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Behavioral Health Management of Space Dwelling Groups: Safe Passage Beyond Earth Orbit

Henry H. Emurian & Joseph V. Brady

Plans to pursue space expeditionary missions beyond Earth orbit have occasioned renewed concern that crew behavioral health and performance effectiveness, along with spacecraft habitability, will present major challenges to the success of spaceflight initiatives involving unprecedented increases in time and distance on interplanetary voyages. A programmed environment methodological approach that implements supportive performance and research-based behavioral technologies can contribute to meeting these challenges in furtherance of overcoming the ecologically constrained and inherently stressful circumstances of long-duration spaceflight missions by members of confined microsocieties. This paper presents the background context and rationale for applying behavior analytic methods and procedures to support individual and crew performance effectiveness and adaptation for long-duration spaceflight missions beyond Earth orbit, such as a mission to Mars.

Keywords: Programmed environment, behavioral program, confined microsocieties.

NASA's *Vision for Space Exploration* calls for humans to return to the moon by the end of the next decade, paving the way for eventual journeys to Mars and beyond¹. Orion is the vehicle that NASA's *Constellation Program* is developing to carry a new generation of explorers back to the moon and later to Mars. Orion will succeed the space shuttle as NASA's primary vehicle for human space exploration. According to a recent statement by Robert Zubrin, President of The Mars Society and advocate of the Mars Direct plan (Zubrin, 2000), "We could be on Mars in 10 years without a doubt" (Sullivan, 2006). And a conclusion stated within the 2004 Garriott-Griffin report² on a strategy for the proposed U.S. space exploration policy was as follows: "We believe that human landings on the Moon or on Mars can begin about 2020" (p. 8). In that regard, Manzey (2004) estimates that a low-energy trajectory mission to Mars will require a minimum of 800 days, to include 200 days to reach Mars, 400 days on the surface of Mars, and 200 days to return to Earth.

Despite these encouraging developments, expectations, and estimates that are based on the overwhelming technological success of previous manned space initiatives, one consideration remains almost constant: life in space will not be easy for space dwelling groups. Evidence from many international sources supports this conclusion, but two recent committee reports are especially compelling, as noted below.

First, in response to a request from NASA, the Institute of Medicine convened a committee to address astronaut health during long-duration missions. The *Committee on Creating a Vision for Space Medicine During Travel Beyond Earth Orbit* was charged with making recommendations regarding the infrastructure for a health system in space to deal with such problems as radiation, loss of bone mineral density, and behavioral adaptation ("behavioral health"). The full report is available in Ball and Evans (2001), and the basic findings were as follows:

¹ http://www.nasa.gov/mission_pages/exploration/main/ 

² The Garriott-Griffin Report: Extending Human Presence into the Solar System, The Planetary Society, 2004. http://www.planetary.org/programs/projects/aim_for_mars/study-report.pdf

1. Not enough is yet known about the risks to humans of long-duration missions, such as to Mars, or about what can effectively mitigate those risks to enable humans to travel and work safely in the environment of deep space.
2. Everything reasonable should be done to gain the necessary information before humans are sent on missions of space exploration.

Second, in 2003 a NASA-funded workshop (*New Directions in Behavioral Health: A Workshop Integrating Research and Application*) consisting of behavioral researchers, operational support personnel, and NASA managers convened at the University of California, Davis to promote a dialogue among these representative participants to expand understanding of psychological, interpersonal, and cultural adaptation to space. The resulting 28 reports generated by this workshop were published in 2005 in a special issue of *Aviation, Space, and Environmental Medicine*, edited by Williams and Davis (2005). In an overview of the workshop, Harrison (2005) warned as follows: “We have to be wary of the expedient belief that ‘nice to have’ items such as private crew quarters, and separate areas for eating, and crew hygiene, time for recreation and other items that enhance the psychological health of the crew can be omitted or cut due to cost and schedule. In fact such items may be important, even crucial for mission success” (p. B10).

As reported by Kanas, Salnitskiy, Gushin, Weiss, Grund, Flynn, Kozerenko, Sled, and Marmar (2001), Russian social scientists use the term “asthenia” to describe fatigue, emotional lability, decreased work capacity, and sleep disturbances that have been observed in cosmonauts. Similar decrements in vigor and concentration effectiveness have been reported in military participants exposed to stressful events over time (Harris, Hancock, & Harris, 2005), indicating a continuity of individual performance consequences across disparate antecedent and stress-provoking circumstances. Moreover, the explosive confrontations that occurred among the multinational crew participants during the 240-day SFINCSS-99 simulation study³ (Karash, 2000; Sandal, 2004), leading to the withdrawal of one crewmember volunteer, call attention to the “human behavior element” as the most complex component of plans and designs for extended long-duration space exploration missions beyond Earth orbit (Brady, 2005). In addition, experts continue to warn that previous success of spaceflight missions, to include stays in space for over a year, should not be taken to indicate that current approaches to spacelife management will be successful for the unprecedented durations associated with an expeditionary mission to Mars. For example, within NASA’s *Man-Systems Integration Standards* (NASA-STD-3000⁴) is presented the following warning: “The user must keep in mind that much is still unknown about the over-all, long term effects of various space environments on performance capabilities.” As stated by Manzey (2004), “Our current psychological knowledge derived from orbital spaceflight and analogue environments is not sufficient to assess the specific risks of missions into outer space” (p. 781).

The history of manned orbital spaceflight missions to date, however, shows clearly that humans are capable of enduring demanding spacelife work schedules in isolation and confinement for periods lasting more than a year in orbit. For example, cosmonaut Valery Polyakov holds the record for the longest stay in orbit (438 days) in 1994-1995⁵. On occasion, however, space dwelling crews have not been able to keep pace with scheduled work, as evidenced by the infamous 24-hour “vacation” taken by the Skylab-4⁶ astronauts during the then record-breaking 84-day manned flight ending on February 8, 1974⁷. Much later, former Apollo 8 astronaut James Lovell commented on that event: “The people on the

³ http://www.imbp.ru/WebPages/engl/SFINCSS-99/sfincss_e.html

⁴ These standards, which were codified in 1995, are in the process of being updated:

<http://hefd.jsc.nasa.gov/standards.htm>

⁵ <http://liftoff.msfc.nasa.gov/news/2001/news-EndIsMir.asp>

⁶ <http://chapters.marssociety.org/usa/oh/aero5.htm>

⁷ <http://www-pao.ksc.nasa.gov/history/skylab/skylab-4.htm>

ground have to realize what the conditions are in the spacecraft to be able to accomplish the tasks that you give the crew. In the early days, this was a lot of times not thought about until the crews sort of rebelled and went back to the controllers or mission planners and said, ‘Look. Here’s what we can do, and here’s how we have to stretch out the agenda’” (Dick & Cowing, 2004, p. 35). And as the distance traveled and the time spent in space habitats increase for expeditionary missions, the needs and aspirations of those “sent” may be anticipated to become increasingly autonomous from the expectations and directives of the “senders.”

