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A Personal History of the Human Exploration Initiative with Commentary on the Pivotal Role for Life Support Research

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In 1961, President Kennedy announced an initiative to land a man (you would now say a human) on the Moon and return him safely to Earth. It was a political statement, and everybody knows that. However, it represented a straightforward, simple mandate to an engineering organization such as NASA. Engineers really like, culturally, to receive sets of requirements and turn out a product designed to satisfy those requirements. Apollo, in some sense, was an ideal example. The task to accomplish was specific: land a human being on the Moon, and get him or her back safely back to Earth. Within that context, they could build transportation systems and develop the technology necessary to accomplish that.

It was a very happy time. NASA had a lot of money and a lot of support from the nation. The task was a very important thing to do, so it was pleasant duty and a lot of fun in a new organization. As the Apollo program actually started to come to fruition in the late 1960's, questions arose as to what to do next for an encore and how to continue this line of discovery. There were things called Apollo applications, aimed at extending stay times on the Moon and so on.

In fact, President Nixon in 1968 asked Vice-President Agnew to head up a Space Task Group to draw up a set of plans beyond Apollo. That report is really interesting to read because it talks about space stations, lunar bases, and bases on Mars. If you look at the time-lines, funding curves and schedules in that report, we should have been on Mars about 5 to 8 years ago; by now we should have a permanent base up there, along with the permanent base on the Moon.

Well, that didn't happen. What really happened, of course, was that when this plan was taken to the Office of Management and Budget by NASA's Administrator, Tom Paine, he was basically told, "No way — we've got budget cuts to deal with."

I have read the history books; I wasn't there. The history books and the analyses say that Dr. Paine just was not aware of the level of political difficulty he was in at the time he presented his plan. He went directly to the President to argue that this ought to be done, ought to be accomplished, and he lost. And when you go directly to the President and lose, you can really lose big.

President Nixon had other priorities on his mind — the Viet Nam war for one, and the Great Society program that Lyndon Johnson had put through the Congress which now had to be funded. Those two things were getting a lot of attention in the Congress. Funding for the space program seemed like a luxury. After all, we did beat the Russians to the Moon; perhaps it was time to move on.

NASA backed off its plans for bases on the Moon and on Mars and, instead, proposed an Earth-orbiting manned Space Station. That proposal was cut back in negotiations with the Nixon Administration until the only piece left was an Earth-to-orbit logistics vehicle, which came to be called the Space Shuttle.

The design philosophy of the Space Shuttle was to lower launch costs to orbit by analogy to the operation of airlines: build a small number of vehicles and keep them flying through rapid turnaround on the ground. According to testimony to Congress in the early 1970's, the Shuttle would fly 50 times a year and, therefore, the launch cost to Earth orbit would fall dramatically. It didn't work that way, and the reasons were not necessarily all technical. Some design decisions on the Shuttle program reflect requirements set by the military (whose support was needed in Congress) and by restrictive budgets.

If you look at the history of NASA during the 1970's, you find it preoccupied with making the Shuttle work and with planning a Space Station. The whole context of space exploration set by the plans of the Space Task Group somehow got dropped from the corporate memory. Gradually, activities called "Advanced Planning" in NASA were eliminated.

In 1980, the Space Shuttle, behind schedule and having difficulties, still had not flown its first mission. The new Reagan Administration had come in under a banner of austerity and less government, intending to cut spending and eliminate programs. Of course that sent a tremor of fear through the Federal bureaucracy, of which I am a part.

The new NASA Deputy Administrator, appointed in the very beginning of the Reagan Administration, also had very definite ideas about priorities within the space program. He made known his opinion that the limited resources of the Agency ought to be put into making the Shuttle work. That might mean cutting back on other things, among them the planetary exploration program. In fact, the rumor mill said that the planetary science budget was going to zero over three years, leaving the Agency to concentrate on manned exploration. At some point in time, once the Shuttle was an operational vehicle, we would resurrect the planetary programs, like Lazarus, and start exploring the solar system again. That scenario sent shock waves through the scientific community (of which I was a part), and a number of things happened.

