Chapter 2
From Earth Analogues to Space: Learning How to Boldly Go

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Abstract The need to find relevant terrestrial substitutes, that is, analogues, for teams operating in extraterrestrial and microgravity environments is driven by extraordinary demands for mission success. Unlike past frontiers where failure on the part of various groups to succeed represented far more limited implications for continued progress within these environments, accidents like *Challenger* in 1986 and *Columbia* in 2003 underscored the magnified cost of failure for space missions. Where past human frontiers were characterized by centralized decisions to engage in exploration and development largely under the dictates of authoritarian governments or individual sponsors, the exploration of space has been significantly influenced by the general public's perception of "acceptable risk" and fiscal worthiness. To date, space missions have failed due to technological deficiencies. However, history is replete with examples of exploration and colonization that failed due to human frailties, including those that reflect failures of the group. Both historical literature and research on teams operating within extreme environments, including space, have clearly indicated that psychological and sociocultural factors are components critical for individual and group success. Given the limited access to the space frontier and the investment in collective effort and resources, our ability to study individual and group functioning in the actual space environment has been, and will continue to be, severely limited. Thus, studying groups in terrestrial extreme environments as analogues has been sought to provide *predictive* insight into the many factors that impact group performance, health, and well-being in challenging environments.

This chapter provides an overview of the evolution of research utilizing terrestrial analogues and addresses the challenges for selecting, training, and supporting teams for long-duration space missions. An examination of how analogue environments can contribute to our knowledge of factors affecting functioning

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and well-being at both the physiological and the psychological levels will help define the focus for future research.

2.1 Introduction

Humans have long speculated about, studied, and striven to explore the heavens. Many of our earliest myths, such as the flight of Daedalus and Icarus too close to the Sun on wings made of wax, expressed our desire to explore beyond the boundaries of Earth as well as our willingness to push current technology to its limits. Considerations by the earliest philosophers and scientists, including Archimedes, Galileo Galilei, Nicolaus Copernicus, Leonardo da Vinci, Sir Isaac Newton, Jules Verne, H. G. Wells, or Percival Lowell, eventually generated a whole new genre of fictional literature built upon scientific extrapolations, dubbed “science fiction,” and gave voice to their speculations about the nature of extraterrestrial environments. Modern scientists and pioneers led by the Wright brothers, Robert Goddard, Konstantin Tsiolkovsky, Hermann Oberth, Wernher von Braun, Sergey Korolev, Yuri Gagarin, and Neil Armstrong pushed the boundaries of knowledge about flight and extended human inquiry beyond our terrestrial boundaries into our local and extended galactic neighborhood. For serious considerations of how humans will fare in space, we have had to extrapolate from human experience on Earth in environments that challenge us in, ideally, similar ways. However, the search for space analogue environments in which to systematically study individual and group adaptation has had to grapple with some significant limitations, i.e., the impossibility of a substitute for a microgravity or reduced-gravity environment or environments that holistically mimic radiation profiles and their inherent danger for those beyond Earth’s magnetic field. Since there is no direct equivalent for space, all analogue environments are simulations of greater or lesser fidelity along varying dimensions of interest. Some analogue environments provide extremely good characterizations of expected challenges in testing equipment or hardware, e.g., environmental chambers such as the Space Shuttle mockups of the various decks or the cargo bay in NASA’s Weightless Environmental Training Facility (WET-F), but lacks any relevance to assessing how human operators will fare psychologically or as a team. Others, like chamber studies, address important components of human adaptation, e.g., confinement, but fail utterly to incorporate true environmental threats. Others allow for the impact of true dangerous, unpredictable environments but lack any way to systematically compare across specific environments. The spectrum of fidelity to space among terrestrial analogues ranges from laboratory studies where the impact of environmental threat and physical hardship, as well as true isolation and confinement, are limited and, even, sometimes absent, to real teams in real, extreme environments characterized by very little control over extraneous variables.

This, then, is the challenge. Unlike the testing of hardware where various components can be reliably evaluated separately, the study of humans and teams, in particular, is a dynamic endeavor requiring in situ study of the collective.

To develop reliable protocols based on empirical evidence to select, monitor, and support teams effectively in space necessarily involves the demand to study teams in analogue environments that replicate a wide range of physiological, psychological, and psychosocial factors interacting both with the environment and within the team. The high degree of reliance on technology for life support, task performance, and communication must be integrated with new measurement methodologies to overcome heretofore intrusive measurement modalities. The growing frequency of multinational and multicultural teams and the demand for longer-duration missions both further compound the complexity of the challenge. While the primary goal has been the assurance of human health and well-being, the expectation has been that such priorities will naturally lead to improved chances for performance and mission success. Yet achieving this goal depends largely on how well our analogues prepare us for living and working in space.

Analogues for human individual and group performance in space has involved two basic approaches: (1) constructing an environment within a laboratory setting with maximum control over extraneous variables and utilizing volunteer research subjects or (2) studying naturally occurring real-world groups in real environments characterized by a number of confounds (Haythorn and Altman 1966; Zubek 1969). Each comes with its own limitations and strengths. In any assessment of the value of the analogue, the pros and cons of each environment need to be kept in mind. This is especially true when assessing the generalizability of insight of psychosocial factors from substitute environments for space.

Before we began deliberately constructing controlled laboratory environments, there were the records of early expeditionary explorations into various places on Earth (Greely 1986; Stefansson 1925; Pearce 1930). The tradition of publishing personal diaries and mission recounts has been similarly observed by the earliest explorers of space (Lebedev 1988; Lovell and Kluger 1994). Secondary analyses of historical expeditions have become increasingly popular in recent years (Stuster 1996). The very character of natural environments typically guarantees that there will be at least some, if not substantial, periods of inaccessibility, lack of communication or contact, little accessibility of real-time support, and great demands on individuals and groups to engage in autonomous decision-making, problem-solving, conflict resolution, self-monitoring, and self-regulation. These demands inherently build in the potential for conflict with external mission support personnel and researchers who find adherence to mission schedules and timelines far easier to maintain than do those actually on the mission. Shared perspective between these groups becomes increasingly difficult to promote as mission duration, distance, and environmental demands play larger roles in daily decisions of the teams than do seemingly arbitrary mission schedules.

