J. R. MUIR

Review

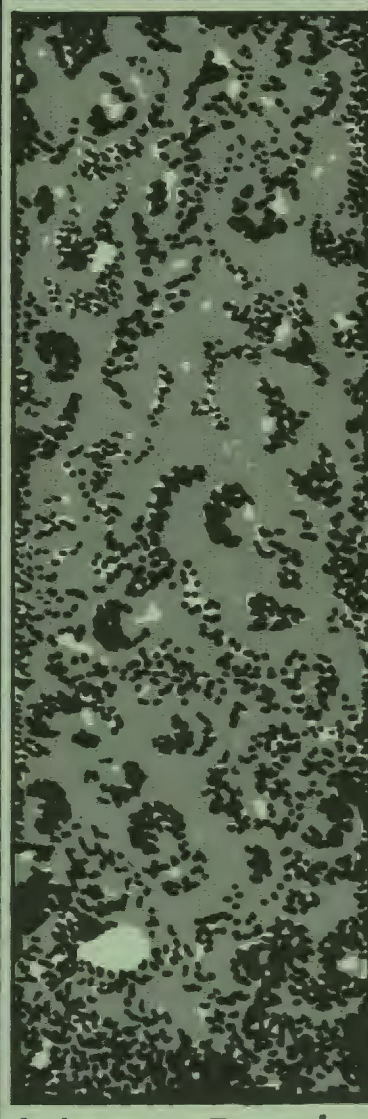
SPRING 1970

OAK RIDGE NATIONAL LABORATORY

The NEL Proposal

AMW COMMENTS

Edge of Matter



BOOKS

WASTE HEAT

Moon Rocks

Review

OAK RIDGE NATIONAL LABORATORY

VOLUME 3, NUMBER 4 **SPRING 1970**

THE COVER: This issue of the *Review* demonstrates the wide range of interests motivating ORNL research, a range that may include involvement with environmental problems to the extent that they can be seen to have a technological orientation. Significantly, however, the feature article concerns itself with the kind of frontier research that has historically characterized the Laboratory, affording the expertise that uniquely qualifies it to direct attention to broader issues. The story of ORNL's transuranium program begins on page 1.

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Graphic assistance is provided by Graphic Arts and Photography Departments of the ORNL Division of Technical Information.

The *Review* is published quarterly and distributed to employees and others associated with the Oak Ridge National Laboratory. The editorial office is in Room 283, Building 4500-North, Oak Ridge National Laboratory, P. O. Box X, Oak Ridge, Tenn. 37830. Telephone: 483-8611, Extension 3-6510 (FTS No. 615-483-6510).

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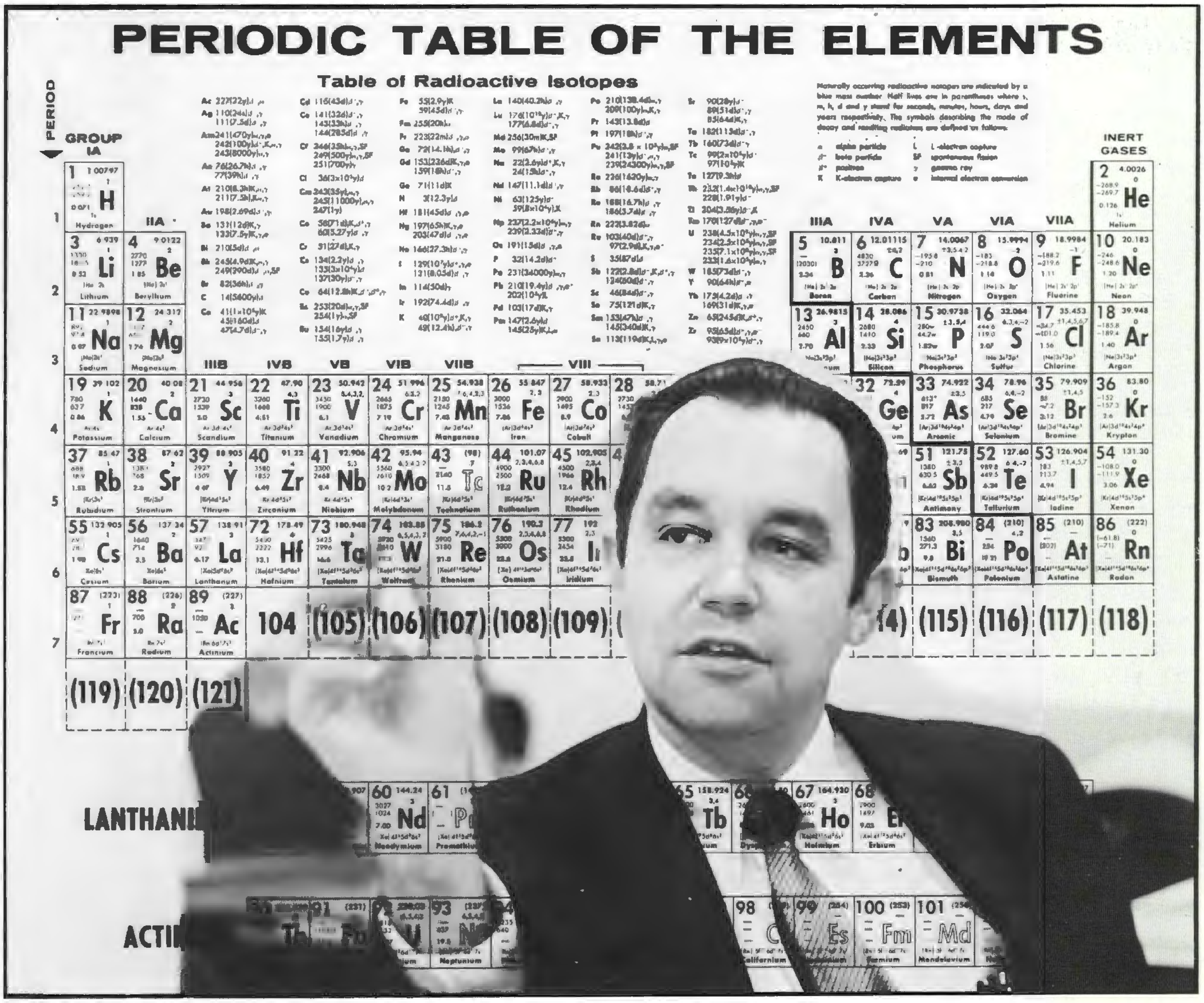


Explorations on the Edge of Matter

An account of the accomplishments and hopes of the workers in the forefront of transuranium research

By O. L. Keller

THE TRANSURANIUM ELEMENTS, the elements beyond uranium, occur at the top end, the open end, of the Periodic System. These elements are therefore the frontier for furthering our knowledge of the chemical and nuclear properties of matter. They are all man-made. The elements through number 100 (fermium) are made by neutron irradiation of transuranium element targets in our

Lew Keller joined the staff of ORNL's Chemistry Division in 1960 from MIT where he received his doctorate in physical chemistry to work in the transuranium elements program. The production of heavy actinides in the HFIR, and their use as target materials for the isochronous cyclotron beams, have permitted the study of the elements above 100. Keller's principal personal research interest is now the development of the structure of the Periodic System in this critical region at the end of the actinide series and the beginning of a new series. As director of ORNL's Transuranium Research Laboratory, he is in intimate touch with the most recent developments in the heavy elements studies, some of which he recounts here.

High Flux Isotope Reactor, while elements above 100 (currently up to 104) are investigated by bombarding targets of transuranium elements with beams of ions in our isochronous cyclotron, ORIC.

At the time of their discovery, the transplutonium elements were merely laboratory curiosities. The motivation of the researchers was purely scientific, and although there was no idea that any applications for them would ever be found, some of them since then have indeed found application—in arms control, for example, and health, and space exploration, with the apparent promise of many more to come. Our main effort at ORNL, however, is directed toward ferreting out their nuclear and chemical properties in order to lay a base for a general understanding of the field.

In the area of fundamental exploration a most exciting possibility has been opened up by nuclear theorists who predict that elements much heavier than those currently known may exist in an "island of stability." One of the earliest calculations, in fact, was carried out at ORNL by Felix Wong, in the Physics Division. Glenn Seaborg has pointed out a useful analogy by considering regions of nuclear stability as land masses in a sea of instability. He has contrived a three-dimensional graph, with the proton and neutron numbers that differentiate the nuclei along the y and x axes respectively, and the z axis, or height, denoting the degree of stability. Thus, certain features appearing as "mountains" on the land mass represent especially stable nuclei resulting from a combination of a so-called "magic" number of protons and/or neutrons. At about element 106 or 107 the half lives get very short and the land mass disappears into the sea of instability only to reappear as an island of stability higher up around element 114. The superheavy elements fit into the framework of nuclear physics in a way that is analogous to the way artificial radioactivity and fission fitted in before they were discovered. The island of stability, if it exists, can reasonably be expected to offer a rich field for exploration in much the same way as other fundamental discoveries.

Uses of Transuranics

An isotope of element 98 (named californium for the state and university where it was discovered) is an intense neutron source that appears to have a promising future. One gram of the californium isotope of mass 252 emits 2.4×10^{12} neutrons per second. The neutrons are capable of penetrating containers surrounding nuclear materials and inducing fission in isotopes such as uranium-235 or plutonium-239. Characteristic radiations resulting from such fission may allow accurate analyses to be carried out. Thus, one possible application of such an intense, portable neutron source may be as an interrogator for weapons and safeguarded nuclear materials, a method useful, for example, to the policing of the Nuclear Non-Proliferation Treaty.

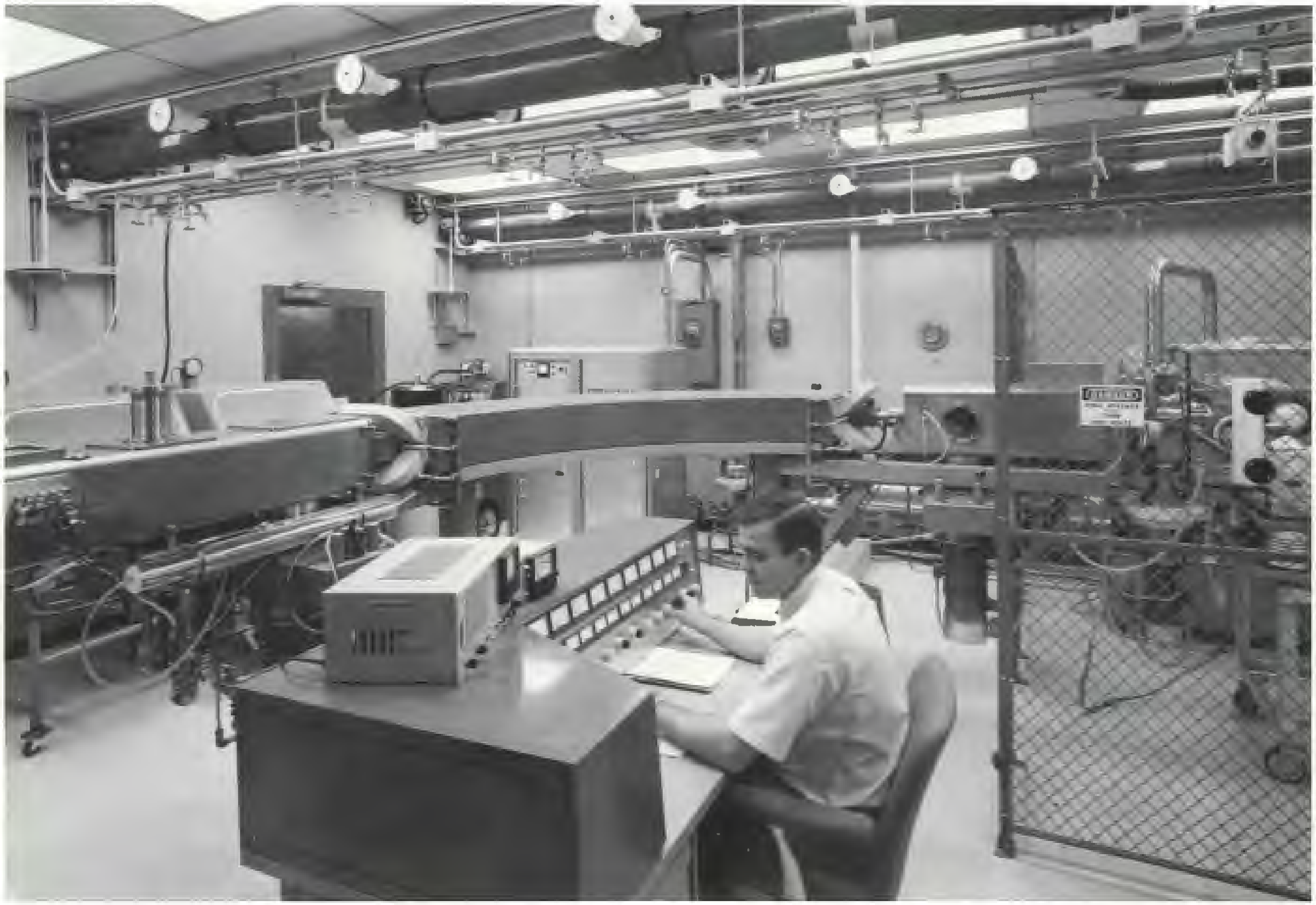
Californium-252 is also being investigated for its use in medical applications. Perhaps its greatest use will be to produce very short-lived isotopes on location in hospitals for immediate use in patients. Another possible use currently under study is as a source of neutrons to destroy cancerous tumors by implantation of a "californium needle." Radium needles, giving off gamma rays, are already in use, but there is evidence that the gamma rays are not as effective in the anoxic parts of the tumors as neutrons.

