Applications of Space Technologies to Commercial Sector

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Abstract: Several nations across the globe are actively pursuing the exploration of space through space observatories, robotic systems, and humans. These efforts are enabled by the development of needed transformative technologies and methodologies. The complexity of these efforts is underscored by the need to use planetary resources and reuse resources taken from Earth to ensure the safety and cost effectiveness of future exploration missions. With revolutionary logistics methodologies, these efforts will enable sustainable and affordable space exploration. The importance of new technologies for energizing the economic engines of many nations is making it essential to transfer space technologies to the commercial sector. The U.S., through NASA, has implemented programs to transfer patented technologies to the commercial sector for marketplace products and services. In this presentation, examples of several space technologies that have been successfully transferred to the commercial sector are detailed. This multi-use of technologies results not only in addressing unique market needs, but also results in new products that can disruptively influence older technologies and methodologies. Technology transfer areas include health/medical, communication, environment monitoring, sustainability, national security, Earth phenomena sensing, home/office, and recreation. Some of these will be discussed in this paper. A brief mention will also be included on the process of technology transfer.

Keywords: Space exploration, Space missions, Logistics, Computer simulations, Innovative, Technology needs,Safety, Cost effective, Technology transfer process, Markets, Government sector, Commercial sector.

Introduction

Human development and evolution have been fueled by the explorative nature of humans. Exploring what is beyond the pastures, forests, hills, rivers, oceans, and mountains has spread and dispersed humankind here on the Earth. Space is calling on the same human spirit to find the origin of universe and life within it. Programs aimed at launching hardware to sense radiation and observe scenes and phenomena related to pervading energy and matter in the universe are expanding in complexity and frequency. In addition, several nations involved in this enterprise are also pursuing human missions to include the human dimension in space exploration and habitation. Launching of systems and humans into space and proper operation and functioning of space-borne hardware and safe and productive environments for humans in space or on planetary surfaces make the development of innovative technologies and methodologies necessary. As a consequence, nations involved in space exploration are also pursuing the development of these technologies and methodologies [1].For example, in the past 2 years NASA developed a list of grand challenges for space exploration. These listed grand challenges are to:make space accessible and economic; manage climate change; protect astronaut health; prevent orbital debris; develop personalized science, technology, engineering, and math learning; provide economical energy on demand; provide participatory exploration of space; engineer faster space vehicles; secure the planet from space threats;engineer the tools of scientific discovery;develop routine satellite servicing; improve spacecraft safety and reliability;unleash machine intelligence; understand the physics governing the universe; discover life beyond
Earth; forecast natural disasters; provide carbon-neutral mobility; use space resources to explore; and establish conditions for a permanent human presence in space.

To address these grand challenges, NASA has developed detailed Aerospace Technology Area Roadmaps. The areas covered are by these roadmaps are: launch propulsion systems; in-space propulsion technologies; space power and energy storage; and robotics, and tele-robotics as well as autonomous systems; communication and navigation; human health, life support, and habitation systems; human exploration destination systems; science instruments, observatories, and sensor systems; entry, descent, and landing systems; nanotechnology; modeling; simulation; information technology and processing; materials, structures, mechanical systems, and manufacturing; ground and launch systems processing; thermal management; and aeronautics.

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Funding priorities result from a thorough review of the multiple mission technology needs for the near-future NASA program as stated in the NASA Strategic Plan. These funded programs advance the stateoftheart in disciplines that are applicable to the mission, reduce the risk to the flight projects for adopting these technologies, and lower overall life cycle cost. In addition, they formulate and implement technology projects that deliver the required performance on time and within cost and deliver technology products that are used in the flight programs. Consequently, numerous new technologies and methods have resulted from these efforts.

One distinguishing feature of space technology development is the unique space environment in which these technologies must operate. Logistics, cost, and safety considerations also make it necessary to reduce mass, increase reliability and lifetime, and decrease launch size and operating power consumption of the systems. One way to have greater insight into the multidimensional aspects of space technology development is to use computer simulations of the systems in the simulated space environment. This mathematical modeling is deemed to have most the significant payoff in identifying successful designs and resultant technology needs. Some of these aspects will be discussed in this paper. Thus, technologies for space have to be modified for cost-effective (in comparison with other technologies in use) production and operation on Earth. In view of this, innovative space technologies are constantly being evaluated to identify their potential for the commercial sector. Usually market needs dictate the path for technology transfer. We will detail some examples of this technology transfer in this paper.

