

The Space Base and Science Fiction

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by

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Introduction:

The goal of this project is to compare and assess alternative conceptions of what an artificial environment capable of supporting and sustaining human life in the otherwise inhospitable environment of the Moon or Mars. The images of the contained habitat under consideration were written in the 1950's and 1960's at the dawn of the space age. How one would support human colonist at such places as the surface of the Moon or Mars was highly speculative at the time and our understanding of the conditions they would face was very incomplete. My particular goal is to explore the point of view and ideas presented on this topic by the best known science fiction writers of past time periods. To accomplish this I conducted a survey of the science fiction literature produced over the last century with the help of a few bibliographical sources. I focused particularly on those ideas presented involving the development of artificial human habitat by humans for human survival in naturally uninhabitable places, such as space colonies. The ideas of these authors will hopefully assist us in the development of actual Moon and Mars bases before 2050.

Prior to this literature search over ten weeks was spent researching the topic of Moon bases and engaging in debate with other members of my former project team. Much was discussed as to the scale of operations and to the time frame involved. While much of the group wished to focus on finer details with a smaller scale of an initial base of operations for a handful of people. I was more interested in thinking about a larger more general image of what a full scale town sized space habitat would be like. I was thinking 2050 to 2070 while my partners were thinking 2020 to 2030. For this reason I sectioned off from the group and did my own project. My project was basically to pool together ideas from various fictional accounts of space habitats, and then performs a critical evaluation of these ideas, identifying the best ones. I wanted to think about what the habitat goal should be, not what the initial construction encampment would look like.

Concepts of space stations were obtained from three key English and American authors, Heinlein, Clarke and Asimov. Another contemporary German author not included in this study but worth mention is Willy Ley. He is given credit for getting the game started in the United States after he fled Nazi Germany. Like the others he was a notable science fiction author of his time, and his works probably helped to influence my three authors as well as others, but my focus was the English language literature. All three of these authors take great care to provide technological consistency throughout their works. They build on

one another. Also, the logistical concerns that they address are realistic based on the actual factors of space exploration and colonialization. The technical grounding of the authors makes them good choices for this survey, but of the three Clarke, the engineer, is the most technically sophisticated.

The results of this study discuss the different ways in which four fictional accounts of space colonies address and solve the five major concerns pertaining to habitat that I have identified. These core factors discussed are physical structure, air, food, water, and energy. The solutions for each of these basic needs will be compared to each other and evaluated on the criteria of realism, elegance and inventiveness. The overall feasibility of the solution will be considered, as well as how useful the ideas might be to the actual designers of a real artificial habitat for man's adaptation for survival in extra-terrestrial environments.

To better understand man's desire to conquer space and the material universe, it may be helpful to examine man's relationship with himself and the technology he has created, over the last century in particular.

Philosophic Overview on Why Technology Shapes Our View of the World:

The human mind has always been intrigued by the world around it. Man's probing of his own reality has persisted throughout known time. At present, as well as at practically all points in historical time with which we have solid communication via tangible evidence, we define our existence by our level of understanding and control of this reality. The human mind is a product of the perceived reality around it. It is influenced by all stimuli and information it encounters and interprets a single reality imposed upon the mind, and is held fast by physical existence of tangible evidence all around us. This physical evidence may be perceived simultaneously by alternate consciences existing in the same time, therefore people of the same time period experience a similar perceptive perspective or point of view of the universe.

Furthermore the mind's point of view is greatly influenced by its definition of what occurred in the past as well as their perceptions of the absolute nature of the universe. Both of which also are products of the reality that one exists, and has existed in. The universe is dynamic and subject to change, changes from things we understand, changes from things we can't understand, and changes from things we know nothing of. I remember a very old saying that was written under a picture of a mountainside. The

mountainside was rocky and marked with long lines of erosion from a cascading stream, it read “the years experience changes that the days never see.” In the same way does our reality change and hence so does our point of view. If one were to consider the controversial “metaphysical” or that intangible but still influential part of our universe the applications of an ever changing reality may quickly rise to a scope far beyond the grasp of our consciences.

It is possible that change while by definition brings about the birth of something may also bring about the simultaneous death of something else. This death may not need encompass the object itself perhaps just the idea of it. A change in prominence may equal a change in point of view. For example there was a time in the minds of men not too long ago when a single figure clad in armor wielding a sword or axe perhaps on horseback could rise to the front of the deadliest of melees and single handedly influence the tide of battle. A king could lead his army from the front, and the names of certain single warriors struck fear into the hearts of brutal hordes. The technological boom of the nineteenth century accompanied by the industrial revolution and a corresponding increase in production capability completely altered the face of warfare.

Warfare though history has always been the *ultimate* deciding factor in the solution of all human conflict, therefore when the nature of warfare is so dramatically altered so will be our physics. It is true that some of my previous imagery had been in part deterred by the development of firearms and long range artillery by use of cannon, in the late middle ages; however that was small in comparison to the way the dream was shattered in the nineteenth century. Rapid small arms development in the middle of the century by private manufacturing enterprises such as Colt produced the repeating pistol in many consecutive improvements, the cartridge, and in 1861 the Henry rifle, the first repeating rifle, this culminated in the invention of semi-automatic pistols in the 1890's. In addition the development of other weapons never before seen such as machine guns, tanks, flame-throwers, poison gas, longer range artillery, barbed wire, all contributed to the overall change in what war was.

I am not contending that war was ever pleasant, but what was already horrific was now augmented by an order of magnitude in a terrifying but not all together comprehensible direction. What was very clear to society as a whole was the place of a single man in this modern war machine. This was exactly what it had become. The modern battlefield had slipped from the control of men and into that of technological

beasts to that of giants, children of the industrial and technological revolutions: tanks, machine guns, flamethrowers, poison gas etc. The battlefield had grown enormous and hence a single man once noticeable was now just a tiny spec in the shadow of this monster of our own creation. At this point it might be inferred that we have witnessed what may be the death of the single-handed man as the arbitrator of battle. Instead our image shifts to masses of nameless figures pushing through the darkness illuminated by the sparks of explosions as they are destroyed almost systematically by the aberrations of modern technology. Their venerability contrasting sharply with the mechanisms of the war machine which flail the earth with a constant onslaught of power and destruction. It is of note that despite his comparable weakness in this ultimate battlefield the mere presence and sometimes survival in such conditions still emphasized the power of the human will for survival. This was the condition the first half of the twentieth century. The completion and successful executions of the atom bomb in 1945 created an unfathomable change in nature of ultimate warfare instantaneously. Now our image shifts to that of total instantaneous and unbiased destruction at the hands of our new master, the atom bomb. Advances in air warfare as well as missile delivery systems, satellite and space technology all contribute to miniaturize the human condition in relation to modern warfare.

We have witnessed the death of the single warrior but it is not completely definable. We have not witnessed the death of man, or of man's abilities to control his universe, quite contrary, he now has more abilities, we have now increased our control of tangible reality. Also there is no defined time exactly when this death occurred, rather a gradient of change. Also unclear is what was lost. As stated technological development caused increased conscience control over our reality this was largely beneficial as was reflected in the utopian mindset that dominated the late nineteenth and early twentieth centuries. As people began to experience the benefits of technology and manufactured goods in their everyday lives (i.e. electricity), or in modern society (i.e. airplanes), they began to take comfort in mankind's increased control over the natural forces of the world. What was lost was more internal, it was a piece of man's ego, a change in his perspective, or in the way he viewed, respected and revered himself relative to the universe.

It is quite evident that at the turn of the century the majority of the population had taken a largely optimistic attitude towards the current technological advances. In their eyes the continued advances would eventually lead to a utopian paradise. This can be shown not only in the analysis of the scientists and

sociologists of the time but also in other contemporary sources such as literary fiction. Although the knowledge of man's new ability to destroy at an unprecedented level did not go unnoticed it was largely undermined by inaccurate assumptions regarding his nature. It was actually the contention of some intellectuals at the time that we would never fight another war, based on the fact that modern weaponry had grown too powerful to actually use in real life.

It is of note that even at this time authors such as H.G. Wells, apparently with a more accurate understanding of human nature, wrote of a darker more ominous future made possible by these same technological improvements. Also some professionals such as Frederick Soddy, who contributed greatly to the exploration of the nature of the atom at the beginning of the century, seemed to change their point of view regarding this utopian future. Soddy was fascinated with the transmutation of the atom. He realized however that ultimately control over changing one element to another would result in the development of a device of unimaginable destructive power. Soddy took a more sociological role in the later part of his life, trying to increase the awareness of the scientific community and the general public of these dangers looming on the horizon.

The First World War, considered by some as the first modern war, turned the predominantly optimistic public attitude about our utopian future, to that of a fearful awareness of possibilities created by technological advancement. Once again this can be seen by the evaluations of social scientists at the time as well as in the literature produced during that period. Once the atom bomb was widespread public knowledge the world and the physic of its inhabitants was forever changed. People had now entered a period not of blissful optimism but of fearful uncertainty, for waiting in the shadows was the ultimate destruction of their entire world, not in the hands of God as in the time of Noah but in the hand of man. Fear of this time can be evidenced in sociological evaluations, public policy, and even physically (i.e. air raid drills, fallout shelters). The literature of the time also reflects this fear. Books such as *Alas Babylon* try to give us an image of life after a nuclear war, struggling to survive. Reading *Alas Babylon* by itself one may see a horrible depressing future, but this view is actually very optimistic compared to other fictional interpretations such as *On The Beach*, where there is no one struggling to survive, everybody in the world simply dies.

This attitude has persisted into today, for we still possess these weapons. The development of other technologies (such as rockets, improved fighter planes, lasers, computers, DNA discoveries, increased manufacturing capabilities, space flight and exploration, as well as more personal items such as TV, VCRs, PC's, cell phones, automobiles), in the second half of the twentieth century has also effected the public's physics as a whole. Coupled with ever changing foreign and personal relations and propaganda it is obvious that over the last century the human mind has experienced an unprecedented and not all-definable change. The change in part encompassed the conscience mind and since everyone is touched by it there is no absolute reference point, there is no observer that exists within the universe who is wholly unaffected by it. Despite the existence of so called independent thinkers no consciences can accurately claim not to be an absolute product of the reality in which it exists, you can't take a mind and displace it from its system and carry out an accurate analysis. The mind and the reality in which it exists must be taken as a single entity.

For this reason I believe that although we may be thought of to possess all the cumulative knowledge of the past, we have not retained the point of view of any particular time. By examining the point of view of someone from the past we may be given new insight into technology and even into our future. For at that time they may have developed a point of view that we are incapable of now, therefore they force us to perceive things in a new way or give us new ideas never before considered. I think that particularly the science fiction literature of a given time may be insightful in our assessment of technology. Considering particularly the predictions of the future created by such literature.

Specifically helpful in our discussion of space habitat will be those fictional accounts of actual space colonies that can be found in the popular literature.

Literature Search:

A thorough literature search was conducted of a wide range of science fiction titles and descriptions. Specifically I looked for anything that was set on a human space colony. Of great assistance to my search was a reference source titled Survey of Science Fiction Literature, its five volumes gives a 5000 word essay describing each of 500 different works of science fiction. It was written in the 1970's and covers all the science fiction of the previous century. Using this I was able to obtain 15 useful sources, half of which looked very promising, these I narrowed down based on availability.