Our particular group, being civil servants, couldn't participate in activities like Political Action Committees being formed by scientific societies. We looked at strategic planning taking place in the NASA Headquarters Planetary Program Office in response to this and felt it was flawed. We were forced to reexamine our performance as a scientific research group to understand how to restructure and set priorities to remain competitive in what would be a highly restricted funding environment. We formed some internal committees to examine various options.

One of the things we revisited was the Lunar Polar Orbiter, a mission we had proposed in the early 1970's but which had never flown. In its original incarnation it was to have been a very minimal mission, intended to be launched on a Delta rocket to the Moon. However, under the guidelines of the early 1980's such a mission would fly on the Space Shuttle; the increased payload capacity of the Shuttle over a Delta would give the whole mission a great deal of capability. Thus, it seemed like a good idea to look into the technical issues associated with launching a lunar satellite from the Space Shuttle and become acquainted with a very broad spectrum of opportunities and possibilities in this "future space program." We could accomplish this at the Johnson Space Center by walking across the campus and talking to the engineers.

Those of you who don't work in NASA may not be aware how little working level communication there is between the engineering side and the science side. Even though located at the Field Center for manned flight, as a scientific organization, we rarely dealt with the engineers in the manned programs. Our time was spent with individual research projects and conferences about the planets and so on. However, at this point we had a real need to talk to those guys.

We made a couple of rather startling finds (to us) about NASA's future. We, of course, knew about the Space Shuttle, but we learned that it was called the National Space Transportation System, a name which implied there was something more to it than just the Shuttle itself. A Space Station was on the drawing boards and, back in the dusty corners, engineers were talking about spaceships called Orbital Transfer Vehicles (OTV) that could carry payloads from a Space Station into high orbits. These hypothetical vehicles (which would exist in the mid 1990's) would be able to take payloads not only to places like geostationary orbit but also literally to lunar orbit, without any changes in their propulsive capability.

That connection lit a great light bulb in my brain — for scientists who were interested in the Moon, the late 90's were going to be a real Golden Age, a new era of discovery. As this transportation capability came into service, our little dinky payloads could go up there all the time, collecting data on the Moon. Probably there would be a base on the Moon and other activities beyond low Earth orbit.

Exploring these possibilities within NASA, we found that such ideas were considered crazy stuff. NASA was having plenty of trouble getting a Space Station — if we were to talk about the Moon, then Congress will never allocate money for the Space Station. This type of thinking seemed to imply that the space program would never be more than a short term activity. We could not accept that, so we started an effort to map the long range structure of the space program.

At the very beginning of this activity, in early 1982, we began a collaboration with the Los Alamos National Laboratories, where we discovered (accidentally) that similar discussions were taking place. Jointly our group and the Los Alamos group developed a set of premises about space development, and then began expanding the dialogue to senior people in the space business who also had concerns about the future. Principally, we concluded that it was inappropriate to think of a Space Station or a lunar base as simply "a next logical step" as NASA moved from one project to another. What we were really looking at was the very beginnings of a process of moving human beings off the planet into the solar system.

Unfortunately, characterizing NASA programs in terms of grand, historical processes was not acceptable to the internal bureaucracy. That kind of talk was considered fantasy, given perennially tight budgets. Thus, our first step was to get the idea across that it was actually okay to talk in such terms. In other words, we needed to legitimize the concept of human exploration of space in general and the idea of a lunar base in particular. To that end we employed a number of tools such as workshops, lectures, sessions at technical conferences, and articles in the public media. I have a number of clippings from 1983 and 1984 that talk about lunar bases as if they were part of the NASA pantheon even though the agency itself was doing almost nothing in the field.

This orchestrated legitimization process led to a conference in 1984 that we held at the National Academy of Sciences resulting in the book that some of you have seen, entitled *Lunar Bases and Space Activities of the 21st Century.*

In late 1984 and in 1985, other people began arguing for piloted missions to Mars. Carl Sagan and Jack Schmitt were both lobbying James Beggs, the NASA Administrator, about missions to Mars for totally different reasons. Sagan wanted to go to Mars with the Russians as a world project to resolve global political tensions through technological cooperation. Jack Schmitt thought the Russians were going to do it and leave us behind in the dust.

