NSBRI Technology Development Strategic Plan

13.0 Technology Development

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13.1 INTRODUCTION

The Technology Development Program (Team) of the National Space Biomedical Research Institute (NSBRI) is chartered with developing technologies that will lead to a better understanding of the barriers to long-duration space exploration and assist in the development of countermeasures to assure safe and productive missions. The primary focus of the Technology Development Program is directed toward those technologies that support the ground-based and space-based research of the other NSBRI research teams and space life science research community at large. Accordingly, it creates systems and tools such as sensors, instruments, devices, and intelligent software. Requirements for these tools and technologies are predicated on the carefully developed needs of the other research teams. In particular, the Technology Development Team selects projects that: (1) support the investigation of the effects of spaceflight on human physiology and behavior; (2) apply this information toward the development of techniques, technologies, instruments, and countermeasures that will sustain humans during future long-duration space missions; and (3) benefit the quality of life and medical care on Earth.

Synergism is a key element of the program and the Technology Development Team strives to bring the engineering and biological science disciplines together in the identification and development of devices, instrumentation, and systems that address the fundamental research issues critical to the human exploration of space. A unique feature of the Technology Development Team's projects are their ability to bring an integrated systems engineering perspective (cross discipline) to bear on technology development as it supports the basic research. An important by-product of this integrated approach is the cross-education of the basic and applied science researchers in engineering and technology disciplines and the applied research and development engineers in biological and medical science.

13.2 IDENTIFYING TECHNOLOGY NEEDS

Identifying technology and technology development projects that are important to the requirements of the other NSBRI teams and the human exploration of space is a critical element of the Technology Development Team's charter. These technology identification activities fall in three general areas: (1) assessing the developments in science, technology, and engineering by industry, academia, and government that may impact the conduct of both space- and ground-based research in support of the human exploration of space; (2) monitoring the risks to spaceflight and NASA's humans in space roadmap to ensure that the current and future technological developments align with the major risk areas; and (3) fostering close communications between NASA, the NSBRI, and the industrial and academic communities to focus the new technologies and revolutionary developments on specific methods of risk reduction and countermeasures.

While all fields of engineering and applied science are rapidly changing as new materials, tools, and processes come on line, a few areas important to medical and biological sciences and NSBRI research can be identified. These areas include miniaturized devices and sensors, engineered materials, wireless communications, information processing and storage, and autonomous control and operation. The world of microelectronics continues its revolution with more and more active devices being placed on a single chip (i.e., a piece of semiconductor material the size of a human fingernail). The processing and science used to achieve the fantastic densities of active devices on a single chip (100 million to 1 billion) has been applied to several adjunct fields which hold promise in the biological arena, especially sensors. In particular, microelectromechanical systems (MEMS) can produce miniaturized mechanical parts that move under the action of an applied electric field or other stimulus. Such technology offers great possibilities for detectors and samplers that can be used to collect biological samples and provide on a chip analysis work. Other miniaturized and materials technologies will lead to entire analysis systems on chip. Nanotechnology and its associated self-assembly techniques will be a major underpinning of all advanced materials and composite structures. It will have far reaching effects on the biological and medical worlds ranging from the impregnation of bandage material with silver nanoparticles to promote wound and burn healing while preventing infection to the development of the fully-instrumented human by utilizing smart garments composed of composites with embedded nanofibers for sensing and control of the body environment.

The wireless communications explosion will have a significant impact on human communications as well as the control and readout of scientific information. Wireless interfaces will do much to improve clutter in cramped spacecraft as well as speed data collection and improve the comfort of astronauts during the experimental process. Advances in signal processing and information storage and processing will allow vast amounts of information to be stored on board the spacecraft as well as effective data compression for scientific information transmission. The exploitation of autonomous systems and automated control offer significant advantages for reducing the experimental burden on both the research scientist and the astronaut. Such systems range from the robotic control of machines and machine processes (e.g., blood sampling and analysis) to improving the quality of health delivery during long-duration space missions by using smart medical systems.

Since such a myriad of potentially useful technologies, devices, and instruments could have significant impact on an astronaut's health and his ability to perform his mission, it is important for the Technology Development Team to identify the most important of NASA's risk factors for humans in space and then from these risk factors identify technology applications and devices that might produce significant risk countermeasures or aid human adaptation or health care in prolonged flight environments.

The Critical Path Roadmap (CPR) provides the foundation needed by NASA to ensure that human spaceflight now and in the future is as safe, productive, and healthy as possible (within the mission constraints) regardless of the mission duration or destination. The CPR provides a framework for risk identification, risk prevention, and the need for viable countermeasures associated with humans in long-duration spaceflight. The Technology Development Team uses this roadmap as one means of prioritizing project selection. For example, bone loss in microgravity is considered one of the most serious risk factors (Type 1). Two NSBRI research teams are addressing bone loss and the causal or associated muscle alteration in space. The Technology Development Team has ongoing projects that directly support the efforts of both the bone and muscle teams.

Using the roadmap alone is not sufficient to identify all technology needs of the NSBRI research teams as well as the needs for human spaceflight. The Technology Development Team actively engages members from the other research teams, the medical science community, and NASA to assess additional technical requirements. Through various individual team leader and working group interactions, the needs are identified, distilled, and then focused into a technology development program.