I then searched the combined works of the authors of the chosen books in order to extend my search beyond the 70's. I managed to find many more potential sources of both books and short stories, and gathered the ones I could. It turned out that many of the best sources contained the same award-winning authors. I was able to obtain an account of a Moon base by Heinlein, an account of a Mars base by Asimov, and two separate accounts by Clarke, one of a lunar base and one of a Mars colony. We shall systematically compare their views of the first space bases as rendered in both books and short stories. The selection of works that was chosen represents a wide basis of perspective and imagery of human space colonies, from which we can draw information on artificial habitat.

Literature Review:

The Moon Is a Harsh Mistress by Robert A. Heinlein was the first book in my survey that I read in completion. I selected it because it was one of the most promising in giving information about possible artificial space habitats. The setting of this book is a fictional moon colony in the near future. The book was published in 1965 and Heinlein seemed rather well informed about many technical issues concerning space and machinery. The plot occurs mainly from the period of 2075-2076AD, in the largest of six colonies on the moon. The action is centered on the main character Manual and his relationship with a super computer that has controls the entire moon base. This computer, named Mike, somehow obtained independent thought and became self-aware. Manual meets a young lady named Wyoming, and an old friend, the professor, and is convinced to help them form a lunar revolution to achieve independence from Earth. Manual uses his special relationship with Mike to help them overthrow the present government on the moon and then eventually force the Earth authority to recognize the moon as a separate nation. Throughout the story an in depth description of the colony's physical attributes as well as its working functions was given, in addition to the life cycle of the people living there and their personal tendencies. Heinlein forms a complete image of the habitat of the people of the moon colonies set place 110 years in his future, but only 70 years into our future.

It appears that in Heinlein's setting, considerations of the external environmental conditions on the moon were factored as scientifically accurately as possible. The moon is a cold barren wasteland. Its most abundant resource is rocks. The surface has no oxygen (in fact no air) at all, so no atmospheric pressure

either. A large portion of the book was devoted to talking about P suits or pressure suits. “Didn’t need to open helmet to know this steel can had not stayed gas tight, knew at once, naturally, from the way p-suits felt”[pg. 174] In addition he also considers that protection is also needed from the harmful radiation at the moon’s surface. Specifically outlining the details of the habitat were the descriptions of the general structure of the colony, the way they obtain their food, the way they obtain their water, the way they obtain their air supply, and the energy source of the colony.

Anyone wishing to establish a living environment to sustain human life in a hostile alien world for any length of time would have these as basic concerns. These will provide challenging problems to those who initially establish a moon base, but they will also be of concern for all that will ever live on the moon in a colony. The main characters in his story incorporate their necessities in the basic slogan of the revolution. “Move to amend to make it “free air *and* water” –because you didn’t have “freedom” or “security” unless you had both air and water. Air, water and *food*. Air, water, food and *cubic*. Air, water, food, cubic and *heat*. No, make “heat” read “power” and you had it all covered. Everything.” [pg.164]

Lunar City was the largest of six moon colonies. Each colony originally represented a country from Earth but they no longer hold much ethnic resemblance to their original hosts. For example one of the main characters Wyoming was from the “Chinee” colony Hong Kong, and like most people from Hong Kong she had blond hair, and was very white. Each major city/colony was surrounded by warrens, which were like smaller towns, and private farms. All of this was in relative close location to the center hub city location. Particularly since practically all habitats are connected even remotely by pressure tunnel, so there are six main habitat units functioning completely independent of one another. These six cities support a total of about 3 million people.

All habitats are located under ground. It is also evident that the city itself is built on a level system, (although some rooms cover more than one level). Lunar City seems to possess over six levels. Higher and lower levels are connected to one another by way of ramps. These ramps though traversed easily by Loonie’s, possessed untold hazards to those not accustomed to one-sixth gravity, and accounted largely for the upset in the foot battle between loonie revolutionaries and authority Earth troops. “But these troopers wound up dead; was on ramps we got them. ...No trooper got farther down than level six in any warren... people in bottom alley didn’t even know..”

Rooms (homes, farming tunnels, shops, etc.), tunnels, and corridors, are what paint the world of the moon colony inhabitants. The colony itself serves all the functions of a human city. The corridors function like city streets within inner Lunar City, different shops, bars, and service industry are located off these corridors. The inner structure of these areas as well as farms and private houses are also similar to this structure for the most part. Lunar City (and other moon colonies) is basically an expanding network of tunnels. It apparently started as one big tunnel and as time went on consecutive improvements accumulated and developed the City into what it was. Authority workmen (government organization) laser drilled most of the main basic structure out all at once originally. Each city was a little different, but fundamentally they ran by the same principle.

New colonists can set up near outskirts of city and burrow in their own holes. Manual was a drill man before losing his arm, being a drill man was quite advantageous in this environment for obvious reasons. You laser drilled out yourself rooms for everything you needed which was basically for living space and farming. Then you would be connected to the city by pressurized tunnel. You would buy power from Lunar City authority via power line, also you would buy phone service also routed through authority and by electric line.

The difference between the corridors and tunnels is that metal and structure cover the corridors, everything is airtight and the corridors have pressure locks. The tunnels are just drilled out caves in the underground rock, without the metal "interior casing". The tunnels, however, are kept pressurized. The rock appears to be very stable and in order to ensure no leaks a type of sealant is applied to the inner surfaces. Rooms in shops, houses, and administrative buildings for the most part have the corridor type of structure. Home farming areas often only had the drilled out rock with sealer. Most of the city streets are the corridor type structure, but there were some exceptions. It is also of note that pressure locks to the surface were readily available, these consist of two air locks the inner must be sealed then the cycle button is hit and the outer door opens to moons surface and depressurizes the chamber. In addition to using these to enter and leave the colony they were the almost exclusive method of execution.

The "Old Dome" which functioned as a sort of town square for lunar city appears to be a sizable area occupying many levels as well. It is a "natural bubble cave" needing no corridor structure. "Impossible to get all of L-City inside Old Dome—but looked as if they tried. I estimated an area ten

meters square, tried to count heads, got over two hundred not half through and gave up. *Lunatic* placed crowd at thirty thousand, seems impossible.”[pg. 226] If there was 400 people in a space of 10 square meters then 30,000 people would occupy 750 square meters or over 3800 square feet. This is quite a sizeable area, most likely part of the original structure it acted as a central rallying point, and a common locale from which to build the basic components of the city.

The notation “Old” in “Old Dome as well as this being central to the base structure of the city indicates that the “Old Dome” is in fact old. The use of only sealer on the inner rock structure of the dome may indicate that original landmarking for the city was done rapidly. To me this means the author envisions a large-scale laser drilling operation to lay down the basic utilities. Using sealer only at first, then installing corridors later as needed, some areas may simply have been neglected as they no longer were exterior and in need of sealant. It is of note that many layers of structure protected the main computer Mike’s central location, he was deep enough to survive a hydrogen bombing.

All the main colonies and most warrens were protected by this multi-level corridor system with pressure lockouts to contain leaks. The exception was Tycho Under, one of the smaller main cities, which was completely designed like the Old Dome. “One cubic, lowest level of Complex where central part of Mike lived, had been designed to withstand bombing. On other hand Tycho Under was a big natural bubble cave like Old Dome and roof was only meters thick; sealer on under side was kept warm with hot water pipes to make sure new cracks sealed—would not take much of a bomb to crack Tycho Under.” [pg.237]. Overly rapid development to maximize profit revenue had resulted in weak city structure, as Heinlein envisioned it.

Since pressure is centralized and everything is connected though an intricate and vast underground complex most people have little need for a pressure suit in their daily lives. Sufficient it to say that most people never venture to the hazardous surface and spend their lives in this artificial underground habitat which provides them with all the necessities of life. The *cubic* or physical structure of the colony as described is rather contained and well defined. This knowledge of the habitat in which they live as well as its position of ever-present danger of a breach in the seal pervades the minds of Heinlein’s colonists on all levels. “..when I heard and felt a sound that scares a Loonie more than anything else –a chuff! in distance followed by a draft.”[pg. 245]

The Lunar colonies were self-sufficient for the basic needs of life including a power supply. Almost everything on the moon colonies, whether Heinlein intended it or not, seems to run on some sort of electrical system. Heinlein generously allots his future society with the ability to control and conduct free fusion. All large main components to the infrastructure of the colonies, as well as space ships, and space catapults are all powered by hydrogen-fusion power plants. Most of the colonists buy power from authority. This means that the local government on the Moon controls and maintains several hydrogen-fusion power plants, and distributes the power not used by core infrastructure of the colony among the private habitats of the Lunar inhabitants. This was done with a traditional metering system.

Government energy lined in from the central authority was not the only choice of a Loonie that needed to supply a private habitat with juice. Several references were made to “sunshine screens,” (assuming solar energy), which many independent farms utilized to supply power. If larger corporate interests had the need and the money, (as well as authority’s permission), they could construct their own hydrogen-fusion power plant. “You can’t buy or build a hydrogen-fusion power plant [for such an application] and not have it noticed.” [pg.109]. Although the average citizen complains about paying a marked up price for power, in practicality, supplying affordable power to the lunar bases is not a problem due to hydrogen fusion plants. With regard to an energy supply the colonies have obtained practical autonomy, except for importing the hydrogen.

The moon’s resident population consists of government employees, independent contractors (repairmen, pilots, builders etc.), merchants, traders, ice miners (drillmen, also good for rock tunneling for habitat structure building), scientists, technical assistants, tourists, convicts, scoundrels, bums, and a fairly large population of farmers. These farmers produce food that is consumed by their families; some is sold to shops in the colony cities, while the remaining surplus, (mostly grain crops), is shipped to catapult head for launch to Earth. Concerns to food, the moon colony was not only self-sufficient but provided massive food surplus to Terra. Food on the moon is cheap, and farmers do not receive high prices for their crops, but they can be self-sufficient. This high food production in part can be accredited to a large amount of growing space provided by way of farming tunnels. Loonies would tell you that the moon is nothing *but* space, all you need do is tunnel it out. The high agricultural production was also due to an advanced hydroponics setup.

Hydroponics can utilize the sides of the walls as well as the floor of the tunnels and, can produce crops quicker, can provide denser yields, and does not require as much soil. The roots of the plants are held in a type of substrate, (quite likely that one-sixth gravity would make anchoring wall growing plants easier), while nutrient full water is constantly feed through this reusable substrate, in a recycling system. Powerful grow lights must be used to cause photosynthesis when no sunlight is available, as is the case when growing in an underground rock tunnel. The necessary ingredients are mixed up with the water mainly these consist of nitrates and phosphates. The nitrates and phosphates are obtained from moon rocks. Miners “crack open” these rocks and extract the valuable minerals from them.

Plant nutrients, like everything else on Luna is, recycled, used and reused over and over again. The colonies are a closed system, (minus the exports to Terra), like the biosphere on Earth but much smaller. Excess organic plant material, as well as all human and animal waste materials are sterilized and reused as plant food. Due to obvious environmental factors sterilization of organic waste on the moon is incredibly cheap and easy, by putting it outside. Nitrate and Phosphate material is taken from moon rock purified and entered into the system as plant food. These plants are eaten or fed to animals such as chicken or cattle, (the colonists keep all sorts of animals even bees), the animals in turn are butchered and eaten. The nutrients go that go through a full nutrient cycle would travel from the plants, to the animals, to the humans, then to human waste, then back to plant food and the cycle continues.

