the result of searching for the word “radiation”.

The screenshot shows the THREE website interface. At the top, the logo 'THREE' is displayed in a stylized, colorful font, with the tagline 'The Health Risks of Extraterrestrial Environments' below it. Navigation links include 'Home', 'THREE Encyclopedia', 'Bibliography', 'Archive', and 'Glossary'. A search bar on the right contains the word 'radiation'. On the left sidebar, there is a circular logo for the 'SPACE RADIATION ELEMENT HUMAN RESEARCH PROGRAM' and a list of links: 'Statement of Policies', 'Instructions to Authors', 'Annual Report', 'Space Radiation Element', and 'NSRL'.

The main content area is titled 'Search' and shows results for 'radiation'. It includes a search bar with 'radiation' entered and a 'Search' button. Below the search bar, there are tabs for 'Bibliography Results', 'Encyclopedia Results', and 'In The News Results'. The 'Encyclopedia Results' tab is selected, showing a list of 5 entries. The first entry is titled 'Radiation Risks in a Mission to Mars for a SolarParticle Event Similar to the AD993/4 Event' by Zaman, F.A.; Townsend, L.W.; Burahmah, N.T. Aerospace2021,8, 143. The second entry is titled 'The Badhwar-O'Neill 2020 GCR model' by Slaba, T. C., & Whitman, K. (2020). Space Weather, 18, e2020SW002456. The third entry is titled 'Solar modulation of the GCR flux and' by Life Sciences in Space Research, 26. Dachev, T.P.

Section	Subsection	Title	Citation	Summary
Basic Concepts of Space Radiation	The Space Radiation Environment	Radiation Risks in a Mission to Mars for a SolarParticle Event Similar to the AD993/4 Event	Zaman, F.A.; Townsend, L.W.; Burahmah, N.T. Aerospace2021,8, 143	Recent studies of excess atmospheric ^{14}C production in tree rings and in annually resolved measurements of ^{10}Be in Arctic and Antarctic ice cores, indicate that an extremely large solar particle event (SPE) occurred in AD 993/4. The production of cosmogenic nuclei (e.g., ^{36}Cl) indicate that the event possessed a very energetic "hard" particle spectrum, comparable to the February 1956 SPE. Estimates of the potential radiation risk to male and female crew members on a mission to Mars, from an event comparable to the AD 993/4 one, are reported in this paper. These estimates suggest that severe consequences to a crew in transit to Mars are possible. However, on the Martian surface, the additional protection afforded by the Mars atmosphere reduces but does not eliminate the risk from such an event.
Basic Concepts of Space Radiation	The Space Radiation Environment	The Badhwar-O'Neill 2020 GCR model	Slaba, T. C., & Whitman, K. (2020). Space Weather, 18, e2020SW002456.	The galactic cosmic ray environment includes a spectrum of particles from hydrogen through nickel with energies extending beyond hundreds of GeV/n. Accurately characterizing this environment is a critical aspect of mission planning, shield design, and risk assessment. The Badhwar-O'Neill (BON) GCR model is widely used by NASA and other agencies in such applications and has been recently updated. The new model, BON2020, has been calibrated to available balloon and satellite measurements including the high precision data from AMS-02 and PAMELA. Solar modulation (i.e. time dependence) is now characterized by using daily observations from the ACE/CRIS satellite. The average relative error of the BON2020 model compared to all available measurements is <1%, and is shown to be within $\pm 15\%$ of a large fraction of the available measurements (26,269 of 27,646 \rightarrow 95%).
Basic Concepts of Space Radiation	The Space Radiation Environment	Solar modulation of the GCR flux and	Life Sciences in Space Research, 26. Dachev, T.P.,	The paper presents the solar modulation of the long-term galactic cosmic rays (GCR) flux and dose rate variations, observed during 14 space experiments by 10 Bulgarian build

Figure 6. Result of searching for "radiation".

6 THREE EVOLUTION

In consultation with NASA management, the scope of THREE was redefined to include the topics shown in Table II and incorporated into the updated Instructions for Authors. At present, there are some topics that do not yet have articles associated with them, but they constitute a goal for author recruitment. A plan for THREE evolution was developed in order to map the existing contents of the Encyclopedia and Bibliography pages into the contents defined by the new scope of THREE, expand participation, and increase its value to the space radiation research community. It is expected that this plan will begin to be implemented in 2022. Incentives to overcome current difficulties in recruiting authors will be developed by Radiation Element.