Measurement of these factors is compromised as teams become preoccupied with dealing with the environment, become antagonistic to external evaluation, become noncompliant with schedules that become unimportant to participants, and engage in a general reprioritization of activities that emphasizes near-term, more salient goals (e.g., personal comfort, leisure) over and above long-term mission goals (e.g., study data). Such difficulties have raised questions about the worth of studying groups in real-world environments. In actuality, these conditions are *exactly* what is needed to simulate space missions that have grown in duration, distance from Earth, complexity, and challenge. However, space missions will also be, at least for the foreseeable future, characterized by an extraordinary degree of control, from selecting who goes to establishing the daily details of mission tasks and schedules—elements that are far more variable in real-world groups, such as those in Antarctica or part of polar or mountaineering expeditions. In real-world groups that have higher degrees of structure and control, such as military teams, the command and control structure is distinctly different from the current scientist-astronaut organizational structure of space missions. Fundamental differences in group structures, such as leadership and authority, represent significant elements in whether findings from terrestrial analogues translate to future space crews.

The need for control over the inherent chaos of real-world environments in order to definitively identify critical factors that affect individual and group performance was the driver behind the development of constructed environments of various complexities. Useful data from such artificial environments depend on whether participants are truly immersed in the fiction of a simulation and are responding in the same way they would if the environment were real. This is the paradox researchers in analogue environments face: In laboratory studies, the very attributes of the environment that have the greatest impact on performance are removed (e.g., real danger, uncontrolled events, situational ambiguity, uncertainty, or the interaction with the extreme environment itself). If these features are compromised, as many have argued, then is there value in conducting such laboratory studies? (Palinkas 2003a; Suedfeld 1998). On the pro side, laboratory chamber studies have provided opportunities to evaluate methods of monitoring psychological and interpersonal parameters for subsequent application during real flights and have identified issues that might cause psychological and interpersonal problems in space. They have also provided empirical evidence for a number of behavioral issues anecdotally reported from space, e.g., the tendency of crews to direct aggression toward personnel at Mission Control (Kanas et al. 2000; Sandal, Vaernes, Ursin 1995; Gushin et al. 1996, 1997). They are well suited to first-line inquiry when there is a need to investigate the characteristics of a particular phenomenon suspected of being present. However, complexity is a key defining trait of stressed operational environments. Total reliance on laboratory studies and the presumption of broad generalizability, particularly for research on high-stress, high-risk environments, is highly likely to lead to dissociation between actual operational findings and laboratory and experimental studies (Baddeley 1972; McCarthy 1988; Mears and Cleary 1980; Wilson, Skelly, Purvis 1989). Conversely, data on real-world groups situated in extreme environments has provided insight into a host of factors that impact group performance, health, and well-being emergent from the interaction between the individual, the team, and the environment. The differences found between studies conducted in experimentally controlled chambers and those conducted in messy, noisy, in situ real environments appears to be due to the critical presence of real environmental threat and physical hardship, as well as true isolation and confinement, which have proven to be key factors in individual and group coping. Additionally, when comparing extreme environments with non-extreme natural environments in which people normally operate, the level, intensity, rate of change, and diversity of physical and social stimuli, as well as behavior settings and possible behaviors within an extreme environment, are far more restricted (Suedfeld 1998).

Thus, real teams in extreme environments have validated or corrected findings from chamber studies where critical environmental factors are typically absent or blunted. Real extreme environments allow us to examine various aspects of the psychophysiological relationship that are essential to fully understanding the adaptation of humans to the stresses of these environments and, ultimately, to space. Space, of course, will be the final testing ground for our accumulated knowledge. But are we stuck with choosing between chamber studies and naturally occurring opportunistic teams in real extreme environments? A more recent, hybrid approach of situating research facilities within extreme environments offers a good compromise between the artificial conditions of the laboratory and the open-ended, full access of an expeditionary mission. When teams or individuals operate in extreme environments, their responses are more purely a product of either situational drivers or internal personal characteristics. To the extent that an extreme environment is well characterized and known, it gains in fidelity and allows more accurate inferences about key phenomena to be drawn. For these very reasons, Palinkas has strongly argued that the cumulative experience with year-round presence in Antarctica makes it an ideal laboratory for investigating the impact of seasonal variation on behavior, gaining understanding about how biological mechanisms and psychological processes interact, and allowing us to look at a variety of health and adaptation effects (Palinkas 2003a).

2.2 Psychology and Space

> One important fact, which has emerged during decades of research, is that in the study of capsule environments there are few main effect variables. Almost every outcome is due to an interaction among a host of physical and social environmental variables and personality factors. Thus, although we conceptually deconstruct the situation into particular sources of variance, we must remember that how people experience an environment is more important than the objective characteristics of the environment (Suedfeld and Steel 2000, p. 230).

Investigations into psychological and psychosocial adaptation to extreme environments as substitutes for space are recent phenomena. Expeditions and forays into these environments have historically been for the purposes of exploration, and the primary metric of successful adaptation was survival. One could argue that chronicles such as the *Iliad* and the *Odyssey* were early examples of the more familiar diaries such as those that recounted the historic race to reach the South Pole between modern polar expeditions lead by Roald Amundsen, who reached the South Pole in 1911, and Robert F. Scott, who reached the South Pole in 1912. Humans have been periodically living and working in Antarctica, one of the most challenging environments on Earth, for over a 100 years. The first winter-over in Antarctica occurred during 1898–1899 on board an icebound ship, the *Belgica*, on which Amundsen served as a second mate. A continuous presence on our further-most southern continent has only been in place since the International Geophysical Year of 1956–1957. Systematic research on isolated, confined environments can arguably be dated as beginning as recently as the late 1950s by the military, and much of the early work focused on purely physiological parameters. In their seminal collection of papers dealing with isolated environments from Antarctica to outer space, A. A. Harrison, Y. A. Clearwater, and C. McKay pointed out that early work on psychological factors in extreme environments is often recounted as beginning with C. S. Mullin's research on states of consciousness; E. K. E. Gunderson and colleagues' comprehensive work on adaptation to Antarctica; and classic laboratory studies on group dynamics conducted by I. Altman, W. W. Haythorn, and associates (Harrison et al. 1991a; Mullin 1960; Gunderson 1973, 1974; Altman 1973; Haythorn 1973).

