THRIVE

The Health Risks of Extraterrestrial Environments

2019 Annual Report

January 2020

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

The Health Risks of Extraterrestrial Environments (THREE)

2019 Annual Report

Submitted by:

Walter Schimmerling, PhD
THREE Chief Editor

January 29, 2020
Date

Nicholas Meyer
THREE Page Editor

February 6, 2020
Date

Table of Contents

1.1 EXECUTIVE SUMMARY 2
1.2 INTRODUCTION 3
1.3 ORGANIZATION 3
1.4 WEBSITE STRUCTURE CHANGES 4
1.4.1 HOME PAGE 4
1.4.2 ARTICLES 6
1.4.3 BOOK REVIEWS 7
1.4.4 NEWS ITEMS 7
1.4.5 CITATIONS 8
1.4.6 ARCHIVE 9
1.5 ACTIVE OUTREACH 11
1.6 USAGE 11
1.7 SUMMARY 14
APPENDIX A ..... THREE ENCYCLOPEDIA CONTENTS (ARTICLES) I

List of Tables and Figures

Figure 1. THREE Home Page – Content Buttons 5
Figure 2. THREE Home Page – Navigation Menu 5
Figure 3. THREE Article Process 6
Figure 4. THREE Book Review Process 7
Figure 5. THREE News Item Process 8
Figure 6. THREE Citation Process 8
Figure 7. THREE Citations Posted in 2019 9
Figure 8. THREE Archive 10
Figure 9. THREE Average Monthly Web Usage by Year 11
Figure 10. THREE Web Statistics 12
Figure 11. THREE Annual Web Usage by Year 12
Figure 12. THREE Most Requested Articles for 2019 13

1.1 EXECUTIVE SUMMARY

The Health Risks of Extraterrestrial Environments (THREE) website completed another successful year in 2019 with increased use as well as improved website structure and content.

THREE served over 29K distinct users in 2019, with over 804K webpages displayed and over 8.6K files downloaded (from 34K, 770K, and 10K respectively in 2018). This decrease can be attributed to 28 days lost to the 2019 government shutdown (when public-facing websites including THREE were disabled). However, an overall trend of increased year over year usage can be seen.

Several changes were made to the website and supporting processes during 2019. New content added to the website in 2019 included 2 articles, 52 citations, as well as multiple general news items and additional archive contents. The template created and employed to simplify monthly website content update requests to NASA IT was updated and turned out to be a useful tool in routine use.

THREE continued to communicate with the international space radiation community in 2019. THREE web statistics were distributed via email to just under 1K recipients each month. A poster presentation given at the HRP Investigators' Workshop (Galveston) further increased exposure to THREE, as evidenced by the subsequent requests to link to THREE on their website's education page.

THREE continued to be a valued resource in the space radiation community in 2019. 2020 usage is expected to maintain or increase levels seen in 2019, and content will continue to be developed and added through the efforts of the THREE Editorial Board.

We mourn the death of longtime Associate Editor, David Boothman, Ph.D., from a stroke on November 1, 2019. David was an Associate Editor of THREE since 2013. An obituary may be found at https://three.jsc.nasa.gov/#main&section=main

1.2 INTRODUCTION

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

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.

1.3 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 2019 there were seven Associate Editors on the THREE Editorial Board. Two terms set to expire at the end of 2019 were renewed and extended to 2023 at the recommendation of the Chief Editor and by invitation of the SR Chief Scientist. 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 2020)
    - Dudley Goodhead (term expires 2022)
    - Derek Lowenstein (term expires 2022)
    - Marianne Sowa (term expires 2020)
    - Michael Weil (term expires 2023)

The THREE Editorial Board met monthly via teleconference in 2019 (nominally on the first Wednesday of each month) to manage the development of new THREE content. The January meeting is held in-person (as possible) at the HRP Investigators' Workshop.

In addition to the Editorial Board, a Page Editor and NASA IT specialist supported the development and implementation of THREE website content. The Chief Editor and Page Editor held weekly teleconference meetings in 2019 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 sendout of THREE monthly website usage information – there are currently 797 members of this distribution list, which is modified to include new THREE authors by default and to add or remove persons as explicitly requested.