Table II. THREE Topics

NASA and Exploration	Cellular Responses to Radiation	Radioprotectants and mitigation
Space Radiation Element	DNA damage	Shielding
Mission	DNA Repair	Biomarkers
Strategy	Chromosome Aberrations	<i>Inflammatory markers</i>
Roles and Responsibilities	Mutations	<i>miRNA</i>
Space	Immunity and inflammation	<i>Gene expression profiling</i>
Space Weather	Senescence and aging	<i>Circulating cell-free DNA</i>
Space Radiation Environment	Oxidative Stress	<i>Exosomes</i>
Space analogs	Genetic variability	<i>Proteomics</i>
Particle Accelerators	Mitochondrial impact	<i>Metabolomics</i>
World-wide experiment facilities	Impact on energy metabolism	<i>Microbiome</i>
NSRL	Tissue Responses to Radiation	Biological countermeasures
Neutron, gamma sources	Carcinogenesis	Diagnoses and treatment
Radiation therapy	CVD Risks	<i>Medical Surveillance</i>
Particle Physics & Chemistry	CNS Risks	<i>Early Diagnosis</i>
Interactions of Radiation with Matter	Bone	<i>Therapeutic approaches</i>
Radiation Chemistry	Cataracts	Clinical radioprotectors
Track Structure	Abscopal effects	Acute radiation syndrome
Dosimetry	Synergies	Mechanisms of radiation response
Dose and Dose Rate		Experimental models
		Computational models
		Risk Management
		Radiation epidemiology
		Space radiation protection

7 ACTIVE OUTREACH

Monthly website summaries were sent to a large distribution of approximately 1000 subscribers. These summaries include announcement of newly posted articles, website usage statistics, and a list of the top 10 most requested articles for the prior month.

8 USAGE

Average monthly website usage has continued to increase annually as shown in Table III.. Statistics by month for 2021 are shown in Figure 7.

Table III. THREE Average Monthly Web Usage by Year.

	2015	2016	2017	2018	2019	2020	2021
Web Pages Visited	17,803	18,537	40,279	64,193	66,013	108,150	141,458
Number of Users	2,225	2,053	3,334	3,791	3,420	2,782	1,115
Number of Files Downloaded	381	536	1,600	2,728	1,589	1,213	2,857