Everything is reused, usually even the Loonie’s own dead are recycled into the organic matter of the system. Manual’s family had a special garden where they kept the remains of their predecessors, just flowers and cosmetic plants not for eating, but just to be recycled back into the garden. It was a smaller, closed organic system. The moon people, though their own necessities of life, may have developed an interesting concept of the eternal perpetuation of live, or the endless cycle of life and death. Since their life cycle or complete system is much smaller than that of a Terran’s, moon colonists have a larger concept of their overall habitat. “...Hans showed him hydroponic farming and Stu got dirty and sweaty and sloshed around in tunnels with out boys—helped harvest out Chinee fish ponds—got stung by our bees—learned to handle a P-suit and went up with me to make adjustments on solar battery—helped Anna butcher a hog and learned about tanning leather—learned to grind flour...”[pg.137].

The lunar colonists had also obtained autonomy with regard to air. Air is very similar to food, as it is a by-product of some sort of farming operation. The overall amount of air is conserved, (as a gas in closed system), nearly completely with the exception of the inevitable air leaks. I assume these air leaks occur almost entirely from use of pressure locks, since you will lose the air in the inner chamber. The colony's original air was brought from Earth, and the colonies can keep pressurized tanks of air for replenishing leaks. Leaks however, are small as a percentage of the entire mass of air in the system.

The main problem with the air in habitat systems used for supporting humans is the need for producing Oxygen and the need to get rid of Carbon Dioxide. This is accomplished by balancing the cycle with the large amounts of farming plants. Plants use up Carbon Dioxide, (excess CO₂ can also be removed by scrubbers), and produce Oxygen. Individual farms collect the Oxygen by-product of their crop like the way they would harvest food. Similarly farmers can use what they need for themselves and sell the rest. The only difference is that colonist can only sell air to the central colonial authority. The central authority controls the distribution of air and charges everyone a standard rate. "...No one asked you because you've paid. For you, is part of round-trip ticket; for me it's a quarterly charge." [pg. 129] Despite the fact that each colonist pays for imported air, the oxygen-carbon dioxide or the human-plant respiration cycle is closed and self-sustaining.

In addition to a reusable mass of air and nutrients, the moon colony's systems also run on a conserved quantity of water. Water is essential in the function of all habitat operations and of all the elements involved, water is the hardest one to keep in the system, since there are many ways to lose it. Water is sanitized, (also easy on the moon), purified, and then returned to the system. The water, however, is usually used several times, not just once per cycle. Every use without cleansing process downgrades the water's level of useful utilization. Firsthand water may be used for drinking or bathing, while secondhand just bathing, third cleaning, etc. "Mannie would you like to bathe in it first? Secondhand water is good enough for this makeup and that stink you complained about. Unmetered water, dear. Run it deep. Oh, what luxury! At home I use the same bath water three days running.... Are you wealthy Mannie?" [pg.30]

For the most part the moon colonists take great effort to conserve all the water in their supply but the water that does leak out needs to be replaced and more water is also needed to support new colonists and new hydroponics farms. The primary and almost only source of water renewal back into the system is

from melted ice, mined from “underground ice pockets”. The miners collect all the water after state change and sell it at market. In the book these ice pockets are located randomly throughout the moons surface. The laser drills used for boring rock structure work well in mining and melting ice, although any drilling work in p-suits at surface conditions is considered hazardous, water is precious and would warrant the risk.

The book mentions that ice pockets must first be searched for and located, in order for mining operations to take place. Heinlein is aware that the continued mining of this ice at an increased rate would rapidly deplete this very limited resource. “Fred Hauser told us that ice is harder to find. Too true—bad news now and disastrous for our grandchildren.”[pg.25]. Despite this, many processes exist and are implemented for the conservation of water, and mining the moon’s ice is a rather innovative way of replenishing supplies. Theoretically the lunar colonists are self-sufficient in regard to water, due to a mentality of conservation and these technically advanced recycling processes.

Not only were the colonies set up well for housing, transporting, and protecting human colonist, but they were self-sufficient in food production, and could distribute this food throughout themselves. Also they were self sufficient in oxygen and carbon dioxide recycling in the air, were nearly autonomous in their use of water, and had an almost unlimited energy source. This covers all the basic needs of a human habitat. The lunar colonies had formed a system that was completely self-sustaining in all fundamental senses. It was to all intents and purposes an independent nation on the moon. There was a problem with their system however; it was a closed system with a *leak* in it.

The leak had to do with politics and the export nature of the moon’s economic situation, modeled as it was on the Australia penal colony. As mentioned Luna could provide for basic human needs, and hence self perpetuate its artificial habitat. They even yielded a large food surplus that they exported to Earth. Luna colonies, despite a good agricultural base, had very little manufacturing capability. Maintaining a moon base requires a large number of technical components and most of these had to be shipped from Earth. “But we don’t need water and plant chemicals, what we need is not so massy. Instruments. Drugs. Processes. Some machinery. Control tapes...”[pg. 25]

A moon colony also requires trained professionals for repair and maintenance work. These Lunar colonies were also short of these and shipping professionals to and from “Earthside” was expensive. Our main character was a repairman, and was particularly adept at his job since he could substitute different

arms to fix machines like different tools for each purpose. This gave Manuel an advantage. Since he was a moon resident it was much cheaper and more desirable for the colonial authority to hire him to fix problems with main systems, before considering bringing in an expert from Earth. Earth people could not stay very long without losing the ability to function on Earth.

In addition to the problem of needing to ship more complex manufactured goods from Earth and a shortage of professional labor, the moon had another problem. Lunar colonists suffered from a lopsided trade balance due to a colonial-mother country advantage trade relationship. Lunar farmers exported nearly all their crops Earthside, but the prices they received for their goods at catapult head were only a tiny fraction of what they raised at Earth markets. This is because lunar authority controlled a giant space catapult, which was the only method for transporting the goods to Earth (spaceships came from Terra occasionally but no one on Luna owned one). Farmers transported their goods, by way of shuttle, through tunnels to the launch point of the space catapult. Lunar authority set the price of the goods that the farmers would receive, shipped the goods cheaply, and the section of authority located Earthside sold it there at Terran prices and reaped a tremendous profit.

“You’re a wheat farmer—going broke. Do you know how much a Hindu housewife pays for a kilo of flour made from your wheat? How much a tonne of your wheat fetches in Bombay? How little it costs the Authority to get it from catapult head to Indian Ocean? Downhill all the way! Just solid-fuel retros to brake it.”[pg.22]

An unbalanced trade relationship is never good for the losing side, but this unique one had more particular problems due to the specific nature of such a closed ecosystem as that which supported the lunar base. While the moon colonies imported a small amount of technical goods, they exported large quantities of organic material in the form of farm products. This organic material, (usually grain), contained the nitrates and phosphates that were so valued and carefully recycled on Luna. In addition to shipping valuable plant food out of the system, the farm product always contained large quantities of water. Extensive efforts had to be made to mine ice and moon rock for water and nutrients to add to the system in an attempt to replace the losses from exports to Terra. Earth was not sending back any nutrients or water, leave aside the amount as they were taking, so the Moon's otherwise closed self-sustaining ecosystem was

slowly running itself out. This process of decline was speeded up by population increases, (mainly due to births), and delayed by mining operations.

In the story the main characters figure out that this economic trade upset would soon diminish the levels of their basic recyclable resources to nothing. Meaning an inadequate supply of food and water for the population would cause food riots, and eventually mass starvation. This was one of the bases on which the lunar revolution was launched. “Seven Years... I ran several thousand solutions using many assumptions. The happiest answer came from assuming no increase in tonnage; no increase in lunar population-restriction of births strongly enforced-and a greatly enhanced search for ice in order to maintain the water supply. That gave an answer of slightly over twenty years before the demise of the moon habitat. All other answers were worse.”[pg. 74].

The professor tried to convince the Earth authority of the problem and recommends exports from Earth to solve the problem. “Put down a hose in the limitless Indian Ocean. Line up those millions of cattle here in India; collect their end product and ship it to us. Collect your own night soil—don’t bother to sterilize it; we’ve learned to do such things cheaply and easily. Send us briny sea water, rotten fish, dead animals, city sewage, cow manure, offal of any sort—and we will send it back tonne for tonne as golden grain.”[pg. 192]. This was a good sentiment aimed at proposing a viable solution to the Moon’s economic dilemma that would also seem extremely appealing to Earth Authority. In the end however, the only way to gain independence was to fight for it. Trade solutions with Earth countries were eventually worked out after the revolution was over, but first the moon had to fight for and establish its own autonomy. Heinlein’s vision of a lunar habitat capable of supporting a large population was complete and self-sustaining, only after the revolution.

Other information given in the book that would be of interest in the study of space habitat would be Heinlein’s constant references to gravity and to the effects of it on the lunar inhabitants. He makes it clear that the low gravity on the moon causes you with time to be unable to function in a 1g environment. Even the strongest loonies can barely walk up a flight of stairs when on Earth; the weakest ones are wheeled around and may die from the stress. Their bodies simply weigh too much, they pass out and their hearts fail in particular, among other things. References were made to a centrifuge, (spinning rotary, which creates artificial g forces), which moon inhabitants would use to prepare them for a trip to Earth. There are

a few other ways they would prepare, "...exercising in hotel room three hours a day, and sleeping in three hundred kilograms of lead pajamas"[pg.111].

Also of interest is that much of the plot of The Moon Is a Harsh Mistress revolves around two giant space catapults located near the colonies. These catapults are the method by which the moon farmers transport their goods. At the time of the story Earth had no catapults since it would require a much more powerful design. This is because of the low gravity on the moon coupled with Earth's gravity well. Basically Earth to the moon is uphill moon to the Earth is downhill.

Heinlein's catapult functioned primarily like a very long electromagnetic cannon with the "rings" increasing in distance towards the exit point, which is sloped upward at a slight angle from the launch point. The ship to be sent to Earth was simply a bullet-like reentry device, equipped with computer controlled solid fuel rockets. The rockets functioned as retros and to go into and from parking orbit. One of the lunar catapults was 100 kilometers long and 3g's, (force shipment is subject to at launch), and the other one was 30 kilometers long and 10g's.

The Moon Is a Harsh Mistress provided a large amount of information pertaining to the habitat and the life of colonist living on a fictional moon base. The author backs up his concept of the lunar setting with sound scientific explanation. The details are connected in such a way as to give a full image of a functional habitat. This book was a good selection for this survey.

The Other Side of the Sky, (1957), by Arthur C. Clarke was another very helpful selection for this survey. This book is a collection of 24 short stories. Twelve of these stories comprise their own topic, another two groups of stories "The Other Side of the Sky" and "Venture to the moon" each contain six short stories with the same setting and fitting into a general plot. The main plot of "The Other Side of the Sky" pertained to the development of a system of orbiting space stations above the Earth in geosynchronous orbit. "Venture to the Moon" was written presumably as the next stage in space exploration. It entails the simultaneous landing and establishment of moon bases by Americans, English, and Russians. These bases each contain a couple dozen people and all the bases work together and help each other out despite completely separate command structures. The mission was to live on the moon for five months and to

conduct exploration and scientific experimentation. Much information with consideration to near future technology and space exploration can be found in this source.