Beggs realized that NASA had not thought very much about going to Mars in the Shuttle Era. In late 1984 he called the Director of the Johnson Space Center because he knew that a group there had been working on some of these ideas. Beggs asked that they put together a NASA-wide study to review how we would reply to the President if he said, "Go to Mars!" That study was done in about six months in the first half of 1985 and was published in 1986 as a Marshall Space Flight Center document.

At about that time, Congress mandated the President to appoint a National Commission on Space (NCOS) to look at the long range future. President Reagan finally did that, after some delay, in early 1985.

These activities began to gather some momentum and start to be recognized in some sense, but future goals never got on the charts (NASA viewgraphs). For example, in the justifications for a Space Station, the top reason was microgravity research or commercial development or better ball bearings. An engineer once told me after one of my presentations that I was talking about transportation of human beings into space and that was the seventh of seven reasons for the Space Station. I acknowledged the problem but emphasized that I saw the Space Station not so much as a research laboratory but rather as a stepping stone toward permanent human presence in space.

By the end of 1985 a new paradigm for the Space Station was beginning to emerge in a lot of people's minds, but it was still not manifested in any way in NASA officialdom. That was the state of affairs in early 1986 when the Challenger disaster occurred. The NCOS had its report ready to present to the President, and this terrible thing happened.

However, one of the results of the Challenger explosion was the bursting of the bubble of the Shuttle fantasy in the High Councils. At the time the system was working toward 16 flights a year and not 50 any more, but even that goal was beginning to be seen as a tough problem. A realization was dawning that the vehicle was essentially a research and development tool, not an operational system. There was real risk involved. NASA suffered a great deal of examination and critique.

Nevertheless, the Challenger tragedy generated a tremendous outpouring of public support. I think people at the top of NASA were surprised by the positive feelings because they live in a highly political environment in Washington, DC where they are constantly beset by negative and critical views. That is really all they hear. Do you want homes in space, or do you want homes for the homeless? This is the trade you are making. I think that even though they may have known intellectually that there were people who loved the space program, the support that came out in the national media and everywhere was something of a surprise. And it encouraged them to think more about the future.

The NASA Administrator accepted the NCOS report and later that year asked Sally Ride to study possible future initiatives for the U.S. space program. Neither the NCOS operation nor the Ride Study was large enough to have an independent technical staff. Both groups had to draw on preexisting information, and almost all of the recent stuff was our bootlegged work of the previous four or five years on lunar bases and the Mars mission study. Most of it was very conceptual, but it became the basis for much thinking.

The National Commission on Space report, *Pioneering the Space Frontier,* had a very grand vision that philosophically broached the question of human settlement of the solar system. Later, that idea appeared in the Reagan space policy of February 1988. Thus the report was very important, even though people thought of it as a "blue-sky" study destined to molder on the shelf. It created an important philosophical basis for things that would come later.

The Sally Ride study posed four grand options for NASA: Mission to Planet Earth (which you heard about last night); Robotic Exploration of the Solar System; Outpost on the Moon; and Piloted Missions to Mars. Those sound like four distinct choices but, in reality, they are different scales of activity. As I said earlier, I have to agree with Mel Averner that Mission to Planet Earth is really not in the same league as Outpost on the Moon or Missions to Mars. When you really look at a Mission to Planet Earth program, even on as grand a scale as has now developed, it is something like a factor of five or so smaller than a lunar base program. A Mars program started from scratch is probably another factor of two larger than a lunar base program in terms of expense.

NASA formed an organization called the Office of Exploration (OExp) to continue the work of the Ride Report and to explore these options in more detail. However, that organization was chartered to study mainly the Moon and Mars missions. It was assumed that the planetary exploration element is really being taken care of very well within the current offices of NASA. The Mission to Planet Earth is really something a little broader and larger than NASA, not necessarily a NASA program and not of the ultimate scale of human exploration of the solar system.