Some Technology Development Challenges for Space Exploration

The space and planetary surface environments pose multiple technology development, system design, and operational challenges. Space technology needs are continually being researched to reflect new insights gained in the space and surface environmental parameters. A few of these technology needs and environmental aspects are covered in Reference 2 and will be briefly mentioned here. Low-Earth orbits such as that of the International Space Station (ISS) are characterized by microgravity, vacuum, solar cosmic radiation and high-energy particles, unique temperature and lighting conditions, and moving debris. Some of these parameters change with time, location of the spacecraft in the orbit, and location on the spacecraft. Therefore, spacecraft systems and imbedded technology have to operate safely in such a dynamic environment. For example, the temperature on the ISS can vary from approximately -300°F to +300°F depending on the location on the ISS and the location of the spacecraft in the orbit. Systems therefore have to be developed either to be able to function within this range of temperatures,or to be put in an enclosure controlled through active or passive thermal temperature stabilization to allow them to operate within their individual safe operating temperature ranges. Orbital debris of sizes ranging from a few millimeters to tens of centimeters has grown considerably in the past 2 decades. There have been encounters with the shuttle and close encounters with ISS. Consequently, attention has to be paid to materials and shielding systems as well as to mission execution to operate a spacecraft safely in Earth orbits. The solar cosmic radiation and high-energy particles emanate from solar activity and have a cyclic nature, as shown in Figure 1[3].These solar-generated radiation and particles haveboth sporadic and cumulative effects and can cause single event effects (SEEs) and single event upsets (SEUs) in electronic systems. Thus, systems that can operate with specified total ionized doze (TID) andmean time between failures (MTBF) are needed. The effects of solar radiation and particles on astronauts show that these can increase the occurrence of cancer, cardiovascular disease, and cataracts, and can also cause damage to the central nervous system. Therefore, solar radiation and particles are considered a major concern for long-duration human space missions. Consequently, biological and technological innovations are necessary to minimize these human health risks.

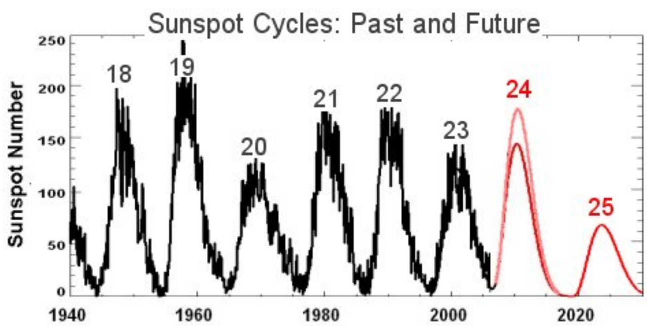

Figure 1. Sunspot number past and future prediction.

In choosing any outpost location on an asteroid, Mars, or the Earth's moon, consideration has tobe given to having an area with the least possibility of experiencing falling meteorites and minimal solar cosmic radiation and particles. The area should also be of scientific interest, provide a suitable landing site, be useful for oxygen production, have sunlight available, have line-of-sight communication with

Earth, and host nearby permanently shadowed areas for potential in-situ water production. At some of the possible outpost locations, the lunar surface temperatures can range from –299°F to 250°F[4]. The predicted maximum diurnal lunar surface temperature is shown to decrease from about 250°F to 88°F[4] and from 0- to 70-deg latitude (Figure 2).

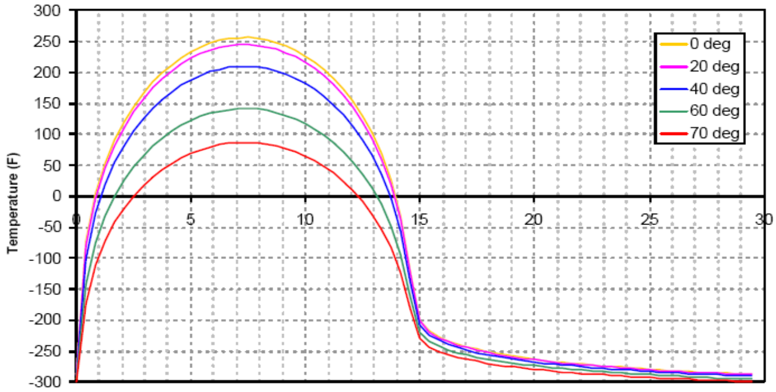

Figure 2. Predicted diurnal lunar surface temperatures as a function of latitude[2].

