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FORUM:

Gerard K. O'Neill on "Space Colonization and SETI"

High energy physicist, teacher, astro-engineer and space colonizer, like a Columbus or a Magellan, O'Neill charts a course into a cosmic future.

[This interview with Gerard K. O'Neill was made by John Kraus of **COSMIC SEARCH**.]

O'Neill

COSMIC SEARCH: To what extent do you think civilizations elsewhere in our galaxy or beyond may have colonized space?

O'NEILL: There is a fair amount of evidence that we may be alone in this galaxy as a material-oriented civilization. I emphasize the *material oriented*. There is a possibility, I think, that others may have gone before us, but only if there is some kind of undiscovered universal rule of life stating that material orientation rather than *spiritual or non-material orientation* of a civilization is a very brief episode in its evolution, and that every civilization goes through that period very quickly.

COSMIC SEARCH: Would you please enlarge a little on what you mean by a materially-oriented civilization?

O'NEILL: I mean one which produces artifacts, makes use of energy, communicates by means of the electromagnetic spectrum—in other words, an energy-and-material oriented civilization like our own.

COSMIC SEARCH: So, then, we are such a civilization.

O'NEILL: Yes, very much so.

COSMIC SEARCH: Now you alluded to a spiritually-oriented one. What did you have in mind?

O'NEILL: Suppose it is possible for beings to develop which are not tied to matter

at all, communicating by some portion of the electromagnetic spectrum that we are not sensitive enough to notice. Suppose also that they have no interest whatever in the physical universe. In order for us not to be alone, I almost have to conclude that there is a universal rule of life that every civilization evolves very quickly to this end state of non-material orientation.

COSMIC SEARCH: Do you believe that colonization of space is a normal step in the evolution of any society?

O'NEILL: With the proviso that we don't talk about the totally nonmaterial path, yes, I think it is an inevitable step. I think it is unlikely that a civilization will last very long on a galactic time scale without developing space colonies, because the fragility of a civilization confined to the biosphere of one planetary surface is very great when that civilization possesses nuclear weapons in large quantities. You can imagine holding things together for a few decades, but the only end points that seem reasonable are either the statistical possibility (or a statistical certainty if you wait long enough) of a massive nuclear war that sets a civilization way, way back, or else a steady state society under a rigid dictatorship which confiscates all military weapons and keeps things constant for evermore. These are certainly possible outcomes and would not result in the establishment of space colonies.

COSMIC SEARCH: This would be a condition of stagnation?

O'NEILL: That's right. I see three possibilities for a civilization that gets to about our stage. One is *stagnation*, one is *annihilation*, and the third is *expansion* out into space through space colonies.

COSMIC SEARCH: That is an interesting trilogy.

O'NEILL: Logically it is hard for me to see any other possibilities. At the moment we see the first step of that transition just before us, that critical step of escaping the planetary biosphere and going out beyond the earth to establish colonies there. But it is important to realize that once that quantum jump has been made, all of the transitions after it become very much easier. It seems almost inevitable, considering the physics, that in a time scale which is very short in galactic terms a civilization that developed space colonies would spread throughout a galaxy.

COSMIC SEARCH: If we were to receive a signal from another civilization, say a 1000 light years distant from us, do you think that would be a good thing?

O'NEILL: It depends on the kind of signal. I tend not to place a high probability on receiving a signal. If we do get one and it is only a beacon, some thing that just gives the information "We're here or at least at one time, we were here," I think that kind of signal would be a great help in drawing us outward from the earth. In contrast a detailed exposition, for example, of all the scientific knowledge that we have yet to find on our own could have a very stultifying effect. Advanced western civilization has had a destructive effect on all primitive civilizations it has come in contact with, even in those cases where every attempt was made to preserve and guard the primitive civilization. In part, the reason for the destruction is that all of the knowledge base and the value system that had been built up by what you might call the client civilization became valueless overnight. I don't see any reason at all why the same thing would not happen to us if we were to be put into that situation. For example, speaking as a scientist, suppose I have the choice between laboring to try to do an important experiment and learn another fundamental fact of nature or simply turning on my television set and waiting until the broadcast comes through that will give me the answer. The enormous difference in one's view of one's own value is why I feel that something that has almost no information in it beyond the fact that it is there and that it is artificial could be very valuable. Anything that's much more detailed would almost certainly be harmful.