Regardless of which analogue is used to understand what helps or hinders individuals and groups in functioning well under extreme environmental challenges, it is necessary to characterize what we need to know for space. Although specific conditions of the setting vary, most extreme environments share common characteristics: (1) a high reliance on technology for life support and task performance; (2) notable degrees of physical and social isolation and confinement; (3) inherent high risks and associated costs of failure; (4) high physical/physiological, psychological, psychosocial, and cognitive demands; (5) multiple critical interfaces (human-human, human-technology, and human-environment); and (6) critical requirements for team coordination, cooperation, and communication (Bishop 2006a). This last is not insignificant. The accumulated knowledge to date is still fairly rudimentary, given the short historical emergence of the "Space Age." Drawing on research from a number of fields (e.g., social psychology, human factors, military science, management, anthropology, and sociology), researchers easily identified a number of factors that need further investigation. As early as the 1980s, psychological and sociocultural issues had been acknowledged by the National Commission on Space (1986), the National Science Board (1987), and the Space Science Board (1987) to be critical components to mission success, as robust evidence from Antarctica clearly showed psychological issues to impact human behavior and performance significantly in most challenging environments, especially those characterized by isolation and confinement (National Science Board 1987). The most recent roadmap detailing critical strategic and tactical research needed is NASA's Human Research Program Integrated Research Plan whose risk reduction strategy relies on the use of low cost, high fidelity ground analogues to characterize and assess three identified key risks (i.e., sleep/circadian rhythms, workload and fatigue; team adaptation, cohesion and performance; and behavioral symptoms and psychiatric disorders); validate approaches and proof-of-concepts already tested and proven in laboratory studies; and to test and validate countermeasure tools, technologies and protocols prior to spaceflight (NASA 2011). Studies in a variety of analogue environments, e.g., Antarctica, underwater capsules, submarines, caving and polar expeditions, and chamber studies, have confirmed that mission parameters have a significant influence upon the type of "best-fit" crew needed and have isolated a number of psychosocial issues that may negatively affect crewmembers during multinational space missions (Palinkas Gunderson, Burr 1989; Palinkas 1989, 1990, 1991, 2003; Anderson 1991; Ursin 1991; Palinkas, Gunderson, Holland 2000; Bishop and Primeau 2001; Palinkas 2003b; Gilluly 1970; Sexner 1968; Sandal et al. 1999; Bishop, Santy, Faulk 1998; Sandal et al. 1996; Bishop, Grobler, Schjøll, 2001; Kanas 1985). These issues include (1) tension resulting from external stress, (2) factors related to crew heterogeneity (e.g., differences in personality, gender, and career motivation); (3) variability in the cohesion of the crew; (4) improper use of leadership roles (e.g., task/instrumental versus emotional/supportive); (5) cultural differences; and (6) language differences. Of particular uniqueness to challenging environments is the fact that successful performance requires *competent* team interaction, including coordination, communication, and cooperation. The functioning of the operational team often determines the success or failure of the mission. Experience in spaceflight, aviation, polar, and other domains indicates that the stressors present in extreme environments, such as fatigue, physical danger, interpersonal conflict, automation complexity, risk, and confusion, often challenge team processes. The contribution of interpersonal and intrapersonal factors is substantial. For instance, a robust body of evidence from both civilian and military aviation identifies the majority of aircraft accidents as due to human and crew-related performance factors (The Boeing Company 1994; Raymond and Moser 1995; Ricketson, Brown, Graham 1980; Weiner, Kanki, Helmreich 1993; Wiegmann and Shappel 1997; Yacovone 1990). Analyses of critical incidents in medical operating rooms indicate that 70–80% of medical mishaps are due to team and interpersonal interactions among the operating room team (Sexton et al. 1996; Williamson et al. 1993). From pilot to surgeon, firefighter, polar expeditioner or astronaut, we need to know if the characteristics that define adaptable and functional individuals and teams have commonalities across various environments. A comprehensive review of over 50 years of research on team effectiveness conducted by Kozlowski and Ilgen in 2006 identified key team processes involving cognitive, motivational and behavioral processes that contributed substantially to team effectiveness as well as identifying three primary types of interventions (team training and development, team leadership and dynamic regulation of team member behavior) with the potential to improve team processes and team effectiveness (Kozlowski and Ilgen 2006). It is therefore critical that teamwork in these environments be examined and understood. A fundamental need to enable these investigations is developing reliable, minimally intrusive and valid methodologies for assessing individual and group responses to these stressors and identifying dysfunctional and functional coping responses (NASA 2011). The use of extreme environments with characteristics relevant to those inherent in space travel and habitation will play a crucial role in preparing humans for egress from planet Earth.

Given the disparate nature of these various environments, Suedfeld has proposed five key principles that may be useful guides in assessing the relevance of various extreme environments as viable analogues for space or providing the basis for cross-comparisons:

Principle 1: Researchers should think in terms of experiences within environments rather than of environmental characteristics;
Principle 2: Researchers should study differences and similarities between experiences, which are not the same as those between environments;
Principle 3: Analogies should be based on similarities of experience, not necessarily of environment;
Principle 4: Research should look at systematic links between personality factors and experience; and
Principle 5: Experience is continuous and integrated (Suedfeld 1991).

2.3 Critical Psychosocial Issues for Space

The research on teams has, to date, focused on and identified needs for further research under four broad categories. The intent here is not to recite the spectrum of findings across analogues within these areas, but to articulate how analogue environments can address these areas.

- *Selection issues* deal with the evaluation of existing ability, trainability, and adaptability of prospective team members. It is not merely a matter of selecting-out pathological tendencies, but, as importantly, selecting-in desirable characteristics. How can analogue environments allow us to investigate the impact of various individual and group characteristics upon individual and group performance?
- The impact of *isolation and confinement* has been shown to be significantly impacted by various moderator variables, e.g., the difficulty of rescue. While an emergency on the International Space Station certainly poses difficulties regarding time to rescue, one can argue that the difficulties inherent in a Mars mission or even here on Earth from the Antarctic in midwinter, where weather conditions may absolutely make rescue impossible for long periods, carry a qualitatively different psychological impact. An emergency on a mission to Mars will preclude any chance of rescue and necessitate a high degree of autonomy for the crew in making decisions without any real-time mission support. The degree to which such factors magnify the negative effects of isolation and confinement is critical to assess.
- *Group interaction and group processes* are not a simple sum of the individuals that make up the group. Complex interactions can reinforce, undermine, or create new behaviors in the individuals involved. Identification of group fusion (factors that encourage group cohesion) and fission (factors that contribute to group conflict) variables are elementary to creating habitats and work schedules, composing groups, and a myriad of other factors that will enable groups to function effectively and ensure individual and group well-being. For instance, in

a study of Antarctic winter-over personnel, Palinkas found that personnel at Palmer (a small station) spent 60% of their waking hours alone and retreated to their bedrooms extensively for privacy. These behaviors could be considered fission factors as they promote withdrawal, social isolation, and distancing from one's teammates. On the other hand, if the use of privacy served to control the amount of contact and decreased tensions and group conflict, they would be considered fusion factors. He also found that intermittent communication was a major source of conflict and misunderstanding between crews and external support personnel, a clear source of fission influence. Examples of fusion factors for this group were effective leadership styles, which played a significant role in station and crew functioning, as well as the ability to move furniture and decorate both common and private areas, which facilitated adaptation and adjustment (Palinkas 1990).