13.3 GOALS

The Technology Development Team has the following goals for its program:

Goal 1: *Identifying new technological advancements and developments that can have a major impact on space biomedical research and astronaut health.*

Goal 2: *Contribute to risk reduction in each CPR priority area by developing new medical instruments and devices for both ground- and space-based research and countermeasure development.*

Goal 3: *Exploit the developments and advances made by Technology Development Team projects to improve the quality of life and health care delivery on Earth.*

Goal 4: *Promote the transfer of NSBRI-developed technological advances to industry for the benefit of Earth-based medical care.*

Goal 5: *Integrate technology development needs across other NSBRI teams, medical science community, and NASA through service and communication to become recognized as an important service arm that helps these researchers develop needed tools and instrumentation.*

13.4 DESCRIPTION AND EVALUATION OF THE CURRENT PROGRAM

Description of Current Projects

The risks associated with long-term exposure to microgravity and a high radiation environment are numerous; they represent the basis for the research program pursued by the NSBRI. Most of the ongoing NSBRI research is vertically integrated within a specific thrust area. For instance, the research teams typically have a core research topic that is combined with several special topic areas to form a disciplined approach to addressing a number of related issues.

The Technology Development Program is implemented in a different manner. The funded projects are selected, among other reasons, for their ability to provide necessary and enabling technologies for the basic research areas. Thus, the thrust area is laterally integrated with the other research areas. Figure 13.1 is a diagram showing the interaction between the eight current Technology Development Team projects and the other ten NSBRI research teams. As can be seen in Figure 13.1, the current Technology Development Team projects support nine of these remaining ten research areas.

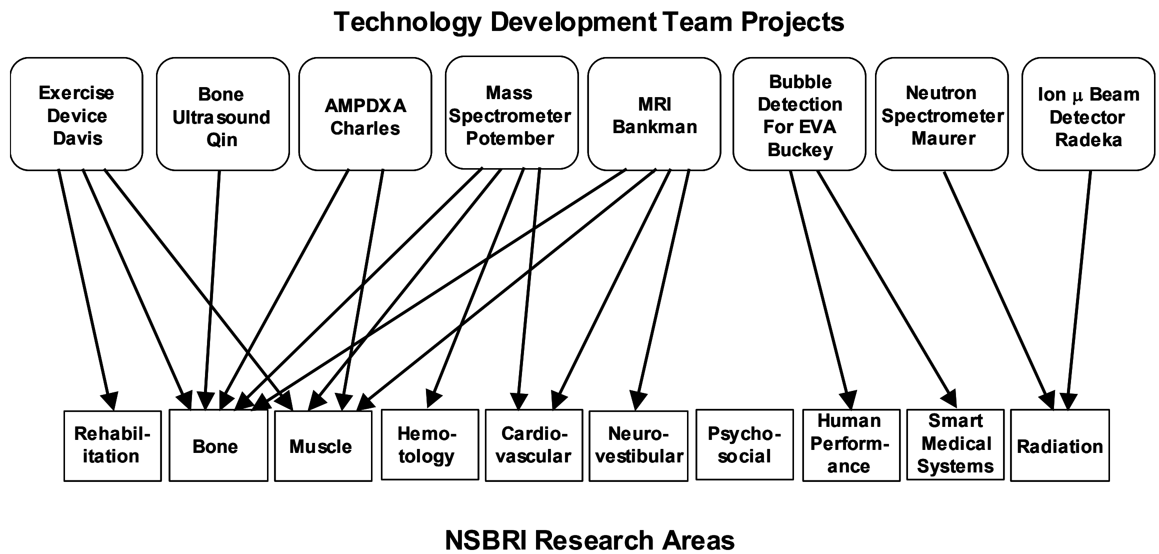

Figure 13.1. Mapping of current NSBRI Technology Development Team projects into the remaining ten NSBRI research areas.

The Technology Development Team generally focuses on projects that will deliver a specific product (e.g., sensor, instrument, etc.) in a specified period of time, typically one to three years. Of particular interest are projects that have strong technology transfer potential to industry so that the products of the development can be made available to support the research activities of other teams and achieve maximum societal benefit. Projects under the Technology Development Team umbrella are encouraged to interact with industry early in the development cycle. The NSBRI's Industry Forum can foster such interactions.

Proposals to the NSBRI Technology Development Program are expected to be of sufficient maturity (i.e., NASA Phase A (Conceptual Design)) so that: (1) the critical research issues can be readily identified, (2) the relevance of the technology development to the key research needs of the other NSBRI research teams and human spaceflight is evident, and (3) the technical approach and development plan directly lead to a deliverable (instrument, sensor, countermeasure device, etc.) within a reasonable timeframe.

Currently, there are eight projects under the umbrella of the NSBRI Technology Development Team: three projects continuing from the first research cycle (1998-2000) and five new projects that were nominally started in February 2001. Some projects had slightly later starts due to funding transfer issues. Due to budget cuts and change in Principal Investigators, one project, the Space Qualifiable MRI, has been delayed to Summer 2002. As shown in Figure 13.1, the Technology Development Team projects address research needs and risk reductions in nine of the ten NSBRI basic research areas. The research activities for each of the Technology Development Team projects are listed in Table 13.1 and described below.

