Production of Nuclear Fuel in Space

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Research Objective

The proposed study characterizes the feasibility of producing nuclear fuel in space by means of irradiating fertile materials selected and prepared to become useful nuclear fuel upon receiving irradiation from an onboard particle accelerator.

Significance of Research

The capability of producing nuclear fuel in space opens the door to new mission concepts and architectures. The cost and hazards associated with production, handling, transport, vehicle integration, and launch of fissile material often are prohibitive. Producing the nuclear fuel in space would eliminate most of these constraints. Also, the ability to manufacture nuclear fuel in space from material obtained from other terrestrial bodies opens the door to sustainable colonization without massive fuel enrichment facilities at those locations. Mars and the Moon[i] have both been found to possess significant uranium at or near the surface which could be used for power someday.

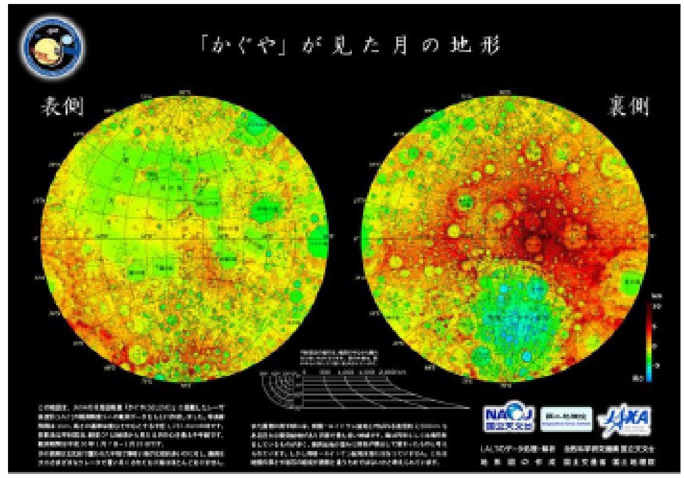


Figure 1: Map of Lunar Uranium from the Kaguya Spacecraft

Applicability to NIAC

This study has particular relavence to the NIAC solicitation. The technology would revolutionize and disrupt current methods of deep space exploration. Ground and flight operations as well as mission profiles can dramatically improve if the nuclear fuel is produced in space. Current nuclear mission planning can be dominated by supply shortages of Pu-238[ii] or the controversial and hitherto overpowering safety and political risks of launching enriched uranium or plutonium. Future missions don't need to be so hindered. The upcoming Juno mission to Jupiter has had to avoided nuclear power altogether, settling to operate on less than half a kilowatt from a comparatively massive 650 square feet of solar arrays. This will be the farthest a solar powered spacecraft has ever traveled into the region where the sun's energy has decayed exponentially to a small fraction of what it is at Earth.

The affordable, acceptable safe nuclear power that the proposed technology enables may greatly enhance NASA's future missions and exploration capability with space based nuclear fuel depots and production providing affordable abundant power, efficient in-space transportation, and shorter trip times promoting space health for astronauts to survive the extreme radiation environment of space. These imperatives are specifically named in the *Space Technology Grand Challenges* as crucial to a robust and vibrant space program. Indeed, space colonization with indigenously supplied nuclear reactors from recently discovered Lunar and Martian uranium and thorium is possible. Proliferation of dangerous material made during the nuclear fuel process is all but eliminated when then entire fuel process if moved into space. Furthermore, this technology has applicability to our security and power challenges on earth, as it opens the door to emplacing a nuclear system in locations that otherwise don't lend themselves to the transport of nuclear material, such as an Afghan mountainside or the South Pole.

Background

Conventional Space Nuclear Systems

Benefits

The benefits of conventional space nuclear power systems have been documented and demonstrated repeatedly. Nuclear power categorically affords lower mass systems for high power systems or exploration to the outer planets. Nuclear systems perform independent of distance from the Sun, shadowing, or day and night cycles. These attributes translate into:

- Higher power for outer planetary payloads
- High specific impulse thermal or electric space propulsion
- Longer duration stay times in space

In planetary science missions, radioisotope power generators have been used repeatedly to provide long lived, constant thermal or electric power to payloads extending to distances beyond the edge of the solar system. Nuclear fission has also shown promise in allowing shorter trip times and increased data collection and communication rates for missions to the outer planets.[iii] For human planetary exploration, multiple studies have shown nuclear thermal and nuclear electric propulsion to provide significant reductions in both launch mass and trip times to Mars.[iv,v,vi].

Safety Issues

Using conventional space nuclear power systems entails risk. One is possible launch vehicle failure. In such a case, nuclear material can be dispersed causing environmental and health problems. Proliferation due to potential loss of highly enriched material during ground operations must be managed. Designers currently address these risks through reactor and mission design. Reactors can be designed to remain intact through reentry and subcritical upon impact, or to disassemble on reentry, or by launching to an established "nuclear safe orbit" with a sufficient decay time (thousands of years) in the case of a system malfunction. [vii] All these options impose constraints and penalties on the system or spacecraft.

Space Activated Nuclear Systems (SANS)

Description of SANS

A Space Activated Nuclear System is a system in which the fissile material is created or transmutated from non fissile but fertile material after the spacecraft has reached outer space, or even an escape trajectory from Earth. This may be better than some other nuclear systems that launch "cold" fissile material that will not achieve criticality until the onboard control mechanisms are configured to foster a sustained chain reaction. The proposed method is to use an onboard particle accelerator to collide ions into a neutron producing target that sends neutrons into fertile material. After this process has converted enough fertile material into fuel, the accelerator (and its power supply) is not needed and may be inactivated, reused, or jettisoned.