- *Individual and crew performance* is perhaps the clearest, most frequently studied outcome. Yet there are challenges in defining what constitutes acceptable outcomes at both the individual and group levels. They are not always the same thing, as investigations into missions that failed to meet expectations have repeatedly confirmed. It is a mistake to try to assess and maximize performance without understanding group dynamics, the effects of isolation and confinement or the environment in general on inhabitants. Given that our selection criteria have been little more than ruling out pathology and matching task requirements with technical proficiency within individuals, it is of little surprise that our efforts to implement performance improvements have been only modestly successful and fraught with inconsistent results. It is necessary to take the next steps to identify which individual and group characteristics are maximally associated with adaptation and functioning in these high-challenge environments. This is, in fact, one of the core principles of NASA's Human Research Program Integrated Research Plan (NASA 2011).

2.4 Terrestrial Analogues for Space

There are surprising similarities and differences found across environments. G. M. Sandal et al. found that coping strategies during confinement on polar expeditions were different from those in hyperbaric chambers (Sandal et al. 1996). Whereas polar teams evidenced a delay interval with a marked drop in aggression until after the first quarter, with concomitant increase in homesickness, chamber teams displayed a steady gradual increase in coping over time. A number of researchers have noted that it is not the site that seems to matter, but rather it is the differences in the mission profiles, e.g., tasks (daily achievement of a distance goal versus station-keeping) or duration (short versus long).

In fact, studies addressing Suedfeld's Principle four investigating personality characteristics have produced supporting evidence for a focus on the experience as the defining factor rather than the environment per se. The most persistently investigated personality assessment for the last 15 years has been the NEO-PI by Costa and McCrae (1978, 1985, 1989, 1991). This instrument assesses five global dimensions of personality: neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness. These dimensions have been found to be associated with the previous personality “right stuff/wrong stuff/no stuff” profiles identified by Helmreich et al. in longitudinal studies of American astronaut candidate performance (McFadden et al. 1994). Additionally, measures of achievement motivation, interpersonal orientation, Type A, stress, and coping have been frequently evaluated. Recent studies have found evidence that agreeableness and conscientiousness seem to better predict performance at the global level, along with specific facets of extraversion (Suedfeld and Steel 2000; Rose et al. 1994; McCrae and Allik 2002). Conscientiousness, extraversion, and agreeableness have been found to be related more strongly to constructive change-oriented communication and cooperative behavior than to task performance. Cognitive ability appears to be related more strongly to task performance than to constructive change-oriented communication or cooperative behavior. Results also demonstrate contrasting relationships for agreeableness (positive with cooperative behavior and negative with constructive change-oriented communication) (Barrick et al. 1998; Ferguson et al. 2003; LePine 2003; Judge and Ilies 2002). However, another personality cluster has been identified in studies of successful polar trekking groups that is distinctly different from the “right stuff” profile in which factors indicative of individuals who are loners seem to be supportive of adaptation, i.e., happier alone than dependent on others, highly autonomous, independent, uncomfortable about and relatively uninterested in accommodating others in a group, task-oriented and somewhat competitive (Rosnet, Le Scanff, Sagal 2000). Since we do not have enough data to reliably draw inferences about these individuals, it is mere speculation at this time that perhaps the intense task focus of a polar trek, in which each individual is highly autonomous and individually self-reliant during the long travel each day, situated in an environment that precludes group interaction except for fundamental coordination of locomotion across the terrain, *selects for* individuals that are distinctly different from those who would occupy a habitat or confined environment for long durations. In other words, only individuals with this inward, self-focused personality would find such challenges rewarding and be successful at these tasks. Similarly, an apparently adaptive personality profile has emerged from winter-overers that is characterized by low levels of neuroticism, desire for affection, boredom, and need for order, as well as a high tolerance for lack of achievement, which would fit well in an environment where isolation and confinement prevented accomplishments and the participants experienced frequent shortages and problems (Palinkas et al. 2000). Those that would best adapt would be those who could more quickly adjust their expectations to the immediate situation and tolerate such obstacles. If this hypothesis is substantiated, then we must carefully match the characteristics of the individual to the environment as well as the group in order to maximize successful adaptation and performance.

Psychological research to date seems to support two general findings: (1) there do seem to be consistencies in the personality profile of functional and dysfunctional teams, and (2) characteristics of the mission may define very different personality profiles as best fit. Insomuch as it is possible to select for hardier and better-fit personalities by filtering individuals and teams through environmental challenges, selecting analogues with highly salient and relevant characteristics that match space mission profiles (e.g., long versus short duration, station-keeping versus expedition profiles) will be important.

2.4.1 The Expeditionary Analogue

Expeditions, by definition, revolve around movement. Expeditionary analogues (e.g., oceanic, polar, desert, caving, mountaineering) include various exploratory goals that are characterized by moving from one place to another rather than inhibiting a locale. Historical exploratory expeditions typically involved long durations (i.e., months to years) characterized by significant known and unknown risks, broad goals, a high degree of situationally driven contingency decision-making, and expectations of autonomy and self-sufficiency. Modern expeditions, in contrast, are typically of short duration (i.e., 2 weeks to 3 months), utilize the advantages of technology to minimize risks (e.g., weather forecasts to take advantage of the best weather of a region and satellite communications to maintain contact), are more narrowly goal-oriented and task-focused, and involve members with specialized roles and skills. In both expeditionary scenarios, teams were/are formed around appropriate skill sets and availability and a notable lack of any attempt to screen individuals psychologically except for medical factors. Research on team functioning is often secondary to expedition goals, personal goals, schedules, and contingencies. The expedition may be intended to recreate experiences of earlier explorers, such as the Polynesian *Kon-Tiki* oceanic traverse; set records or discover new territory, e.g., discover a route to India or explore a cave system; achieve personal challenges, such as climbing mountains or skiing to the North Pole; conduct scientific research, e.g., by means of oceangoing research vessels or polar ice drilling teams; or conduct commercial exploration, such as mineral and oil exploration (Bishop et al. 1998; Heyerdahl 1950; Bernard and Killworth 1973, 1974; Mallis and Deroshia 2005).

