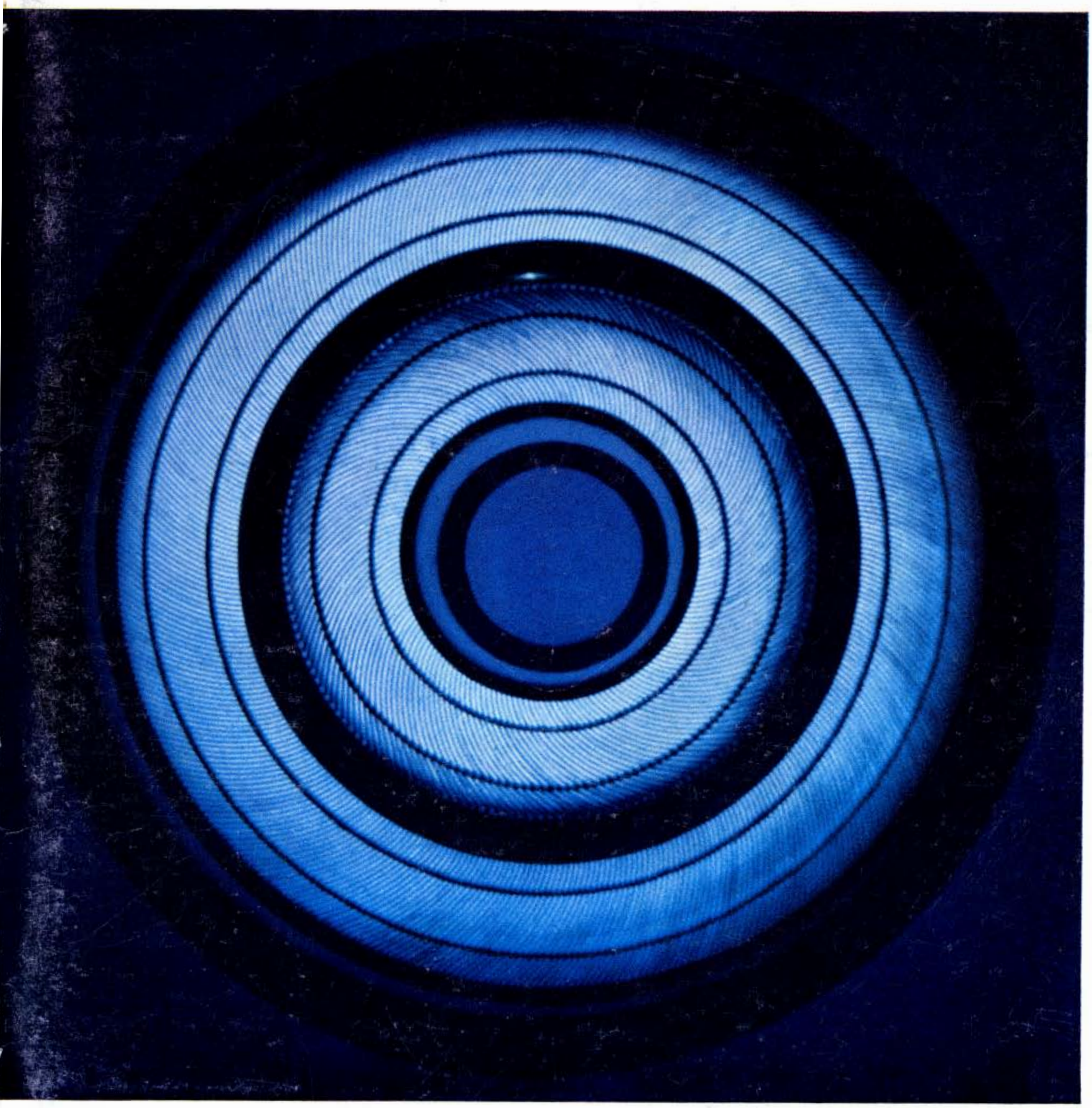
SCIENTIFIC AMERICAN



SYNTHETIC ELEMENTS

SEVENTY-FIVE CENTS

April 1969

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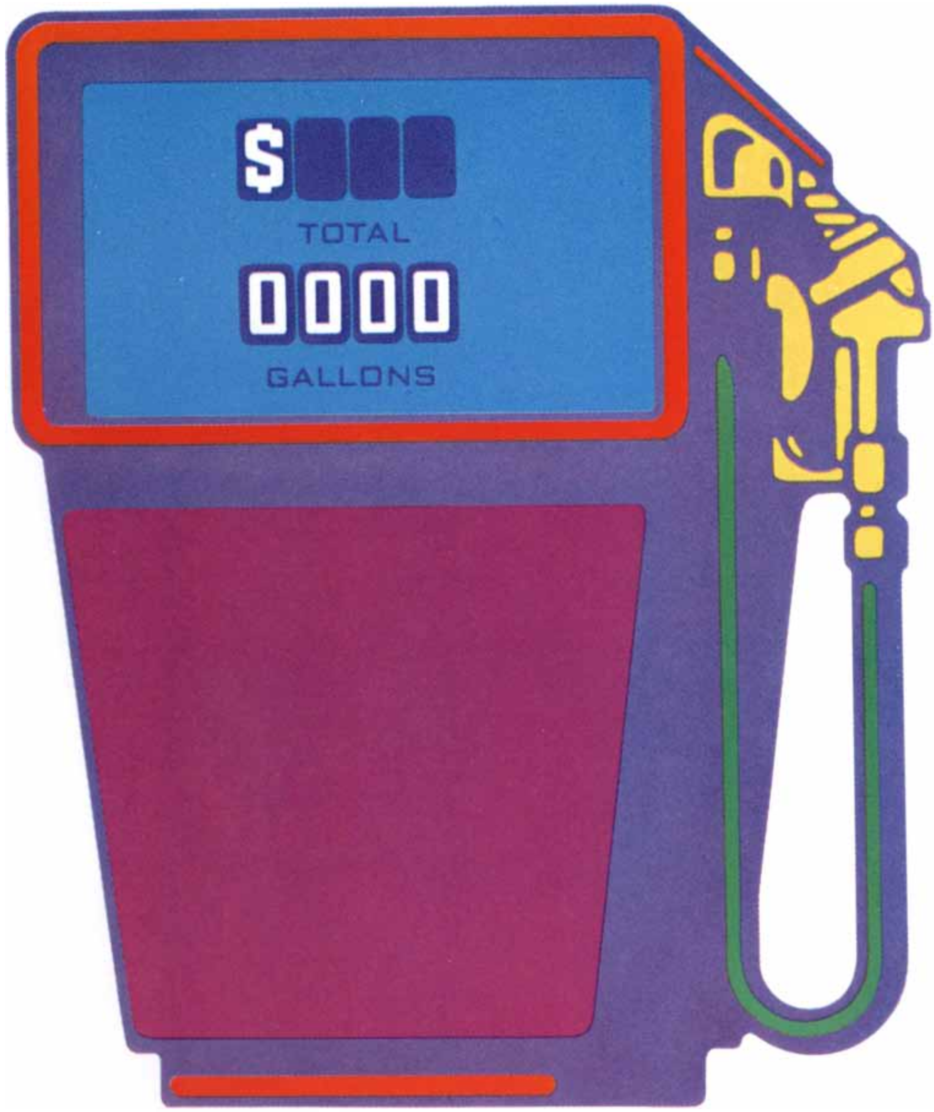

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Established 1845 SCIENTIFIC AMERICAN April 1969 Volume 220 Number 4

ARTICLES

DEPARTMENTS

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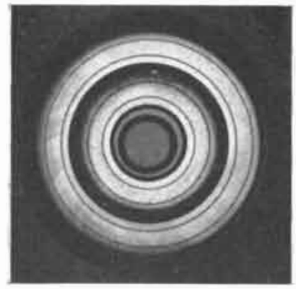

THE COVER

The photograph on the cover shows the core assembly of a nuclear reactor cooling in a pool of water at the Oak Ridge National Laboratory. The assembly has been removed from the high-flux isotope reactor, where neutrons from the uranium in the assembly have been used to bombard plutonium to create isotopes of synthetic elements such as californium (see "The Synthetic Elements: IV," page 56). When the core is taken out of the reactor, it is hot in terms of both radioactivity and temperature. The blue color, which is typically seen when sources of intense radioactivity are in water, arises from Cerenkov radiation resulting from the passage of high-speed electrons through the water. The slight distortion in the photograph is the result of turbulence in the water generated by heat from the core assembly. The inner fuel element, consisting of 171 curved plates each .05 inch thick and 24 inches long, has an outside diameter of 10½ inches; the outer fuel element has 369 plates and is 17⅛ inches in outside diameter.

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SCIENCE/SCOPE

The largest and most powerful communications satellite launched to date was put into synchronous orbit February 9 over the Pacific. Built for the Department of Defense by Hughes, the 1600-pound experimental giant is two stories tall and more than eight feet in diameter. It is so powerful its signals can be received by all types of ground terminals, including those with antennas as small as one foot in diameter. It will be used by the Army, Navy and Air Force to determine the feasibility of using synchronous satellites for tactical communications with small mobile ground stations, aircraft, and ships at sea.

Undergoing space test for the first time is a new concept of spacecraft stabilization called Gyrostat. It enables the DOD satellite -- despite its enormous size and weight -- to spin on its minor axis so that its mechanically "de-spun" cluster of antennas is always pointed toward earth. Construction of the new satellite was directed by the U.S. Air Force Space and Missile System Organization (SAMSO).

A small, speedy, fourth-generation computer, designed to meet the military's highly sophisticated command-and-control requirements in the 1970s and beyond, is being built by Hughes under a multi-million-dollar company-funded program. Basic size is only 4½ cubic feet. It will handle up to five million operations a second and store up to 256,000 words in its memory, and is designed for modular expansion in both hardware and software to meet changing requirements.

A new pictorial area-navigation system is being tested by United Air Lines on its Chicago-New York and Chicago-Minneapolis routes. The Hughes-developed Navigation Direction System, with its compact digital computer, uses 35mm film to project navigational charts on a cockpit display.

The seven-inch-diameter screen displays a moving map upon which are superimposed a symbol for the aircraft and all navigational guidance information. System enables pilots to plan a desired course to destination and shows aircraft position and guidance in relation to it. Additional features include display readouts of ground speed, distance, and "time-to-go" to selected check points or destination.

New development programs at Hughes have created immediate opportunities for Circuits, Communications, Display, Electronics Packaging, Electro-Optical, Radar, Solid State Microwave, Sonar, Systems, and Test Equipment Engineers. Requirements: engineering degree, at least two years of related experience, U.S. citizenship. Please send your resume to Mr. J. C. Cox, Hughes Aircraft Co., P.O. Box 90515, Los Angeles, 90009. An equal opportunity employer.

NASA's Project Viking plans to softland an unmanned spacecraft on Mars in 1973. The project calls for two 5,000-lb. spacecraft consisting of a Surveyor-type softlander and a Mars/Mariner orbiter, and will use a Titan 3D-Centaur launch vehicle. One of the softlander's missions will be to determine whether extraterrestial life exists. Hughes, member of the Project Viking industrial team formed by Boeing, designed and built the five Surveyor spacecraft that landed on the moon to pave the way for Apollo astronauts.

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LETTERS

Sirs:

In L. Sprague de Camp's February article on the "monkey war" he writes that "in a sense the defense in the Scopes case won after all." Unfortunately, in spite of the ridicule heaped on the Fundamentalists, the truth is that they accomplished exactly what they desired. Although public attention has been almost exclusively on the antievolution laws, a far more significant phenomenon has been virtually ignored: what happened to high school biology textbooks following the Scopes affair. Within two years after the trial virtually every textbook was revised so as to gloss over or eliminate entirely the thorny issue of evolution. The publishers were naturally loath to risk losing the Southern market for their books, so that all school systems, North as well as South, had to be satisfied with an emasculated version of evolution. Truman Moon's *Modern Biology* (published by Holt) is the best and most widely used example of this placating of the Fundamentalists.

Not until the late 1950's and the introduction of the Biological Sciences Curriculum Study (BSCS) textbooks was evolution reintroduced to high school biology texts to a significant degree (although there were a few good but seldom used texts available). Only then did the quality of the treatment of evolution generally available to the high school student actually surpass (or even equal) that of the pre-Scopes era. Thus the entire history of the Scopes trial and its aftermath shows us quite clearly just how effective social pressures against science can be, even when they are dismissed by the educated citizenry as sheer nonsense.

PETER D. MILLER

Cleveland Heights, Ohio

Sirs:

Whilst on passage from Panama to Charleston, S.C., our vessel was proceeding up the Florida Strait on the evening of January 7.

When we were some 18 nautical miles east of Jupiter Inlet at about 19:40 E.S.T. we saw first two luminous clouds and then a third appear in the sky above the western horizon over Florida.

As the clouds grew in size and changed

in shape they were finally identified by reference to the November 1968 issue of *Scientific American* as being artificial plasma clouds in space. Their behavior was exactly as predicted in the article by Gerhard Haerendel and Reimar Lüst, including the separation of the ionized particles along the lines of force in the earth's magnetic field.

A social psychologist might be interested to note the initial reactions of the bewildered observers at sea. The captain suggested that the strange lights were the arrival of the Angel of the Lord. The mate put forward the idea of invading Martians. The teen-age apprentice believed it to be a stunt to advertise the opening of a new supermarket, "seeing as it's over Florida." The closest guess was that of a Scottish sailor from the Shetland Islands, who thought the Northern Lights had wandered off course.

May I thank you for your articles? This one was certainly a guide to perplexed laymen.

G. C. WALLIS

Master
SS Pacuare
New York, N.Y.

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NAME

NEW ADDRESS

OLD ADDRESS

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

APRIL, 1919: "Each week brings forth new entries in the great trans-Atlantic flight contest. Already there are well over a half-dozen recognized participants, and many more are about to announce their entry in the greatest competition in aviation history. In fact, the trans-Atlantic flight is rapidly becoming a race, for there can be little doubt that several participants will succeed in making the crossing within the next few months. The British have several dirigibles of great cruising range available for the flight, and aviation men have momentarily expected to hear of a British dirigible landing in Nova Scotia or Newfoundland after a successful crossing. In addition, there is Captain Sunstedt with his graceful seaplane; the British with the Sopwith two-seater, to be piloted by Harry Hawker and Lieut.-Com. McKenzie Grieve, and the Porte triplane; the Americans with the Model T flying boat, which has five Liberty motors and has a cruising range well over 2,000 miles; the French with their Caudron, which has a range well over 1,200 miles, making it eligible for the shorter southern route; the Italians with their Capronis, which, it is understood, are being rushed for the competition; and many others not yet announced. Sometime in April ought to mark the first flight across the Atlantic, with either the British or the Americans as the most likely winners of the *London Daily Mail* prize of $50,000."

"The steamer *George Washington*, which has been carrying President Wilson back and forth between the United States and Europe, is no doubt the best-equipped ship afloat as regards radio equipment. Indeed, it has been referred to as a floating laboratory for wireless experimentation and research. The radio equipment on the first trip with the President consisted of one low-power spark transmitter, one 16,900-meter long-wave receiving set, one short-wave 600-meter receiving set for spark signals, one short-range radio-telephone transmitting and receiving set, one vacuum-tube 450-meter receiving set. The escorting battleship *Pennsylvania* received messages transmitted from the high-powered stations at Annapolis, New Brunswick and Tuckerton in the U.S., and Lyons in France, intended for the President and relayed them by the vacuum-tube and radio-telephone sets simultaneously. Messages from the President destined for the U.S. or France were sent from the *George Washington* to the *Pennsylvania* by the vacuum-tube or radio-telephone set, and relayed by the battleship's 30-kilowatt arc transmitter."

"With the death of Sir William Crookes, which took place on April 4th, the world of science mourns the loss of an investigator who belonged to a type which is very seldom met with in modern times. Nowadays specialization is so intense that it is hard to find a physicist who has done work in more than one or two branches of physics, or a chemist who has done work in more than one or two branches of chemistry, but in Sir William Crookes we have a man who was a direct descendant of the giants of old, men who could turn their attention with equal ease to several of the great divisions of science and achieve work of lasting importance in each. Sir William's striking combination of diverse gifts, keen observation, patient and inexhaustible experimental skill, together with the glowing mind and imagination of a poet, have assured him for all time a settled place in the great list of English men of science."

"According to a note in the *Chemical Trade Journal*, a new radio-active element of considerable emissive power has been detected in the residue from pitchblende, the mineral source of radium. This residue was subjected to treatment which finally left undissolved only the members of the tantalum group; and this remainder showed a radiation that proceeded mainly from the evolution of actinium and indicated the presence of the new element 'protactinium.' "

SCIENTIFIC AMERICAN

APRIL, 1869: "There are only 75 miles of rail remaining to be laid on the Pacific Railroad, and it is expected that a locomotive will run through to San Francisco early in the summer."

"A good needlewoman with her needle makes from 25 to 30 stitches per minute, whereas a modern sewing machine will make 1,600. Yet we cannot call this last a *labor-saving* machine, so far as regards the operator on it. As compared with sewing by hand, sewing by machine is really a very laborious and fatiguing occupation. Our stage and street horses are changed several times a day, but sewing girls at their machines are expected to work for 10 or 12 consecutive hours with intermittent but continually repeated motions of the muscles of the lower limbs. We have before us a very interesting report, addressed to the Société Médicale des Hôpitaux by Doctor Guibout, on the sanitary condition of the many sewing machine operators who came under his personal notice in the public hospitals of Paris. Hollow cheeks, pale and discolored faces, arched backs, epigastric pains, predisposition to lung disease and other special symptoms too numerous to be specified were found to be the general characteristics of all the patients. These disastrous effects must eventually tend toward the deterioration of our race and deserve, from a humanitarian point of view, the most serious consideration of all friends of mankind."

"A noteworthy feature of a recent display of velocipede riding on Clinton Street in Brooklyn was the fact that not a solitary horse shied at the velocipedes, much to the disgust of those who had prophesied that bicycles would lead to endless accidents from frightening horses in the street."

"Immense discoveries of gold placers are reported from Alaska. The locations are on the mainland, 120 miles from Kodiak Island, at latitude 61 degrees north and longitude 152 degrees west. There several discoveries have been made; the first on Kuyack river and Chigmet mountains, the second about 60 miles above Sitka, the third on an ocean island, the name of which is unknown."

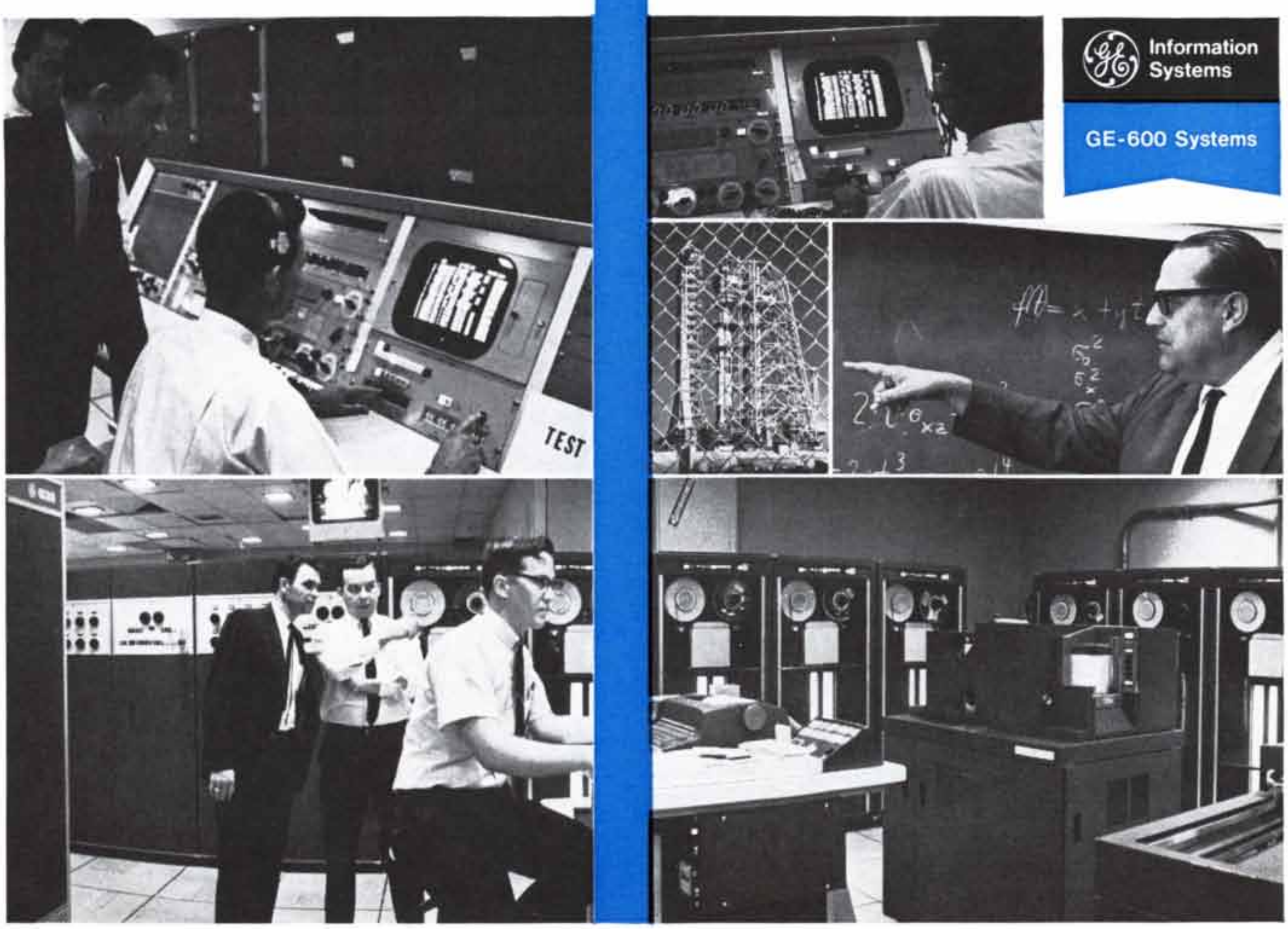
"Under-sea tunnels are attracting the attention of English engineers. In addition to the projected tunnel under the English Channel between Dover and Calais, it is now proposed to unite Scotland and Ireland by a tunnel running from a point on the north-east coast of Antrim, Ireland, to Glenstrone, Scotland, passing through the high rocky peninsula called the Mull of Cantyre. The total length of the tunnel is estimated at 14 miles three furlongs. The ground through which it would have to be dug, it is asserted, is exactly suited for tunneling operations, and the sandstone for lining it can be had in any quantity on the Irish side. It is proposed to construct the tunnel for a single line only, the extreme depth being 21 feet and the clear width at the level of the rails 15 feet. Three lines of rails, to accommodate wide- and narrow-gage carriages, however, are to be laid. The time estimated for completing the tunnel is about six years, and the cost $21,250,000."