It must be acknowledged, however, that despite the corrective crew events onboard Skylab-4, that mission concluded with unprecedented productivity by the crew⁸, although those astronauts never again participated in a spaceflight mission for, perhaps, obvious reasons. At the very least, then, these observations indicate that the design of space dwelling microsocieties for long-duration spaceflight must give realistic consideration to the limitations of even highly trained and motivated astronauts to sustain overbearing work-related schedules. Although conditions aboard the International Space Station (ISS) favor intense work schedules by the crew to maximize the scientific returns of such infrequent and hugely expensive undertakings⁹, perhaps with the expectation that mission participants will be living close to the edge of their short-term endurance, a three-year expeditionary mission to Mars obviously requires favoring crew behavioral health throughout the duration of the mission, even when that means fewer scientific returns.

In general, enhancing human performance in long-duration spaceflight missions involves consideration of selection, training, equipment, pharmacology, and even surgery, which might involve prophylactic appendectomy and corneal remodeling (Gibson, 2006). NASA’s *Bioastronautics Roadmap* addresses areas of risk associated with long-duration spaceflight and proposes interventions (“countermeasures”) to address or overcome them¹⁰. Countermeasures may be grouped as proactive or reactive. Proactive countermeasures may include crew selection and training, onboard approaches to overcome the effects of radiation and microgravity, and work and habitat design, “as design is a critical strategy in ensuring behavioral health during extended-duration space missions” (Williams & Davis, 2005). Reactive countermeasures would address such problems as medical emergencies, depression and related emotional problems, circadian desynchronization, crew autonomy from mission control, group fragmentation and interpersonal conflict, and loss of skilled performance. There is, however, an interplay between proactive and reactive countermeasures, and a human performance technology applied to space dwelling groups would be anticipated to encompass both types.

The ongoing calls for the development of evidence-based countermeasures, however, reflect the challenges associated with proposing specific recommendations for interventions that qualify to meet the urgent demands for reversing or preventing untoward individual and group events that might take place during a long-duration spaceflight mission. Current inflight countermeasures include monitoring of individual behavior, intervening directly or through the flight surgeon when necessary and appropriate, and facilitating crewmember contact with clinical and social support systems (Palinkas, 2001, p. 27). Existing countermeasures intended to promote psychological adaptation include inflight support such as leisure activities, arrangement of communication with family members, “care packages” that serve as reminders of loved ones on the ground, and adjustments to work schedules. An exception to these approaches that are targeted to brief-duration orbital missions, perhaps, is the development of computer-based training modules to manage interpersonal conflict and depression that might occur during long-duration spaceflight missions (Carter, Buckey, Greenhalgh, Holland, & Hegel, 2005).

⁸ <http://spaceline.org/flightchron/skylab4.html>

⁹ <http://spaceflight.nasa.gov/living/spacework/index.html>

¹⁰ <http://bioastroroadmap.nasa.gov/User/risk.jsp>

And the ever-increasing refinements of measurements of space crew behavior, which now include assessments such as WinSCAT (Kane, Short, Sipes, & Flynn, 2005), MiniCog (Shephard & Kosslyn, 2005), and related behavioral test batteries (*e.g.*, Kelly, Hienz, Zarccone, Wurster, & Brady, 2005), have not always led to recommendations in terms of proposing specific countermeasures or spacelife schedule designs. For example, based on a series of ethological observations of isolated and confined teams, Tafforin (2005) concluded: "Optimizing such human factors is one of the challenges we will face in order for Mars teams to be efficient" (p. 1087). Additionally, Carl Walz, acting director of the Advanced Capabilities Office in NASA's Exploration Systems Mission Directorate stated recently that "psychological and physical effects on the astronauts for a Mars mission are a major concern" (Ramstack, 2006). These are only representative comments within the context of ongoing considerations of how to meet the behavioral health challenges associated with extended-duration spaceflight missions (Williams & Davis, 2005). In the distant future, even genetic manipulation might be considered an ethical approach to human performance enhancement for spaceflight (Gibson, 2006).

These conditions, then, create an unprecedented and compelling need for extending the evidence base and technology on the organization of general living conditions and the performance requirements for small groups of humans traveling, living, and working together in isolated and confined microsocieties over extended time intervals. Importantly, journeying in a spacecraft on extended exploratory missions beyond Earth orbit does not constitute an ecological setting to which familiar pre-flight routines of living are easily applied. This unique and foreign ecology requires an applied human systems engineering technology functionally relevant to inherently unfamiliar settings that provides for a comprehensive status-assessment of a confined microsociety beyond what is available from even a fine-grained, multi-dimensional individual evaluation. Unforeseen events taking place on such expeditionary missions beyond Earth orbit require possible "countermeasure" interventions at the integrative human systems engineering level rather than at the level of an individual crewmember.

Despite uncertainties regarding the requirements of projected spaceflight initiatives beyond Earth orbit, a common feature of such expeditionary endeavors over the next half century will be extended stays by human groups in extraterrestrial vehicles and habitats. The imperatives and opportunities associated with the development and configuration of functional ecological models for such space dwelling human microsocieties must be based upon sound scientific principles for the behavioral management of semi-permanent as well as permanent groups with both operational and space science missions (Brady, 1992, *in press*).

CURRENT APPROACH TO SPACELIFE MANAGEMENT

Astronauts aboard the International Space Station (ISS) follow a precisely controlled schedule of activities that are intended to maximize the scientific returns of a mission and to ensure the crewmembers' physiological health as evidenced by exercise, sleep, and nutrition requirements. **Figure 1**, for

04:50-05:00		Acoustic dosimeters: hardware setup for static measurements
05:00-05:55	FE-2	BREAKFAST
05:55-06:15		Prep for Work
06:00-06:15	CDR	Orlan height adjustment
06:15-07:15	FE-1	Orlan height adjustment
06:15-06:20	FE-2	Payload status check
06:15-07:15	CDR	Spacesuit and БCC [Orlan interface unit] leak checks and valve tests
06:20-07:15	FE-2	EMU cooling loop filtration to prevent biomaterials and solid particles
07:15-07:35		Nutrition: urine collection
07:15-07:45	CDR	Physical Exercise (RED)
07:15-08:15	FE-1	Spacesuit and БCC [Orlan interface unit] leak checks and valve tests
07:35-07:45	FE-2	Nutrition: urine sample insertion in MELFI
07:45-09:15	CDR	Physical Exercise (TVIS + CEVIS)
07:45-08:45	FE-2	Physical Exercise (RED)

Figure 1. A four-hour interval of activities scheduled for astronauts aboard the ISS.

example, taken from NASA's daily posting of the ISS flight plan timelines¹¹ in GMT, shows an approximately four-hour interval of activities for the three astronauts as scheduled for February 16, 2007. The schedule is precisely controlled to maximize work performance within a setting that requires sharing of resources, including exercise equipment and personal hygiene facilities. Some activities are scheduled for as few as five minutes (e.g., Payload status check for FE-2), and others for as many as 90 minutes (e.g., Physical Exercise for CDR). The continued presence of others is an enforced socialization.