"I see three possibilities for a civilization that gets to about our stage: stagnation, annihilation and expansion out into space through space colonies."

COSMIC SEARCH: It is possible that another culture could have evolved under such radically different circumstances that there would be very little in common and for a long time all that we would learn from it is that it exists or did exist and much detailed information might be difficult to obtain.

O'NEILL: With the exception, of course, of scientific information because information from the hard sciences is universal.

COSMIC SEARCH: Yes, that is they will be familiar with numbers, with the galaxy and the universe and this gives a base for communication.

O'NEILL: I would go farther than that. We know already from astronomical and other measurements the value of the charge on the electron, the size of Planck's constant, and things of that sort which are universal constants of nature; we know that subjects like physics, mathematics, chemistry are all universal scientific subjects, which means that a civilization that is even as tiny an amount as 1000 years ahead of us already knows so much more than we do that all the science we know would seem very primitive.

COSMIC SEARCH: This is a possibility.

O'NEILL: I would be more categorical and say it's a certainty. Newton's laws, Maxwell's equations and the rest are identically the same from one end of the universe to the other, no matter who discovers them. Logically, I don't see any escape from it. In the soft sciences, though, the alien equivalents of anthropology, psychology and so on would presumably be quite different from ours.

COSMIC SEARCH: What do you consider might be the most likely way that we might learn of the existence of another civilization?

O'Neill and mass launcher

O'NEILL: I've thought about that quite a bit. Let me answer the question by outlining what seems to be the most logical way that a civilization would move throughout a galaxy or would communicate with another civilization. Let us put ourselves not in the shoes of the receiver but of the transmitter. First of all we must get a feeling for time scale. We are at a particular very, very unusual moment in our own history. We have just barely, within the past few decades, (just a microsecond on the cosmic time scale) arrived at the point where we are able to use radio communication. Within at most another few decades, another microsecond, we'll be able to spread throughout the entire galaxy. We happen to be poised just on that knife edge between the two. That gives us a strange and, I think, a very distorted view of what's practical and possible. But if there are beings who are going to communicate they are presumably very far advanced over our present status, even if the very far only means a thousand years or two. It is much more likely that they would be hundreds of thousands of years more advanced. Now, of course, one of the most important characteristics of the spread into the galaxy, of which the space colonies are the first step, is the escape from the stultifying decay and stagnation which is one of the likely end points that determines the lifetime of a communicating civilization. The civilization would then undergo cultural evolution in many different directions, some of which would indeed be dead ends, but others presumably would give rise to vigorous offspring which would continue. Let's think about what a civilization even a thousand years more advanced than our own would do if it wanted to communicate. The first thing it would do as it began to spread throughout the galaxy is to say, "We'll get some information." If you assume

that the spreading time of a civilization throughout the galaxy is a tenth the speed of light, you presuppose only that we are able to do technically what we can now understand scientifically, namely to store matter and antimatter and allow them to react to give energy. If we can do that, we will get a tenth of the speed of light. At that rate a civilization could spread throughout the galaxy in less than a million years.

COSMIC SEARCH: Hardly even a geological epoch.

O'NEILL: Yes. A million years, of course, is only one ten thousandth part of the age of the galaxy so even that is an instant. The first thing a civilization in the first 1000 years out of that million would be likely to do is to try to get all of the information about the galaxy that it could, and to do so in a way that would be totally safe. One of the obvious avenues available to such a civilization is a very cheap one, namely building one highly sophisticated robot probe which is capable of self-replication, contains a great store of knowledge, and has transmitting capability.

COSMIC SEARCH: Is this like a Bracewell probe?

O'NEILL: I don't recall seeing Ron Bracewell's studies. The concept may be very similar. As I describe it you may be able to tell me that it is identical. My concept of such a probe is that it would go to another star system, neighboring the original one. It would use the asteroidal material available there, since there's presumably debris around every star, and use the energy which is certainly there. In a period of a few years, or maybe it would be a hundred years, it would replicate itself. It would then leave one of itself at that star and move off to the next star and so on. As it went, it would establish two-way communication, point-to-point, not a broadcast at all, but from one of these replicator probes to the next. You can work out the numbers, John, and it turns out that by any reasonable standards such a probe system could spread throughout the galaxy and cover essentially every star in the galaxy within a time of no more than half a million years or substantially less than the time required for a civilization to spread out. The obvious thing for such a probe system is never to get involved in sending high powered signals because it's an ideal example of a telephone or television network with a series of amplifiers, one at each star.