Office of Exploration began its work, I guess, in late 1986. In December of that year, the NASA Administrator circulated a memo to all NASA employees declaring that one of NASA's major goals was to expand human presence beyond the Earth into the solar system. Little notice was taken of that statement, but it was echoed about a year later in the February 1988 space policy issued by the Reagan Administration. That was really important for it allowed NASA to actually think about human space exploration in terms of long range goals. You have no idea how important it is to a bureaucratic government organization to be given permission to think about strategic issues.

Given that permission, the Office of Exploration took it upon themselves to come up with a long term strategy for the space program. However, they first felt a need to educate themselves about the implications of various choices. Let's take "Outpost on the Moon", for example. A lunar base could be a Chevette or a Cadillac. You can just put people up there, plant the flag, and bring them home; or you can establish the beginnings of communities.

What about bases on Mars? Do we go there, land a couple of places, and say, well, we did that, i.e., "Little Jack Horner sat in a corner, stuck in his thumb, pulled out a plum, said, 'What a good boy am I'?"

There are all sorts of scales to these things, and we don't always understand what it means to adopt one or the other of these scenarios. The Office of Exploration wanted to provide recommendations, alternatives in the early 1990's. The target date for a final recommendation was 1992: the 500th anniversary of the discovery of America, the International Space Year.

Rather than sit down and try to develop a plan immediately, they chose to do a series of homework problems. The approach was to formulate a series of problem statements of the sort you might find at the end of a textbook chapter. Solving these exercises would give insights to the workings of the methodology and to the implications of various decisions. They were very careful to refer to their work as "case studies", not scenarios. The word "scenario", as Gerry Soffen pointed out earlier, implies that you have converged to a plan. If the press thinks you are developing a scenario, they assume the it is the first draft of the final plan. In reality, we were doing practice runs, and they were called case studies to emphasize that.

In that process they arrived at some generalizations from these case studies. One was a classification called *Human Expeditions,* or "flags and footprints" as it is called informally. A human expedition means that you are just demonstrating capability and, perhaps, collecting information. The Lewis and Clark Expedition explored and reported back but didn't leave behind any outposts or settlements. If a facility or some scientific experiments is established which can be revisited, we refer to it as an outpost. An outpost does not have to be permanently staffed.

Finally, there is a rather revolutionary notion called *Evolutionary Expansion* in which a permanent presence is established with an intent to grow to self-sufficiency in an economic or material sense. This latter concept begins to transcend a simple programmatic decision and has the potential to inaugurate a historical process.

I came to the conclusion some time ago that the inevitable maturation of space transportation technology implied that the human race was ready to begin permanent settlement off the Earth. The only question in my mind was whether Americans would be leaders in this process, whether our values and ideals would become part of the foundations of space-faring societies.

A vague, philosophical idea like evolutionary expansion is difficult to deal with in an engineering-oriented organization such as NASA because it doesn't immediately lead to a set of requirements against which engineers can design machines, or give you a series of steps toward a specific goal. So I sat in interesting meetings, watching the mind trained in the engineering culture struggle with really philosophical issues where you had to derive what you wanted to do from a general cultural imperative. That was a very difficult exercise within this organization, but some good progress was made, ultimately.

One case study, or problem statement, investigated was a human expedition to Phobos. By landing on Phobos, you don't have carry the mass with you to land on Mars. The objective is to get somebody into the Martian system as quickly as possible with technology that you have at hand. That was the intent of studying that issue. It didn't necessarily mean that they were trying to advocate landing only on Phobos. In fact, the case study included robotic exploration of the surface of Mars, using teleoperation from Phobos as a base. This is an old idea that Fred Singer came up with as part of his PhD thesis, I think in the 1950's. It may even predate Fred, I don't really know, but he certainly popularized the idea.

Doing this problem forced you into some on-orbit operations, but required only modest mass in low Earth orbit (LEO) and less time for program development — characteristics which made it an important case to understand. Of course, a lot of people thought it was just crazy to go to the Mars system and not land on the planet. Therefore, you also had to include the case study involving human exploration of Mars.