Observations of space crews living and working under such rigorously imposed schedules, however, indicate that compliance with the timelines and work demands is not always easily accomplished, if at all¹². Variability exists with respect to scheduled events, and there is an ongoing interaction between crew participants and mission control regarding adjustments that are essential when imposed schedules cannot be met. And the rigorous time-oriented schedule offers meals when crewmembers may not be hungry and expects sleep when crewmembers may not be sleepy. An alternative to such time-based activity requirements is almost certainly to be required for long-duration spaceflight beyond Earth orbit, and later sections of this paper will propose such an alternative.

Over time within the isolated and confined conditions of long-duration spaceflight, superordinate consequences for regimen/schedule compliance can be anticipated to lose force in sustaining effective individual and team mission-critical performances. Contingency management operations that involve such outcomes as financial rewards or directive and exhortational interactions with mission control will likely be ineffective. Given the ecologically impoverished conditions of space life, inter-operant management of scarce resources may be promising in the design of a confined micro-society that is topographically and functionally prosthetic, at the levels of individual and group, for its crewmember participants. The importance of activity as a countermeasure to the stresses of isolation and confinement was acknowledged by a NASA astronaut who identified being "meaningfully busy" as the single most important factor on a long-duration flight (Herring, 1997, p. 44; cited in Kanas & Manzey, 2003).

The implausibility, if not impossibility, of pre-mission ground-based empirical verification of an optimal set of spacelife parameters supportive of members of expeditionary missions beyond Earth orbit suggests the need for a *heuristic approach* to the design of an isolated and confined micro-society. Such a

¹¹ <http://spaceflight.nasa.gov/living/index.html>

¹² J.V. Brady, personal communication.

heuristic, technological, and analytic behavioral application will reflect the "...process of applying sometimes tentative principles of behavior to the improvement of specific behaviors" (Baer, Wolf, & Risley, 1968, p. 91). In that regard, multi-operant models of inter-operant relationships (Findley, 1962) were extended to the design of a mono-inhabited micro-society that supported the multi-dimensional repertoire of a single human volunteer residing in a programmed environment for over six months (Findley, 1966). The orderliness observed in the animal models provided a heuristic context for extending the underlying principles and technology to the generation and support of a multi-operant human performance repertoire. Such an extension follows the principle of "systematic replication" (Sidman, 1960). In much the same way that behavior analysis is challenged to predict the exact instant when a laboratory animal may press a lever for food under a variable-interval schedule of reinforcement or the exact response topography, the orderliness of a human multi-operant repertoire need not require prediction of each instance of an activity selection or engagement. Behavioral "control," in the sense of knowledge of the conditions that promote a desired performance steady-state, is evidenced at the meta-operant level of analysis. The steady-state, obtained with a variable-interval schedule for the laboratory animal and for a multi-operant repertoire for a human, is to be understood as a function of at least one set of antecedent conditions whose implementation is taken to "control" the production of the desired performance repertoires.

A spacelife systems engineering approach, then, reflects the goal of programming inter-operant schedules to optimize the value and access impact of available resources under conditions that promote intra-system motivation and novelty within the context of superordinate steady-states that are operationalized by the disposition of crewmembers to exhibit mission-critical performances during recurrent traversals of a flexibly oriented regimen to achieve mission objectives.

MULTI-OPERANT APPROACHES

One of the first groups of psychologists to be involved in considering the challenges of undertaking experiments with space-going animals consisted of C. B. Ferster, D. Meyer, C. G. Mueller, F. Ratliffe, and H. Schlosberg, and it was convened by the Behavioral Sciences Advisory Committee of the USAF Air Research and Development Command (Rohles, 1960). Early efforts targeted mice, but the transition to primates was soon underway, supported by scientists from the Walter Reed Army Institute of Research (Brady, 2005). Although Skinner was perhaps the first aerospace comparative psychologist (Skinner, 1960), scientists from the latter Institute were instrumental in providing the behavioral training for the primates named Able and Baker, launched in the nose cone of a rocket in 1958 (Brady, 1990). Operant techniques were instrumental in evaluating the performance effects of subsequent flights by the rhesus monkey named SAM (*S*chool of *A*erospace *M*edicine), on December 4, 1959, and the chimpanzee named HAM (*H*olloman *A*ero*M*edical Laboratory), on January 31, 1961 (Rohles, 1992). Both discrete and free operant shock-avoidance tasks were programmed in these initial flights, with subsequent flights using more complex schedules of reinforcement (Rohles, 1966).

Figure 2 shows chimpanzee Ham in the flight couch for the Mercury-Redstone 2 (MR-2) suborbital test flight.¹³ On January 31, 1961, a Mercury-Redstone launch from Cape Canaveral carried

¹³ http://lsda.jsc.nasa.gov/scripts/photoGallery/detail_result.cfm?image_id=1813 Use of this and other similar photographs follows NASA's guidelines regarding the use or reproduction of NASA material obtained from a JSC web page: <http://www.jsc.nasa.gov/policies.html#Guidelines>



Figure 2. Ham in the flight couch.

him over 640 kilometers down range in an arching trajectory that reached a peak of 254 kilometers above Earth. The flight lasted 16 minutes, 39 seconds.¹⁴

Figure 3 shows the test apparatus supporting the discrete and free-operant avoidance tasks performed by Ham during his journey¹⁵. **Figure 4** shows Ham greeting a handler at the conclusion of his

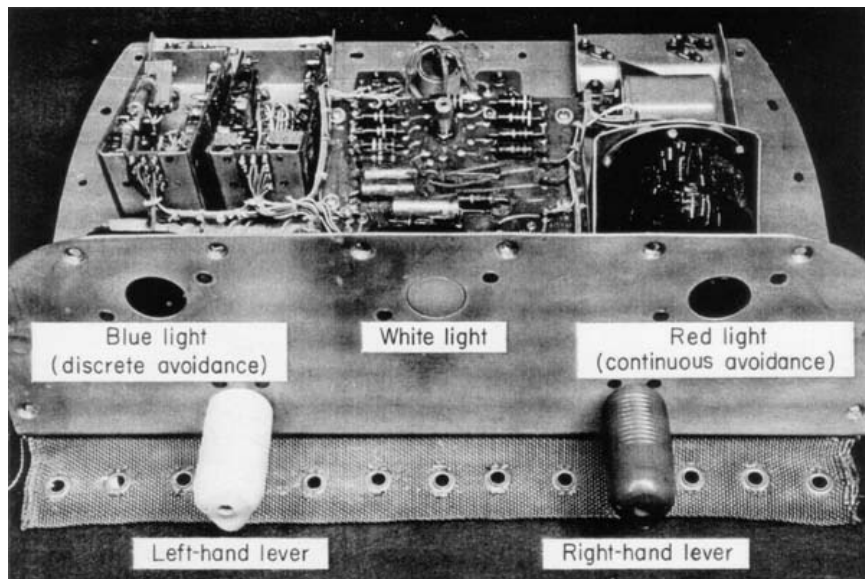


Figure 3. Test apparatus for Ham.