Project 1

PI/Project Title: Harry K. Charles, Jr., Ph.D.
Advanced Multiple Projection Dual Energy X-ray Absorptiometry (AMPDXA) System

Need(s) Addressed: Provide accurate measurement of bone and muscle loss both in space and on Earth. Measure the location of the bone loss and assess the integrity of the bone structure.

Countermeasures Target: Provide highly accurate bone mass loss and structural information so that appropriate countermeasures can be developed, applied, and monitored.

Project Description: The purpose of the Advanced Multiple Projection Dual Energy X-ray Absorptiometry (AMPDXA) Scanning System project is to design, build, and test a precision scanning system for monitoring the deleterious effects of weightlessness on the human musculoskeletal system during prolonged spaceflight. The instrument uses dual energy X-ray absorptiometry (DXA) principles and is designed to measure bone mineral density (BMD), decompose soft tissue into fat and muscle, and derive structural properties (cross-sections, moments of inertia). Such data permits assessment of microgravity effects on bone and muscle and the associated fracture risk upon returning to planetary gravity levels. Multiple projections, coupled with axial translation, provide three-dimensional geometric properties suitable for accurate structural analysis. This structural analysis, coupled with bone models and estimated loads, defines the fracture risk. The scanner will be designed to minimize volume and mass (46 kg goal), while maintaining the required mechanical stability for high-precision measurement. The AMPDXA will be able to detect 1% changes in bone mass and geometry and 5% changes in muscle mass.

Two instruments (the Laboratory Test Bed (LTB) and a Clinical Test System (CTS)) have been constructed to date. The LTB has been used to develop source and substrate parameters and to test human bone segments. The CTS will allow human patient testing. The LTB has been fully operational for the last three years. It has allowed the AMPDXA project to develop sources, detectors, and software algorithms necessary for the high-precision detection of BMD and bone structure. In this current period, the LTB has allowed the refinement of our BMD and structure extraction algorithms as well as continued progress on the high-resolution separation of soft tissue from bone. Multiple-projection analysis enables the user to evaluate bone structural properties (e.g., bending strength) independent of subject position and orientation. Empirical evaluations to date have demonstrated an average coefficient of variation in the maximum and minimum moment of inertia of less than 3%. It is projected that further processing refinement will reduce the error in a three-projection estimate to <1%; adding more projections will also reduce the error.

The CTS is operational and initial human testing trials are about to begin. Initial results of the CTS (using phantoms and cadaver parts) have shown even greater precision than the highly accurate LTB results.

Project 2

PI/Project Title: Richard H. Maurer, Ph.D.
Neutron Spectrometer

Need(s) Addressed: Monitor the neutron radiation environment inside spacecraft, large space habitats, and on planetary surfaces.

Countermeasure Target: Provide highly accurate neutron radiation monitoring so that appropriate countermeasures can be developed, applied, and monitored.

Project Description: A Neutron Energy Spectrometer is being developed to monitor the flight radiation environment on the International Space Station (ISS), an interplanetary transport vehicle, or on a planetary surface. Detector types were selected for the complete neutron energy range and experimentally validated the concept for the low- and high-energy intervals. The effectiveness of our charged particle discrimination system was demonstrated. Data analysis and modeling efforts have verified the experimental results to date and the procedure for deconvolving deposited energy spectra into incident neutron energy spectra. The engineering prototype instrument was successfully flown on a NASA aircraft, demonstrating the robustness and operational capability of our design. A balloon flight is planned that will yield scientifically interesting data on the high-energy neutron environment. The balloon altitude was selected to simulate the incoming or downward neutron environment of the surface of a planet like Mars.

Project 3

PI/Project Title: Richard S. Potember, Ph.D.
Miniature Time-of-Flight Mass Spectrometer

Need(s) Addressed: Develop a miniaturized instrument that can quantitatively measure critical biomarkers from breath, body fluids, products of infection, etc.

Countermeasure Target: Provide a highly accurate measure of human biomarkers associated with many of the deleterious effects and conditions caused by microgravity and prolonged spaceflight so that appropriate countermeasures can be developed, applied, and monitored.

Project Description: The long-term objective of the Miniature Time-of-Flight Mass Spectrometer (TOFMS) project is to design, build, and launch a flight-qualified TOFMS for use on space platforms such as the Shuttle, ISS, or a planetary mission. The TOFMS can identify and quantitatively measure critical biomarkers associated with the deleterious effects of microgravity and long-duration spaceflight. The biomarkers can be determined from the analysis of breath, body fluids, products of infection, and, perhaps, DNA repair products and DNA mutations. As currently configured, the system appears to be of particular value to both the Bone and Muscle Teams, but biomarkers important to several other research teams can also be obtained. The TOFMS system being developed is small (less than 1 cubic foot), lightweight (less than 5 kg), low power (less than 50 W), and rugged. This NSBRI-sponsored TOFMS is building upon technology developed for DARPA to analyze chemical and biological weapons, while being optimized for astronaut use and the identification and quantification of biomarkers. To date, the TOFMS has shown spectra of compounds ranging from under 100 to beyond 10,000 atomic mass units (amu). Sensitivities for such biomarkers in the parts per million to parts per trillion range have been achieved.