1.4 WEBSITE STRUCTURE CHANGES

1.4.1 HOME PAGE

To increase user ease of use, the content buttons on the Home Page were updated as shown in Figure 1. General news items are now listed under the "In the News" link; they are removed when no longer relevant and are not archived. Citations are now listed under the "Current Research Citations" link for approximately one year; they are archived in the appropriate section of the Bibliography.

In addition, the left-hand navigation menu on the Home Page was updated as shown in Figure 2. "Viewing Slide Presentations" was moved into the Encyclopedia section of the website. The "Statement of Policies" button was split into two buttons, "Statement of Policies" and "Instructions to Authors".

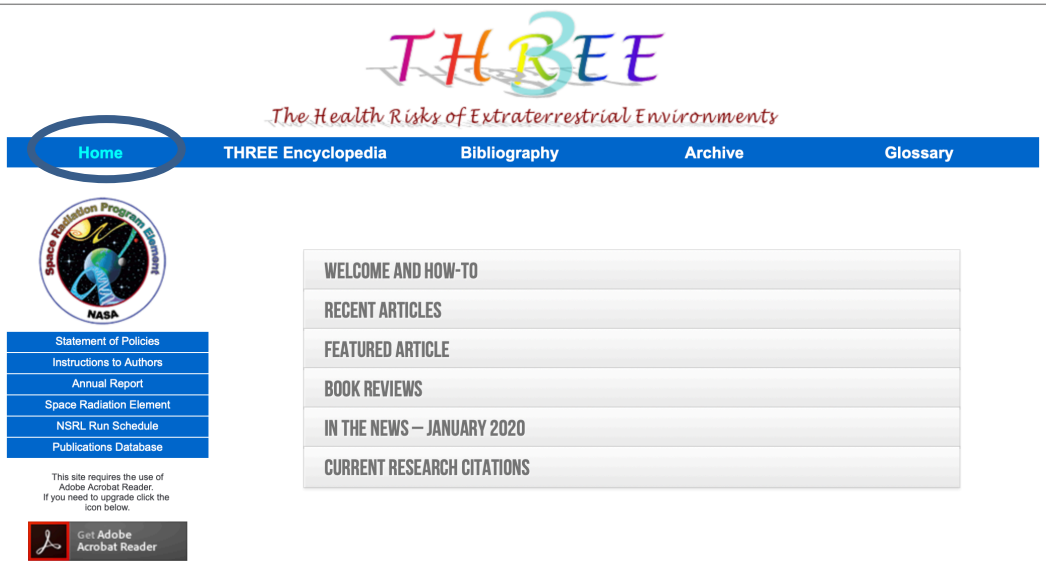

Figure 1. THREE Home Page (updated monthly) – Content Buttons

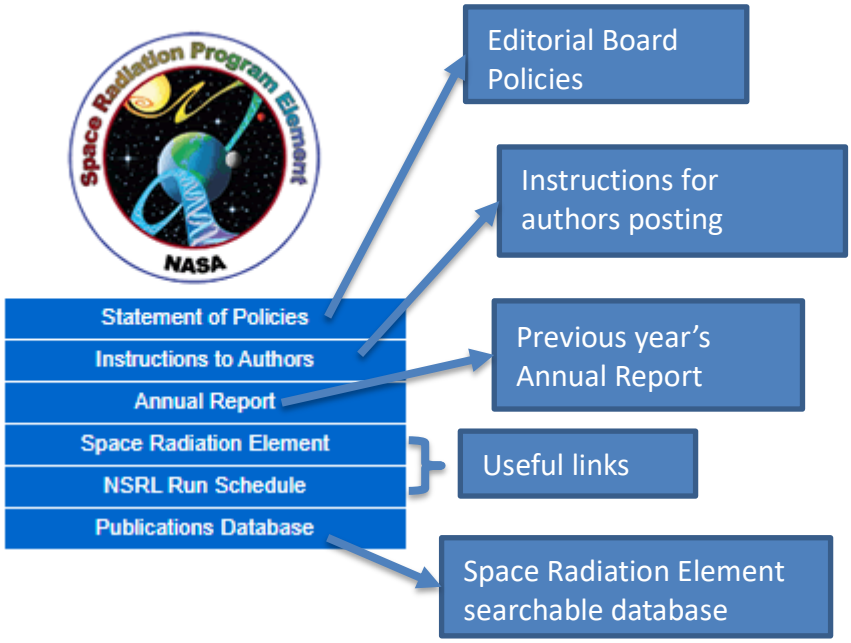

Figure 2. THREE Home Page – Navigation Menu

1.4.2 ARTICLES

THREE articles are original reports contributed by NASA internal or external authors on topics relevant to THREE. Acceptance and posting follow the process shown in Figure 3. Articles can be requested by THREE Editorial Board members or suggested by authors. All articles are peer-reviewed under the management of an Editorial Board member. New articles undergo NASA Export Control review prior to posting and are formatted to be in compliance with Section 508 of the Rehabilitation **Act** of 1973. New articles are listed for