Figure 3 shows approximate values of temperature cycle on the Mars ranging from –225°F to +64°F. This is based on Mars Pathfinder data and NASA calculations. Asteroid, lunar,or Mars locations will be chosen to optimize the objectives set by a particular nation. These objectives may include conducting scientific

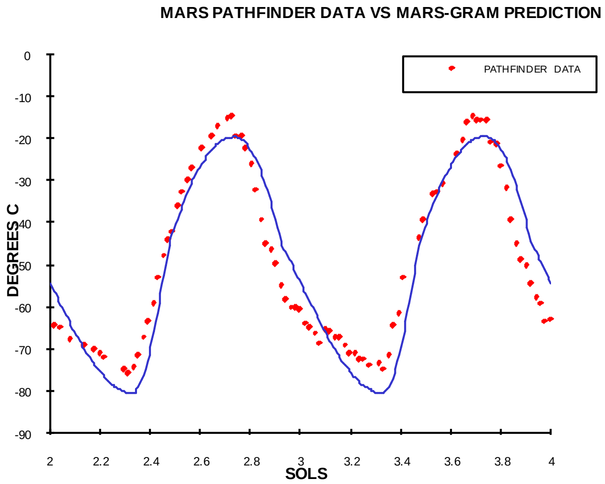

Figure 3. Typical Mars daily temperature at Pathfinder location.

investigations, learning to survive on another planet, and overcoming the health and logistics issues of journeys. The lunar surface with the lower maximum temperatures exists above 70 deg latitude. Further analysis and measurements need to be conducted to determine the maximum and minimum temperatures on latitudes above 70 deg on the moon. It should be noted that there may be an absence of sunlight at the higher lunar latitudes. As mentioned earlier, ionizing radiation is one of the most significant hazards for both hardware and humans in space. This hazard will have to be addressed for all destinations in space.

Mars atmospheric pressure varies from .1 to .15 psia, as compared to 14.7 psia on Earth. Approximately 95% of the martianatmosphere is carbon dioxide. It also has small percentages of oxygen, nitrogen, and argon. The Mars atmosphere can be used to produce oxygen for human and other uses. The unpredictable environmental factor on Mars is the presence of regional dust storms. These storms can be thousands of miles wide and produce severe effects on both infrastructure and mission operations. In addition, as with the moon, water production/harvesting may need unique technology to make it economically viable.

A significant environmental factor on the moon is lunar dust. This dust is abrasive and prevalent everywhere. During the Apollo Program, astronaut spacesuits and equipment were covered with lunar dust within hours into the mission (Figure 4). Furthermore, the dust caused lens scratches and corrosion of the seals. Some astronauts experienced an allergic reaction to the dust. Risks for prolonged exposure to lunar dust will include mechanical failures in spacesuits and airlocks, lung disease, and decreased efficiency of solar energy panels. Mars dust will have similar consequences.

Figure 4. Lunar dust covers the lower part of Astronaut Harrison Schmitt's spacesuit during the Apollo 17 mission.

The solar light and galactic radiation environment will continue to have a pronounced influence on many aspects of the lunar outpost and a human mission to Mars. The moon has no atmosphere, which results in direct incidence of sunlight and galactic cosmic rays (GCR) and particles. As a result, there is no scattering, diffusion, and attenuation resulting in no bending of light and other radiation. In addition, the reflection coefficient of the moon is very low for visible light. Thus, there is no multiple scattering on the surface. All these effects lead to an extremely high contrast between dark and lighted areas. Partial atmosphere on Mars makes the light environment complex and highly variable because of winds and dust in the atmosphere. For both the moon and Mars, energetic and sporadic GCR can add to the complexity of the light environment.