Ben Finney, Professor Emeritus in Anthropology at the University of Hawai'i and noted for his work on applying anthropological perspectives to humankind's expansion into space, has argued that from the earliest voyages to have scientific goals, "cultural" differences between scientists and seamen have led to conflict and that this inherent conflict of cultures is similarly reflected in our space program's structural differentiation between pilots and astronaut-scientists (Finney 1991). Voyages of scientific discovery began in the late eighteenth century, an age, Finney points out, that many have argued foreshadowed the space race of the 1960s (Goetzmann 1986). The first exploratory voyage to include scientists as crew and mission goals with explicit scientific objectives instead of commercial goals that serendipitously collected science data was the 3-year-long English expedition of the

Endeavour to Tahiti, 1768–1771, led by Captain James Cook. The on-board scientists were tasked to observe the transit of Venus across the face of the Sun to provide data needed to calculate the distance between Earth and the Sun. The success of the *Endeavour*'s expedition led to a second expedition, which sailed with a number of scientists, two astronomers, and a naturalist, an expedition that, in contrast to the first expedition, was rife with contentious relationships between the seamen and the scientists. Subsequent voyages with scientists on board were similarly plagued by conflicts between those pursuing scientific goals and those tasked with the piloting and maintenance of the ship. Historically, the English naval command eventually imposed an unofficial moratorium on the inclusion of non-naval scientists on board and pursued a policy of assigning any scientific duties to members of the crew. Not until a 100 years after Cook, in 1872, would the Royal Navy's *Challenger*, a three-masted, square-rigged, wooden vessel with a steam engine, sail around the world with six marine scientists and a crew and captain who were totally dedicated to the research (Linklater 1972).

Such troubles were not limited to the English. The French followed a similar pattern, beginning in 1766 and continuing through 1800, when scientists sailed with numerous expeditions that were summarily characterized by conflict and contention between the crews and scientists (Dunmore 1965, 1969). Finney further notes that such complaints are found in journals of early Russian scientists, as well as American scientists on the 4-year-long United States Exploring Expedition that sailed from Norfolk in 1838 with a contingent of 12 scientists (von Chamisso 1856, Stanton 1975).

Modern development of specialized ships complete with laboratories and equipment dedicated to oceanographic research has been primarily organized and maintained by universities and oceanographic institutes. Yet even aboard these dedicated floating research vessels, conflict between the ship's crew and the scientists whom they serve has not been eliminated. A dissertation study conducted by a resident at the Scripps Institute of Oceanography during 1973 concluded that tension between the two groups was inevitable because they formed two essentially separate and distinct subcultures with different values and goals, as well as different educational backgrounds and class memberships (Bernard and Killworth, 1973, 1974).

Finney argues that the same subcultures have become evident in the space program with the development of the role of payload specialists, who are considered visiting scientists rather than part of the elite astronaut corps. Tensions between payload specialists in pursuit of the scientific goals and the crew in pursuit of mission completion have routinely been in evidence. Finney eloquently states:

> . . . [I]f space research were to be made as routine to the extent that ocean research now is, subcultural differences, and hence tensions, between scientist and those pilots, station-keepers, and others whose job it will be to enable researchers to carry out their tasks in space may become critical considerations. If so, space analogues of the mechanisms that have evolved to accommodate differences between scientists and seamen aboard oceanographic ships may have to be developed (Finney 1991, p. 100).

The number and variety of expeditions examined for relevance to space is ever increasing as both modern expeditions and analyses of historical expeditions are scrutinized. An example of how examination of the records from past expeditions contributes to the current state of knowledge and provides the impetus for future studies in space can be seen in a meta-study by M. Dudley-Rowley et al. that examines written records from a sample of space missions and polar expeditions for similarities and differences in conflicts and perceptions of subjective duration of the mission. Ten missions were compared across a number of dimensions (Dudley-Rowley et al. 2000). The meta-study included three space missions that represented both long- and short-duration mission profiles: Apollo 11 (1969) and Apollo 13 (1970), ranging from 6 to 8 days apiece, and Salyut 7 (1982), which lasted over 200 days. Four Antarctic expeditions were included: the western party field trip of the Terra Nova Expedition (1913, 48 days), an International Geophysical Year (IGY) traverse (1957–1958, 88 days), the Frozen Sea expedition (1982–84, 480 days), and the International Trans-Antarctica Expedition (1990, 224 days). Finally, three early Arctic expeditions were also included: the Lady Franklin Bay (1881–1884, 1,080 days), Wrangel Island (1921–23, 720 days), and Dominion Explorers' (1929, 72 days). Seven factors emerged that seemed to coincide with the subjectivization of time and the differentiation of situational reality for the crews from baseline:

1. Increasing distance from rescue in case of emergency (lessening chances of "returnability");
2. Increasing proximity to unknown or little-understood phenomena (which could include increasing distance from Earth);
3. Increasing reliance on a limited, contained environment (where a breach of environmental seals means death or where a fire inside could rapidly replace atmosphere with toxins);
4. Increasing difficulties in communicating with Ground or Base;
5. Increasing reliance on a group of companions who come to compose a microsociety as time, confinement, and distance leave the larger society behind, in a situation where innovative norms may emerge in response to the new sociophysical environment;
6. Increasing autonomy from Ground's or Base's technological aid or advice; and
7. Diminishing available resources needed for life and the enjoyment of life.