Justification for SANS

Such a system is beneficial because in the eventuality of a launch vehicle failure, such as explosion on the launch pad, during ascent, or during orbital insertion, the possibility of releasing fissile radioactive material into the atmosphere is reduced to zero. If no fissile material is launched, then fissile material can not be released, as happened with the Tansit-5BN-3 satellite (which released plutonium over Madagascar), the Nimbus B-1 (whose RTG crashed in the ocean after an uncontrolled launch vehicle's flight had to be terminated), the Soviet Kosmos 954 (which strew debris over a large area of Canada in 1978), the Kosmos 1402[viii] (whose core crashed 1100 miles east of Brazil 1983), the 1973 RORSAT spacecraft (whose launch vehicle failure in 1973 deposited the reactor into the pacific ocean north of Japan), and the Apollo 13 lunar module (which plunged the onboard SNAP 27 RTG into the Tonga Trench.) Even if all technical and safety problem are solved, the public trust and confidence may be so low as to "seriously affect the planned use of nuclear technology on space science missions."[ix]

Physics

Beam – Target Interactions

Ion accelerators come in all shapes and sizes. In medical, security, and research applications, accelerators hurl protons at stationary targets such as beryllium, lithium, and tritium. The targets generate neutrons when struck through fission. Alternatively, a deuteron beam on a tritiated target will cause non-sustained fusion producing energetic 14 MeV neutrons. A third application involves an ion beam on a heavy metal targets such as uranium which undergoes fission or transmutation. The 1940 discovery of plutonium by Glenn Seaborg happened when he bombarded uranium with accelerated deuterons.

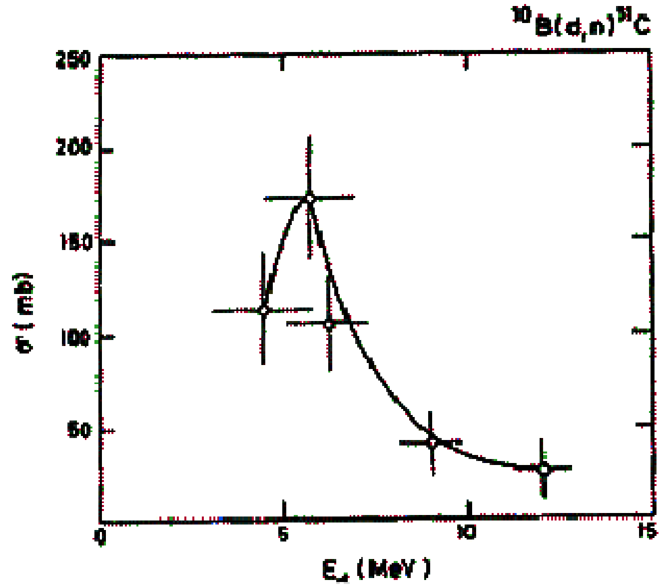


Figure 2: Beryllium Neutron Activation Cross Section

n – U Interactions

In reactors across the world, uranium is converted to plutonium when uranium 238 is struck by neutrons. Although this may not be the purpose of the many reactors, it is a commonplace reaction. When the neutrons are low energy, the uranium 238 will absorb the neutron and become plutonium 239. When the neutrons are high energy, the uranium 238 will fission and release large numbers of additional neutrons. Thorium 232 behaves in a similar manner when it absorbs a neutron and produces uranium 233, an attractive reactor fuel.

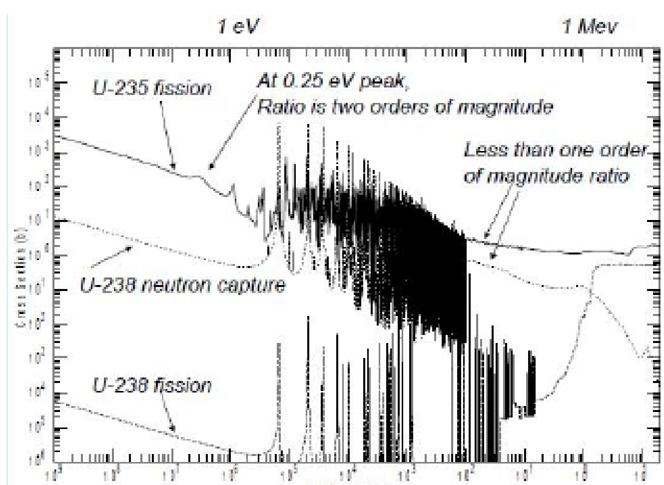


Figure 3: Uranium Neutron Capture and Fission Cross Section

Key Figures of Merit

A high-performance space activated nuclear system performs well in the following ways:

- Low kilowatt-hours to criticality
- Low kilowatt-hours to net positive energy
- Low mass
- High post activation thermal output
- Optimal fuel loading profiles

Technical Predecessors

Terrestrial systems similar to SANS have been built. Although such systems are unsuitable for use in a self contained and closed loop spacecraft, the available components and subsystems serve to provide a strong base for SANS development.