In that study it became clear that the Space Station was needed for assembly in LEO because you can't bring up everything at once in big pieces. On Mars we have robotic exploration of the Martian moons instead of vice versa. Much technology development and operations experience was needed at the Space Station, particularly research in life sciences.

As I sat in the meetings in 1985 for the Manned Mars Mission study, I had realized for the first time how much the decisions related to the Mars missions were driven by our ignorance of the life sciences. Our limitation was not engineering or ability to design the transportation systems — our limitation was our understanding of the human being and how that human being might adapt and perform on a three year round trip. That kind of experience is like the old sailing voyages around the world in the 16th century.

Mars landing requires a lot of vehicular and space systems infrastructure within a launch window that opens only once every 26 months. A huge spaceship has to be built in LEO, and if you happen to fall behind schedule a few weeks, you maintain it there for another 26 months. An enormous management operation is involved just to meet that schedule. Something like 500 tons of propellants alone have to be shipped to orbit once you have built the spacecraft — an imposing challenge, considering how we do business today.

The case study designed to evaluate lunar activity was taken to be a science outpost on the far side, using an optical interferometer located on the lunar surface — an idea Bernie Burke published first in a book which I edited, *Lunar Bases and Space Activities of the 21st Century.* The lunar surface is extraordinarily stable platform and therefore a unique location for the elements of an optical interferometer. We are examining now the broader and broader categories of scientific experiments that are possible on the Moon but not possible on the Earth or in orbit somewhere.

Of course, the more traditional sort of concept is the Arecibo style radiotelescope in a crater. This idea appears in NASA viewgraphs as early as 1971. I have always thought this scale of project was pretty ambitious and only a nice thing for artists to draw. However, at a symposium on Astronomy from the Moon, held in 1986, Frank Drake pointed out that the Arecibo telescope in Puerto Rico is built suspended from only three pylons on the sides of the crater. All the structure is supported by cables. When you realize that, the civil engineering problem doesn't seem nearly so difficult.

The lunar case study focussed on operating a long duration science facility on the Moon that would be man-tended but not necessarily permanently manned. Clearly, substantial scientific capability could be put on the Moon within a relatively short time. Massive human presence is not required, but human interaction would greatly enhance the performance of the installation in terms of maintenance and change-out of instruments. The mass launched to LEO to do this kind of operation on the Moon is much less than for Mars missions.

Finally, there was a case study called evolutionary expansion. A long time was occupied in even getting a grip on what that meant. It was not studied as deeply because there were so many false starts over its formulation. Nevertheless, one of the ideas very prominent in evolutionary expansion was to somehow use the Moon as an outpost early on to build your infrastructure, test your systems, and learn how to live on planets. It might even be possible to increase your ability to operate in space with oxygen production on the lunar surface. Thus, lunar activities really become a building block on the way from Space Station to Mars to the rest of the solar system. This idea of achieving plateaus or "terraces" in capability and technology has often been advocated by Peter Glaser.

Now, that turns out to be the idea that is manifested in President Bush's speech of July 20, 1989. A lot of people, particularly reporters, complained to me that the speech was "wimpy" because the President didn't give any schedules or details or cost figures. I disagreed and, in fact, thought it to be extraordinarily important because, as Lee Tilton of Stennis Space Center said to me last night, it cut off almost all the branches from this vast decision tree that NASA likes to build. NASA has the idea, and probably rightly so, that it should not make policy decisions. NASA only can provide options to someone else, presumably the President, who will make a decision. All these studies going on inside NASA are suddenly now coming to a screeching halt, and we can really start to focus on specific tasks and accomplishments.

I personally believe that the approach enunciated by the President is the right one. It is one that I have been talking about for a few years, anyway. This way, you end up with a fairly complex infrastructure including lunar surface activities, (maybe manufactured propellants), science laboratories, and vehicles going to Mars. Most importantly, there is an interconnection between things that happen in planetary exploration and things that happen on the Moon. We have sort of a building block approach.