The interesting thing in the “The Other Side of the Sky” series was that Clarke gives definite reason for the space station and the artificial habitat accompanying it. The space stations were for relaying signals for TV programs and phone calls, as well as for viewing weather trends, (pretty accurate). It seemed obvious to Clarke that people would be up there, like the construction workers and maintenance men of his time, to perform necessary functions to the station. Also what better place for a meteorologist to live and work. “I’m afraid that you people down on Earth take the space stations for granted, forgetting the skill and science and courage that went to make them. How often do you stop to think that all your long-distance phone calls, and most of your TV programs are routed through one or the other of the satellites? And... weather forecasts are no longer the joke they were to our grandfathers, but are dead accurate ninety-nine percent of the time?”[pg. 26].

The first story in the “The Other Side of the Sky” group was titled “Special Delivery”. It was an interesting account and I was able to gather much specific data about the habitat of the first builders of the space station. After the space station had been established for a while a contained pressurized system (living quarters, corridors, labs, recreational areas, etc.) was taken for granted by all that lived and worked in the station. In order for all this to exist, construction engineers had to build it; therefore these people who came before the later station inhabitants did not have this secure man made environment. These station builders in the early stages of construction, (and in latter as well), did not build so much as assemble prefabricated parts shipped up from Earth. “it looked like a junk pile adrift in space. Prefabricated parts were floating around in hopeless confusion, and it seemed impossible that any order could ever emerge from this chaos” [pg. 27].

So in the first stage of construction the technical staff and assembly crews doing the work had to be housed in no longer working ferry rockets, (nicknamed the Hulks). The interiors of the ferry rockets were completely gutted out except for the air purifier. Each man had just enough space for himself and a couple cubic feet for his belongings. “There was a fine irony in the fact that we were living in the mist of infinite space ---and hadn’t room to swing a cat” [pg. 27]. This is a very practical idea for early construction since space-ferrying ships will have a contained habitat system.

The unfortunate but slightly humorous plot emphasizes the importance of proper living quarters. The main construction of the space station was done on Earth so the biggest problem was getting the necessary parts up to the base. This was usually done by ferry rocket once the specialized manufacturing facilities on the surface completed their tasks. Eventually the first pressurized living quarters were sent up to the space workers. These quarters included needle jet showers that could function in the zero gravity conditions. "We could throw away our damp sponges and feel really clean at last" [pg.27]. Also being sent to them was an inflatable lounge that was made to hold up to eight people, a microfilm library, a magnetic billiard table, lightweight chess sets and other recreational things. These things would be the real beginning of the space stations habitat system.

This load like all shipments was delivered by ferry rocket, which usually ran on autopilot and took six hours to lift to the stations orbiting speed and altitude of twenty two thousand miles. Once in parallel orbit workers in space suits could secure it. The unfortunate thing about this particular trip was that the autopilot jammed and the rocket burned up all its fuel, (enough for return trip also), in one continuous blast and blew by the station. The good thing about the situation was that the future trajectory of the mail could be accurately calculated and it didn't escape the sun's gravity completely. It was bound to come back around and could be retrieved if there was a ship ready for it. The bad thing was this wouldn't happen until early spring in the year A.D. 15,862.

The next story in the "The Other Side of the Sky" series was titled "Feathered Friend". This gives a good account of Sven, one of the best construction men, performing building operations in space. Clarke describes the task as specialized and tricky, collecting assorted girders and juggling them in free fall to the correct positions and then "fusing" the pieces together when dovetailed to the exact pattern. All this is made more difficult by the fact that it must all be done while in a space suit, since it's a deep space operation. The process of the station's assembly was done by crews of workers. The author describes watching the station grow like a giant jigsaw puzzle under the hands of Sven's crew. "Sven's team had one great advantage over the construction gangs you see putting up skyscrapers down on Earth. They could step back and admire their handiwork without being abruptly parted from it by gravity." [pg. 29].

This story deals with a small yellow canary that Sven smuggled on board as a pet. This turned out to be a good choice of pets since due to a canary's extremely small size relative to a person. Her food

requirements were practically nothing. In addition since Claribel was a bird she wasn't bothered by the lack of gravity. Most of the time it was pretty easy to keep her a secret from high-ranking space officials and VIPs when they frequented the station. One day they found Claribel keeled over, the medical officer tried to help her by putting her in an oxygen mask, this revived her but she passed out again when exposed to the regular breathing air in the station habitat. To make a long story short there was a problem with the air purifier and the oxygen level in the atmosphere was dropping. If it wasn't for Claribel the whole station might have been wiped out.

This story shed some light on the station's airflow processes as well as on some electronic control systems. It is quite obvious that similar to Heilein's base the space station has a contained mass of air that is cycled between proper amounts of carbon dioxide and oxygen. However, unlike Heilein's moon colony that relies primarily on the life cycle of their plants to remove the CO₂ and create O₂, Clarke's space station has an air purifier that does the same job. One problem in this story is that a rare eclipse by Earth's shadow at night had caused part of the air purifier to freeze up. In case of emergencies the station also has a spare oxygen tank with a breathing mask. The problem is that it does no good if you don't know there is something wrong with the oxygen level. There is usually a double safety circuit on the alarm if something happens to the air purifier, but the station was just being assembled and the second circuit had not been hooked up yet. Now you might hear the sound of canaries when visiting a space station, as an extra precaution.

The third story in the series was "Take a Deep Breath". This story provides much information about habitat via the account by a builder, of something that happened while they were in the last stages of building communications satellite two. Living quarters for the building crews was a giant wheel with individual bunkhouses on the outer rim, like a bike wheel with sausages, instead of a tire, on the outside. The wheel was two hundred feet in diameter. Each of these sausages was an individual cabin with its own individual life support. The cabins however were dependent upon their connection to the main system. The spin of the giant wheel produced an artificial gravity to those in the cabins, which were designed so as to utilize this rotation. The wheel base spun at an angular velocity that gave the outer rim a speed of thirty miles per hour. Inside the bunkhouse no movement was noticeable but one was subject to the effects of ½

gravity. It can be inferred from the story that these cabins were built to house at least four people, but probably not to many more.

In the story's plot the storytellers cabin becomes dislodged from the main station one night while he and his bunkmates were sleeping. Breaking through the centripetal force which normally holds the bunkhouse in rotation sends the cabin flying away from the station at thirty miles per hour. Since their main concern was the oxygen supply it seems that each cabin did not have its own air purifier, however it did have an oxygen gauge. As they were drifting through space, pressure as well was a concern to think about since they could hear a steady whistling sound that told them there was a slight leak somewhere. There were air circulation vents connecting the small habitat to the larger one. It is mentioned that these closed automatically once they were disconnected to the main system. Since a sudden disconnection from the base caused a steady leak it also can be inferred that some sort of air circulation tubes as well connect the air mass within the cabins to that of the main system.

Other habitat factors such as power supply and communications can be recognized in this suspenseful tale. The fact that the power supply in the cabin was off and the lights didn't work was the first hint to what had happened, indicates that the power (electrical) was connected to the individual living quarter by electric line. Though connected to the main, each cabin had its own emergency battery, and emergency lights that go on automatically. Communications with the rest of the base were also by way of line, and once dislodged the storyteller's bunkhouse could not contact the station. It is interesting that individual cabins did not possess radio communication facilities.

The built in safety precautions of the air vents automatically closing and the backup power supply gave the builders a contained habitat that could sustain them for at least a little while. Eventually a rescue ship was able to get them but by that time their oxygen gauge read nearly zero. There was no time to tow the cabin back but the rescue ship was only a few feet away with its airlock open, so the unfortunate bunkmates had to cross this space without spacesuits. In order to emphasize the technical points of this story, Clarke provides much detail on artificial habitat, and why a human could (briefly) survive such a passage if their courage didn't fail them.

The next story "Freedom of Space" was able to provide a little more insight to the habitat of the space station as well as to Clarke's vision of its specific function. The plot of this story revolves around the

first occurrence of a *World Broadcast*. Made possible only by the completion of the third and final main communication base. This very much publicized and anticipated television broadcast would be hosted live from the space station and the show would switch off to cameras all around the world. The main problem was in finding a compere or master of ceremonies to travel to the station and host the event. All the big names wanted the job but the top dogs canceled each other out, and a relatively unknown TV personality got the job. This particular gig would gain him much public recognition.

The author describes some of the basic modular components of the space stations before assembly. The implications of their assembly to habitat are apparent. "The three stations spaced around Earth were no longer piles of girders, air cylinders, and plastic pressure chambers. Their assembly had been completed, we had moved aboard, and could now work in comfort, unhampered by space suits. And we had gravity again, now that the stations had been set slowly spinning." [pg. 35]. It is likely that the pressure chambers were rooms and corridors, while the air cylinders functioned as elevators and tubes between chambers. The girders no doubt were assembly devices used to connect and hold sections in place. This use of modularization is both ingenious and practical.

In the end of the story the television personality selected for the job decided, (much to the confusion of the rocket pilot sent to pick him up), not to return to Earth. He gave up inevitable fortune and fame in order to stay in space as a second class meteorologist. There were a few reasons that he gave among which was the improved quality of the air as well as the fact that the $\frac{1}{2}$ gravity made him feel like superman. "This air you make, he said, it beats the stuff we have to breathe down in New York. This is the first time my sinus trouble has gone since I went into TV." [pg. 36]. It is very possible that the air in a space habitat would be cleaner, and purer than common Earth air. This would be due to the careful and intensive cycling system as well as the monitoring of the atmosphere conditions. Very likely that to the average person the air in a space station would seem more pleasant to breathe. However given our present knowledge of the effects of a zero or low gravity environment it is likely that a modern colony would spin for full gravity and not the $\frac{1}{2}$ g's of this fictional station.

"Passerby" is a very interesting story in this collection. It deals with a station worker who lives and works on main Satellite Two; his college sweat-heart was also transferred to the orbiting space station. Unfortunately she is on the Solar Observatory satellite, the same distance up but a couple of degrees

eastward along the orbit. This added up to 900 miles of empty space between the two sections. Clarke indicates that there is a TV communication circuit with which one can talk to Earth or other sections of the station. He, through luck, becomes a transportation section leader and manages to discretely arrange periodic trips to travel over to the Solar Observatory by way of rocket scooter to visit his sweat-heart.

There are a few details of the base structure in this account. Very interesting is the description given of looking through a telescope while in space, since great distances can be seen in space with an unmatched clarity. Also the telescopes employed were indeed powerful. "I could use enormous magnifications, and could see every detail of our neighbors' equipment—the solar telescopes, the pressurized spheres of the living quarters that housed the staff, the slim pencils of visiting ferry rockets that had climbed up from Earth." [pg. 38]. Another interesting detail was that the rocket scooter used to travel between the sections of the station was little more than a cockpit and control system connected to a powerful rocket. In fact in order to slow down one would turn the rocket around. Docking would involve floating up a tube, through an airlock and into a pressurized bay.

The main plot of the story involves an object that our narrator sees half way through his return visit from the space observatory satellite. He only got a glimpse of it as it came close for a brief second and then pulled away. Initially he picked it up on radar but didn't look down to see how close it came. It could have been an oddly shaped meteorite or maybe it was an ancient alien spaceship. Our narrator will never know, nor did he know its size since he never knew its distance. This is one concept that Clarke often presents in his writing. The fact that due to the crystal clarity of space one must know either the size of the object observed or its distance, in order to know the other. If you don't know either there is no relative plane from which to determine things. "It could have been a small object a hundred feet away—or a very large one, ten miles off. There is no sense of perspective in space, and unless you know what you are looking at, you cannot judge its distance." [pg. 40].