The use of solar energy for powering surface systems; making human habitation productive and pleasant; and growing plants in asteroid, lunar and Mars zeoponic soils will require new technological solutions. The lack of atmosphere on the moon and the presence of the martian atmosphere will present differing challenges for solar energy utilization. The presence of dust on planetary surfaces can be detrimental to human health and damaging to the surface systems and extravehicular suits. The presence of atmosphere on Mars compounds the complexities for experimentation and habitation because of dust storms. The gravity on Mars is approximately 38% of the value on Earth. For the moon it is about 17%. For the asteroids, it will depend on the asteroid we decide to explore.This gravity environment will affect functioning of some systems/instruments and human health and productivity on the asteroids,moon, and Mars. The effects of partial gravity on humans and living organisms are not fully understood and need further study. Results todate have shown a profound effect on the health of humans in microgravity environments. Thus, new methodologies and technologies need to be developed to keep humans healthy and productive and to grow crops and recycle resources in this environment.All of these environmental parameters have to be considered in identifying needs and developing technologies for space exploration.

Space Technology Transfer to Commercial Sector

Technology transfer has been referred as the means to the shift of tools, techniques, procedures, and/or the legal titles thereto used to accomplish some human purpose[5]. The U.S. Geological Survey uses the following definition: "A process through which technical information and products developed by the definition for technology transfer adopted by federal government are provided to potential users in a manner that encourages and accelerates their evaluation and/or use."

For NASA such transfer is aimed at the incorporation of new/modified technology in space endeavors characterized by mission hardware, ground and space operations and laboratories, and commercial use of the technology. In the private sector, technology is normally developed and adopted in four main stages: 1) research, 2) development, 3) application, and 4) marketing. The common element technology transfer is that there is something being achieved within the research and development activities of an organization that will fulfill the mission, and that these results have value to others. The U.S. federal government has created programs in several agencies to share this value where it is needed, especially in the private sector[6].

Innovative technology development in U.S. federal agencies is justified on the basis of need for agency systems, projects, and programs. Thus, each agency assigns high priority to the infusion of new technology to its systems, projects, and programs[7]. In fact, within the agency technology transfer becomes successful as a result of developing focused technology by closely addressing the needs identified by its missions, programs, and projects offices. A continual dialogue between the developers and the users/customers of the technology is necessary for the successful utilization of the newly developed technology.A critical element is providing solution to an identified need during this interactive period.

Examples of NASA Technology Transfer

A lifesaving example of NASA technology transfer is the Ventricular Assist Device (VAD) [8]. This device was developed to bridge the gap between heart failure and transplant. Early devices were cumbersome, damaged red blood cells, and increased the risk of developing dangerous blood clots.A relationship between NASA and Drs. DeBakey and Noon was thus formed, and the group worked to develop a low-cost, low-power, implantable VAD. The VAD design used NASA turbopump technology and computational fluid dynamics analysis capabilities to optimize performance. NASA patented the technology that was adapted to reduce pumping damage to red blood cells and the design of a continuous flow heart pump.The technology and methodology were licensed exclusively to MicroMed Technology, Inc., USA. Figure 5 shows a cross section of the earlier VAD and its root, the shuttle with the implanting scheme. Figure 6 is the recent VAD.These pictures are from NASA and MicroMed Cardiovascular Inc. [8].

In late 1998 MicroMedreceived international quality and electronic certifications and began clinical trials in Europe. Todate more than440 implants worldwide have been successfully carried out, accounting for more than 130 patient years of life.