typically one year on the Home Page under "Recent Articles" but are permanently housed in the Encyclopedia. Articles of particular interest to the space radiation community may also be designated as "Featured Articles" with their abstract and a Figure chosen for highlighting under the "Featured Articles" button on the Home Page for an unspecified duration until the next Featured Article is posted.

In 2019, two new articles were posted to THREE. All were initially posted as Featured Articles:

- Space Radiation-Induced Cognitive Deficits Following Head-Only, Whole Body, or Body-Only Exposures (Catherine M. Davis and Bernard M. Rabin) - Posted September 11, 2019
- 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) – Posted December 6, 2019

The full list of all 95 articles currently contained in the THREE Encyclopedia is included in Appendix A.

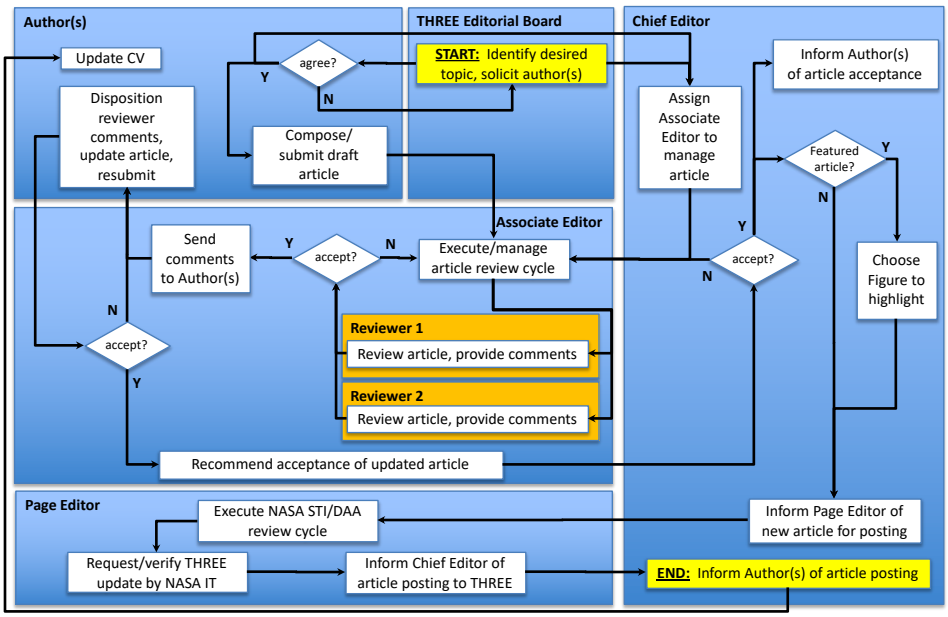

Figure 3. THREE Article Process

1.4.3 BOOK REVIEWS

THREE book reviews are a relatively new feature of THREE and are intended to be original reviews contributed by NASA internal or external authors on books relevant to THREE that follow the process shown in Figure 4. Book reviews can be requested by THREE Editorial Board members or suggested by authors. All book reviews are reviewed by two Associate Editors. New reviews undergo NASA Export Control review prior to posting and are formatted to be in Section 508 compliance.

No new book reviews were developed in 2019.

