# THE EARTH as a MAN-CONTROLLED SPACE SHIP

*The following is based on an after-dinner talk at the Colorado Springs meeting of the Division of Plasma Physics of the American Physical Society in November 1961. The author retired in January of this year from his post as Technical Associate Director of the Los Alamos Scientific Laboratory after having served as a member of the LASL staff for more than eighteen years.*

*By Darol Froman*

I AM very happy to have the opportunity tonight to express the pleasure of the Los Alamos Scientific Laboratory in cosponsoring this meeting on Plasma Physics. The fine facilities and cooperation of the Air Force and the excellent accommodations in this hotel certainty constitute a fitting environment for the scholarly papers and discussion I heard today.

Now, I don't know much about plasma physics, so I'll talk about something else, but something which touches on plasma physics and fusion. I would like to make a few remarks about possible long-range applications and economics of fusion without much attention to some of the practical aspects. However, what I shall say is based upon such fundamental concepts as the conservation of energy and momentum.

We all know the interest of the Air Force in space and one can hardly study so potent a physical phenomenon as fusion without looking for its possibilities in space applications. To begin with I wish to remind you that it is essentially impossible to make a return space-ship trip to a near star and return in a human lifetime. Edward Purcell [1] pointed this out very clearly about a year ago. He considered two of the best imaginable engines: one which derived its power by conversion of protons to alpha particles and one in which matter and antimatter were annihilated. We can't approach such high performance with D-D and D-T reactions, but on the other hand, if I understand some of the plasma physicists correctly, there is some chance we may learn how to get such reactions in a controlled way very soon—perhaps even in less than a million years. We can, of course, get it explosively now. We are a long way from learning how to get four protons to combine and even further from making and containing half a million pounds of antimatter.

Let's get a few basic numbers in hand. The oceans contain about one third of a billion cubic miles of water. The total deuterium content is about $5 \times 10^{13}$ tons. The total energy available in complete D-D and D-T combustion is about 5 MeV = 8 microergs per deuteron or $2.4 \times 10^{24}$ ergs/ton. Thus, the total energy available from all the deuterium in the oceans is about $10^{38}$ ergs, an awesome number.

Now, let us invent a rocket engine which either squirts the products of the D-D and D-T reactions out the back end at their velocity of formation or allows the products to thermalize. If the reaction goes fast enough to burn essentially all the deuterium, there will not be much difference in the specific impulses in these cases. What kind of specific impulse would we have? A simple calculation shows it to be $2.2 \times 10^6$ sec. Perhaps I should remind you that specific impulse means the number of pounds of thrust exerted per second per pound of propellant ejected. In proper units it is equal to the exhaust velocity of the propellant gases measured relative to the vehicle, divided by $g$, the acceleration of gravity, and has the dimension of time. Table 1 gives other specific impulses for comparison. Our engine is not so bad when one considers that only the first three or four of those listed are in current practice or close to it.

Now with our rocket and D-D engine we can go out to capture asteroids and bring them home. This is a

**Table 1. Specific Impulses**

| *Propellant* | $I_{sp}$ *in sec* | $m_0/m_b$* |
|---|---|---|
| Solid Propellant | $2.25 \times 10^2$ | 200 |
| LOX-kerosene | $2.75 \times 10^2$ | 65 |
| LOX-$H_2$ | $4 \times 10^2$ | 17 |
| $H_2$ at 3000°K (nuclear heat) | $1 \times 10^3$ | 3.2 |
| $U^{235}$ fission products | $1.3 \times 10^6$ | 1.001 |
| D-D, T products | $2.2 \times 10^6$ | 1.0005 |
| $4H \rightarrow He^4$ | $3.7 \times 10^6$ | 1.0003 |
| Matter-antimatter | $3 \times 10^7$ | 1.00003 |

* Mass ratio of single-stage vehicle for escape from earth's gravitational field.

[1] Edward Purcell, Brookhaven Lecture, November 1960.

well-known and ancient idea. The order of magnitude of the effort in accelerating and decelerating an asteroid might be like two earth-escape missions with it—i.e., $m_0/m_b = (1.0005)^2 = 1.001$. So at the best, not counting getting our locomotive to the load and with a 100% efficient engine, we will need to burn about 1 ton of $D_2$ for each 1000 tons of asteroid we bring back. Now I don't know what asteroids are made of, but maybe they are half nickel. Nickel is worth about 50¢ a pound and $D_2$ about $100 a pound. So for $1 million we can buy 5 tons of $D_2$ and with it bring back 2500 tons of nickel worth $2.5 million. I've been thinking of organizing the American Asteroidal Mining and Transportation Co. whose equipment is illustrated in Fig. 1. With a substantial subsidy from Uncle Sam to pay part of the development and operations costs, it might be a good thing. Anyone in the audience with a large bank account who wants in on the ground floor should see me after the meeting.