Transuranium elements are already in space. Several Surveyor spacecrafts have soft-landed on the moon. In one of their experiments they were set up to analyze lunar soil using alpha particles emitted by an isotope of element 96, curium. The devices that detected the scattered alpha particles were calibrated using an isotope of element 99, einsteinium. Also, several experiments left by the two Apollo crews that visited the moon are using plutonium-238 as sources of energy.

Many more applications are under study, including oil well logging and prospecting for mineral deposits (such as gold and silver) on the ocean floor as well as on land.

At the TRL, Enzo Ricci and Tom Handley of Analytical Chemistry have found californium-252

Curt Bemis at the controls of TRL's electromagnetic isotope separator.



to have several virtues as a neutron source for activation analysis. These include its portability and absence of maintenance problems as compared to reactors and other neutron generators.

Since useful lasers have been made with ions in the lanthanide rare-earth series, it is important to evaluate transuranium ions, which occur in the actinide rare-earth series, as potential laser materials. This evaluation has involved a study in the TRL of the spectroscopic properties of the actinides in suitable media. There are only two intense solid state lasers: the ruby and neodymium in glass; and only a few liquid laser systems. The actinides could therefore be important in this field if they could supply new wavelengths at high intensities. The survey of the actinides has involved extensive fundamental spectroscopic investigations that can be used to forecast the success of a potential laser candidate. These studies have been carried out by Len Nugent, Jim Tarrant, and John Burnett in Chemistry; George Werner in Physics; Cabell Finch in Metals and Ceramics; Russ Baybarz in Chemical Technology; and Peter Tanner, of the University of West Florida in Pensacola. The systems which look most promising are americium in calcium tungstate for the solid state and curium in heavy water for the liquid. In heavy water, curium glows much more brightly than in light water. Apparatus is being assembled to allow a test of these laser systems.

Nuclear Chemical Aspects

By making new isotopes of the heaviest elements, and investigating their modes of decay, we are exploring the currently known edge of matter to see what factors hold nuclei together under conditions of extreme instability. In carrying out these investigations we have two important instruments: the ORIC and the High Flux Isotope Reactor.

In a recent experiment Curt Bemis of the Chemistry Division and Livermore's Ken Hulet and Ron Lougheed used the ultra high neutron flux of 4.2 $\times 10^{15}$ at the HFIR to make the most sensitive test yet carried out for the possible existence of a heavy isotope of element 100, fermium–258. This isotope has proven most elusive in that it has never been made in a reactor or even in experiments where explosions of thermonuclear devices furnished a very intense burst of neutrons. The HFIR experiment consisted of neutron irradiations of about 10^8 atoms of 97-day fermium–257 which had been produced in the HFIR and recovered in the adjacent Transuranium Processing Plant (TRU). The fermium was chemically purified to make sure no other fissionable isotopes were present, and then deposited on the end of a cylinder (called a "rabbit") of ultra-pure beryllium. Using a high-speed pneumatic tube transfer assembly, the researchers repeatedly cycled the rabbit between the center of the HFIR core and the counting station with a transit time of 270 milliseconds. Although any fermium–258 resulting from the addition of a neutron to the fermium–257 would decay by spontaneous fission, no such fission events were detected. The experiment allows 30 milliseconds to be set as the upper limit for the half life of this still undiscovered isotope. Its unexpectedly short half life is not yet understood in the framework of current theory.

Carbon and nitrogen beams have recently been developed at the ORIC for use in making isotopes of the heaviest elements for chemical and nuclear study. Our first efforts have involved discovery experiments for two new isotopes of californium, element 98. The targets are uranium isotopes that have been highly enriched by the calutron electromagnetic separators at Y-12. Bob Silva, Dick Hahn, Curt Bemis, Merrit Mallory, Pete Dittner and I (all in Chemistry) and Ken Toth from Electronuclear now have strong indications that they have discovered californium–241 and most probably californium–240. Confirmatory experiments are in progress.

The availability of relatively large quantities of 2.6-year californium–252 has allowed its use in the measurement of the energy spectrum of delayed neutrons in spontaneous fission. The studies to date have been carried out by Gene Chulick and Paul Reeder of Washington University, St. Louis; and ORNL nuclear chemists Gene Eichler and Curt Bemis. In addition to being a novel form of nuclear spectroscopy, the measurements are of importance in the field of fast reactor kinetics and control. Using time-of-flight methods, about 30 discrete neutron energy groups have been resolved. An attempt is currently underway to identify these energy groups with specific delayed neutron half-life groups by appropriate variation of collection and counting intervals to emphasize particular half-life periods.

The Role of the Chemist

Let me digress here briefly to describe the interactions of chemistry with nuclear physics. Over the years, the most significant way chemistry has affected nuclear physics has been through the identification of the atomic numbers of unknown elements and isotopes. To realize this, one need only remember that first-class chemistry was the key to the discovery of fission. In 1938, fission of the atomic nucleus was thought to be impossible. In order to dispel this preconceived idea, Hahn and Strassmann had to establish beyond the shadow of a doubt that the "radium" and "actinium" activities being seen upon irradiation of uranium with neutrons were really due to the chemically similar elements barium and lanthanum, respectively.

Similarly, since chemical properties are related closely to atomic number, chemistry has proved most important in establishing the identity of newly discovered elements. For example, the recent chemical identification of the atomic number of element 102 (nobelium) was the final piece in a puzzle that took ten years to solve. The isotopes of 102, discovered first at the heavy ion research centers of Berkeley and Dubna, had half lives that were too short to allow chemical experiments of other than a corroborative nature to be performed. Of necessity, therefore, the identification rested mainly on nuclear results not directly connected with the atomic number. The current developments at Oak Ridge, Berkeley, and Dubna toward fast, definitive, chemical methods give promise of alleviating the situation with respect to future element discoveries, including the superheavies, and preventing a repeat of the long, drawn out controversy that surrounded the nobelium work.

An illustration of these developments is furnished by the recent nobelium work. The first phase was carried out at Berkeley last year by Bob Silva, now with ORNL, in collaboration with Berkeley's J. Maly, T. Sikkeland, A. Ghiorso, and M. Nurmia. Their most important experiments involved the measurement of the stability of No^{2+} relative to No^{3+} in aqueous solutions. This relationship, characterized by the so-called "II-III oxidation potential," is a fundamental chemical property of nobelium. For this measured potential to become convincing proof that the isotope under study was indeed of element 102, it had to be shown to fit in logically with the oxidation potentials of the elements around 102 in the Periodic Table. The insight for the required correlation was furnished by Nugent, Burnett, and Baybarz. Their results, obtained by a combination of theory and experiment, show the lanthanide II-III oxidation potentials and the analogous actinide values. The II-III oxidation potential measured by Silva and coworkers at Berkeley for nobelium is seen to fit in nicely with those of the neighboring elements on the basis of the actinide hypothesis.

TRL Research

Other recent developments at TRL include the first preparation of berkelium metal (UT's Joe Peterson and Jim Fahey, with Baybarz) and the first preparation of volatile organometallic compounds of berkelium, californium and curium (by P. G. Laubereau of Technische Hochschule, Munich). Some volatile compounds of americium have been characterized by Merlin Danford, Cecil Higgins and Willis Baldwin, also of Chemistry. Volatile compounds are of great interest to us since we hope to study the chemistry of accelerator-produced atoms of elements 103, 104, 105 and 106 using gas chromatography.

Curt Bemis has designed and superintended the construction of an electron spectrometer. Although the instrument is now being used for studies of direct nuclear interest, it will also serve to pose a particularly intriguing inquiry into what the electrons are doing in compounds containing the actinide elements. This study, as well as our other chemical studies, is designed to tell us what properties are imparted to matter by the electrons that uniquely characterize the actinide elements, the so-called "5f electrons." If we want to find out what these properties are, the actinide elements are the only place to do it.

One of our most imposing instruments is the TRL electromagnetic isotope separator. The mass separator is used to prepare isotopically pure nuclides for spectroscopic studies of their nuclear properties. For example, the instrument has enabled Bemis and Joe Halperin (Chemistry) to make a precise measurement of neutron cross sections of ^{253}Cf and ^{252}Cf, a study of vital importance to the HFIR production program of ^{252}Cf and other transuranium isotopes. These cross sections are also critical for the ^{252}Cf production program plans at Savannah River.

National Program

The TRL provides a center for transuranium elements research at Oak Ridge. But Oak Ridge is itself the center of the larger, national picture of the production, research, developments and applications in the transuranium elements program. The elements produced in the HFIR and chemically separated in the TRU facility are sent to government, industrial and university laboratories all over the country; and, in some cases, to foreign countries.

In transuranium work, it is not sufficient to talk about elements only. Since different isotopes of the same element can have vastly different properties, isotope separation is of the utmost importance. ORNL's Electromagnetic Separation Group is using its calutrons to prepare pure isotopes of plutonium for use as targets in heavy ion accelerators (new elements research), for low temperature solid state studies of plutonium metal and compounds, and for fission studies. This group has also recently demonstrated in small scale experiments that they can separate large quantities of much-needed curium isotopes, as soon as they are empowered to build a properly contained facility. Several of these curium isotopes have the very long half lives needed for solid state and chemical studies. The small quantities separated in the demonstration runs have allowed neutron cross sections to be measured that are needed in the reactor program development at Savannah River.

In terms of both facilities and personnel, Oak Ridge currently has the most powerful transuranium program in the world. The carbon and nitrogen beams at the ORIC allow us to carry out chemical and nuclear studies of the elements above 100; the HFIR's unexcelled continuous neutron flux of $2\text{–}5 \times 10^{15}$ makes it a unique production and research facility; the calutrons are separating large quantities of valuable plutonium isotopes; and the TRU and TRL allow chemical and solid state studies to be made on these heaviest elements.

BOOKS

By Alex Zucker

COMING TO GRIPS WITH TECHNOLOGY

Technology: Processes of Assessment and Choice, a Report of the National Academy of Sciences by the Panel on Technology Assessment, Harvey Brooks, Chairman, to the Committee on Science and Astronautics, U.S. House of Representatives, 1969. U.S. Government Printing House, 163 pages, 75 cents.

IT IS A MISTAKE TO VIEW THE CURRENT CONCERN with environment as a passing preoccupation initiated by a few nature lovers, and propagated by the news media because dead fish and heaps of garbage are so photogenic. The matter goes much deeper. At the core we find that again man must change his view of himself, of his place in the world and his relationship to it.