The Evolutionary Expansion case study carried out space development and exploration in a gradual buildup through the Space Station to the surface of the Moon. As I mentioned earlier, my experience with the Manned Mars Mission studies in 1985 persuaded me that the critical path decisions in the Human Exploration Initiative require prominent programs in life science research. The role of the Space Station ought to be to address these issues. The concept of the research laboratory in space in materials science could be satisfied by Joe Allen and his crew with the Industrial Space Facility or its NASA-generated generic equivalent. Astronomers and Earth-observing scientists have

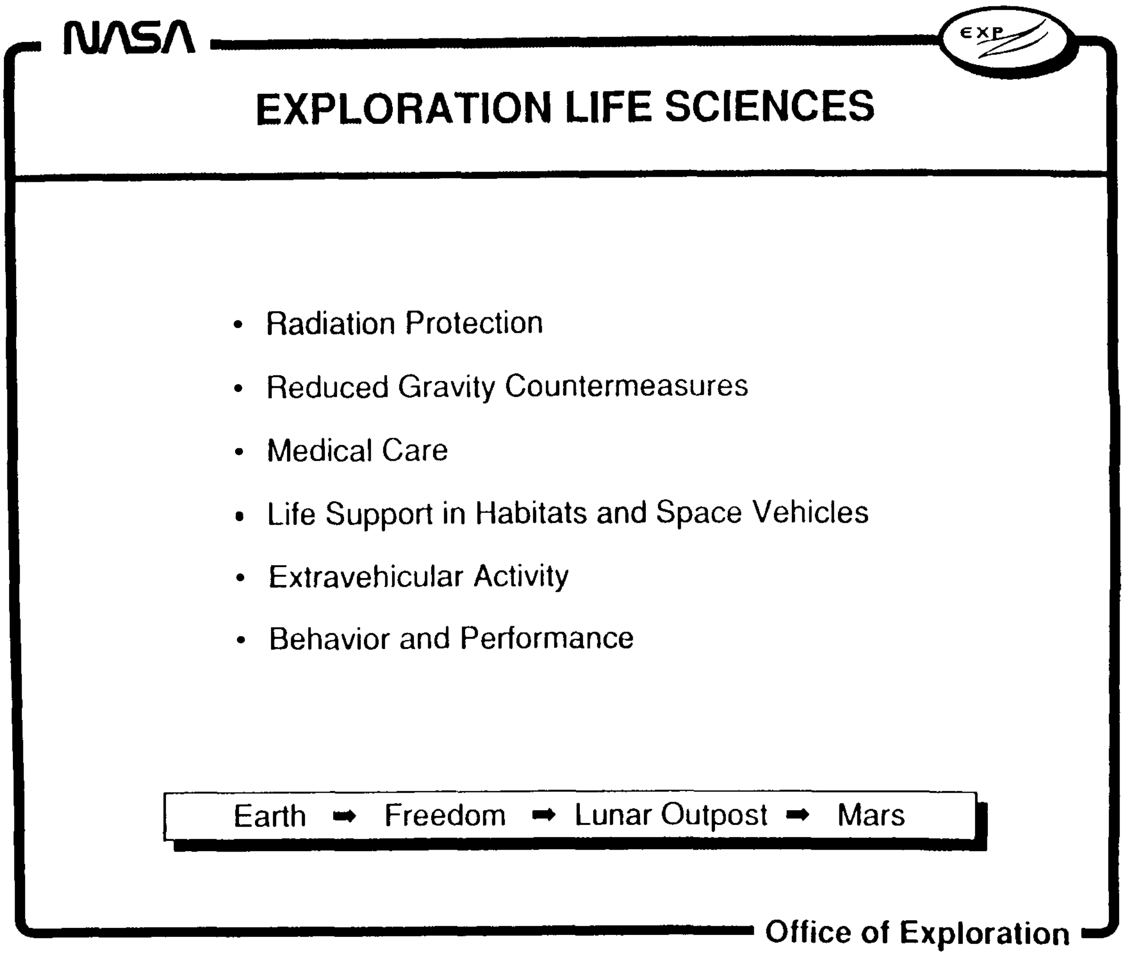

Figure 1. Life sciences issues for manned space exploration and bases.

platforms for their work which are probably more suitable than a vibrating, dirty manned Space Station.