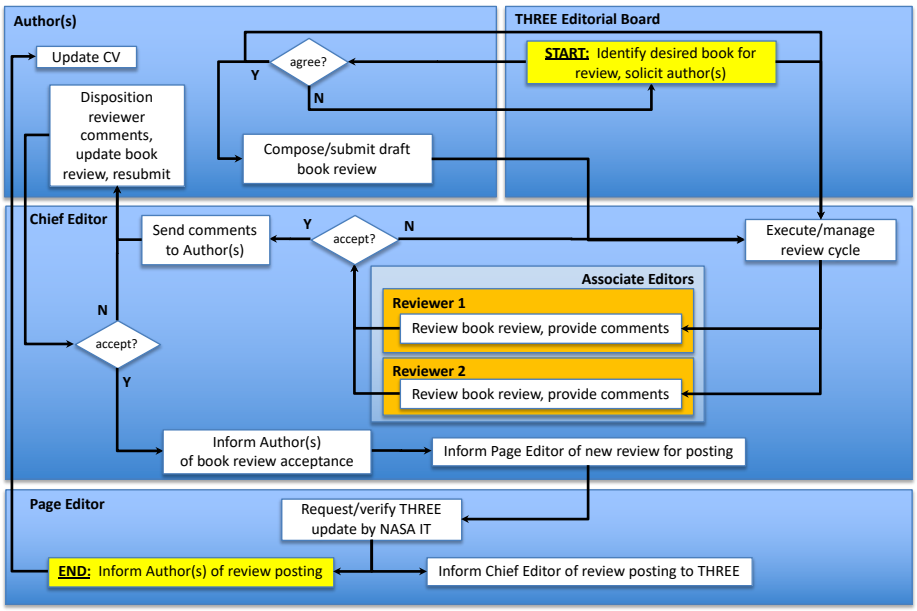

Figure 4. THREE Book Review Process

1.4.4 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 and follow the process shown in Figure 5. News items are removed from the website when no longer timely or relevant.

Multiple news items were posted to THREE in 2019.

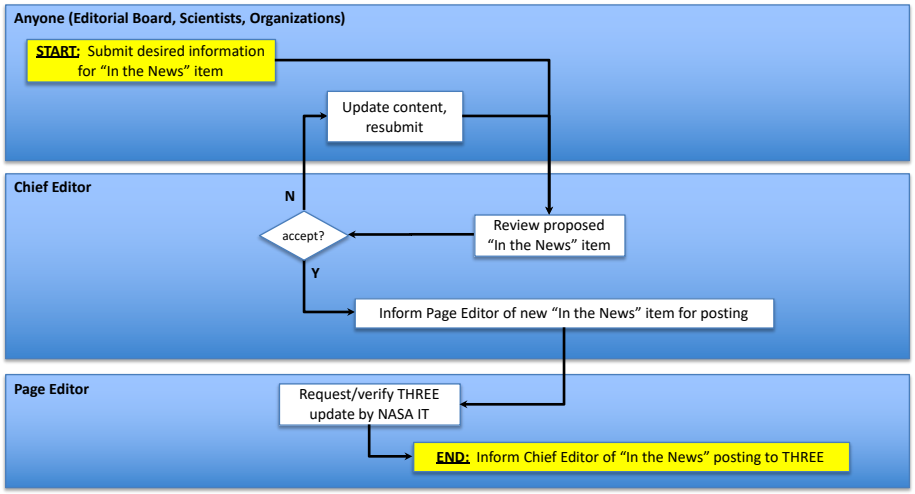

Figure 5. THREE News Item Process

1.4.5 CITATIONS

THREE citations are brief summaries of and links to published journal articles of interest to the general space radiation investigator community that are contributed by NASA internal or external authors and follow the process shown in Figure 6. New citations are listed for typically one year on the Home Page under "Current Research Citations" but are permanently housed under the appropriate topical heading in the Bibliography.