In the distant past, we may conjecture, man thought of himself as part of nature, at the mercy of natural forces and invented divinities. In the West this view slowly changed, spurred no doubt by the Greek invention of humanism and the Jewish invention of monotheism. The result was the belief that man was at the center of the universe both astronomically and metaphysically. The Christian God was conceived to be exclusively and benevolently concerned with the human condition.

We all know how this position eroded, bit by bit. First, the earth was removed from the center of the universe, then a mechanistic philosophy launched by the Newtonian discoveries removed God from his intimate concern with man, and as a final blow, the divine creation gave way to natural evolution from, of all things, primeval slime.

We now know that we inhabit a small planet of a very average star, and that there are a hundred billion such stars in our galaxy and millions of galaxies in the observed portion of the universe. Not terribly uplifting; this was the view that gave rise to the black pessimism of Schopenhauer, that drove Nietzsche to hyperbolic exertions to make man at least a demigod.

But still there was something left for man. He might be insignificant cosmically, he might have originated in slime, but here at home on his planet he was boss. The same scientific discoveries that tumbled him from his throne gave him the power to exploit his own planet and to make life easier, richer and abundant for far more people than had ever dreamed of this even fifty years ago.

It was at this point that two catastrophes occurred. One was foreseen by Schopenhauer: "... for every wish that is fulfilled there are at least ten denied. Furthermore, craving lasts long, demands are infinite; fulfillment is short and finite. But finite satisfaction itself is only apparent: one wish fulfilled gives way to another: the one is a recognized, the other a still unrealized error. Lasting satisfaction that will not vanish . . . is like the alms thrown to the beggar, that sustain life today only to increase his torture tomorrow . . ;" the other by Malthus: "I see no way by which man can escape from the weight of this law which pervades all nature. No fancied equality, no regulations, in their utmost extent, could remove the pressure of it even for a single century . . . The vices of mankind are active and able ministers . . . They are the precursors in the great army of destruction; and often finish the dreadful work themselves. But should they fail in this war of extermination . . . gigantic, inevitable famine stalks in the rear, and with one mighty blow levels the population with the food of the world."

The promise of abundance has proved an empty one, since the quest for it requires an exponentiating material affluence. In the course of this quest, in the past ten years, the cruelest blow was struck. Man is not really boss of his planet. Instead he is a slave, fettered to it, condemned forever to exist on what is available. He cannot dump offal into his rivers, lest his children have no water to drink. He cannot push his highways into the wilderness if he wants to preserve the wilderness for his heirs. And he cannot drive one of his three cars into the city because a) there will be a monster traffic jam in the approaches, b) the exhaust of cars will make his eyes burn, and c) when he gets into the city he cannot walk around because the crime will get him.

All of a sudden we have passed from the ownership of a planet into bondage; man's view of himself must undergo yet another change, yet another step down in a previously divine hierarchy. He is thrown back on the limited resources of his planet and his own understanding.

The book under review is one response to this changed condition. A slim pamphlet, written by a distinguished committee, it is a towering work, full of good sense and incisive argument, fit to serve as a beacon in the dark days ahead. Its theme is how to plan intelligently for the future and at the same time preserve most of the features of our political and economic system. The objective is "the exploration of trends in technological development, working outward toward the effects on society, the environment, and the individual . . . to identify what seem . . . the most critical deficiencies in existing processes of assessment and decision-making with respect to the evolution of technology. . ." The problem is to foresee technical problems before these become overwhelmingly ingrained in the economic and social life of the nation, to forestall the degradation of the human environment and to carry out this task within the framework of our present political system. The task set is truly enormous. The spectrum of problems is broad beyond any past experience. We have problems in pollution—of the air, of fresh waters and of oceans; we have problems in transportation—highways, airports, parking; there are garbage disposal, noise pollution, and crime in the cities. These are all familiar and receive much space daily in the press. Less obvious are the crises in our supporting systems: court schedules are jammed because of the huge backlog of automobile accident cases, the government is groaning overcrowded and too costly, the tax base is stretched every year. Lurking a bit farther behind is the communications industry, frequently accused of heightening expectations beyond any possibility of fulfillment, a direct cause of our social turbulence. Health care, overpopulation, food technology, drug control, all these are upon us now, but who is getting ready for the time when natural resources begin to run out? The rarer materials, copper and helium, will go first, but how long will we have iron ore? How do we assign land for food, for recreation, for conservation?

We can all make lists and end up with nothing to show for it but a headache. But the problem has another dimension. In any category we face questions that are very urgent, very complex: a bewildering mixture of technology, economics, politics, individual welfare, etc. Take, for example, the rather simple case of maximum truck sizes. The problem is debated in federal and state legislatures, but as the Report points out, "... there exists today no reliable source to which the Congress—or anyone else—can turn for a 'snapshot' of the assessment situation even with respect to so uncomplicated a technological proposal . . . One simply cannot obtain a clear picture of what prior and contemporaneous evaluations have been or are being made, what their frames of reference and findings were or are, and what issues remain inadequately explored. Without such a picture, one is tempted either to pass the buck—to assume that somebody, someplace, has asked or will ask the right questions—or to dissipate one's efforts in as 'comprehensive' an evaluation as one can imagine, while paying the inevitable price of duplicated effort and, worse still, superficial analysis. The natural tendency is to err on the side of buck-passing, and the inevitable result is that incremental decisions, such as periodic increases in truck size and weight, may accumulate so much momentum and consolidate so many interests that continuing technological development may pass beyond any effective control even by those who appropriate the funds that fuel its progress." The situation is obviously in a hopeless muddle, and bear in mind that truck weight limits constitute one of the simplest problems that face us.

All this is not to say that there is no technology assessment operating now. To the contrary, many government and private institutions exist whose primary duty is assessment, usually in some well defined area. In some form it is exercised throughout industry and in many federal, state, and municipal departments. But with time, some of those charged with assessment will turn into promoters, and new areas will open in which no assessment exists at all. Continuous and self-rejuvenating vigilance is required; attention must be paid!

So, what exactly is to be done?

The Report is very specific; that is one of the golden virtues, among many, of this book. It proposes that three existing government bodies get massively involved in technology assessment:

First, establish in the Office of Science and Technology, close to the center of executive power, a specific and highly visible Technology Assessment function. It would be the duty of this branch to maintain an information center, to issue an annual report about current programs and future problem areas ripe for assessment, to sponsor conferences and symposia that deal with technology assessment on the broadest as well as the most detailed levels, and finally to issue position papers for the use of the executive branch about specific problem areas, possible options, and the economic, social and technological factors involved.

Second, establish in the National Science Foundation a Technology Assessment Division whose task it would be to let contracts with various public or private institutions for specific assessment studies; to support, at universities and other research institutions, basic research on unsolicited problems related to technology assessment; to review assessments by other agencies; and to help establish a science dealing with the assessment methods themselves.

Third, in order to extend the roots of technology assessment beyond the executive branch, and the university-science stronghold of the NSF, the Report suggests a permanent and effective entrenchment in the Congress either through a Joint Committee or a Congress-wide Technology Assessment Office. It is expected that through this branch of the assessment triumvirate the electorate would have access to the decision-making process.

A balance is to be achieved among the bureaucrats, the scientists and the politicians, to make the assessment process at once protective of our natural resources, in their very broadest sense; to make it neither so weak as to be a figurehead and whipping boy nor so strict as to stultify all technical progress; and to give it vision that will carry beyond "today's crisis."

This is a tall order, but the Report makes a most impressive beginning. It calls us all to arms: the Congress, the Executive and the scientific-university community. I only cavil at the scope. The Report urges a budget of $50 million, a sum far too small for what is really a close look at an $800 billion economy. The Report was written before the invention of National Environmental Laboratories, and these are institutions that could provide much impartial expertise, serve as repositories of data, and develop assessment procedures as well as provide assessments in urgent situations. The problems are so formidable and the NEL so patently the right instrument to tackle them, there is almost a historical inevitability: the right institution at the right time.

Beyond this, I have a more important objection, not to the Report, but to the whole idea of technology assessment. It proposes a way of dealing with the symptoms, of patching here, plastering over there, and perhaps excising whole chunks elsewhere. But it cannot cure. The problems of modern society, including technology, environment, social conflicts—the lot—are embedded in the fabric of our civilization. We must look deeply into ourselves if we wish to save what has been wrought. But that is the subject of another book. I hope somebody writes it soon.

Sam Beall, director of ORNL's Reactor Division, has been in the nuclear reactor business ever since 1943, when he joined the Metallurgy Laboratory at the University of Chicago as a UT engineer graduate. Since then his career has been uninterruptedly identified with reactor development, and his interest in the use of this source of energy to solve the world's power needs is at the base of the accompanying article. The Laboratory is undertaking six studies related to the problems surrounding the release of the abundant heat that is the byproduct of all power stations; five of these studies have been conducted by researchers under Beall's direction. Much has been said recently by way of deploring thermal pollution. Here, then, are some suggestions on how to benefit from it. . .

USES OF WASTE HEAT

A thoughtful and constructive approach to the problems of thermal pollution

By S. E. Beall

JUST AS A WEED is a plant for which there is not *yet* a use, so thermal pollution is heat for which a beneficial use has not yet been found. Unfortunately, in most places where heat is available, it is not used because it cannot be delivered economically, reliability is uncertain, or the temperature is not sufficiently high. Like any other commodity or service to be sold, heat must be made attractive to prospective customers.

The paradox of the "waste heat" situation is that if the temperature at the turbine exhaust is raised to a temperature which is useful for a variety of purposes, then we may have more waste heat than we have uses. So we try to strike a balance between keeping the temperature in the useful range and still not have more heat than can be used for all the different applications. Obviously, if we could do this for every new power plant that is built, then we could at least postpone the problem of thermal pollution.

"Six hundred acres of greenhouses could supply vegetables for a city the size of Denver." (Photo courtesy of National Greenhouse Co., Pana, Ill.)

Summer Uses Crucial

It is probably not necessary to say it, but summertime is the critical time to make use of the heat. In the wintertime when outside temperatures are low, disposing of the heat is usually not a problem. From the standpoint of thermal pollution abatement, it is not good enough to have only cold weather application.

Assuming present-day pressurized water reactors with a 32% efficiency, you see that the ratio of waste heat (around 90°F) to electrical output is 2:1; that is, two units of heat must be discarded for every unit of electricity generated. High temperature gas cooled reactors, such as the Fort St. Vrain station being built near Denver, will have about 40% efficiency. The molten salt breeder reactor, the liquid-metal cooled breeder, and the fast gas cooled breeder all will eventually be operated at higher efficiency and should have ratios close to 1:1 when they become available. It is possible that thermal efficiencies will increase beyond 50% but as the consensus now goes, it is not likely for many years. It is not generally realized that the overall efficiency of a power plant can be increased more easily by reuse of heat than by improving electrical conversion efficiencies.

Unfortunately, there are not many uses for heat at 90°F, and it is expensive to transport much heat at this temperature. Heat at temperatures above 200°F is applicable to many needs, but 300°F or higher is needed to make long distribution systems profitable.

City Heat Needs

Both urban and rural sites offer opportunities for applying low-temperature heat to useful purposes. Let us first consider urban sites, recognizing that although reactors cannot yet be built within cities, fossil-fired plants can be.

It is informative to look at a comparison of electrical and heat consumption in the United States in 1965, with extrapolation to 1980. According to a study made by Texas Gas Transmission Co., nine times more heat from burning fuels was consumed in 1965 than was electricity, and this ratio should drop to 6.5 to 1 by 1980. These numbers include high-temperature heat as well as low-temperature uses which we wish to consider. However, even if we assume that only a fraction of the residential and commercial needs could be reasonably delivered from a central source, and that only the low-temperature industrial users (foods, textiles, chemicals, etc.) would be prospective customers, it appears reasonable to conclude that a city should be able to use at least several times as much heat as electricity.

