Fiscal Year:	FY 2016	**Task Last Updated:**	FY 08/01/2016
PI Name:	Norbury, John Ph.D.		
Project Title:	Measurements and Transport Phase 2 Physics Project		
Division Name:	Human Research		
Program/Discipline:	HUMAN RESEARCH		
Program/Discipline--Element/Subdiscipline:	HUMAN RESEARCH--Radiation health		
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	(1) **SR**:Space Radiation		
Human Research Program Risks:	(1) **ARS**:Risk of Acute Radiation Syndromes Due to Solar Particle Events (SPEs) (2) **Cancer**:Risk of Radiation Carcinogenesis (3) **CNS**:Risk of Acute (In-flight) and Late Central Nervous System Effects from Radiation Exposure (4) **Degen**:Risk of Cardiovascular Disease and Other Degenerative Tissue Effects From Radiation Exposure and Secondary Spaceflight Stressors		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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PI Organization Type:	NASA CENTER	**Phone:**	757-864-1480
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City:	Hampton	**State:**	VA
Zip Code:	23681-2199	**Congressional District:**	1
Comments:			
Project Type:	GROUND	**Solicitation / Funding Source:**	Directed Research
Start Date:	10/01/2007	**End Date:**	03/31/2016
No. of Post Docs:	1	**No. of PhD Degrees:**	0
No. of PhD Candidates:	1	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	0	**Monitoring Center:**	NASA LaRC
Contact Monitor:	Simonsen, Lisa	**Contact Phone:**	
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Flight Program:			
Flight Assignment:	NOTE: Extended to 3/31/2016 per S. Monk/LaRC (Ed., 9/14/15) NOTE: Extended to 12/31/2015 per S. Monk/LaRC (Ed., 6/17/15)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Blattnig, Steve (NASA Langley Research Center) Clowdsley, Martha (NASA Langley Research Center) Slaba, Tony (NASA Langley Research Center) Werneth, Charles (NASA Langley Research Center) Norman, Ryan (NASA Langley Research Center)		
Grant/Contract No.:	Directed Research		
Performance Goal No.:			
Performance Goal Text:			

Task Description:	Currently, the deterministic space radiation transport code HZETRN (High charge (Z) and Energy TRaNsport), is the major tool used by NASA to evaluate radiation environments inside spacecraft. Deterministic codes have been shown to be superior to Monte Carlo transport for engineering studies. However HZETRN is a one dimensional transport code. The transport of heavy ions ($Z > 2$) has been shown to be valid in the one dimensional approximation because the relativistic heavy ions found in the space radiation spectrum pass through materials relatively un-deflected from their initial trajectories. The cross sections required for one dimensional transport are total absorption and spectral distributions. Meson production and the associated electromagnetic cascade have not yet been incorporated into HZETRN. Phase 1 studies have shown the importance of these processes, which must be included in Phase 2. This project implements the recommendations of several workshops by emphasizing the development of a more accurate description of neutron and light ion transport. Neutrons and light ions scatter at large angles and the one dimensional approximation is no longer valid. Therefore, the one dimensional code HZETRN must begin to include the three dimensional transport of light ions and neutrons to more accurately quantify secondary radiation environments in tissue while maintaining computational speed and efficiency. Such a three dimensional transport code in turn requires fully double differential cross sections as input. Phase II Measurements and Physics Project focuses on light ion production and transport to develop space radiation transport codes capable of predicting primary and secondary spectra of space radiation environment interaction behind typical spacecraft shielding, planetary surfaces, and atmospheres with increased accuracy. Configuration managed V&V'ed source codes are released to the radiation user community including Exploration, RHO (radiation health officer), and Operations as well as industry partners or commercial entities. Current exploration vehicle requirements specify that HZETRN shall be utilized by the government for radiation requirement verification. Transport codes directly support verification of NASA STD 3001 Vol. 2 requirements. Phase 2 focus: • Current focus is on light ion and neutron transport and production including 3-D effects of neutron backscattered and inclusion of dose received from pion production • Future nuclear physics improvements will focus on improved models needed for definition of Mars Surface Environment Implementation of Phase 2 Physics supports closing the following gaps, • Cancer - 11: What are the most effective shielding approaches to mitigate cancer risks? • Cancer - 12: What level of accuracy do NASA’s space environment, transport code and cross sections describe radiation environments in space (International Space Station-ISS, Lunar, or Mars)? Pion production models are also being worked on.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	The radiation transport codes developed at NASA Langley Research Center can potentially be used in other applications such as proton and heavy ion therapy treatments for cancer.