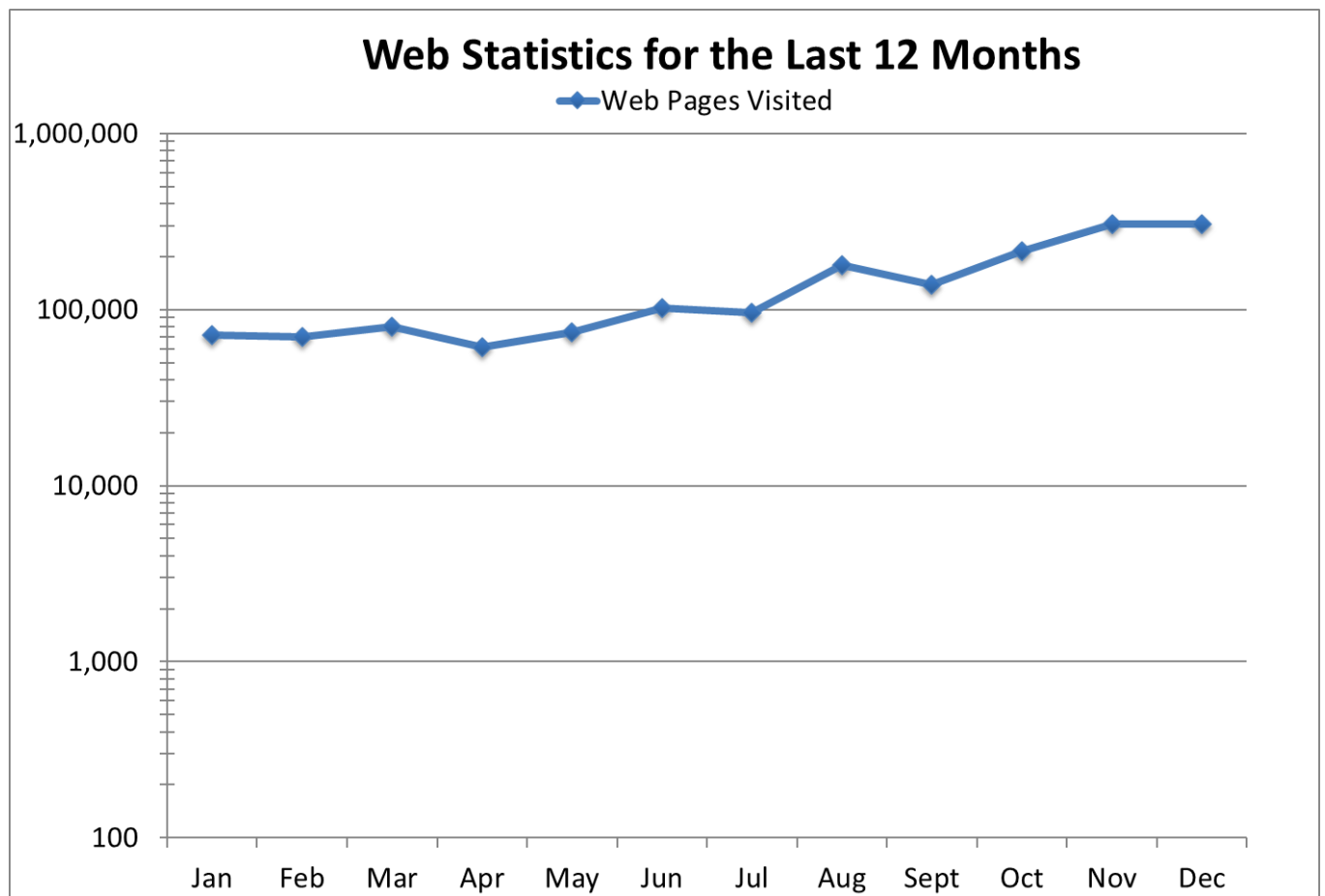


Figure 7. 2021 THREE Web Statistics.

Annual web usage by year for the past two years is shown in Table IV..

Table IV. THREE Annual Web Usage by Year.

	2019	2020	2021	% Change from 2020
<i>Web Pages Visited</i>	801,906	1,297,801	1,697,490	24%

The most requested articles in 2021 are shown in Table V. These “top 10” articles accounted for 32% of the total file downloads in 2021. The data presented shows month over month steady, frequent use of the THREE site. Frequent updates to THREE as well as citation and articles covering areas of research interest within the broader community have helped make THREE a useful and growing resource for the scientific community.

The broad range of articles in Table V are further evidence that THREE serves a diverse scientific community, whose interest in space derives from a wide range of disciplines.

Table V. Most requested articles in 2021.

Article Title	Author(s)	Article Rank	Number of Requests
Energetic and chemical reactivity of atomic and molecular oxygen (pdf) Radiation Shielding (pdf)	Turner	#1	2685
Neutron Properties and Definitions (pdf) Solar Particle Events and Radiation Exposure in Space (pdf)	Hu	#2	2244
Radiation chemistry and oxidative stress (pdf)	Plante	#3	1884
Cosmic Ray Detectors: Principles of Operation and a Brief Overview of (Mostly) U.S. Flight Instruments (pdf)	Zeitlin	#4	1652
Radiation Risk Acceptability and Limitations (pdf)	Cucinotta	#5	1476
Clinical Proton Therapy at Loma Linda University Medical Center (pdf)	Slater	#6	1417
Space Radiation Dosimetry (pdf)	Schimmerling	#7	1306
The Local Effect Model – Principles and Applications (pdf)	Friedrich	#8	1012
Monte Carlo Transport Codes for use in the Space Radiation Environment (pdf)	Goorley	#9	1006
Exploration Systems Radiation Monitoring Requirements (pdf)	Turner	#10	979

9 FUTURE PLANS

Several improvements have been postponed due to budgetary limits on IT availability in FY2021 and are planned for FY2022. Among them:

- Implementation of improved analytics to track the use of the website.
- Extension of the website Search function to material in the Archive page.
- Adding links to missing Investigator Workshops and to future webinars.
- Adding Annual Reports to the Archive page.
- Replacement of the current Statement of Policies with an updated statement of Policies and Procedures
- Updating the Instructions to Authors with page limitation information if approved by the Board of Editors
- Introducing descriptive graphics in the display of Recent Articles to improve Home page appeal.
- Improve the recruitment of article authors

