

CRITICAL TECHNOLOGIES AND CAPABILITIES FOR HUMAN SPACEFLIGHT

SPACE RADIATION MODELING	<ul style="list-style-type: none"> ▪ Space weather simulation/visualization system to assess developing radiation conditions ▪ Model(s) to describe dynamic behavior of trapped radiation belts ▪ Model(s) of geomagnetic cutoff, including diurnal, seasonal, and solar cycle activity dependence ▪ Quantitatively assess radiation risks ▪ Model(s) of interaction of heavy ions in galactic cosmic rays with spacecraft, planetary atmospheres, and regoliths ▪ Improved radiation transport and shielding codes
RADIOBIOLOGY	<ul style="list-style-type: none"> ▪ Models, sensors, and systems to measure and predict effects of radiation on humans ▪ Determination of RBEs (radiobiological equivalents) for neoplastic transformation of human cells ▪ Radiophysical models for neoplastic transformation ▪ Determination of RBEs for lung and mammary cancers ▪ Method(s) of calculating probabilities of cancer induction at organ level ▪ Methods for determining genetic effects of high LET (linear energy transfer) radiation on humans ▪ Strategies for determining and evaluating potential microgravity-radiation synergism ▪ Operational measures (e.g., mission planning and operations, safe shelters, etc.) ▪ Chemical and biological modifiers and radioprotectants
SPACE RADIATION MONITORING	<ul style="list-style-type: none"> ▪ Space-based neutron monitor (spectrometer/dosimeter) capable of measuring neutron energies to at least 20 MeV in the presence of high proton levels ▪ Early warning system for predicting solar particle events and their size based on x-ray and gamma ray spectral characteristics of observed solar flares ▪ Small, portable electronic dosimeter to be used in EVA suits and habitable volumes (will provide dose and dose-equivalent rates and integrated values) ▪ New and advanced/improved techniques and materials for passive dosimetry, including biological radiation sensors
ENVIRONMENTAL PHYSIOLOGY & BIOPHYSICS	<ul style="list-style-type: none"> ▪ Determine effects of changing pressure, especially in decompression illness (DCI) ▪ Determine effects of temperature on health and performance of crew in spacecraft and during EVA ▪ Measure metabolic rates, especially during EVA, and to relate them to fatigue and risk of DCI ▪ Measure effects of different gas species such as oxygen, water, carbon dioxide, and ionized particles ▪ Treat DCI, with methods such as hyperbaric therapy and/or hyperbaric/oxygen therapy ▪ Understanding how spacecraft bioelectromagnetic fields and non-ionizing radiation affects crew ▪ In-flight/in-suit Doppler systems ▪ Methods for treating decompression illness
PHYSICAL PERFORMANCE	<ul style="list-style-type: none"> ▪ Monitor effectiveness of nutritional supplements, pharmacological agents, exercise, and myostimulation ▪ Assess lean body mass, aerobic/anaerobic capacity, muscle endurance/strength, thermal regulation, neuromuscular control, and compliance in use of countermeasures