COSMIC SEARCH: These would be relay stations.

O'NEILL: Yes, and also very effective observation stationsmdash;observation stations not dependent on beacons or other voluntary action on the part of the civilizations being observed. If you want to find out about who's alive out there, it's stupid to wait until the other guy develops radio communication. It makes much more sense simply to build a system of these replicator probes which can do highly sophisticated monitoring of every individual planet of every star system and give you probably many millions of years warning before a civilization is even going to develop.

"Newton's laws and Maxwell's equations are identically the same from one end of the universe to the other, no matter who discovers them."

COSMIC SEARCH: The replicator probe concept appears to me to be an extension of the basic Bracewell probe idea. It's like a very advanced reconnaissance system.

O'NEILL: You can call it very advanced, but on the other hand it is probably something that we would be capable of building ourselves within far less than a thousand years, maybe as little as a hundred. Therefore, the most logical development is that a very short time after the first civilization in a galaxy arrives at a level comparable to our own, say within a thousand years from then, there would be the beginnings of the spreading out of a robot probe system to every star and that within about half a million to a million years or so that process would be complete. That then raises an interesting question. If there is anybody who has come out in the galaxy before us, their probe is overwhelmingly likely already in place. In which case they could have communicated with us at any time in the last few million years. Even without radio they could flash light bulbs at us if they wanted to and the fact that they have not leaves us with the following possibilities: namely, that we are alone in the galaxy, meaning to say that we are the first civilization that has developed, or that probes are set to trigger only on a civilization that solves its self-destruction problems on its own. For example, the probes could be so equipped that they don't respond to any signal they detect until a thousand years of continued radio broadcasts after the last detected atomic bomb blast. There are all sorts of codes. The last possibility is that if there was a previous

civilization in the galaxy, it seeded the galaxy with probes that were destructive of life. But I think this is unlikely because if it were true we would very likely have been wiped out ourselves long before we started radiating television signals.

COSMIC SEARCH: What would have been the motivation for this latter action to wipe out life?

O'NEILL: Some of the same ones that we have seen pretty recently in our own civilization. The first and the strongest who comes out of the litter proceeds to kill the rest so as to get all of what is left for himself.

COSMIC SEARCH: Get all the spoils.

O'NEILL: I think, though, there is good evidence that that has not happened. If, in fact, there is a civilization which develops in the galaxy and which is hostile to other life, it would be foolish for it to wait until the other life gets to the level where they start having star wars. It makes far more sense for them to destroy that other life at a very primitive level when it is totally incapable of defending itself.

Space city (NASA)

COSMIC SEARCH: You have talked about these probes going out preparatory to the colonization of the galaxy. This could not be a coordinated effort because when the colonizing groups become separated, by say 100 light years, they would become independent.

O'NEILL: If you're speaking now of the human movement, it is quite true that by the time they had spread out even to as little as two or three stellar distances they would be, for all

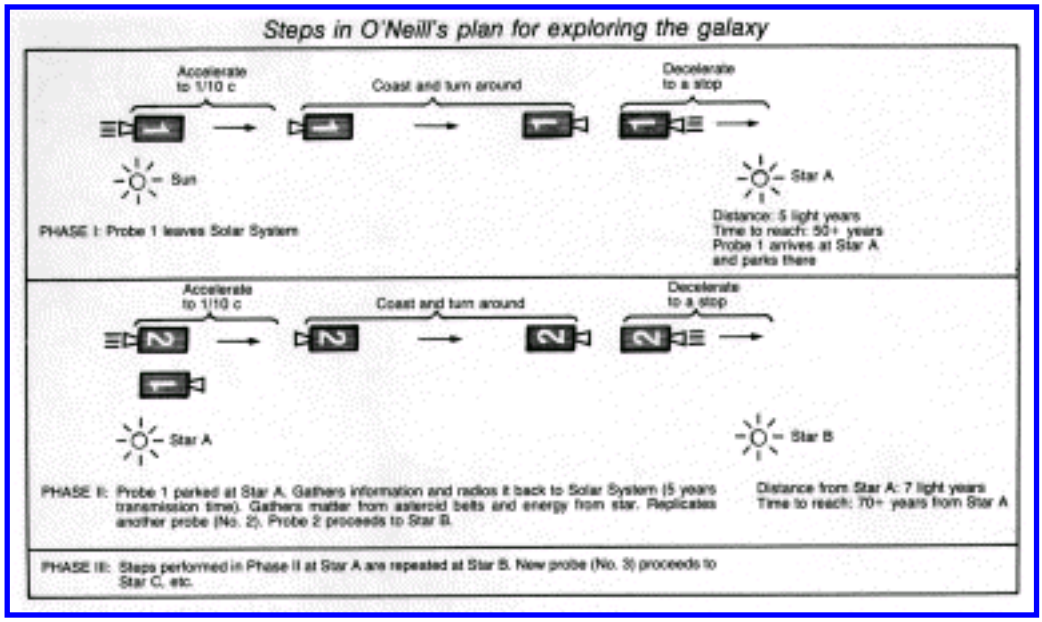
practical purposes, independent. However, there would be no need to have more than one probe system, the initial system, because the information that it would send would simply be relayed across the galaxy from the point of origin of the information and there would be no way of telling, even if you tapped into the transmission, where in the galaxy the original civilization was. This safety element would presumably be designed into it.

