ety would be much lower than the present system. Not only because so much is now certified about each individual that is irrelevant to a specific application, but because without the insistence on in-school certification, the schools themselves could be more effective and far less costly. Both local and national funds could go much further if they were diverted from the demands of certification and were applied to the broader range of educational environments that have been developing during the past half century.

Kids play hooky from school to come to the Exploratorium. That is supposed to be bad, but I think it is good and maybe the beginning of a trend.

FRANK OPPENHEIMER
The Exploratorium
San Francisco, California

Fusion reactor hazards

Bernard Cohen's letter in the November issue (page 15) correctly points out that fusion power reactors may generate as much as 10^5 times as much tritium as fission power reactors presently do, and he expresses a legitimate concern regarding the containment and control of that inventory. We in the Division of Controlled Thermonuclear Research have appreciated these problems ever since they surfaced in our first fusion-reactor conceptual designs some years ago. From the first, we have accepted as a basic premise that fusion power reactors must control routine and accidental radioactive effluents and resultant offsite exposures at least as well as the "as low as practicable" guidelines for fission-reactor designs.

In all of our conceptual design work we have been proceeding on the basis that tritium releases cannot exceed the current stringent controls on fission reactors, and we have included specifications (such as tritium monitoring, containment, extraction, recycle and disposal systems) to ensure "near zero release" of tritium from these preliminary reactor designs. We have instituted a vigorous R&D program with the specific aim of developing and demonstrating tritium control systems that will perform at least as well, in terms of *total* curies released, as do tritium control systems for fission power reactors. We are happy to say that all of our preliminary design studies to date indicate that the tritium in fusion reactors can be contained and controlled to the point where total tritium released from fusion power reactors will not be any more of a problem than it is in fission reactors. In this regard, we would like to reiterate a major point made by Cohen: If tritium releases can be kept to the level obtained in fission systems, the exposure of the public to radioactive releases will be truly negligible in the context of present-day power systems. The tritium release problem in fusion reactors appears to us readily manageable and should in no way require the public to make any safety tradeoff in accepting fusion power as an energy source.

BENNETT MILLER
FRANKLIN E. COFFMAN
Division of Controlled Thermonuclear Research
USAEC, Washington, D.C.

Colonies in space

I read with interest and pleasure Gerald K. O'Neill's article "The colonization of space" (September, page 32). As an avid science-fiction reader, however, I was distressed to see that O'Neill did not mention two recent stories directly related to his concepts. These stories are "Rendezvous with Rama" by Arthur C. Clark (1973, Ballantine Books) and "Ringworld" by Larry Niven (1972, Ballantine Books). The first of these discusses the cylindrical geometry in considerable detail, and the second scales up the concept to a ring of about 1 AU radius, about 200 000-km wide and with 100-km sidewalls. I hope some of your readers will read these books as well as the fascinating article.