The last story in the "The Other Side of the Sky" series is entitled "The Call of the Stars". This story gives us a general perspective of the large-scale development of space habitat systems. The plot of this story is about a man remembering the story of his struggle with his father. His father fought with him all his young life not to go to the space station. In the end his son left and he never saw him again.

Although living in space at the orbiting station, this man must now go say goodbye to his son who is leaving on the Martian expedition.

This shows how Clarke seemed to have a pretty clear general plan for mans colonization of space. It starts with the building of the space base right above the Earth. Once this, and presumably a moon base (Clarke seems to prefer to concentrate on Mars), is completed an expedition to colonize Mars would soon follow. The necessary components of the Martian base would be transported and docked through the station. With the aid of the orbiting bases and their workers most of the assembly of the Mars colony was done right there in space next to the station. It was conducted in the same modularized fashion as the assembly of the station itself.

Once everything was prepared the entire works was blasted off towards Mars on what seemed to be a lifelong commitment. Clarke's predictions although seemingly plausible display the overly optimistic assumptions regarding time scale characteristic of science fiction writers of his time. His set time for the blast off of the prefabricated Martian colony after the building of the orbiting stations was exactly on 2000. "floating there in space, only a mile away are the ships of the first Martian expedition. For two years I have watched them grow, assembled piece by piece, as the space station itself was built by the men I worked with a generation ago." [pg. 41]. Despite an inaccurate time scale Clarke's detailed presentation of space colonization could easily be a realistic plan give enough time for its development. "The Other Side of the Sky" collection of stories formed a quite complete image of Clarks fictional space habitat.

The other section of stories was titled "Venture to the Moon" and encompassed a five month joint venture at colonizing the moon by English, Russian, and American forces. The first story in this series was titled "The Starting Line", and explained the first moon landings which immediately preceded this first live-in colonization experiment. The initial stages of development, preparation, and implementation of the moon base were similar to those previously describing Clarke's predictions regarding the launch of the first Martian colony. "ships were assembled in the orbit of Space Station Three, five hundred miles above the Earth, from components flown up by relays of freight rockets. Though all the parts had been prefabricated, the assembly and testing of the ships took over two years..." [pg. 71]. It was an international co-operative venture however extra prestige would come to the first ship to actually land on the moon. Despite a similar

attempt at trickery by all three ships at the beginning of the run, all three countries touched down on the moon at exactly the same time.

The second story in the “The Venture to the Moon” selection was titled “Robin Hood F.R.S.”, and has been very informative in describing the colony setup on the moon. Since it was only a five-month mission the living quarters had to be strong and reliable but did not have to be completely permanent. This was accomplished by the use of igloos that were blown up like balloons and made of a material described as tough flexible plastic. These igloos functioned as the colony homes, offices and labs. Once the igloos were blown up, partitions were connected inside to section off rooms. Air locks gave the ability to access the outside. Rooms of plants inside the ships performed the function of purifying the air and what was described as a good deal of plumbing connected the igloos internal habitats to that of the ship. The igloos even had sinks and the American igloo had a washing machine. It is also specified that if the need arose they could live in their ships, but it would be cramped.

This section also gives details about exploring around the base. It is stated that besides walking the astronauts other way of traveling on the surface of the moon was by means of electric powered tractors and scooters. When exploring, they relied on charts and maps created primarily from aerial photographs. While helpful, these guides could sometimes be misleading in reality. “What had been marked as a small hill on a chart often looked like a mountain to a man toiling along in a space suit, and apparently smooth plains were often covered knee-deep with dust, which made progress extremely slow and tedious.”[pg. 75]. It is mentioned that the lower gravity of the moon however helped out by compensating for some of the difficulties of exploring.

Food and water for the lunar habitat as well as other supplies were provided to the colony by automatic supply rockets that arrived periodically from Earth. Once they had obtained lunar orbit these rockets used a radar guidance and an advanced computer control system to land themselves on the surface. The main plot of the story concerns one of these supply rockets that found itself a poor location to land. “It spotted the only really unclimbable hill in the neighborhood, locked its beam onto the summit of it, and settled down there like an eagle descending upon its mountain aerie.”[pg. 76]. The rocket was eventually reached by use of a homemade bow and arrow and a grappling hook.

The next story in this series is titled "Green Fingers". It was about the attempt to invent a plant that would grow on the moon by a botanist astronaut who was a member of the Russian group. It gives much information about the food and water situation on the lunar bases. A network of transparent plastic tubes surrounded the Russian base. These tubes like the igloos were pressurized with air locks to the outside. Inside this tube system the Russian botanist grew a variety of plant life. It mentions that he employs hydroponics to grow his plants, some of which included vegetables and dwarf fruit trees. The Russians were able to use some of the vegetation harvest to supplement their food supply. This would be useful even if the Russian base would have a higher amount to initially transport as well as a higher setup time and a higher water requirement due to the hydroponics setup.

The Americans and English figured the economics of the deal and calculated that it would be more cost effective if they just sent all the food via supply rocket. This decision was based mainly on the relatively short time duration of the mission. It was mentioned that the other two groups would have also employed a similar hydroponic-pressurized tube setup if in conjunction with the establishment of a permanent moon base. This decision was made completely from the standpoint of food vs. money, and did not take into consideration all of the factors. Most important thing about the transparent tube garden was the effect it had on the astronaut's morale. Five months is a long time to spend in those little colonies on the moon even if they were always busy. It was stated that after the initial novelty of being on the moon wore off one quickly tired of the gray monotonous landscape. The colorful and lively garden was an oasis for all those who viewed it.

The fourth story in the "Venture to the Moon" series was titled "All that Glitters". I was able to ascertain a good deal of knowledge about how these lunar explorers conduct their longer exploratory missions and how they handle their habitat concerns during these missions. The main plot of the story concerns a geologist astronaut's exploratory mission to a giant crater. The geologist and the crew traveled to the bottom of the crater where they drilled down deep as they could and took rock samples. This type of mission certainly would be a common part of any real life moon base situation, and Clarke bases his story on sound technological reasoning.

When journey sets out the party leaves the main base in a special tractor with a pressurized cab. All of the supplies and equipment necessary for the completion of the mission are attached to and carried

by this tractor. Many of these individual expeditions could last around 48 hours but it is unlikely that the explorers got much sleep if any at all, since Clarke describes the use of “booster drugs” in order to stay awake. It is known that such an independent party exploring on the moon is equipped with its own radio communication device. Also stated was that once they were over the curve of the moon, (not nearly the distance it is on Earth), they could no longer send a direct signal to the base. The procedure to rectify this problem was that the party would not contact the moon colony directly instead they would radio Earth which would then relay the signal to the base and vice versa.

When the expedition reached the crater, (which was almost two miles from rim to rim), they first camped out on the outside. They had carried a pressurized igloo with them and inflated it at that spot. They then unpacked their equipment and set up a wide range of instrumentation to monitor their habitat among many other things. They then eventually traveled down to the crater bed to get as deep a geological sample as possible. The lower altitude would help but they were working with a relatively small drill, due to the fact that it had to be portable. This is a sensible way in which to conduct a surface mission in a lunar environment. All the equipment is designed to be modular, and to be able to be packed up to a fraction of its deployed size. This ingrained versatility allows the exploratory crew to travel conveniently with their supplies, equipment, as well as their artificial habitat. Setup of one of the igloos that the lunar explores carry with them would be pretty much identical to that of one of the igloos comprising the more permanent main base. Since the astronauts would have had practical experience from the initial ground fall it would be even easier to set up the modular igloo.

The portable habitat would be required to be extremely tough and resistant to all sorts of severe conditions. Tiny leaks due thermal expansions could easily destroy the functionality of such a delicate pressure system. In a vacuum such as the moon’s environment a small leak could quickly kill the habitat system of a single igloo. Fortunately, for that reason the bases each contain many igloos with their own independent habitat system. Also a leaking igloo can be patched rather easily. It is also quite evident that in order to pressurize and deploy an igloo a source of pressurized air (most likely tank-valve system) would be necessary. A small lunar expedition wishing to set up their igloo would have to carry such a compressed air tank with them. Similarly the main mission would have to possess such a compressed and accessible air supply carried with them from Earth and mandatory for initial setup.

For the most part as far as habitat is concerned the single surface missions are much like microcosms of the larger colonization mission. Due to modularization the igloo, instrumentation, and equipment set up at the temporary site function as a smaller moon base. All the supplies needed are also carried from base, which limits the duration of individual missions. The good technical concept presented in this work give us a sensible outline for the practical control of the habitat during a semi-permanent moon base colonization attempt.

The next story in this selection was titled "Watch This Space". The plot of this story involves the launching of a rocket on the moon whose purpose was to study the small amount of atmosphere that the moon possessed. Upon reaching a certain altitude the rocket released a large quantity of sodium that created a bright glow in the moon sky, this facilitated in the use of certain scientific instrumentation enabling rare opportunities of scientific investigation to those on the lunar surface. This story was interesting however it provided little specific information about the colony's habitat.

The last story in the "Venture to the Moon" series was "Question of Residency". It is set at the time near the end of the lunar expedition. After five months everything the mission objectives set out to do had been accomplished to reasonable satisfaction. The narrator claims that the knowledge that they had gathered would keep the scientists of Earth busy for generations. The astronauts on the base were also very tired and although none of the anticipated psychological problems had arisen, the crews were salty and eager to return. The time had come to go home. The only problem was that there were instruments strewn all over the moon's landscape. Many of these were still recording and required manual radioing of information to Earth. Although predominately done some of the scientific experiments and studies had to be finished up, but this would only require one crew. There was no need for the other two crews to stay behind. The plot concerns deciding which group would sacrifice the glory of the initial return to Earth, and stayed behind to do what needed to be done.

It was stated plainly that the moon bases had little to worry about in regard to their main habitat concerns. It was noted that food, water and air could be continuously provided by automatic freight rockets for however long that they wished to stay on the moon. It seems that the functionality of their basic equipment and mainly the intactness of pressure systems would be the limiting factor on the length of a lunar visit. All the more reason for providing very durable equipment. In addition to straight technical

detail the common imagery of the setting gives much detail to the fictional habitat. “Skipper, he said, balancing himself on the all-to-collapsible table I used as my working desk inside the igloo,”[pg. 91].

This detailed series describing the first colonization of the moon ends with a realistic description and explanation of the return trip to Earth. Everything they needed to return with was packed up, final instrument readings were taken and specimens and samples were carefully loaded aboard the ship. The story narrator describes blasting off from the lunar surface. “Below us the rugged lunar landscape, which we had grown to know so well, fell swiftly away; within seconds we could see no sign at all of the buildings and instruments we had so laboriously erected and which future explorers would one day use.”[pg. 93]. The rocket ship is docked at the space station when it reaches Earth and the astronauts are ferried down to Earth for the completion of their journey. The information about the moon base in “Venture to the Moon” is complete and the author, writing from an informed point of view, has taken great care not to create technical contradictions. These facts make the creativity utilized in the story very useful, since a realistic science fiction setting combined with good ideas and imagery gives some very plausible notions for a real moon base.