Finally, there is the new concept of establishing permanent infrastructure on a planetary surface. Among the communities that I have been able to get interested in this latter point are the civil engineers and the process industry. As I have pointed out to them, historically, you have explorers who open the frontiers and who are the demigods and celebrities. The builders and settlers come after them. To my mind, there is no fundamental reason why the Space Station has to be built by rocket scientists rather than civil engineers.

A more obvious case is a lunar base where you have construction, manufacturing, processing, and general logistics support taking place. If such a facility were being designed and constructed on the Earth, you would not find NASA involved. For this kind of work you go to Bechtel or Shimizu in Japan or Brown & Root or some other constructor-engineer company. They have the relevant experience but are not now involved in the space program.

When we describe these surface infrastructure elements to those companies, their reaction is that it is a piece of cake but flying to the Moon is impossible. When we go to NASA the reaction is that getting to the Moon is straightforward but building that stuff is impossible. There is no experience in either community that gives confidence in the unfamiliar element. We are trying to close this gap, and it has been closed to some extent within the Office of Exploration.

I have pulled out are a few charts from standard NASA packages that list life science "tall poles" (Figure 1). We can see issues in medical care, zero or low gravity countermeasures, artificial gravity, radiation, life support, and human factors, which is often ignored in NASA. Crew interactions are very much more, I think, an integral part of the Soviet program. They have more concern with these things than NASA does, particularly crew psychological relationships. Extravehicular activity is another question, which is as much a space suit technology issue as it is a human issue.