APPENDIX A UPGRADE REQUIREMENTS

1. The website shall be accessible to viewers in the public domain such that user authentication and authorization is not required to access the THREE website.
2. The website will maintain the same public web URL `three.jsc.nasa.gov` so that Google Scholar will continue to crawl the site.
 - 2.1. The THREE public website will be available 24/7 to public users.
3. The THREE website “look and feel” should be updated to be consistent with the Space Radiation site on the NASA public portal as part of the NASA Web Modernization Design effort.
4. The website shall display the "THREE" website header and sub header “The Health Risks of Extraterrestrial Environments” graphics of the current site so that the site identity is maintained for public readers.
 - 4.1. The website header and sub header shall persist throughout navigation of the site.
5. The website shall display the Human Research Program patch logo on the site header to maintain the site identity for public readers.
 - 5.1. The program patch logo shall persist with the site header throughout navigation of the website.
6. The website shall provide and display the main navigation links for Home, THREE Encyclopedia, Bibliography, Archive and Glossary site pages.
 - 6.1. The main header navigation bar shall persist throughout the navigation of the website.
 - 6.2. When the user clicks on the Home menu item, the Home page shall display inside the THREE website main content frame.
 - 6.3. When the user clicks on the THREE Encyclopedia menu item, the THREE Encyclopedia page shall display inside the THREE website main content frame.
 - 6.4. When the user clicks on the Bibliography menu item, the Bibliography page shall display inside the THREE website main content frame.
 - 6.5. When the user clicks on the Archive menu item, the Archive page shall display inside the THREE website main content frame.
 - 6.6. When the user clicks on the Glossary menu item, the Glossary page shall display inside the THREE website main content frame.
7. The website shall maintain a search feature in the header area of all site pages to allow users to enter search criteria from anywhere in the site.
8. The website shall provide left side navigation hyperlinks to Statement of Policies, Instructions to Authors, Annual Report, Space Radiation Element and NSRL Run Schedule.
 - 8.1. The "Statement of Policies" link shall be linked to a pdf file and when clicked shall open and display in a separate browser tab.
 - 8.2. The "Instructions to Authors" link shall be linked to a pdf file and when clicked shall open and display in a separate browser tab.
 - 8.3. The "Annual Report" link shall be linked to a pdf file and when clicked shall open and display in a separate browser tab.

- 8.4. The Space Radiation Element link, when clicked, shall open the external website <https://www.nasa.gov/hrp/elements/radiation> in a separate browser tab.
- 8.5. The "NSRL Run Schedule" link shall be linked to a pdf file and when clicked shall open and display in a separate browser tab.
- 8.6. The left side navigation hyperlinks shall persist throughout the navigation of the THREE website.
9. The website shall provide a navigation link and site page that provides search options for the Space Radiation Element Publications Database.
 - 9.1. The Home page shall provide the link "Publications Database" on the Home page left-side navigation.
 - 9.2. When the user clicks the Publications Database link, the Space Radiation Program Element Publications Database search page shall open inside the THREE website main content frame.
10. The website shall display a footer that supports the hyperlinks for Page Last Updated, Page Editor, Contact Us and verbiage for 508 compliance for PDF files.
 - 10.1. The "Page Editor:" text in the footer shall be followed by the name "Nicholas Meyer" as hypertext with the link as <mailto:nicholas.b.meyer@nasa.gov>.
 - 10.2. When the user clicks on the Page Editor name, the application shall open the user's email application message form with the To field populated with the Page Editor mailto address.
 - 10.3. The "Contact Us" text in the footer shall display as hypertext with the link as <mailto:jsc-hrp-space-radiation-element@mail.nasa.gov>.
 - 10.4. When the user clicks the Contact Us link, the application shall open the user's email application message form with the To field populated with the Contact Us mailto address.
 - 10.5. Removed from scope for this release.
 - 10.6. The "Page Last Updated:" text shall be followed by the date that the current site page had changed with date format as FullMonthName DD, YYYY.
 - 10.7. Removed from scope for this release.
 - 10.8. The footer shall display the text "Contact Page Editor for a 508 compliant PDF"
11. The website footer shall provide the NASA required text and hyperlinks for Curator, NASA Official and Privacy Policy.
 - 11.1. The "NASA Official:" text in the footer shall be followed by the name "Pamela Bieri".
 - 11.2. Removed from scope for this release.
 - 11.3. The "Curator:" text in the footer shall be followed by the name to be determined.
 - 11.4. Removed from scope for this release.
 - 11.5. The "Privacy Policy" text in the footer shall be displayed as a hypertext link to the site "https://www.nasa.gov/about/highlights/HP_Privacy.html".
 - 11.6. When the user clicks on the "Privacy Policy" hyperlink, the linked site shall open in a separate browser tab.
12. The website footer shall display the NASA meatball graphic.