Many of the biomarker identification procedures are complex, requiring special protocols and associated laboratory equipment. To carry the equipment and chemical supplies required to monitor the health of an astronaut would be weight prohibitive, would necessitate specialized training, and would require a significant fraction of the astronaut's time. The TOFMS provides a small, efficient, broadband diagnostic instrument that can rapidly identify biomarkers important for successful human space exploration.

Project 4

PI/Project Title: Jay C. Buckey, Jr., M.D.
Improved Bubble Detection for Extra-Vehicular Activity

Need(s) Addressed: Careful monitoring and understanding of the bubble nucleation process associated with decompression sickness is required to reduce astronaut risks associated with extra-vehicular activity.

Countermeasure Target: Provide an understanding of blood bubble nucleation and growth so that effective countermeasures can be developed, applied, and monitored.

Project Description: The Improved Bubble Detection for Extra-Vehicular Activity (EVA) project goal is to improve current bubble detection methods. The assembly of the ISS requires extensive and unprecedented extra-vehicular activity. Because spacesuits operate at low internal pressures, the astronauts are highly susceptible to decompression sickness (DCS) (gas bubbles in the blood). A range of pre-breathe strategies, as well as suit gas mixtures and pressures, are employed to mitigate the risk. During ISS construction, in-suit Doppler bubble monitoring will be provided to detect conditions that increase DCS risk. Doppler bubble detection, while effective, has three primary limitations: (1) it is motion sensitive; (2) it detects only moving bubbles; and (3) it does not detect bubbles with diameters less than 80 μm.

The Improved Bubble Detection for EVA project will exploit two transcutaneous ultrasonic bubble detection and sizing instruments under development by NASA. These instruments utilize bubble resonance (not Doppler) techniques, thus allowing the instruments to measure stationary bubbles as well as bubbles of smaller size. One instrument is optimized for intravascular bubble detection in the size range of 30 to 200 μm. The other monitors extravascular bubbles in the 1- to 10-µm-size range. Both instruments in *in-vitro* trials have demonstrated bubble detection at their lower range limits.

Project 5

PI/Project Title: Yi-Xian Qin, Ph.D.
Scanning Confocal Acoustic Diagnostic (SCAD) System

Need(s) Addressed: Measurement of bone loss in space so that appropriate countermeasures can be developed, applied, and monitored.

Countermeasure Target: Provide measurement of bone material properties and relate to countermeasure development and processing.

Program Description: The Scanning Confocal Acoustic Diagnostic (SCAD) System project is focused on the measurement of bone loss is space. On Earth, early diagnosis and proper treatment of progressive bone loss (and/or poor bone quality) can dramatically reduce the risk of bone fracture. Ultrasound systems have the potential for determining the material properties of bone in a safe, repeatable, and highly accurate manner. Limitations in the performance of current ultrasound systems restrict their application to first-order screening, rather than the clinical standard upon which osteoporotic diagnosis and treatment regimens are based.

The SCAD is usable not only for ground-based determination of bone's physical properties; but, because of its low weight and size, it is also suitable for monitoring subtle changes in bone density and strength during extended spaceflight. The SCAD project is divided into four basic parts: (1) development of the SCAD system hardware, (2) correlation of SCAD-determined sound velocity and attenuation measurement with micro-CT bone BMD and structure, (3) prediction of the risk of trabecular bone failure associated with osteoporosis in the animal model, and (4) correlation of SCAD-derived BMD and structural modules with DXA measurements.

Project 6

PI/Project Title: Veljko Radeka, Ph.D.
Heavy Ion Microbeam and Micron Resolution Detector

Need(s) Addressed: The micron resolution detector, together with the microbeam, will allow the localized position of an ion impact within a cell to be determined. This is an enabling technique for radiobiology studies.

Countermeasure Targets: Understanding of the effects of radiation damage within the cell so effective countermeasures can be developed.

Program Description: The Heavy Ion Microbeam and Micron Resolution Detector System is aimed at studying radiation effects at the cellular level. Using microbeam irradiation facilities, it is now possible to place discrete numbers of particles in defined cellular and extracellular locations. Such facilities permit heavy-ion radiobiologists to explore the impact of signal transduction between cellular compartments as well as issues related to intercellular communication at low limiting fluences where not all cells in a population have been traversed. A high-energy, heavy-ion microbeam will allow an important unanswered question to be addressed, i.e., whether neurons that survive transversal by high-energy heavy ion (HZE) particles develop changes as a late consequence of the damage they incurred. These low-fluence studies will increase the understanding of the consequences of exposure to high, linear energy transfer (LET) radiation, such as encountered in the space radiation environment. (See the NES project above.) Currently, the microbeam detector has been designed and simulated.

The purpose of the Heavy Ion Microbeam and Micron Resolution Detector project is to allow such radiation studies as described above to take place by developing the following tools: (1) a microbeam (diameter 10 μm) of heavy ions (e.g., iron) at energies higher than existing ion microprobes (3 GeV/nucleon), and (2) an electronic position-sensitive detector for heavy ions with a position resolution better than 1 μm. Interactions between the Heavy Ion Microbeam and Micron Resolution Detector project and the Radiation Team have taken place.