"The old hypothesis of Herschel, still also copied in some of our school books, that the sun is a dark, cold, solid body, surrounded by a luminous atmosphere, is utterly disproved by means of one of the most valuable inventions of our decade—the spectroscope. Indeed, this instrument has proved not only that the sun possesses a high temperature but also that this high temperature is not the result of a permanent combustion, like the high temperature of our earth (excepting volcanic fires), and also that this temperature is so high that most substances solid on our earth are surrounding the globe of the sun as an atmosphere in the state of vapor, as some of our metals, iron, nickel, sodium, etc."

"In 1817 Sir Humphry Davy published his theory on the causes of the illuminating properties of flames. He stated that this phenomenon is due to the presence in the midst of the flame of solid particles, which, undergoing partial combustion only, were rendered incandescent. In a candle there were supposed to be solid particles of carbon. Recent experiments made by Dr. Edward Frankland seem to have entirely overthrown this theory. According to the researches of this eminent chemist many brilliant flames exist in nature which cannot possibly contain any solid matter whatever. The conclusions arrived at by Frankland are that it is not solid particles which produce luminosity but that the intensity of the flame depends on the radiation of dense but transparent hydrocarbon or other vapors. The experiments of Frankland have elicited great attention from men of science, and a controversy is at present taking place on the subject at the Academy of Sciences in Paris. The conclusive experiments will soon be begun in France at the École Normale, by order of the Emperor Napoleon III."

"Bauxite is the name of a new mineral that has recently been discovered in France. It is reported to be a hydrated oxide of alumina, in which iron has been replaced by alumina. Bauxite is therefore a source of aluminum."

A GE-635 handles the Apollo launches.



Information Systems

GE-600 Systems

THE AUTHORS

GEORGE W. RATHJENS ("The Dynamics of the Arms Race") is visiting professor of political science at the Massachusetts Institute of Technology. After his graduation from Yale University in 1946 he took his Ph.D. at the University of California at Berkeley in 1951. He taught chemistry at Columbia University from 1950 to 1953. From 1953 to 1958 he was on the staff of the Weapons Systems Evaluation Group in the Department of Defense. After a year as a research fellow at Harvard University he returned to Washington as a member of the staff of the special assistant to the President for science and technology. In 1961 he was chief scientist in the Advanced Research Projects Agency of the Department of Defense, becoming deputy director of the agency later that year. From 1962 to 1965 he held various administrative posts with the U.S. Arms Control and Disarmament Agency, and from 1965 until he went to M.I.T. he was director of the Weapons Systems Evaluation Division of the Institute for Defense Analyses. Later this year he will become vice-president for research at Cornell University. Much of the material in his article also appeared in *The Future of the Strategic Arms Race: Options for the 1970's,* a pamphlet by Rathjens that was published earlier this year by the Carnegie Endowment for International Peace.

BORIS EPHRUSSI and MARY C. WEISS ("Hybrid Somatic Cells") are at the Centre de Génétique Moléculaire of the Centre National de la Recherche Scientifique in France; Ephrussi is director of the laboratory and Miss Weiss is an investigator there. Ephrussi, who was born in Moscow but has been a French citizen since 1932, is in addition professor of genetics at the University of Paris, where he obtained his D.Sc. in 1932. He has spent several extended periods in the U.S., notably at the California Institute of Technology as a Rockefeller Foundation Fellow for studies in genetics in 1927, 1934 and 1936, three years (1941–1944) as associate professor at Johns Hopkins University and five years (1962–1967) as professor at Western Reserve University. From 1928 to 1940 he was at the genetics laboratory of the Rothschild Foundation in Paris. Miss Weiss was graduated from Newcomb College for Women at Tulane University in 1962 and received her Ph.D. from Western Reserve University in 1966. She was a postdoctoral fellow of the U.S. Public Health Service at the New York University School of Medicine in 1966–1967 and at the Carnegie Institution of Washington in 1967–1968.

RALPH NORMAN HABER ("Eidetic Images") is professor of psychology and chairman of the department of psychology at the University of Rochester. As an undergraduate at the University of Michigan he was a philosophy major. He took his master's degree in psychology at Wesleyan University in 1954 and his Ph.D. at Stanford University in 1957. He went to Rochester in 1964 after teaching at San Francisco State College and at Yale University. Much of the research reported in this article represented a collaboration with Jan Leask Fentress, who is now at the University of Oregon.

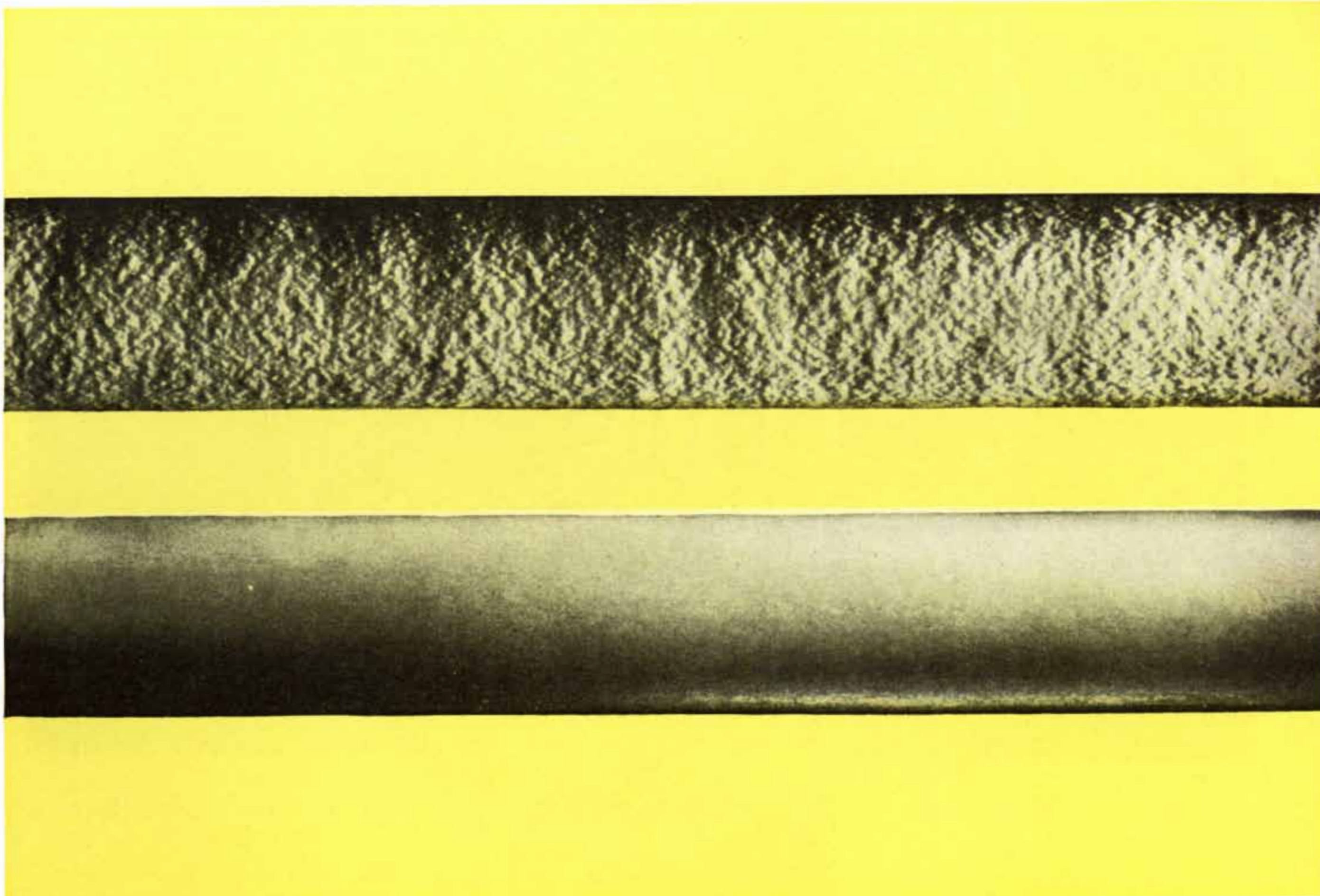
GLENN T. SEABORG and JUSTIN L. BLOOM ("The Synthetic Elements: IV") are respectively chairman of the U.S. Atomic Energy Commission and technical assistant to the chairman. Seaborg is best known for his work on synthesizing elements heavier than uranium; he is codiscoverer of nine of the 11 generally recognized transuranium elements. For his work on the chemistry of the transuranium elements he shared with his colleague E. M. McMillan of the University of California at Berkeley the Nobel prize for chemistry in 1951. Seaborg, who was graduated from the University of California at Los Angeles in 1934, took his Ph.D. at Berkeley in 1937 and remained there for a number of years; he is still on leave as professor of chemistry at Berkeley. During World War II he was chiefly responsible for the development of the chemical-separation procedures used in the manufacture of plutonium. Returning to Berkeley in 1946, he was chancellor of the university from 1958 until his appointment as chairman of the AEC in 1961. Bloom, who was graduated from the California Institute of Technology in 1948, has served in several technical and managerial capacities on the AEC staff since 1956.

SALLY R. BINFORD and LEWIS R. BINFORD ("Stone Tools and Human Behavior") are associate professors of anthropology at the University of New Mexico. Mrs. Binford did both undergraduate and graduate work at the University of Chicago, taking her Ph.D. there in 1962. Her husband was graduated from the University of North Carolina and received his Ph.D. from the University of Michigan in 1964. Until recently the Binfords were in the department of anthropology at the University of California at Los Angeles.

CLIVE A. EDWARDS ("Soil Pollutants and Soil Animals") is principal scientific officer in the department of entomology at the Rothamsted Experimental Station, a research organization maintained in England by the nations of the British Commonwealth. He was graduated from the University of Bristol in 1952 and obtained a master's degree in zoology there in 1954. In 1955 he began an association with the University of Wisconsin that brought him another master's degree in 1956 and his Ph.D. in 1957. He was at Rothamsted from 1960 to 1966 and then spent two years at Purdue University, where he worked on the breakdown of residues of corn plants in soil and on the use of radioactive isotopes in following food chains in soil ecosystems. He notes that he is "currently writing two books," one on the ecology of soil invertebrates and the other on the biology of earthworms.

WALTER HOSSLI ("Steam Turbines") is chief engineer in the steam turbine division of Brown, Boveri & Company Limited in Switzerland. He was born and educated in Zurich, entering the Federal Institute of Technology there after four years of apprenticeship as an engineer and two years of college. He was graduated from the institute in 1956 with a degree in mechanical engineering. In 1957 he joined the steam turbine division of Brown, Boveri as a calculation engineer, becoming head of the calculation department in 1960 and chief engineer in 1964.

WALTER MODELL ("Horns and Antlers") is professor of pharmacology at the Cornell University Medical College. "I am a clinical pharmacologist," he writes. "I am interested in the way drugs work in man. I like to think of myself as a scientist specializing in human biology, subspecialty human responses to drugs." Modell was graduated from the College of the City of New York in 1928 and obtained his M.D. at the Cornell University Medical College in 1932. He taught part-time there until 1955, working also as a consultant in cardiology, and then he took up full-time work at Cornell. His interest in horns and antlers is of long standing, and he plans to prepare an atlas on the subject. He also occasionally takes chisel in hand and becomes a sculptor working in wood.



Which is the slippery wire?

The seemingly simple problem of pulling telephone wires through conduit has important economic implications. In large buildings, for example, we would like to add more wires in existing conduits as the need for communications services grows. But friction between the wires eventually prevents more from being drawn through. Then, a new conduit must be installed, even though the previous one is not really full. What is needed is slippery wire.

Recently, Bell Laboratories and Western Electric greatly increased the useful capacity of conduits by developing a new low-friction polyvinyl insulation for the Bell System's general-purpose wire. Since the new wire slides more easily, it needs less tensile strength, and so it can be smaller. This further increases the number of wires a conduit can hold. Twenty-three wires now fit into a conduit that previously held only four.

We did several things to make the new wire more slippery. We made its jacket harder—by reducing the amount of plasticizer (vinyl softener). We added paraffin wax for permanent lubrication.

And we made the jacket rougher—not smoother. (The low-friction wire, enlarged about eight times, is the top one in the picture.) Smooth surfaces lead to more intimate contact and, therefore, more friction.

As a result of this work at Bell Laboratories, Western Electric altered its manufacturing process: previously, the hot vinyl jackets were cooled by water under high pressure as they emerged from an extruder. This created a smooth finish. Now, Western Electric avoids applying pressure during the cooling process and thus obtains a micro-rough, low-friction surface.

This kind of interaction between Bell Laboratories and Western Electric is a major factor in making improvements quickly available to operating telephone companies.

From the Research and Development Unit of the Bell System.

Bell Labs

Established 1845 SCIENTIFIC AMERICAN April 1969 Volume 220 Number 4

The Dynamics of the Arms Race

Recent decisions by the U.S. and the U.S.S.R. threaten to upset the stability of the present strategic military balance. The net result may be simply to decrease the security of both countries

by George W. Rathjens

The world stands at a critical juncture in the history of the strategic arms race. Within the past two years both the U.S. and the U.S.S.R. have decided to deploy new generations of offensive and defensive nuclear weapons systems. These developments, stimulated in part by the emergence of China as a nuclear power, threaten to upset the qualitatively stable "balance of terror" that has prevailed between the two superpowers during most of the 1960's. The new weapons programs portend for the 1970's a decade of greatly increased military budgets, with all the concomitant social and political costs these entail for both countries. Moreover, it appears virtually certain that at the end of all this effort and all this spending neither nation will have significantly advanced its own security. On the contrary, it seems likely that another upward spiral in the arms race would simply make a nuclear exchange more probable, more damaging or both.

As an alternative to this prospect, the expectation of serious arms-limitation talks between the U.S. and the U.S.S.R. holds forth the possibility of at least preventing an acceleration of the arms race. In the circumstances it seems worthwhile to inquire into the nature of the forces that impel an arms race. In doing so we may determine how best to damp this newest cycle of military competition, either by mutual agreement or by unilateral restraint, before it is beyond control.

There are a number of new weapons systems under development in both the U.S. and the U.S.S.R., but the possibilities that are likely to be at the center of discussion not only in the forthcoming negotiations but also in the current Congressional debate are the anti-ballistic-missile (ABM) concept and the multiple-independently-targeted-reentry-vehicle (MIRV) concept. These systems, one defensive and the other offensive, can usefully be discussed together because of the way they interact. In fact, the intrinsic dynamics of the arms race can be effectively illustrated by concentrating on these two developments.

It is now 18 months since former Secretary of Defense McNamara announced the decision of the Johnson Administration to proceed with the deployment of the Sentinel system: a "thin" ABM system originally described as being intended to cope with a hypothetical Chinese missile attack during the 1970's. The technology of the Sentinel system and some of the means a determined adversary might employ to defeat it were discussed in some detail a year ago in this magazine [see "Anti-Ballistic-Missile Systems," by Richard L. Garwin and Hans A. Bethe; SCIENTIFIC AMERICAN, March, 1968]. At this point I should like to review some of the background of the ABM problem.

Before the Sentinel decision most of the interest in a ballistic-missile defense for the U.S. was focused on the Nike-X program. This concept involved the use of two kinds of interceptor to protect the population and industry of the country against a hypothetical Russian missile attack. Interception would first be attempted outside the earth's atmosphere with Spartans, long-range missiles with nuclear warheads in the megaton range. The effectiveness of the defense, however, would depend primarily on the use of Sprints, short-range missiles with kiloton-yield warheads designed to intercept incoming missiles after they have reentered the atmosphere. The system also envisaged suitable radars and computers to control the engagement.

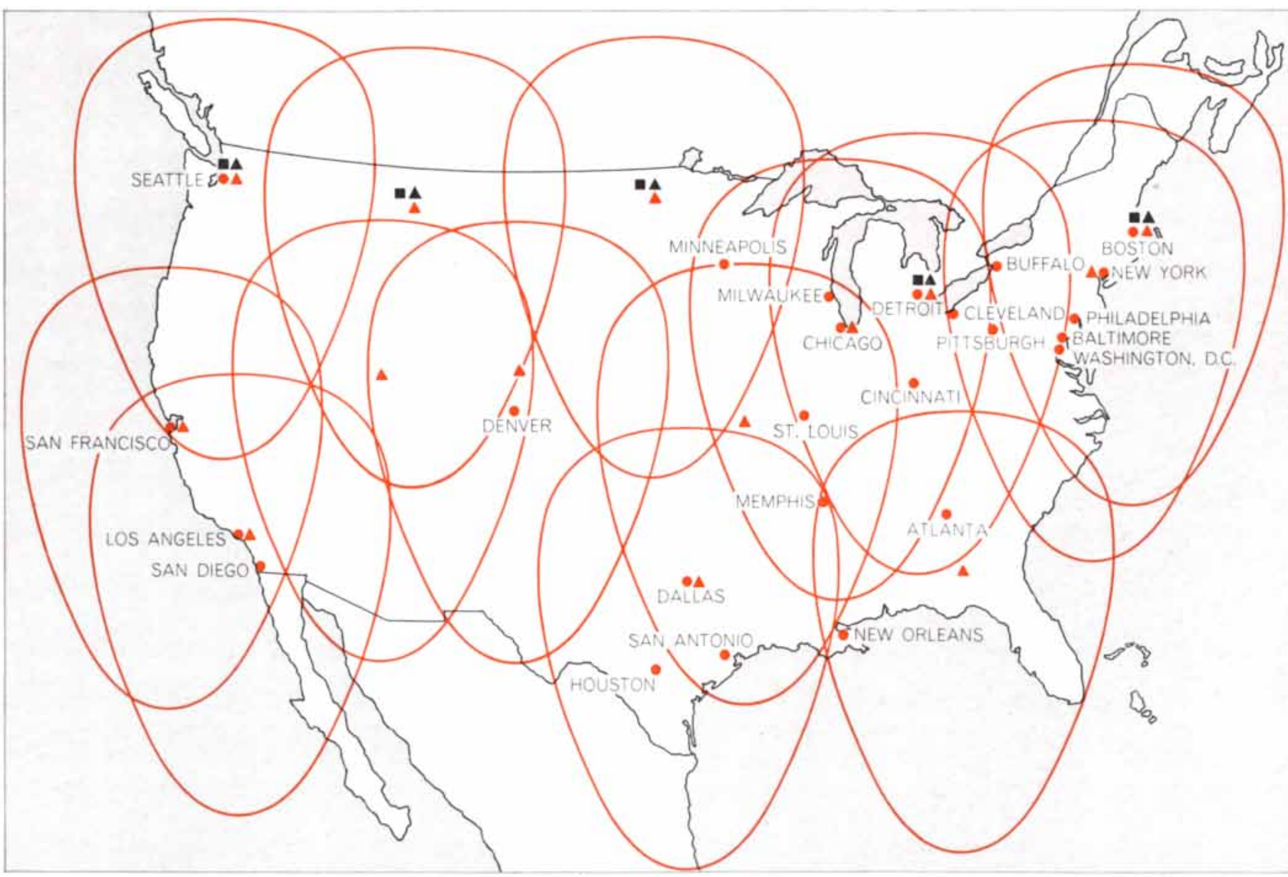
The Spartans could in principle defend large areas; indeed, about a dozen sites could defend the entire country. A defense based solely on them could be rendered ineffective, however, by fairly simple countermeasures, in particular by large numbers of lightweight decoys (which would be indistinguishable to a radar from an actual reentry vehicle containing a warhead) or by measures that would make the radar ineffective, for example the use of nuclear explosions, electronic jammers or light, widely dispersed metal "chaff."