Accelerator Driven Systems (ADS)

Nobel Prize winner Carlo Rubbia proposed the accelerator driven system in 1993[x], in which a subcritical mass of fuel is pushed over the neutron threshold to sustain a reaction by neutrons supplied from an accelerator spallation neutron source. This concept contains most of the elements of a space activated nuclear system, and has been built and tested in various embodiments.[xi]

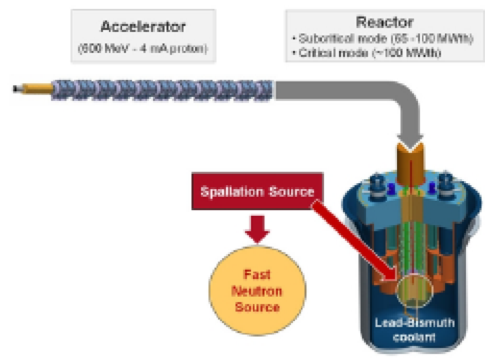


Figure 4: Accelerator Driven System

Beam Experiment Aboard Rocket (BEAR)

In 1989, as part of the Strategic Defense Initiative, a spacecraft was launched with a MeV accelerator assembly weighing 1100 KG and measuring 4 meters long, including non-trivial structural rigid supports. It successfully operated for a sustained period of time. “Factor-of-10 weight and size reductions and increased operational reliability relative to a typical ground-based system were achieved.”[xii] This mission demonstrated flight deployment of an accelerator similar to one that would be necessary for a SANS system.

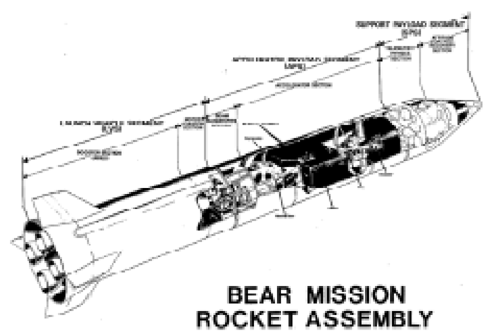


Figure 5: 1989 Spacecraft Accelerator

Accelerator Breeder Reactors (ABR)

Terrestrial reactors using particle beams to produce nuclear fuel have been proposed from time to time, although usually requiring massive GeV proton accelerators as opposed to the comparatively small MeV deuteron accelerators that would be used for space systems.[xiii] “238U ABRs are relatively simple in their construction. They consist of a 238U block, which serves as both the primary and the secondary targets... The main goal of a 238U ABR is the production of 239Pu.” Some of these designs use completely unenriched uranium 238 as the initial fuel. Terrestrial accelerator breeder reactors generally require mechanical and chemical processing of the fuel before it can be used.[xiv]

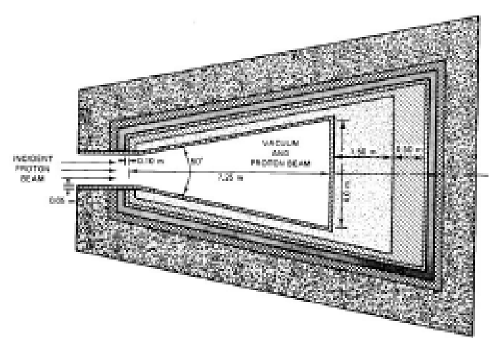


Figure 6: ORNL Electronuclear Fuel Producer

Technical Approach

The SANS concept involves serial processes: generation of a high energy ion beam, production of neutrons by beam-target interactions, and neutron-nucleus interactions in the core. This process is to be characterized in the proposed study through computational analysis.

Beam-Target Configurations

Beam-target interactions are the primary expertise of Linac Systems, which will leverage its extensive expertise in developing accelerator neutron sources to provide initial neutron flux data from their historical database. These cases are shown in Table 1. These results will serve as input to the core activation calculations. The second item in Table 1 results in fusion 14.3 MeV neutrons. In the other processes, the neutron energies are dependent on the beam energy.

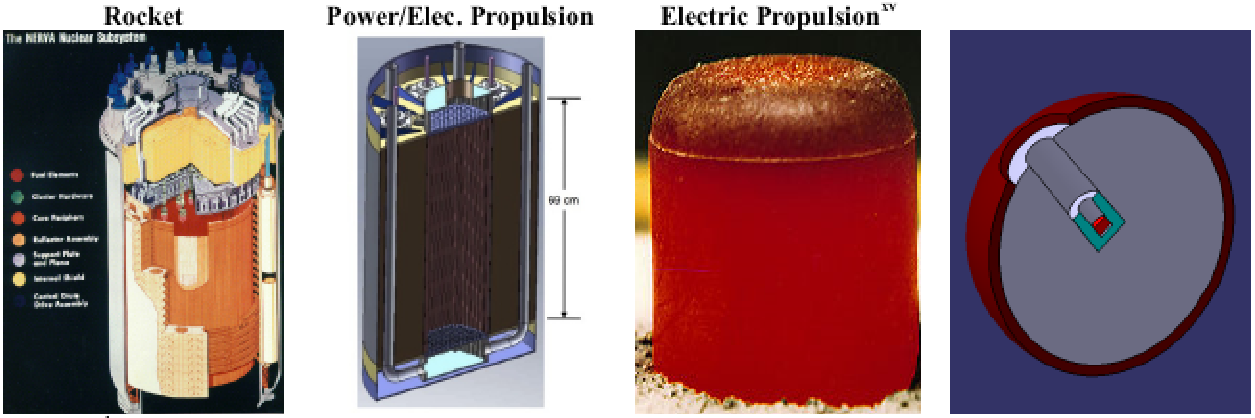
Table 1: Representative beam- target calculations

Beam Species	Beam Energy	Target	Core material
Deuteron	1.5 MeV	Li, Be	U238, Th232
Deuteron	200 keV	Tritium (T)	U238, Th232
Deuteron	10 MeV	U238	N/A

Core Configurations

To maximize relevance ongoing NASA research and future missions, the nominal cases for analysis in this study are to be based on the currently considered NASA geometries with both Uranium 238 and Thorium 232 fuel. Figure 7 shows the range of reactor types including criticality limited, burn up limited, non critical radioisotope thermal generator, and a simple reflected sphere.