Project 7

PI/Project Title: Brian L. Davis, Ph.D.
Dynamic Exercise Countermeasure Device (DECD)

Need(s) Addressed: Demonstrate that proper in-flight exercise can counter the microgravity-induced bone and muscle loss.

Countermeasure Target: Develop a direct countermeasure to bone and muscle loss in space.

Program Description: The Dynamic Exercise Countermeasures Device (DECD) is aimed at developing a countermeasure to bone and muscle loss in space. Bone demineralization (bone mass loss) is a well-documented physiologic effect of long-duration spaceflight and microgravity. Animal experiments on Earth have clearly indicated that: (1) certain bone strains and strain rates stimulate bone deposition, and (2) repetitive loading of the lower extremity can increase osteonal bone formation even as proximally as the vertebral column. Such studies have also indicated that a relatively small number of appropriate weight-loading cycles may be sufficient to stimulate bone deposition. Based on prior research with weight-loading experiments upon the foot, a dynamic exercise countermeasure device that utilizes jumping as the mode of exercise for the astronauts is under development. The DECD project is divided into three phases: (1) develop a lightweight, vibration-isolated exercise device, suitable for use on the ISS, that will permit dynamic jumping exercise within microgravity; (2) perform system testing using zero-gravity simulation; and (3) verify DECD efficacy in true microgravity through KC-135 experiments. Currently, a prototype device is in operation.

Project 8

PI/Project Title: Isaac Bankman, Ph.D.
Space Qualifiable Magnetic Resonance Imaging (MRI) System
Need(s) Addressed: MRI needed in space for animal studies and peripheral (limb) measurements on humans.

Countermeasure Target: Provide highly accurate bone and soft tissue measurements to verify countermeasures in space-based animal studies.

Program Description: The goal of the Space Qualifiable Magnetic Resonance Imaging (MRI) System is to develop a proof-of-concept engineering model of a space-qualified MRI system for small animals and astronaut limbs with a mass of less than 130 kg and low average power (<1 kW quiescent and <1.2 kW when scanning). An on-board processor or personal computer can be adapted to display the collected information. MRIs provide high-resolution, high-quality anatomical information without ionizing radiation, so they can be safely and repeatably used to track changes without deleterious effects.

As a result, the study of physiological alterations in space and the development, verification, and maintenance of countermeasures will be significantly enhanced. Mice and small rat models are useful surrogates to carry out in-orbit physiological studies. In-flight MR imaging of these animals will be of particular benefit to countermeasure development by several of the NSBRI research teams. Measurement of alterations in the limbs of the astronauts, especially the lower limbs, will provide partial confirmation of countermeasure effectiveness and of the utility of

Earth-based animal models. The MRI system is particularly amenable to the study of soft tissue and bone. To date, magnet trade-off studies and initial system designs have taken place.

Evaluation of Program

The seven active NSBRI Technology Development Team projects are making significant progress against their development goals. The three continuing projects have operating instruments, while the relatively new projects are in various phases of instrumentation development. For example, the two AMPDXA instruments (LTB and CTS) are operational and the CTS is being readied for human trials. In addition, commercialization discussions are underway to transfer the technology to industry. The neutron spectrometer is being readied for a high altitude balloon flight after completing several successful aircraft flight tests. The TOFMS has identified with high sensitivity several biomarkers associated with bone and muscle loss. The heavy ion microbeam and detector system has been designed and the detector fabricated. When completed, this resource will address several very current and significant issues in cellular biology. The SCAD system is operational and is performing correlation studies between measurements in the extremities and the weight-bearing bones. The bubble detection project has developed prototype equipment that has detected microbubble formation at various nucleation sites within the body. The DECD is in its second prototype design phase. Each of the projects and prototype instruments is addressing the major goals of the Technology Development Team, the NSBRI, and NASA by either developing research tools that facilitate the measurement and analysis of critical parameters necessary for the research of the other NSBRI teams or creating direct countermeasures to the risks encountered in long-duration spaceflight.

The Technology Development Team is constantly on the alert for technological developments and advancements (Goal 1) that will have impact on both the NSBRI and space life science research. For example, working closely with the Bone Team, the Technology Development Team was able to identify two major impediments to the development of countermeasures for bone demineralization: understanding of the bone mineral loss process and being able to monitor the instantaneous conditions of the subjects' bones. The TOFMS (Project No. 3) has been adapted to monitor the biomarkers for bone loss. While the TOFMS was developed under DARPA funding for solids analysis, newly invented methods of sample preparation and fixing techniques has allowed its applicability to biological specimen analysis. Historically, space-based monitoring of such biomarkers has typically relied on collection of specimens (urine, blood, etc.) and then storage of the specimens until Earthly return. Specimen analysis may, under good conditions, be completed many months after completion of the mission, but certainly does not afford the ability to provide closed-loop monitoring and control of countermeasures (Goal 2).

The AMPDXA project (No. 1) and the SCAD project (No. 5) specifically address the monitoring issue. Both these projects have completed engineering model instrumentation developments (Goal 2) and have demonstrated the ability to provide quantitative information that is critical to the current and future research of the Bone Team. These devices have been designed to be directly adaptable for in-space use. Size, weight, and power are currently, or soon will be, appropriate for routine launch and regular use on-orbit or in missions beyond Earth. Using advanced automation techniques (Goal 1), these devices and their associated analysis methods can be operated by individuals with very little training. Thus, the devices have broad utility in both space- and Earth-based applications.