¹⁴ http://lsda.jsc.nasa.gov/scripts/experiment/exper.cfm?exp_index=907

¹⁵ http://lsda.jsc.nasa.gov/scripts/photoGallery/detail_result.cfm?image_id=1817



Figure 4. Ham at the conclusion of his flight.

flight.¹⁶ As stated in the report, Ham's flight on MR-2 met all of its objectives, and it was a significant accomplishment toward manned U.S. space flight.

The results of the flight showed no significant change in Ham's physiological state or psychomotor performance¹⁷, and an examination of Figure 4 would suggest that Ham experienced no enduring ill effects of his journey into space and back.

Mercury-Atlas 5 (MA-5), the second chimpanzee flight, was launched on November 29, 1961. During this flight, which lasted 3 hours and 21 minutes, a chimpanzee named Enos performed a complex multiple operant task while orbiting the earth twice. As stated in the description of MA-5¹⁸, the performance test panel used for the MA-5 flight was specifically designed for the orbital flight. The MA-5 performance test panel consisted of three miniature inline digital displays and three levers. The panel also controlled a pellet feeder that was incorporated into the panel and a lip-lever activated drinking tube that was attached to the flight couch near the head of Enos. The performance task for the MA-5 flight consisted of a five-component multiple-operant schedule combining appetitive and avoidance tasks. At the conclusion of this flight, the data showed no significant disturbance in Enos' performance that could be attributed to the weightless state, to the other conditions accompanying the flight, or even to a lever malfunction during the second orbital pass.

A general finding based upon the flights by Ham and Enos was as follows. A 7-minute (MR-2) and a 3-hour (MA-5) exposure to weightlessness was experienced by the subjects in the context of an experimental design that left visual and tactile references unimpaired. There was no significant change in either animal's physiological state or performance as measured during a series of tasks of graded motivation and difficulty.¹⁹

¹⁶ http://lsda.jsc.nasa.gov/scripts/photoGallery/detail_result.cfm?image_id=1804

¹⁷ http://lsda.jsc.nasa.gov/scripts/mission/miss.cfm?mis_index=164

¹⁸ http://lsda.jsc.nasa.gov/scripts/experiment/exp_descrp_pop_up.cfm?exp_id=CHIMP&string=¤t_string=

¹⁹ http://lsda.jsc.nasa.gov/scripts/experiment/exp_descrp_pop_up.cfm?exp_id=CHIMP&string=¤t_string=

These remarkable findings with Ham and Enos clearly showed the applicability of basic operant techniques to sustain a complex set of performances under obviously difficult circumstances. From the perspective of behavior analysis, both Ham and Enos were residents in a programmed environment during training and during the rigors of their respective spaceflights. The environments of both of these chimpanzees were designed to support an increasingly complex set of performances under increasingly challenging schedules of reinforcement.

Along with these early developments with space-going animals, an attempt was being made to advance behavior analysis by complicating simple performance units into sequences of operants (Findley, 1962), where an operant is operationalized as a class of responses, any of which will produce a specified consequence under a given set of environmental circumstances (Skinner, 1953, p. 65). This important work led to the conceptualization of multi-operant behavior as “the experimental demonstration of several related operants, where each operant is defined in terms of explicit operations and experimental control” (Findley, 1962, p. 114). In contrast to a strictly serial sequence of operants, this research program led to the demonstration of stable performance repertoires maintained by the interacting reinforcing value of operant engagement alternatives that were available to the organism at various transition points in a sequence. The resulting steady-state performances observed within the context of iterations that involved different choices at the transitions points (“trees”) were shown to exhibit properties of a unitary operant, based upon the sensitivity of a tree to stimulus control and influence by DRL and FR schedules of reinforcement.

The extension of this multi-operant model to the challenge of maintaining the health and productivity of a human was undertaken by Findley, Migler, and Brady (1963). A male volunteer entered a programmed environment for what was to be an indeterminate period of time, and the schedules in effect for work, sleep, and recreation showed continuity between the multi-operant procedures used in animals and those in this single-human study. **Figure 5** presents a diagram of the environment, which consisted of a central living and sleeping area, an adjacent work room, and an adjacent bathroom. **Figure 6** presents a diagram of the behavioral program that determined how the resources in the environment

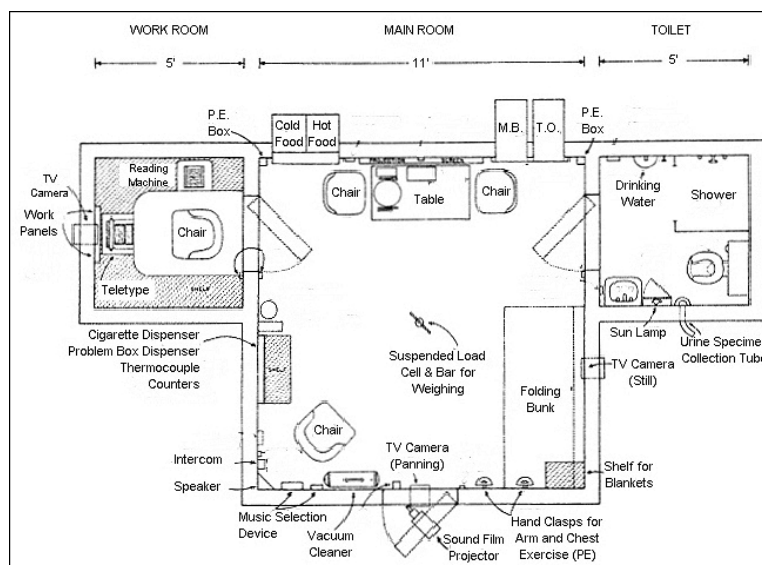


Figure 5. Schematic diagram of the single-subject programmed environment. Taken from NASA Report NASA-CR-52913²⁰ (Findley, Migler, & Brady, 1963, p. 12).