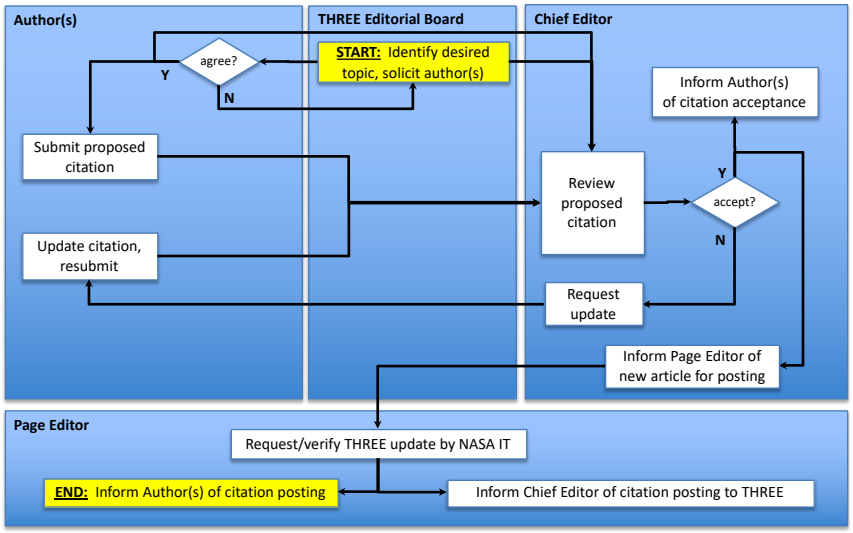

Figure 6. THREE Citation Process

52 new citations were added to the THREE Bibliography in 2019, under the topical headings shown in Figure 7.

NASA and exploration	**4**
Basic Concepts of Space Radiation	**6**
The Space Radiation Environment	*1*
Track Structure	*1*
Interactions of Radiation with Matter	*4*
Proton and HZE Accelerator Sources	**2**
Radiation Measurements	**-**
Radiation Chemistry	**1**
System Biology	**-**
Cell Damage and Repair	**6**
Tissue Biology and Pathology	**18**
Models	*2*
CNS Effects	*13*
Degenerative Effects	*2*
Solid Cancers	*1*
Leukemia	*-*
Health Effects	**1**
Radiation Therapy	**2**
Non-Radiation Risks	**3**
Radiation Risk Management	**8**
NASA Program Documents	*-*
Reports	*-*
Articles	*8*
Computer Tools	**1**
Total Citations added in 2019	52

Figure 7. THREE Citations Posted in 2019

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 2019 was for 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.

1.4.6 ARCHIVE

The THREE Archive page features historical content. This page was rearranged into three categories in 2019 as shown in Figure 8: NASA Space Radiation Summer School, Space

Radiation Investigators' Workshops, and Multimedia (the new "Multimedia" link in the Archive page connects to the content previously linked to the Multimedia tab, which was removed). .

. A significant amount of material was added to the Summer School content thanks to contributions from a former director of the Summer School who serves on the THREE Editorial Board. In addition, additional documentation for Space Radiation Investigator's Workshops was posted. It is anticipated that all workshops, from the initial to present day will be posted in 2020.

