Fiscal Year:	FY 2015	**Task Last Updated:**	FY 07/08/2015
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		
PI Email:	John.w.norbury@nasa.gov	**Fax:**	FY
PI Organization Type:	NASA CENTER	**Phone:**	757-864-1480
Organization Name:	NASA Langley Research Center		
PI Address 1:	Mail Stop 188E		
PI Address 2:	LaRC-D309		
PI Web Page:			
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:**	
Contact Email:	lisa.c.simonsen@nasa.gov		
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) Simonsen, Lisa (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:	Active magnetic radiation shielding was re-evaluated. Many active magnetic shielding designs have been proposed in order to reduce the radiation exposure received by astronauts on long duration, deep space missions. While these designs are promising, they pose significant engineering challenges. This work presents a survey of the major systems required for such unconfined magnetic field design, allowing the identification of key technologies for future development. Basic mass calculations are developed for each system and are used to determine the resulting galactic cosmic radiation exposure for a generic solenoid design, using a range of magnetic field strength and thickness values, allowing some of the basic characteristics of such a design to be observed. The study focused on a solenoid shaped, active magnetic shield design; however, many of the principles discussed are applicable regardless of the exact design configuration, particularly the key technologies cited. Shielding evaluation for solar particle events was studied and detailed analyses of Solar Particle Events (SPE) were performed to calculate primary and secondary particle spectra behind aluminum, at various thicknesses in water. The simulations were based on Monte Carlo (MC) radiation transport codes, MCNPX and PHITS, and the space radiation analysis website called OLTARIS (On-Line Tool for the Assessment of Radiation in Space) version 3.4 (uses deterministic code, HZETRN, for transport). The study investigated the impact of SPEs spectra transporting through 10 or 20 g/cm^2 Al shield followed by 30 g/cm2 of water slab. Four historical SPE events were selected and used as input source spectra and particle differential spectra for protons, neutrons, and photons are presented. The total particle fluence as a function of depth is presented. In addition to particle flux, the dose and dose equivalent values are calculated and compared between the codes and with the other published results. Overall, the particle fluence spectra from all three codes show good agreement with the MC codes showing closer agreement compared to the OLTARIS results. The neutron particle fluence from OLTARIS is lower than the results from MC codes at lower energies (E<100MeV). Based on mean square difference analysis the results from MCNPX and PHITS agree better for fluence, dose, and dose equivalent when compared to OLTARIS results. Elastic differential cross sections for space radiation applications were evaluated. The eikonal, partial wave (PW) Lippmann-Schwinger, and three-dimensional Lippmann-Schwinger (LS3D) methods are compared for nuclear reactions that are relevant for space radiation applications. Numerical convergence of the eikonal method is readily achieved when exact formulas of the optical potential are used for light nuclei, and the momentum-space representation of the optical potential is used for heavier nuclei. The PW solution method is known to be numerically unstable for systems that require a large number of partial waves, and, as a result, the LS3D method is employed. The effect of relativistic kinematics is studied with the PWand LS3D methods and is compared to eikonal results. It is recommended that the LS3D method be used for high-energy nucleon-nucleus reactions and nucleus-nucleus reactions at all energies because of its rapid numerical convergence and stability. The new trapped environment AE9/AP9/SPM at low Earth orbit was evaluated. The completion of the International Space Station (ISS) in 2011 has provided the space research community an ideal proving ground for future long duration human activities in space. Ionizing radiation measurements in ISS form the ideal tool for the validation of radiation environmental models, nuclear transport codes, and nuclear reaction cross sections. Indeed, prior measurements on the space transportation system (STS; shuttle) provided vital information impacting both the environmental models and the nuclear transport code developments by indicating the need for an improved dynamic model of the low Earth orbit (LEO) trapped environment. Additional studies using thermo-luminescent detector (TLD), tissue equivalent proportional counter (TEPC) area monitors, and computer aided design (CAD) model of earlier ISS configurations, confirmed STS observations that, as input, computational dosimetry requires an environmental model with dynamic and directional (anisotropic) behavior, as well as an accurate six degree of freedom (DOF) definition of the vehicle attitude and orientation along