ROBERT N. NELSON
Georgia Southern College
Statesboro, Georgia

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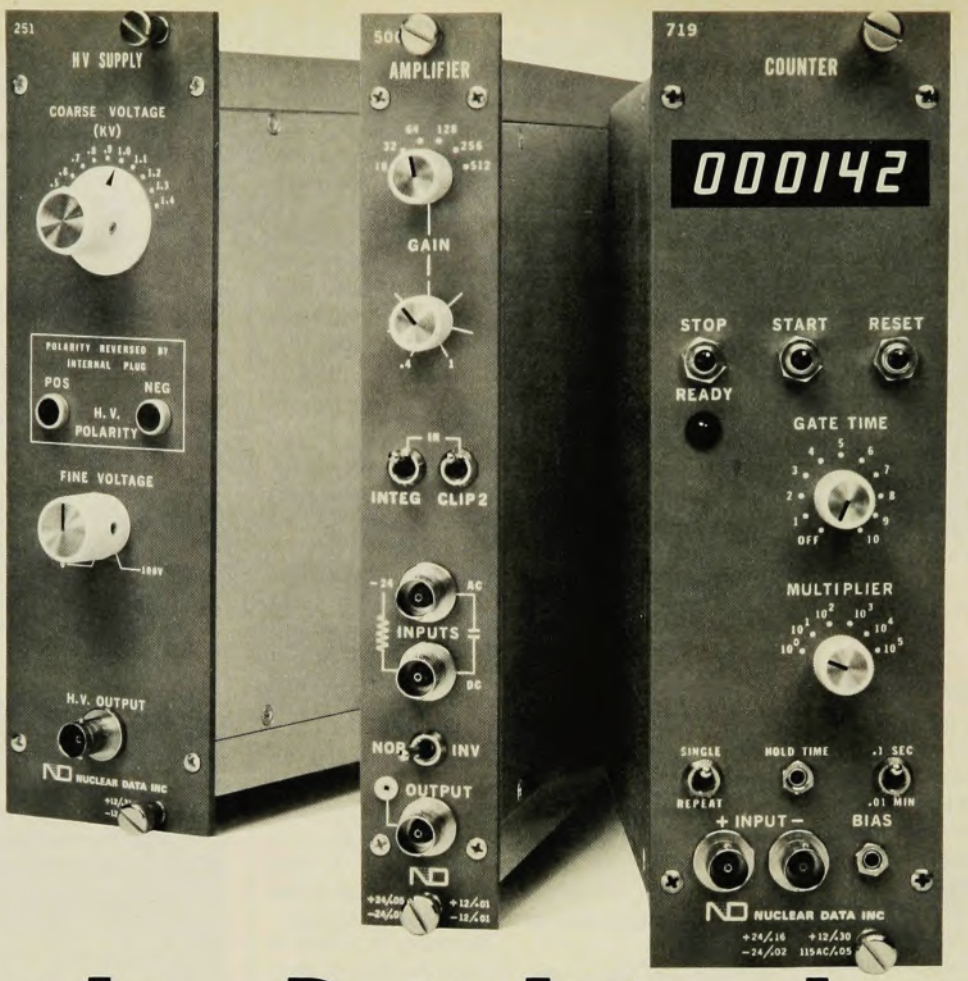
Although O'Neill's article gives a detailed discussion of how to live and work in space, including the transportation of needed raw materials from off-Earth sources, he ignores the matter of getting the colonists off the Earth. Using his figures for the reduction of the population level from 16.5 billion to 1.2 billion within 30 years, and assuming that the population growth remains at 1.98% per year, one finds that in 2050 it will be necessary to remove 621 people/minute, just to keep the population stable. This is the equivalent of 2 jumbo jets, every minute, around the clock. By ignoring population growth, we find that 970 people/minute must leave to achieve the desired reduction in 30 years. Combining growth with backlog, we find that to meet the stated program we must start out launching 1531 people/minute, and gradually taper off to 1015 people/minute until the optimum population of 1.2 billion is reached. Then a leisurely 45 colonists/minute will suffice to maintain the status quo. Even ignoring the complexities of severing the colonists' ties on Earth, such as homes, jobs, and so on, he sees that the logistics of "The Great Exodus" would tax the Earth's waning resources to nearly the same magnitude



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letters

as the actual construction of the colonies.

Also, past migrations, such as the colonization of the New World, have shown that few people are willing to undertake such a venture, especially when mass restrictions would dictate that virtually nothing of the old life could be taken along. Unless we resort to forced deportation, I believe that we will have to rely on ZPG combined with the colony program to draw off those who for one reason or another are too restless to fit into society.

ALAN P. BIDDLE
Jacksonville, Arkansas

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O'Neill's proposed colonization of space cannot possibly solve the problem of population growth either in the US or in the rest of the world. We would need to launch over 1000 Apollo spaceships each day just to transport the daily increase of the US to the space stations (present growth rate is 1.5 million people per year). The world would need to launch over 60 000 Apollo spaceships each day (present growth rate is 70 million people per year). These feats are certainly not feasible by the 1980's, if ever, especially when one realizes how many months of exacting labor it takes to prepare just one Apollo spaceship for launch.

ELIZABETH B. FRASER-SMITH
Los Altos, California

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O'Neill's article fails to come to grips with the major question—*should* we colonize space? In his article O'Neill says "the ultimate size of the human race on the newly available frontier could be at least 20 000 times the present value." But I ask, what is the value of increasing our numbers 20 000-fold? What anthropocentricism impels Man to think he has the right to procreate until he fills every recess of the universe?

O'Neill also suggests that if in the first 500 years we use up all the materials of the asteroids to build space colonies, we could gain another 500 years by using up the moons of the outer planets. Where does all this all end? On Earth, we have in the course of a thousand years destroyed a balance it took nature a billion to achieve. Must we go on to pollute and pillage the entire universe?

The solution to overpopulation and pollution does not lie in trying to flee our world and build new worlds out of metal and glass. The only true solution lies in accepting the natural limitations of our environment and in attempting to live in harmony with nature, rather than trying to conquer and exploit it.

BRUCE HARTENECK
San Jose, California

THE AUTHOR REPLIES: Although I admire the work of Arthur Clarke and Larry Niven, the recent science-fiction stories were not mentioned because, in my opinion, they contained no useful ideas contributory to a practical scheme for space colonization. In particular, neither contained the geometry described in the September article. Clarke's early work on electromagnetic acceleration, on the other hand, was directly relevant and was therefore credited, though I had been unaware of it when my own work was done.