²⁰ NASA Terms and Conditions of Use: <http://ntrs.nasa.gov/NTRS.NACA.2005.Copyright.htm>

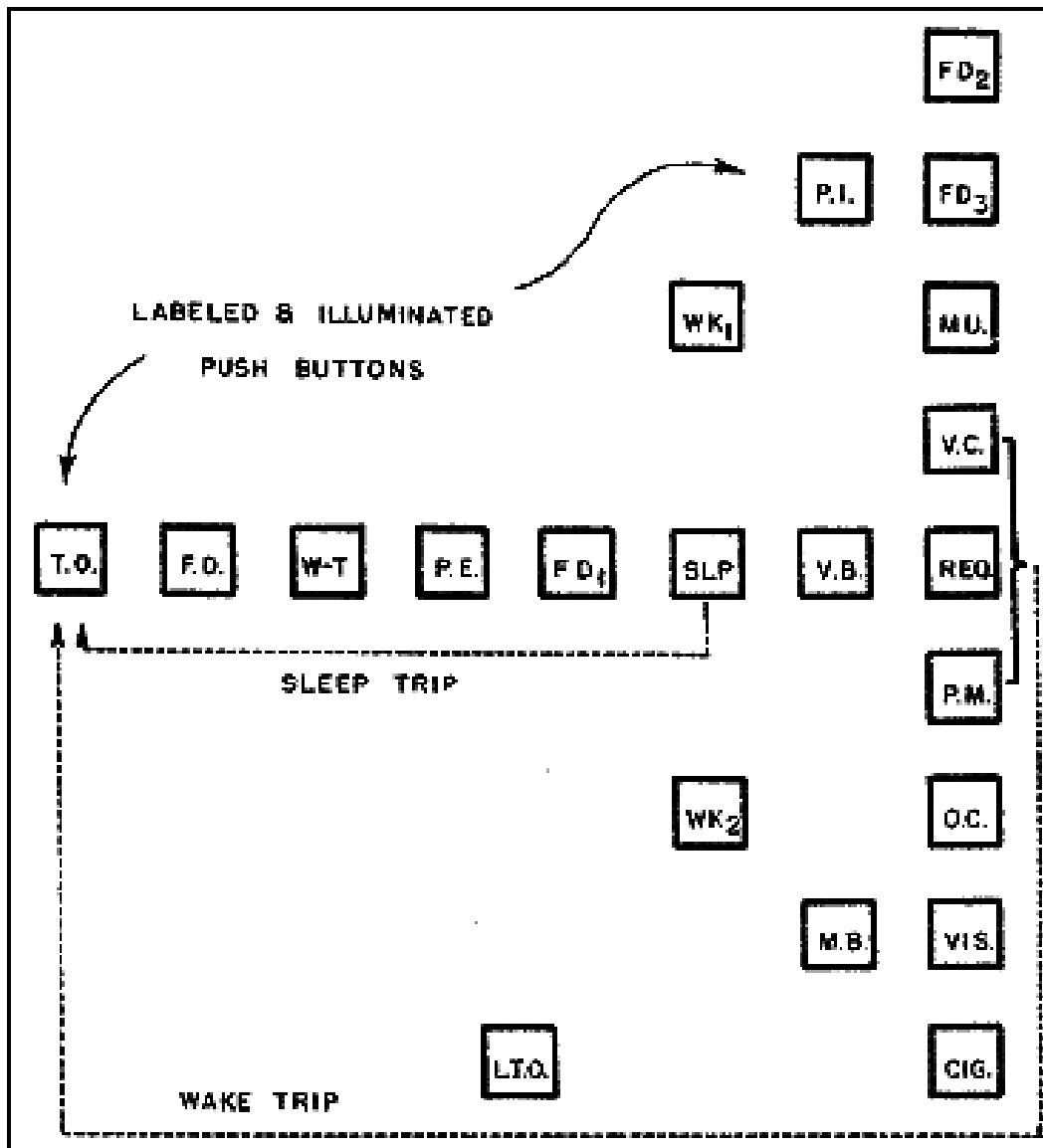


Figure 6. A diagram of the behavioral program. Taken from NASA Report NASA-CR-52913²¹ (Findley, Migler, & Brady, 1963, p. 16).

were to be accessed and used. Each box in the behavioral program represents an activity unit, and all requirements associated with a given activity unit had to be met before the occupant could transition from one activity to another in the sequence.

Beginning at the left of the diagram, a “Sleep trip” consisted of all activities between and including *Toilet Operations* (T.O.) and *Sleep* (SLP). The arrow from SLP to T.O. designates a minimum loop of fixed activities designed to assess and maintain the participant’s health. The multi-operant aspects of the program are reflected in the alternatives available to the resident within the right-most three columns of activity units. The first set of alternatives came after Food One (FD₁), which was a light meal. After SLP, one of the following three activities was available for selection: (1) Work One (WK₁), which

²¹ NASA Terms and Conditions of Use: <http://ntrs.nasa.gov/NTRS.NACA.2005.Copyright.htm>

was a tracking task within the work room; (2) SLP, providing access to the bunk for an unlimited period of time; or (3) Work Two (WK₂), which required a range of intellectual, clerical, or manual behaviors. The final two columns were intended to provide a progressively greater selection of activities having increasing reinforcing strength. For example, Programmed Instruction (P.I.) provided access to reading material in frames, and Manual Behavior (M.B.) provided access to art material. Within the last column are nine activity units, and the participant was allowed to select and complete four units before transitioning to T.O. at the beginning of the program. The sequence of selections constituted a "Wake Trip." Reinforcing activities within the last column included Food Two (FD₂), which was a major meal, access to Music (M.U.), and access to Cigarettes (CIG.), which were earned by operating a manipulandum. A full description of the environment and the behavioral program is presented in Findley, Migler, and Brady (1963) and Findley (1966).

The behavioral program was designed to support the full range of the participant's work, recreational, and health maintenance activities: behavioral health. The boundaries between successive activities insured that all requirements for a given activity unit were satisfied before transition to a subsequent fixed or alternative activity was permitted. This also provided the opportunity to assess performance within any given activity, such as error frequency on the tracking task, and to assess activity choices and durations over time. More importantly, perhaps, the behavioral program was designed so that all incentives to sustain performance were intrinsic to the programmatic sequencing of the fixed and alternative selections. The participant's full behavioral repertoire was maintained throughout the 152 days with no incentives external to the programmatic sequence. This clearly showed the value of the behavioral program's design to support an individual's motivation to engage in tasks essential to the "mission" and to the welfare of the participant over an extended time period in isolation and confinement.

The programmed environment reflected the following: "In summary, then, the techniques of the animal laboratory, that is, the specification of contingencies, the stimulus control of behavior, the organization of complex sequences of behavior, and the use of the continuous experimental environment all combine to provide, in principle, most of the elements employed here for the design of an experimental environment for human research" (Findley et al., 1963, p. 8). Among the report's recommendations to NASA was the following: "First and foremost is the fact that this environment sustained the subject in good health and maintained good work performance at a variety of tasks under conditions of extreme social isolation and confinement for an unprecedented duration of 152 days, or approximately five months" (Findley et al., 1963, p. 111).²²

To extend this approach to groups, a residential laboratory was established at The Johns Hopkins University School of Medicine, and early reports of this work were given by Bigelow, Emurian, and Brady (1973) and Brady, Bigelow, Emurian, and Williams (1975). **Figure 7** presents a diagram of this

Figure 7, Next page!

²² The participant, Whilden Breen, Jr., is identified by name in the report. *Life Magazine* published a description of his experiences within the May 17, 1963 issue.