The effectiveness of a Sprint defense would be less degraded by such countermeasures. Light decoys could be distinguished from actual reentry vehicles because they would be disproportionately slowed by the atmosphere and possibly because their wake in the atmosphere would be different. Radar blackout would also be much less of a problem. Because of their short range, however, Sprints could defend only those targets in their immediate vicinity. Thus an adversary could choose to attack some cities with enough weapons to overwhelm the defense while leaving others untargeted. Heavy radioactive fallout could also be produced over large parts of the country by an adversary's delivering large-yield weapons outside the areas covered by Sprint defenses. A nationwide defense of the Sprint type would therefore require a nationwide fallout-shelter program.

Although combining Sprints and Spartans in a single system, as was proposed for the Nike-X system, would complicate an adversary's penetration problem, in a competition with a determined and resourceful adversary the advantage in an offense-defense duel would still lie with the offense. As a result, in spite of strong advocacy by the Army and support from the other branches of the military and from members of Congress, the decision to deploy the Nike-X system was never made.

At the heart of the debate about whether or not to deploy the Nike-X system was the question of what the Russian reaction to such a decision would be. It was generally conceded that the system might well save large numbers of lives in the event of war, if the U.S.S.R. were simply to employ the forces projected in the available intelligence estimates. On that basis proponents argued in favor of deployment in spite of the high costs, variously estimated as being from $13 billion to $50 billion. Such deployment was opposed, particularly by Secretary McNamara, because of the belief that the U.S.S.R. could and would improve its offensive capabilities in order to negate whatever effectiveness the system might have had. Indeed, because the deployment of a U.S. ABM system would introduce large uncertainties into the calculus of the strategic balance, there were occasional expressions of concern that the U.S.S.R. might overreact. Hence the damage inflicted on us in the event of war might even be greater than it would be if the Nike-X system were not deployed.

The Sentinel system announced in 1967 would have far less capability than



▲ SPARTAN SITE

▲ SPRINT SITE

■ PAR SITE

● 25 LARGEST CITIES

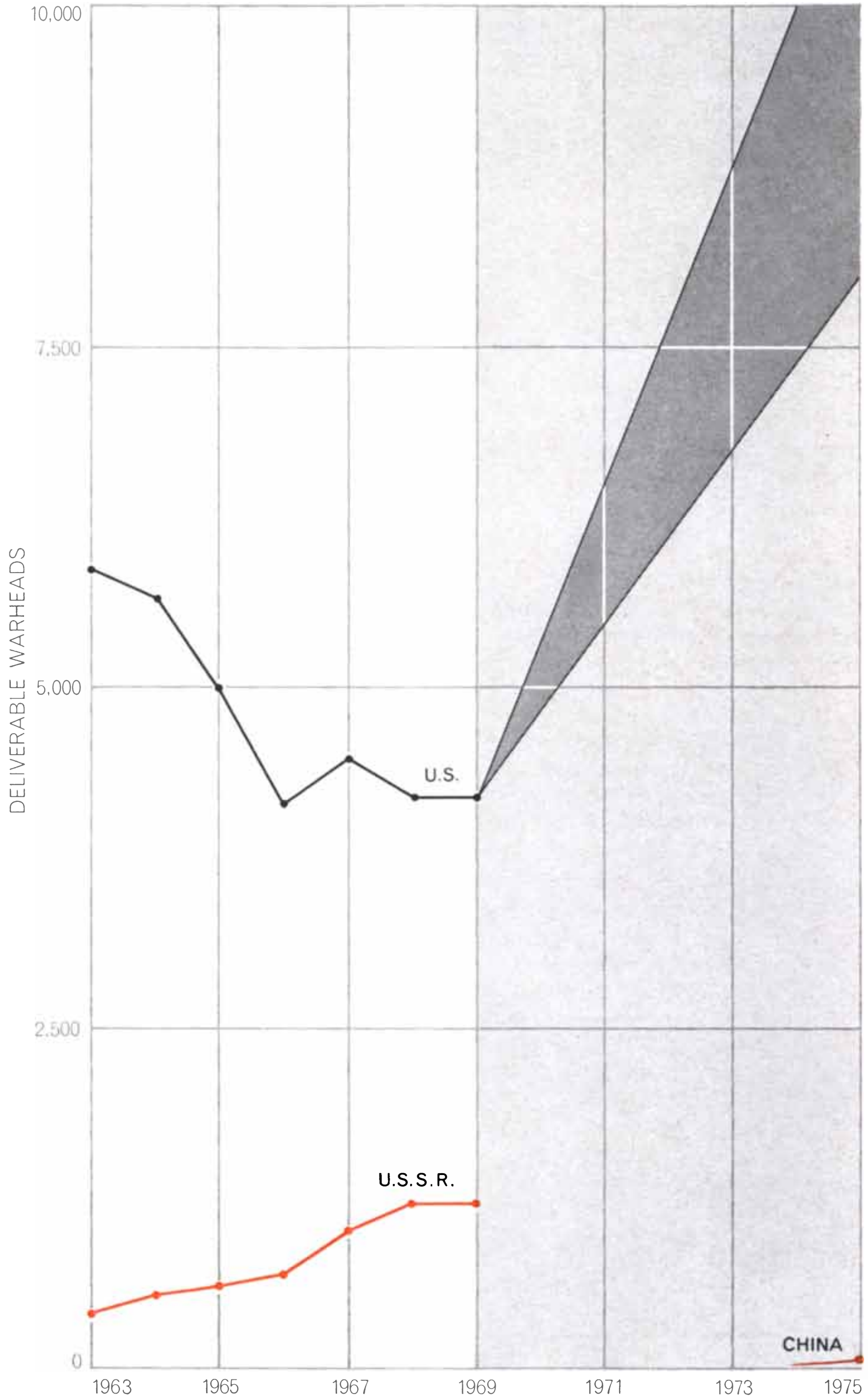
SENTINEL SYSTEM, a "thin" anti-ballistic-missile (ABM) system described by the Johnson Administration as being intended to defend the U.S. against a hypothetical Chinese missile attack in the 1970's, is depicted on this map in its original form. The main defense would be provided by Spartan missiles, long-range ABM missiles with nuclear warheads in the megaton range, designed to intercept incoming missiles outside the earth's atmosphere. The Spartans would be deployed at about 14 locations in order to provide a "thin" or "light" area defense of the whole country. The range of each "farm" of Spartans is indicated by the egg-shaped area around it; for missiles attacking over the northern horizon, the intercept range of the Spartan is elongated somewhat to the south. The Sentinel system would also include some Sprint missiles, short-range ABM missiles with much smaller warheads, designed to intercept incoming missiles after they have reentered the atmosphere. The Sprints were originally to be deployed to defend only the five or six perimeter acquisition radars, or PAR's, which were to be deployed across the northern part of the country. In President Nixon's proposed modification of the Sentinel scheme Spartans, Sprints and PAR sites would be deployed in a somewhat different array to provide additional protection for our land-based retaliatory forces against a hypothetical surprise attack by the Russians.

the Nike-X system. It would include some Sprint missiles to defend key radars (five or six perimeter acquisition radars, or PAR's, to be deployed across the northern part of the country), but the main defense would be provided by Spartan missiles located to provide a "thin" or "light" defense for the entire country [*see illustration on opposite page*]. Spokesmen for the Johnson Administration argued that such a deployment would be almost completely effective in dealing with a possible Chinese missile attack during the 1970's, but that it would be so ineffective against a possible Russian attack that the U.S.S.R. would not feel obliged to improve its strategic offensive forces as a response to the decision. Both arguments were seriously questioned.

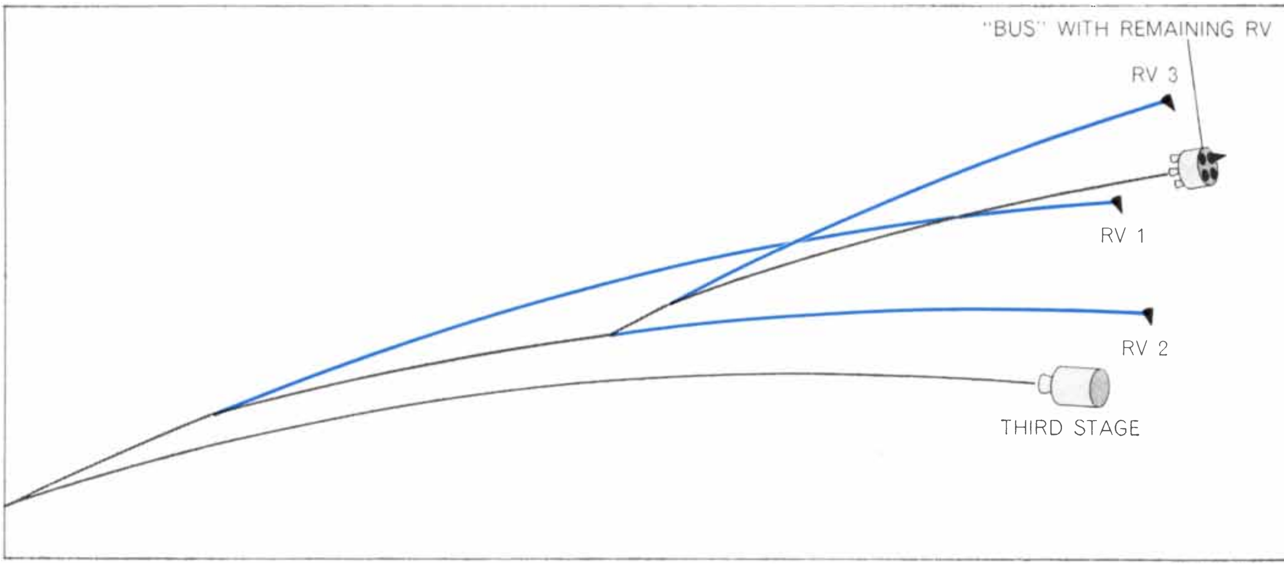
Garwin and Bethe, for example, contended that even the first-generation Chinese missiles might well be equipped with penetration aids that would defeat the Sentinel system. Other experts pointed out that the system, like the Nike-X system, could never be tested adequately short of actual war, and that in view of its complexity there would be a high probability of a catastrophic failure.

The contention that the U.S.S.R. would not react to the Sentinel decision seemed at least as questionable as the assertions of great effectiveness against the Chinese. Whatever the initial capability of the Sentinel system, it seemed clear that the Sentinel decision would at least shorten the lead time for the deployment of a system of the Nike-X type. Moreover, the fact that Sentinel was strongly and publicly supported as a first step toward an "anti-Soviet" system could hardly escape the attention of Russian decision-makers.

Since the announcement of the Sentinel decision, and particularly since the change in the Administration, the arguments in favor of the decision have become confused. It has been variously suggested by Administration spokesmen that the primary purpose would be (1) to defend the American population and industry against a possible Chinese attack, (2) to provide at least some protection for population and industry against a possible Russian attack, (3) to defend Minuteman missile sites against a possible Russian attack and (4) to serve as a bargaining counter in strategic-arms-limitation talks with the U.S.S.R. It might be noted that no one in recent months has seriously suggested that a Russian reaction to the decision is unlikely. In fact, all but the first



STRATEGIC OFFENSIVE FORCES of the U.S., the U.S.S.R. and China are compared here in terms of the number of megaton-range nuclear warheads the U.S. could deliver against either of the two other powers as of a given date, and vice versa. The U.S. missile force grew rapidly during the 1960's, offsetting a partial phasing-out of intercontinental bombers. The Russian bomber force, meanwhile, has remained at a constant level, while their missile force has grown steadily and shows no sign of leveling off. Thus at present the U.S. maintains a superiority over the U.S.S.R. of about four to one in numbers of deliverable warheads. The hypothetical Chinese strategic force was recently estimated by Secretary of Defense Laird to be 20 to 30 deliverable warheads by the mid-1970's. The effect of the present U.S. program to equip its Minuteman III and its Poseidon missiles with multiple independently targeted reentry vehicles (MIRV's) would be to increase greatly the number of U.S. deliverable warheads by 1975 (*dark gray area*). It is not known what compensating actions, if any, will be taken by the other powers in response to this development. It has been estimated by former Secretary of Defense McNamara that 400 one-megaton warheads would suffice to destroy 75 percent of the industry and 33 percent of the population of the U.S.S.R.



MIRV CONCEPT on which the current U.S. Minuteman III and Poseidon programs are based is illustrated by the idealized drawings on these two pages. Each offensive missile will carry aloft a "bus," containing a number of individual reentry vehicles, or RV's (in this example four are shown). A single guidance and propulsion system will control the orientation and velocity of the bus, from which the reentry vehicles will be released sequentially (*left*). After each release there will be a further adjustment in the velocity

of the arguments cited above imply the likelihood of a Russian response.

President Nixon's reaffirmation, albeit with some modification, of the Sentinel decision was presumably made on the basis of his judgment that the first and third of the aforementioned arguments justify the costs of such a system, not only the direct dollar cost but also the cost in terms of the impact on Russian decision-making and any other costs that may be imputed to the system. Whether or not his decision is correct depends strongly on how serious the possibility of a Russian reaction is. Before dealing further with that question it will be useful to bring MIRV's into the picture.

The problem of simulating an actual warhead reentry vehicle is a comparatively easy one, provided that the attacker need not be concerned with differences in the interaction of decoys and warheads with the atmosphere during reentry. If one wishes to build decoys and warheads that will be indistinguishable down to low altitudes, however, the problem is a formidable one, particularly if one demands high confidence in the indistinguishability of the two types of object. Improved radar resolution and increased traffic-handling and data-processing capability make the problem of effective decoy design increasingly difficult. The development of interceptors capable of high acceleration will also complicate the offense's problem. With such interceptors the decision to engage reentering objects can be deferred until they are well down into the atmosphere; the longer the defense can wait, the more stringent are the demands of decoy simulation on the offense.

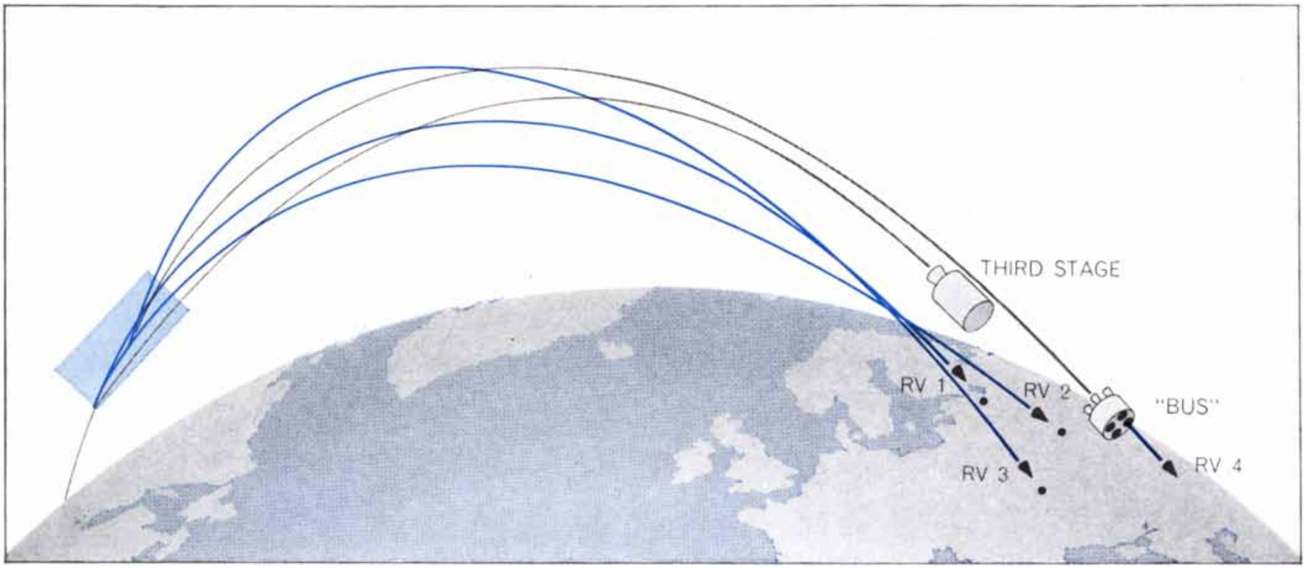
As the problem becomes more difficult, the ratio of decoy weight to warhead weight increases. There comes a point at which, if one wants really high confidence of penetration, one might just as well use several warheads on each missile rather than a single warhead and several decoys, each of which may be as heavy, or nearly as heavy, as a warhead. Hence multiple warheads are in a sense the ultimate in high-confidence penetration aids (assuming that one relies on exhaustion or saturation of defense capabilities as the preferred tactic for defeating the defense). To be effective, however, multiple warheads must be sufficiently separated so that a single interceptor burst will not destroy more than one incoming warhead. Moreover, the utility of multiple warheads for destroying targets, particularly small ones that would not justify attack by more than one or two small warheads, will be greatly enhanced if they can be individually guided.

In principle each reentry vehicle could have its own "post-boost" guidance and propulsion system. That, however, is not the concept of the MIRV's in our Poseidon and Minuteman III missile systems, which are now under development. Rather, a single guidance and propulsion system will control the orientation and velocity of a "bus" from which reentry vehicles will be released sequentially [*see illustration on these two pages*]. After each release there will be a further adjustment in the velocity and direction of the bus. Thus each reentry vehicle can be directed to a separate target. The targets can be rather widely separated, the actual separation depending on how much energy (and therefore weight) one is willing to expend in the post-boost maneuvers of the bus. It is an ingenious—and demanding—concept.

Two rationales have been advanced for the decision to proceed with the U.S. MIRV programs. One is that with MIRV's the U.S. can have a high confidence of being able to penetrate an adversary's ABM defenses. The apparent deployment of a limited Russian ABM system in the vicinity of Moscow and U.S. concern about a possibly more widespread Russian ABM-system deployment have been important considerations in the decision to go ahead with the U.S. MIRV programs.

The second rationale is that a MIRV system enables one to strike more targets with a given number of boosters than would be the case if one were using one warhead per missile. This rationale has been important for two reasons.

First, it enabled spokesmen for the Johnson Administration to argue against expanding the size of our strategic missile force during a period when Russian forces were growing rapidly. They were able to contend in the face of political opposition on both flanks that, whereas



and the direction of the bus. Thus each reentry vehicle can be directed to a separate target (*right*). The actual separation of the targets depends on how much energy (and therefore weight) one is willing to expend in the post-boost maneuvers of the bus. Besides being a potentially attractive means of penetrating an adversary's ABM defenses, MIRV's could conceivably be effective some day as a "counterforce" weapon, that is, a system capable of destroying the adversary's strategic offensive forces in a preemptive attack.

we did not contemplate expanding the number of our offensive missiles, the number of warheads we could deliver would increase rapidly.

Second, it raised the prospect of a missile force that could be used as a very effective "counterforce" weapon. This means that with MIRV's a limited number of missiles might be capable of destroying a larger intercontinental-ballistic-missile (ICBM) force in a preemptive attack. To achieve this performance, however, particularly against hardened offensive missile sites, would require a substantial improvement in accuracy and a high post-boost reliability—no mean feats with a device as complicated as the MIRV bus.

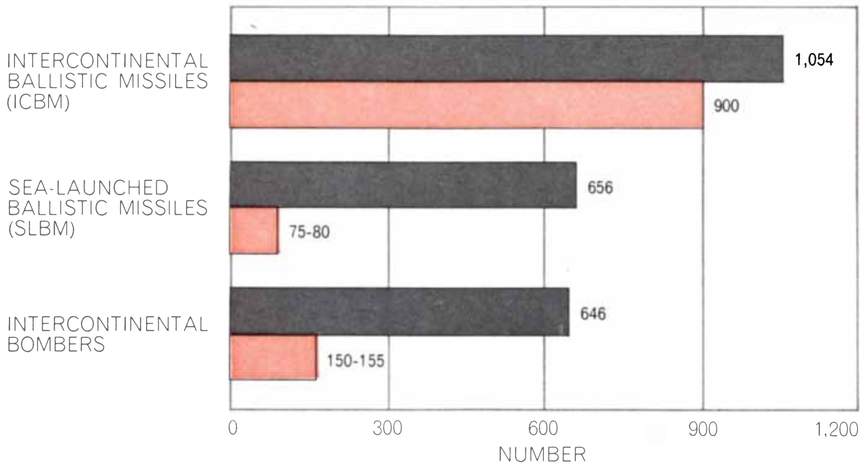
What bearing will the deployment of the ABM and the MIRV systems have on the future of the arms race? In attempting to answer this difficult question it is instructive to consider the extent to which the choices of each of the superpowers regarding strategic weapons have been influenced by the other's decisions.

The actual role of this action-reaction phenomenon is a matter of considerable debate in American defense circles. Indeed, the differences in views on this question account for most of the dispute of the past few years regarding the objectives to be served by strategic forces and their desired size and qualities. Thus whether the U.S. should be content with an adequate retaliatory, or "assured destruction," capability or go further and try to build a capability that would permit us to reduce damage to ourselves in the event of war must clearly depend on a judgment on whether Russian defense decisions could be influenced significantly by our decisions. Those who have felt that Russian defense planning would be responsive to our actions have held that for the most part any attempt by us to develop such "damage-limiting" capabilities with respect to the U.S.S.R. would be an effort doomed to failure. The U.S.S.R. would simply improve its offensive capabilities to offset the effects of any measures we might take. This was the basis for the rejection by the American leadership of the requests by the Army for large-scale ABM-system deployment and for the rejection of requests by the Air Force for much larger ICBM forces.