Now let's look at more distant horizons. I do not understand at all why would-be astronauts want to go tootling off into interstellar space. The quarters and food are likely to be miserable. To get anywhere and back in a lifetime, the speed will have to be very high so as to take advantage of the relativistic change in clock rates. Let's say the speed is to be 99% of the velocity of light. To attain this is not too hard on the pilot and crew. It takes only about a year at an acceleration of $g$ to reach such a speed. There is, however, as Purcell pointed out, a little shielding problem because of the interstellar hydrogen. It is estimated that there is one atom of H per cubic centimeter in space. A fair-sized rocket traveling at $0.99c$ through this stuff would then receive about a 5-mA current of 6-BeV protons. This 30-MW beam would produce quite a radiation field. Some of the problems of such space travel are illustrated in Fig. 2. There should be some way to get around these troubles. I got to feeling sorry

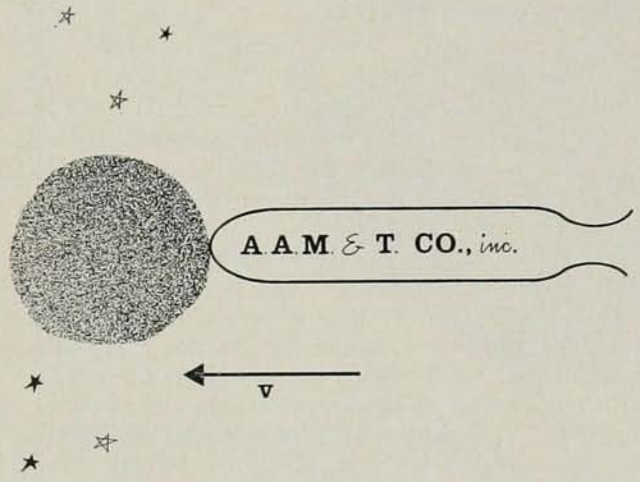


*Fig. 1.* An American Asteroidal Mining and Transportation Company locomotive bringing home a cargo

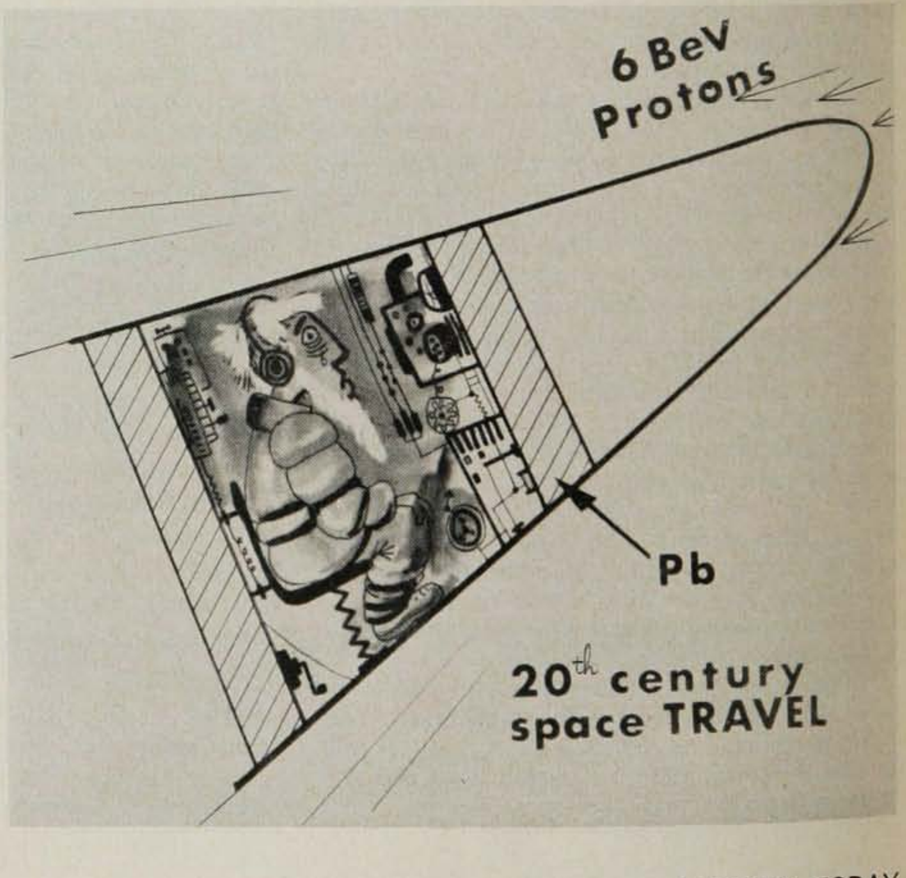


*Fig. 2.* The mode of space travel in vogue in this century presents some difficulties