The Other Side of the Sky was a great source for description of artificial habitats. Although it was a collection of short stories and only a little bit of setting could be presented at a time, the stories were all closely intertwined and details were always consistent between stories. All the functional information that Clarke provides adds up to give a complete vision of the development and implementation of artificial habitats built for man’s survival in space and the moon. A technical time scale is also provided giving the space development of the near future in a chronological format. Although his time scale is inaccurate from the standpoint of when the events would actually happen, their logic and order are credible. Realistic as well are the core ideas centering around the function of space habitats, for this reason the two series of short stories “The Other Side of the Sky” and “Venture to the Moon” were invaluable to this survey.

The next source in this survey was a novel by Arthur C. Clarke titled The Sands of Mars (1952). This stories plot concerned a middle aged science/science fiction, writer/journalist, named Gibson, who travels to Mars to visit the Martian colonies in order to gain a first hand account and report about it. This novel gives a complete image of the colonies, their habitat, their way of life, and the scope of their operations. Much has been learned about Mars since this story was written; however the environmental

conditions of Mars that Clarke describes were fundamentally accurate and sufficient consideration for the development of human habitat had to be made. The main idea was to give an image of the Martian frontier by Gibson's touring of the human establishments, which caused his subsequent juxtaposition.

The major difference between Clarke's Mars and the one we know is the consideration of pressure. The atmosphere is described as extremely thin, (too thin to breathe), and lacking Oxygen as well, breathing masks with air tanks had to always be used on the surface. Although not breathable the atmosphere was enough to keep the human body from near instantaneous failure the way it would in the vacuum of space or on the surface of the moon. The lack of pressure still made it uncomfortable to be outside, and special conditioning as well and drugs had to be used to help compensate. "Gibson felt his exposed skin tingle uncomfortably; the atmosphere around him was now thinner than the peak of Mount Everest... and all the resources of modern medical science were needed, to enable him to step out on the surface of Mars with no more protection of a simple oxygen mask." [pg. 84].

Although somewhat established, the level of Martian colonization was still in its early frontier state. Gibson's initial landing was at Port Lowell, the biggest city of Mars, with no more than two thousand people. When visitors from Earth first view the largest Martian city they are usually not impressed at all by its size, but after spending some time in the Martian countryside one was eager to get back to the "big city". There were also several smaller cities, all with the same basic setup, as well as many different labs and observatory buildings across the surface of Mars. It is of note that the primary purpose of the Martian colonies was of scientific investigation. The colonies did not really produce anything else that was of value in terms of interplanetary trade. Life on Mars was difficult; it took a lot of skill and constant hard work to survive. Martian life was also unpleasantly void of luxuries, not to mention scenery. Despite the dedication of the colonist and the sustained struggle for self-sufficiency, the colonies were still dependent upon Earth, and as viewed from Earth they were a great money sink, which meant the Spartan conditions would persist.

Besides describing the Martian colonies, a good deal of the book's setting occurred in the spaceship that brought Gibson to the red planet, therefore some discussion of the ship's artificial habitat may be useful. The ship was shaped like a dumbbell, all the engines and equipment were in the back section with a bridge connecting to the front section that contained all the living quarters. The entire ship was filled with

normal air pressurized to atmosphere level, although there was no gravity. Clarke assumes inaccurately however that the hull of the ship would be able to sustain many small leaks, due to holes made by tiny meteorites, as long as the pressure drop they caused didn't exceed a critical level.

All the food and water needed for the crews survival was carried with them and rationed out during the hundred-day journey. On the journey it is evident that they dumped their garbage into space so it is likely all waste would have been disposed of in the same fashion. This is explained when Gibson takes a short space walk outside the ship and to his astonishment finds a piece of paper. The captain explains that it isn't so amazing since they had been dumping garbage constantly and had had no change in acceleration in a long time. The garbage stays next to the ship not moving in a relative sense but when they slow down it shoots out of the solar system.

Another interesting feature was the design of the space suits used for traveling in space. They function as any sufficient space suit should, by providing breathable air and atmospheric pressure within a protective self-contained environment significantly insulated and heated against the cold of space. The suit had arms and a clear dome at the top to look through, however it had no legs a person just sat in it, and movement could be achieved by use of small jets.

The journey itself was described rather technically. Starting with the main character being launched in a rocket up to a space station orbiting Earth. The space station was designed very similar to those in Clarke's later works. It was a ring station, using its spin to create an artificial gravity. However the entire station and its habitat system were connected so not just the outer ring was used, but there were different gravity levels in different parts of the station. The center of the station itself had a special room with no gravity due to the lack of spin there. Gibson then left the station on the space ship Ares for the main portion of his voyage. It is of note that on its way to Mars the Ares passed close to the moon and some description was given of the moon colonies setup there. "... minute sparks of light were burning like fireflies in the dusk. They had not been there fifty years ago; they were the lights of the first lunar cities, telling the stars that life had come at last to the moon after a billion years of waiting." [pg. 21].

At the end of its leg of the journey the Ares docked on the surface of Deimos, one of Mars's moons. The docking area was described as a wide-open space among the rocks with a large metal cradle with cables strung everywhere. Setting the ship down was done gently and easily since Deimos has less

than a thousandth of the Earth's gravity. Gibson then disembarked from the Ares and was ferried down to Mars on a rocket ship.

The colonies of Mars in the most basic sense were giant domes, which were all designed and erected in a similar fashion. The city of Port Lowell consisted of six domes, and a seventh larger dome was being finished at the time of the story. Originally before the building of Dome 1, according to the mayor, the city was just a group of pressurized huts. Observatories, labs, and other buildings designed to house personnel on the surface of Mars in less populated areas operate similarly, as self contained controlled environment units. The dome's purpose is to cover a very wide area used for human habitat, and completely enclose it in a giant bubble of breathable, pressurized air. The domes are hundreds of feet high and the largest one is half a kilometer in diameter. Under the domes exist all the buildings of the colony, scientific, administrative and commercial. Since there is a contained environment, people can walk around outside the colony buildings and carry out their business under the domes without any habitat aids needed.

The colossal half spheres are all connected to one another by way of metal tubes with great doors that close automatically if air escapes from any of the domes. "On Mars, we don't believe in putting all our eggs in one basket!"[pg. 128]. The outside is also accessible from within a dome by way of similar tubes. These surface tubes are excessively protected from atmosphere loss. Each tube contains four doors that must be walked through in order to get in or out of the giant structure. A safety mechanism makes it so that in order to open one door the other three must be closed. Each dome has its own special buildings, which are necessary for the colony's survival, and all the domes connected act as a single interdependent colony/habitat system. Most colonists do not venture outside regularly, instead they remain and function within the giant artificial habit created by the domes.

Some of the special buildings within Port Lowell were almost as high as the dome roof, but most residential houses had a uniform design. They were two stories high, had a completely metal exterior, with rounded corners and rather small windows, each housing two families. Each house has a porch that would look strange to an outsider until they realized that it was designed to act as an airlock in an emergency. Drills are conducted once a month in the event of a rupture of the flexible plastic material comprising the dome, and the subsequent blowout of the gas and pressure comprising the main habitat system. In the event of an emergency each house can seal itself off and become its own environmental unit with enough air

for several hours. When the signal of three consecutive ground explosions goes off everyone must rush for cover. Since every building functions as a shelter it should be fairly easy to get inside in time. If you are inside and see someone on the street that can't make it, you grab your air mask and go help them.

The description of the inflation of Dome 7 was very useful in helping to complete the image of the colonies physical structure. Dome 7 was the largest dome yet, about 500 meters in diameter and proportionally high, it could house a thousand people. The entire circular space was surrounded by a wall of glass bricks twice as high as a man. It was through this transparent wall that all the tubes leading to the other domes and the outside were connected. Fastened to the top of the wall and covering over the whole area was a thin sheet of cellophane-like plastic that was lying limp on the ground in huge folds like a giant deflated balloon. This dome material was described as very strong, flexible, and almost perfectly transparent. Air was pumped as rapidly as possible into the structure. A giant bubble of air a hundred meters wide formed near the middle; this kept moving around and growing, after about a day of pumping the Dome began to take shape. Up until this point there was still hardly any pressure under the plastic so the workers had to wear breathing masks the whole time. When the dome had taken shape the workers could remove their masks even though the atmosphere was not at full pressure. The next few days were spent testing the structure and looking for leaks. Once this was done, they finished pumping in air until they reached the maximum pressure.

Of primary concern on Mars seems to be the production of oxygen to sustain their artificial habitat. The carbon dioxide is removed from the air by plants and air purifiers but the colony has a large demand for the production of oxygen. Fortunately the Martian sand (or more accurately metallurgical powder) proved extremely useful. Not only could one extract almost every type of metal element needed but also the metal oxides provided an ample supply of O₂. The building where the production of this atmospheric gas takes place is located in Dome 1 and is called Main Air. "This, truly was the heart of Port Lowell; if it ever ceased to function, the city and all those it held would soon be dead." [pg. 98]. In addition to producing oxygen, Main Air also stores the oxygen and is responsible for keeping the pressure in the city at its correct value. A conveyor belt heaped with the crimson Martian sand was constantly flowing into Main Air. This metal sand powder was cracked in an electric furnace and the oxygen drawn off. The

oxygen was purified and then the gas was compressed and placed in tanks. After the oxygen removal process was over, remaining materials were sent on for more complicated operations.

Another basic habitat concern for any colony's fundamental needs is water. Water is needed for drinking, bathing, hydroponic farming, and countless other necessary processes. It is mentioned that Main Air also produces water using some of the oxygen from the previous process. I suspect they may extract the hydrogen from the Martian soil as well, and if not they must have had another convenient and abundant source. It was stated that Main Air produced almost enough water for the needs of the settlement, but there were other sources. It was also stated that they were going to put a small lake in Dome 7 and it would be the only one on Mars since free water would not last long in the open. So other sources must be either underground or ice pockets or both, it is mentioned that the poles are frozen. The chief of the city told Gibson that in the beginning the first colonial expedition had to carry *everything* with them but now they can provide all the basic necessities of life from their own resources. So although water was definitely transported from Earth in the beginning this would no longer be a source at this point. Particularly since it seems like the colony's acquisition of water was fairly easy.

Food is one of the basic necessities of life that would be of primary concern to the colonists. One of the structures housed in Dome 3 was a giant food production facility nicknamed "the farm". The farm grew a variety of plants for human food consumption. The vegetation was all produced using hydroponic growing methods. Inside this facility was humid and it obviously had a large demand for water. Clarke also describes the use of grow lights but describes them as batteries of fluorescent tubes that allow growth to continue day and night. While they could grow many types of foods they could not produce meat, since they didn't have the room to keep animals. However the space pioneers found a way to produce meat synthetically by growing extensive tissue cultures in great vats of nutrient fluid. This was effective but most Martian colonist agreed that it wasn't the real thing. "They go together like fish and chips, or ham and eggs. Don't! pleaded the other with such a depth of feeling that Gibson apologized at once for his lack of tact. He had forgotten that no one on Mars had tasted such things for years." [pg. 209].