Propulsive Thermal Rocket	**Surface or Spacecraft Power/Elec. Propulsion**	**RTG for Payload Power, Electric Propulsion[xv]**	**Reflected Sphere**



367[xvi]-1500 MWt	**186 KWt**	**500 Wt**	**TBD**
10 hour life	**8 year life**	**17 year life**	**TBD**

Figure 7: Reactor Fuel Configurations to be Characterized

The dimensions and materials for these reactors are well known, and the actual concepts will provide relevant comparisons for the results of the SANS analyses. In some cases, MCNP model geometries of the cores previously developed in NASA and DOE studies may be available for incorporation into the SANS activation modeling.

Numerical Analysis of Activation Process

The activation process for the actual core will be studied using several industry standard neutronics codes. The analysis will incorporate the neutron flux data provided by Linac Systems as input to the code to assess core activation and all associated reactions. Rather than convert to fuel, some of the fertile material may undergo fission directly and provide additional neutrons to affect conversion of other atoms. This must be considered in the analysis, as this affect may dominate the total neutron intensity. In the analysis, the MCNPX transport code and the ORIGEN burn up code are run in tandem using the MONTEBURNS package to link the results. This is necessary to track both transport of the beam and fission neutrons. A representative example of such an analysis is shown in Figure 8. In this analysis, 14.3 MeV neutrons are created at the center of a cylinder of uranium 238. The profile of activation rate is illustrated. Full analysis would involve integrating this process over an extended period of time while updating the composition of the material to account for the changing reactivity and intermediary products.

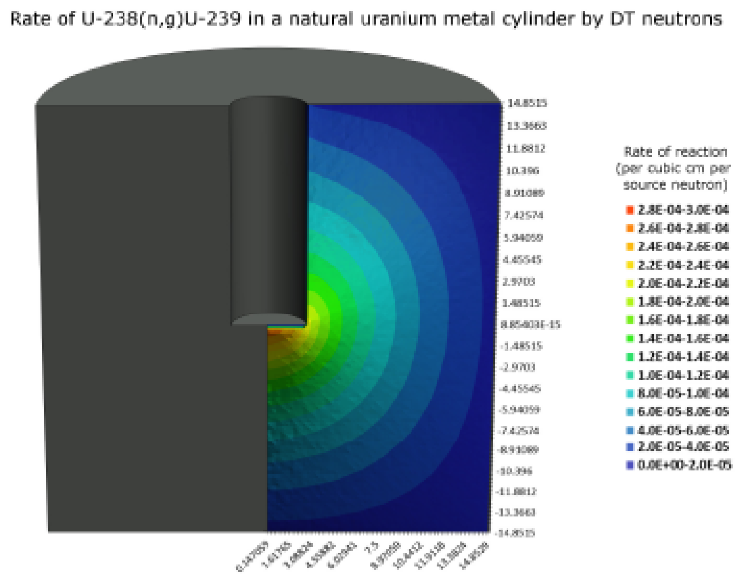


Figure 8: Uranium Transmutation Rate from a D-T Neutron Source.

Characterization of SANS Performance vs. Conventional Systems

The goal of phase one of this research program is to established weather or not criticality can be achieved and how the system will perform after criticality. The specific configurations will not be optimized for performance, rather they will be easy to model and compare to the conventional systems upon whose geometry they are based. The post-critical thermal power generation capabilities of the systems will be compared (in units of KWt per KG) between conventional and SANS reactors. Future studies, such as NIAC phase two, will identify optimal geometries and fuel loading to maximize thermal output and minimize activation time.

Assessment of Beam/Target Requirements

The activation calculations of time to criticality will be integrated with corresponding beam parameters to determine beam power, voltage, sizing and mass requirements. For a space based system, the total system will include the solar power system, electronics, thermal management, reactor, and accelerator subsystem. The power, mass, and neutron flux requirements will drive the design of the beam and neutron target subsystem.

Work Plan

The team will meet two to four times a month and submit bi-monthly status reports to NASA.

Milestones

There are three main phases of the effort: Initial data gathering and requirements definition, neutronic analysis and component characterization, and roll up to system and mission capabilities.

Component Interface and Geometry Requirements Complete (Sep 2011)

After an initial data gathering exercise on currently proposed and studied space nuclear systems and an assessment of launch vehicle payload capabilities, we will define the requirement for the alternative reactor geometries, fuel chemical and isotopic compositions, and accelerator sizing & power envelope. Also, the performance measures to be used in the final report to assess architecture and mission capabilities shall be defined. This data will be delivered to Linac Systems. Upon delivery, Linac Systems will have all the information necessary to execute the component initial design and performance characterizations.