*Fig. 3.* Travel in comfort the American Earth Moving Co. way

not only for the poor astronaut in the picture whose troubles have been described in the doggerel verse you found on the table (see Appendix 1) but also for the stay-at-home folk who, if the sun runs true to form, will someday get fried to a crisp and the remains left out in the cold. According to Hoyle (Fred Hoyle, that is), it will become too hot on the earth for comfort, even for life, in about two billion years. This constitutes a real reason for going elsewhere and about the only compelling one I know. It occurred to me that for most of us the most comfortable space ship imaginable would be the earth itself. So if we don't like it here because the sun is dying or something, let's go elsewhere, earth and all. We will not have to worry about all the usual hardships of space travel. For example, the radiation problem will disappear because of the atmosphere and because we will be going at low speed. The ease and comfort of this mode of travel are shown in Fig. 3.

How are we equipped energy-wise to handle this job? First of all, what about heat and light? We will be a long time away from the sun or other near star. The power received from the sun and re-radiated from the earth to space is, as everyone knows, 1.9 cal/min/cm$^2$ normal to the sun's rays. Assuming an albedo of 0.5, the total power received by the earth in this way is $10^{17}$ watts. We saw that the oceans' deuterium content could supply $10^{38}$ ergs. So this deuterium could supply our heat and light (away from the sun) for three million years. There is no problem here. Or maybe there is a little problem. At this rate we would use $3 \times 10^{10}$ lb of deuterium per year which, at $100 per lb, would cost about 100 times the current Air Force annual budget. Perhaps we could get it in quantity for wholesale prices.

But how about getting away from the sun? The energy required for the earth to escape from the sun's gravitational field is about $2.4 \times 10^{40}$ ergs. This is much more than all our deuterium can give us, so we shall have to seek some other energy source.

There is clearly no point in using antimatter for this purpose because, as we shall see, the specific impulse is much too high and the conversion of energy to enough antimatter would be difficult. It would take much too long to collect the energy from sunlight. If we collected all the sunshine falling on the earth it would take about fifteen times the estimated remaining life of the sun to accumulate sufficient energy to accomplish the escape of the earth from the solar system.

I believe we shall have to go to the $4p \rightarrow He^4$ reaction. With this reaction, all the protons in all the oceans can give us about $10^4$ times as much energy as all the deuterium, i.e., about $10^{42}$ ergs. This gives us forty times as much energy as we need to get away from the sun. To just get away we will need effectively to double the earth's kinetic energy which means adding an increment in velocity, $\Delta v = 1.25 \times 10^6$ cm/sec. Using the specific impulse given in Table 1 for the proton reaction we find that in the ordinary way of propelling rockets we would need to expel fifteen times the total mass of hydrogen available.

This presents us a case in propulsion we are not very used to. What we usually ask for is the highest possible $I_{sp}$ in order to minimize the amount of propellant. In this case, we wish to conserve our energy resources for a long flight and we search more for minimum energy than for minimum mass of propellant. On the other hand we don't wish to use up any large fraction of the mass of the earth as propellant. As a compromise, I suggest we allocate about 25% of the available energy to getting out of the solar system, save about 25% in case we may eventually want to get into another similar one and use the remaining 50% for heat, light, and interstellar propulsion. A little figuring suggests the following fuel and reaction for an engine with 50% efficiency:

$$2\ H_2O + 1000\ SiO_2 \rightarrow He + 2002\ O + 1000\ Si + 26.7\ \text{MeV}.$$

With equipartition of energy, this propellant has a specific impulse of $2.9 \times 10^4$ sec.

To get out of the solar system with this propellant we will need to exhaust 4% of the earth's mass, but I guess we can afford it. We can get a quarter of it by using the moon which will be no good to us anyway away from the sun. We need to leave the solar system in a time short compared to our estimate of the stable life of the sun and also because we do not wish to use up too much of our available light and heat energy at low speeds not getting anywhere. I suggest 100 million years for this stage. This would require a mass flow rate of propellant (mostly sand) of $8.7 \times 10^4$ tons/sec.

Actually, this formula goes with using an engine efficiency of about 50%. By using a 100% efficient engine we can reduce the amount of sand and get by with expelling only 2% of the earth's mass. If we don't wish to save enough propellant capacity to get back into a similar orbit around some other sun, we can use only the mass in the moon and 40% of our available energy.

Table 2 illustrates what can be done by changing the ratio of sand to water in the propellant.