The bone demineralization conditions that astronauts experience in space are similar to those that exist in clinical populations (e.g., age-related osteoporosis, quadriplegic, etc.) on Earth. Thus, the research supported by the AMPDXA, SCAN, and TOFMS is expected to have a direct positive influence on health care delivery on Earth (Goal 3). In addition, the technology itself has demonstrated better performance than commercially available devices. In particular, commercialization (Goal 4) of a clinical version of the AMPDXA is being pursued that has great potential to improve screening and treatment for age-related osteoporosis.

Muscle alteration research faces the same challenges of loss mechanism determination and monitoring as noted above for bone. Both the AMPDXA and TOFMS provide the same capabilities (i.e., monitoring and biomarker determination, respectively) in support of risk reduction for muscle as they do for bone. Advanced AMPDXA muscle algorithms (Goal 1), coupled with a radical new x-ray source (Goal 1), offer a promise of similar precision measurements of muscle as has been demonstrated for bone. The DECD (Project No. 7) offers the potential to directly countermeasure muscle loss in space (Goal 2).

Exposure to radiation in space is a threat that can lead to an increased risk of cancer and DNA damage. A significant portion of the exposure, between 30-60%, results from neutron sources that are extremely difficult to monitor, let alone characterize, in real-time. The absence of a portable, quantitative, real-time neutron spectrometer results in an exposure safety risk for astronauts (Goal 1). The Neuron Energy Spectrometer Project (No. 2) is developing a spectrometer (Goal 2) that can supply information on the neutron environment to the Radiation Effects Team in support of assessing radiation damage and cancer risk. The prototype of this unit is operational and has just completed several flight tests in F15 aircraft. The Ion Microbeam Project (No. 6) will address radiation damage at the cellular level.

Orthostatic intolerance can result in syncope when an individual is subjected to gravitational influence after exposure to microgravity. This situation can pose severe risks to astronauts who have to execute unassisted emergency procedures or extraterrestrial landings. The need to predict, prevent, or control orthostatic intolerance and its effects is significant to the space program. Both the TOFMS and the MRI project (No. 8) have the ability to provide near real-time monitoring of parameters related to orthostatic intolerance. The TOFMS can detect various heart-related biomarkers and the MRI will be able to monitor soft tissue, including vein and artery blood volumes and fluid shifts, in animals and potentially on the extremities of the astronauts. Previously in the first research cycle, the Technology Development Team created the cardiovascular systems identification (CSI) instrumentation (Goal 2). The CSI is a self-contained, automated device for measuring and characterizing alterations in cardiovascular regulation. The CSI is being commercialized and transfer to industry is underway (Goal 4) for use in Earth-bound clinical settings (Goal 3).

To identify and appropriately fund these pipeline projects requires constant interaction between the NSBRI research teams and the Technology Development Team. To promote this integration, which satisfies much of Goal 5, the Technology Development Team established the Technology Working Group (TWG) as a formal mechanism for this liaison. Meetings of the TWG will be conducted more frequently with expanded participation from academia, industry, and government. In addition, Technology Development Team participation in the annual retreats of the other teams will also foster cooperation and the synergism necessary to identify the technical requirements (Goal 1). Such input from NSBRI research teams, coupled with strong industrial and academic input, will allow the Technology Development Team to develop calls for research that address technological solutions for the risk factors associated with long-duration spaceflight that are in concert with the established research goals of the other NSBRI teams. Part of the strategic growth plan for the Technology Development Team will be the ability to direct key technology development efforts in addition to or in conjunction with the projects received in response to the research announcements. Such responses may leave gaps in the envisioned technology development requirements. A recent meeting of the TWG identified over thirty instruments or technology development needs of the space research community that are not currently being addressed by the NSBRI Technology Development Program. These gaps offer opportunities to foster important research that could accelerate the overall space effort. Support sources for such selected top-down driven research will have to be developed.

The Technology Development Team also envisions itself as a bridge between the other NSBRI research teams and the extensive resources for technology development that exist within the participating institutions as well as in academia and industry. Bridging activities will include information exchanges on technology, contacts for development efforts, etc. Integration activities, as mentioned above, are described in Table 13.2. Table 13.3 presents the phases of technology development and insertion for the current Technology Development Team projects.

13.5 OBJECTIVES AND STRATEGIC ACTIVITIES

Summarized below are the objectives underlying each goal and the strategic activities that the Technology Development Team plans to use to achieve the goals and objectives of its program.

Goal 1: *Identify new technological advancements and developments that can have a major impact on space biomedical research and astronaut health.*

Objective 1A: Technology assessment to determine most applicable developments:

- Increase the Team's interdisciplinary membership, both in the skill base of its members and the diversity of participating institutions.
- Have team members attend conferences, meetings, and other forums where advanced technology and its applications are discussed.
- Participate in NASA space life sciences programs, conferences, and forums on the issues associated with long-duration human spaceflight.
- Establish ties with non-NSBRI institutions that have technology ideas and resources necessary for solving the issues surrounding human spaceflight.