All of these things begin with the Space Station

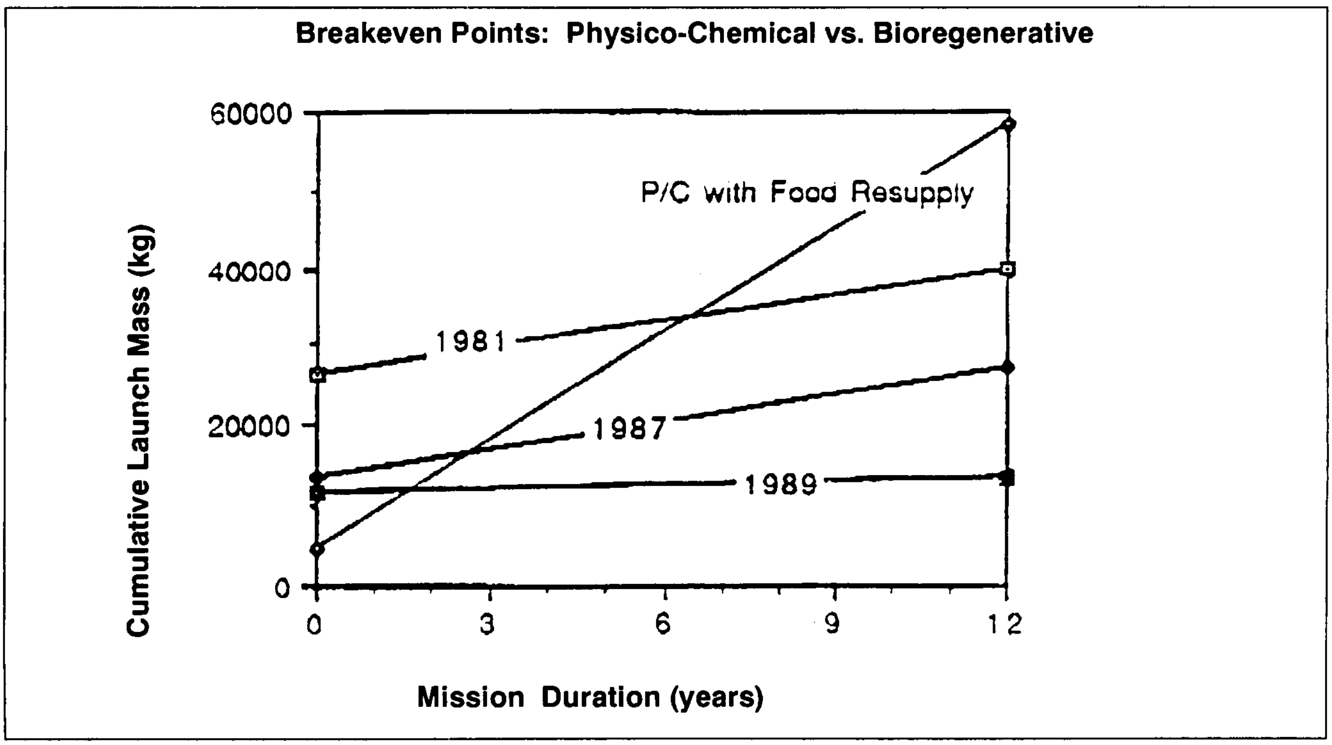

Figure 2. Breakeven points for physico-chemical vs. bioregenerative life support systems for space missions.

Freedom, which gives you the long duration experience, life science research, advanced technology, and so on. Notice how high these Space Station research issues fall on the chart. That is a real change that comes from working on a real problem rather than from generation of rationale for the Space Station by making it up, as in some sense was done in the original proposals.

In the Lunar Evolution concept you want to try to understand the requirements for permanent, self-supporting facilities. Those are really important words: "permanent self-supporting." You also want the capability to be a learning center for long duration planetary missions. So that is a good analogy to what you guys are doing here at the Biosphere 2 Project, developing a learning center and working to be self-supporting and so on.

I have some other charts that were given to me by Barney Roberts, but were given to him by Hatice Cullingford, who has been working on some of the CELSS requirements. These are really things which Mel Averner knows more about than I do. I have run overtime, so I will just pull out a couple of the major ones.

I want to ask you about this chart, Mel, because I wonder about it. This chart (Figure 2) shows that we have learned enough about CELSS during 1981 to 1989 that our crossover point for replacing physical, chemical regenerative systems becomes mission durations on the order of a year. Is that correct?

> *Mel Averner: "First, like you, I had some questions about that. The calculations are based on a study done by Lockheed. I recently talked to a Boeing Aerospace person who independently did the same study from their own point of view and they came out with exactly the same results of a break-even point of about one year. So I now have a good deal more confidence in the report."*

That conclusion is an important one, and new to me. It is important because that implies that projects like lunar bases ought to start investing more in this technology and put more emphasis on it than in the past. It really makes bioregenerative life support a major issue of technology development. I am not sure that this knowledge is reflected in the current planning that is going on. This is sort of new information, so it is something we really need to work on in getting it into the NASA plans.

Another question is whether we can take and derive the lunar habitat from the Space Station *Freedom* with some new technology and then upgrade it to 8 to 12 people, using more and more CELSS technology. I think the pathway that we choose from here through this will be extraordinarily important to efficiently and quickly provide the capability for human beings to live and work in space. Thus, closely connected with all these human exploration goals are some very important and exciting requirements for the life sciences.

It is very sensitive to talk about the report in preparation to the President right now (The 90 Day Report on the Human Exploration Initiative, authored by Aaron Cohen, NASA Johnson Space Center), but the thinking is couched in terms of an emplacement phase, a consolidation phase, and the utilization phase both on the Moon and on Mars. Much of the technology emphasis is on the Moon because we want to develop these systems, make sure they are reliable, and make sure they work in a low gravity environment before we entrust peoples' lives to them all the way to the planet Mars. The Moon is a more forgiving place due to its accessibility by the transportation system.

I would like to conclude with a reflection. This is a magical time, when we have an opportunity within the space program to embark on a truly grand and historical process of human exploration of the solar system. If we can figure how to do that within the constraints imposed by our society and the international environment, there is an opportunity — particularly for the younger people here — to be part of one of the grandest occurrences in the whole history of the human race. We can actually talk about the beginnings of a multi-planet species. The important issues are the ones that Joe Allen raised in his talk — not necessarily the technical ones, but those having to do with the institutional and management structures. Those issues are not as clear and easy to address as are the nuts and bolts, the calculations and the physics.