Although there is considerable evidence to support the claim that the action-reaction phenomenon does apply to defense decision-making, to explain all the major decisions of the superpowers in terms of an action-reaction hypothesis is an obvious oversimplification. The American MIRV deployment has been rationalized as a logical response to a possible Russian ABM-system deployment, but there were also other motivations that were important: the desire to keep our total missile force constant while increasing the number of warheads we could deploy, the long-term possibility of MIRV's giving us an effective counterforce capability, and finally the simple desire to bring to fruition an interesting and elegant technological concept.

Nevertheless, the action-reaction phenomenon, with the reaction often premature and/or exaggerated, has clearly been a major stimulant of the strategic arms race. Examples from the past can be cited to support this point: (1) the American reaction, indeed overreaction, to uncertainty at the time of the "missile gap," which played a central role in the 1960 Presidential election but was soon afterward shown by improved intelligence to be, if anything, in favor of the U.S.; (2) the Russian decision to deploy the "Tallinn" air-defense system, possibly made in the mistaken expectation that the U.S. would go ahead with the deployment of B-70 bombers or SR-71 strike-reconnaissance aircraft; (3) the U.S. response to the Tallinn system (which until recently was thought to be an ABM system) and to the possible extension of the Moscow ABM system into a countrywide system. It was in order to have high assurance of its ability to get through these possible Russian ABM defenses that the U.S. embarked on the development of various penetration aids and even of new missiles: Minuteman III and Poseidon.

These examples have in common the fact that if doubt exists about the capabilities or intentions of an adversary, prudence normally requires that one respond not on the basis of what one expects but on a considerably more pessimistic projection. The U.S. generally



INVENTORY of the intercontinental delivery vehicles possessed by the U.S. (*gray*) and the U.S.S.R. (*color*) as of October, 1968, shows that in this category also the U.S. continues to hold a clear superiority over the U.S.S.R. This measure is not entirely satisfactory, however, in that it does not take into account qualitative differences in the various systems, the expected interactions during a nuclear exchange or the match of the weapons with the targets. When such factors are taken into account, the differences between the U.S. and the U.S.S.R. are not significant. In his final "posture" statement for fiscal 1969, for example, former Secretary McNamara estimated that, barring drastic changes in the strategic balance, in an all-out nuclear exchange in the mid-1970's each country could inflict a minimum of 120 million fatalities on the other—regardless of which country struck first.

bases its plans—and makes much of the fact—on what has become known as the "greater-than-expected threat." In so doing, the Americans (and presumably the Russians) have often overreacted. The extent of the overreaction is directly dependent on the degree of uncertainty about any adversary's intentions and capabilities.

The problem is compounded by lead-time requirements for response. According to the Johnson Administration, the decisions to go ahead with Minuteman III, Poseidon and Sentinel had to be made when they were because of the possibility that in the mid-1970's the Russians might have a reasonably effective ABM system and the Chinese an ICBM capability. The Russians had to make a decision to develop the Tallinn system (if the decision was made because of the B-70 program) long before we ourselves knew whether or not we would deploy an operational B-70 force.

Once the decisions to respond to ambiguous indications of adversary activity were made it often proved impossible to modify the response, even when new intelligence became available. For example, between the time the Sentinel decision was announced and the first Congressional debate on the appropriation took place during the summer of 1968, evidence became available that the Chinese threat was not developing as rapidly as had been feared. Yet in spite of this information those in Congress who attempted at that time to defer the appropriation for Sentinel failed. Similarly, at this writing, as the Poseidon and Minuteman III programs begin to gain momentum, it seems much less likely than it did at the time of their conception that the U.S.S.R. will deploy the kind of ABM system that was the Johnson Administration's main rationale for these programs. On the Russian side, the Tallinn deployment continued long after it became clear that no operational B-70 force would ever be built.

Of the kinds of weapons development that can stimulate overresponse on the part of one's adversary, it is hard to imagine one more troublesome than ABM defenses. In addition to uncertainty about adversary intentions and the need (because of lead-time requirements) for early response to what the adversary might do, there is the added fact that the uncertainties about how well an ABM system might perform are far larger than they are for strategic offensive systems. The conservative defense planner will design his ABM system on the assumption that it may not work as well as he hopes, that is, he will overdesign it to take into account as fully as he can all imaginable modes of failure and enemy offensive threats. The offensive planner, on the other hand, will assume that the defense might perform much better than he expects and will overdesign his response. Thus there is overreaction on both sides. These uncertainties result in a divergent process: an arms race with no apparent limits other than economic ones, each round being more expensive than the last. Moreover, because of overreaction on the part of the offense there may be an increase in the ability of each side to inflict damage on the other.

All one needs to make this possibility a reality is a triggering mechanism. The Russian ABM program, by stimulating the Minuteman III and Poseidon programs, may have served that purpose. The Chinese nuclear program may also have triggered an action-reaction chain, of which the Sentinel response is the second link [*see illustration on page 24*].

It can be assumed that there will be considerable pressure and effort to make Sentinel highly effective against a "greater than expected" Chinese threat. Such a system will undoubtedly have some capability against Russian ICBM's. Russian decision-makers, who must assume that Sentinel might perform better than they expect, will at least have to consider this possibility as they plan their offensive capabilities. More important, they will have to respond on the assumption that the Sentinel decision may foreshadow a decision to build an anti-Russian ABM system. Hence it is probably not a question of whether the U.S.S.R. will respond to Sentinel but rather of whether the U.S.S.R. will limit its response to one that does not require a U.S. counterresponse, and of whether it is too late to stop the Sentinel deployment.

It is apparent that reduction in uncertainty about adversary intentions and capabilities is a *sine qua non* to curtailing the strategic arms race. There are a number of ways to accomplish this (in addition to the gathering of intelligence, which obviously makes a great contribution).

First, there is unilateral disclosure. In the case of the U.S. there has been a conscious effort to inform both the American public and the Russian leadership of the rationale for many American decisions regarding strategic systems and, to the extent consistent with security, of U.S. capabilities. This has been done particularly through the release by the Secretary of Defense of an annual "posture" statement, a practice that, it is hoped, will be continued by the U.S. and will be emulated someday by the U.S.S.R. This would be in the interest of both countries. Because there has been no corresponding effort by the Russians the U.S. probably overreacts to Russian decisions more than the U.S.S.R. does to American decisions. (At least it is easier to trace a causal relationship between Russian decisions and U.S. reactions than it is between U.S. decisions and Russian reactions.)

Second, negotiations to curtail the arms race (even if abortive) or any other dialogue may be very useful if such efforts result in a reduction of uncertainty about the policies, capabilities or intentions of the parties.

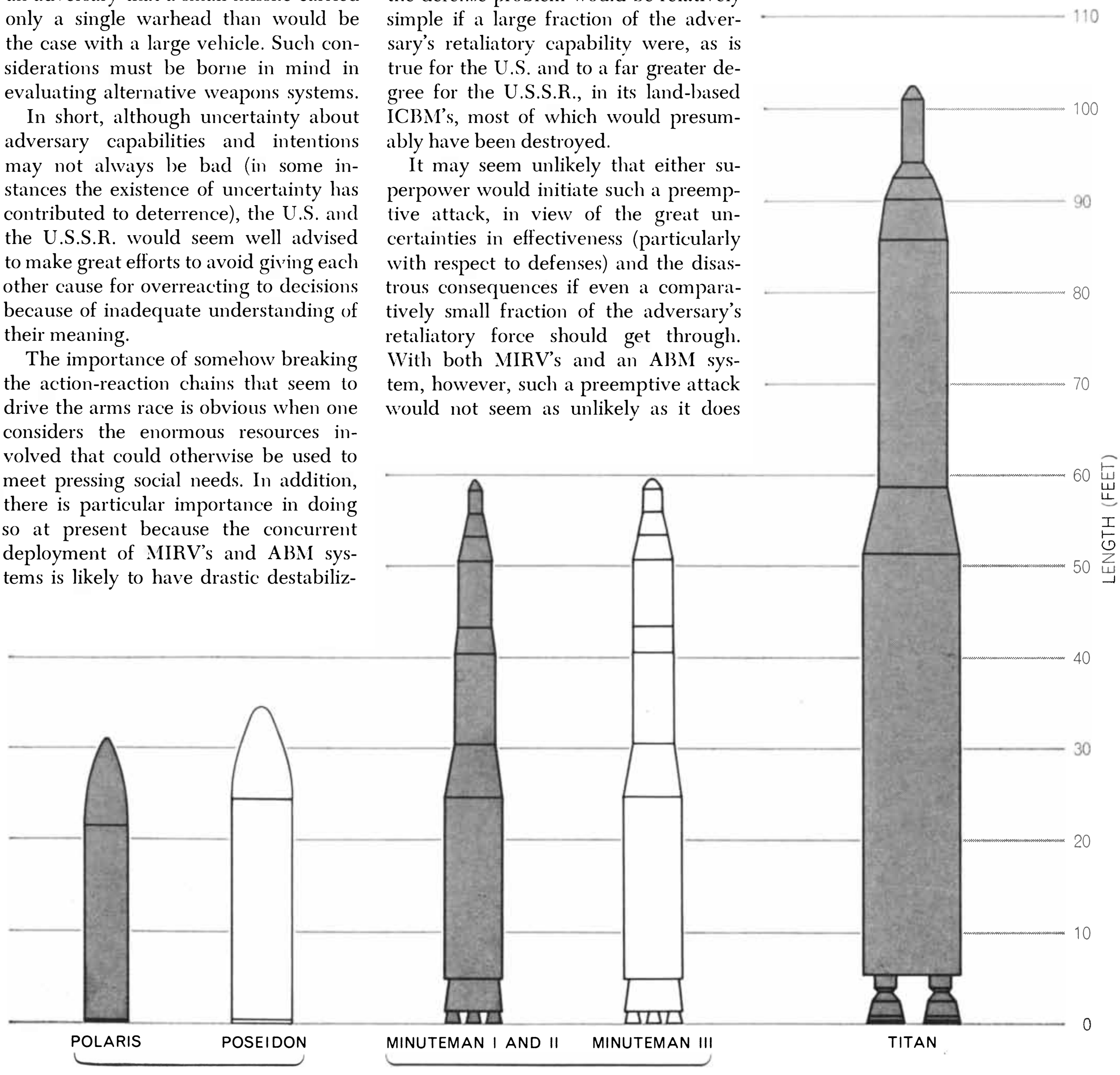
Third, some weapons systems may be less productive of uncertainty than others that might be chosen instead. For example, it is likely to be less difficult to measure the size of a force of submarine-launched or fixed missiles than it is to measure the size of a mobile land force. Similarly, it would be easier to persuade an adversary that a small missile carried only a single warhead than would be the case with a large vehicle. Such considerations must be borne in mind in evaluating alternative weapons systems.

In short, although uncertainty about adversary capabilities and intentions may not always be bad (in some instances the existence of uncertainty has contributed to deterrence), the U.S. and the U.S.S.R. would seem well advised to make great efforts to avoid giving each other cause for overreacting to decisions because of inadequate understanding of their meaning.

The importance of somehow breaking the action-reaction chains that seem to drive the arms race is obvious when one considers the enormous resources involved that could otherwise be used to meet pressing social needs. In addition, there is particular importance in doing so at present because the concurrent deployment of MIRV's and ABM systems is likely to have drastic destabilizing consequences. It is conceivable that one of the superpowers with an ABM system might develop MIRV's to the point where it could use them to destroy the bulk of its adversary's ICBM force in a preemptive attack. Its air and ABM defenses would then have to deal with a much degraded retaliatory blow, consisting of the sea-launched forces and any ICBM's and aircraft that might have survived the preemptive attack. The problems of defense in such a contingency would remain formidable. They would be significantly less difficult, however, than if the adversary's ICBM force had not been seriously depleted. In fact, the defense problem would be relatively simple if a large fraction of the adversary's retaliatory capability were, as is true for the U.S. and to a far greater degree for the U.S.S.R., in its land-based ICBM's, most of which would presumably have been destroyed.

It may seem unlikely that either superpower would initiate such a preemptive attack, in view of the great uncertainties in effectiveness (particularly with respect to defenses) and the disastrous consequences if even a comparatively small fraction of the adversary's retaliatory force should get through. With both MIRV's and an ABM system, however, such a preemptive attack would not seem as unlikely as it does now. It might not appear irrational to some, for example, if an uncontrollable nuclear exchange seemed almost certain, and if by striking first one could limit damage to a significantly lower level than if the adversary were to strike the first blow. In short, if one or both of the two superpowers had such capabilities, the world would be a much more unstable place than it is now.

Obviously neither superpower would permit its adversary to develop such capabilities without responding, if it could, by strengthening its retaliatory forces. The response problem becomes more

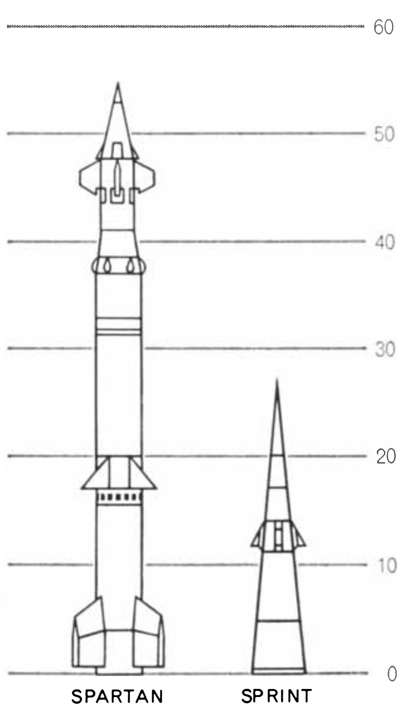


U.S. OFFENSIVE MISSILES currently deployed or under development are drawn here to scale. The sea-based Polaris and Poseidon and the land-based Minutemen are capable of carrying warheads with a total explosive yield of about one megaton each. The land-based Titan II can carry a warhead of more than five megatons. Poseidon and Minuteman III, which are under development, are designed to carry MIRV warheads. The total number of missiles scheduled for deployment in each category is indicated at the bottom.

difficult, however, if the adversary develops both MIRV's and an ABM system than if only one is developed.

Against a MIRV threat alone there are such obvious responses as defense of ICBM sites or greater reliance on sea-launched or other mobile systems. Such responses are likely to be acceptable because, whereas the costs of highly invulnerable systems are large (perhaps several times larger than the costs of simple undefended ICBM's), only relatively small numbers of such secure retaliatory weapons would be required to provide an adequate "assured destruction" capability. Indeed, a force the size of the present Polaris submarine fleet would seem to be more than adequate. The response to an ABM system alone might also be kept within acceptable limits because the expenditures required to offset the effects of defense are likely to be small compared with the costs of the defense.

If it is necessary to acquire retaliatory capabilities that are comparatively invulnerable to MIRV attack in numbers sufficient to saturate or exhaust ABM defenses, however, the total cost could be very great. In fact, if one continued to rely heavily on exhaustion of defenses as the preferred technique for penetration, the offense might no longer have a significant cost-effectiveness advantage over the defense. Thus the concurrent development of MIRV's and ABM systems raises the specter of a more precarious balance of terror a few years hence, a rapidly escalating arms race in the attempt to prevent the instabilities from getting out of hand, or quite possibly both.



U.S. DEFENSIVE MISSILES currently being deployed as part of the modified Sentinel system are drawn here to scale. The Spartan and Sprint carry warheads in the megaton range and kiloton range respectively.

With this background about the roles of uncertainty and the action-reaction phenomenon in stimulating the arms race, one can draw some general conclusions about the functions and qualities of future strategic forces. We must first recognize that two kinds of instability must be considered: crisis instability (the possibility that when war seems imminent, one side or the other will be motivated to attack preemptively in the hope of limiting damage to itself) and arms-race instability (the possibility that the development or deployment decisions of one country, or even the possibility of such decisions, may trigger new development or deployment decisions by another country).

The first kind of instability is illustrated in the chart on the opposite page, which is based on former Secretary McNamara's posture statement for fiscal 1967. This shows that—assuming two possible expanded Russian threats, various damage-limiting efforts by the U.S. and failure of the U.S.S.R. to react to extensive U.S. damage-limiting efforts by improving its retaliatory capability—American fatalities in 1975 would be only about a third as great in the event of a U.S. first strike as they would be in the case of a Russian first strike. (In the present situation the advantage of the attacker is negligible.) Obviously if war seemed imminent, with the strategic balances assumed in this example, there would be tremendous pressure on the U.S. to strike first. There would be corresponding pressure on the U.S.S.R. to do likewise if a Russian first strike could result not only in a much higher level of damage to the U.S. but also in a diminution in damage to the U.S.S.R. The incentives would be mutually reinforcing.

To minimize the chance of a failure of deterrence in a time of crisis, it seems important for both the U.S. and the U.S.S.R. to develop strategic postures such that preemptive attack would have as small an effect as possible on the anticipated outcome of a thermonuclear exchange. Actually, of course, it is extremely unlikely that the Russians would passively watch the U.S. develop the extensive damage-limiting postures assumed in the foregoing example. Instead they would probably react by modifying their posture so that the advantage to the U.S. of attacking preemptively would be less than is indicated in the chart. Thus the example can also be used to illustrate the second kind of instability.

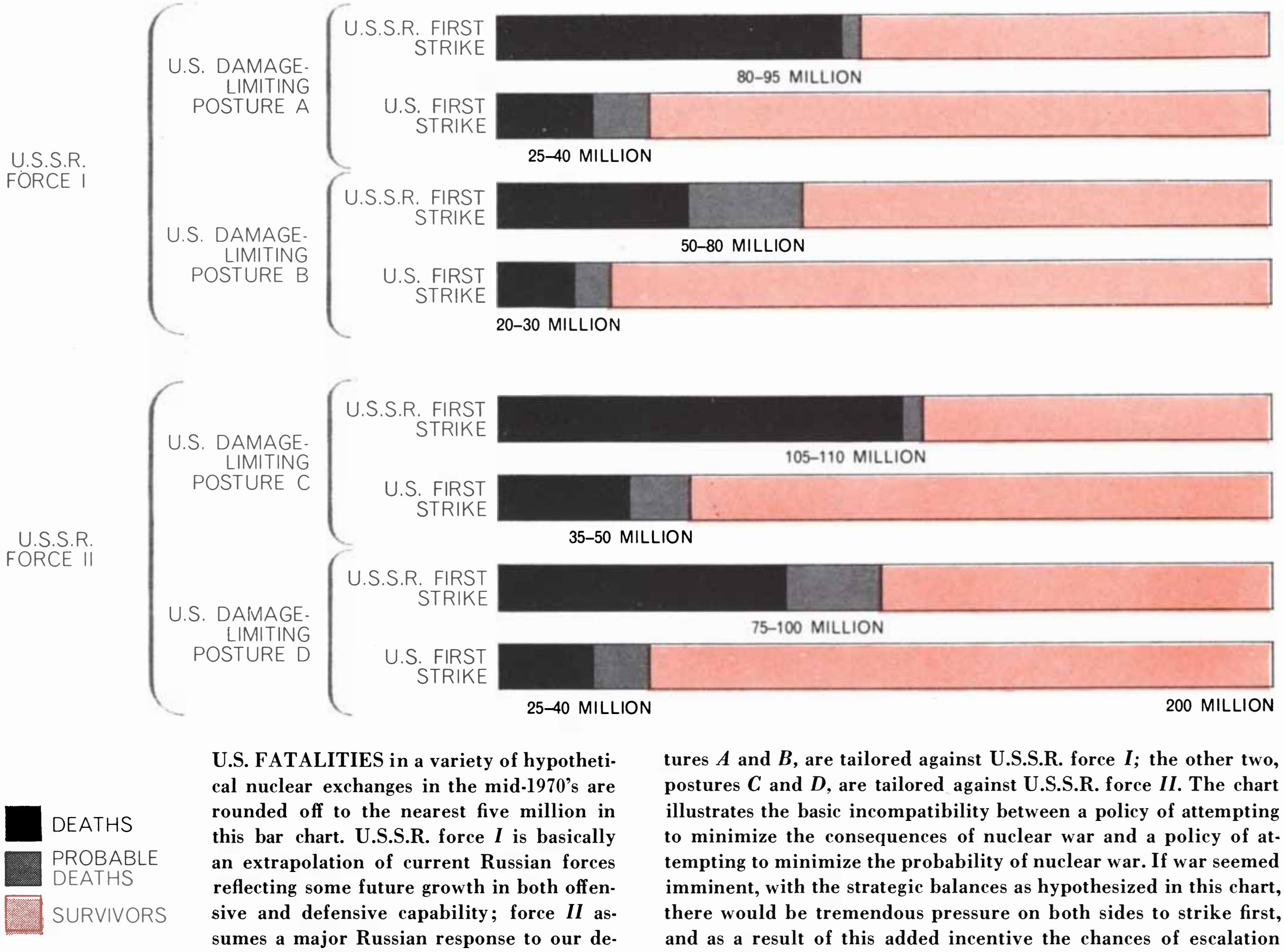
To the extent that one accepts the action-reaction view of the arms race, one is forced to conclude that virtually anything we might attempt in order to reduce damage to ourselves in the event of war is likely to provoke an escalation in the race. Moreover, many of the choices we might make with damage-limitation in mind are likely to make preemptive attack more attractive and war therefore more probable. The concurrent development of MIRV's and ABM systems is a particularly good example of this.