After this stage (i.e., getting out of the solar system), we will wish to use our hydrogen as propellant at the same rate we need to use it for heat and light in order to maximize the distance we can go. This results in a mass flow rate of only 300 lb/sec and an acceleration of about $8 \times 10^{-17}$ $g$ which is certainly quite comfortable. We can then travel this way for $8 \times 10^9$ years which is at least four or five times longer than we are allowed if we stay here. In this time if, for example, we accelerate half the way and slow down the other half, we can go about 1300 light years. In this time and distance we should be able to figure out how to refuel (i.e., fill an ocean or two) from some handy planet and keep the earth operating indefinitely. With all our oceans we are not able to get going fast enough to collect enough hydrogen from interstellar space to make any appreciable contribution to our energy store even if we go through luminous nebulae, where the density of hydrogen is relatively high, perhaps 500 atoms per cubic centimeter.

**Table 2. Earth escape possibilities with various propellant mixtures**

| Propellant-ratio: | | | |
|---|---|---|---|
| molecules $SiO_2$ / molecules $H_2O$ | 500 | 125 | 50 |
| $I_{sp}$ in sec. | $2.9\times10^4$ | $5.7\times10^4$ | $9.2\times10^4$ |
| Engine efficiency, % | 50 | 100 | 100 |
| % of earth's oceans required | 24 | 25 | 40 |
| % of earth (+moon) expelled | 4 | 2 | 1 (=moon) |

In our interstellar travel it will take very little energy to guide us through space. We can literally "guide by the stars"—i.e., select, using only a little energy, the impact parameter for a star near our path and, thus, the appropriate hyperbolic trajectory to put us in the desired direction.

We had better begin to learn how to combine protons before long. Time is running out. We have already passed two thirds of the useful life of the sun. I predict a pleasant existence in space—we will get away from the daily grind. Perhaps we shall not wish to join another star—life in space may be more desirable. (I haven't yet figured out a good way to leave certain people behind. It has been suggested that we use them for propellant. The human body is not constituted with quite as good proportions of the elements for our propellant as is damp sand. Nevertheless, the proportions are not too bad and we can in this way take care of the problem of overpopulation.)

The best groups in the world to undertake this project are assembled here tonight. There are really only two problems to solve. One is scientific, namely, learning how to make four protons combine into an alpha particle. The plasma physicists here can easily tackle this problem. The second problem is just engineering, although on a fantastically large scale. I am sure you will agree that the United States Air Force is the most experienced group in the world in letting and monitoring the development and manufacturing contracts for the engines, nozzles, and feed systems we shall need for propulsion of the earth.

Appendix 1

# *the last astronaut*

Now a solar sail is of no avail
In an astronaut's terrible plight
In the all pervading night
Of his intergalactic flight.

For the rare photon and bare proton,
At a millimicro lux
And with isotropic flux,
Fail the problem's central crux.

Expired its guarantee for high *I* SP
Is the nuclear engine's thrust,
'Cause the nozzle's all riddled with rust
And the propellant tankage is bust.

The ion expulsion for better propulsion
Was made by the AEC
At NASA's requested eV
For ARPA's requirement, you see.

But the ion gun had failed to run
Since the cesium plasma fell
Down temperatures open well
In the thermoelectric cell.

The heat was supplied from the fission inside
Which stopped when the fuel burned out;
And the poisons, all gathered about,
Had dealt *k* effective a clout.

The final injection for plasma ejection
By the patented mirror machine
Was made ere the coolant had been
Spilled out through the holes we have seen.

And the magnetic bottle, in obeying the throttle
To admix antimatter with real,
Sprung a leak in its B-theta seal
And squirted the coils a good deal.

Thus came the destruction of the superconduction
Which kept the magnetic field high.
This let all the antistuff fly
Away to react in the sky.

The missile's main mission when powered by fission
In the rocket motor's core
Was to visit planets galore
To expand the economy more.

And to find life space for the human race
Whose reproductive yen
Spewed forth so many men
No room was left for a wren.

He had got off his course beyond gravity's force
In the solar orbit desired.
And the added speed he acquired
'Till all the engines expired.

Nearly stopped all his clocks and kept his brown locks
From aging and turning to gray.
While he frigged around for a day
Earth's clocks ticked eons away.

Then he looked off afar and saw a bright star
And thought of Orion's strong belt
Whose impact had often been felt
When a push to the platform was dealt.

So he unpacked a bomb and directed it from
A gyro that stable had been
Toward a signal he'd seen
On his fluorescent screen.

The speed was decreased through momentum released
By the unidirectional blast;
But the rocket was going so fast
He had to use all but the last.

Then about a year later (the time seemed much greater
And it was on the Earth and the sun)
He returned where the trip had begun
And planned for his homecoming fun.

But the sun had grown dim, and way out on the rim
Of the dead solar system he spied
The Earth, where the people had tried
To expand the space nature supplied.

And things were not nice on that spheroid of ice
With its atmosphere turned into snow,
And not even a creature below
To start a new family to grow.

So he pulled out the string on that last man made thing,
And he thought himself clever
To have solved thus forever—
—Boom—.