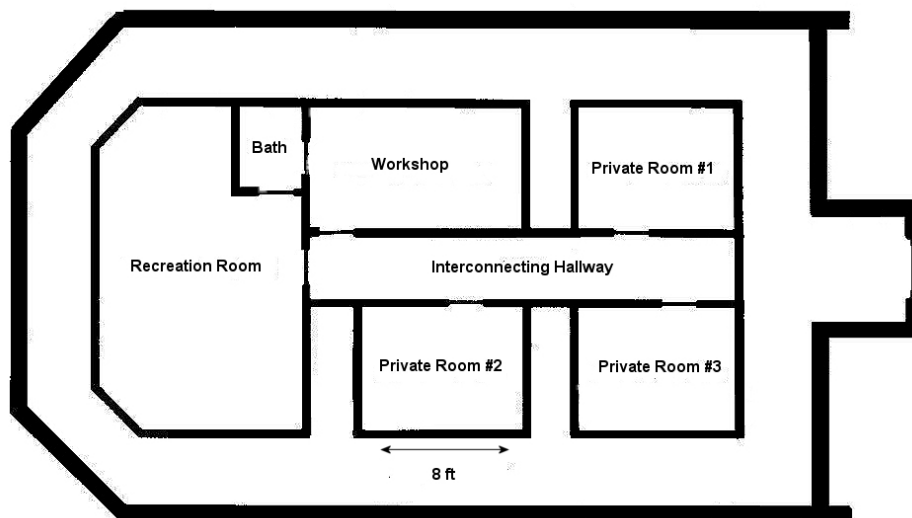


Figure 7. A diagram of the three-person programmed environment.

three-person residential laboratory. The laboratory supported the implementation of a continuously programmed environment methodology as a tool to implement interbehavioral research and applications programs supporting individual and group adjustment to the rigors of isolation and confinement (Brady, 1992). The methodological approach is a direct descendent of the work reported in Findley et al. (1963), and it constitutes a systematic replication (Sidman, 1960). The resulting research methodology brings within the laboratory a broad range of complex and naturalistic features of the habitation/behavior environment for experimental analysis, permits programming, monitoring, objective recording, and quantitative measurement of interaction patterns, and provides for controlled study of both *individuals and groups* under experimental conditions of long durations without sacrifice of methodological rigor (Brady, Bernstein, Foltin, & Nellis, 1988).

Similar to Findley et al. (1963), a behavioral program, which is implemented within the context of a continuously programmed environment, is operationalized by an array of individual and group activities or behavioral units and the rules determining the relationships among them. **Figure 8** presents a representation of a behavioral program designed for several typical applications within the residential

Figure 8, Next Page!

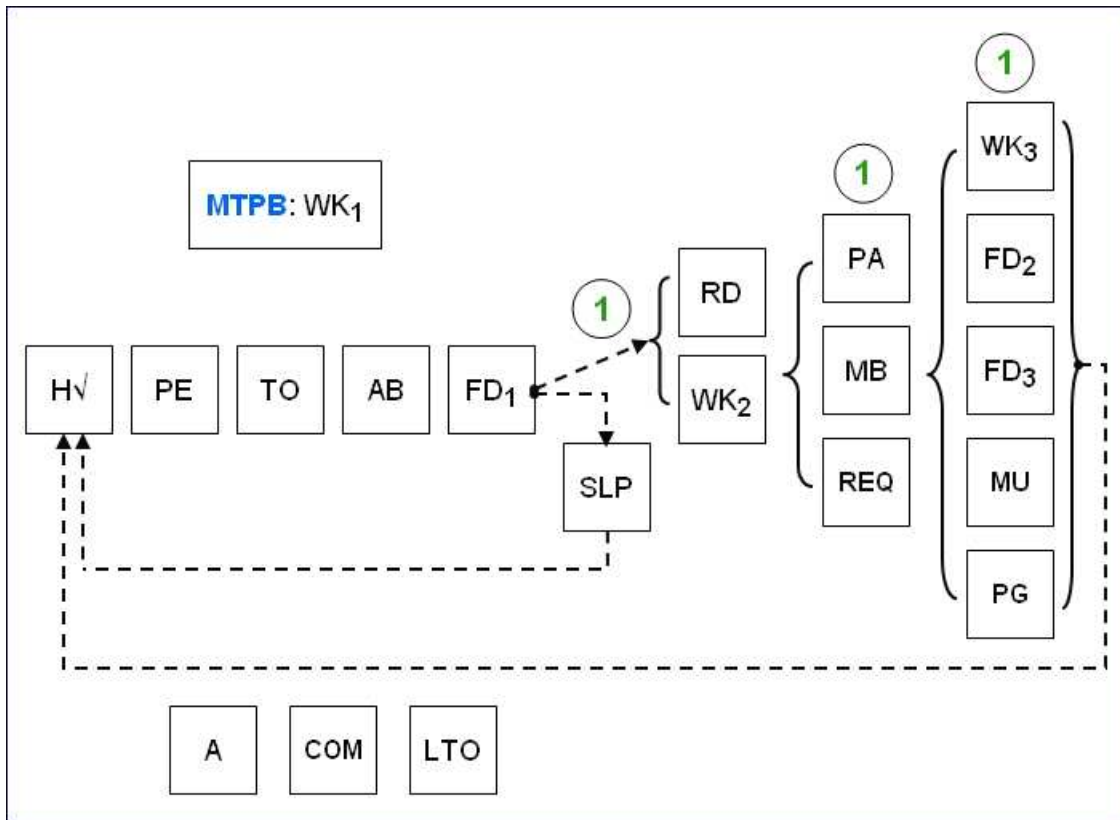


Figure 8. A prototypical behavioral program used within the residential environment for group analyses.

environment. **Figure 9** presents a brief description of the activities represented by the acronyms displayed in **Figure 8**. This behavioral program is structurally and functionally similar to the one adopted in the single-participant study with the notable addition of social episodes.

Figure 9, Next page!