In response to Alan Biddle and Elizabeth Fraser-Smith, may I point out that the September article concentrated on the initial problem (Model 1 construction) because continuing technology is certain to invalidate any detailed plans made now on how to solve a problem that will not arise for at least some forty years. A conservative, existence-proof approach would use the technology of the composite engine on which much research was done in the 1960's. The necessary fleet of single-stage-to-orbit composite-engine shuttles, fully reusable, is comparable size to the present fleet of commercial jets, as is to be expected. From orbit to L5, one would probably use large ships powered by TLA reaction engines, with lunar materials as reaction mass, powdered or vaporized. Both the shuttles and the ships could be built at L5, where there could at that time be a large aerospace industry using low-cost solar power and titanium-rich lunar materials. A cost calculation based on the same amortization schedules that now govern ticket prices on commercial jets, but assuming vehicle costs more than three times higher per unit vehicle mass, leads to an estimated ticket price, Earth to L5, equivalent to about three month's salary for an average worker in the productive environment of L5, assuming present-day salary scales in developed countries. To indicate the practicality of such a development, one should compare the 40-year timespan from now to 2014 with the 40-year timespan from 1922 to 1962. In 1922, the number of people who had crossed the Atlantic by air was comparable to or less than the number of astronauts who have now been to the Moon. By 1962, mass transport across the Atlantic in commercial jets was commonplace.

With references to Bruce Harteneck's comments, the confusion is between the limits to growth and the optimum size of a population. If human beings now and during the next several hundred or next several thousand years are to have as many options as possible (so that all people can reach a high standard of ma-

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terial well-being and can be as free as possible to develop their potentialities as they wish) then a way must be found to free humankind from immediate, hard limits on energy, on materials, and on the usage of both within the human habitat. Every projection made so far of a stable society, living within the constraints of fixed land area, expensive energy, limited materials and tight limits on allowable energy flow into the biosphere, concludes that such a society must necessarily be coercive, with many rules and only limited options on behavior. I believe that space colonization, which can remove those limits, offers the best hope for a future that contains a high living standard for all human beings, together with the greatest opportunity for diversity and freedom in lifestyles. Nowhere in my article did I state that I desired a human population of some given size. Incidentally, there is no reason why "pollution and pillage" should characterize space colonization: With unlimited low-cost energy for recycling, and habitats small enough so that recovery of pollutants is easier than on Earth, there is every reason to suppose that a space-community could run forever (or at least for the several-billion year life of the Sun) without causing any pollution either internally or externally.

G. K. O'NEILL
Princeton University
Princeton, New Jersey

Three relative quanta

c plus *c* equals *c*
1 plus 1 equals 1
Bother me not with reason old man
The universe has its own logic.

Lambda equals *h* over *p* sheds light upon light
Uniting contradiction
Its existence forcing the world
To change its mind.

Delta *p* delta *x* equals *h* bar over 2 means I am not sure
Where I am, or how fast I am going where
But I think maybe I can guess
How far off course I am.

DAVID DAVIS
Tucson, Arizona

Record authorship

In the June issue (page 37) Steven Weinberg raises the question whether 55 names on a paper sets a record. The answer is no, it falls considerably short. The Bucharest-Budapest-Cracow-Dubna-Hanoi-Serpukhov-Sofia-Tashkent-Tblisi-Ulan Bator-Warsaw collaboration has published a series of papers in *Nuclear Physics* all of which surpass 55 authors. In volume **B52** 414 (1973) the number of participants is 89. Subsequently the strength of the group fell off, bottoming at 67 in **B79** 57 (1974).

VIRGIL L. HIGHLAND
Temple University

British education

I read with interest the review of the ten-volume Harper and Row series on "Solids, Liquids and Gases" by A. A. Strassenburg in the March issue (page 45). While I have not yet been able to look over the books I feel that the disappointment expressed in the review may arise, in large part, from the reviewer's failure to appreciate the not inconsiderable difference in emphasis between American and British educational curricula.

A typical British grammar-school student who intends to specialize in the sciences will start calculus at sixteen years of age. At age eighteen he or she will be presumed to be of such a standard that a typical college-entrance program was that of oblique impact between balls with non-unit coefficient of restitution. At the time when I attended Imperial College one had merely four months in which to attain final-degree standard in four mathematics papers—and in under two years one reached "special" (more usually termed "honors") level in one's major subject. The pace was indeed hot and furious—and some persons claimed that one had no time to assimilate the finer aspects of the material, or, indeed, to become aware of developments in related areas. While the above comments apply to honors degrees, they also apply to a lesser extent to the general-degree awards. In this context, some of the dismay expressed by your reviewer may be understandable.

P. E. LILEY
Purdue University
West Lafayette, Indiana

More on 1910

I noticed in your April issue (page 13) and in the October issue certain identifications of physicists who attended the 1910 meeting of The American Physical Society at the National Bureau of Standards. In the October issue, no. 29 was tentatively identified as Albert A. Michelson. I am confident that this is not Michelson, as it has no resemblance to any of the pictures of him that I have seen or have in my own files. Furthermore, it is unlikely that Michelson would have attended a meeting at the National Bureau of Standards at this time because he and Samuel Stratton, the Director, were very much at odds for many years due to the fact that Stratton had left the University of Chicago to accept the Directorship.