Task Progress:	Galactic cosmic ray (GCR) simulation has been studied for development at the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory (BNL) on Long Island, New York. The space radiation environment consists of a wide variety of ion species with a continuous range of energies. However, most accelerator-based space radiation experiments have been performed with single ion beams at fixed energies. Thanks to recent developments in beam switching technology implemented at NSRL, it is now possible to rapidly switch ion species and energies, allowing for the possibility to more realistically simulate the actual radiation environment found in space. A variety of issues related to implementation of GCR simulation at NSRL, especially for experiments in radiobiology, have been studied. Reference field specification and beam selection strategies at NSRL have been examined and a recommended GCR simulation strategy at NSRL has been outlined. Comparisons have been made between direct simulation of the external, free space GCR field and simulation of the induced tissue field behind shielding. It was found that upper energy constraints at NSRL limit the ability to simulate the external, free space field directly (i.e., shielding placed in the beam line in front of a biological target and exposed to a free space spectrum). Also, variation in the induced tissue field associated with shielding configuration and solar activity has been addressed. It was found that the observed variation is likely within the uncertainty associated with representing any GCR reference field with discrete ion beams in the laboratory, given current facility constraints. An approach for selecting beams at NSRL to simulate the designated reference field has been worked out. This represents the first important step in the full development of GCR simulation at NSRL. The effects of relativistic kinematics have been studied for general nuclear collisions between a projectile and target nucleus. Relativistic effects are seen to come into play at high energies for non-equal mass nuclei. However, a very surprising result was found. When the mass of the projectile and target are the same, then relativistic kinematic effects disappear! The Lippman-Schwinger equation with the first order optical potential was analysed and the resulting differential cross sections calculated with and without relativistic effects become indistinguishable because the relativistic and non-relativistic elastic scattering amplitudes are essentially indistinguishable. The 3-Dimensional High charge (Z) and Energy TRaNsport (3DHZETRN) formalism was developed as an extension to HZETRN with an emphasis on 3D corrections for neutrons and light ions. Comparisons to Monte Carlo (MC) simulations were used to verify the 3DHZETRN methodology in slab and spherical geometry, and it was shown that 3DHZETRN agrees with MC codes to the degree that various MC codes agree among themselves. One limitation of such comparisons is that all of the codes (3DHZETRN and three MC codes) utilize different nuclear models/databases; additionally, using a common nuclear model is impractical due to the complexity of the software. It was therefore difficult to ascertain if observed discrepancies are caused by transport code approximations or nuclear model differences. Previous transport model results in specific geometries have now been combined with additional results in related geometries to study neutron leakage using the Webber 1956 solar particle event as a source boundary condition. It has been found that although the current version of 3DHZETRN is reasonably accurate compared to MC simulations, improved leakage estimates can be obtained by replacing the isotropic/straight-ahead approximation with more detailed descriptions.

	This report was compiled from abstracts of papers listed in the bibliography.
Bibliography Type:	Description: (Last Updated: 01/11/2021)
Articles in Peer-reviewed Journals	Norbury JW, Schimmerling W, Slaba TC, Azzam E, Badavi FF, Baiocco G, Benton E, Bindi V, Blakely EA, Blattnig SR, Boothman DA, Borak TB, Britten RA, Curtis S, Dingfelder M, Durante M, Dynan W, Eisch AJ, Robin Elgart S, Goodhead DT, Guida PM, Heilbronn LH, Hellweg CE, Huff JL, Kronenberg A, La Tessa C, Lowenstein D, Miller J, Morita T, Narici L, Nelson GA, Norman RB, Ottolenghi A, Patel ZS, Reitz G, Rusek A, Schreurs A-S, Scott-Carnell LA, Semones E, Shay JW, Shurshakov VA, Sihver L, Simonsen LC, Story M, Turker MS, Uchihori Y, Williams J, Zeitlin CJ. "Galactic cosmic ray simulation at the NASA Space Radiation Laboratory." Life Science in Space Research. 2016 Feb;8:38-51. http://dx.doi.org/10.1016/j.lssr.2016.02.001 ; PMID: 26948012 , Feb-2016