13. The website footer shall persist throughout navigation of the site.
14. The website Home page should organize and display the contents in a way that is intuitive and easy to navigate.
 - 14.1. The Home page shall display the "About THREE", "In The News" and "Featured Article" contents on the page. See the proposed mockup in section 5.1 Mockup Layout of Home page contents Figure 1.
 - 14.2. The Home page shall organize and display the "Welcome", "Recent Articles", "Book Reviews" and "Current Research Citations" as collapsed sections. See the proposed mockup in section 5.2 Mockup of Home Page Content Sections Figure 2.
 - 14.3. When the user clicks the Welcome section link, the Welcome section shall open and display in the Home page.
 - 14.4. When the user clicks the Recent Articles section link, the Recent Articles section shall open and display in the Home page.
 - 14.5. When the user clicks the Book Reviews section link, the Book Reviews section shall open and display in the Home page.
 - 14.6. When the user clicks the Current Research Citations section link, the Current Research Citations section shall open and display in the Home page.
 - 14.7. The Current Research Citations section shall include a link after each citation entry that navigates the user to the top of the list of citations when clicked, for example "Return to Top" returns the user to the top of the list within the citation section.
15. The THREE Encyclopedia page shall organize and display the content by categorized sections and subsections with an intuitive drill down approach to reach and display the content details and links. See reference document Encyclopedia redesign2020 draft v2.
 - 15.1. The THREE Encyclopedia shall support content as text with a link to various content types including pdf, html presentations, abstract page or link to an external website.
 - 15.2. When an Encyclopedia article link is clicked, the article abstract and associated link shall display in a new THREE web page in a separate browser tab.
16. The Bibliography page shall organize and display the content by categorized sections and subsections with an intuitive drill down approach to reach the content details and links.
 - 16.1. The Bibliography sections and subsections shall include a link after each citation entry that navigates the user to the top of the currently selected section when clicked, for example "Return to Top" returns the user to the top of the list within the citation category or subcategory section.
17. The Encyclopedia and Bibliography pages shall maintain the same categorization and display of content as the current pages, except for the modifications identified in reference document Encyclopedia redesign2020 draft v2.
18. The Archive page shall maintain the same categorization and display of content as the current Archive page for NASA Space Radiation Summer School, Space Radiation Investigators' Workshops, Multimedia and In Memoriam topics.
19. The Glossary page shall maintain the same layout and display of content as the current Glossary page.

20. The website shall support display of content in the form of rich text with hypertext links to pdf files and slide presentations.
21. The website shall support the upload and display of pdf files and slide presentations with embedded animations.
22. The website shall support publishing of hypertext and hyperlinks to external public web addresses.
23. The website shall support publishing of an article or abstract of an article as text on the web page with a link to the full article in PDF.
24. When a user clicks a link to a pdf file, the pdf file shall open in the application as specified by the user's browser settings or operating system.
25. The Help contents shall display only in the Encyclopedia page with updated content to be provided.
26. The system shall provide site viewers the capability to search for a keyword or term across the THREE site pages and return links to the matched content.
27. The scope of the site search shall include the published contents of the Home, THREE Encyclopedia and Bibliography pages.
28. Search results shall identify/display the THREE page name, section and subsection, if applicable, of the matched search term.
29. The search results shall display the full text entry from the page with the term highlighted.
30. The user shall be able to click on a search results link to navigate to the content where the search term is used.
31. The user shall have the ability to navigate through the search results list to the next item and back.
32. The website shall implement a Content Management framework such that the managed content can be dynamically updated (or published), i.e. does not require change management or software development.
33. The website shall provide a secured content management portal to allow the Page Editor to maintain/upload content on an as needed basis.
34. The content management portal shall support the format that is required by Google Scholarly Search.
35. The Page Editor shall have the ability to maintain/upload site contents to the Home, Encyclopedia, Bibliography, Archive and Glossary pages.
36. The Page Editor shall have the ability to delete/remove published content from the website as they are deemed no longer relevant.
37. Removed from scope for this release.
38. The Page Editor shall have the ability to publish the same article in "Featured Articles", "Recent Articles" and in the Encyclopedia in its relative category.
39. "Current Research Citations" shall include a Posting Date for when the citation is posted.
40. "Current Research Citations" shall also appear in the Bibliography but without the Posted Date displayed
41. The website shall allow the Page Last Updated field on each page footer to be updated as content is updated on the page.

42. The website shall have the capability to capture website statistics including identification of recent updates, number of web pages visited, number of users, number of files downloaded and most recently accessed articles such that they are accessible by a system administrator for reporting on a monthly basis to provide to the Page Editor.
43. The website shall support the migration of the content in the form of text, rich text, pdf files, slide presentations, animations, multimedia, links and cold fusion pages to the appropriate site pages for display.
44. Data conversion shall be applied where needed to ensure support of the content migration.
45. The current Encyclopedia sections, subsections and section contents shall be migrated to the new website with slight modifications to the sections.

APPENDIX B THREE ENCYCLOPEDIA CONTENTS (ARTICLES)