SKELETAL INTEGRITY	<ul style="list-style-type: none"> ▪ Inflight, compact, light weight dual energy x-ray absorption to perform hip, spine, and heel bone mineral density measurements ▪ Automated urine collection, measurement, and sample storage/analysis equipment ▪ Load cells in pedals of cycle ergometer and angle measurement for hub and pedals ▪ Inflight dynamometers for hip, knee, and ankle measurements ▪ Finite element (FE) approach for skeleton measurements/analysis using minimal radiation (FE model incorporates bone morphology and bone density)
CALCIUM DEPOSITION (STONES)	<ul style="list-style-type: none"> ▪ Measure calcium levels during flight and quantify effects on neurosensory, cardiac, muscle, or other systems ▪ Countermeasures (procedures and pharmacologic/nutritional agents) that prevent ectopic calcium deposition in 99% of population
ORTHOSTATIC TOLERANCE	<ul style="list-style-type: none"> ▪ Hardware for an integrated countermeasures program to maintain orthostatic tolerance for landing, planetary excursion, emergency, entry, egress, and postflight rehabilitation ▪ Technologies for exercise, pharmacologic agents (e.g. mineral corticosteroid, fluid augmentation), fluid therapy, neurostimulation, compression garment
ARTIFICIAL GRAVITY COUNTERMEASURES	<ul style="list-style-type: none"> ▪ Hardware to assess artificial gravity as a countermeasure ▪ Systems to determine most efficient combination of g-level and exposure duration for intermittent AND continuous centrifuge operation ▪ Systems to verify centrifuge effectiveness in maintaining skeletal integrity, calcium metabolism, physical performance, orthostatic tolerance, neurosensory function, and other physiological functions, identifying positive and negative side effects ▪ Systems to verify effect of intermittent and continuous centrifuge exposure on humans at several gravity values, including near-zero, 1/6 g (lunar surface), 3/8 g (Mars) and 1 g
NEUROSENSORY AND SENSORIMOTOR FUNCTION	<ul style="list-style-type: none"> ▪ Ultra-lightweight binocular 3-D video eye movement monitoring ▪ Ultra-lightweight 6-degree-of-freedom head movement monitoring ▪ Non-head coupled visual display system ▪ Wide field stereo head mounted display (HMD) with eye and head movement monitoring and see-through capability ▪ Dynamic visual acuity testing and analysis system;3-D video eye movement capture and analysis software ▪ Develop mathematical models of visual-vestibular integration and adaptation ▪ Head-body tracking system ▪ Develop mathematical models of postural and locomotor control ▪ Dynamic posturography system ▪ Evaluate role of proprioceptive and somatosensory information in sensorimotor functions ▪ Human-rated angular and linear whole-body acceleration devices ▪ Measure orientation and perceptual disturbances ▪ Evaluate ability to perform mental rotation on Earth and in space (tests/devices) ▪ Evaluate adaptive changes in spatial orientation during spaceflight ▪ Improved pre-flight and in-flight adaptation to altered vestibular, proprioceptive and somatosensory inputs (tests/devices) ▪ Evaluate changes in sensory-motor performance
NEUROSENSORY AND SENSORIMOTOR COUNTERMEASURES	<ul style="list-style-type: none"> ▪ Sensory substitution using electrical and/or magnetic stimulation ▪ Preflight adaptation to altered sensory inputs to reduce sensorimotor disturbances, spatial orientation and perceptual disturbances, and space motion sickness ▪ Inflight maintenance of 1 g sensorimotor and perceptual function, including a short-arm centrifuge, 3-D eye-head movement monitor with visual display system, and foot pressure (somatosensory) input device ▪ Vibrotactile orientation system/device for inflight maintenance of spatial orientation, particularly during EVAs