Notation	Full Name	Description
H√	Health Check	Temperature, pulse, weight, mood and general status report
PE	Physical Exercise	Aerobic conditioning and/or weight training
TO	Toilet Operations	Access to shower and fresh clothes, general housecleaning maintenance
AB	Autogenic Behavior	Relaxation and meditation exercises, biofeedback
FD1	Food One	Light meal in the private room
SLP	Sleep	Access to sleeping area
RD	Reading	Access to reading materials such as books and e-learning resources, programmed instruction
WK2	Work Two	Assortment of structured problems, assembly projects, and experiments
PA	Puzzle Assembly	Assemble a puzzle
MB	Manual Behavior	Access to art supplies for drawing and painting
REQ	Requisition	Earn delayed delivery of high-valued items such as special foods.
WK3	Work Three	Access to workshop area containing washer and dryer
FD2	Food Two	Major meal in the private room
FD3	Food Three	Access to major meal in recreation room; solitary, dyad, or triad
MU	Music	Earn access to instruments or media such as DVDs
PG	Private Games	Access to game assortment in private room
MTPB	Multiple Task Performance Battery	Synthetic performance task, solitary and 3-person team versions.
A	Audit	Observe MTPB work tallies for team members
COM	Communication	Access to intercom for inter-member communications
LTO	Limited Toilet Operations	Access to essential toilet facilities

Figure 9. An inventory of activities constituting a typical behavioral program

Beginning with Health Check, participants follow the behavioral program sequentially from left to right. In general, activities that were heuristically judged to show relatively high reinforcing “force” are positioned later in the sequence, and more choices are available. The circled “1” indicates that one choice could be made among those activities designated by the adjacent arrows. At the completion of either Sleep or an activity within the last column, the participant returns to Health Check. There are, then, two iterative sequences with this program. The first sequence, ranging from Health Check to Sleep, is designed to maintain and assess the participant’s health if he or she were otherwise indisposed to engage in the broader selection of activities. The second sequence commenced by a choice other than Sleep when Food One was terminated. That latter sequence consisted of alternative activity opportunities, and successive iterations through the program potentially consisted of different sequences of activities.

Several activity selections are outside the scope of the sequential design of the full behavioral program. For example, the individual multiple task performance battery (MTPB), which was a variant of that developed by Morgan and Alluisi (1972), could be selected between any two activities within the full program, and it was presented on a computer terminal within the private room. In most studies, a participant’s remuneration was a function of earning performance “points” on that task. In some studies

(e.g., Emurian, Brady, Ray, Meyerhoff, & Mougey, 1984), a team version of the MTPB was programmed such that three participants were required simultaneously to enter a correct response on designated sub-tasks while working on separate terminals, all located within the workshop area of the laboratory.

Access to social activities required participants to select the activity concurrently. For example, Food Three was a major social meal in the recreation room, and access to that opportunity required either two or three participants' schedules to be synchronized on any given access occasion. Such a contingency required communications between and among the participants to ensure that schedules were, in fact, synchronized for that social activity opportunity.

A behavioral program provides a promising solution to the problem of structuring the limited resources and information that may be available to members of a confined micro-society (Emurian, 1988). The functional interdependencies among activities ensure that performances of value to the welfare of the individual (e.g., physical exercise), to the welfare of the group (e.g., social recreation), and to the welfare of a mission (e.g., sustained individual and team performance effectiveness) occur recurrently over time. These interbehavioral and functional interdependencies reflect the "motivational" properties inherent within successive progressions through the program, and all incentives to maintain the overall operational status of the confined micro-society can reside within the design of the behavioral schedule itself. The necessarily reduced resource opportunities available to spaceflight participants require this behavioral program technology to optimize the impact of resource access to ensure continued value to crewmembers over extended durations.

The behavioral program not only structures access to resources, but it also makes all corresponding activity units available for measurement. The boundaries between successive activities in the program impose rigor on the assessment of individual and group preferences and effectiveness with those activities. Additionally, the program has the advantage of providing a comprehensive range of variables for observation and measurement, together reflecting the behavioral health of the organization. Although free-running spacelife schedules may impact and shift wake-sleep cycle routines and circadian rhythms (Kanas & Manzey, 2003, p. 136), it is not at all certain that inflexible work-rest routines will best serve the behavioral health of crew members under conditions of spaceflight durations associated with a Mars expeditionary mission.

The effectiveness of a multi-operant behavioral program was affirmed repeatedly over a series of investigations where such a program was implemented (Brady & Emurian, 1978; Brady & Emurian, 1983; Emurian, Brady, Meyerhoff, & Mougey, 1983; Emurian, Emurian, & Brady, 1978; Emurian, Emurian, & Brady, 1985; Emurian, Emurian, & Brady, 1982; Emurian, Emurian, Bigelow, & Brady, 1976). Although experimental operations were performed during the course of those studies, the adoption of the behavioral program as the over-arching approach to generating and sustaining both individual and social work and recreational activities best reflects, perhaps, the technique of systematic replication by "affirming the consequent" (Sidman, 1960, p. 127), which was evidenced by the behavioral outcomes that were observed dependably across different groups and across different experimental interventions.

Given the unavailability of concurrent access by crewmembers to many critical resources aboard the spacecraft, a programmatic schedule will likely require a combination of temporally bounded activity opportunities for each astronaut presented in concert with multi-operant sequences and options on other occasions. It is this intersection of two schedule design approaches that provides the occasion for a *behavioral economics* management model to be considered to bridge the inter-behavioral relationships among successful engagement and completion of critical mission "high-cost" activities and later engagement and completion of "high-demand" activities, the latter in support of maintaining optimal behavioral health during long-duration expeditionary missions.

Behavioral economics (Kagel & Winkler, 1972; Lambert, 2006) provides the conceptual framework for scheduling and interpreting inter-operant relationships within the behavioral program for fixed inter-behavioral sequencing of performance units and for choice management on those occasions where a selection of required and optional activity units is available for use. In particular, consideration of demand elasticity associated with valued activities, together with potential substitutability of one valued activity for another, has direct relevance to managing the resources available to members of a closed economy (Hursh, 1980). Such management is to be understood in terms of suggesting baseline behavioral program ingredients and parameters and countermeasure responses when a dynamic change in the organizational context of a micro-society, as determined by the interactions among multi-operant units, is detected.

Behavioral economics will provide an analytical decision support tool for interpreting the reinforcing strength of access to activity units that may be delayed, temporally and sequentially, for selection due to antecedent performance requirements that precede the opportunity to engage in such optional units. And when an otherwise reinforcing unit having anticipated beneficial side-effects to crew cohesion, such as social occasions, is determined to show a loss of strength as evidenced by decreased engagement, a behavioral economics management model can suggest a reorientation of available high-value opportunities in support of social occasions whose occurrence now relates to a requirement, rather than an option. Similar re-stabilization of the meta-operant behavioral program is anticipated to occur in response to dynamic changes in individual and crew adjustment to isolation and confinement and to dynamic alterations of the value of access to available environmental resources and performance requirements. Under conditions of extreme isolation and confinement, it should be anticipated that activity units will exhibit a combination of performance requirements (*i.e.*, “cost”) and reinforcing value (*i.e.*, “demand”) and that these properties will change over time. The fact that instructional control of work-schedule compliance, which leaves uncertain the precise controlling variables independent of a training history (Kelly et al., 2005), may be compromised by crew autonomy during long-duration expeditionary missions (Brady, 2005) calls attention to the need for realistically alternative approaches to maintain vital individual and crew performances under conditions of isolation and confinement.

MISSION TO MARS

An expeditionary mission to Mars is projected to take up to three years (Manzey, 2004). Despite the impressive accomplishments in the areas of crewmember screening, selection, and training for spaceflight operations, evidence-based countermeasures to the demands on behavioral health of such a mission have yet to be developed. How a behavioral program might be integrated into a traditionally time-oriented schedule is considered here as a potential countermeasure.