In our ongoing study of urban heat consumption for the Department of Housing and Urban Development, we have already reached several conclusions about "waste heat" uses. First, Art Miller has determined that 300°F to 380°F steam or hot water from a 500-Mw (electrical) reactor (or fossil plant)

can be competitive with present heat sources even if the power plant is 10 miles from the heat distribution point. Second, in most United States cities, more heat can be used for air cooling during the crucial (from a thermal pollution standpoint) summer period than is needed in winter for residential and commercial heating. I should explain that heat is commonly employed for cooling in absorption (ammonia or lithium bromide) air-conditioning systems, and we have assumed these systems in our studies.

A typical "energy center" for a city of one million people would have two 500-Mw (electrical) reactors and produce about 3000 Mw heat at 300°F. Oil-fired boilers capable of 1500 Mw (thermal) would be installed as emergency standby units to insure reliability of supply. The cost of heat from such a dual-purpose center would be about 30¢/million Btu if the electricity were sold at 4.3 mills/kwh. If the reactor were located 10 miles from downtown, the delivery cost would be 20¢/million Btu. The cost of distribution from that point, and profit, would increase the consumer's price to $1 or more per million Btu. The price could be $1.50 and still be competitive with fossil-fuel heat in most cities.

Complete thermal pollution abatement is probably not possible for an urban energy center because there are many days, especially in the spring and fall, when the demand for heating or cooling is small. During these periods the waste heat would have to be disposed of in the normal fashion—to cooling water or cooling towers. Nevertheless, our studies indicate that the average reduction in waste heat disposal would be 60%, which is a worthwhile reduction. By increasing the number of "base load" customers, that is, water heaters, industrial processes, waste water renovation, etc., thermal pollution could be reduced more. Of course, we must recognize that these reductions in thermal pollution are accomplished by transferring the heat disposal problem from the power plant to many scattered locations, that is, cooling towers on building roofs or coolers in industrial processes. But by using this heat to replace many individual boilers or electrically driven systems, we are reducing the total heat discharge to the biosphere and air pollution from fossil fuels.

Reuse of Water

Irving Spiewak studied how sewage and waste water from a city might be treated for reuse. One of his schemes was to use part of our power plant heat to evaporate the waste water. Here we should make the point that the dissolved solids content of waste waters discharged to streams should not exceed 500 ppm. In passing through a city, water collects 250 to 300 ppm dissolved solids which is, of course, added to the solids originally in the water supply. The waste waters from many cities already exceed the 500-ppm limit, and it will soon be necessary to remove dissolved solids by some process—evaporation, reverse osmosis, or other desalting treatments.

A vertical tube evaporator was chosen as the basis for Spiewak's application. By evaporating 34.5 million gallons per day (which requires 400 Mw heat) and blending the distillate with 65.5 mgd filtered, carbon-treated, secondary effluent and 50 mgd from the treated natural water supply, the full 150 mgd supply for the city of a million population can be provided at a cost of 20¢ to 22¢/thousand gallons. Note that no credit is taken for *not* polluting a stream with the sewage effluent. Moreover, as will be seen later, the concentrated nutrient stream from the evaporator has uses which may result in a credit.

If one does not need to reuse the waste water, he can still avoid polluting streams with it, and take care of the stream heat pollution problem, by using the waste water as the cooling tower cooling medium. At least two steam plants (one is at Los Alamos) in water-short areas do this now. The tower blowdown containing most of the dissolved solids can be evaporated to dryness to avoid any stream pollution.

Any such waste water evaporation capacity which can be varied depending on the availability of heat and the need for water is an "interruptable" load which tends to increase the power plant's heat load factor, and is thus a valuable type of load. And because the heat is being used a second time (after generating electricity), it is reducing the overall pollution problem.

A similar application of heat reuse to waste water distillation is brackish or salt water distillation. Many cities located on or near the coast could provide their potable water makeup supply (or irrigation water) from a distillation plant. We all recall Southern California Metropolitan Water District's abandoned Bolsa Island project, which was an electricity–fresh water production project. The cost of the water from that dual-purpose plant was too high (estimated at 35¢ to 40¢ per thousand gallons) by comparison to the cost of other water sources, but the proposition will undoubtedly look more attractive at other places and other times.

Art Fraas has looked briefly at using steam storage tanks to drive buses and switch engines. With a tank holding 40 cubic feet of water at 380°F, a typical city bus carrying 40 passengers could travel 20 miles. Operating cost for "fuel" would be only 0.2 to 0.8¢/mile (without tax). Maintenance costs should be lower for the steam engine.

There are other possible uses of heat in cities but we have not yet examined them in detail because they are winter uses and do not alleviate the summer situation. Snowmelting and outdoor heating can consume extremely large quantities of heat at times. Recreation lakes and shipping lanes in cold climates can be kept open longer, as a Canadian AECL study of the St. Lawrence River has shown.

Heat for Food Production

The best possible use of waste heat is one that uses all of the heat all of the time, and in a profitable way. Such a use is the heating and cooling of greenhouses and poultry houses and/or heating of aquaculture ponds. These applications become more attractive if the food-growing structures can be located in the reactor exclusion area (which is normally 500 acres or more of idle land), so that the *normal* turbine condenser cooling water can be circulated to the houses.

There are many large cities in the United States which depend heavily on truck and rail shipments for their fresh vegetable, poultry and fish supplies. I have studied the city of Denver as an example and estimate that it would require more than 600 acres of greenhouses to provide the city's consumption of tomatoes, peppers, cucumbers, lettuce, etc.

Garland Samuels, in a study with R. S. Holcomb, found that since temperatures below 100°F are sufficient for greenhouse heating, it is not necessary to reduce the efficiency of the power plant by raising the turbine exhaust pressure. The normally discarded heat from a 1000-Mw (electrical) reactor is sufficient to heat 300 to 500 acres of greenhouses, depending on the location. At a location like Denver, with low wet-bulb temperatures, we find that it is possible to *replace* the cooling tower of the power plant with cheap evaporative cooler-heaters located in the greenhouses or poultry houses. The houses can be cooled to at least 75°F in the summer by evaporating 92°F water from the turbine condenser with once-through air. In the winter the evaporative pads can be operated in an air-recirculating mode so that the air temperature is maintained above 65°F with a zero outside temperature.

The University of Arizona, in cooperation with the University of Sonora, Mexico, has an experiment under way at Puerto Penasco, Sonora, Mexico, demonstrating how a combined desalting, diesel-electrical generation and greenhouse-heating operation can be managed. The success of the venture is indicated by the recent announcement that the Shaik of Abu Dhabi (on the Persian Gulf) has appropriated $3,200,000 for the design and installation of a 20-acre greenhouse complex with desalting and electrical generation for that city of 20,000 people. The expected production of vegetables is two million pounds per year.

Extrapolating the experience at Puerto Penasco to our Denver situation, we estimate that 60 million pounds of fresh vegetables can be produced in a 500-acre greenhouse complex, with an average produce value of $27,000 per acre, wholesale.

Although preliminary capital and operating cost estimates for the 500-acre greenhouse installation showed some profit before taxes, a more thorough cost study must be made before economic feasibility can be argued. However, if present commercial cultivation of vegetables in greenhouses is profitable (and it certainly is for tomatoes) with heat from oil-fired heaters at $1 to $1.50/million Btu, reactor heat at 20¢/million Btu could produce an additional profit of $4,000 to $6,000 per acre. Just as important is the increased income to the reactor operator. Selling the heat at 20¢/million Btu to a 500-acre greenhouse range could increase the reactor operating profit by $500,000 to $1,000,000 per year. This would be an additional 10 to 15% net profit for a 1000-Mw (electrical) plant operating 8000 hours per year, which might normally expect a profit of $6 or $9 million per year from the sale of electricity.

Admittedly, a 500-acre greenhouse operation would be a big undertaking anywhere in the world. But it is not necessary that all the heat be used for greenhouse heating. Broiler and egg production and animal husbandry are also large potential customers of heat and they are normally housed in light, uninsulated structures which could accommodate the evaporative cooling-heating system. The Denver area could support a 200-acre spread of broiler and laying houses. We hope to study these possibilities later.

The evaporative system proposed for the above applications required a constant blowdown of a few percentage of the total flow to avoid a buildup of salts in the circulating water. For a 1000-Mw (electrical) power plant, the blowdown rate could be as much as 10,000 gpm. If we choose to discharge warm water either from cooling tower blowdown or by once-through cooling, it could be used to maintain temperatures in pools for algae growing and fish culture. Several studies have shown that a combination of controlled warm temperatures and nutrient supply from animal wastes or city sewage effluent could produce heavy yields of algae—up to 30,000 pounds per acre. The algae can be centrifuged, dried, and used as food for fish, fowl or animals. Several organizations (Nuclear Utilities Services and the University of California) have large-scale experiments in progress. In our combined greenhouse-poultry-algae operation—depending on how we choose to use the heat—we could operate from 50 acres of algae ponds (with the 10,000-gpm blowdown flow) to 1500 acres (using most of the condenser flow) with yields of 1.5 to 45 million pounds per year. Assuming the algae can be used as animal or fish food, it would be worth 3 to 5¢/lb and the culture operation could be profitable if it could be credited for reducing waste sewage or hot water disposal costs.

Aquaculture Applications

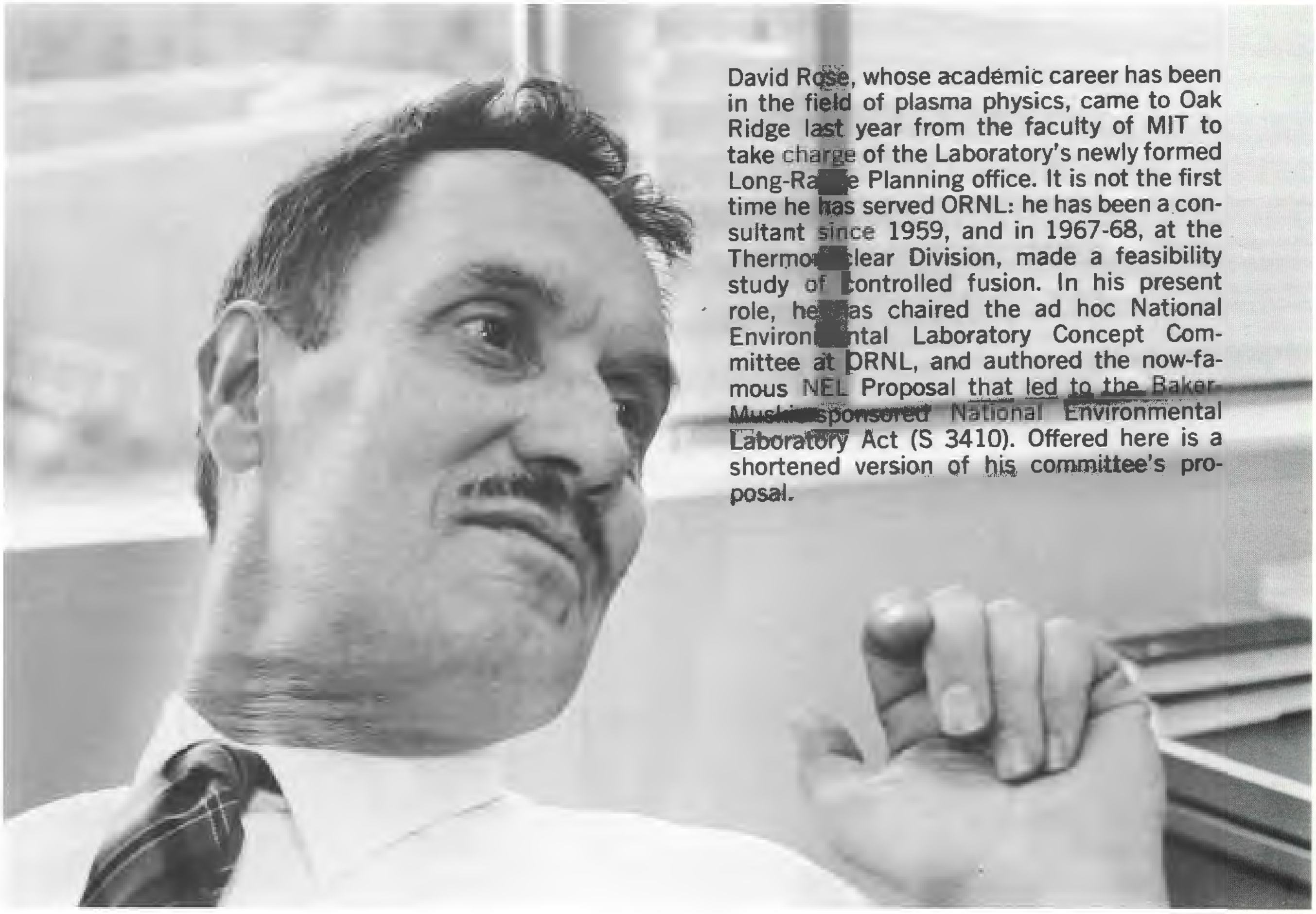
Depending on the particular reactor site, there are several other possibilities for applying warm water effluents to aquaculture operations. Higher yields of fish, shellfish, and crustaceans have been demonstrated where optimum growth rates could be maintained with regulated water temperatures. The Long Island Lighting Company, at their Northport Long Island plant, is engaged in a cooperative experiment in oyster culture and is planning on commercial-scale operations. The Maine Power and Light Company is supporting an experiment on improving lobster growth rates with warm water. At the University of Miami Marine Laboratory, on Biscayne Bay south of Miami, experiments are being conducted with shrimp culture in water similar to that to be discharged from the Turkey Point station of the Florida Power and Light Company. At Panama City and Key West commercial shrimp farms are being established. It is hoped that harvests of 2000 lb or more shrimp per acre can be demonstrated, as has been done in Japan. W. C. Yee has collected information that indicates trout and catfish yields of 5000 to 10,000 pounds per acre are possible on a commercial scale if optimum temperatures can be maintained by using warm water throughout the year.