MONITORING, DIAGNOSIS & THERAPY	<ul style="list-style-type: none"> ▪ Laboratory diagnostics (clinical chemistry, hematology, pathology, microbiology, etc.) ▪ Imaging diagnostics (radiographic, magnetic resonance, ultrasound, etc.). ▪ Non- or minimally invasive monitors (ECG, BP, SpO₂, HR, T, etc.) that employ implantable/injectable/ingestible sensors ▪ Telemetry to/from sensors and processing systems ▪ Autonomous/expert systems for all elements of care: monitoring, diagnosis, therapy, and surgical assistance ▪ Multimedia technologies for maintaining medical records ▪ Advanced user interfaces for diagnosis, therapy and training (VR, haptic, etc.) ▪ Advanced computer-based medical training and simulation techniques and systems ▪ Robotic (autonomous) and tele-operated medical assistance systems
IMMUNE PROTECTION	<ul style="list-style-type: none"> ▪ Means to determine maximal acceptable decrements of cellular and humoral protective mechanisms, relation of immune system dysfunction to incidence of infection, cancer induction, allergy, and autoimmune disease manifestations ▪ Pharmacological agent(s) as a countermeasure ▪ Means to decrease "stress response" ▪ Means to improve current Preflight Health Stabilization Program ▪ In-flight cytometer, delayed type hypersensitivity test device ("skin test"), in-flight enzyme-linked immunosorbent assay (ELISA) system, in-flight blood collection and distribution system, and a cell culture and challenge system
MEDICAL INTERVENTION	<ul style="list-style-type: none"> ▪ Systems for emergency surgery and critical care ▪ Systems for rescue, resuscitation, stabilization, and transport ▪ Fluid therapy systems, with infusion pumps, on-site production of sterile fluids, nutritional support, blood and blood component replacement ▪ Extended (3 year) shelf-life pharmaceuticals ▪ Medical waste management system ▪ Advanced medical storage systems (samples, pharmaceuticals, etc.) ▪ Equipment and protocols for microsurgery and microtherapeutics ▪ Hyperbarics for use in microgravity and on planetary surfaces ▪ Portable (inflatable) hyperbaric chamber
PSYCHOSOCIAL STABILITY	<ul style="list-style-type: none"> ▪ An integrated countermeasures program that encompasses preflight training, group support, self help, pharmacologic treatment, exercise, etc. ▪ Systems designed to measure, evaluate, and preserve psychosocial stability
CREW PRODUCTIVITY	<ul style="list-style-type: none"> ▪ Tools and models for determining acceptable performance ranges for different types of tasks ▪ Tools for modeling complex missions with multiple participants, assessing predicted vs. actual productivity, and updating model status to identify potential problems or failures
PROFICIENCY & SKILLS	<ul style="list-style-type: none"> ▪ Authoring tools optimized for computerized training for unique or unusual skills or tasks ▪ Non-intrusive technologies for monitoring individual and group performance over mission duration ▪ Advanced virtual reality systems with low power, volume, and mass requirements, which provide position tracking, wide field-of-view head mounted displays, and haptic feedback for on-board refresher training and skill monitoring ▪ Authoring languages for VR training systems that incorporate error feedback to user, prompting, and tools for data collection and performance assessment

<p style="text-align: center;">CREW ACCOMMODATIONS</p>	<ul style="list-style-type: none"> ▪ New methods of trash disposal to reclaim useful materials while minimizing or eliminating disposal volume, such as plastics ▪ 0 g and/or partial g washing and drying of clothes ▪ Provide crew consumables (food, water, etc.) in a wide variety of emergency situations with least possible mass ▪ Repair systems without Earth support ▪ Analyze spares requirements, document repair procedures at very low level (e.g. components rather than boards), and develop multipurpose troubleshooting tools ▪ Improve cleaning technologies ▪ Method of tracking location and status (e.g., health, functional state, etc.) of all onboard objects items
<p style="text-align: center;">FOOD AND GALLEY</p>	<ul style="list-style-type: none"> ▪ Shelf life extension to store a complete and acceptable diet for 3 - 5 years as required by 1000-day mission scenarios ▪ Advanced food packaging to minimize waste and trash ▪ Means for food preparation for crew ▪ Reduction in waste generated (both food and packaging wastes) ▪ Enhancements in acceptability, palatability, and variety
<p style="text-align: center;">BIOMASS PROCESSING</p>	<ul style="list-style-type: none"> ▪ Harvesting technologies ▪ Processing (e.g., drying, grinding, or making bread from flour) ▪ Sugar and oil production compatible with human-rated chambers
<p style="text-align: center;">HABITABILITY</p>	<ul style="list-style-type: none"> ▪ Measure personal space, time, and privacy requirements ▪ Measure actual and preferred levels of habitability factors such as volume and area, noise, vibration, odor, temperature, and humidity, and their relationship to crew performance and productivity over mission duration ▪ Tools to measure personal preference for habitability factors in individual crew members ▪ Model that can continuously estimate likelihood of potential critical events
<p style="text-align: center;">CONTINGENCIES</p>	<ul style="list-style-type: none"> ▪ Analytical model that identifies and evaluates potential responses to critical events for a decision support system ▪ Advanced and/or improved models of human decision-making that provide assistance in predicting and resolving contingencies or critical events in human-human or human-system situations

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