COSMIC SEARCH: What do you think would happen to your plans for space colonization in case evidence was obtained of another civilization? What effect would it have?

O'NEILL: It might have some positive effect, but I would guess that the main drives to move out into space are really independent of the existence of other civilizations. I have described why I think it is pretty unlikely we would be hearing anything, and, as you probably know, there are a number of other people, Josef Shklovsky is one, and Sebastian von Hoerner is another, who in the past year have been thinking along lines very similar to those I have described to you. In fact, I had a very interesting discussion with Shklovsky about this in Prague last year, and it turned out that independently we had come to much the same conclusions. I got a letter from Sebastian von Hoerner expressing much the same thing. But leaving that aside as a civilization moves out into the galaxy, by the time individual colonies are as little as 10 or 20 or 30 light years apart they are effectively not in communication except in the most general way. And similarly I think that the reasons we would move into space would not be much affected by the existence of another civilization.

Steps in O'Neill's plan for exploring the galaxy

COSMIC SEARCH: Do you think that the space colonization activities will significantly increase the probability of another civilization detecting us through all our radio transmissions?



O'NEILL: I wouldn't guess so because in many respects communication between space colonies could be a lot more efficient and done at much lower power and radiate less stray energy than our present difficult communications which are after all around the outside of a sphere which is opaque to radio. Most of the radiated power that we are putting out, the kind that would go really long distances, is from the big military radars. There the issue is not whether space colonies exist but whether militarism continues and whether it escalates.

COSMIC SEARCH: But the radars may be quite directional so that the probability may be small that somebody would chance upon it.

O'NEILL: I wouldn't bet on it. After all, the military radars by definition try to obtain total coverage over a wide angular range because they are searching for incoming aircraft or missiles. So they do cover a wide range and only a few pulses need to be received to identify something as being artificial.

COSMIC SEARCH: Then you believe that the radars are more likely to give us away than the television stations?

O'NEILL: I think so, although there is the issue of the relative amount of noise in the galaxy at various frequencies so that I shouldn't comment from a technical viewpoint. It may be, for example, that when you look at the noise spectrum in detail there is some unsuspected part of the spectrum that would turn out to be the biggest give-away.

COSMIC SEARCH: Do you think we should institute a radio blackout to keep our existence as quiet as possible?

O'NEILL: It's probably a bit late for that.

COSMIC SEARCH: You think the cat's out of the bag?

O'NEILL: I think so, but also, as I mentioned before, I believe that if there is anybody out there who is hostile to us we wouldn't have been allowed to get as far along as we are now. I don't think radio communication is the critical development point at all. If there were another civilization that preceded us in the galaxy, whether hostile or non-hostile, they would be detecting our presence not by radio, but by having their own sophisticated probe in orbit around the sun. They would have seen every stage in our development from the most primitive.

COSMIC SEARCH: Do you think there is enough in common between SETI and space colonization for either of these activities to be helpful to the other? Are they complementary?

O'NEILL: I think they are fairly independent. I would guess there are a fair number of people whose primary interest is in one of these areas but who take a friendly interest in the other—or who enjoy speculating about it. But I don't see there being any direct tie-in at all.

COSMIC SEARCH: I feel that space colonization could give mankind a common goal and help prevent stagnation but if funding can't be generated it will never occur —I am thinking of federal funding. What about private enterprise doing it like the East India Company or the Hudson's Bay Company opened new avenues of commerce?