Note: Italicized articles were previously Featured Articles of the THREE Website

NASA and Exploration	Introduction – Walter Schimmerling
	NASA's Mission – Frank Sulzman
	Space Flight History – Gregory Nelson Introduction
	Collaboration with Other Agencies
	<ul style="list-style-type: none"> NASA Space Radiation Program: Interagency Collaboration - Walter Schimmerling
	<ul style="list-style-type: none"> European Space Agency
	<ul style="list-style-type: none"> Low Dose Radiation Research Program
Basic Concepts of Space Radiation	<ul style="list-style-type: none"> National Institute of Allergy and Infectious Diseases (NIAID) "Preparations for Mitigation and Treatment of Injuries from a Radiation Incident"- Andrea L. DiCarlo-Cohen
	The Space Radiation Environment
	<ul style="list-style-type: none"> <i>The Natural space Ionizing Radiation Environment – Patrick O'Neill</i>
	<ul style="list-style-type: none"> Fluence Rates, Delta Rays and Cell Nucleus Hit Rates from Galactic Cosmic Rays – Stanley B Curtis
	<ul style="list-style-type: none"> <i>Solar Particle Events and Radiation Exposure in Space – Shaowen Hu</i>
	Interactions of Radiation with Matter – Walter Schimmerling
	<ul style="list-style-type: none"> Particle Interactions Overview – Lawrence Heilbronn
	<ul style="list-style-type: none"> Physics Summary – Lawrence Heilbronn
	<ul style="list-style-type: none"> Neutron Properties and Definitions – Lawrence Heilbronn
	<ul style="list-style-type: none"> Neutron Lectures Supplement – Lawrence Heilbronn
	Dose and Dose Rate Effectiveness Factors – Walter Schimmerling
	<ul style="list-style-type: none"> Low LET Physics Topics – Gregory Nelson Introduction
	<ul style="list-style-type: none"> A Note On The Dose-Rate-Effectiveness Factor and its Progeny DDREF - R.J.M. Fry
	Track Structure
	<ul style="list-style-type: none"> Introduction to Track Structure and z^2/β^2 - Stanley B. Curtis
	<ul style="list-style-type: none"> Radiation Quality and Space Radiation Risks – Francis Cucinotta
	<ul style="list-style-type: none"> Development of Monte Carlo Track Structure Codes – Larry Toburen
	<ul style="list-style-type: none"> Microdosimetry and Detector Responses – Leslie A. Braby
	<ul style="list-style-type: none"> Interpreting Microdosimetric Spectra – J. F. Dicello and F. A Cucinotta
	<ul style="list-style-type: none"> Monte Carlo Track Simulations – Michael Dingfelder
Proton and HZE Accelerator Sources	<ul style="list-style-type: none"> Radiation Track Structure – Dudley T. Goodhead Abstract
	<ul style="list-style-type: none"> Track structure and the quality factor for space radiation cancer risk - Dudley T. Goodhead
	Elementary Concepts of Shielding – Walter Schimmerling
	<ul style="list-style-type: none"> Heavy Ions and Shielding Physics – Lawrence Heilbronn
	Ground-Based Particle Accelerator Facilities - Walter Schimmerling
	Accelerators Made Simple - Derek Lowenstein Introduction
	Accelerator-based Space Physics - Cary Zeitlin, Lawrence Heilbronn, John Norbury
	Accelerator-based Sources of Albedo Neutrons – Lawrence Heilbronn
	<i>NASA Space Radiation Laboratory – D.I. Lowenstein, P. Guida, A. Rusek</i>

	A New Low Energy Irradiation Facility at BNL – P. Thieberger
	GCR Simulator Reference Field and a Spectral Approach for Laboratory Simulation - Tony C. Slaba, Steve R. Blattnig, John W. Norbury, Adam Rusek, Chiara La Tessa, and Steven A. Walker
	Microbeams and Other Radiation Sources
	<ul style="list-style-type: none"> • Ion Microbeams and Their Role in Radiobiology Research in Europe, B.E. Fischer • High/Low LET Microbeams, Gerhard Randers-Pehrson
	<i>The Galactic Cosmic Ray Simulator at the NASA Space Radiation Research Laboratory – Lisa C. Simonsen, Tony C. Slaba, Peter Guida, and Adam Rusek</i>
Radiation Measurements	Space Radiation Dosimetry – Walter Schimmerling
	Dosimetry – Lawrence Heilbronn
	Detection Methods Lawrence Heilbronn
	Cosmic Ray Detectors: Principles of Operation and a Brief Overview of (Mostly) U.S. Flight Instruments – Cary Zeitlin
	Space Radiation Passive Dosimetry – Eric Benton
	Exploration Systems Radiation Monitoring Requirements – Ronald Turner
	Biological Dosimetry in Astronauts – Kerry George
	MATROSHKA - A research Platform for Reducing Radiation Risk in Space – Guenther Reitz
	Current Active Detectors for Dosimetry and Spectrometry on the International Space Station - Cary Zeitlin, Larry Pinsky
Radiation Chemistry	Yields of Chemical Species – Jay LaVerne
	Radiation chemistry and oxidative stress – Ianik Plante
	Energetic and chemical reactivity of atomic and molecular oxygen – Ianik Plante
	An Assessment of How Radiation Incurred During a Mars Mission Could Affect Food and Pharmaceuticals - Myung-Hee Y. Kim and Ianik Plante
	Radiation Chemistry and DNA Damage - Peter O'Neill
	Essentials of Mammalian DNA Repair - Paul Wilson
	Oxygen in Space Radiation Biology - Paul Todd
Systems Biology	Introduction - Walter Schimmerling
	Kinetics, Systems Biology and other Models – Francis Cucinotta
	A Systems Biology Approach to Radiation Biology – Mary Helen Barcellos-Hoff
	Radiation-perturbed signalling and systems radiation biology – Luca Mariotti and Andrea Ottolenghi (Revised)
	Systems Radiation Biology and Radiation Induced Cell Signals – Mary Helen Barcellos-Hoff
	Signal transduction processes in response to low dose ionizing radiation doses expected during space flight