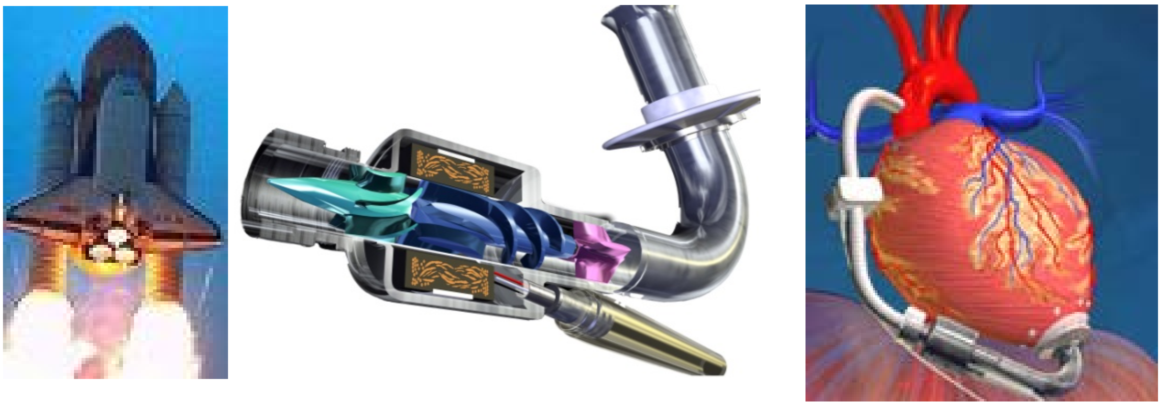

Figure 5. Cross section of the earlier VAD and its root, the shuttle and implanting scheme.

Figure 6. Recent VAD (Picture courtesy of MicroMed Cardiovascular Inc.).

NASA researchers at the Johnson Space Center (JSC) were investigating the effects of long-term microgravity on human tissues. To provide a method for recreating such conditions on Earth, Dr. David Wolf, Tinh Trinh, and Ray Schwarz developed a horizontal, rotating devicecalled a rotating wall bioreactorin the mid-1980s [9]. This device allowed a three-dimensional growth of human cells. Dr. Thomas Goodwin of JSC proved the bioreactor could successfully cultivate cells using simulated microgravity. In this way three-dimensional tissues that more closely approximate those in the body could be produced.Further bioreactor experiments conducted on the Russian Mir space station and on space shuttle missions demonstrated that theperformance was enhanced and resulted in remarkable level of tissue formation.

As stated in Reference 10, "A closed tubular cylinder forms the bioreactor's cell culture chamber, which is filled with a liquid medium in which cells grow. The chamber rotates around a horizontal axis, allowing the cells to develop in an environment similar to the free fall of microgravity. Oxygen, required by cells for growth, is fed into the liquid medium through a [silicon membrane which is not porous] in the chamber. The importance of this cell culture technique is that fluid mechanical conditions obtained in microgravity, and emulated on Earth, allow the growth of tissues in the laboratory that cannot be grown any other way."

Furthermore, as stated in this reference: "Lab-grown cell cultures tend to be small, flat and two-dimensional, unlike normal tissues in the body. However, tissues grown in the bioreactor are larger and three-dimensional, with structural and chemical characteristics similar to normal tissue. The bioreactor has no internal moving parts, which minimizes forces that might damage the delicatecellcultures."

In Reference 10 the licensing arrangements of NASA for bioreactor are given as follows: "The bioreactor is a spinoff technology that entered the commercial world when Synthecon licensed it in 1993. Regenetech Inc. licensed 11 patents from [JSC] in 2001 to produce three-dimensional tissues in the bioreactor. Regenetech, through a special NASA agreement, provides the technology to researchers pursuing rare disease treatments. In December 2010, Emerging Healthcare Solutions Inc. acquired a sublicense from

Regenetech to use the bioreactor. The bioreactor is manufactured for commercial sale by Synthecon.

The progress made in using the low-shear microgravity environment offered by bioreactor systems is detailed in Reference 11. In this paper the rotating wall vessel (RWV) is used for bioreactor systems. This paper states that there are a number of therapeutic applications in which tissues engineered in RWV are approaching clinical use.The photographs in Figure 7, which were provided by Synthecon, show several configurations of the systems for various applications produced by this business.

Figure 7. Photographs of bioreactors (RWVs) manufactured by Synthecon.

A rotating device developed by NASA inventors to grow better living tissue specimens was inducted into the Space Technology Hall of Fame Thursday, April 14, 2011[10].To be eligible for induction, the technology has to have a worldwide market impact in addition to having a success story of great significance for the small business.

Five NASA JSC Small Business Innovation Research(SBIR) and Small Business Technology Transfer Research (STTR) technologies have been inducted in the Space Hall of Fame since 2004[12,13]. Two technologies developed underthe JSC SBIR Program were inducted in the Space Technology Hall of Fame in 2004. One of these is the LadarVision 4000 – Alcon (Figure 8), which was originally developed by Autonomous Technologies. Laser-assisted in-situ keratomileusis (LASIK) is the most widely performed procedure for vision correction. It uses a laser and an eye tracking device to reshape the cornea.