The missions and expeditions were ranked by prevalence of the seven factors that might correspond with the differentiation in the subjectivization of the passage of time and in the situational reality for the crews from baseline. From highest to lowest in compromising factors, the rankings fell in the following order: Lady Franklin Bay (7); Wrangel Island, Apollo 13 (6); Salyut 7 (5); Terra Nova, Apollo 11 (4); Dominion Explorers' (3); Frozen Sea (2); IGY (1); International Trans-Arctic Expedition (0). The Lady Franklin Bay Expedition suffered 18 deaths of its complement of 25, and the rest were starving when found. The Wrangel Island expedition suffered four deaths out of its crew of five. Apollo 13 was a catastrophe that was remarkable in its recovery of the crew intact. The Salyut 7 mission, the Terra Nova western field party, and the Apollo 11 mission all had high degrees of risk. The later polar expeditions rank below these missions.

Both the space missions and the earliest polar expeditions are above or hover just below the median (3.5). Although the authors correctly note that the sample is too small to draw conclusions, the presence of similar factors in space and early polar exploration that contributed to perceptions of mission/expedition duration or of how their situational reality deviates from baseline is important to note. These results suggest that as control over their environment decreases, team members' subjective experiences of time and the situation increasingly differ from their baselines. The strong parallel between early expeditions and modern space missions lends support for historical analogues as viable substitutes for space.

2.4.2 Chamber Studies

Early evaluations for astronaut selection drew upon a history of sensory deprivation research initially begun by the military throughout the 1950s and 1960s to address performance concerns about two-person crews confined to armored vehicles for long durations and continued most notably through the series of studies conducted by J. P. Zubek (Zubek 1969; Honingfeld 1965). Initially, it was believed that space would represent a significant loss of normal sensory stimulation due to isolation from people, reduction in physical stimulation, and restricted mobility. Thus, sensory deprivation chambers were argued to be good analogues for astronauts (Flaherty 1961). Selection procedures, therefore, included stints in dark, small, enclosed spaces for several hours to observe how potential astronauts handled the confinement and loss of perceptual cues. As Dr. Bernard Harris, the first African American to walk in space, recounts, "They put me in this little box where I couldn't move or see or hear anything. As I recall, I fell asleep after a while until the test ended" (Harris 1995).

The first systematic attempts to investigate psychological adaptation factors to isolation and confinement in simulated operational environments were conducted in the 1960s and early 1970s by putting volunteers in closed rooms for several days, subjecting them to sleep deprivation and/or various levels of task demands by having them complete repetitive research tasks to evaluate various aspects of performance decrements (Haythorn and Altman 1966; Altman 1991). Chamber research, as it was to become known, encompassed a variety of artificial, constructed environments whose raison d'être was control over all factors not specifically under study. Later, specially constructed confinement laboratories such as the facility at the Johns Hopkins University School of Medicine or simulators at Marshall Space Fight Center in Huntsville, Alabama; the McDonnell Douglas Corporation in Huntington Beach, California; or Ames Research Center at Moffett Field, California, housed small groups of three to six individuals in programmed environments for weeks to months of continuous residence to address a variety of space-science-related human biobehavioral issues related to group dynamics (e.g., cohesion, motivation, effects of joining and leaving established groups), performance and work productivity, communication patterns, team cooperation, and social habitability factors. Other types of chambers have been utilized to evaluate various countermeasures, especially for stress and anxiety provoked by physiological stressors expected to be present in the space environment. For instance, Chinese behavioral scientists are the latest to employ the use of centrifuge training to test the efficacy of guided imagery to reduce anxiety, heart rates and heart rate variability (Jing et al. 2011). Critics of this approach point out such environments constitute *confinement* but not necessarily isolation. The stress of isolation is far more complex than that of confinement and involves a psychological dimension of separateness that may not be inherent in artificial chamber studies.

The epitome example of chamber research may be the series of five hyperbaric-chamber studies, sponsored by the European Space Agency investigating psychosocial functioning, in which groups were confined for periods lasting from 28 to 520 days (Sandal et al. 1995; Sandal 2004). Full mission protocols specifying all medical, technical, and operational parameters approximating expected living conditions of astronauts on a space station were used. The studies were intended to evaluate the efficacy of various psychosocial monitoring and assessment techniques for implementation on real space missions, as well as to investigate persistent occurrences of communication and interaction breakdowns between on-orbit teams and Mission Control anecdotally reported from space (Kanas et al. 2000; Sandal et al. 1995; Gushin et al. 1996). A number of opportunities and advances came from these studies, e.g., evaluating the efficacy of communication training for space teams or the opportunity to examine factors involved in an unplanned meltdown between crews precipitated by differences in cultural attitudes and norms about genders, authority, and control (Sandal 2004; Manzey 1998). However, skepticism regarding the verisimilitude of studies in which discontented members can simply quit has continued to raise real concerns as to how generalizable the findings from chamber studies are to space missions.

2.4.3 The Middle Ground: Capsule Habitats in Extreme Unusual Environments

Occupying the middle ground between traditional expeditionary missions with moving trajectories and the artificiality of laboratory spaces designated as space station habitats are capsule habitats, sharing the controlled, defined enclosure of the laboratory situated within an extreme unusual environment (EUE) (Suedfeld and Steel 2000). Characterized by a controlled, highly technological habitat that provides protection and life support from an environment that is harsh, dangerous, and life-threatening, capsule habitats occupy a wide range of environments. Some are true operational bases with missions in which biobehavioral research is only secondary. Others run the gamut from fundamental "tuna can" habitats with spartan support capabilities situated in locations of varying access to a full-fidelity Antarctic base constructed solely for the purposes of biobehavioral space analogue research.

2.4.3.1 Submersible Habitats

Due to their high military relevance, the best-studied of capsule habitats are submarines. As an analogue for space, submarines share a number of common characteristics: pressurization concerns (hyperpressurization for submarines and loss of pressurization for space), catastrophic outcomes for loss of power (e.g., the inability to return to the surface for submarines and degraded orbits for space), dependence on atmosphere revitalization and decontamination, radiation effects, and severe space restrictions. Prenuclear submarine environments were limited in the duration of submersions (72 h), crew size (9 officers and 64 enlisted men), and deployment periods without restocking of fuel and supplies. Structurally, these short-duration mission parameters mimicked those of the early years of space, albeit with vastly larger crews. With the launch of the nuclear-powered *Nautilus* in 1954, the verisimilitude of the submersible environment as an analogue for long-duration space missions was vastly improved. With the nuclear submarine, mission durations were extended to 60–90 days, crews were increased to 16 officers and 148 enlisted men, and resupply could be delayed for months (Weybrew 1991). Generalizing from submarine research to space regarding psychological and human factors related to adjustment and well-being, researchers have identified several salient issues:

- Atmospheric revitalization and contamination control;
- Development and validation of procedures for the medical and psychological screening of recruits;
- Identification of techniques for initiating and sustaining individual motivation and group morale; and
- Identification of stressors, assessment of the severity of patterns of stress reactivity, and development of effective stress coping strategies (Weybrew, Helmreich, Howard, 1986; Weybrew 1991).