	<p>– David Boothman, Tracy Criswell, Eva Goetz, Dmitri Klovov, Yonglong Zou, and Xiuquan Luo</p> <p>MALDI-MSI: Biomarker Discovery for Radiation Exposures – Claire L. Carter, Thomas J. MacVittie, Maureen A. Kane</p> <p><i>Developing omics-based approaches for short- and long-term space radiation risk assessment – Kamal Datta, Shubhankar Suman, Daniel Hyduke, Jerry W. Shay, Albert J. Fornace Jr.</i></p>
Cell Damage and Repair	Radiobiology I – Eric Hall
	Biological Responses to High LET Radiation – Eric Hall
	Oxidative Stress – Peter O'Neill
	The Effects of Space Radiation-changed MiRNAs on Tumorigenesis – Ya Wang
	Mammalian DNA Damage Responses – Carl Anderson
	DNA Repair – HZE Damaged DNA – Susan Bailey
	RNA Transcription Factors and R-Loops – David Boothman
	<i>Precise Genome Engineering and the CRISPR Revolution (Boldly Going Where No Technology Has Gone Before) – Eric A. Hendrickson</i>
	Radiosensitivity and the Cell Cycle – Michael Joiner
	The Use of Biomarkers to Predict Radiation Dose and Risk During Space Flights – Antone Brooks
	Chromosomal Aberrations Cytogenetic Effects of Ionizing Radiation – Marco Durante
	Using Flow Cytometry to Detect High-LET Radiation Induced Apoptosis and Necrosis – Peter Guida
	Abortive apoptosis and its profound effects on radiation - , chemical - , and oncogene induced carcinogenesis – Xinjian Liu, Ian Cartwright, Fang Li, and Chuan-Yuan Li
	Stochastic Distribution of DNA Damage and Foci Formation – Artem Ponomarev
	Radiation Induced Foci Use and Abuse – Sylvain Costes
	Radiation-Induced Non-Targeted Effects – Edouard Azzam
	The Radiation Response in Cells Not Directly Traversed by High Charge and High Energy Particles: The Bystander Effect of Space Radiation – Edouard Azzam and Jason Domogauer
	Essentials of Mammalian DNA Repair – Paul Wilson
	<i>Epigenetic Memory of Space Radiation Exposure – Elizabeth M. Kennedy, Karen N. Conneely and Paula M. Vertino</i>
	The Emerging Role of Exosomes in the Biological Processes Initiated by Ionizing Radiation – Munira A Kadhim, Scott J Bright, Ammar H J Al-Mayah, and Edwin Goodwin
Tissue Biology and Pathology	Models
	<ul style="list-style-type: none"> • Animal Studies/Radiation Carcinogenesis – Michael Weil
	<ul style="list-style-type: none"> • Animal Studies/Genetics – Michael Weil
	<ul style="list-style-type: none"> • Transgenic Mouse Models and Novel Imaging Approaches – David Kirsch