Figure 8. 2004 Inductee LadarVision 4000 –Alcon.

The eye tracker in the LASIK system (Figure 8) is based on technology used to assist spacecraft in delicate docking maneuvers. This technology enables LASIK to provide unmatched spatial precision for laser vision correction surgery. As a consequence of the success of LASIK surgery, fewer people now need eyeglasses or contact lenses.

Figure 9. The MedStar Monitoring System.

The other 2004 inductee is the MedStar Monitoring System (Figure 9) developed by Cybernet. This research was funded by NASA, the National Institute of Mental Health, and the Defense Advanced Research Projects Agency. It resulted in a miniature physiological monitoring device capable of collecting and analyzing a multitude of signals in real time. This device is also used to monitor ISS astronauts.

The cost of caring for the chronically ill at home, in remote locations, and in inaccessible areas continues to grow. The monitoring and remotely prescribing remedial actions via telemetry show significant patient health improvements. This innovation promises worldwide applications to health care.

Figure 10. 2005 Inductee NanoCeram.

One of the technologies inducted in 2005 is the Nano Ceramic Sterilization Filter by Argonide Corporation (Figure 10). This technology is based on NanoCeram alumina fibers, only 2 nanometers in diameter, which can be produced in multi-kilo quantities.

The fibers are highly electropositive in water and attract and retain electronegative particles, such as virus, bacteria, mammalian cells (osteoblasts), endotoxins, and macromolecules such as DNA and RNA.Key applications for this technology are chromatography; filtration of DNA, RNA, and endotoxins; sterilization of pharmaceuticals and medical serums; production of potable water; medical and dental office applications; and as a collector for biological warfare detectors.

In October 2002, the firm's new point-of-use microbiological filters received a major Environmental Protection Agency (EPA) grant for removing arsenic from drinking water to meet the new 10-µg/L standard. NanoCeram fibers, owing to their high surface area, are capable of removing trace toxic metals from water. The EPA award funds the development of a household filter capable of removing arsenic from drinking water to satisfy the new 10 µg/L specification. The unique property exhibited by the newly identified family of oxide fibers is its ultra-small, 2-nanometer diameter with an aspect ratio from 20 to 100. NanoCeram fibers deliver substantially increased strength, support, and insulation to metals, plastics, polymer-matrix, and biomaterials.

Figure 11. 2005 Inductee Outlast liners.

The other 2005 inductee is the Triangle R&D Corporation/Outlast Technologies, Inc.-developed spacesuit glove liner with enhanced thermal properties for improved comfort (Figure 11).The technology is based on micro-encapsulated phase change materials (MPCMs) as a newthermal management system for fibers and fabrics.

MPCM can be as much as four times more effective than systems that use trapped air for insulation. Boston Harbour, LLC of New York City has partnered with Outlast Technologies, Inc. of Boulder, Colo. to launch a complete line of men's and women's casual outerwear, using Outlast liners with revolutionary Adaptive Comfort technology. Under the brand PROSHIELD "Smart Apparel" consumers can experience all-day comfort powered by Outlast's patented phase-change fabric technology. This technology is also used in EvenTemp Bedding by Wamsutta. Marketed under the trade name Outlast Temperature Regulation and your Own Comfort Zone, this technology is covered by multiple U.S., European, and Japanese patents.

In 2007 the microbial check valve (MCV), developed by Umpqua Research, was inducted into the Space Technology Hall of Fame (Figure 12). The MCV system was originally developed for NASA to provide advanced water purification for the space shuttle and eventually the ISS. This technology eliminates bacteria and viruses in contaminated water using a patented ion exchange resin feature that removes virtually allresidual iodine from treated water and is the core of the water purification systems now deployed in rural areas and developing countries.

Figure 12. 2007 Inductee MCV.

Another example of NASA space technology that will be greatly used on Earth is the SolarPower Refrigeration System. This NASA-patented system consists of a photovoltaic (PV) panel, vapor compressor, thermal storage and reservoir, and electronic controls (Figure 13).