An extension of the submersible operational environment of a military submarine is the NASA Extreme Environment Mission Operations program (NEEMO) being conducted in the Aquarius underwater habitat situated off Key Largo, Florida—the only undersea research laboratory in the world. Owned by the U.S. National Oceanic and Atmospheric Administration (NOAA) and operated by the National Undersea Research Center (NURC) of the University of North Carolina at Wilmington on behalf of NOAA, Aquarius is the submerged analogue to NOAA oceanic research vessels. First deployed in 1988 in the U.S. Virgin Islands and relocated to Key Largo in 1992, the underwater facility has hosted more than 80 missions and 13 crews of astronauts and space researchers since 2001. Aquarius provides a capsule habitat uniquely situated within an environment that replicates many of the closed-loop constraints of the vacuum of space: a hostile, alien environment that requires total dependency on life support; poses significant restrictions to escape or access to immediate help; and is defined by limited, confined habitable space and physical isolation. The complexity of NEEMO missions further parallels space missions in their mission architecture, with similar requirements for extensive planning, training, control, and monitoring via an external mission control entity. However, it has only been the most recent NEEMO missions in which stress, fatigue, and cognitive fitness, as well as individual and intrapersonal mood and interaction, have been the focus of study.

2.4.3.2 Polar Stations

First and foremost, Antarctica springs to mind when polar space analogues are raised. While there are other polar bases in the Arctic and subarctic, the bulk of sustained psychological research has been conducted in Antarctica (Harrison et al. 1991). G. M. Sandal, G. Leon, and L. Palinkas conducted a recent, extensive review of the literature on psychosocial adaptation by polar work groups, expedition teams, Antarctic bases, simulation, and space crews (Sandal et al. 2006). There are 47 stations throughout the Antarctic and sub-Antarctic regions, operated by 20 different nations, with populations running from 14 to 1,100 men and women in the summer to 10–250 during the winter months. The base populations vary from mixed-gendered crews to male-only crews, from intact families (Chile) to unattached singletons, for assignments that last from a few months to 3 years.

In 1958, after the IGY (1956–57) produced the first permanent bases in Antarctica, C. S. Mullin, H. Connery, and F. Wouters conducted the first systematic psychological study of 85 men wintering over in Antarctica (Mullin et al. 1958). Their study was the first of many to identify the Antarctic fugue state later dubbed the "big-eye," characterized by pronounced absent-mindedness, wandering of attention, and deterioration in situational awareness that surfaced after only a few months in isolation. The majority of subsequent studies up through the 1980s focused on the physiological changes evidenced in winter-over adaptation. Those that did address psychosocial factors tended to focus on the negative or pathological problems of psychological adjustment to Antarctic isolation and confinement, with persistent findings of depression, hostility, sleep disturbance, and impaired cognition, which quickly came to be classified as the "winter-over syndrome" (Gunderson 1973, 1974; Strange and Klein 1974). Sprinkled among Antarctic research have been findings that also report positive, or salutogenic, aspects of the winter-over experience in which winter-overers have reported enhanced self-growth, positive impacts to careers, and opportunities for reflection and self-improvement (Mullin 1960; Taylor and Shurley 1971; Wilson 1965; Palinkas 1986; Oliver 1991; Suedfeld 2005).

One of Antarctica's most prolific researchers, Dr. Larry Palinkas has analyzed 1,100 Americans who wintered over between 1963 and 2003 over four decades of research in Antarctica and proposed four distinct characteristics to psychosocial adaptation to isolation, confinement, and the extreme environment:

1. Adaptation follows a seasonal or cyclical pattern that seems to be associated with the altered diurnal cycle and psychological segmentation of the mission.

2. Adaptation is highly situational. Because of unique features of the station's social and physical environment and the lack of resources typically used to cope, baseline psychological measures are not as good predictors of depressed mood and performance evaluations as are concurrent psychological measures.
3. Adaptation is social. The structure of the group directly impacts individual well-being. Crews with clique structures report significantly more depression, anxiety, anger, fatigue, and confusion than crews with core-periphery structures.
4. Adaptation can also be "salutogenic," i.e., having a positive effect for individuals seeking challenging experiences in extreme environments (Palinkas 2003a).

Palinkas found that a depressed mood was inversely associated with the severity of station physical environments—that is, the better the environment, the worse the depression—and that the winter-over experience was associated with reduced subsequent rates of hospital admissions (Palinkas 2003a). He and others have speculated that the experience of adapting to the isolation and confinement, in general, improved an individual's self-efficacy and self-reliance and engendered coping skills that they used in other areas of life to buffer subsequent stress and resultant illnesses (Palinkas 2003a; Suedfeld 2005).

2.4.3.3 Concordia

In 1992, France initiated plans for a new Antarctic station on the Antarctic Plateau and was later joined by Italy. In 1996, the first French-Italian team established a summer camp at Dome C to provide logistical support for the European Project for Ice Coring in Antarctica (EPICA) and begin the construction of the permanent research station. Concordia Station became operational in 2005; the first winter-over took place in February 2005 with a staff of 13. The station consists of three buildings, which are interlinked by enclosed walkways. Two large, cylindrical three-story buildings provide the station's main living and working quarters, while the third building houses technical equipment, like the electrical power plant and boiler room. The station can accommodate 16 people during the winter and 32 people during the summer season. The typical winter population consists of four technicians for the station maintenance, nine scientists or technicians for the science projects, a chief, a cook, and a medical doctor.

Dome C is one of the coldest places on Earth, with temperatures hardly rising above -25 °C in summer and falling below -80 °C in winter. Situated on top of the Antarctic plateau, the world's largest desert, it is extraordinarily dry and supports no animals or plants. The first summer campaign lasted 96 days, from 5 November 2005 until 8 February 2006, with 95 persons participating. The 2006 season included seven crewmembers with two medical experiments and the first two psychological experiments sponsored by the European Space Agency for which the crew acted as subjects during their stay. The two experiments investigated psychological adaptation to the environment and the process of developing group identity, issues that will also be important factors for humans traveling to Mars. For this research, the crew completed questionnaires at regular intervals throughout their stay. The ESA's Mistacoba experiment to profile how microbes spread and evolve in the station—an isolated and confined environment—over time started in the 2005 season, when the first crew started living at the station, and has also continued with subsequent crews. Starting from a newly built clean environment, those conducting the study took samples from fixed locations in the base as well as from crewmembers themselves (The Concordia Station 2007).