Oyster culture in thermally enriched effluent. (Photo from Long Island Lighting Co., Hicksville, NY)

Pacific Northwest Studies

Utility companies and state government agencies in the Pacific Northwest have begun the sort of regional study which should be undertaken elsewhere in the United States. So far, all of the power needs in that area have been met with hydrogenerating capacity, but they are looking ahead at the problems, especially thermal pollution, that will accompany steam power stations. The Washington State Research Center is spending $430,000 on a study of possible plant sites and agricultural development along the Columbia River. The Eugene (Oregon) Water and Electric Board is financing several experimental farms (totaling 170 acres) to study irrigation with water as hot as 104°F. Their studies indicate that water at this temperature, sprayed from a height of 8 or 10 ft, will cool to ambient air temperature by the time it reaches the ground, and will not damage field crops in hot weather. They hope that the spring and fall growing sessions can be extended past the light-frost periods as a result of this additional heat input. The State of Washington is supporting similar work at Washington State University. At Oregon State University there is an investigation of the effect (on crop growth) of underground pipes heated with condenser discharge water. Depending on the site, the warm water might also be distributed through existing irrigation canals but, of course, it would cool to ambient air temperature within a few miles.

In conclusion, I would suggest that the choice of a particular beneficial use of low-temperature heat will depend on the needs of the particular site chosen for the power station. The site should first be studied from the standpoint of its resources and its needs. For a coastal site in a warm, arid region, one mix of uses (desalting, irrigation, aquaculture, industrial chemicals) would apply, whereas for an inland urban site in the Northeast, another mix (urban heating and cooling, greenhouses, fish culture, industrial, waste water recovery, snowmelting, etc.) would be attractive. At any new site I believe that a large fraction of the heat normally wasted, if not all of it, can be put to beneficial uses—and in most cases at a profit.



David Rose, whose academic career has been in the field of plasma physics, came to Oak Ridge last year from the faculty of MIT to take charge of the Laboratory's newly formed Long-Range Planning office. It is not the first time he has served ORNL: he has been a consultant since 1959, and in 1967-68, at the Thermonuclear Division, made a feasibility study of controlled fusion. In his present role, he has chaired the ad hoc National Environmental Laboratory Concept Committee at ORNL, and authored the now-famous NEL Proposal that led to the Baker-Muskie-sponsored National Environmental Laboratory Act (S 3410). Offered here is a shortened version of his committee's proposal.

The NEL Proposal – an Abridgement

A new mission for the natural and social sciences is presented in this concept of a system of National Environmental Laboratories

By David J. Rose

FEW WILL DISPUTE that we must live with grace, with dignity, with style, and with social justice. But these aims seem strangely unfulfilled in many ways, sometimes perversely frustrated by our very attempts to achieve them. Everyone points to pollution, to sources of it, and to others for having limited his options: a recreation area gone, a too-early disability, a garbage-strewn urban misery. Are these problems technological, or ones of moral commitment, or different problems in a not fully recognized way?

Problems We Solve Poorly

The answer to each of these choices is in part Yes. For example, consider two environmental problems, the first very simple: a diesel truck with smoky exhaust, because the driver enriched his fuel mixture to obtain 15% more power. Do we need a technological solution, or enforcement of regulations, or development of a more charitable spirit and consideration for others? All three enter.

The second problem is also related to energy and its transformation (as also are many other environmental difficulties): central station power for the future. Parts of the topic are familiar to many at ORNL. We all surely agree that the problem can't be resolved without evaluating possibilities for nuclear and fossil fuel devices. Thus conventional power engineers, nuclear reactor engineers, heat transfer specialists and so forth are needed. Full resolution also requires consideration of how the waste heat (in the most modern plants still a larger amount of energy than all the electricity generated) is to be disposed of. Hence comes a requirement for experts on water and air resources. This might seem to make a tidy package, but the problem size hasn't yet appeared. Perhaps the reader imagines us about to include the indirect and direct costs of strip mining for coal, or radioactive effluents from nuclear fuel reprocessing plants, or long-distance power transmission costs (which help determine whether to put the power plants near or far). And so they are included, making the true scale of the problem much broader than before. Perhaps this is enough?

Not so; reflect upon what follows. Power economists in England point out that the average UK use of all central station plants is about 50% (because of reserve capacity for peak loads, some old units saved for emergencies, etc.). But in London the average use is about 33%, caused by high workday demand and low demand at all other times. Old power plant sites in London are small. An economic study made on this basis would show that the future requirement is for small low capital cost (per unit of power) plants. Fuel cost would be secondarily important.

"These matters touch on public and individual conscience and will."

Maybe this is the correct solution, but maybe it is totally wrong. Land is cheap for a power plant compared to the plant cost itself, even in London. What about the alternate scheme of a few very large plants with low fuel and operating cost? Off-peak power could be made very cheap—perhaps free to some classes of users and attractively cheap to others. That kind of power policy could be used to stimulate an entirely different approach to the inner city problem of London. And where was included a host of purely sociological factors—for example, the hard fact that some communities just will not permit the power plant to be built inside their boundaries, irrespective of all arguments?

Then what is the policy to be? We face the future with less certainty than before. It is in all these issues together and not in each separately that the true scale of problems appears—problems which are born whole and flourish throughout society. Subdividing them at intermediate levels—into "power plants" or "urban plants" or "heat disposal"—is a necessary operation, in order to assign specific tasks as meaningfully as possible. Thus the need exists and will continue to exist for organizations like the Federal Water Pollution Control Administration, National Air Pollution Control Agency, Federal Power Commission, and so on. But we contend that even though special agencies work competently (and sometimes brilliantly), yet the fragmentation of present approaches makes the effort inadequate, because no one considers the whole system. We are in danger of comforting ourselves falsely while an undetected layer of problems becomes even more intractable.

No instrumentality currently exists capable of working on all parts of such tasks. Thus we develop the thesis of organizing certain institutions more meaningfully to match science and technology to the national environmental and technological assessment problems that we face. The organizations envisaged—National Environmental Laboratories (NELs)— would have interacting components from many physical and social sciences. By their structure and method of working they would be able to cut across the fabric of environmental problems, in directions not hitherto possible.

The NEL Concept

Many of these ideas and the need for new capabilities have been expressed before. Senator Muskie's Subcommittee held two years of hearings. Rep. Daddario calls for increased utilization of federal laboratories. The American Chemical Society has made a detailed study of needed environmental tasks. Both the National Academy of Sciences and of Engineering last year published eloquent treatises on technology assessment, which is part of the same topic, although often not recognized that way. Solving present environmental problems is a task related to past mistakes, and difficult enough. But difficult in a different way and inseparably joined is the prospective task of arranging our future in ways least likely to cause uninvited trouble. We have then two outlooks, as the two faces of Janus: one showing foresight, the other retrospective correction. Too often the environmental restoration aspect dominates discussion; but clearly one makes little sense without the other. Because the forward directions are unclear, technology assessment must be broad and may be the more expensive operation. As an example, exploring several methods of developing nuclear power is in part an exercise in technology assessment; not all will be put into service. As another example, a 500,000-ton oil tanker may be a greater hazard than all its beneficial economies permit; the earlier that question can be resolved, the better we will feel.

The Commitment

The missions and methods of working of NELs can be described in a number of ways. Most broadly speaking, the policy of NELs will comprise: 1) for problems affecting the existing or future environment, developing and presenting to decision makers ordered sets of alternates whose costs and benefits are clearly defined; 2) making sure that all sectors in the nation can be aware of available options; 3) as an important exclusion, no decision-making or regulatory functions.

Regarding the first of these, we take a position contra those who suggest that scientists must present in clinical sterility only the data, from which the decisions can then be deduced or inferred by policy makers. If the "sterile data concept" had worked, we wouldn't be facing so many environmental problems today. Regarding the second, we feel that lack of information and communication are correctable faults in our present society. Regarding the third, because NELs must interact across many government departments and agencies, assigning them executive power would be both undesirable and unacceptable.

"...NELs must have very considerable discretionary power in arranging their own programs."

Next, two broad working principles can be stated as:

—Reintegration at both the working and advisory levels of all the disparate parts of these national problems. It is this synergism and the methods to achieve it that permit the new approaches, the cuts in new directions across the fabric.

—Maximizing the mobility of relevant information and of ideas. Detailed actions derive from these considerations: in-depth analysis of environmental problems, information accumulation, applicable basic research, evaluation, technological development, systems analysis and assessment; studies of biological, ecological, and sociological effects; communication of all kinds; and cooperation with many

"There is a public need to know how the environment is being maintained . . ."

other public and private agencies. Much more could be added.

A number of other features must be recognized, in addition to breadth and past-future aspects.

Most important environmental problems are not properly definable in terms of single specific tasks or even as a sum of such separate tasks. This basic point influences our whole approach. In early times, when man's relations with his fellows and with the environment were so weak that the environment appeared as an infinite resource, each activity was generally describable separately; separate cures – for a dirty stream, for instance – could meaningfully be prepared. The optimum solution consisted of optimizing each part independently. Today our activities have grown until the environment appears finite in comparison; the relations are coupled, a situation that generates conditions and solutions of quite different character. Very importantly, optimizing the whole system is by no means approachable by any process of optimizing each segment individually. As a simple example, optimizing any one sector by itself (pulp and paper manufacture) exacerbates other difficulties (water pollution). Charges and costs that are inadvertently (and sometimes advertently) put upon us all by this process of too narrow specialization are called "external diseconomies," which significantly weren't recognized in economic theory until fairly recently. In the paper manufacture example above, polluted waste water dumped into a river rather than being cleaned beforehand represents an external diseconomy. Throw-away beer bottles and automobile graveyards are others.

Again, this interdisciplinary complexity impedes both problem recognition and a will to commitment by those in specific technical fields who might have offered imaginative solutions. The fact that any effective solution or abatement procedure changes the environment that was being studied bespeaks a degree of coupling often found scientifically uncomfortable.

The tasks of technological abatement (of present problems) or technological assessment (of future ones) have large technological components, which might sound like a tautology; but there is a point yet to be emphasized. We believe that these environmental tasks, both retrospective and prospective, must proceed in the atmosphere of large working laboratories and not in think tanks. It is all too easy to lose sight of alternates, to assume that solutions exist where they do not, or to miss exploitable developments.