Neutronic Analysis and Component Characterization Complete (Apr 2012)

- Beam Characterization: There are three main requirements on the beam: The heat rejection and power supply ability that a spacecraft bus would realistically be able to provide (driven primarily by the mass of the launch vehicle) and the requirement on the beam from the neutron target and nuclear reactor, which call for a certain species, energy, and intensity of incoming particles. The neutron target itself is at the interface of the beam and the nuclear reactor, and will be defined collaboratively and iteratively between the processes of defining the accelerator and the reactor.
- Neutronic Analysis: With the beam spectrum defined and the behavior of the target characterized, the MONTEBURNS and MCNPX code will be used to integrate the reaction rate with the changing isotopic composition of the reactor to assess the distribution of fissile material over time through criticality. After this distribution has been defined from the initial time to the point at which the accelerator is no longer needed to achieve criticality and a sustained reaction in the reactor core, MCNPX and MONTEBURNS will be used to characterize the thermal output of the reactors with a given control mechanism configuration.

Roll-up to System/Mission Capabilities (Jul 2012)

- Systems Analysis: Data on activation time and post activation thermal output, trajectory analysis and space mission design for realistic spacecraft mass will be determined to quantify the payload ability, power generation ability, and mission concept of operations that would be possible with the given nuclear power and propulsion systems.

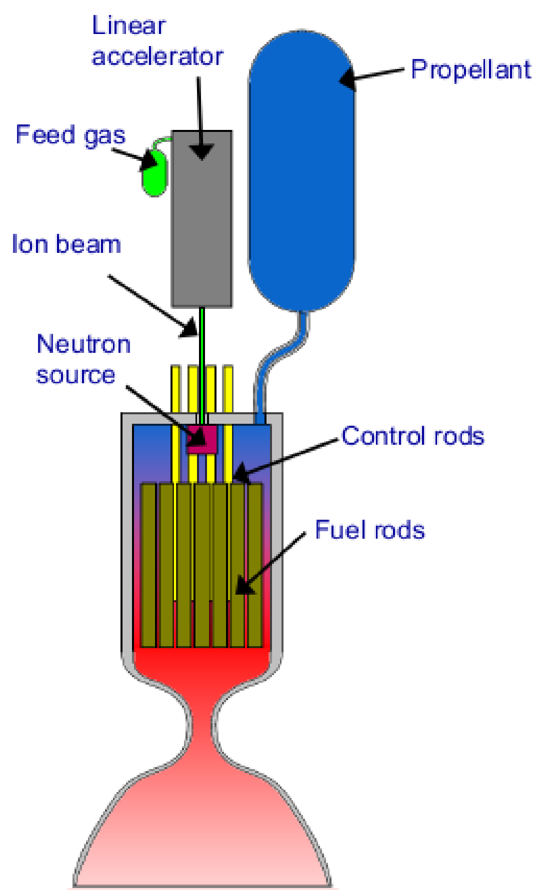


Figure 9: SANS NTR

- Final Report: The final report will use the data obtained from the neutronic analysis and consultation with civil servants at NASA-GRC to address the different classes of missions enabled by this technology, as well as the required activation time and accelerator power levels required. It will also put this information into context with the regulatory environment for space missions with nuclear systems, and the likely regulatory requirement levied on a SANS mission.

Capabilities/Responsibilities of Team Members

- John Benac will conduct a literature review and work with technical mangers at NASA-GRC to obtain geometry data for currently studied space nuclear systems. He will use that data to generate requirements that Linac Systems will use to perform the neutronic analysis and size the accelerator. John will use the outputs from Linac Systems to assess the capabilities of enabled NASA missions and architectures using the SANS technology.
- Dr. Jim Gilland will collect and interpret existing NASA space nuclear reactor concepts for activation analysis, and provide systems modeling of the overall SANS system including and power and thermal management.
- Dr. Carl Willis will model the reactor systems with the MCNP code and use the ORIGEN and MONTEBURNS codes to characterize the end-to-end behavior when in operating conditions. Dr Willis will also collaborate with Dr. Swenson to identify the correct neutron target composition and behavior for the various reactors considered.
- Dr. Donald Swenson will use the given power and environmental requirements as well as his collaboration with Dr Willis on the target configuration for defining the accelerators that provide the necessary beam characteristics for the different test cases.

Impact to the State of Knowledge in the Field

Answering the questions about the integrated behavior over time of irradiated fertile uranium and thorium compounds configured in space activated nuclear systems will provide a basis by which a multitude of space system architectures can be developed in the future. The MCNP code will also set the stage for ground testing using readily available accelerators and neutron spectroscopy techniques to validate the results of this study. As this technology matures, mission planners and program administrators will find that the superior performance of space nuclear systems is within reach, and our exploration will likely accelerate as mission planners come to more efficiently use these resources. SANS will enable the missions to the outer solar system that NASA plans to implement while solving critical environmental and safety concerns. The NASA technology roadmap declares that "if the Pu238 availability issue is not resolved, there is a need to develop and qualify alternative nuclear heat sources."[xvii] This method gives us the new heat source.

Data-Sharing Plan

Beyond full participation in the NIAC Fellows Conference, the results of this work are intended to be submitted for publication in a scientific publication, and presented at an appropriate technical conference such as the Space Nuclear Power and Propulsion Conference. OAI researchers are also available for guest lectures and meeting with students at member universities to further discuss the results of the study.