One is struck by the fact that there is an inherent inconsonance in the objectives spelled out in our basic military policy, namely "to deter aggression at any level and, should deterrence fail, to terminate hostilities in concert with our allies under conditions of relative advantage while limiting damage to the U.S. and allied interests." Hard choices must be made between attempting to minimize the chance of war's occurring in a time of crisis and attempting to minimize the consequences if it does occur.

The decisions made by U.S. planners in recent years with respect to new weapons development and deployment reflect a somewhat inconsistent philosophy on this point. The U.S. has generally avoided actions whose primary rationale was to limit damage that the U.S.S.R. might inflict on it, actions to which the Russians would probably respond. Accordingly the U.S. has not deployed an anti-Russian ABM system and has given air defense a low priority.

On the other hand, where there were reasons other than a desire to improve American damage-limiting capability with respect to the U.S.S.R., the U.S. has proceeded with programs in spite of their probably escalating effect on the arms race or their effect on first-strike incentives. This was true in the case of the MIRV's and Sentinel.

The U.S. will face more such decisions. For example, it may appear necessary to change the U.S. strategic offensive posture in order to make American forces less vulnerable to possible Russian MIRV attack. The nature of these decisions will depend on the importance attached to the action-reaction phenomenon and to the effect of improved counterforce capabilities on the probability of war. Emphasis on these two factors



U.S. FATALITIES in a variety of hypothetical nuclear exchanges in the mid-1970's are rounded off to the nearest five million in this bar chart. U.S.S.R. force *I* is basically an extrapolation of current Russian forces reflecting some future growth in both offensive and defensive capability; force *II* assumes a major Russian response to our deployment of an ABM system. Two of the four U.S. damage-limiting programs, postures *A* and *B*, are tailored against U.S.S.R. force *I;* the other two, postures *C* and *D*, are tailored against U.S.S.R. force *II*. The chart illustrates the basic incompatibility between a policy of attempting to minimize the consequences of nuclear war and a policy of attempting to minimize the probability of nuclear war. If war seemed imminent, with the strategic balances as hypothesized in this chart, there would be tremendous pressure on both sides to strike first, and as a result of this added incentive the chances of escalation would be enhanced. The chart is based on information contained in former Secretary McNamara's posture statement for fiscal 1967.

implies discounting options that would increase U.S. counterforce capability against Russian strategic forces, which in turn might provoke an expansion of Russian offensive forces. Options requiring long lead times would also be discounted, since decisions regarding them might have to be made while there was still uncertainty about whether the U.S.S.R. was developing MIRV's.

Should more weight be given in the future to developing damage-limiting capabilities? Or should more weight be given to minimizing the probability of a thermonuclear exchange and curtailing the strategic arms race? It is hard to see how one can have it both ways.

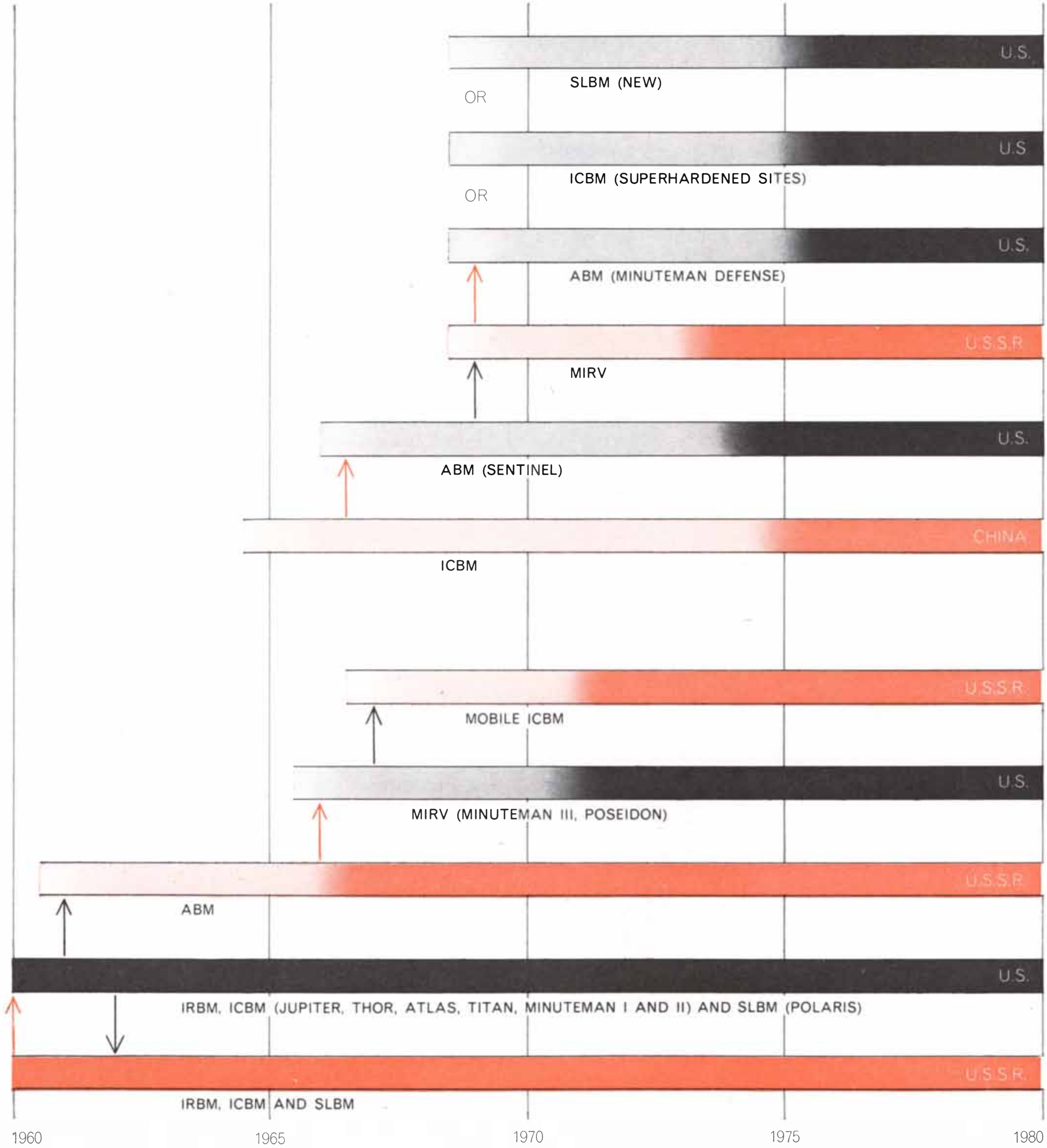
In spite of some changes in technology, there is little to indicate that the U.S. could get very far with damage-limiting efforts, considering the determination of the Russians and the options available to them for denying the attainment of such U.S. capabilities. The emergence of new nuclear powers, the rapid pace of technological advance and the other important demands on American resources suggest that a clear first priority should be assigned to moderating the action-reaction cycle. Moving toward greater emphasis on damage-limitation would seem justified only if the U.S. can persuade itself that the Russians will not react to American moves as the U.S. would to theirs, and if means can be chosen that will not increase the probability of war.

No treatment of the dynamics of the strategic arms race would be complete without some discussion of the possibility of ending it, or at least curtailing it, through negotiations. Both the urgency and the opportunity are great, but the latter may be waning. This opportunity is in part a consequence of the present military balance, as well as of somewhat changed views in both the U.S. and the U.S.S.R. about strategic capabilities and objectives.

With the rapid growth in its strategic offensive forces during the past few years, the U.S.S.R. can at long last enter negotiations without conceding inferiority or (which is worse from the Russian point of view) exposing itself to the possibility of being frozen in such a position. Moreover, the U.S.S.R. may at long last be prepared to accept the prevailing American view about the action-reaction phenomenon, and about the intrinsic advantage of the offense and the futility of defense. The apparent decision of the Russians not to proceed with a nationwide ABM system at present, and their professed willingness to enter into negotiations to control both offensive and defensive systems, may be evidence of this convergence of viewpoints.

On the American side there is at long last a quite general, if not yet universal, acceptance of the concept of nuclear "sufficiency": the idea that beyond a certain point increased nuclear force cannot be translated into useful political power. Acceptance of this concept is an almost necessary condition to termination of the arms race.

In considering negotiations with the U.S.S.R. on the strategic arms problem, the first factor to be kept in mind is the objectives to be sought. It would be a mistake to expect too much or to aspire to too little. One obvious aim is to re-



ACTION-REACTION PHENOMENON, stimulated in most cases by uncertainty about an adversary's intentions and capabilities, characterizes the dynamics of the arms race. Starting at bottom left, American overreaction to uncertainty at the time of the erroneous "missile gap" in 1960 led to the massive growth of U.S. missile forces during the 1960's. The scale of this deployment may have led in turn to the recent large Russian buildup in strategic offensive forces and also to the deployment of a limited ABM system around Moscow. The U.S. response to the possible extension of the Moscow ABM system into a countrywide system (and to the deployment of a Russian anti-aircraft system, which until recently was thought to be a countrywide ABM system) was to equip its Minuteman III and Poseidon missiles with MIRV warheads. A likely Russian reaction to the potential counterforce threat posed by the MIRV's is the development of land-mobile ICBM's. Another action-reaction chain may have been triggered by the emergence of China as a nuclear power. The resulting deployment of the U.S. Sentinel system, particularly in its expanded versions, seems certain to have an effect on Russian planners, who may push for the development of their own MIRV systems, provoking a variety of American counterresponses. In the author's view, breaking the action-reaction cycle by limiting ABM defenses should be given first priority in any forthcoming arms-control talks.

duce strategic armaments in order to lessen significantly the damage that would be sustained by the U.S. (and the U.S.S.R.) in the event of a nuclear exchange. Regrettably this goal is not likely to be realized in the near future. In the first place, any initial understandings will probably not involve reductions in strategic forces. Even if they did, the reductions would be limited. One cannot expect potential damage levels to be lowered by more than a few percent, even with fairly substantial cuts in strategic forces, because the capabilities of the superpowers are already so great.

Other objectives have been considered: reducing the incentives to strike preemptively in time of crisis, reducing the probability of accident or miscalculation, and increasing the time available for decision-making in the hope that the increased opportunity for communication might prevent a nuclear exchange from running its full course. Last but not least, one might also hope to change the international political climate so as to lessen tension, to reduce the incentive for powers that currently do not have nuclear weapons to acquire them and to increase the possibility for agreement by the superpowers on other meaningful arms-control measures.

It is reasonable to expect that successful negotiations might to some degree achieve all these objectives except the first: the reduction of potential damage. To focus on any one objective, or combination of objectives, however, is to obscure the immediate problem. In spite of the restraint of the U.S. in its choices regarding strategic weapons development and deployment during the first two-thirds of this decade, it now appears that in the absence of some understanding between the U.S. and the U.S.S.R. the action-reaction sequence that impels the arms race will not be broken. Therefore the immediate objective of any negotiations must be simply to bring that sequence to a halt, or to moderate its pace so that there will be a better chance of ending the arms race than is offered by continuing the policies of the past two decades.

In retrospect, controlling or reversing the growth of strategic capabilities could have been accomplished more easily a few years ago, when the possibility of ABM-system deployment seemed to be the main factor that would trigger another round in the arms race. Now the prospect of ABM systems is more troublesome because of technological advances. In addition, there are the two other stimuli already discussed: the possibility of effective counterforce capabilities as a result of the development of MIRV's, and the possibility that the Chinese nuclear capability may serve as a catalyst to the Russian-American action-reaction phenomenon.

Obviously, short of destroying China by nuclear attack, there is little the U.S. can do about Chinese capabilities except to make sure that it does not give them more weight in its thinking than they deserve. This leaves the option of trying to break the ABM-MIRV chain by focusing on the control of MIRV's or ABM defenses.

Whereas one might hope to limit both, if a choice must be made the focus should clearly be on the control of ABM defenses. Verification of compliance would be relatively simple and could probably be accomplished without intrusive inspection. In addition, the incentive to acquire MIRV's for penetrating defenses would be eliminated, although the incentive to acquire them for counterforce purposes would remain.

The problems of verifying compliance with an agreement to control MIRV's would be much more difficult. Moreover, if an ABM system were deployed, there would be great pressure to abrogate or violate any agreement prohibiting MIRV deployment because MIRV's offer high assurance for penetrating defenses. Although reversing the MIRV decision would be difficult, reversing the Sentinel one would present less of a problem.

To be attractive to the U.S.S.R. any proposal to limit defenses would almost certainly have to be coupled with an agreement to limit, if not reduce, inventories of deployed strategic offensive forces. In principle this should not be difficult, since it need not involve serious verification problems.

Complicating any attempt to reach an understanding with the U.S.S.R. on the strategic balance, however, is the fact that the American and Russian positions are not symmetrical. The U.S. has allies and bases around the periphery of the U.S.S.R., whereas the latter has neither near the U.S., unless one counts Cuba. It is clear that a Pandora's box of complications could be opened by any attempt in the context of negotiations on the strategic balance to deal with the threat to America's allies posed by short-range Russian delivery systems, and with the potential threat to the U.S.S.R. of systems in Europe that could reach the U.S.S.R. even though they are primarily tactical in nature. One may hope that initial understandings will not have to include specific agreements on such thorny issues as foreign bases and dual-purpose systems.

Virtually all the above is based on the premise that for the foreseeable future each side will probably insist on maintaining substantial deterrent capabilities. For some time to come there will unfortunately be little basis for expecting negotiations with the U.S.S.R. to result in a strategic balance with each side relying on a few dozen weapons as a deterrent. The difficulties and importance of verification of compliance at such low levels, the problem of China, the existence of large numbers of tactical nuclear weapons on both sides and the general political climate all militate against this. At the other extreme, negotiations would almost necessarily fail if either party based its negotiating position on the expectation that it might achieve a significant damage-limiting capability with respect to the other.

Thus the range of possible agreement is quite narrow. There is a basis for hope, if both sides can accept the fact that for some time the most they can expect to achieve is a strategic balance at quite high, but less rapidly escalating, force levels, and if both recognize that breaking the action-reaction cycle should be given first priority in any negotiations, and also in unilateral decisions.

There will be risks in negotiating arms limitation. These must be weighed not against the risks that might characterize the peaceful world in which everyone would like to live, or even against the risks of the present. Rather, the risks implicit in any agreement must be weighed against the risks and costs that in the absence of agreement one will probably have to confront in the 1970's.

Whether the superpowers strive to curtail the strategic arms race through mutual agreement or through a combination of unilateral restraint and improved dialogue, they should not do so in the mistaken belief that the bases for the Russian-American confrontation of the past two decades will soon be eliminated. Many of the sources of tension have their origins deep in the social structures and political institutions of the two countries. Resolution of these differences will not be accomplished overnight. Restraining the arms race, however, may shorten the time required for resolution of the more basic conflicts between the two superpowers, it may increase the chances of survival during that period, and it may enable the U.S.S.R. and the U.S. to work more effectively on the other large problems that confront the two societies.

Hybrid Somatic Cells

Body cells of different species can now be crossed to form somatic hybrids. This alternative to sexual breeding should facilitate the study of human genetics and provide insights into differentiation

by Boris Ephrussi and Mary C. Weiss

One of the most powerful tools available to the biologist is genetic analysis, through which the structure of the hereditary material and its relation to the functions of cells and organisms are revealed in great detail and with high resolution by the manner in which various characteristics are passed from one generation to the next. At first this analysis was made through sexual breeding, which is easily accomplished in such organisms as the fruit fly *Drosophila* or the mold *Neurospora*. Much of modern genetics, however, rests on information gained by taking advantage of processes that represent alternatives to sexual breeding. These alternatives were first exploited for the genetic analysis of bacteria and viruses. Now such an alternative to sexual breeding has been developed for the genetic analysis of higher animals, including man. The new procedure stems from the discovery that somatic cells (body cells, as opposed to eggs and sperm) can be crossed to form hybrid cells that live and multiply.

The technique was discovered in 1960 by George Barski, Serge Sorieul and Francine Cornefert of the Institut Gustave Roussy in Paris. They had mixed together cultures of two different mouse-cancer cells that could be distinguished by differences in cell morphology and in the shapes of some of their chromosomes, the threadlike structures in which the genes are arranged. After a few months they saw that a few cells of a new type had appeared, containing in a single nucleus the chromosomes of both parents. They were hybrid cells; they had arisen by the fusion of pairs of cells of the two different types. Barski and his colleagues went on to produce pure cultures of these hybrid cells and grow them successfully. Soon other somatic hybrids were produced by crossing various pairs of cell lines.

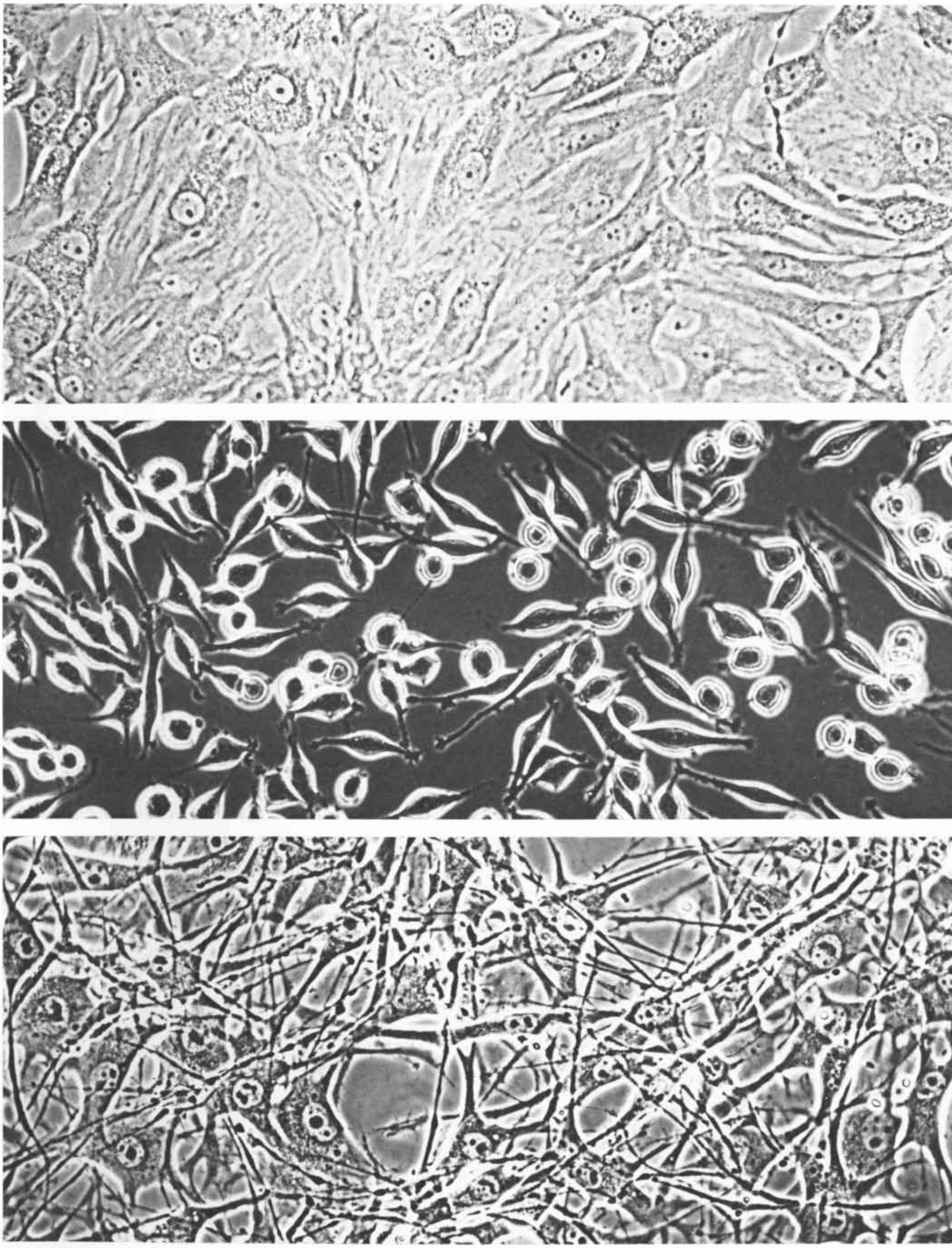
It became clear that the hybrids were not mere curiosities. They have two properties that make them suitable for genetic analysis. First, both sets of chromosomes are functional, and the hybrids therefore exhibit the hereditary characteristics of both parents. Second, as the hybrids multiply they lose some of their chromosomes, and this process produces cells with many different constellations of "parental" genes.

The genetic analysis of hybrid cells has been brought to bear on a number of biological problems. One problem is the formal genetics of higher animals, including man: the location of genes on specific chromosomes. Breeding analysis, which is effective for this purpose in lower animals and plants, is too slow in mammals (even in mice the generation time is about three months), and it is impossible in man. The analysis of somatic cells, on the other hand, proceeds without any breeding of individuals, and the generation time for somatic cells (from one cell division to another) is generally between 12 and 24 hours. Another problem under study is that of cellular differentiation, the process whereby cells that presumably have the same genetic equipment become differently specialized in form and function. To investigate the mechanisms that bring this about one must work with cells that have undergone differentiation; somatic hybridization makes it possible for the first time to apply genetic analysis to differentiated cells. We shall give an account of the first results in both areas of investigation after describing the methods of somatic hybridization and the relevant properties of hybrid cells.