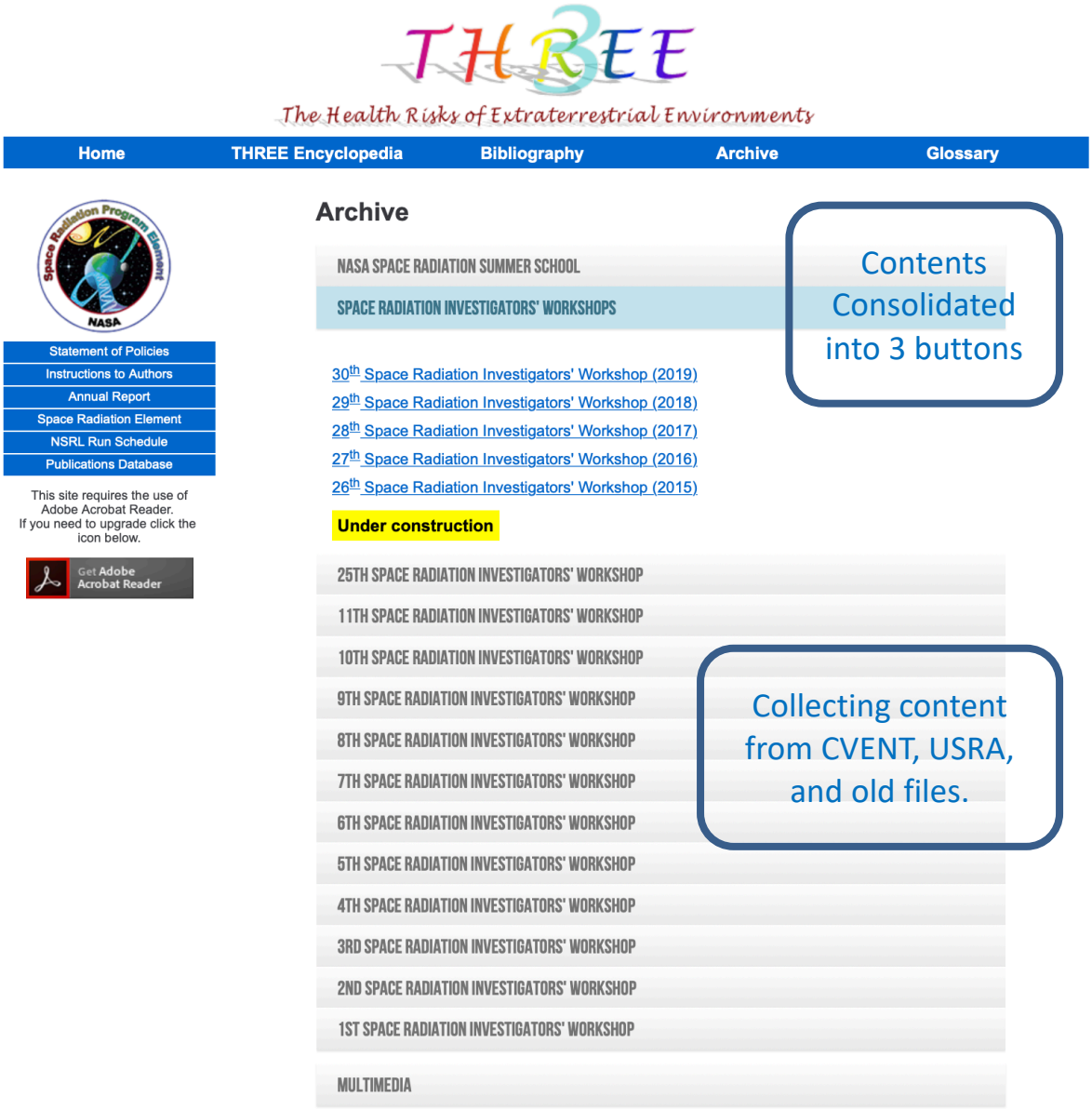

Figure 8. THREE Archive

1.5 ACTIVE OUTREACH

Although THREE by its very nature is an outreach tool, several 2019 efforts involved active communication with current and potential users.

Posters were presented at HRP Investigators' Workshops (January 2018 and 2019, Galveston) and at a Radiation Research Society annual meeting (September 2018, Chicago). These posters provided an overview of website contents and the process for developing new content.

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.

1.6 USAGE

Average monthly website usage has continued to increase annually as shown in Figure 9. Statistics by month for 2019 are shown in Figure 10. The percent changes from 2018 to 2019 are shown in Figure 11. The most requested articles in 2019 are shown in Figure 12.

	2015	2016	2017	2018	2019
Web Pages Visited	**17,803**	**18,537**	**40,279**	**64,193**	**66,013**
Number of Users	**2,225**	**2,053**	**3,334**	**3,791**	**3,420**
Nbr of Files Downloaded	**381**	**536**	**1,600**	**2,728**	**1,589**