2.4.3.4 Haughton-Mars Project

One of the first of dedicated research hybrid facilities was the Haughton-Mars Project (HMP), initiated in 1996 when the National Research Council of the U.S. National Academy of Sciences and NASA Ames Research Center sponsored a postdoctoral proposal to study the Haughton Crater on Devon Island in the Canadian Arctic as a potential analogue for Mars. The program has expanded from a four-member team in 1997 to a permanent habitat that hosts 8-week arctic summer field seasons with 50–90 participants, multiple teams, and research projects that run from instrument testing and development to biomedical and psychological evaluation. HMP routinely supports participation by NASA; the Canadian Space Agency (CSA); the Russian Institute for Space Research (IKI); various research institutions and universities in the United States, Canada, and the United Kingdom; and the U.S. Marine Corps. It has been the subject of various documentaries made by such groups as the National Geographic Society and Discovery Channel Canada (The Mars Institute 2007).

2.4.3.5 Flashline Mars Arctic Research Station

In 2000, a second dedicated research facility was deployed on Devon Island, jointly sponsored by the Haughton-Mars Project and the Mars Society: the Flashline Mars Arctic Research Station (FMARS). Running concurrently with HMP, the FMARS facility was the first of four proposed analogue research facilities to be built by the Mars Society, supporting smaller six-person crews for typically 2–8-week seasons. In summer 2007, the first 4-month-long FMARS mission was successfully completed with a crew of seven and a full complement of research studies covering technology, human factors, medicine, psychology, and communications. Results from this first attempt to extend, heretofore, short duration missions in a habitat developed specifically for research (instead of operational environments such as bases in Antarctica) revealed a number of issues (e.g., multicultural conflicts, coping inefficiencies) that underscore the need for longer studies situated in real environments that pose true isolation and risk (Bishop et al. 2010).

2.4.3.6 Mars Desert Research Station

The second Mars Society station, the Mars Desert Research Station (MDRS), came online in December 2001 and is situated in the Utah desert in the American Southwest. Because of its ease of access, the American station is considered well suited as a test bed for equipment that will later be sent to more remote and unforgiving locations. For the same reason, the American station has been the focus of short-duration isolation and confinement studies since its inception. A wide range of psychological studies investigating crew factors in short-duration missions has been in place since 2002. However, beyond preliminary descriptive results presented at conferences, the small sample size of crews has necessitated waiting until enough teams have rotated through the facility to allow meta-analyses (Bishop et al. 2004, 2006). Several international teams have also used the MDRS for studies investigating comparisons between homogeneous-gendered teams, comparisons between mission teams and backup crews, and international cultural factors, among others (Bishop et al. 2005, Bishop 2006).

The Mars Society plans additional facilities in Iceland and Australia that will capitalize on geological features that present opportunities to practice Mars exobiology field work. The Mars Society's Mars Analog Research Station Project envisions three prime goals to be served by these habitats (The Mars Society 2007):

- The stations will serve as effective test beds for field operations studies in preparation for human missions to Mars. They will facilitate the development and testing of key habitat design features, field exploration strategies, tools, technologies, and crew selection protocols that will enable and help optimize the productive exploration of Mars by humans. In order to achieve this goal, each station must be a realistic and adaptable habitat.
- The stations will serve as useful field research facilities at selected Mars analogue sites on Earth and will help further understanding of the geology, biology, and environmental conditions on Earth and on Mars. In order to achieve this objective, each station must provide safe shelter and be an effective field laboratory.
- The stations will generate public support for sending humans to Mars. They will inform and inspire audiences around the world. As the Mars Society's flagship program, the Mars Analog Research project will serve as the foundation of a series of bold steps that will pave the way to the eventual human exploration of Mars.

2.5 Conclusion

The use of analogues for space is an emergent field whose very short track record examining team dynamics and psychosocial factors impacting individual and group functioning vigorously supports the real value of these environments and generalizability to space environments. Unlike laboratory studies, where the threat of real danger is usually absent, teams operating within real extreme environments have unknown situational and environmental challenges to face. Even in circumstances in which death or injury occurs, there will always be questions regarding the ability to avoid negative outcomes. While post-mission analyses of behavior and performance add insight into contributing factors, it is seriously doubtful whether we will ever be able to accurately predict the entire range and complexity of interaction between the human-environment factors and the human-human factors. Risk is inherent in human exploration. Even so, the value of analogue experiences cannot be underestimated, regardless of whether they help us grapple with defining our levels of adequate preparation in the face of ideally predefined levels of "acceptable risk" or even "acceptable losses" (a concept familiar to those who perform military risk assessments).

One key methodological and validity issue is the added value of utilizing consistent measures across various analogues, allowing more accurate comparisons of individuals and teams across environments, including space. The necessity to validate multicultural questionnaires and methodologies that are relevant, reliable, and valid for international teams is of paramount importance as our reliance on these multinational teams will only increase in the future. To that extent, the various research endeavors in analogue environments have contributed significantly to validating such assessment instruments in a variety of teams.

Findings from analogues have clearly identified three major intervention points to affect group functioning outcomes:

- Selection: the development of reliable and valid methods of choosing the best fit at both the individual and the group levels.
- Training: improving the fitness of the group by prepping skills needed for interpersonal group dynamics as well as high-functioning self-monitoring and appropriate adaptation.
- Support: taking the form of prevention first, then early, proactive intervention second. To be successful, research to date strongly suggests that the support must include the group, the family, and all external participants (e.g., Mission Control) as partners.

A large portion of the current research represents opportunities to examine team dynamics and factors that impact team function in real-world groups that have been brought together for particular purposes that have little to do with research, e.g., geological field teams. Similarly, examinations of historical sources of past expeditions will continue to inform and provide additional insight into factors that have contributed to the success or failure of previous efforts. However, we need larger, more systematic studies in which the composition of the team is one of the driving factors under investigation instead of simply an extraneous variable. Our greatest hope lies with the new research facilities now available and coming online dedicated to such research.

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