The basic techniques of cell hybridization are those of standard cell culture, in which cells taken from a bit of tissue are allowed to settle out of a suspension and proliferate to form a layer on the bottom of a laboratory dish [*see illustration on page 28*]. To give the cells room to grow the layer is periodically broken up, and a few of the cells are transferred to a new dish; these "serial passages" can be repeated many times, and some cells go on multiplying indefinitely. Such a culture is heterogeneous, having been derived from a fragment containing several cell types. In order to obtain uniform populations of cells one must inoculate a culture dish with a very small number of highly dispersed cells, so that each produces a discrete "clone," or a colony that represents the progeny of a single cell.

Experiments in hybridization begin with a mixed culture of two parent cell lines, each characterized by the presence of marker chromosomes not found in the other. After a few days or weeks of growth one can identify hybrid cells by examining chromosome preparations. The drug colchicine is added to the medium to arrest cell division in metaphase, a stage that is favorable for observation of the chromosomes. The cells are fixed, pipetted onto a slide and stained. Under the microscope such preparations show many normal metaphase chromosome sets of both parental types, each recognizable by the number and shape of the chromosomes. If any hybrid cells have been formed, there will also be hybrid metaphases, recognizable by the large number of chromosomes and by the presence of marker chromosomes from both parents [*see illustration on page 29*].

In Barski's first hybridization experiment, performed in this manner, the hybrids turned out to have a selective advantage over the parental cells and grew

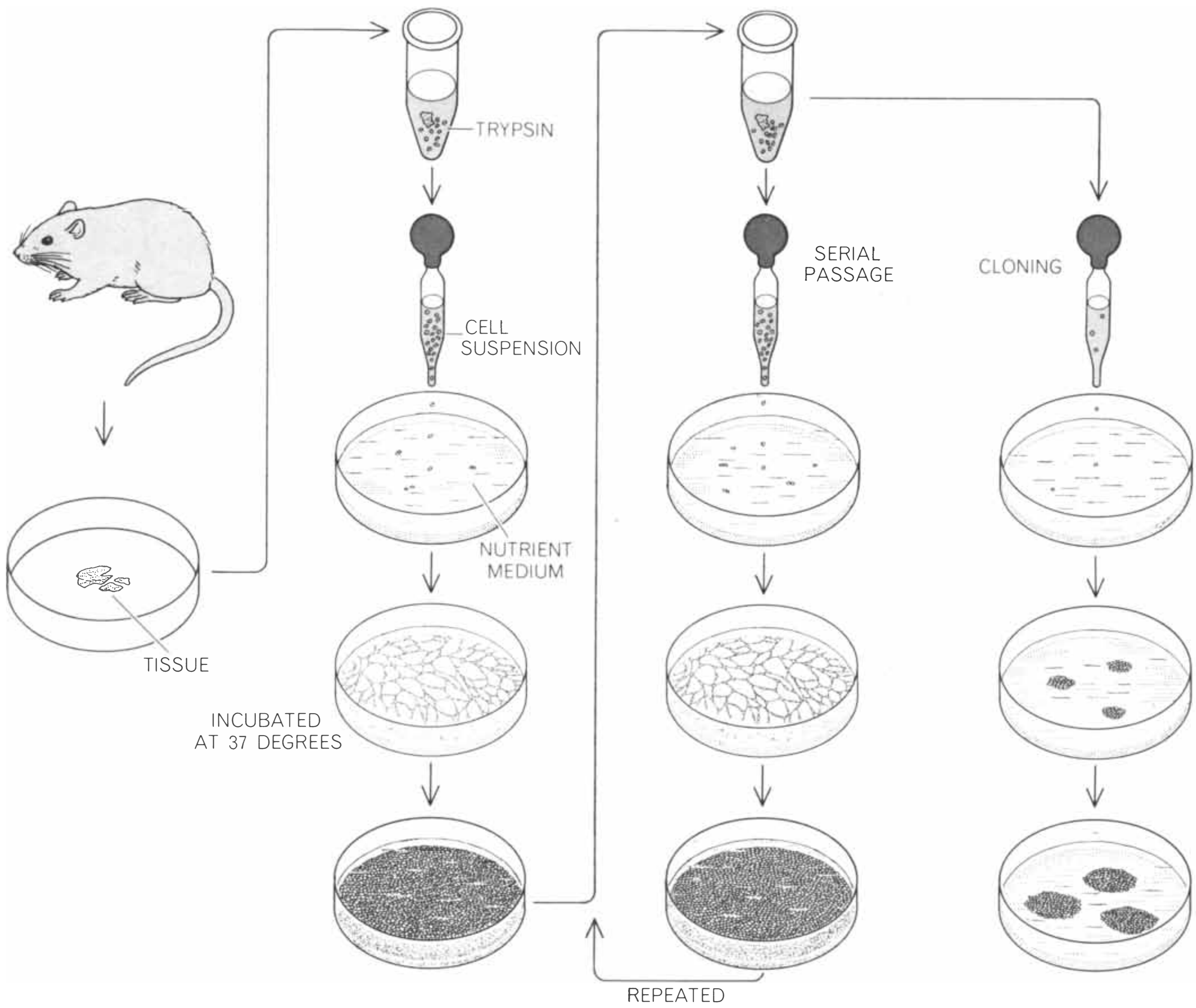


HYBRID CELLS and their parent cells are seen in a set of phase-contrast photomicrographs made by the authors. Rat cells (*top*) and mouse cells (*middle*) are grown together in a cell culture. Some of them fuse and form hybrids, which are isolated and grown in a pure culture (*bottom*). The rat cells tend to flatten out on the surface of the glass culture dish and so they appear thin. The mouse cells attach more loosely to the glass and therefore appear more refractile. The hybrid cells combine the morphological characteristics of both parent lines: they are more refractile than the mouse cells but they attach more completely than the rat cells.

more rapidly, and so they soon constituted a large enough fraction of the total cell population to be isolated by cloning. One of us (Ephrussi), together with co-workers first at the Laboratoire de Génétique Physiologique at Gif in France and then at Western Reserve University, isolated a number of other somatic hybrids. In each case success depended on the hybrid's having a selective advantage in the mixed culture. Since hybrids were rare and it took a long time for enough of them to accumulate so that they could be isolated, and since some crosses were almost surely failing only because the hybrids had no selective advantage, it was clear that a method conferring a decisive selective advantage on hybrid cells would be extremely valuable.

In 1964 John W. Littlefield of the Harvard Medical School devised a system for the selective isolation of hybrid cells [*see illustrations on page 30 and at top of page 31*]. He cultured, in a medium containing the drug aminopterin, two kinds of mutant cells, each of which lacked a different enzyme necessary for growth in the presence of aminopterin. When hybrid cells were formed, they were able to grow in the aminopterin medium by virtue of mutual complementation: each parent supplied the gene for the enzyme the other parent lacked. Littlefield's selective medium therefore kills cells of both parent lines but allows the survival and unhampered growth of hybrid cells. In the course of his experiments Littlefield established that one hybrid cell was produced per 200,000 parental cells (half of each kind).

With Richard L. Davidson, one of us (Ephrussi) then modified Littlefield's method to devise a "half-selective" system that is more generally applicable, in which only one parent cell line lacks one of the enzymes necessary for growth in Littlefield's medium. The other parent can be a normal line, carrying no selective marker, provided that it grows slowly or is inoculated in small numbers. Assume, for example, that a dish is inoculated with a million enzyme-deficient cells and only 100 normal cells. In the selective medium the majority parent degenerates, leaving discrete colonies of the minority parent and of hybrid cells. The hybrids can usually be recognized by their shape, and their hybrid nature



CELL CULTURE begins with minced pieces of tissue from an adult animal or embryo. Incubating the pieces in a digestive enzyme such as trypsin breaks them up into a suspension of single cells. Inoculated into a liquid nutrient medium and incubated, the cells attach to the bottom of the culture dish and divide, producing a continuous sheet. The sheet is again digested with trypsin. If a large fraction of the cells are thereupon inoculated in new medium, the process is repeated. Such serial passages yield heterogeneous cultures because the tissue pieces contained several kinds of cells. If instead a few dispersed cells are inoculated (*right*), they divide to form discrete "clones," or colonies of the progeny of one cell. One clone is then selected with which to start a pure culture.

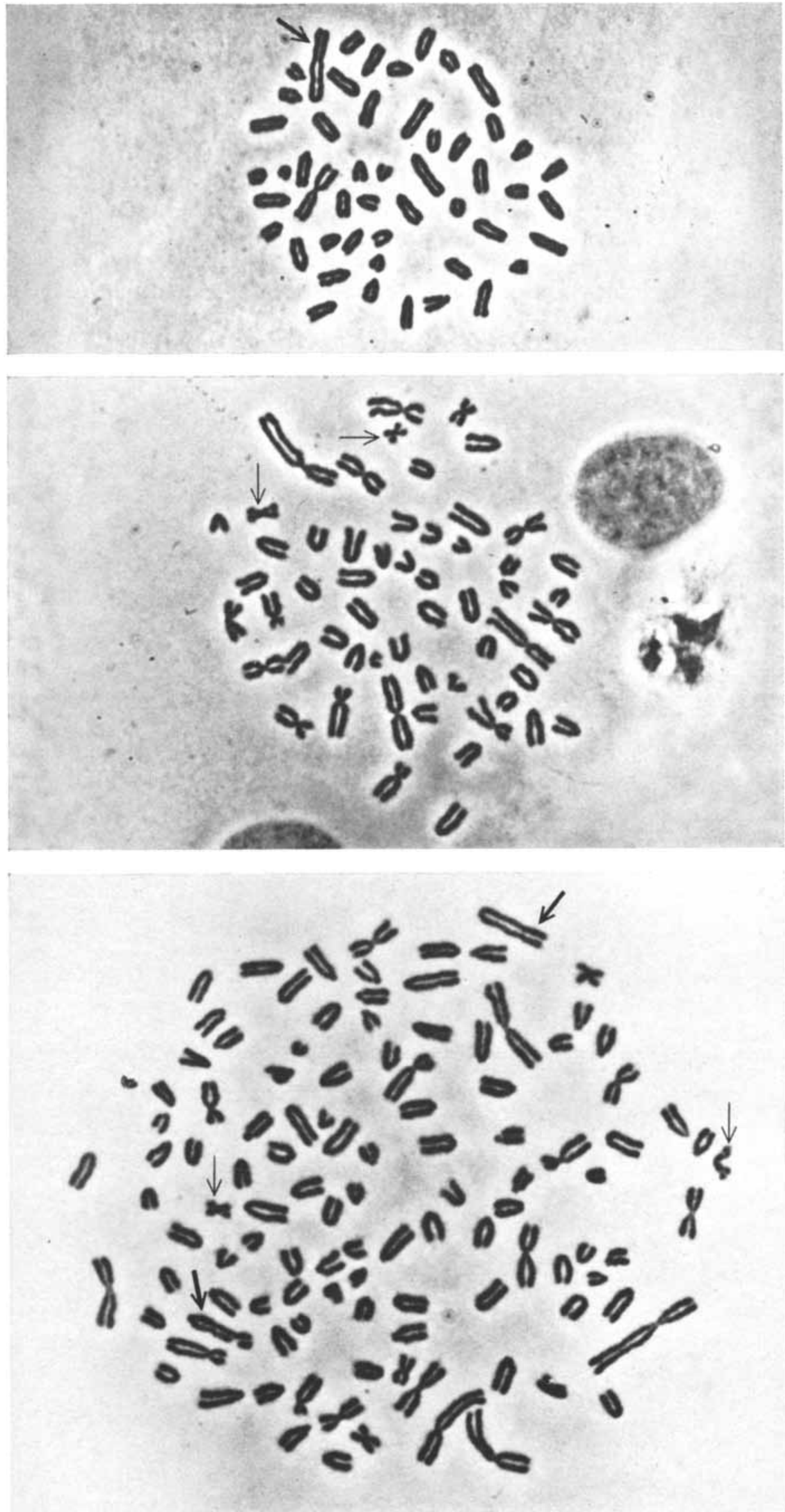
is confirmed by examination of the chromosomes.

These selective systems were first applied to intraspecific crosses (between different cell lines of the same species, usually the mouse). Then we managed to cross cells of different species. The first of these interspecific crosses involved rat and mouse cells; later hamster-mouse hybrids and finally mouse-human hybrids were obtained. Most of the current experimentation is being done with interspecific hybrid cells. The reason is that they fulfill the two requirements for genetic analysis much better than the intraspecific hybrids do.

Since a gene can be recognized only when it mutates to an alternative form that is recognizable in the progeny, the existence of distinguishing genetic markers in the two parents that can be traced in the progeny is a *sine qua non* of genetic analysis. In microbial genetics the most valuable markers have been enzymes that exist in a normal form and also in a form altered by mutation. Such enzyme markers could serve in mammalian-cell studies too, but the trouble is that the necessary mutations are rare and are more difficult to induce in mammalian cultured cells than they are, for example, in bacteria. This paucity of markers led us in 1965 to undertake crosses between different species. We knew that as a consequence of evolution many animal species have come to possess variants of the same enzyme that differ in their structure. These differences affect the physical properties of the enzymes, so that the two variants can be distinguished by such methods as electrophoresis and chromatography. We could expect, therefore, that crossing cells of different species would yield hybrid cells endowed with many built-in enzyme markers.

The only question remaining was whether or not the genes of both parents would in such cases be functional in the hybrids. Fortunately that proved to be the case. For example, in rat-mouse hybrid cells both of the parental forms of the enzyme lactate dehydrogenase (LDH) are synthesized [*see bottom illustration on page 31*]. Malate dehydrogenase and beta-glucuronidase are two other enzymes that have been found in both parental forms in interspecific hybrid cells.

The wealth of genetic markers in interspecific hybrids fulfilled the first prerequisite for genetic analysis. We soon found that the second requirement was fulfilled too: successive generations of



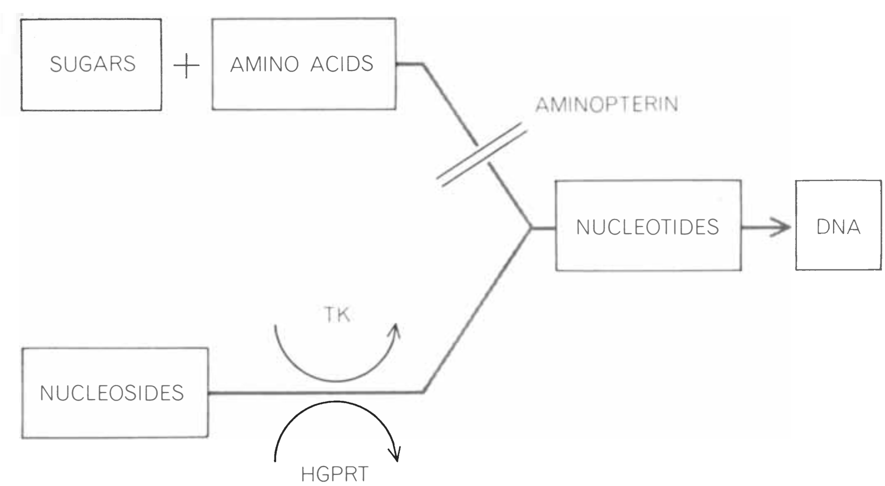
METAPHASE chromosome preparations of the two mouse tumor cells first used in somatic hybridization are shown (*top and middle*) along with a metaphase of the hybrid cell (*bottom*). The chromosomal DNA has been replicated and the two copies of each chromosome are joined to form *V*-shaped or *X*-shaped double chromosomes. The cells of one line (*top*) have two extra-long *V*-shaped chromosomes, one of which is seen in this metaphase (*heavy arrow*). The other line has many *X*-shaped chromosomes (*middle*), two of which are distinctive (*thin arrows*). The hybrid cell (*bottom*) contains the chromosomes of both parent lines.

the interspecific hybrid cells contain decreasing numbers of chromosomes as a result of the loss of chromosomes during cell division. The rate and the extent of the loss vary in different hybrids, but they are generally greater than they are in the intraspecific hybrids.

As an example of an intraspecific cross, consider the hybrids derived from two lines of mouse cells. Detailed analysis of the chromosomal changes is not possible because all normal mouse chromosomes are about the same shape and most cultured mouse cells contain only a few marker chromosomes. In general the karyotype, or chromosomal constitution, of hybrid mouse cells is rather stable. There is some loss—as one might expect, since the hybrids contain an excess of most genes and can therefore survive the loss of some chromosomes. The loss usually does not exceed 10 to 20 percent of the number of chromosomes in the original fused nucleus, however, so that even after hundreds of generations the hybrid cells retain most of the chromosomes of both parents.

In contrast to the intraspecific hybrids, those produced by the fusion of cells of different species have a great many marker chromosomes, since there are large differences in the shapes and sizes of the two species' chromosomes [*see illustration on page 32*]. Analysis of the numbers and kinds of chromosomes in successive generations of rat-mouse hybrids showed that although the decrease in the total number of chromosomes is not much greater than it is in mouse-mouse hybrids, the loss is slightly preferential: significantly more of the rat chromosomes than of the mouse chromosomes disappear. In hamster-mouse hybrids there is greater loss of the mouse chromosomes than of the hamster chromosomes.

In 1967 one of us (Weiss) and Howard Green, working at the New York University School of Medicine, succeeded in crossing mouse cells with human cells and found that the hybrids presented an extreme case of preferential chromosome loss. The mouse-human hybrid cells appeared from the beginning to be different from other interspecific hybrids. Instead of having some of the characteristics of each parent, they looked much more like the mouse cells than the human cells [*see illustration on page 34*]. The reason became clear when their karyotype was examined: the cells contained all the expected mouse chromosomes but only from two to 15 of the 46 human chromosomes. Apparently these hybrids had lost most of their human chromosomes soon after being formed. They continued to lose them as they were cultivated. After 100 generations some of the clones had lost all their human chromosomes; the others retained no more than 10 of them. Because it is possible to obtain cells that contain all the mouse chromosomes and either no human ones or very few, the mouse-human hybrids lend themselves, as we shall see, to studies of human genetics.

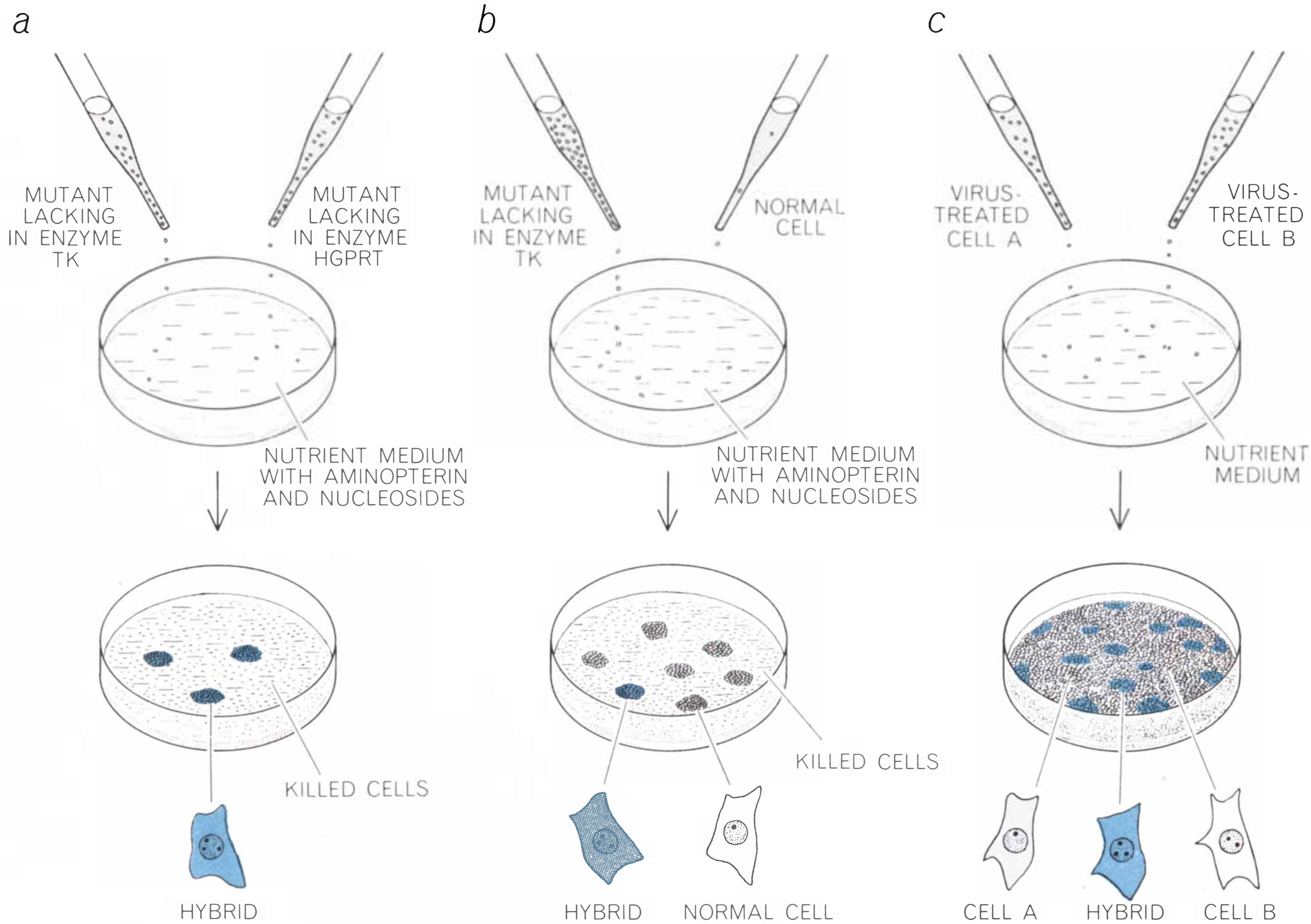


DNA SYNTHESIS from sugars and amino acids is blocked by aminopterin (*top*). An alternative pathway depends on preformed nucleosides (DNA precursors) and the enzymes thymidine kinase (TK) and hypoxanthine guanine phosphoribosyl transferase (HGPRT). Cells with these enzymes can grow in a medium containing aminopterin and nucleosides.