Objective 1B: Risk assessment to determine the most urgent needs:

- Continue interactions with NASA and the other NSBRI research teams.
- Conduct more frequent TWG meetings with expanded participation from academia, industry, and government.
- Participate in the annual retreats of other NSBRI research teams.

Goal 2: *Contribute to risk reduction in each critical path roadmap priority area by developing new medical instruments and devices for both ground- and space-based research and countermeasure development.*

Objective 2A: Current monitoring and capability development activities:

- Complete projects developing instrumentation to monitor bone and muscle loss (AMPDXA, SCAD, and MRI projects).
- Demonstrate that precision measurement of bone loss and structure will shed light on the bone loss mechanisms in space.
- Complete neutron radiation monitoring instrument.
- Complete development of heavy ion microbeam to facilitate cellular level radiation damage research.
- Complete TOFMS and demonstrate its ability to monitor biomarkers for major human risk factors.
- Verify the origin of the bubbles present in decompression sickness and develop effective measurement equipment.

Objective 2B: Current countermeasure development activities:

- Complete development of dynamic countermeasures device and verify the exercise and jumping loads will inhibit bone and muscle loss in space.
- Expand program to include more projects that directly develop countermeasures.

Goal 3: *Exploit the developments and advances made by Technology Development Team projects to improve the quality of life and health care delivery on Earth.*

Objective 3A: Technology readiness:

- Publish results of instrument development and experimental results.
- Work with medical researchers to demonstrate the utility and versatility of the instrumentation development.
- Develop funding mechanisms to allow prototype-developed instruments to be placed in appropriate clinical settings.

Objective 3B: Technology market penetration:

- Develop presentations and marketing material (literature) that not only touts the progress on current projects, but also makes the entire NSBRI team aware of the technological resources available at participating institutions.
- Expand Technology Development Program to include all ten NSBRI research areas with better balance between the areas. Currently, nine of these areas have overlap with the technology projects, but the technology projects are heavily focused in a few areas.

Goal 4: *Promote the transfer of NSBRI-developed technological advances to industry for the benefit of Earth-based medical care.*

Objective 4A: Establish ties with industry:

- Work closely with members of the NSBRI Industry Forum on the performance and capabilities of the developed instruments.
- Serve as a resource to bring NASA's needs and industry's capabilities together in the solution to health risks associated with long-term spaceflight.

Objective 4B: Facilitate technology transfer:

- Develop sources of funding to help in the investigator's technology transfer process.
- Make instrument developers aware of opportunities for direct funding from NASA and other sources once projects have reached a certain level of maturity.

- Provide information on how to pursue technology transfer (licensing, start-up company, etc.).

Goal 5: *Integrate technology development needs across other NSBRI teams, medical science community, and NASA through service and communication to become recognized as an important service arm that helps these researchers develop needed tools and instrumentation.*

Objective 5A: Develop support to other teams:

- Develop calls for research that address technological solutions for the risk factors associated with long-duration spaceflight that are in concert with the established research goals of other teams.
- Identify gaps left in the NSBRI's technology development requirements from the proposal responses.
- Develop support resources for filling these gaps to effectively foster and accelerate the overall goals of the other teams.

Objective 5B: Technology awareness:

- Facilitate information exchanges and provide technology information to the other teams.
- Serve as resource to help facilitate technology liaison with industry, academia, or government laboratories.

13.6 SUMMARY

The objective of the Technology Development Program of the National Space Biomedical Research Institute is to develop devices, instrument systems, and associated algorithms and software that lead to a better understanding of the barriers to long-duration space exploration and assist in the development of countermeasures to assure safe and productive space missions. The primary focus of the Technology Development Program is directed towards those technologies that support the ground-based and space-based activities of the other NSBRI research teams. The unique feature of this program is the opportunity to bring an integrated system engineering perspective to bear on the technological developments necessary to support basic research. Multidisciplinary development teams have been established to work on strategically focused projects that integrate individuals and institutions with vastly different capabilities into a cohesive team.

Identification of the technology development research needs of the NSBRI teams and space life sciences community in general is made through vigilant review of current technology development advances that may impact or advance NSBRI research; monitoring of the Critical Path Roadmap; and creating forums for discussion and communication on technological needs with NSBRI teams, NASA, industry, and academia.

In the next 3- to 5-year time span, the Technology Development Team should be able to point to many successes from its current program. Indications are that several of its projects are reaching high enough technology readiness levels that sources of funding other than the NSBRI should be available to carry these developments into space, or be widely available to support Earth-based research and, in some cases, to be part of the medical health care delivery system. While these successes are extremely important, it is also just as important to keep the pipeline filled with high-quality, on-going development efforts that address the technology needs of the other NSBRI research teams and support the overall requirements of the NASA Space Life Science Program.

Summary Diagrams

Table 13.1 summarizes the Technology Development Team's project research activities and phases of development.

Table 13.2 summarizes the Technology Development Team's project integration activities.

Table 13.3 summarizes the phases in technology development and insertion for the current Technology Development Team projects.