The final primary concern for sustainment of an artificial habitat on any kind of space colony is an energy source. Everything technical that was described on Mars, from the surface airplane systems, to the electric furnaces, to the grow lights, to internal mechanisms, was run electrically. Much mention was also

made of the extremely cold conditions on Mars. Even though Port Lowell was located near the equator, during much of the year (as well as at night) it got quite cold. The heating of the city, (I assume this is electrical), given the area under the dome, must require enormous quantities of energy. When going outside during colder times suits supplement the breathing apparatus these suits have special heating units powered by electrical batteries. Clarke gives no mention of the basic source of this energy. It is likely that the Mars settlers may have a powerful electrical generator installed, from which they are able to draw the tremendous amount of power necessary.

The image of the first stage of Martian colonization that Clarke gives is not a glamorous one but it is a realistic one. This work was particularly useful since ideas he gives are full of technical details and explanation. As a science fiction writer Clarke generally displays more technical knowledge than most of his contemporaries. He also provides many unique solutions to common basic problems of artificial habitat that though somewhat eccentric still appear very plausible from a strictly technical point of view. For these reasons The Sands of Mars, though slightly dated, was a great source for this survey.

The next source that I investigated was The Martian Chronicles (1946) by Ray Bradbury. This describes encounters of people from Earth when they traveled to Mars by way of rocket ship. Since it was a relatively early work, the description of the environmental conditions on Mars is completely inaccurate. Bradbury assumes that the air on Mars is breathable and that there is a normal atmospheric pressure level. He also assumes that there are other intelligent man-like beings that already live there. The habitat for the most part is the same as Earth. "It was so cold when they first came from the rocket into the night that Spender began to gather the dry Martian wood and build a small fire. He didn't say anything about a celebration; he merely gathered the wood, set it to fire, and watched it burn." [pg. 67]. Indeed once you arrive at Mars setting up in reality would be much more complicated.

There were some interesting living structures described in this work; however nothing related directly to any area of artificial habitat structure that pertained to the description of this survey. For that reason I shall not provide information on any habitat descriptions. I included this source in the survey to complement the other works in demonstrating the rapid change in the 40s and 50s as to our knowledge, approach and view of what would be necessary for interplanetary colonization.

Another source that mentions human expeditions to Mars but has an inaccurate image of the environmental conditions that man must overcome was "A Martian Odyssey", (1934), by Stanley G Weinbaum. In this tale the habitat that you would find on Mars would be very similar to that of an area of Earth like Egypt, (complete with pyramids). Human survival on the surface of Mars was not contingent on any sort of extra concern regarding the creation of an artificial habitat system. This story was included to show that prior to the middle of the twentieth century increased knowledge of the existence of the planets along with the event of human flight and advancing rocket technology, had sparked the interest and imagination of a large portion of the public. Although for the most part from a technical standpoint these authors were writing little more than fairy tales, the works they created represented the desire behind the goal of man's interplanetary colonization.

A much more technically sound source for the fictional creation of artificial human habitat necessary for man's survival in a realistic space environment was "The Martian Way" by Isaac Asimov. The *Martian way* that the title refers to is rendered deep meaning in the story. It is the way in which the people of Mars live. This way is a product of the fact that they have adapted to a hostile alien environment. Asimov establishes the fact that humans may not survive on the surface of Mars without a space suit. Much mention is given to artificial habitat both on Mars and on the space ships where some colonists spend so much of their time. These particular Martians are called scavengers and they embody the Martian way. Life on the Martian frontier was described as a difficult struggle, and extensive consideration was given to acquisition of resources.

The human base on Mars houses, protects, and provides a comfortable habitat in with the colonists function. At the time of the story fifty thousand people live on the planet's surface. The entire colony is located as one base, and the structural setup of the colony is described from the point of view of the inside. It is apparent that there are city blocks, and buildings of all varieties that exist under some sort of larger structure that protects it from the hostile outside environment. "Ted Long found the breadth and height of the city's main thoroughfare exhilarating... The roof of the avenue was painted a luminous light blue, perhaps as an old-fashion imitation of Earth's sky. Ted wasn't sure. The walls were lit with the store window that pierced it." [pg. 98]. Residential areas are also accessible in this manner.

It is mentioned that there is a constant blasting of channels in the solid rock in order to expand the size of the city. This means that the roof of the major structure encasing the artificial human habitat within, although above the surface, must be built over channels that act to increase the effective volume of the habitat area without requiring too many additional materials. I assume that some would still have to be used to maintain no leaks in the pressurized system. Some areas such as administrative buildings are sectioned under their own structure. "Digby rose and stepped to the window. He looked out upon the low domes of other buildings; red, rocky, completely desolate plain in between..."[pg. 110].

The size and scale of the operations on Mars was mentioned as well at the earlier development of the base from its feeble beginnings. The leader of the government on Mars was Martian Commissioner Hamish Sankov; he was a hardy old man who had come to Mars nearly a lifetime ago. Back then there was no such thing as a native Martian, now there were a couple hundred babies whose grandfathers had been born there. Sankov's own memories provide a concise but informative image of the initial development of the base. "When he had come as a boy in his teens, Mars had been scarcely more than a huddle of grounded spaceships connected by sealed underground tunnels. Through the years, he had seen buildings grow and burrow widely, thrusting blunt snouts up into the thin, unbreathable atmosphere. He had seen huge storage depots spring up into which spaceships and their loads could be swallowed whole. He had seen the mines grow from nothing to a huge gouge in the Martian crust, while the population of Mars grew from fifty to fifty thousand."[pg. 107].

Primary concern to the plot of the story was the acquisition of resources. It seems that the Mars colony is still reliant on Earth for all of its basic needs. Packaged air, food, and water must be shipped from Earth. The city has a ventilation system which purifies the air, I infer that there is a method by which they replenish the air with oxygen, but it costs money. The food that they eat is referred to as rations, protomeal, or the condensed crud they ship us from Earth. "Listen to him, said Dora scornfully. What do you know about fresh food? You've never eaten any. I've eaten more than you think. Do you remember those carrots I picked up once?"[pg. 103]. At the time of the story one of the things the colony is trying to accomplish is the setting up of hydroponics tanks, after which the colony would be able to produce its own fresh foods and be less reliant upon Earth. The main problem preventing the utilization of the hydroponics system is the scarcity of water.

Energy in this future costs money. "Considering that we're not even going to make expenses this trip, the way it looks, any power drain at all is outside reason...but this is space, not a heated office at the iron mines. Rioz swung the thermostat control down to minimum..."[pg. 88]. However, new convenient and abundant sources have been found. These new energy sources sound mysterious; some allusions were given to the use of plankton farms for energy, but the proton micropile was basic to the story. The proton micropile was described as a cheap power source that could heat up any liquid until it is a gas under tremendous pressure. Since rocket propulsion is caused by the displacement of mass in a direction opposite the rocket's movement, theoretically almost any substance could be used as rocket fuel as long as it could be displaced properly. The proton micropile could "heat up *any* liquid until it is a gas under *tremendous pressure*, therefore they used the largest most convenient source of liquid that could be found. The rocket ships that are used for human travel in space are usually each powered by about a million tons of water.

By far the largest concern on Mars is the water supply, a need that makes them completely subject to Earth. It is mentioned that most houses have a water tap and that an extensive system exists for piping in water from the polar caps. This however supplies an extremely small part of the total amount of water needed. Water as mentioned is not only needed for drinking, bathing, hydroponics, and industry use, but by the millions of tons to power space flight. Although there is no real danger of even coming close to depleting Earth's water supply of one and half-quintillion tons of water, the water drain required to support the Martian colony is putting a large strain on relations with Earth. One Earth politician in particular, named Hilder is trying to shut down the space colony altogether by manipulating the numbers and swaying popular public opinion by way of propaganda. He is convincing people that sending so much water to Mars will eventually deplete the Earth of this valuable resource.

The lack of water even effects the lifestyle of the people, for example if you were to go visit someone you would bring your own water. "...viewed the newcomer with a synthetic smile, and said, Hello Mario. Coffee for you, too? Yeah, he said, reaching automatically for his canteen. Just use some more of my water, Dora, said Long quickly. He'll owe it to me."[pg. 101] As many ways as possible were used to conserve water. "...Long caught a glimpse of dishes sitting in Secoterg, the waterless cleaner that soaks up and absorbs grease and dirt in a twinkling. One ounce of water will rinse eight square feet of dish surface clean as clean. Buy Secoterg. Secoterg just cleans it right, makes your dishes shiny bright, does

away with water waste...”[pg. 101]. In the middle of the story Earth has set a quota on the amount of water to be used per space trip, this is just the beginning of the end and every body knows that they have to do something about it. A smart, concerned, and crafty scavenger named Ted Long, takes matters into his own hands and with a leap of faith the colonist set about a plan by which to obtain their own water.

I mentioned before a certain profession of Martians, called “scavengers” that spent most of their time in space. They earned their living by material acquisition, by patrolling the space between Earth and Mars, tracking and capturing shells. Every time a rocket ship leaves Mars or particularly Earth it travels in stages and once the fuel in one rocket is discharged the cartridge is released. All sorts of “shells” of various sizes float around between the two planets. The scavenger tracks and captures these shells for the valuable metal alloys that can be salvaged from them. Scavengers usually work in groups of two per ship and each ship has its own territory or zone in which they hunt shells. Once a shell is spotted on the radar it is chased down and magnetic cables are used to bring it to bay and rope it in. After the shell is secure someone goes out in a space suit and laser burns the ship’s serial number on it. It is then pushed off on a path that in a day or so sends it to the receiving station on Mars’s moon of Deimos, where they get credit for it. The space colony needs raw materials so the scavengers are an integral part of the Mars economy. This scavenging of resources gives Hilder, whom terms them wasters, another weapon in his propaganda war against Martians.

It is said that the Martian way is assimilation to survival in space. Earthmen can’t handle being in space for prolonged durations. Long contends that the Martian scavengers can better handle being in the confines of a ship so much longer because they are used to it. Martians have been in a ship all their lives since the colony is just one big ship with fifty thousand people. It is true that the habitat accommodations on the ships are almost identical to those in the colony. Also, the highly advanced radar navigation and tracking system of the space ships augment the finely tuned abilities of these spacers. Long needed to utilize all these things if his plan was to work.

Most importantly he knew the strengths of the scavengers. “All right, said Long, suppose you tell me how you know we can only stay in space six months. Its common knowledge damn it. Because it’s in the handbook of space flight. It’s data compiled by Earth scientists from experience with Earth pilots and spacemen. You’re still thinking still thinking grounder style. You won’t think the Martian way. A

Martian may be a Martian but he's still a man. But how can you be so blind? How many times have you fellows been out for over six months with out a break...because we are not on a flight we can put back any time we want to. But you *don't* want to. That's my point...We can do it. Don't you see we can? Earthmen can't. They've got a real world. They've got open sky and fresh food, all the air and water they want. Getting into a ship is a terrible change for them. More than six months is too much for them for that very reason.”[pg. 105].

With the permission of Sankov in their most desperate hour Long took twenty five ships and fifty of the best scavengers they had and against all odds set out on the, thought to be impossible, seven hundred million mile journey towards Saturn. They all knew quite well that if what they expected wasn't waiting for them they would have neither the fuel nor the food to return. No one had yet ventured past the asteroid belt but spectrograph imaging of Saturn told that there was ice in the outer rings. Although there was ice elsewhere in the solar system they had to venture to Saturn because that was the only place with giant floating chunks of pure ice. They managed to make it to the outer rings of Saturn. A giant planetoid of about a cubic mile of pure ice was found they then set to work.