Articles in Peer-reviewed Journals	Slaba TC, Blattnig SR, Norbury JW, Rusek A, La Tessa C. "Reference field specification and preliminary beam selection strategy for accelerator-based GCR simulation." Life Sciences in Space Research. 2016 Feb;8:52-67. http://dx.doi.org/10.1016/j.lssr.2016.01.001 ; PubMed PMID: 26948013 , Feb-2016
Articles in Peer-reviewed Journals	Werneth CM, Maung KM, Ford WP. "Relativistic elastic differential cross sections for equal mass nuclei." Physics Letters B. 2015 Oct 7;749:331-6. http://dx.doi.org/10.1016/j.physletb.2015.08.002 , Oct-2015
Articles in Peer-reviewed Journals	Wilson JW, Slaba TC, Badavi FF, Reddell BD, Bahadori AA. "3DHZETRN: Neutron leakage in finite objects." Life Sciences in Space Research. 2015 Nov;7:27-38. http://dx.doi.org/10.1016/j.lssr.2015.09.003 , Nov-2015
Articles in Peer-reviewed Journals	Wilson JW, Slaba TC, Badavi FF, Reddell BD, Bahadori AA. "Solar proton exposure of an ICRU sphere within a complex structure Part I: Combinatorial geometry." Life Sciences and Space Research. 2016 Jun;9:69-76. http://dx.doi.org/10.1016/j.lssr.2016.05.002 ; PubMed PMID: 27345203 , Jun-2016
Articles in Peer-reviewed Journals	Slaba TC, Wilson JW, Badavi FF, Reddell BD, Bahadori AA. "Solar proton exposure of an ICRU sphere within a complex structure part II: Ray-trace geometry." Life Sciences and Space Research. 2016 Jun;9:77-83. http://dx.doi.org/10.1016/j.lssr.2016.05.001 ; PubMed PMID: 27345204 , Jun-2016
Articles in Peer-reviewed Journals	Heilbronn LH, Borak TB, Townsend LW, Tsai PE, Burnham CA, McBeth RA. "Neutron yields and effective doses produced by Galactic Cosmic Ray interactions in shielded environments in space." Life Sciences and Space Research. 2015 Nov;7:90-9. http://dx.doi.org/10.1016/j.lssr.2015.10.005 ; PubMed PMID: 26553642 , Nov-2015
Articles in Peer-reviewed Journals	Gronoff G, Norman RB, Mertens CJ. "Computation of cosmic ray ionization and dose at Mars. I: A comparison of HZETRN and Planetocosmics for proton and alpha particles." Advances in Space Research. 2015 Apr;55:1799-805. http://dx.doi.org/10.1016/j.asr.2015.01.028 , Apr-2015
Articles in Peer-reviewed Journals	Straume T, Slaba TC, Bhattacharya S, Braby LA. "Cosmic-ray interaction data for designing biological experiments in space." Life Sci Space Res (Amst). 2017 May;13:51-59. https://doi.org/10.1016/j.lssr.2017.04.002 ; PubMed PMID: 28554510 , May-2017
Articles in Peer-reviewed Journals	Norbury JW, Slaba TC, Sobolevsky N, Reddell B. "Comparing HZETRN, SHIELD, FLUKA and GEANT transport codes." Life Sci Space Res (Amst). 2017 Aug;14:64-73. Epub 2017 Apr 20. https://doi.org/10.1016/j.lssr.2017.04.001 ; PubMed PMID: 28887946 , Aug-2017
Articles in Peer-reviewed Journals	Slaba TC, Stoffle NN. "Evaluation of HZETRN on the Martian surface: Sensitivity tests and model results." Life Sci Space Res. 2017 Aug;14:29-35. https://doi.org/10.1016/j.lssr.2017.03.001 ; PubMed PMID: 28887940 , Aug-2017
Articles in Peer-reviewed Journals	Warner JE, Norman RB, Blattnig SR. "HZETRN radiation transport validation using balloon-based experimental data." Life Sci Space Res. 2018 May;17:23-31. https://doi.org/10.1016/j.lssr.2018.02.003 ; PMID: 29753410 , May-2018
Articles in Peer-reviewed Journals	Norbury JW, Slaba TC, Aghara S, Badavi FF, Blattnig SR, Clowdsley MS, Heilbronn LH, Lee K, Maung KM, Mertens CJ, Miller J, Norman RB, Sandridge CA, Singleterry R, Sobolevsky N, Spangler JL, Townsend LW, Werneth CM, Whitman K, Wilson JW, Xu SX, Zeitlin C. "Advances in space radiation physics and transport at NASA." Life Sci Space Res (Amst). 2019 Aug;22:98-124. https://doi.org/10.1016/j.lssr.2019.07.003 ; PMID: 31421854. , Aug-2019
NASA Technical Documents	Wilson JW, Slaba TC, Badavi FF, Reddell BD, Bahadori AA. "Solar Proton Transport within an ICRU Sphere Surrounded by a Complex Shield: Combinatorial Geometry." Hampton, VA: NASA Langley Research Center, 2015. NASA Technical Publication 218980. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160001628.pdf , Nov-2015
NASA Technical Documents	Slaba TC, Wilson JW, Badavi FF, Reddell BD, Bahadori AA. "Solar Proton Transport within an ICRU Sphere Surrounded by a Complex Shield: Ray-Trace Geometry." Hampton, VA: NASA Langley Research Center, 2015. NASA Technical Publication 218994. http://spaceradiation.larc.nasa.gov/nasapapers/NASA-TP-2015-218994.pdf , Dec-2015