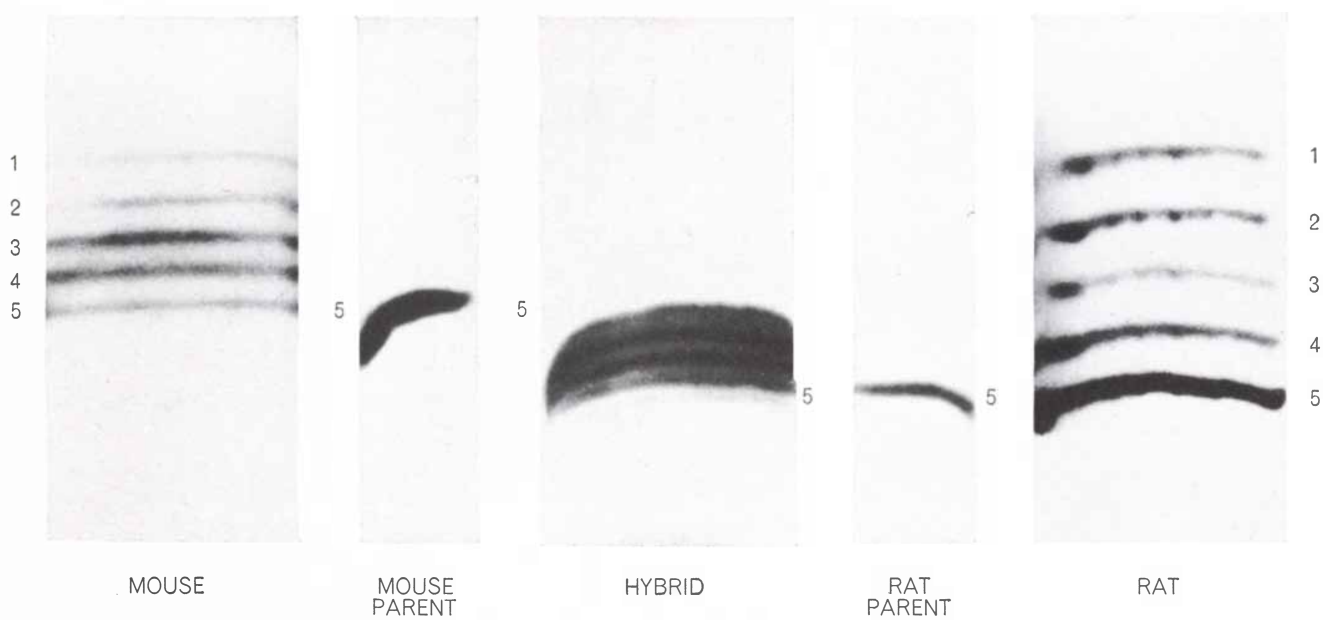
MUTATIONS produce some cells that lack TK but produce HGPRT (*black dots*) and some that lack HGPRT but produce TK (*colored dots*). If such cells are crossed, the hybrid cells contain the genes from both parent lines and therefore produce both parental enzymes.

One would like to be able to cross any two cell types at will. Although Littlefield's system and the half-selective system are in principle applicable to a large number of crosses, they depend on the introduction of specific mutations into the cells to be crossed. In mammalian cells this is a difficult and time-consuming process, and for some kinds of cells it may be impossible. During the time it takes to select cells with the mutation resulting in the required enzyme deficiency, for example, other changes may occur that alter other cell properties one would like to retain. There are two ways in which one might bypass this difficulty: either by devising a selective system based on naturally occurring markers or by somehow increasing the frequency of cell fusion to such an extent that the hybrids no longer need to be selected. The second of these approaches has proved to be rewarding.

Some years ago Y. Okada of Osaka University reported that the Sendai strain of parainfluenza virus causes animal cells in suspension to clump together and that many of the clumped cells undergo multiple fusions. With this observation in mind Henry Harris and J. F. Watkins of the University of Oxford were able in 1965 to bring about the fusion of different types of cells with Sendai virus that had been rendered noninfectious by ultraviolet irradiation. The virus treatment induced the formation of giant cells with from two to 10 or more nuclei—in some cases heterokaryons, or cells with nuclei from different parents. Some of these nuclei fused, yielding hybrid karyotypes, but Harris and Watkins saw no hybrids capable of more than a few divisions. Yet the occurrence of nuclear fusion, hybridization and some cell division, and the absence of viral infection (since the virus was inactivated), implied that the method



SELECTIVE SYSTEMS are required in order to isolate the rare hybrid cells from the proliferating parent lines. One selective system (*a*) depends on the enzyme activity outlined in the illustration on the opposite page. Cells lacking either enzyme are killed; hybrids, which have both enzymes, live and form colonies (*color*). In the half-selective system (*b*) only one parent cell lacks an enzyme, but since only a few of the other (normal) cells are inoculated, the rare but discrete hybrid colonies can be isolated. In virus-induced hybridization (*c*) any two cells can be crossed. The virus causes them to clump and fuse, promoting hybrid formation.



ENZYME MARKERS are available in somatic cells because different species contain slightly different forms of the same enzyme. These forms can be separated on the basis of their mobility in an electric field. Electrophoresis of the LDH found in mouse and rat diaphragm yields five different LDH bands in each (*left and right*). The two No. 5 bands are present in the parental cells used in hybridization. The hybrid has both parental bands and also has three intermediate bands representing hybrid molecules (*center*).

CHROMOSOMES of the rat, mouse and rat-mouse hybrid cells illustrated on page 27 are displayed here in two forms: metaphase figures (*left*) and karyograms (*right*), in which the chromosomes are arranged in groups on the basis of shape and size. The 42 rat chromosomes (*top*) include large ones like unbalanced *X*'s (*thin arrows*) and small *X*-shaped ones. The mouse parental cell (*middle*) has an abnormal number of chromosomes, 54 instead of the usual 40, and a distinctive *X*-shaped one (*heavy arrow*) as well as the usual *V*-shaped ones. The hybrid from which this preparation was made (*bottom*) has 89 chromosomes, of both parental types.

could be developed to provide large numbers of hybrids capable of prolonged multiplication.

This was achieved by George Yerganian and M. B. Nell of the Children's Cancer Research Foundation in Boston and then by Hayden Coon and one of us (Weiss) at the Department of Embryology of the Carnegie Institution of Washington. In the latter case the cell lines involved were such that the frequency of virus-induced hybrids could be compared with that of spontaneous hybrids isolated by the selective techniques, and so it was possible to determine the effectiveness of the virus in promoting hybridization. Viable hybrids appeared from 100 to 1,000 times more frequently in cultures treated with inactivated virus than they did in cultures left to spontaneous hybridization. The virus-induced hybrids proved to have the same properties as the spontaneous ones and can therefore be used for the same kinds of experiments. It is now possible to make crosses between cells to which no selective system is applicable, and this should mean that almost any two cells can be crossed and the resulting hybrid can be isolated.

One of the most interesting findings of somatic-hybridization studies is the very fact that somatic cells of different origins are compatible. The incompatibility between the sperm of one species and the egg of another is well established; in extreme cases an egg fertilized by a sperm of another species immediately expels the nucleus of the sperm. It is therefore surprising to see that the nuclei of cells of two different species fuse and in most cases at once begin to function harmoniously. This implies that the intracellular signals that dictate the sequence of biochemical events in one parent's division cycle must be "understood" by the components of the other cell—in spite of the millions of years during which mammalian species have diverged from their common ancestors by accumulating gene mutations.

A related finding is that the hybrid cells synthesize hybrid enzymes that function satisfactorily. As we mentioned before, rat-mouse hybrids synthesize both parental forms of the enzyme LDH. We have found, moreover, that in the hybrids some of the active enzyme molecules, which are composed of four subunits, are themselves hybrid in nature, formed by the random association of rat subunits and mouse subunits. Several other examples of hybrid enzyme molecules have been reported in interspecific hybrids; since many enzymes are composed of subunits, molecules of this kind are probably common in hybrid cells. The existence of functional hybrid enzymes was not in itself a surprise. Clement L. Markert of Johns Hopkins University had earlier produced such LDH molecules by chemical methods. What is surprising is to find that homologous genes that have diverged as widely as is suggested by the different structures of the enzymes they specify can still produce proteins similar enough to associate into molecules whose enzyme activity can fully satisfy the requirements of a living cell.

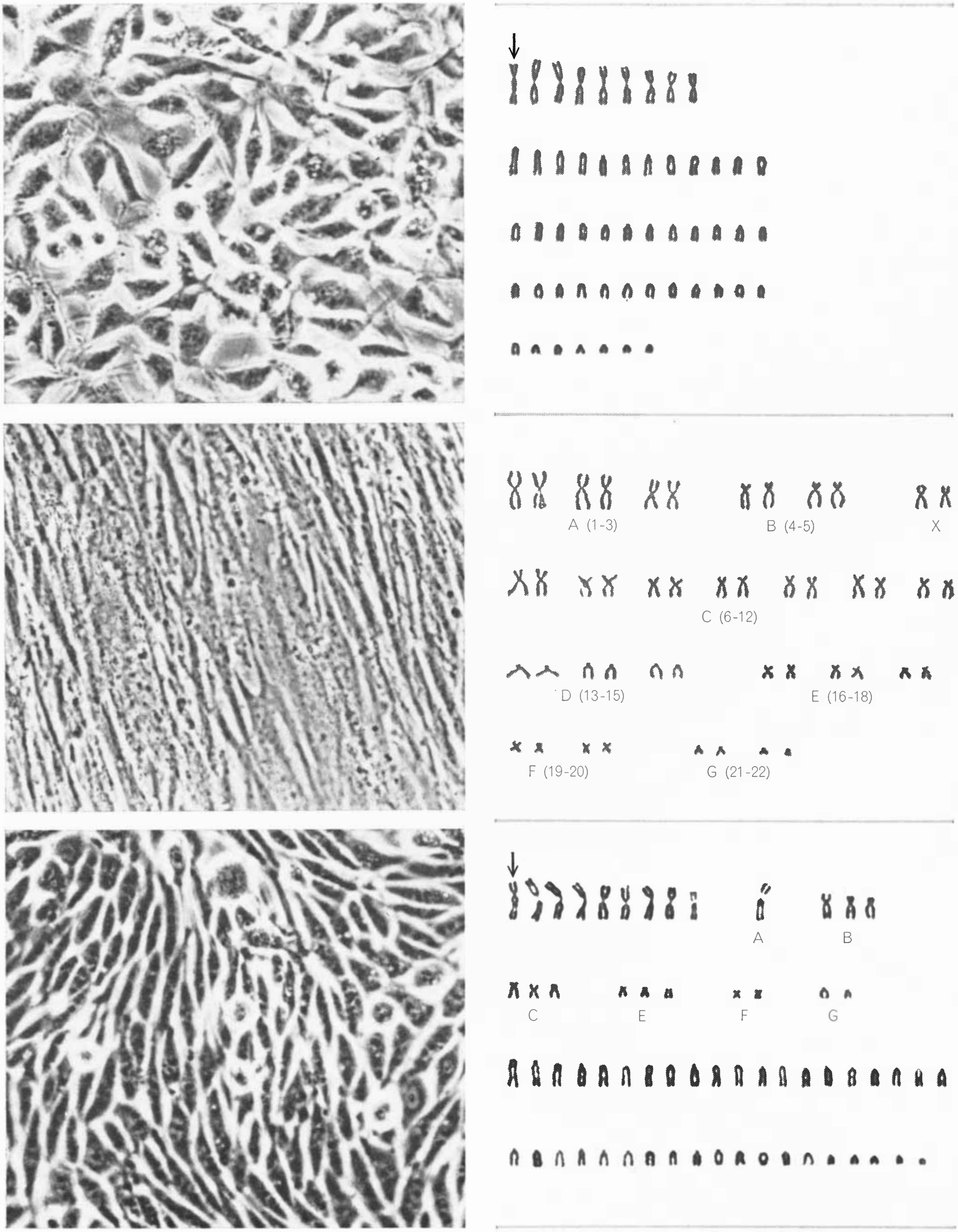
The two examples we shall give of current experiments utilizing somatic hybridization have to do with the formal genetics of man and with the study of gene expression and its control in cellular differentiation.

Study of the formal genetics of any organism begins with the determination of linkage groups and the assignment of genes to specific chromosomes. Then genes are localized in specific segments of the chromosomes, establishing genetic maps for the species. The required data are ordinarily obtained by sexual breeding over many generations, each involving segregation and recombination: the processes, which occur during formation of the germ cells, by which the various parental genes are distributed in different assortments to different daughter cells, resulting in progeny with a range of different characteristics. In effect, the loss of chromosomes by successive generations of somatic hybrid cells takes the place of the segregation and recombination that occur in germ cells, making it possible to begin to determine human linkage groups.

Mouse-human hybrids eventually lose all their human chromosomes. By studying them at a stage when they contain only a few, one can correlate the loss of a specific human gene product with the loss of a specific chromosome. So far this has been done for one enzyme. The mouse cells Weiss and Green used were deficient in thymidine kinase, one of the enzymes required for growth in Littlefield's medium. The survival and growth of hybrid cells maintained in the selective medium therefore depend on the presence of the human gene for thymidine kinase. In several clones of hybrid cells only from one to three human chromosomes remained after 100 to 150 generations [*see illustration on page 35*]. In each of them one specific human chromosome was still present: a small one of the group designated *E*. Presumably this chromosome carries the thymidine kinase gene. This was confirmed when the clones were removed from the selective medium and exposed to bromodeoxyuridine, which kills cells containing thymidine kinase. None of the cells that survived this treatment contained the chromosome in question.

The mouse-human hybrids can surely be used to locate other genes in specific chromosomes. The gene need not be for an enzyme that is missing from the mouse parent as in the case of thymidine kinase. Because of the physical differences between mouse and human forms of many enzymes, one can find out which human enzymes are retained in various hybrid populations and so correlate the presence of the enzyme with that of a specific chromosome. Similar experiments should reveal the location in human chromosomes of genes that determine the presence of antigens. Somatic hybridization has already shown that genes for human antigens must be widely distributed among the human chromosomes since the human antigenic activity of the hybrid cells is proportional to the number of human chromosomes they contain. Adding a purified antiserum that acts against a specific antigen should make it possible to trace that antigen's gene to a single chromosome. In short, it appears likely that within a few years a number of human genes will have been assigned to specific chromosomes. Whether more refined genetic analysis and mapping will be possible with somatic hybrids depends on whether genetic events comparable to those that produce recombination within the chromosomes of germ cells occur also in mammalian somatic cells.

Crosses between differentiated and undifferentiated cells, or between differently differentiated cells, can provide information on the nature of the regulatory processes involved in cell specialization. The activities of somatic cells can be divided into two general categories. There are "essential" functions that are indispensable for the cells' own maintenance and growth and there are specialized "luxury" functions, such as the formation of muscle fiber, the secretion of hormones and the production of pigment, that are necessary for the survival of the organism but not for the survival of isolated cells. The essential functions are expressed in all growing somatic cells. Each luxury function, on the other hand, is expressed in a different line of specialized cells. In 1961



MOUSE-HUMAN hybrids are illustrated by the cell cultures (*left*) and the karyograms (*right*) of the mouse parent line (*top*), the human parent (*middle*) and the hybrid (*bottom*). The human cells, derived from embryonic lung tissue, contain the normal number of chromosomes (46, or 23 pairs), arranged here in the usual seven groups (plus the two female sex chromosomes). Except for a tendency to align in parallel, the hybrid cells look more like the mouse cells than the human ones. This is in keeping with the fact that the hybrid karyogram contains only 14 of the 46 human chromosomes, which are readily distinguished from mouse chromosomes.

François Jacob and Jacques Monod of the Pasteur Institute in Paris discovered mechanisms that regulate the activity of genes in bacteria. It is generally believed that similar mechanisms are responsible for specialization of somatic cells—that sets of genes governing the various luxury functions are activated or repressed as required in the cells of the different tissues. Since bacterial and mammalian cells have very different properties and requirements, however, it would not be surprising if somatic cells have evolved some unique mechanisms for the regulation of gene activity.

Working with Davidson and Kohtaro Yamamoto at Western Reserve, one of us (Ephrussi) crossed two cells, one of which synthesizes a certain luxury product. This differentiated parent is a line of hamster tumor cells that produce melanin, a dark pigment. When cells of this melanoma line are crossed with cells of a number of different mouse lines that have never produced melanin, the hybrids have a rather stable karyotype and contain most of the chromosomes of both parents. Yet among the many hybrid colonies obtained, none synthesizes melanin or contains the enzyme dopa oxidase, which is required for the synthesis of the pigment and which is present in large quantities in the melanoma cells. Obviously, when the melanoma cells fuse with the unpigmented ones, the synthesis of the enzyme is halted by some regulatory substance produced by the normal cells. Whether this block occurs at the level of the gene specifying dopa oxidase (which was active in the melanoma cell) or at some later step in the process leading to dopa oxidase production is something that remains to be determined.

ENZYME AND CHROMOSOME can be correlated in the clone from which this metaphase was taken. All but three human chromosomes have been lost: two of Group *G* (*thin arrows*) and one of Group *E* (*heavy arrow*) remain. The Group *E* chromosome is always retained in clones grown, as this one was, in a medium in which cells survive only if they produce the enzyme TK. Therefore that chromosome must carry the gene for TK.

Some light may be shed on the mechanism of regulation of gene activity in mammalian cells by examination of highly segregated hybrids between melanoma cells and cells that do not produce the pigment. If the genes responsible for producing melanin are active in the melanoma parent because of some stable change at the chromosome level, and if they are only temporarily repressed in the hybrid cells, then the loss of the repressing chromosomal material should bring a resumption of melanin synthesis. If synthesis does not resume, one will have to conclude that the continuous production of melanin in the melanoma parent was not due to a stable cellular change in the first place.

The melanoma cell is a differentiated cell that synthesizes both a specialized product and all the enzymes necessary for continuous and rapid growth. Some other highly differentiated cells no longer grow at all; the essential syntheses that occur in growing cells are arrested. Does this reflect a total and definitive inactivation of the nucleus associated with extreme differentiation? Harris and his co-workers have shown that it does not. They produced heterokaryons between nucleated red blood cells taken directly from the blood of a hen and actively growing, undifferentiated human cells. The human cells are characterized by rapid synthesis of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA); the hen blood cells synthesize neither and they have small, highly condensed nuclei characteristic of quiescent cells. In the heterokaryons the red-cell nuclei undergo dramatic changes: they swell up, their chromosomal material becomes less condensed and they resume the synthesis of both DNA and RNA. Clearly the red-cell nucleus is reactivated; it must not have been irreversibly inactivated to begin with.

It will be most interesting to determine precisely which of the numerous possible functions are resumed in these reactivated nuclei. Can the nuclei of highly differentiated cells such as the red blood cells be induced to perform not only some essential functions but also specialized functions characteristic of other differentiated cell types? It should be possible to answer this question by determining the nature of the products synthesized by red-cell nuclei that are reactivated by fusion with other differentiated cells. A positive answer would open a new line of biochemical investigation of the factors that control cellular differentiation in embryonic development.

EIDETIC IMAGES

Certain individuals report that they briefly retain an almost photographic image of something they have seen. Experiments with children suggest that such images are a real phenomenon

by Ralph Norman Haber

Many people believe they can retain a vivid image of something they have seen. When such people undertake to describe this ability, it usually turns out that the images are fleeting and lacking in true visual quality; the person describing the images is not quite sure that he is not merely remembering or imagining them. Certain individuals, however, report something rather different: a sharp visual image that persists for many seconds or even minutes. They speak of the image being localized in space in front of their eyes, usually in the same plane as the original stimulus. They maintain that it is so well defined that they can describe it in far more detail than they could from memory alone. They report that the image can be formed when their eyes simply flick over the original scene without fixating it, and also that the image can be scanned as it remains stationary in space.

Such reported images have been named eidetic, after the Greek *eidētikos,* meaning pertaining to images. Eidetic imagery was once the subject of considerable investigation; more than 200 experiments and studies on it have been published, most of them before 1935. This work indicated that whereas eidetic ability is relatively rare after puberty, it is common in young children (an average of 50 percent of the elementary-school-age children who were studied appeared to possess it). These findings were based, however, on widely divergent and often inconsistent methods. In spite of the seeming prevalence of eidetic imagery, the poor methods and an inability to explain the phenomenon tended to lead psychologists to ignore eidetic images, along with most of the other mental states that depend so heavily on subjective reports.