Some informative description was given of the functions of the space suits they used to work in space. “Your suit was warm, it renewed its air automatically, it had food and drink in special containers from which it could be sucked with a minimal motion of the head, it took care of wastes appropriately.” [pg.114]. Also, precipitation is taken care of. “The desiccators within the suit were sucking at maximum and of course, recovering the water and restoring ion-exchanged liquid, containing a careful portion of salt, into the appropriate receptacle.”[pg. 117].

The engines were taken out of the ships and encased in the surface of the ice asteroid. Then built in heat projectors steamed the propulsive fluid directly into the driving cells of the engines. The ships were encased to the front of the giant rock of ice in flight formation and all the control cables necessary to operate the devices were iced in and led back to the engines. Thus the entire fleet became one tremendous fused ship. This way they could draw as much water as possible from the body of the planetoid and create a full out constant burn all the way home. Accelerating to a million miles per hour they traveled home in 1/9th the time it took to get there. They arrived just in time to land in front of Sankov, the congressman from Earth helping to try eliminate the Martian colony, and the entire press crew from Earth. Much to the

amusement of the press Sankov offers to sell Earth water. The landing of that cubic mile of ice meant the end of the colony's dependence on Earth for water. It also brought about the end of John Hilder's political career. This story was both very entertaining and informative to this study, the *Martian Way* itself can be described as man's adaptation to his own artificially created habitat, survival in the hostile reaches of space.

Discussion of Results:

The results obtained during this project provided considerable information with implications for the development of artificial human habitats in space. Extensively examined were the works of three different authors covering four different fictional accounts of technically accurate space bases. These consisted of two Martian colonies and two Moon colonies. All the colonies had the same core concerns to deal with, based on the fact that they had to support human life in a very hostile extra-terrestrial environment. Not only did each author hold a different relative value to these basic habitat factors, but also they each took a different approach to their solution. When examining each case it may be convenient for purposes of this study to separate and compare each of the core functions of the base's habitat system. Specifically these individual items shall be broken down into, structure (includes pressure concerns), air, food, water, energy, and size (not a function but worth consideration). They shall be compared to one another and judged on the criteria of realism, elegance, and inventiveness.

The size and scale of the space base is always an important factor when considering solutions to specific problems. The size may also infer a definite time scale over which the colony's development has occurred. The smallest colony was Clarke's, "Venture to the Moon" it only housed a few dozen people for a five-month duration. The intended time of this expedition was in conjunction with man's first landing on the moon, and presumably around a decade into Clarke's future. In Clarke's The Sands of Mars, the largest base on the surface held three thousand. The writing of this story occurred in the late 40's the time period when it is supposed to occur is in the late 20th century in the 80's or 90's. In "The Martian Way", the plot of the story occurs presumably some time around a century in the future and the colony described holds fifty thousand people. Heinlein sets the stage of The Moon is a Harsh Mistress 110 years in to his future writing in 1965, and his moon base holds 3 million spread out over 6 cities.

The structural design of the physical base itself serves three main purposes, it protects and insulates the people inside from the deadly hazards of the outer environment, it provides housing and storage for the residence and all the necessary facilities, and it maintains a constant and adequate atmospheric pressure. One of the more elaborately described structures was Heinlein's moon base. The fact that it was all underground was technically practical. Particularly creative was his idea of the use of rock sealer to maintain a leak proof environment. Heinlein's structure seems to be a long endless network of tunnels. Although the structure itself is technically sound, I don't think Heinlein gives proper consideration to the actual economics and logistical specifics. Such a network would have required an tremendous amount of maintenance work to stay functional. It is also assumed that the average person would have the tools and skills necessary to drill out, build, seal and pressurize their own space habitat. Heinlein's structure, while theoretically possible, is simply too complicated, given the specialized complexity of mining operations.

Much less complicated was the principal of inflatable igloos, presented in "Venture to the Moon". This principal has much to recommend it in terms of technical feasibility, but of course, that is not a permanent structure either. Although the actual inflation process would require much more consideration, it could easily work. This is presuming that there was an adequate air lock system and a sufficiently tough and flexible material could be found for the structure. The convenience of this type of system is apparent; many of the modular igloos can be connected together to form one big structure, which can be changed or disassembled as needed. Since they can be packed to a fraction of their size, a single unit can also be transported and deployed far from the main base to serve as a secondary habitat system for exploratory missions. In my opinion this is both the most inventive and realistic idea for an initial space colony structure.

Clarke's image of the structure of his Martian colony in The Sands of Mars was quite interesting and ambitious. His idea of a giant inflatable dome makes it easy to pressurize a considerable volume of space and to protect and house sizeable numbers of people. He also covers the event of a dome blowout by making the individual structures under the dome capable of functioning as independent habitats. Also described were complicated systems of airlocks. Although eccentric, this dome idea is simple and makes

sense from a technical standpoint. This is definitely the most elegant image of a base portrayed in the fiction, I reviewed.

Asimov's colony in "The Martian Way" was described with a vague realism. Although not specific, it is known that the base is like a small city with a larger protective structure overhead. His use of channels to supplement structure is particularly inventive. The people in the story also make constant allusions to the fact that the Martian colony itself is practically the same as living in the small artificially produced environment of a space ship. This is the most realistic structural account but the idea that this modest pragmatism would persist into the distant future, is disconcerting. It reflects his pessimism about space travel ever being able to pay for itself in strictly economic terms.

The importance of air was always a factor in these stories. The most elegant method of air recycle was portrayed in The Moon is a Harsh Mistress. The enormous mass of plant life in the underground colony absorbs carbon dioxide as well as releasing oxygen. It is simply a microcosm of the gas recycling system of the Earth. In both Asimov's "The Martian Way" and Clarke's "Venture to the Moon" the air is packaged and shipped from Earth. While this method is by far the most realistic scenario, particularly for the near future, it would not support a large scale colonization movement. In The Sands of Mars the oxygen is extracted from the metal oxides in the sand, while the carbon dioxide is scrubbed out. This was the most inventive process examined.

While practically all mechanical systems in these stories functioned on electrical power, the main energy source utilized was different for each. In Asimov's fictional future new and strange methods of energy production are mentioned. These simple and useful energy sources seem very elegant. However while these were very interesting, (and explained how water can be turned into rocket fuel), they would not be technically feasible with existing technology. In "Venture to the Moon" the colony's limited energy was shipped from Earth. This was a practical method given the duration of their stay and would be most realistic for a near future scenario. Clarke did not give a specific energy source that powered all the electrical systems of his Martian colony in The Sands of Mars. One thing could be sure though; given the tremendous volume of space under his domes combined with the frigid Martian environment, a tremendous amount of energy would be required for heat alone. The use of fusion power plants, supplemented by solar

panels to supply all the power necessary as demonstrated in The Moon is a Harsh Mistress is the most inventive approach.

Another core concern for the survival of humans in an artificial environment is food. It is interesting to note that all in all four cases the use of hydroponic growing systems is mentioned. Growing food hydroponically is practical, realistic, and definitely a good idea to consider when designing a space habitat. I had already strongly considered the idea of hydroponics even before this literature review. The most elegant scheme is represented in The Moon is a Harsh Mistress. Massive amounts of hydroponic farming, as well as the raising of livestock for meat has turned the moon into an agricultural export center. In Asimov's story "The Martian Way" the colony is still shipping condensed food from Earth as they are trying to install a hydroponic system. In "Venture to the Moon" they ship most of their food from Earth but have a small hydroponics farm as well. This once again is the most realistic scenario given our present state of space exploration. The colonists in The Sands of Mars also utilize hydroponics in order to produce edible vegetation but unlike in Heinlein's book they don't have the room to raise animals. Cultivating extensive tissue culture in vats of nutrients creates edible protein mass. This synthetic meat production described by Clarke proves to be the most inventive method of food acquisition.

The last basic concern addressed the way by which the colonies supply water. Water is an essential element for many of a base's functions. Among other things water is needed for drinking, cooking, bathing, and hydroponics. The Martian colony in The Sands of Mars has the least amount of difficulty in securing an adequate water supply. Using the most inventive method described, the components to create water are extracted from the various compounds in the soil. The mining of underground ice pockets on the surface of the moon is how the lunar colonist in The Moon is a Harsh Mistress obtains the water necessary to run their system, which alone is part of a massive trade exchange system. The temporary lunar base in "Venture to the Moon" once again gives us the most realistic solution to this problem at least in the short term. Water is packaged and shipped from Earth. In Asimov's version of a Martian base water is also packaged and shipped from Earth. Even though in "The Martian Way" it is mentioned that an extensive system of piping brings in water from Mars's polar ice caps, additional water still has to be transported from Earth. In the end of the story a method of supplying water while not being dependent on Earth was discovered. Taking a giant planetoid of solid ice from the outer rings of Saturn

and transporting it to Mars was by far the most elegant method of water acquisition for a self-sufficient “scavenging” colony.

Conclusion:

Throughout this comparative study I was able to gather enough information to consider many different ideas pertaining to the way in which man will learn to survive in extra-terrestrial environments. I have focused on the core concerns, which include the actual physical structure of the habitat, the air and pressure, renewal/recycling of the air, (as well as other materials), water, food and energy. Despite many remarkable similarities all of the fictional sources solve these problems in their own unique way. It is interesting to note that different sources often weight the basic needs differently. For example in Clarke’s Mars obtaining water was a trivial concern, while in Asimov’s version of a Martian colony obtaining water was the make or break factor. Reasons for such may be embedded in technical rational, hence the different opinions of these science fiction authors may reflect those of the scientific community as well, caused by a different interpretations of the actual data on Lunar and Mars conditions. Or perhaps, at least in a small part, they may be motivated by the overriding concern of developing an interesting and captivating plot.

It is impossible to ascertain for sure whether or not the space programs of the twentieth century were greatly influenced by the writing of science fiction authors. It is a fact that these works were widely read by all sections of the American public, and hence the information in them could be considered common knowledge. Almost certainly designers of the space programs had been exposed to the works of these authors at some point in their lives. As far as solutions to specific technical problems are concerned an engineering handbook would be a lot more useful in securing an answer. What this literature does is give us a general basis of ideas from with which to work. These ideas can give us a critical edge and may have wide reaching implications for the technological designers of the future. A future project team may actually want to interview NASA’s designers assigned to the Moon and Mars base projects and see how familiar they are with these works, and which authors they admire the most.

Many of these ideas seem like common sense today, but they were once original and today they merge together to form a more complete image of an establishment which could support human life in hostile space environments. Unlike engineers, who may get caught up on a single detail that may hold up all progress, the science fiction author can easily cover over a logical inconsistency or problem by posting

an invention that does something (with no explanation), and focus their attention and energy on the development of the overall concept of the space habitat. None of these works present a complete solution within themselves, but should be used for early on inspiration and initial ideas in the design process of developing an actual space habitat. First, one should consider different scenarios for space colonies presented by this kind of fiction, adding or dropping different elements of each as is practical, and then apply a fine tuned scientific focus which should be the best approach for solving the deeper more specific technical problems that any colony must address.

I think that I benefit from having tackled the problem logically on my own, run into problems, appreciated to the challenge and complexity of the task—and then read this classic space oriented science fiction. I was thus in a better position to both appreciate and critique the seminar work of these three great authors, the elite of the “Golden Age of Science Fiction” (1940-1970), as the space age in the United States was born.

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