NELs will contain large contingents of social scientists: especially resource economists and demographers, but also lawyers, political scientists, social psychologists, and so forth. By interactions among such persons, natural scientists, and engineers, we hope to analyze systems broadly enough even to include some measure of aesthetic value, which certainly enters into decision making.

These matters touch on public and individual conscience and will. Although much abatement and future direction can doubtless be obtained regardless of the state of the public conscience, a compassionate view toward these problems and toward not narrowly maximizing personal gain would help greatly. As the Muskie Subcommitte on Intergovernmental Relations and other congressional hearings on these topics have brought out many times, there must be acceptance of a community responsibility and the development of public understanding of the nature of what we face. If the words seem self-evident, there is still needed recognition of their importance.

Characteristics and Functions of NELs

Having said all this, let us see more specifically what NELs look like. We have in mind several—perhaps five or six—throughout the country, each containing several thousand persons. This size and extensiveness (not only inside institutional buildings but also working outside in the environment) are necessary, in our opinion, to be effective. Some NELs would have particular expertise in specific areas—urban problems or resource management, for example—but all would be closely knit and all would share common capabilities. A system comprising such large organizations would not fit well as an adjunct either to the President's Executive Office or to the Congress; yet NELs must be closely connected to these places. A separate Commission (or equivalently-named organization) reporting jointly to both branches seems to us most appropriate.

Regarding startup, there appears (fortunately) no necessity for NELs to start full-grown, as Minerva from the head of Jove. It is the totality of tasks and other things that makes for large size as much as the size of many of the environmental tasks themselves. Thus, we can imagine smooth and mostly internal adjustments whereby environmental functions are grafted onto existing organizations. By way of example, the Argonne National Laboratory established last December an Environmental Center to focus on a number of its related activities; ORNL has for some time been directing about 10% of its effort (about ten million dollars per year) to environmental problems of many kinds, as integral parts of its program.

One thing seems clear: it must be agreed upon at the start that NELs must have very considerable discretionary power in arranging their own programs. By axiom, no one elsewhere will see the whole scope *a priori*. On a more general note, too rigid control never works well for such tasks anyway: if the qualities of the controlees is such that the control is needed, the wrong people have been put on the job and nothing much will be created. If the putative controlees have the qualities most needed in an NEL, they are the best ones to assume important programmatic roles. In effect, choosing the team establishes *de facto* the trust. This arrangement calls for persons of outstanding quality, without whom the whole idea is unworkable.

Operating Procedures

In looking inside NELs we consider that their method of working is more important than any specific organization chart. Five activities, all interrelated, stand out.

The first of these is *programmatic perception*, basically the answer to such questions as Where is the laboratory headed? and Is this the right direction? With the imagined internal population, and the need for continual reassessment of missions and objectives, we see the need for laboratory-wide guidance and judgment. This is no new thing: the most creative research laboratories and universities operate as participatory democracies.

The second activity is *information gathering and processing*. This is the scientific sensing part of the NEL. It must be able to measure things, as we have said: pollution of air, water, land; such things as transport of nutrients into and out of forests, learning in advance what it really would mean to apply fertilizers widely in silviculture; examples abound. We see many disciplines involved: not just in monitoring, but in predicting, testing predictions, and so forth.

The largest information gathering function of an NEL is not its own measurement program, however; an NEL could aspire to do only some of the measuring. It would arrange to have interactive access to all sorts of activities proceeding elsewhere, leading to a much-needed coordination. This is made possible by the technologies now available for obtaining, storing, correlating, recognizing, and retrieving information. There is thus both a measuring (and diagnostic) function, and a broader, information handling function.

Third comes *systems analysis,* the modeling and assessing of what is to be expected as a result of what action. This increasingly powerful art has already been applied to economic analysis of reactor systems, urban planning, and so forth. Notice again the emphasis on computers and information processing techniques.

Next is *research and development* in its fairly classic sense. Here at ORNL we find little difficulty in understanding and appreciating either the role or the necessity for it. Here we differ from those who propose to operate in think tanks remote from the real benchwork or hardware development; desired synergistic effects would be missed that way.

The required r & d is sometimes small, sometimes large. It will connect with the social sciences—e.g. quantification of aesthetic values—which is a new thing for laboratories of the sort we have in mind. Not all r & d is in-house, of course; the NEL should know the nation's shopping list relevant to environmental problems, and buy important items itself from time to time. Here the concept must be recognized of developing systems to a stage of assessability, whereupon some may be dropped. This winnowing, even on the scale here proposed, is well understood in both public and private industrial sectors.

Fifth and finally is *communication,* perhaps the most important of all, and one often ignored or misunderstood. Maximizing the mobility of ideas was a guiding principle behind our plan.

A continual public dialogue is required for many purposes: to make people aware of developing technologies and their effects, and to provide for independent criticism and countervailing pressures, potentially a powerful balance on the activities of an NEL. Mechanisms to stimulate these interchanges are:

—Public reports and annual national reports.

—Policy of no security classification or privileged documents.

—Open hearings where any activity can be questioned.

—Public lectures.

—Substantial personnel interchange programs among NELs internally, between NELs and industry, universities, and other organizations.

—An aggressive policy of transferring technology to the public sector, through public communication, attitudes that encourage spinoff, and so forth, in addition to the traditional professional methods.

—A function (or section) concerned with advising the Congress and the Executive Branch of major possibilities and developments, and of responding constructively to requests.

—An active international program of exchanging information and personnel.

These communication functions serve many roles besides the most obvious ones of transferring information. They protect the public from the NELs' becoming irrelevant or dictatorial; they infuse the NELs with new ideas and vigor from students; they serve to motivate industry to search within for its own technical solutions as well as to interact with others.

Some NEL Tasks

This may be all very well, but what will an NEL *do,* one might ask. We have had no difficulty finding more than enough tasks to start on, and the experience gained will suggest much more. One example is the central station power problem mentioned earlier; its resolution requires the attention of something like an NEL. At a further level of generalization, the whole question of energy—mobile as well as fixed—seems very ripe for study, and amenable to analysis.

NELs would interact with state and local organizations, as well as with the federal government. We imagine regional activities because some environmental problems can best be worked on that way. For our Laboratory, a cooperative program for regional development with TVA and selected local governments seems very attractive. In that way, all so engaged could learn how the social and natural science components of such programs fit together.

A compelling idea is that of environmental "indices" or "profiles." There is a public need to know how the environment is being maintained, in the simplest meaningful ways, and indices should be developed applicable to air, water, land, etc. This would permit not only comparison of degrees of pollution among different areas, but also the efficacy of specific abatement procedures that are being tried. The idea is not new; already the FWPCA measures and publishes much data on water quality.

A Constructive Dialectic

These ideas about NELs raise a number of questions larger than details of organization or of specific tasks. To some it may seem that we propose just one more way to organize ourselves, to limit our freedom, to impose more government, to interfere in each other's business, to heap contumely upon the bureaucratically disadvantaged. Some of these are distortions of real intents (to organize better); some are real dangers—especially the last ones mentioned.

About the organization: if we demand the fruits of an ever-more-complicated technology, we must be prepared to accept the necessary degree of coordination as well. About the dangers: we have tried to arrange some checks and balances. But in this as in all things a charitable nature will help greatly.

The essay implies that the chasm between the social and natural sciences, into which fall so many of our environmental problems, can be bridged, and that NELs can do it. This is an article of faith, but our limited experience to date supports an optimistic opinion. Here, we strongly contend against the pessimism expressed by some social scientists. Much hinges upon questions of public morality and social commitment. Other countries—for example, The Netherlands—surely have valuable lessons for us.

Perhaps an unbalance appears accidentally in this essay and in our apparent intent; the examples were characteristic, but of what? The social scientist says that problems range from technological A to social Z, and we have gone from A to B, not far enough. A danger of qualitative misunderstanding then arises, of our seeming to propose solutions as if we understood how science, technology, society, and the environment all interacted. In truth, none of us understands very well how the system works, which may be as good a capsule description as any of our difficulties. But we believe that by joining social and natural sciences, technology, and new ways of thinking about large problems, we will make much progress. After all, the gamut of successfully attacked problems really only runs from A to A′ yet, and there is plenty of room for improvement.

A nice balance must be struck between conservationist-environmental and technological assessment outlooks in an NEL, as has been said. In oversimplification, one view tends to suppress technology, the other to promote it. To achieve the balance, we join these concepts in one organization, hoping to produce a most reasonable view.

History brings many examples of environmental problems, both foresight and hindsight, both good and bad. The Romans were the engineers *par excellence* of classic times, and generally applied good sense and style to what they did. But their making of charcoal for iron smelting strongly contributed to the deforestation of much of the Mediterranean lands; and so the region remains to the present day. The continuing need for wood led to transfer of the iron industry and of technical dominance to Germany.

Are we preaching a counsel of unattainable perfection? Not this side of Paradise, not unless we are foolish, unable to see or accept improvement as a guiding principle. If we know the goal and to get there see plainly only the first step, then let us take it; the next will be clearer from the new place. There will even be mistakes along the way, wrong alternates sometimes proposed, wrong decisions taken as a consequence. But with better instrumentalities, our mistakes will be fewer, wherein is the benefit. It is the making things better than hitherto that we try to bring about.

"If we know the goal and . . . see plainly only the first step, then let us take it . . ."

AMW COMMENTS

I finally encountered the politics of confrontation in the most unlikely place—the December meeting of the AAAS in Boston. We in Oak Ridge, living as we do in a sheltered and pleasant scientific lotus-land, just don't know what our colleagues in the beleaguered universities are up against. What a shock it is to go to the hub of the intellectual universe for what one expects to be a rather routine scientific meeting, and to run smack into a full-scale confrontation between the scientific establishment and the Angry Young People. I haven't had such an exciting time in years, certainly never at a scientific meeting.

Those in charge of the meeting made all sorts of unusual arrangements, such as allowing anyone to attend the meetings, or allowing the students to organize their own symposia on such an uncontroversial subject as The Sorry State of Science—A Student Critique. Many of the meetings ended in angry exchanges between the speakers (who were for the most part aged 40 or over and many of whom I suspect once considered themselves to be rather radical) and the shouting, unruly, four-letter-worded young radicals.

I happened to be presenting a paper on energy at a televised symposium entitled "Is There an Optimum Level of Population?" I thought the question was a good one, certainly appropriate for a socially-conscious scientific society like AAAS. I even thought the sharply rationalistic differences in viewpoint, presented by the geologists like Preston Cloud and the other environmentalists on the one hand, and the energy euphoriacs and the economists on the other, made for sobering and serious exchange. Cloud insisted that we simply will run out of the earth's bounty, and that energy, even unlimited energy, is no panacea. The economists said rubbish—future technologists will find substitute materials; energy alone places an ultimate limit on what we can produce. I repeated what I've said so often: that the catalytic nuclear burners (a new and better name for breeder reactors in which ^{239}Pu or ^{233}U are the catalysts for burning ^{238}U or ^{232}Th, or fusion reactors in which tritium is the catalyst for burning ^{6}Li) will save mankind. But I'm afraid this wasn't at all where the action was; the young radicals stole the show. At the entrance they were handing out leaflets asking something like:

"IS THERE AN OPTIMUM POPULATION?"

"Ask a stupid question and you get a stupid answer! What can white, male, affluent, American scientists who are part of a military-industrial complex know about the real problems of population, etc., etc.?"

And when the symposium was about completed, the youngsters tried unsuccessfully to take over with a noisy demonstration.

And so it went, session after

session. Harold Urey, who used to visit Oak Ridge, and who in his younger years had quite a reputation as an infighter for unpopular causes, was fit to be tied! He couldn't understand what was going on, nor could I. We just knew we were mad as hell!