Figure 13. Solar Power Refrigeration.

Sunlight energy is converted into direct current (DC) electrical power through a PV panel. The DC electrical power drives the compressor to circulate refrigerant through a vapor compression refrigeration loop that extracts heat from an insulated enclosure. This enclosure includes the thermal reservoir and a phase change material that freezes as heat is extracted from the enclosure.

This enclosure includes the thermal reservoir and a phase change material that freezes as heat is extracted from the enclosure.

In Reference 14 the history and recent status of this technology are described as follows: "In the midst of developing battery-free, solar-powered refrigeration and air conditioning systems for habitats in space, David Bergeron, the team leader for NASA's Advanced Refrigerator Technology Team at [JSC], acknowledged the need for a comparable solar refrigerator that could operate in conjunction with the simple lighting systems already in place on Earth. Bergeron, a 20-year veteran in the aerospace industry, founded the company Solus Refrigeration, Inc., in 1999 to take the patented advanced refrigeration technology he co- developed with his teammate, Johnson engineer Michael Ewert, to commercial markets. Now known as SunDanze Refrigeration, Inc., Bergeron's company is producing battery-free, PV refrigeration systems under license to NASA, and selling them globally."

Concluding Remarks

The exploration spirit of humans is providing impetus to nations across the globe to plan and implement space missions. The successful conduct of these missions is only possible through new technologies enabling systems and humans to function in space and planetary surface environments. The space environment is challenging in many respects, as has been stated in this paper. Thus, revolutionary technologies are needed for use in space missions. These technologies are simultaneously being investigated for use here on Earth to address marketplace needs. In addition, these technologies bring new products and services to the consumers, thereby priming the economic engines of nations.

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References

[1]Krishen, Kumar, Need for Space Technology and its Impact on Our Lives, Guest Editorial, *Indian Journal of Radio and Space Physics*, Vol. 36, No. 4, pp. 245-247, Aug. 2007.

[2]Krishen,Kumar,Technology Needs for Future Space Exploration, *Institution of Electronics and Telecommunication Engineers Technical Review*, Vol.26, No.4, pp.228-235, Jul-Aug 2009.

[3]Kundrot, Craig E., Susan Steinberg, and John B. Charles, Human System Drivers for Exploration Missions, *NASA Human Research Program Report*, November 2010.

[4]Lunar Architecture Focused Trade Study Final Report, Rickman, *S., NASA/JSC, ESMD-RQ-005*, pp. 562–563, October 22, 2004.

[5]Krishen, Kumar, Multiple Aspects Space Technology Transfer, *Institution of Electronics and Telecommunication Engineers Technical Review*, Vol. 28, Issue 3, pp. 195-206, May-June 2011.

[6]From Invention to Innovation: Commercialization of New Technology by Independent and Small Business Inventors, *U. S. Department of Energy*, May 15, 1989.

[7]Adding Value to NASA through Technology Infusion: An Internal NASA Customer-Focused Approach, *Prepared by NASA Innovative Partnerships Program*, Washington, DC, March, 2008.

[8]Fogarty, Jennifer A., From Shuttle Main Engine to the Human Heart: A Presentation to the Federal Lab Consortium for Technology Transfer, Federal Laboratory Consortium for Technology Transfer (FLC), *The Sky's the Limit*, Albuquerque, New Mexico, USA, April, 2010.

[9]http://www.sti.nasa.gov/tto/Spinoff2009/hm_3.html

[10]http://www.spaceref.com/news/viewpr.html?pid= 33313

[11]Navran, Stephen, The Application of Low Shear Modeled Microgravity to 3-D Cell Biology and Tissue Engineering, *Biotechnology Annual Review*, Vol. 14, pp. 275-296, Elsevier B.V., 2008.

[12]Comstock, Douglas A., NASA, Statement Submitted for the Record before the Subcommittee on Technology and Innovation Committee on Science and Technology, *United States House of Representatives*, June 26, 2007.

[13]Krishen, Kumar, Johnson Space Center SBIR STTR Program Technology Innovations, *Proceedings of the 2007 International Astronautical Congress*, Hyderabad, India, September 24-27, 2007.

[14]http://www.sti.nasa.gov/tto/spinoff2003/er_1.html.