O'NEILL: I think it's fairly unlikely as things now look. The main reason is that this development, this break-out into space, is something that will require roughly 15 years to occur, and that is much longer than the time horizon for any private capital venture which is normally limited to about 5 years. So if you look back to things like the Jamestown colony or the East India Company or the Hudson's Bay Company, those were all ventures in which there was a substantial financial return occurring within as little as 2 or 3 years of the original investment, or well within

the 5 year time horizon which was roughly applicable even back then. Now, on the other hand, there are motivations which are far broader than the distribution of the private ownership system throughout the world. Nationalism is far more general. Competition between nations, hostilities, fears and so on are very widespread. If we look at the historical parallels, it's more likely that the break-out into space is going to happen for competitive reasons rather than for cooperative ones. Whatever language that is used to describe it, I think that we're going to find one nation getting ahead of somebody else in this field, as Russia is getting ahead of the United States now, and that then someone else will begin to play catch-up.

"It's more likely that the break-out into space is going to happen for competitive reasons rather than cooperative ones."

COSMIC SEARCH: Yes, this is the view that Sebastian von Hoerner expressed in the January **COSMIC SEARCH** interview. He has expressed some of these things in a very similar way, that to avoid stagnation we need competition.

O'NEILL: I guess that what I'm saying is that if you look at history it's likely that the competition is going to occur willy-nilly. The U.S. may not be involved in it. I hope that we will be, but it might be Russia and Japan, for example.

COSMIC SEARCH: What kind of a sequence do you envision in colonizing the near space? You've written about the L4 and L5 points. What other locations may be used?

O'NEILL: The various studies that have gone on in the past 2 or 3 years have concluded that there are many possible orbital locations—L4 and L5 among them. The present best guess is that we start out with a high circular orbit maybe two-thirds of the way from the earth to the moon. As I indicated in my book "The High Frontier," if you go through the calculations you find out that you could arrange very comfortable earth-like living conditions in a space colony even out beyond the orbit of the planet Pluto. So certainly there is plenty of room in the solar system.

COSMIC SEARCH: Has your book "The High Frontier" helped generate interest in space colonization?

O'NEILL: Yes, I think that it definitely has. A great many people write to me who have read the book and become very enthusiastic about it as a result. It was a nice little extra when the book won the Phi Beta Kappa Award as the best science book of the year (1977).

COSMIC SEARCH: After the colonization of our solar system what do you see as the next steps?

O'NEILL: I would guess that the time zero for sending out a colony would be comparable, give or take a hundred years, to the time zero for sending out a replicator probe, which means relatively soon. I would guess it would be within the next 100 or 200 years or within a period of 50 years after space colonies were already matter-of-fact and common-place throughout the solar system. Then I would bet that some colonies will push off to the nearby star systems. The limitation is really just the technological limitation of producing weighable quantities of anti-matter at a feasible cost and reasonable energy efficiency. I see anti-matter and ordinary matter as the obvious choice for fuel.

"I would bet that some colonies will push off to the nearby star systems when we can produce weighable quantities of anti-matter."

COSMIC SEARCH: Do you have an idea as to when that might be?

O'NEILL: We can make some very rough guesses. It's an interesting story that Napoleon had several sets of formal flatware for his imperial dining table depending on the particular guests being entertained. The most important potentates or rulers were served with flatware that was made out of aluminum. This, of course, was in the early years of the last century. The visiting royalty of slightly lower rank was served with flatware of platinum and so on down through gold. It is interesting that one goes from the level of near pricelessness of aluminum to the point where about 150 years later we have household aluminum foil and aluminum beer cans. So, within 100 to 200 years I would guess that we would be able to make anti-matter in substantial quantities. We can make it right now if we wanted to try hard enough. It's just that we would only get microscopic quantities and at an enormous cost just as in the case of aluminum in Napoleon's time.

COSMIC SEARCH: Now all of these plans hinge on the funding. Are you optimistic about this aspect or otherwise?

O'NEILL: Well, John, on a time scale of a year or so and restricted to just this one country, I certainly couldn't make any wild guesses. I am very pleased that there is a small modest program now going on, at a total level of less than a half a million dollars a year in a number of grants around the country that relate to this activity. The Congress has generally been quite supportive of such ideas as satellite solar power and space industry. You probably are aware of the High Frontier Feasibility Act introduced by Senator Harrison Williams of New Jersey, which has gone through the Senate and is now in the Senate-House Conference Committee.