	<ul style="list-style-type: none"> • Summary of an integrated experimental and computational approach to study the effects of heavy ion exposures on skin – Jake Pirkkanen, Claere von Neubeck, Marianne B. Sowa
	CNS Effects
	<ul style="list-style-type: none"> • Space Radiation and the Central Nervous System: Potential Risks – M. Kerry O'Banion • Radiation Effects in the Central Nervous System – M. Kerry O'Banion • Neurogenesis – John Fike • Radiation Response of Stem Cells and Neurons – John Fike • An Introduction to Behavior Testing for the Radiobiologist – Bernard Rabin • Radiation Effects on Behavior – Bernard Rabin • <i>Space Radiation-Induced Cognitive Deficits Following Head-Only, Whole Body, or Body-Only Exposures*</i> - Catherine M. Davis and Bernard M. Rabin
	Degenerative Effects
	<ul style="list-style-type: none"> • Cardiovascular <ul style="list-style-type: none"> ○ Cardiovascular Effects of Radiation – Fiona Stewart ○ An introduction to space radiation and its effects on the cardiovascular system – Marjan Boerma ○ Using Proteomics Approaches to Assess Mechanisms Underlying Low Linear Energy Transfer or Galactic Cosmic Radiation-Induced Cardiovascular Disease – Zachary D. Brown, Muath Bishawi, and Dawn E. Bowles • Radiation Degenerative Risks – M. Kerry O'Banion • Immune System – Gregory Nelson Introduction • The role of innate and adaptive immune system in the tissue responses to ionizing radiation – Sandra Demaria • Aging and Cancer: Telomeres, Telomerase and Cancer – Jerry Shay Introduction
	Solid Cancers
	<ul style="list-style-type: none"> • Cell and Animal Models of Lung Cancer – Jerry Shay Introduction • The Use of Human Epithelial Cells and Mouse Models of Human Lung Cancer for Space Radiation Research – Jerry Shay Introduction • Genetically Modified Mouse Models of Lung Cancer – Everett Moding & David Kirsch • Solid Tumor Risk Estimation Outreach Project – Clare Lamont
	Leukemia
	Radiation-Induced Leukemia – Michael Weil Introduction
Health Effects	Acute Effects 1– Tom Seed
	Acute Effects 2 – Ann Kennedy Introduction
	Radiobiology II – Eric Hall
	Normal Late Tissue Effects, Leukemia, Solid Tumors – Jacky Williams
	Radioprotectors
	<ul style="list-style-type: none"> • The use of biological countermeasures to reduce cancer risks from exposures to space radiation – Jerry Shay Introduction • Radioprotectors – Ann Kennedy Introduction
Radiation Therapy	The Physics of Protons for Patient Treatment – Andrew J. Wroe, Jerry D. Slater, James M. Slater
	Rationale for, and Development of, the World's First Hospital-based Proton Therapy System at Loma Linda University Medical Center – James M. Slater

	Clinical Proton Therapy at Loma Linda University Medical Center – Jerry D. Slater
	Carbon-Ion Radiotherapy - Basic and Clinical Studies – Koichi Ando
	Heavy Ion Therapy at GSI – Marco Durante
	History of the Heavy Ion Therapy at GSI – Gerhard Kraft
	The Local Effect Model - Principles and Applications – Thomas Friedrich, Marco Durante, and Michael Scholz
	<i>TOPAS-nBio: A Monte Carlo simulation toolkit for cell-scale radiation effects - J. Schuemann, A. McNamara, J. Ramos, J. Perl, K. Held, H. Zhu, S. Incerti, H. Paganetti, B. Faddegon</i>
Non-Radiation Risks	Introduction - Walter Schimmerling
	Microgravity Effects– Gregory Nelson
Radiation Risk Management	Radiation Risk Acceptability and Limitations – Francis Cucinotta
	Risk Synthesis: NASA Cancer Risk Models – Francis Cucinotta
	Acceptable Risk – Walter Schimmerling
	Radiation Protection – Walter Schimmerling
	Radiation Shielding – Ronald Turner
	The Evolution of Risk Cross Section – Stanley B. Curtis
	Space Radiation Cancer Risk Projections and Uncertainties - 2012 – Francis Cucinotta, Myung-Hee, Y. Kim, Lori J. Chappell
	Probability of Causation for Space Radiation Carcinogenesis following International Space Station, Near Earth Asteroid, and Mars Missions - 2012 – Francis Cucinotta
	Evaluating Shielding Approaches to Reduce Space Radiation Cancer Risks - 2012 – Francis Cucinotta
Computer Tools	NASA Space Radiation Program Integrative Risk Model Toolkit - Myung-Hee Y. Kim, Shaowen Hu, Ianik Plante, and Artem L. Ponomarev
	NSCR – NASA Space Cancer Risk Integrated Tools (NSCR)1, Web Server Release 1.0 – F.A. Cucinotta
	Space Radiation Environment
	HZETRN2015
	Acute Radiation Risk and BRYNTRN Organ Dose (ARRBOD) Projection
	GCR Event-Based Risk Model (GERMcode)
	Relativistic Ion Tracks (RITRACKS)
	Monte Carlo Transport Codes for use in the Space Radiation Environment – Lawrence Pinsky
	• GEANT4 (“GEometry AND Tracking”) – Dennis Wright
	• FLUKA (FLUctuating KAskade) – Alfredo Ferrari and Lawrence Pinsky
	• MCNP6 (Monte Carlo N-Particle) Transport Code – Tim Goorley
	• PHITS (Particle and Heavy Ion Transport code System) – Lembit Shiver

	Cosmic Ray Effects on Micro-Electronics (CREME)
	Lung Cancer Explorer – Yang Xie
	TRIP98 (Treatment Planning for Particles)
	Particle Irradiation Data Ensemble (PIDE) – Thomas Friedrich and Michael Scholz
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