National Space Biomedical Research Institute
TECHNOLOGY DEVELOPMENT TEAM

Table 13.1. Technology Development Program – Project Research Activities

PI/Project	Risk(s) Addressed	Countermeasures Target	Experimental Systems	Phase I (1)	Phase 2 (2)	Phase 3 (3)
Charles/AMPDXA	• Bone loss • Muscle loss	• Not applicable • Allows countermeasure effectivity measurement	• X-ray	• Laboratory test bed	• Clinical test unit • Human Testing	
Maurer/NES	• Radiation • Cancer	• Not applicable • Measures environment	• Radiation detectors	• Accelerator measurements	• Aircraft & balloon flights	
Potember/TOFMS	• Broad applicability • Bone loss	• Not applicable • Analysis tool • General purpose	• Mass spectrometry	• Understand biomarkers	• Detect biomarkers	• Hardware • Protoflight
Buckey/Bubble Detection	• Crew health • Decompression sickness	• Not applicable • Measurement tool	• Ultrasonic detection	• Bubble detection measurements		
Qin/SCAD	• Bone loss	• Not applicable • Measurement tool	• Ultrasound	• Ultrasound • Propagation studies	• Clinical test unit	
Davis/DEDC	• Muscle loss • Bone loss	• Jumping • Exercise training	• Mechanical exercise system	• Bone stress-strain studies	• Exercise machine • KC-135 flights	
Radeka/Microbeam/ Detector	• Radiation • Cellular damage	• Investigative tool	• Neutron source • Radiation detectors			
Bankman/Space MRI	• Muscle loss • Bone loss	• Not applicable • Measurement tool	• Magnetic resonance			

(1) Equipment Development Mechanistic Studies
(2) Equipment Operational Proof-of-Concept
(3) Protoflight Instrument Countermeasure

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Table 13.2. Technology Development Program – Integration Activities

Activity	Charles AMPDXA	Maurer NES	Potember TOFMS	Buckey Bubble Detection	Qin SCAD	Davis DEDC	Radeka Microbeam Detector	Bankman Space MRI
Internal Communication	• Telecons • Retreats • Team meeting	• Telecons • Retreats • Team meeting	• Telecons • Retreats • Team meeting	• Telecons • Retreats • Team meeting	• Telecons • Retreats • Team meeting	• Telecons • Retreats • Team meeting	• Telecons • Retreats • Team meeting	• Telecons • Retreats • Team meeting
NSBRI Teams	• Retreat • Working groups • Individual	• Retreat • Working groups • Individual	• Retreat • Working groups • Individual	• Retreat • Working groups • Individual	• Retreat • Working groups • Individual	• Retreat • Working groups • Individual	• Retreat • Working groups • Individual	
Information Sharing	• Reports • Papers • Patents	• Reports • Papers • Patents	• Reports • Papers • Patents	• Reports • Papers • Patents	• Reports • Papers • Patents	• Reports • Papers • Patents	• Reports • Papers • Patents	
Synergistic Studies/ Opportunities	• With SCAD • With Bone	• With Radiation • With Microbeam	• With Bone, Muscle & Cardiology	• With Crew Health • With SCAD	• With AMPDXA • With Bone	• With Human Fitness	• With Radiation • With NES	

(Shaded) Program about to start.

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TECHNOLOGY DEVELOPMENT TEAM

Table 13.3. Technology Development and Insertion

Technology Development Phases	Pre 2001	2001	2002	2003	2004	2005	2006	2007	2008	200 9	2010	2011	2012
Phase 0: Need Identification													
• AMPDXA (Advanced DXA)													
• Neutron Spectrometer													
• Time of Flight Mass Spectrometer													
• SCAD (Ultrasound)													
• Microbeam/Detector													
• Bubble Detection													
• DECD (Exercise Countermeasure)													
• Space MRI													
Phase 1: Preliminary Instrument/Experiment Design													
• AMPDXA (Advanced DXA)													
• Neutron Spectrometer													
• Time of Flight Mass Spectrometer													
• SCAD (Ultrasound)													
• Microbeam/Detector													
• Bubble Detection													
• DECD (Exercise Countermeasure)													
• Space MRI													
Phase 2: Prototype Instrument/Preliminary Tests													
• AMPDXA (Advanced DXA)													
• Neutron Spectrometer													
• Time of Flight Mass Spectrometer													
• SCAD (Ultrasound)													
• Microbeam/Detector													
• Bubble Detection													
• DECD (Exercise Countermeasure)													
• Space MRI													

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Table 13.3. Technology Development and Insertion (continued)

Technology Development Phases	Pre 2001	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Phase 3: Proof of Concept Experiments/Testing													
• AMPDXA (Advanced DXA)													
• Neutron Spectrometer													
• Time of Flight Mass Spectrometer													
• SCAD (Ultrasound)													
• Microbeam/Detector													
• Bubble Detection													
• DECD (Exercise Countermeasure)													
• Space MRI													
Phase 4: Engineering for Flight or Widespread Use													
• AMPDXA (Advanced DXA)													
• Neutron Spectrometer													
• Time of Flight Mass Spectrometer													
• SCAD (Ultrasound)													
• Microbeam/Detector													
• Bubble Detection													
• DECD (Exercise Countermeasure)													
• Space MRI													
Phase 5: Technology Transfer/Insertion													
• AMPDXA (Advanced DXA)													
• Neutron Spectrometer													
• Time of Flight Mass Spectrometer													
• SCAD (Ultrasound)													
• Microbeam/Detector													
• Bubble Detection													
• DECD (Exercise Countermeasure)													
• Space MRI													