Based initially upon Russian experiences (*e.g.*, Gushin, Kholin, & Ivanovsky, 1993), there is suggestive evidence of stages of spaceflight adaptation (Manzey, 2004). Despite the inconclusive findings regarding the generality of such stages across disparate simulation and actual spaceflight conditions (Kanas & Manzey, 2003, ch. 2), consideration of the potential for time-based reactions to isolation and confinement by space dwelling groups provides the occasion for proposing countermeasures directed toward particular stages of adaptation. For example, Manzey (2004) suggests that after approximately 12 weeks in space, during which crew members have adjusted to the routine of their mission, the deleterious effects of boredom and monotony will begin to impact the crew, with increasing stress becoming evident as a function of time spent under those conditions. Accordingly, a countermeasure to such circumstances is to implement a behavioral program. A spacelife systems engineering approach, then, might consider the use of rigorous time-oriented work and rest routines during the early weeks of a mission, during which the activity level is plausibly intense as the crew concludes a launch and prepares for the long months ahead of the transfer journey to Mars. A transition from such routines to a behavioral program is suggested as a countermeasure to the stress consequences of the early months in space. As the crew approaches Mars

after many more months, a transition back to a time-oriented schedule might occur in preparation for the demands of the landing and residence on Mars. Finally, a recent survey of 11 Russian cosmonauts gave suggestive evidence of a preference by some for crewmember regulation of work and rest schedules depending on the stage of the flight (Nechaev, Polyakov, & Morukov, 2007).

It must be acknowledged, however, that managing the behavioral health of space dwelling groups is but one component among several equally critical health-related issues that must be confronted and overcome if a mission to Mars is to succeed. In that regard, it has been estimated that during the journey to Mars, crewmembers could lose as much as 40% of their muscle mass and 25% of their bone (Hawkey, 2005). In a dramatic example of what could happen, Haddy (2007) posed the following question: “Imagine a radiation sick, sleep-deprived astronaut stepping on Mars; muscle-and-bone weakened and dehydrated, he or she becomes hypotensive, faints, and breaks a leg. What now, Houston” (p. 643)? His argument, which takes into consideration the earlier findings of Krauss (1991), is that insufficient biological science research has been conducted to address and overcome such problems as long-term exposure to radiation and microgravity. Adding such problems to an astronaut already compromised by the cumulative stresses of life in isolation and confinement is to appreciate the compelling need for an aggressive multi-disciplinary research program to provide evidenced-based countermeasures to all challenges associated with a mission to Mars. In that regard, however, Mark G. Benton of *Boeing Space and Intelligence Systems* has published a vehicle architecture for a six-person spaceship, based on technologies currently near the state-of-the-art, that provides both shielding against galactic cosmic rays and artificial gravity to mitigate crew physiological problems on long-duration missions, to include an expeditionary mission to Mars (Benton, 2006). A technical solution to such problems leaves crewmember behavioral health as a major consideration for current research initiatives.

CHALLENGES

There is increasing attention given to the benefits of residential environments to address questions of scientific importance in such areas as behavioral pharmacology (*e.g.*, Donny, Bigelow, & Walsh, 2003), drug effects on learning and cognition (*e.g.*, Kelly, Foltin, & Fischman, 1993), behavioral and physiological effects of phase shifts in sleep cycles (*e.g.*, Hart, Ward, Haney, Nasser, & Foltin, 2003), and properties of reinforcement (Bernstein, 1998). The intent of such work is, for the most part, to understand functional relationships that will account for behavior outside the boundaries of such investigative laboratories (“external validity”). With respect to spaceflight operations, however, the intent is different. In such latter cases, the intent is to understand how best to promote and sustain human performance, adaptation, and endurance under the conditions of an inherently constrained environment (“internal validity”).

Research addressing such considerations, however, is challenged, if not directly undermined, by the prevailing culture of scientific endeavors. As stated by Musson and Helmreich (2005), “The short-term nature of funded research and the expectation of producing meaningful results in the near-term is a result of the culture of experimental scientific research. Such an approach, however, does not seem to suit such settings as human spaceflight... (p. B124).” Although these comments reflected research initiatives relating personality traits to performance in spaceflight and analogue settings, similar challenges exist in undertaking long-duration simulations in ground-based residential laboratories investigating programmed environment management of confined microsocieties. NASA is aware of such challenges, as indicated by Recommendation 4.2 in the Executive Summary of *The National Aeronautics and Space Administration’s Bioastronautics Roadmap*: “How to support the extensive behavioral research program that would be necessary to validate processes or countermeasures such as select-in/select-out criteria (both for individual crew members and for a composite crew), issues related to cultural diversity, crew interactions, and isolation or stress-induced hazards. These issues may well require long lead times to study adequately” (Longnecker & Molins, 2006, p. 13).

These challenges notwithstanding, the report by Ball and Evans (2001) concludes Chapter 5 (*Behavioral Health and Performance*) recommending that NASA should give priority to increasing the knowledge base of the effects of living conditions and behavioral interactions on the health and performance of individuals and groups involved in long-duration missions beyond Earth orbit. Investigative attention should focus on the following factors:

- Understanding group interactions in extreme, confined, and isolated microenvironments;
- Understanding the roles of sex, ethnicity, culture, and other human factors on performance;
- Understanding potentially disruptive behaviors;
- Developing means of behavior monitoring and interventions;
- Developing evidence-based criteria for reliable means of crew selection and training and for the Management of harmonious and productive crew interactions; and
- Training of both space-dwelling and ground-based support groups specifically selected for involvement in operations beyond Earth orbit.

Further investigations, then, should be directed toward the development of countermeasures to overcome such challenges as cultural differences among members of multinational crews, personality differences among members of disparate professional and technical disciplines, the distribution of authority and roles within mixed gender crews, and sexual interactions. In the case of sexual interactions, careful consideration must be given to providing living arrangements that will accommodate this potential challenge to group cohesiveness.

CONCLUSIONS

Everything reasonable must be done to support the development of evidenced-based principles (“countermeasures”) to support the design of confined microsocieties for spaceflight applications (Ball & Evans, 2001). In that regard, the Institute for Biomedical Problems of the Russian Academy of Sciences is currently planning a 500-day ground-based study (Project MARS-500), scheduled to begin in late 2008, to simulate the duration of components of a Mars mission for a 6-person crew.²³ Developing evidenced-based principles to foster and maintain the interest and willingness of inhabitants of confined microsocieties to perform in ways that are beneficial to themselves and to a mission is critically important to the success of future manned space initiatives. The multi-operant behavioral program, which is derived from behavior analytic methods and procedures, provides a promising structural and functional approach to the problem of motivating and monitoring individual and group behavior for the continuous management, observation, and assessment of a confined microsociety. Long-duration simulations and evaluations of this approach, undertaken within a continuously programmed environment ecology, obviously constitute the reasonable next step.

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²³ <http://www.imbp.ru/Mars500/Mars500-e.html>

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