COSMIC SEARCH: Tell me more about that please.

O'Neill and students

O'NEILL: It was a proposal that came totally independently from many of us already working on this. It developed at the senator's own suggestion, and it's a very sensible one, that an agency which does not have an axe to grind in this business like DOE (Dept. of Energy) or NASA (National Aeronautics and Space Administration), take an independent objective look at it and see whether it makes sense and whether it could be of advantage to the country economically. So he put it in the form of an amendment to the National Science Foundation (NSF) authorization act with a request that a study be carried out by the NSF.

COSMIC SEARCH: When did that occur?

O'NEILL: The original bill was introduced, as I recall, about March or April (1977). It went through committee, was reported out, and the whole bill was acted on by the Senate. It's now in Senate-House conference. It would not be a big thing as it's only calling for a quarter of a million dollars in the first year, but it would be an objective study which, again, would be of great help in laying a broader base for

a bigger study later on.

COSMIC SEARCH: But it would be an Act of Congress and that's significant.

O'NEILL: Yes, I think it is, and there are a great number of bills which have now been reported out of Committee in support of satellite power. There was also a very nice resolution that was put forth by Congressman Olin Teague of Texas at the end of last year on this subject so I would say that Congress has been very much aware of the need to open our options and to possibly consider new industries and new markets, things that would be of economic value.

COSMIC SEARCH: You have done a good job informing them. Getting our representatives and senators acquainted with these problems and convinced that they are worthwhile is important. Now I would like to bring up this problem about space activity, including solar power satellites, and the effect all this could have on searching for extra-terrestrial intelligence due to the radio interference the activity would create. Every time you put something up in the sky that has a transmitter, it's a potential interference threat. Do you see ways of reconciling this?

O'NEILL: Yes, I would think so, John. One of the first calculations that our group carried out for large scale industrial activity in space was concerned with building a large SETI-type receiving dish that would be placed at a long distance from the earth and shielded from interference from the earth by a separate disc-like shield sitting in free space. We concluded that the operation looked very cost effective and that a far bigger SETI dish could be built for a comparable price than if it was located on the surface of the earth.

COSMIC SEARCH: You may be familiar with the recent Russian proposal to place some very large antennas, very large dishes, some kilometers in diameter at about the orbit of Saturn, constituting an interferometer with a baseline of about 20 astronomical units. It came as something of a surprise to me that with that kind of spacing and centimeter wavelengths that the entire universe is within the near-field or Fresnel field of the antenna and therefore it is possible in principle to measure the distance to every object in the universe. You could do 3-dimensional mapping—holography. Shklovsky and Kardashev are among those who have proposed this. It is something that tells us that radio astronomers are yet a long way from the end of their tether.

O'NEILL: Absolutely. I think it's a fine idea. It's an excellent example of the kind of radio astronomy that I certainly hope will be done in the next decades.

COSMIC SEARCH: What kind of a picture do you have of how things might go if expansion into space takes place? What kind of steps may occur?

O'NEILL: I think it may be rather haphazard. I would guess that within the next 5 to 10 years some nation, not necessarily the United States, in fact, probably not the United States, will get such a substantial edge on understanding the problems of maintaining people in space for long periods of time and carrying on large scale activities there, that other nations will begin to get scared and that the response will be a mad scramble to get out there. When that happens, presuming we have a president who would support it, as in the case of the Apollo project, I think there would be good Congressional support for a major effort in space and that the net result would be that the United States would be in there among the scramblers. Another 10 years into the future from there—I'm guessing maybe the 1980s for this scramble to begin, so going into the 1990s—there will be several different nations with a space capability and all of them will be carrying on large scale activities. So similarly in that time period it becomes almost a question of semantics when you determine that the first space colony was built. You know how many people are involved, how long they have been there and so on, but you end up with a sort of meaningless question. If you come back 10 years after that, now getting 20 to 30 years into the future, you will conclude that the jump was made even though you can't put your finger on exactly what year it was. Then I would expect that fairly soon in the next century, which is after all not far away, a number of industries could operate more economically in space than they could on the surface of the earth both from the point of view of the availability of materials and the low cost of assured sources of energy.

COSMIC SEARCH: You are assuming now that there will be astro-engineering—mining of the moon and asteroids?