Figure 9. THREE Average Monthly Web Usage by Year

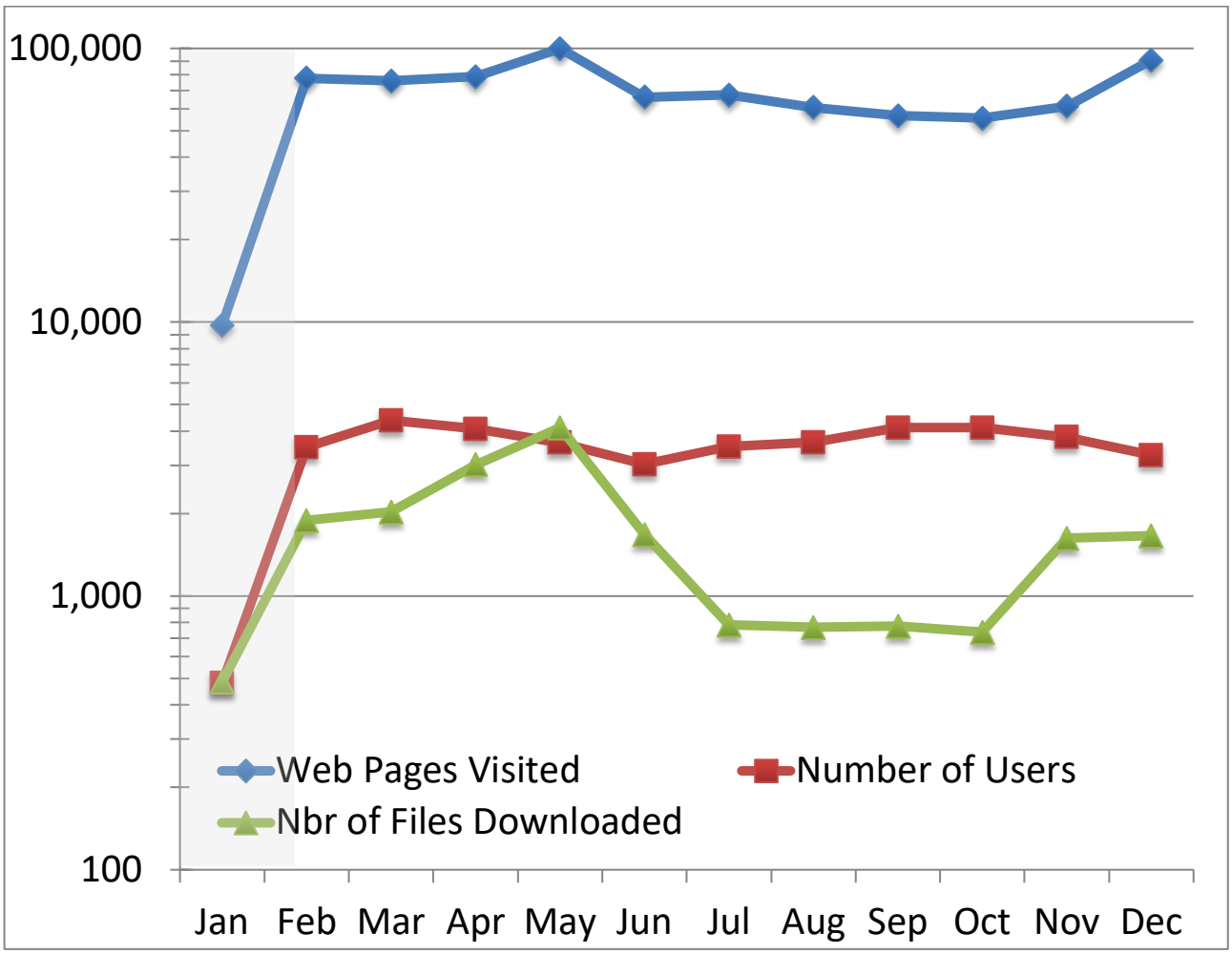

Figure 10. 2019 THREE Web Statistics

Annual web usage by year for the past two years is shown in Figure 11. While the number of website users decreased by 4% in 2019, the degree of usage increased modestly with 4% more page visits but with 40% fewer file downloads than seen in the previous year. Some of this decrease can be attributed to the government shutdown that occurred at the beginning of 2019 when the THREE website was unavailable (shaded area).

	2018	2019	% Change from 2018
Web Pages Visited	**770,313**	**801,906**	**4%**
Number of Users	**45,487**	**41,525**	**-9%**
Nbr of Files Downloaded	**32,734**	**19,553**	**-40%**

Figure 11. THREE Annual Web Usage by Year

The most requested articles in 2019 are shown in Figure 12. These "top 10" articles accounted for 32% of the total file downloads in 2019.

Article Title	Author(s)	Article Rank	Number of Requests
Radiation chemistry and oxidative stress (pdf)	Plante	#1	5109
Neutron Properties and Definitions (pdf)	Heilbronn	#2	4719
Evaluating Shielding Approaches to Reduce Space Radiation Cancer Risks (pdf)	Cucinotta, Kim, Chappell	#3	3723
Clinical Proton Therapy at Loma Linda University Medical Center (pdf)	Slater	#4	3470
Radiation Shielding (pdf)	Turner	#5	3032
History of the Heavy Ion Therapy at GSI (pdf)	Kraft	#6	2331
Solar Particle Events and Radiation Exposure in Space (pdf)	Hu	#7	2079
Radiation Risk Acceptability and Limitations (pdf)	Cucinotta	#8	1837
Preparations for Mitigation and Treatment of Injuries from a Radiation Incident (pdf)	DiCarlo-Cohen	#9	1625
Precise Genome Engineering and The CRISPR Revolution (Boldly Going Where No Technology Has Gone Before) (pdf)	Hendrickson	#10	1429

Figure 12. THREE Most Requested Articles for 2019

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 Figure 12 are further evidence that THREE serves a diverse scientific community, whose interest in space derives from a wide range of disciplines.