References and Citations

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[xvii] V.J. Lyons, "DRAFT Space Power and Energy Storage Roadmap Technology Area 3," National Aeronautics and Space Administration, November 2010

Biographical Sketches

John W Benac

Mechanical Systems Design and Analysis Engineer
Analyze architecture impacts of turbo generator on Thrust Vector Control and Electrical Power systems for Ares 1 and extensibility to future vehicles.
Assemble and provide historical data on payload accommodation methods for SLS with multiple heavy payload manifests
Evaluate mission architectures for flight demonstration of in space cryogenic transfer and storage
Space Station Logistics Engineer, Boeing Space Exploration, Houston TX May 08-Dec 2010
Physically inspect discrepant ISS hardware at KSC and implement repair plan in context of program sparing needs
Resolve configuration & delivery problems of hardware between suppliers, Boeing, & the NASA next level integrator
Use rapid prototyping in development cycle for urine brine and nitrogen & oxygen storage/distribution systems
Derive level 0 requirements for Boeing's CCDev commercial crew capsule system
Special Project, Boeing Space Exploration, Houston TX May 09-Present
Sole inventor for patent application for fundamentally safe "space-activated" nuclear reactor
Developed concept through internal Boeing technical reviews as well as consultation with NASA nuclear surface power and in-space propulsion project leads on site at NASA-Glenn
Built team within Boeing, and with subcontractors to mature technology
Manufacturing Engineer, Boeing Commercial Airplanes, Renton WA May 07-May 08
Designed, Prototyped, and tested improved exit door armrest to reduce manufacturing and maintenance costs
Coded real time online dynamic visualization of design engineering data exchange with suppliers resulting in a 40% reduction of late data submittals
Performed photogrametry on critical geometry of as-built 737 interiors to create 3D model & and provide tolerance data to update hardware envelope requirements levied on suppliers
Teaching Assistant: BYU School of Engineering, Provo UT Jan-May 07
Operated & maintained multi-million dollar robotics & automation lab w/ PLC, electric, hydraulic, & pneumatic equipment
Instructed students on operation of instrumentation, robotic programming, hydraulics, and PLC
University Of Southern California, Masters of Science, 2011
Astronautical Engineering: Courses in Power Systems, Remote Sensing, Structural Strength and Materials, Spacecraft Design, Orbital Mechanics, Space Environment and Spacecraft Interactions, Liquid Rocket Propulsion, and Space Launch and Transporation Systems.
Brigham Young University, Bachelors of Science April 07
Manufacturing Engineering Technology: courses in Lean Manufacturing, Six Sigma, process simulation, CAD design, rapid prototyping, automation, entrepreneurship

Father of Three, Eagle Scout

Dr. James H. Gilland—Co Investigator

Dr. Gilland has over 25 years of experience in plasma propulsion and low thrust mission analysis. His graduate work focused on the effects of size on MPD thruster performance (Princeton), and helicon wave heating of plasmas (University of Wisconsin). He previously worked at NASA Lewis/Glenn Research Center in the area of Nuclear Electric Propulsion (NEP) mission and system analysis from 1987–1993, including service in the Advanced Space Analysis Office (1987–1990) and then as Lead NEP System Engineer in the NASA Nuclear Propulsion Office. In these positions, he performed mission, system and technology assessments of multi-megawatt NEP missions to the Moon and Mars.

At OAI, he has examined advanced high power and electrodeless plasma propulsion concepts, both experimentally and theoretically. His work in quasi-steady MPD thrusters spans a power range from 1–300 MW_e, both at NASA GRC and the Ohio State University. In parallel, Dr. Gilland provided system and mission analysis assessments of both currently available and postulated electric propulsion concepts, including unique system and performance models for advanced thruster concepts. He also provided applications analysis and test support for the DARPA FAST solar power system in 2010. He has authored or co-authored over 25 papers in electric propulsion research and mission design. Dr. Gilland has served on several NASA working groups, most recently the NASA High Energy Power and Propulsion Capabilities Roadmap Team in 2005.

Relevant Publications

Gilland, J. H., "Commercial Electric Propulsion Implications for NASA Missions," Presented at the JANNAF 3rd Spacecraft Propulsion Subcommittee Joint Meeting, Orlando,FL,Dec. 2008.

Gilland, J. H., J. W. Dankanich, and S. R. Oleson, "Radioisotope Electric Propulsion Systems Options for NASA Science Missions," Presented at the JANNAF 3rd Spacecraft Propulsion Subcommittee Joint Meeting, Orlando, FL, Dec. 2008.

Cassady, R., et al., "Recent Advances In Nuclear Powered Electric Propulsion For Space Exploration," J. Energy Convers. Manage., 2007.

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Gilland, J.H., R.M. Myers, J.S. Sovey, and J.R. Brophy, "Nuclear Electric Propulsion: Status and Future," in A Critical Review of Space Nuclear Power and Propulsion 1984-1993, M. S. El-Genk, ed., AIP Press, NY,1994.

Carl A. Willis—Co Investigator

SKILLS HIGHLIGHTS: Experimentalist with experience in radiation detection and measurement, radiation modeling, accelerator target design, and high-voltage and RF power systems.