I finally got in a few licks of my own, and it happened this way. I attended a session, which I thought would be a quiet one, on Allocation of Water Resources. The papers were not very controversial; people from the Bureau of Reclamation spoke about new possibilities for getting water from wells and dams and desalting devices. (I was rather disappointed at the short shrift given to desalting by at least one of the speakers.) But things warmed up during the discussion—particularly when a young assistant professor of ecology from North Carolina made an impromptu speech castigating technology for spoiling the environment. In effect he claimed that ours is a space ship with a limited water supply, that one doesn't defile the drinking water on a space ship, and that we must not do so on earth. His solution was: Down with technology! Then his colleague, equally young, equally impassioned, said he had the solution (though he confessed it was not a popular one), namely, hold the population to 200,000,000 (how he didn't say); but in addition, destroy our polluting technology and go back to a kind of bucolic life circa 1850.

To which Chauncey Starr, chairman of the session, properly replied: "Young man, do you own a car, and if you do, are you ready to give it up?" The answer to the first question was yes; to the second, no, with a sheepish "but I usually ride my bicycle!"

Lunch time was approaching, and the audience had shrunk to about 50, perhaps evenly divided between those over 40 and those under. At this point I couldn't keep quiet any longer. I'd had a hard time, and I felt it was time for rebuttal. So I asked for the floor and began talking, trying all the time to sound fairly calm and not too uptight. I said something like this: I've listened for the past two days, not only at this session, but at all the AAAS sessions I have attended, to the angry voices of revolutionaries who are frustrated by technology. And they vent their frustrations not by using the brains the good Lord gave them, but rather by calling for an irrational Luddism, an anti-machine bias that passes these days for the word of angels. But this is surely a selfish and juvenile, not to say irrational, view. If we give in to the anti-technologists, we give in to Malthusian catastrophe. (Here I came on strong with Perry Stout's tube-well scheme for saving India.) We are told that the earth has only a finite amount of water—but those who say this forget that the oceans are infinite, and all one has to do is take out 35,000 ppm of salt. This takes energy, and a little ingenuity; to succeed in obtaining this energy poses a difficult challenge.

Of course, the modern technologies of abundance have their undesirable aspects, their taints, and their deleterious side effects. But in heaven's name (I was warming to my subject by then) is not the rational, the human way to attack our problem to try to remove the taints, not to destroy or eradicate the technology?

The challenge to our younger generation, who are generously concerned with people, is not to figure out how to stop technology, to stop "progress"; it is to redirect, to improve, to humanize, to sanitize technology. This is a magnificent challenge to the new generation. It is a goal that we oldsters will continue to strive for, but the job can be finished only by the coming generations.

There was a warm round of applause, even a couple of hear, hears when I sat down, a bit shaken. But my good feeling was short-lived. I noticed that the applause, like the audience, was divided 50–50. Everyone in the room around my age was clapping like mad; while every one of the younger people was sitting politely and quietly, realizing, I suppose, that it is not we older technologists who will eventually have much to say about the world in which they will live.

Alvin M. Weinberg

The principal research interests of solid state physicist Bob Weeks, whose doctorate is from Brown University, have been in the areas of dielectric, optical and magnetic properties of solids, and the effects radiation has on these properties. Therefore, when NASA engaged the Laboratory to perform paramagnetic resonance studies on material brought back from the Moon, it was logical that Weeks head up the research team. A highly technical version of his findings may be read in the Moon Issue of Science (January 30, 1970, p. 704), describing work done with his colleagues A. Chatelain and J. L. Kolopus of ORNL, D. Kline of State University of New York, and J. G. Castle of University of Alabama. This article lets us in on some of the inferences and questions about the Moon's beginnings that have resulted from studies of its rocks.

The Message in the Moon Rocks

What can the lunar material contribute to man's knowledge of cosmology and the origin of the solar system?

By R. A. Weeks

RECENTLY AN ARTICLE IN *NATURE* (July 19, 1969) proposed a new theory of lunar origin. It suggested that for a time after the formation of the solar system the second planet from the sun was not Venus but Earth's moon. Because of orbital instabilities resulting from interactions with Venus and Mercury this planet left its orbit and, in its passage out past Venus, was captured by Earth. This proposal is the latest variation of the capture hypothesis.

Another hypothesis is that Earth and Moon formed simultaneously with the rest of the solar system in such a way that in the final stages of condensation the Moon solidified from particles already in orbit about a quasi-solid Earth.

On the other hand, Sir George Darwin has proposed a mechanism by which fission of Earth could occur. Assuming that Earth and Moon were originally one body, and with the same total angular momentum as today, the mass would have been only 1.2% larger than Earth's present mass, but the period of rotation would have been four hours with solar tides of two hours. The greatest period of free vibration of Earth is about two hours, hence a resonance condition could have been established between solar tides and Earth vibrations resulting in a large chunk of Earth being torn loose. However, calculations have shown that several effects, viscous friction being one, are sufficient to dissipate tidal energy and so this last hypothesis has been relegated to a low probability status.

Prior to the Apollo flights' return with lunar material there was general agreement that simultaneous formation of Earth and Moon during the formation of the solar system was the most probable process.

The problem of Moon's origin is related to questions about its age (see below for a comment on the meaning of "age" here) and its present structure. Many students of selenology have thought that Moon's structure was much like Earth's, comprising a crust, a hot plastic mantle and probably a hot liquid core. Such a structure would result in volcanic activity and accordingly the extensive planar regions, called maria, were attributed to lava flows arising from the interior. Contrary to this point of view a number of selenologists proposed that Moon accreted at low temperatures (because Earth's heavier elements are concentrated primarily in the core, Earth then had to accrete at high temperatures where "high" is anything over approximately 1150°C) with subsequent melting of the surface by bombardment from very large bodies, some perhaps as much as a tenth of Moon's total mass. Hence, most of the features of Moon which had been observed (only 57% of Moon's surface can be seen from Earth: the Luna and Orbiter flights gave us our first view of the far side) were due to bombardment from such bodies. The great asymmetry of this bombardment became apparent only after pictures of the far side were televised back to Earth, showing that there are almost ten times as many craters on the far side as there are on the near side. Spacecraft orbiting Moon have experienced perturbations of their orbits from five or six regions on the near side which have higher mass concentrations (mascons) than Moon's average. Only one or two mascons may have been detected on the far side, if any. These mascons seem to be associated with the mare regions.

An important fact bearing on the structural theories is the mean densities of Moon and Earth, which are 3.34 and 5.52, respectively, whereas the mean density of mantle rocks at Earth's surface is 3.3. By comparison, mean densities of Mercury, Venus, and Mars are 5.05, 4.87, and 4.24, respectively, according to Harold Urey, in his book, "The Planets."

Now that there has been an extensive investigation of the properties of a very small fraction of Moon's surface, some of the ideas and notions about Moon's origin, age and structure can begin to be tested. The first Lunar Science Conference was held in Houston in January. All of the conference papers have been published in the January 30 issue of *Science.* For those with an extensive knowledge of geology, mineralogy, petrography, physics, chemistry and biology, not to mention great fortitude, this issue is fascinating. Lacking these prerequisites, I will confine my statements to those things of interest to me, which of course include the studies that my colleagues, Andre Chatelain, J. L. Kolopus, D. Kline, and I have made on the lunar samples we received.

The age of a rock may be understood in two contexts: one is the time that has elapsed since the rock was last a liquid, and the second is how long the rock has been exposed to cosmic rays. The length of time a rock has been solid is determined from the ratio between such radioactive elements as uranium, thorium, rubidium and potassium, and the end products of their radioactive decay. The noble gas end products of some of these elements are dissipated from liquids and from solids at high temperatures. Helium, the end product of ^{238}U and ^{232}Th decay, is retained only after a temperature less than 100°C is attained. Zenon isotopes which result from such decay are lost from rocks and minerals at temperatures greater than approximately 250°C. Hence, rock ages determined from these ratios are representative of the time that has elapsed since the rocks cooled below these respective temperatures.

The oldest rocks that have been found on Earth have been solid for approximately three billion years. Many meteorites are approximately 4.5 billion years old. It is thought that this latter age is representative of the age of the solar system.

Cosmic rays produce radioactive elements from certain non-radioactive elements. Thus, by measuring the number of decay events per unit mass per unit time, and the energy of emitted particles, and by knowing the flux and energy of cosmic rays (assuming they have been constant), an exposure age can be calculated. Cosmic ray exposure age is a function of the rocks' mass, since most cosmic rays only penetrate about three feet into rocks having the density of silicate minerals. Consequently, the interiors of rocks greater than a few feet in diameter will not have a cosmic-ray exposure age. For a rock on the surface of a large body such as the moon, its measurable age will be the length of time the rock has been on the surface, assuming it was exhumed by some past event, like a meteorite excavating a crater, or a volcanic eruption.

It is thought that most of the prominent surface features of the Moon have been formed by impacts, and that lunar surface rocks are exhumed to the surface as a result of these. A few of the craters were formed from primary impacts of extra-lunar origin, but most of them from secondaries, of lunar origin. Thus, fresh subsurface material is continually being raised to the surface with a relatively small input of non-lunar material.

Because of the elaborate instrumentation and its skilled operation needed for age measurements, the age of Moon and the length of time its surface rocks and soil had been on the surface could only be determined by measuring the lunar material on Earth. Studies have been done now on Apollo 11 material by a number of laboratories in the U.S. and Europe. The ages reported by the various laboratories are consistent. The soil and those rocks formed by compaction of the soil (breccias) were at a temperature below 250°C 4.6 billion years ago. This material has not been at a temperature greater than 250°C for any appreciable time (on the order of an hour) since then. Crystalline rocks which still retain the form in which they last solidified reached a temperature below 250°C between 3.5 and 4.1 billion years ago.

Apollo 12 rocks, on the other hand, are approximately 2.3 billion years old. This variation in ages poses the problem of how such widely differing ages were produced. The oldest lunar material (soil and breccias) at Apollo 11 site is the same age as most meteorites, which is not unexpected. The younger crystalline rocks were produced by the event which melted a fraction of the lunar surface in Mare Tranquillitatis approximately 3.5 billion years ago. But if this sequence of events happened how did the older soil and breccias become intimately mixed with the younger rocks? There is no water or air on the Moon, so the erosional processes that move vast amounts of Earth's surface about are not active (gas pressure at the lunar surface is less than 10^{-12} of Earth's atmosphere). It was also expected that the soil would simply have been the result of fragmenting larger rocks by repeated shocks from impact events. (Impact of high velocity projectiles in most rocks produces rock flour when experiments are performed in Earth laboratories.) Not only does this process appear not to have occurred but at the same time many rocks on the lunar surface do have the appearance of having been eroded by some process. Could it be that the soil at Tranquillity Base came from another region of Moon? Armstrong and Aldrin reported that during their descent and ascent material expelled by rocket blast "seemed to travel a great distance (over the horizon) at a high velocity." Thus, it is possible that this soil was ejected from craters formed by impacting objects at high velocity from another region of Moon, perhaps the mountain regions.

If the rocks and soil have been overturned and covered over and new material exposed on the surface by a sequence of impact events, how long have the Apollo 11 and 12 specimens been on the lunar surface? The cosmic-ray exposure ages which determine this time have been measured by a number of researchers, one group being that headed by ORNL's G. D. O'Kelley, in Chemistry. Apollo 11 specimens were on the lunar surface, or within a foot or two of it, for periods ranging from 10 to 400 million years. Apollo 12 specimens have considerably shorter exposure ages; they range from less than a million to 200 million years. These results are indicative of a turnover rate that is surprisingly high. Moreover, the Apollo 12 exposure ages show no correlation with rock types, so that the older soil, breccias and crystalline rocks appear to be well mixed in that layer of surface material that has been exposed on the surface in the last 400 million years.

Other data are also indicative of churning of surface material. Soil to a depth of seven inches was collected by Apollo 11 in coring tubes in such a way that stratification if present was probably not disturbed. The amounts of solar particles—hydrogen, helium, neon, argon and krypton—trapped in a gram of soil from the surface was approximately the same as the amounts from a gram seven inches below the surface. This finding, plus the distribution of cosmic ray exposure ages, support the hypothesis that there has been a churning of the surface. From these data and other measurements it will be possible to determine the rate of turnover of the soil and rocks. Certainly a major fraction of the churning of the surface is due to impact events but other processes as yet undetermined also may be important. Analysis of samples from Apollo 12 core tubes, which penetrated the soil as much as thirty inches, should provide a better understanding of these processes.