the orbit of ISS. A new three dimensional (3D) version of the NASA transport code HZETRN was developed. The computationally efficient HZETRN code has been used in recent trade studies for lunar and Martian exploration and is currently being used in the engineering development of the next generation of space vehicles, habitats, and extra vehicular activity equipment. Code development has been based on a progression of approximations first assuming all particles are produced in the initiator direction of incidence (straight-ahead) later improved by treating neutrons produced in the backward hemisphere as moving straight-back (bi-directional). A new version (3DHZETRN) capable of transporting High charge (Z) and Energy (HZE) and light ions (including neutrons) under space-like boundary conditions with enhanced neutron and light ion propagation in transverse directions is developed. New algorithms for light ion and neutron propagation with well defined convergence criteria in 3D objects were developed and tested against Monte Carlo simulations of 3D effects. A deterministic (non-statistical) two dimensional (2D) computational model describing the transport of electron and photon typical of space radiation environment in various shield media was developed. The 2D formalism is cast into a code which is an extension of a previously developed one dimensional (1D) deterministic electron and photon transport code. For candidate shielding materials, using the trapped electron radiation environments at low Earth orbit (LEO), geosynchronous orbit (GEO), and Jupiter moon Europa, verification of the 2D formalism vs. 1D and an existing Monte Carlo code was studied. A Galactic Cosmic Ray (GCR) simulator was developed and is intended to deliver the broad spectrum of particles and energies encountered in deep space to biological targets in a controlled laboratory setting. In this work, certain aspects of simulating the GCR environment in the laboratory are discussed. Reference field specification and beam selection strategies at the NASA Space Radiation Lab (NSRL) are the main focus, but the analysis presented herein may be modified for other facilities. First, comparisons were 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. Second, variation in the induced tissue field associated with shielding configuration and solar activity is 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. A single reference field for deep space missions is subsequently identified. Third, an approach for selecting beams at NSRL to simulate the designated reference field was developed. Drawbacks of the proposed methodology have been investigated and weighed against alternative simulation strategies. A new Galactic Cosmic Ray Flux Model was developed. The Badhwar-O'Neill (BON) Galactic Cosmic Ray (GCR) model is based on GCR measurements from particle detectors. The model has mainly been used by NASA to certify microelectronic systems and the analysis of radiation health risks to astronauts in space missions. The BON14 model numerically solves the Fokker-Planck equation to account for particle transport in the heliosphere due to diffusion, convection, and adiabatic deceleration under the assumption of a spherically symmetric heliosphere. The model also incorporates an empirical time delay function to account for the lag of the solar activity to reach the boundary of the heliosphere. Using a comprehensive measurement database, it was shown that BON14 is significantly improved over the previous version, BON11. The importance of neutrons and light ions was considered when astronauts spend considerable time in thickly shielded regions of a spacecraft. This may be relevant for space missions both in and beyond low Earth orbit. In addition to heavy ion experiments at accelerators, it is suggested that an increased emphasis on experiments with lighter ions may be useful in reducing biological uncertainties. Estimates of extreme solar particle event radiation exposures on Mars were made. Estimates of effective doses and organ doses for male and female crewmembers are made for solar particle event proton environments comparable to several of the most significant solar particle events, which occurred in the second half of the 19th century. The incident proton energy distributions for these solar particle events are assumed to be similar to that of the November 1960 event, one of the most energetic of the modern space era. The crewmembers are assumed to be located at the mean surface elevation on Mars, at the lowest elevation on Mars in the Hellas Impact Basin, and on the summit of Olympus Mons, the highest surface elevation on Mars. The crewmembers were assumed to be shielded by the overlying carbon dioxide atmosphere of Mars, and locally shielded by a space suit, a surface landing spacecraft, or a surface habitat. These estimates are compared with current NASA Permissible Exposure Limits. This report was compiled from abstracts of papers listed in the bibliography.
Bibliography Type:	Description: (Last Updated: 01/11/2021)
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