EMPLOYMENT, INTERNSHIPS, RESEARCH EXPERIENCE

- Linac Systems, LLC, 2006-present. Development of accelerator target system for boron neutron capture therapy; accelerator radiation-protection calculations and design of accelerator shielding; accelerator operator.
- Los Alamos Neutron Science Center (LANL), summer 2005. NE Graduate Fellowship internship. Worked with G. Muhrer on target neutronics for the NXGENS long-pulse spallation neutron source. Extensive use of MCNPX on Linux parallel-processor platform.
- The Ohio State University Nuclear Engineering Program, 2003-2006. Conducted radiobiology experiments involving mixed-field dosimetry at the OSU Research Reactor with T. E. Blue and R. Barth.
- Linac Systems, LLC, summers 2003-2004. Calculations for accelerator-based neutron activation analysis; EM field modeling for RFI linear accelerator prototype using SOPRANO.
- ERULF (Energy Research for Undergraduates Fellowship), Oak Ridge National Laboratory, Summers 2001-2002. Performance measurement of sol-gel neutron scintillation detectors with S. Dai; Development of control system for acoustic-resonance spectroscopy with D. Bostick.
- REU (Research Experience for Undergraduates), Kansas State University Physics Department, Summer 2000. Development and characterization of a Mo^{3+} PIG ion source.

EDUCATION

- Ph. D. Nuclear Engineering expected 2010, The Ohio State University, Columbus, OH
- M.S. Nuclear Engineering, The Ohio State University, Columbus, OH (2006)
- B.S. Physics and Chemistry, Guilford College, Greensboro, NC (2003)

PUBLICATIONS

- C. Willis, D. Swenson. "High-power lithium target for accelerator-based BNCT," Proc. 24th Linear Accelerator Conference (Linac08), Victoria BC, Sept. 29-Oct. 3 2008
- C. Willis, G. Muhrer. "Target system neutronics study for NXGENS," NIM A 570, 374-383
- "Neutronics and shielding design of an accelerator-based neutron source for neutron activation analysis" (M.S. Thesis, Ohio State University, 2005)
- H. J. Im, C. Willis, M. D. Pavel, S. Saengkerdsub, S. Dai, "Transparent Matrix Structures for Detection of Neutron Particles Based on Di-ureasil Xerogels," App. Phys. Letters 84, 2448-2450.
- "Neutron Activation Using a Farnsworth Fusor" (B.S. Thesis, Guilford College, 2003)

ACTIVITIES

- Secretary, Buckeye Chapter Health Physics Society (2004-5)
- Treasurer, OSU American Nuclear Society Student Chapter (2004-5)
- Treasurer, OSU Amateur Radio Club (2003-5)
- Planning committee, ANS Student Conference 2005
- Extra-class licensed amateur radio operator (KF4KIG)

HONORS / AWARDS

- DOE Nuclear Engineering Graduate Fellowship, 2004-2007
- American Institute of Chemists Senior Award, 2003
- Charles B. Dana Scholar, 2002 & 2003, Guilford College
- Sigma Pi Sigma Physics Honor Society

Dr. Donald A. Swenson—Co Investigator

Chief Scientist, Linac Systems

Dr. Donald Swenson joined the staff of the Midwestern Universities Research Association after completing his PhD in Physics at the University of Minnesota in 1958. His first contributions were made in the development of beam diagnostic techniques and he was the first to observe the negative-mass instability in electron storage rings. When the program on the development of the 200-MeV linear accelerator was initiated, Don contributed by developing the beam dynamics computer program, called PARMILA (Phase And Radial Motion In Linear Accelerators), which continues to be the leading beam dynamics program for linacs at the present time.

Don Swenson has been active in the particle accelerator field throughout his career. He was employed at the Los Alamos National Laboratory from 1964-1983 where he played a leading role in the design and development of the drift-tube linac, invented a method of rf field stabilization using post-couplers, was the Principle Investigator for the PIGMI Program (Pion Ion Generator for Medical Irradiation), and designed and built the first RFQ (Radio Frequency Quadrupole) linear accelerator in the Western World. From 1983 to 1986 Don was a Visiting Professor at Texas A & M University where he continued to develop and improve computer programs useful in accelerator design. During the "Star Wars" years, he worked at Science Applications International Corporation (SAIC) from 1986 until 1991, where he continued to develop the RFQ for more practical applications, designed and built a new linear accelerator structure called the Disk-and Washer structure, and proposed a practical fabrication scheme for a superconducting RFQ linac. He joined the Superconducting Super Collider Laboratory in 1991. He is a founder and the Chief Scientist of Linac Systems, LLC (1991-Present), a company whose mission is to develop compact, reliable, and inexpensive proton and ion linear accelerators (linacs) for scientific, medical, industrial, defense, and homeland security applications. Don is the inventor of the very efficient and compact Rf Focused Interdigital (RFI) linac structure, which promises to be a valuable tool in the field of accelerator technology.

Don is an extremely talented experimental accelerator physicist with the ability to incorporate advanced computer programs into his design efforts. He is recognized for his dogged and single-minded pursuit of an idea that others may have cast aside. New ideas and concepts abound in his professional and personal life. Currently he has over 50 years of practical experience with particle beam systems and over15 years as Principle Investigator of accelerator based projects. He has 17 patents for accelerator and beam diagnostic systems.

Summary:	56 years of practical experience with particle beam systems. 20 years as Principle Investigator of Accelerator-Based projects. Appointed a Fellow at the Los Alamos National Laboratory. 3 years as Professor of Physics, Texas A&M University.
Publications:	Over 75 publications, mostly in the field of Accelerator Technology.
Patents:	20 Patents, all in the field of Accelerator Technology.