O'NEILL: Yes, it is pretty small scale engineering after all. Some of the present contracts are looking into such projects, like the study being carried out by the Lunar and Planetary Institute. A very small scale of engineering is required to get to the point of being economically interesting. One or two bulldozers is all that it takes. So I would guess that that is inevitable at a certain point.

COSMIC SEARCH: There would then be a gradual filling up of space around the earth resulting in a sort of Saturn's ring of space stations?

O'NEILL: Perhaps so if there are satellite power stations, but, of course, they are just one space application. The kind of guesses that I have made with you, John, are not predicated on satellite power turning out to be economically the best way to go. I think that if satellite power does develop as the best possible method for generating large quantities of base load power then the whole movement into space may go somewhat more coherently, perhaps a little bit faster, but it won't make an enormous difference. I think it's going to happen anyway. One of the first things that people are going to discover when they get out into space in substantial numbers is that the region immediately around the earth is not necessarily the best place to locate a space colony. It might make a lot more sense to go to a place which is richer in solar energy, which means moving in closer to the sun, or richer in materials, which means going to the asteroid belt.

COSMIC SEARCH: One of the benefits of SETI is that it gives us a cosmic perspective. We are so earth oriented that this is needed and certainly space colonization will aid in giving this perspective. These are goals that all of mankind can use to enter into a new phase.

O'NEILL: Right.

COSMIC SEARCH: You have given us a cosmic chart for the future. Thank you, Gerry.


O'Neill

Gerard K. O'Neill is Professor of Physics at Princeton University where he has been a faculty member for 25 years. Born in Brooklyn, New York, in 1927, he served with the U. S. Navy from 1944 to 1946, received a bachelor's degree from Swarthmore College in 1950 and a doctor's degree from Cornell University in 1954. In 1956 O'Neill originated the principle of colliding-beam storage rings in which atomic particles circulate in the rings and then meet head-on, resulting in more efficient energy production than in an

ordinary accelerator where moving particles strike a stationary target. Between 1959 and 1965, O'Neill and a team of physicists from Princeton and Stanford Universities constructed the first high-energy particle storage ring and produced head-on particle collisions. Subsequently, many storage rings have been built, the largest, two kilometers in diameter, being at the European Center for Nuclear Research (CERN) at Geneva, Switzerland.

More recently, as an outgrowth of an undergraduate course, O'Neill has become interested in the space colonization concept. His first publication on the subject appeared in the September 1974 issue of PHYSICS TODAY. This article and his book "The High Frontier: Human Colonies in Space" (William Morrow and Co., 1977) have generated widespread interest in his ideas of employing, within the limits of present-day technology, materials and energy freely available in space to construct large manufacturing facilities and human communities in very high orbit above the earth. O'Neill enjoys mountain hiking, sailing boats and flying gliders.

SIDEBAR

Regarding O'Neill's interstellar vehicles, it is easily shown that to achieve one-tenth the velocity of light (using the annihilation energy of matter and anti-matter) about one-tenth of the mass of the interstellar vehicle needs to be in fuel. However, the mass of the "fuel tanks" (or storage tanks) might be considerably more.

The momentum of a vehicle of mass M and velocity v is Mv. The momentum of the photons produced by the annihilation of the mass m of matter and anti-matter is mc, where c is the velocity of light. Equating momenta,

$$Mv=mc \text{ or } m=(V/c)M$$

For a vehicle with a velocity v of one-tenth the velocity of light we have

$$m=(1/10)M$$

Thus, the required mass of the matter-anti-matter fuel is one-tenth that of the vehicle mass. Since an equal amount of fuel will be required for deceleration at the destination star, the total fuel requirement is twice this.

The energy of the vehicle is $(1/2)Mv^2$. The energy produced by annihilation of the mass m of matter and anti-matter is (from Einstein's equation) equal to mc^2. The efficiency of the system is the ratio of these energies or

$$(1/2)Mv^2/mc^2$$

From the conservation of momentum, as above,

$$v=(m/M)c$$

so the efficiency becomes

$$(1/2)(Mm^2c^2)/(M^2mc^2) = (1/2)(m/M)(mc^2)/(mc^2) = (1/2)(m/M)$$

In our example,

$$m=(1/10)M$$

so the efficiency is

1/20 or 5 percent.

Although the above analysis is simplistic, it gives some insight into the considerations involved.

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