If meteoritic impacts are the source of many of the craters then is it possible that some of the Apollo

PRINCIPAL MINERALS IN LUNAR ROCKS, COMPARED WITH TERRESTRIAL BASALTS AND CHONDRITIC METEORITES

Mineral	Moon Samples			Terrestrial Igneous Rocks			Meteorites
	Apollo 11		Apollo 12	vesicular basalt	tholeütic basalt	gabbro	chondrites
	microcrystalline %	crystalline %	crystalline %	%	%	%	%
Pyroxene $Ca(Mg,Fe)Si_2O_6$ $+(Mg,Fe)SiO_3$	46	53	5-75	—	11	35	22
Plagioclase $CaAlSi_2O_8$ $+NaAlSi_3O_8$	31	27	11-75	55	51	50	12
Olivine $Mg(Fe)_2SiO_4$	trace	trace	0-55	14	5	38	—
Ilmenite $FeTiO_3$	11	18	0-20	—	3	—	—
Magnetite Fe_3O_4	—	—	—	5	5	10	26
Glass and Trace Minerals	10	2	0-10	20	16	—	2

11 and 12 specimens are of meteoritic origin? There are several measurements that show that most of the Apollo 11 and 12 specimens are not similar to meteorites that have been found on Earth. The relative abundances of many elements are distinctly different. For example, nickel and cobalt are approximately 500 and 20 times, respectively, more abundant in chondritic meteorites than in Apollo 11 and 12 crystalline rocks, whereas titanium, strontium, barium, zirconium, yttrium are more than ten times as abundant in lunar rocks than in chondritic meteorites. Differences in the relative abundances of other elements are also significant. Careful analysis of soil and rock samples have shown that approximately one percent of the soil and none of the crystalline rocks have elemental abundances or mineral assemblages similar to those chondritic meteorites which have been analyzed. There is a small group of meteorites, called "eucrites," that do not differ from lunar soil in relative abundance of elements as much as chondrites do. By comparison to chondritic meteorites and to those Earth rocks most similar to lunar rocks, the lunar material is deficient in elements with the greatest volatility.

Differences among Apollo 11 material and chondrites and Earth basalts are also very evident in the mineral assemblages into which the elements were combined when solidification occurred, approximately 4.5 billion years ago for the soil and breccias, 3.5 billion years ago for the Apollo 11 crystalline rocks, and 2.5 billion years ago for the Apollo 12 crystalline rocks. Those elements which determine the mineral assemblages are oxygen, silicon, calcium, magnesium, aluminum, sodium, and iron. Crystallization of liquids composed of these elements occur at temperatures in excess of 1100°C. The primary minerals which crystallize from such liquids are olivines, pyroxenes, plagioclases, oxides and sulfides of iron, and iron metal. The relative amounts of these and the oxidation states of iron are determined by the amounts of gaseous oxygen, sulfur, and water present during crystallization. Along with other volatiles, most of these elements and compounds were probably lost from lunar material before solidification began. Hence, Apollo 11 specimens, although composed of many of the same minerals as meteorites and terrestrial basalts, have different percentages. Of these, three new minerals are present in small amounts which have not been detected in either meteorites or igneous Earth rocks. These are pyroxmanganite (a pyroxene-like mineral), ferropseudobrookite, and a chromium-titanium spinel. (It has been suggested that these three minerals be named for the three Apollo 11 astronauts.)

Free metallic iron is rare in igneous Earth rocks but quite common in Apollo 11 rocks; approximately one percent of the iron is metallic. Because of the extremely low abundance of water—about 150 water molecules per one million silicon atoms—alteration of crystals by water has not occurred. Thus moon crystals have a brilliance and transparency not usually seen in corresponding terrestrial crystals.

At ORNL some of the magnetic properties of Apollo 11 and 12 samples are being analyzed. These particular properties can be detected and measured by a magnetic resonance spectrometer. In this spectrometer electromagnetic radiation (microwaves) of constant energy illuminate a sample while it is in a variable magnetic field. The energy absorbed from the microwaves by the lunar sample changes as the strength of the magnetic field changes. The pattern of absorption is a function of the kinds of ions in the sample and also of their concentration. Ions of iron, titanium, manganese, chromium and nickel in their various chemical states have characteristic absorptions. Accordingly, such measurements enable us to determine some of the chemical and magnetic states of these ions. On the basis of this knowledge additional conditions may be defined for the processes by which these rocks and minerals were formed.

The most intense components of electron magnetic resonance absorption in Apollo 11 and 12 samples on which our measurements have been made are due to ions of iron, in metallic form and in the chemical state Fe^{3+}, that is, iron atoms that have three less electrons than the number required for electrical neutrality. About one tenth of one percent of the iron is in the Fe^{3+} state. These iron ions are not uniformly distributed throughout the samples, but occur in small regions. The magnetic interactions between the iron ions are quite strong. It is not yet possible to define the conditions necessary for the formation of these magnetic complexes. However, one possible process by which these states can be attained is by maintaining Fe_2O_3, or hematite, at a high temperature (1000°C) at low oxygen pressure (10^{-4} torr) for some period of time. The spectrum of hematite treated in this way is quite similar to the one observed in lunar soil. Under the conditions of these measurements it is not possible to detect magnetic resonance absorption of Fe^{2+}, the ionization state of approximately 99 percent of the iron ions.

Although metallic iron has been identified, its resonance absorption makes only a small contribution to the total absorption. However, if metallic fragments are removed from the soil, they have a resonance absorption spectrum that is the same as iron particles prepared in the laboratory. A meteoritic iron-nickel flake which we picked out of our sample of soil has just such a spectrum.

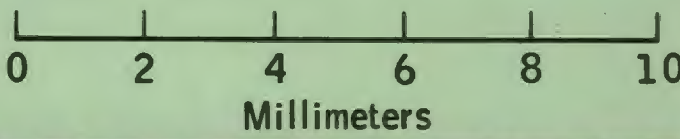
One of the spectral components is due to manganese (Mn^{2+}). The resonance absorption is similar to that of manganese in a glassy material such as window glass (a silicate compound) although the silicate minerals in which the manganese occurs (pyroxene and plagioclase) are crystalline and not glassy. One possible explanation of this apparent contradiction is that the mineral has a well ordered long-range structure but short-range disorder. The usual techniques of observing crystal structure do not detect this kind of disorder, but it is detected by magnetic resonance absorption experiments. Such disorder, if confirmed by additional experiments, may be evidence for a rapid cooling of the crystal from a temperature close to its crystallization temperature (1140°C) to below 200°C. However, other processes in which a highly strained state could be frozen into the crystal cannot be excluded.

Shifting Theories

The fraction of Moon upon which these many measurements have been made is about 6×10^{-23} of its total mass. Despite the smallness of our sample in comparison to the specimen, it has been big enough for the delineation of many new constraints on the process of lunar evolution. Erosional effects have been detected that arise from phenomena unknown on Earth's surface and which are not understood. Microcraters have been observed on the surface of many rocks. Impact of micrometeorites traveling at very high speeds may be the source of these, yet this hypothesis is unproven. Many conjectures about Moon have now been discarded and new ones are being developed. But it will take many more kilograms of rocks from many different places and depths, many more seismometers and magnetometers, and many experiments as yet only dreams before the historians of Moon reconstruct her past. The possibilities for new information in rocks, for instance, brought from Moon's polar regions—material that may have been at a temperature only a few degrees above absolute zero for more than four billion years—offer a tremendous challenge. The structure of such rocks may lead us to an understanding of those ancient events from which the solar system evolved.

In the field of lunar research, we have only scratched the surface.

Microphotograph of a moon rock showing small craters lined with glass. They range in size from approximately 0.1 inch to less than 0.0001 inch. This rock, a breccia, was probably formed by compaction of the lunar soil caused by a heavy impact. The white regions are plagioclase that has been heavily shocked, probably at the time the rock was formed. The craters may have been formed by the impact of micrometeorites moving at such a velocity that upon impact they vaporized, vaporized some of the rock to form the crater, and melted some of the rock to form the glassy walls of the crater.



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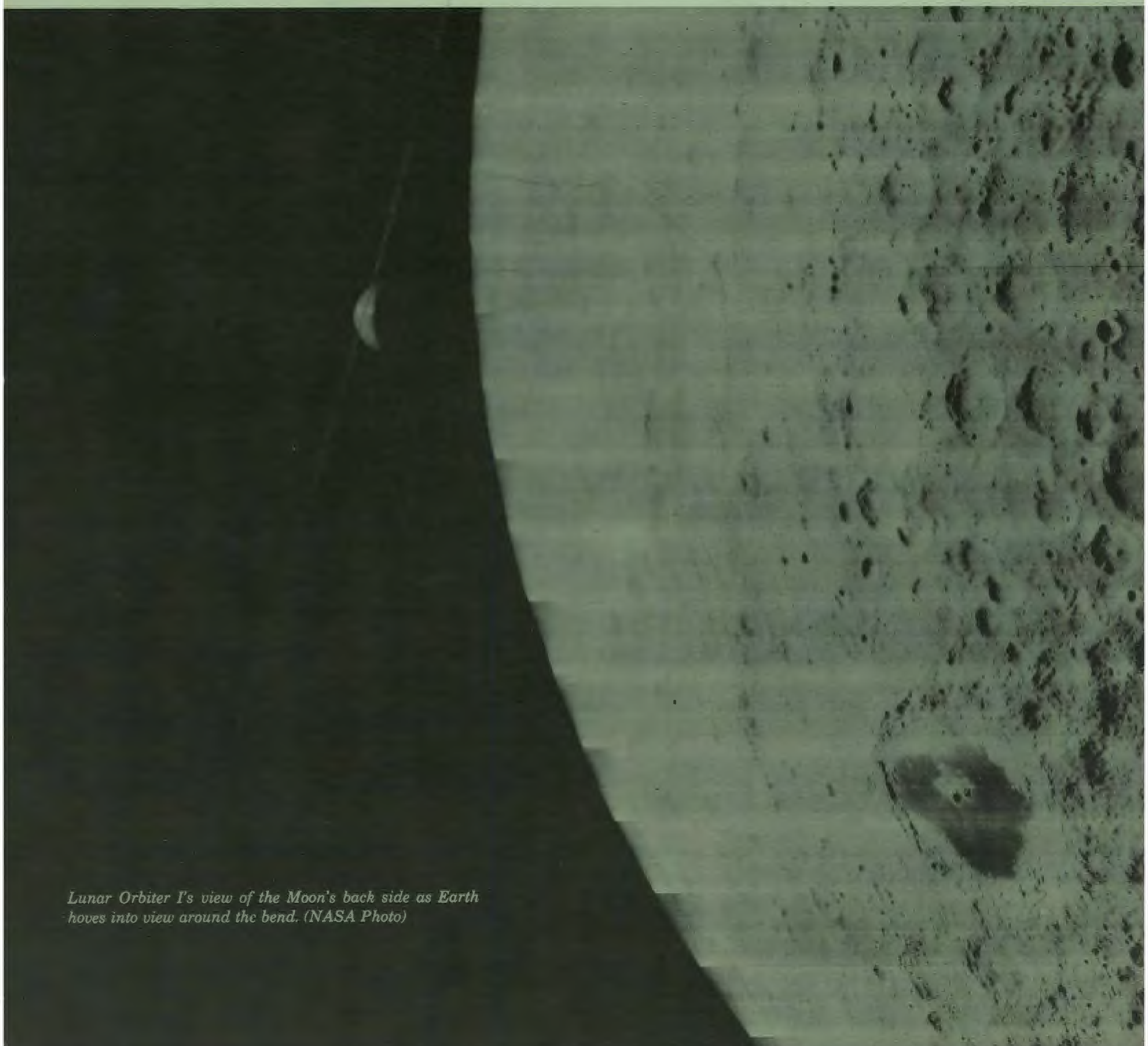

Lunar Orbiter I's view of the Moon's back side as Earth hoves into view around the bend. (NASA Photo)