Current and Pending Support

John Benac is currently supporting the ARES upper stage TVC contract. This is funded by NASA contract NNM07AB03C. In addition to this effort, John is supporting proposal efforts for the NASA Broad Agency Announcement: In-Space Cryogenic Propellant Storage and Transfer Demonstration Mission Concept Studies (NNC11ZCH001K).

Jim Gilland
Pending:

Title: Production of Nuclear Fuel in Space

PI: Mr. John Benac

Co-I: Dr. James Gilland

Solicitation: NNH11ZUA001N

Performance Period: 9/1/11 – 8/31/12

Requested Budget Amount: $

Commitment of Co-I: 10%, or 1 person month per year

Title: The Potential for Ambient Plasma Wave Propulsion

PI: Dr. James Gilland

Solicitation: N1-11NIAC_NOI-0686

Performance Period: 9/1/11 – 8/31/12

Requested Budget Amount: $99,984

Commitment of PI: 40%, or 5 person months per year

Title: Interplanetary Travel with NEO Assist

PI: Dr. George Williams,

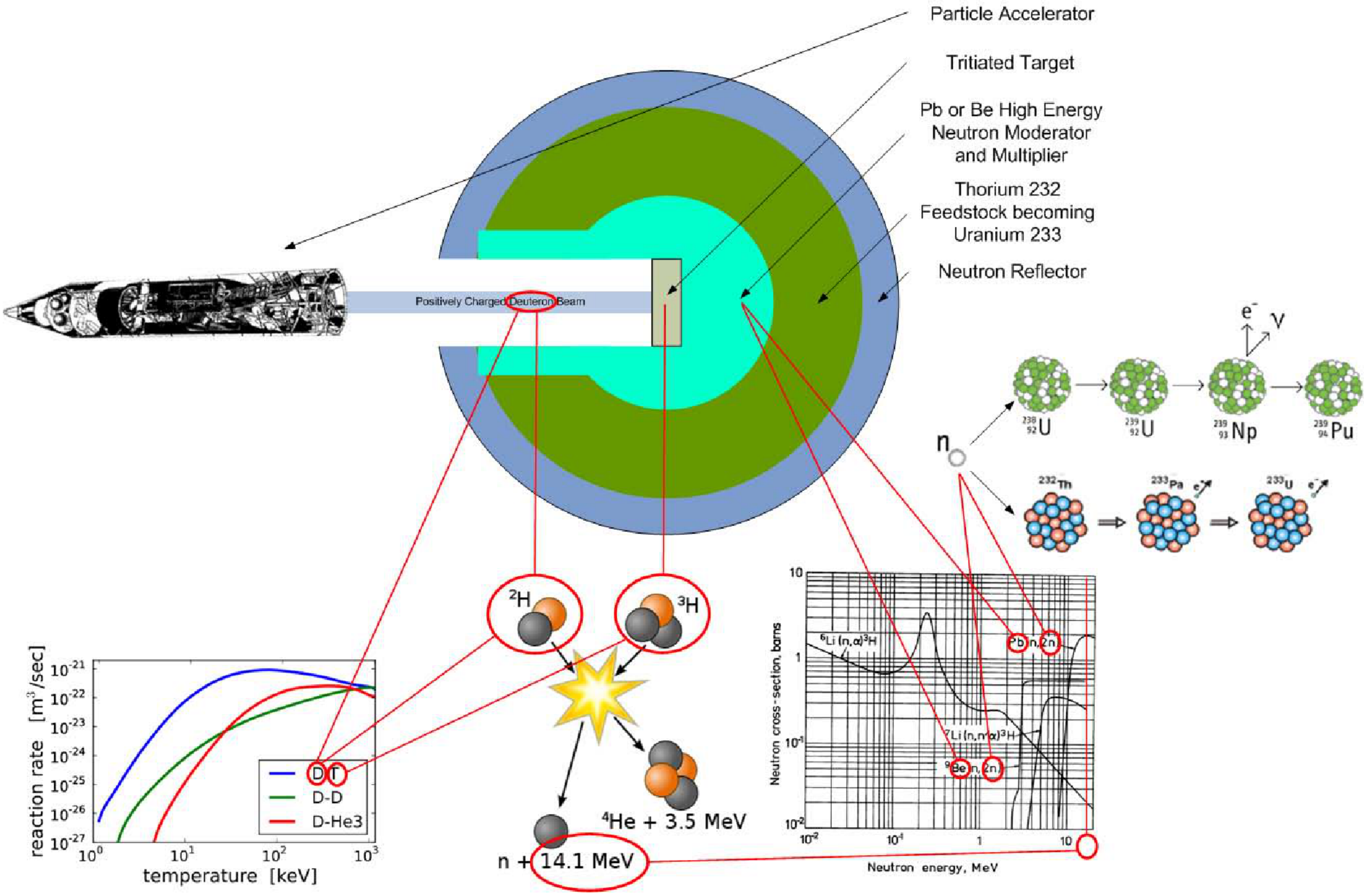
Co-I: Dr. James Gilland

Solicitation: N1-11NIAC_NOI-0334

Performance Period: 9/1/11 – 8/31/12

Requested Budget Amount: $99,980

Commitment of Co-I: 14%, or 3 person months per year



In one implementation of the method, an accelerator fires a ~150 KeV deuteron beam into a tritiated target which in turn produces 14.1 MeV neutrons. The neutrons are multiplied through a lead or beryllium region after which they impact uranium 238 or thorium 232 in order to transmutate those into highly fissile plutonium 239 or uranium 233.