1.7 SUMMARY

THREE continued to be a valued resource in the space radiation community in 2019. Content was updated across the website in 2019 to maintain relevance, and the website structure was adjusted to increase ease of use. 2020 usage is expected to maintain or increase levels seen in 2019, and content will continue to be developed and added through the efforts of the THREE Editorial Board.

APPENDIX A 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
	• NASA Space Radiation Program: Interagency Collaboration - Walter Schimmerling
	• European Space Agency
	• Low Dose Radiation Research Program
	• National Institute of Allergy and Infectious Diseases (NIAID) "Preparations for Mitigation and Treatment of Injuries from a Radiation Incident"- Andrea L. DiCarlo-Cohen
Basic Concepts of Space Radiation	**The Space Radiation Environment**
	• Introduction – Walter Schimmerling
	• *The Natural space Ionizing Radiation Environment – Patrick O'Neill*
	• Fluence Rates, Delta Rays and Cell Nucleus Hit Rates from Galactic Cosmic Rays – Stanley B Curtis
	• *Solar Particle Events and Radiation Exposure in Space – Shaowen Hu*
	Interactions of Radiation with Matter – Walter Schimmerling
	• Particle Interactions Overview – Lawrence Heilbronn
	• Physics Summary – Lawrence Heilbronn
	• Neutron Properties and Definitions – Lawrence Heilbronn
	• Neutron Lectures Supplement – Lawrence Heilbronn
	Dose and Dose Rate Effectiveness Factors – Walter Schimmerling
	• Low LET Physics Topics – Gregory Nelson Introduction
	• A Note On The Dose-Rate-Effectiveness Factor and its Progeny DDREF - R.J.M. Fry
	Track Structure
	• Introduction to Track Structure and z*2/ β 2 - Stanley B. Curtis
	• Radiation Quality and Space Radiation Risks – Francis Cucinotta
	• Development of Monte Carlo Track Structure Codes – Larry Toburen
	• Microdosimetry and Detector Responses – Leslie A. Braby
	• Interpreting Microdosimetric Spectra – J. F. Dicello and F. A Cucinotta
	• Monte Carlo Track Simulations – Michael Dingfelder
	• Radiation Track Structure – Dudley T. Goodhead Abstract
	• Track structure and the quality factor for space radiation cancer risk - Dudley T. Goodhead
	Elementary Concepts of Shielding – Walter Schimmerling
	• Heavy Ions and Shielding Physics – Lawrence Heilbronn
Proton and HZE Accelerator Sources	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

	NASA Space Radiation Laboratory – D.I. Lowenstein, P. Guida, A. Rusek
	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
	• Ion Microbeams and Their Role in Radiobiology Research in Europe, B.E. Fischer
	• High/Low LET Microbeams, Gerhard Randers-Pehrson
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
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 – David Boothman, Tracy Criswell, Eva Goetz, Dmitri Klokov, Yonglong Zou, and Xiuquan Luo
	MALDI-MSI: Biomarker Discovery for Radiation Exposures – Claire L. Carter, Thomas J. MacVittie, Maureen

	A. Kane
	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.
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
	Precise Genome Engineering and the CRISPR Revolution (Boldly Going Where No Technology Has Gone Before) – Eric A. Hendrickson
	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
	Epigenetic Memory of Space Radiation Exposure – Elizabeth M. Kennedy, Karen N. Conneely and Paula M. Vertino
	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**
	• Animal Studies/Radiation Carcinogenesis – Michael Weil
	• Animal Studies/Genetics – Michael Weil
	• Transgenic Mouse Models and Novel Imaging Approaches – David Kirsch
	• 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
	• 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
	• *Space Radiation-Induced Cognitive Deficits Following Head-Only, Whole Body, or Body-Only Exposures* - Catherine M. Davis and Bernard M. Rabin*
	Degenerative Effects
	• Cardiovascular
	○ 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
	• 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
	• 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
	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
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
	OLTARIS
	SPENVIS
Help Section	Search Function
	Citation Instructions