The past decade has witnessed a renewed interest in visual imagery of all kinds, particularly in connection with how images facilitate perceptual memory. It seemed only natural to look again at eidetic imagery, the most enduring and complete kind of imagery. Does it really exist? Can children (or adults) with this ability be found, and if so, in what other ways might their visual perception and perceptual memory be different? Exactly how do eidetic images differ from the ordinary visual memories reported by most adults? How does a child with eidetic imagery prevent his visual experiences from becoming a hopeless muddle? Is eidetic imagery a more primitive or developmentally earlier mode of perception and memory?

To answer some of these questions my colleagues and I (including from the beginning my wife and more recently Jan Leask Fentress) launched a large-scale effort to find eidetic children and examine aspects of their imagery and other perceptual abilities. Because of the elusive nature of the phenomenon, and because of the difficulty of finding a large number of eidetic children, we have conducted comparatively few formal experiments. Even so, we have found answers to a few of the questions listed above (although more questions have been raised). I shall describe how we conducted our search for eidetic children and some of the more outstanding results of the project. I shall also discuss, as I present the evidence, the visual character of eidetic imagery.

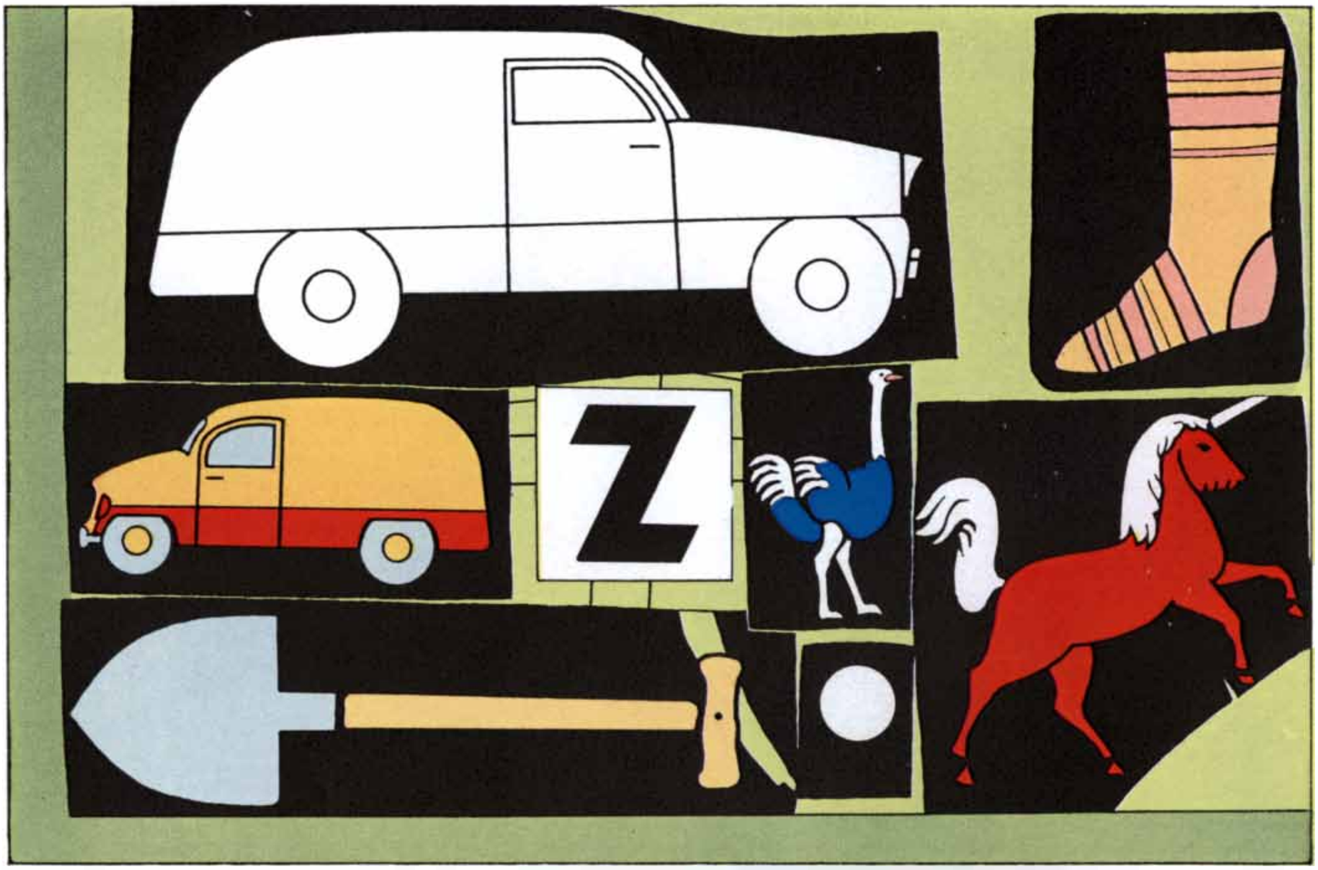
The basic procedures we followed in order to locate eidetic children were adapted from research of 40 years ago. Children from four elementary schools were tested individually, and as it became clear that eidetic imagery was going to be a rare phenomenon, we found it necessary to test large numbers of them. Our results are based on about 20 eidetic children, although more than 500 children have been screened in all.

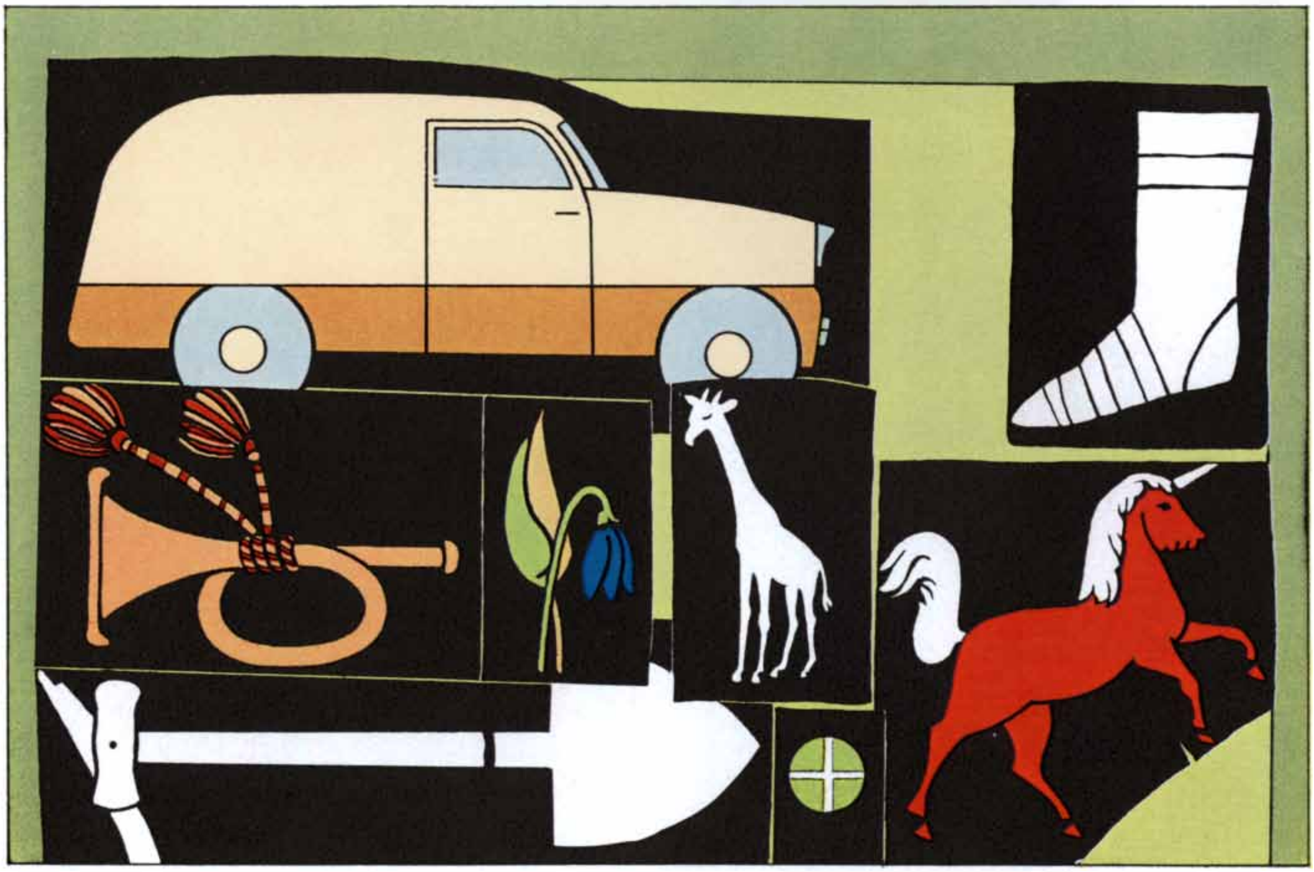
The screening began with a test designed to elicit afterimages, which are a common phenomenon not to be confused with eidetic images. The subject sat before a table on which an easel of a neutral gray color was placed. His eyes were about two feet from the middle of the easel [*see illustration on page 40*]. A tape recorder transcribed the voices of the subject and the experimenter.

The first stimulus placed on the easel was a four-by-four-inch square of red paper mounted on a board of the same material as the easel. After 10 seconds the board was removed, and the subject then reported what he saw on the easel. At the beginning of this test he was instructed to stare at the center of the colored square as hard as he could, trying not to move his eyes. He was told: "After the square is removed, you will still be able to see something there. It is very much like when you stare hard at a light bulb and then look away. You can still see something out there in front of your eyes." If a child acted as if he was unfamiliar with this phenomenon, he was told to try it out with one of the overhead lights in the room. He was also encouraged to report, without waiting to be asked, what he saw after the square was removed and he continued to stare at the place where it had been.

During the exposure the experimenter watched carefully to be sure that the subject did not move his eyes. If, when the square was taken away, the subject said he saw nothing, he was encouraged by being assured that it was all right to see something. If he still said he saw nothing, he was reminded to stare hard and not move his eyes at all, and he was

TEST PICTURE was shown for half a minute to elementary school children; a few then reported eidetic images of it. For example, one boy saw in his image "about 16" stripes in the cat's tail. The picture, painted by Marjorie Torrey, appears in an edition of Lewis Carroll's *Alice in Wonderland* abridged by Josette Frank and is reproduced with the kind permission of Random House.





COMPOSITE PICTURES, closely resembling each other, provided a test of eidetic imagery. A child capable of maintaining eidetic images of both pictures would presumably be better equipped to distinguish between them accurately than would a child without such images who relied solely on his memory of the pictures. The montages were made by Leonard W. Doob of Yale University.

questioned about whether he knew what these instructions meant.

If the subject said he did see something, he was allowed to report spontaneously. Then he was questioned about items he had not reported. Was the image still visible? What was its color and shape? When the subject moved his eyes (he had been asked to try to look slowly toward the top of the easel), did the image move? How did it disappear? After the image had faded completely the experimenter repeated the initial instructions and another square, a blue one, was placed on the easel. The same procedure was followed with a black square and then a yellow one.

After the last square had been reported on, the test for eidetic imagery began. Four pictures were shown: two silhouettes of black paper pasted on a gray board (one showing a family scene and one an Indian hunter) and two illustrations in color taken from books for children. Each picture was presented for 30 seconds. For this test the subject was given the instructions: "Now I am going to show you some pictures. For these, however, I do not want you to stare in one place, but to move your eyes around so that you can be sure you can see all of the details. When I take the picture away, I want you to continue to look hard at the easel where the picture was, and tell me what you can still see after I take it away. After I take it away, you also can move your eyes all over where it was on the easel. And be sure, while the picture is on the easel, that you move your eyes around it to see all of the parts."

During the viewing period the experimenter watched to be sure that the picture was scanned and not fixated. After the first picture was removed the subject was reminded to continue looking at the easel and report whatever he could still see. He was also reminded that he could move his eyes. If a subject reported seeing something, the experimenter asked if he was actually seeing it then or remembering it from when the picture was still on the easel. The subject was frequently asked if he was still seeing something, since subjects would often fail to say that the image had faded and would continue reporting it from memory. The experimenter probed for further description of all objects still visible in the image. He noted the relation between the direction of the subject's gaze and details of his report. This process was repeated for all four pictures. The average time for testing varied from four or five minutes for a young subject with no visual imagery to more than 30 minutes for an older subject with extensive imagery.

The tests were scored by encoding the tape recordings on data sheets. A different coding sheet was set up for each stimulus. The reliability of this condensation of the data was nearly perfect because there were categories for every object in the picture and most of their attributes. The coder rarely had to make a scoring decision.

We have introduced a number of variations in the screening, but these represent the main procedures. When a child was considered to be eidetic, further tests, demonstrations and examinations usually followed. I shall not present them in chronological or systematic order here, since most of the sessions did not constitute formal experiments.

Before discussing specific characteristics of eidetic imagery, let me make a few general comments. About half of the children screened said they saw something on the easel after the picture was removed, but nearly all these reports were of afterimages and the like, that is, the images were fleeting and indistinct. Between 5 and 10 percent of the children, however, reported images that lasted much longer (a half-minute or more) and that possessed some sharp detail. Without committing ourselves, we labeled these children eidetic and observed them further. Hereafter I shall refer to this group as eidetic, although you can judge for yourself whether they can be differentiated from the rest, and whether they have any visual imagery of noteworthy quality. I feel that the answer to both questions is clearly yes.

Let me start by offering an example (taken directly from a tape recording) of a report of an eidetic image. Not all eidetic reports are like this one; on the other hand, it is not atypical. The subject, a 10-year-old boy, was seated before a blank easel from which a picture from *Alice in Wonderland* had just been removed.

Experimenter: Do you see something there?

Subject: I see the tree, gray tree with three limbs. I see the cat with stripes around its tail.

Experimenter: Can you count those stripes?

Subject: Yes (*pause*). There's about 16.

Experimenter: You're counting what? Black, white or both?

Subject: Both.

Experimenter: Tell me what else you see.

Subject: And I can see the flowers on the bottom. There's about three stems, but you can see two pairs of flowers. One on the right has green leaves, red flower on bottom with yellow on top. And I can see the girl with a green dress. She's got blonde hair and a red hair band and there are some leaves in the upper left-hand corner where the tree is.

Experimenter: Can you tell me about the roots of the tree?

Subject: Well, there's two of them going down here (*points*) and there's one that cuts off on the left-hand side of the picture.

Experimenter: What is the cat doing with its paws?

Subject: Well, one of them he's holding out and the other one is on the tree.

Experimenter: What color is the sky?

Subject: Can't tell.

Experimenter: Can't tell at all?

Subject: No. I can see the yellowish ground, though.

Experimenter: Tell me if any of the parts go away or change at all as I'm talking to you. What color is the girl's dress?

Subject: Green. It has some white on it.

Experimenter: How about her legs and feet?

(*The subject looks away from the easel and then back again.*)

Experimenter: Is the image gone?

Subject: Yes, except for the tree.

Experimenter: Tell me when it goes away.

Subject: (*pause*) It went away.

The fact that only about 5 percent of the children reported images as prolonged and vivid as this one raised our immediate concern about the validity of eidetic imagery. How could it shrink in frequency so much in the 35 years since the early investigations? Perhaps it did not exist at all. The children might be faking or be strongly suggestible, giving us answers we led them to expect we want. Or could we as psychologists be fooled into thinking that these few children are describing their imagery when they are only telling us about their vivid memories? All of these have been difficult questions to answer or even to investigate. Furthermore, some of the most convincing evidence in support of visual images comes not from experiments but from incidental observations or comments made by the children that suggest the visual characteristics rather than the memory characteristics of the reports. Instead of listing such evidence out of context I shall consider it in relation to some of the properties of eidetic imagery we measured.

First, who are the eidetic children? Those we labeled as such were distributed fairly evenly over the five grades from the second through the sixth. The absence of eidetics from the first grade and kindergarten (which were also tested) seemed due to the verbal demands of the task that was set, so that we have no way of being sure that younger children are less likely to be eidetic. The sex and racial makeup of the eidetic group mirrored the school populations as closely as such a small sample can. We tested I.Q., reading achievement and aspects of personality, but we could find nothing that differentiated the eidetic group from comparable noneidetic children.

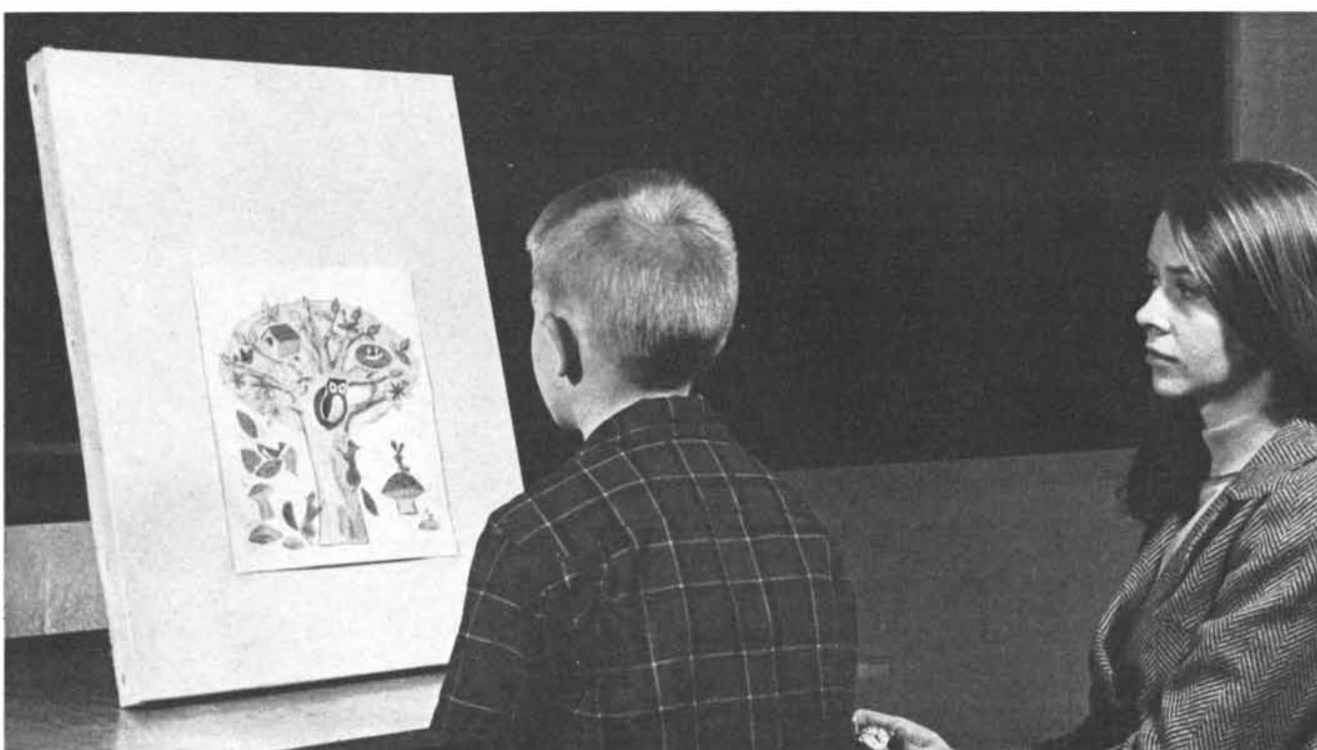
The rather unsuccessful attempt to find some distinguishing characteristic of eidetic children has given us concern, although without further enlightenment. There is no question about the reliability of the testing for eidetic imagery, however. Once labeled this way, an eidetic child always produces such images. We have tested a few of the children four times over a five-year period, and have found no loss in the quality of their imagery.

One aspect of eidetic imagery we measured was the length of exposure time required for the formation of an image. For nearly all the eidetic children a five-second viewing of a picture will lead to an image of at least parts of it (the parts examined during that time). The better eidetic children (those who could more easily report long-lived and complete images) could occasionally form an image after only three seconds. Although we did not make careful measurements, it appears that three to five seconds of central viewing is needed to produce an image, and that the size of such an image is two or three degrees of visual angle. This is roughly the size covered by the fovea, the area of the retina that provides sharp vision. Thus to have a complete image of a typical picture measuring five degrees by five degrees at least four separate fixations would be needed. The children report that they do not have an image of parts of the picture they did not look at long enough, even though they may know and be able to remember what the parts contain. Moreover, the relation between duration of exposure and the production of an eidetic image holds even if the picture is totally familiar to the child. Hence his memory of it could be essentially perfect and complete and yet whether or not he has an image depends on how long his eyes dwell on the picture in the most recent viewing. Observations of this kind further suggest the visual character of eidetic images.

We wondered why eidetic children were not confused by the continual bombardment of images. The children described several ways they controlled the production of images. One way, of course, is not to look at anything too long. Moreover, most of the children indicated that exaggerated eye blinks could serve to "erase" an image. Nearly all the children said that if they moved their eyes from the original surface on which the picture was viewed, the image would disappear. This would further reduce the possibility of an eidetic child's picking up random images as he looks about the world.

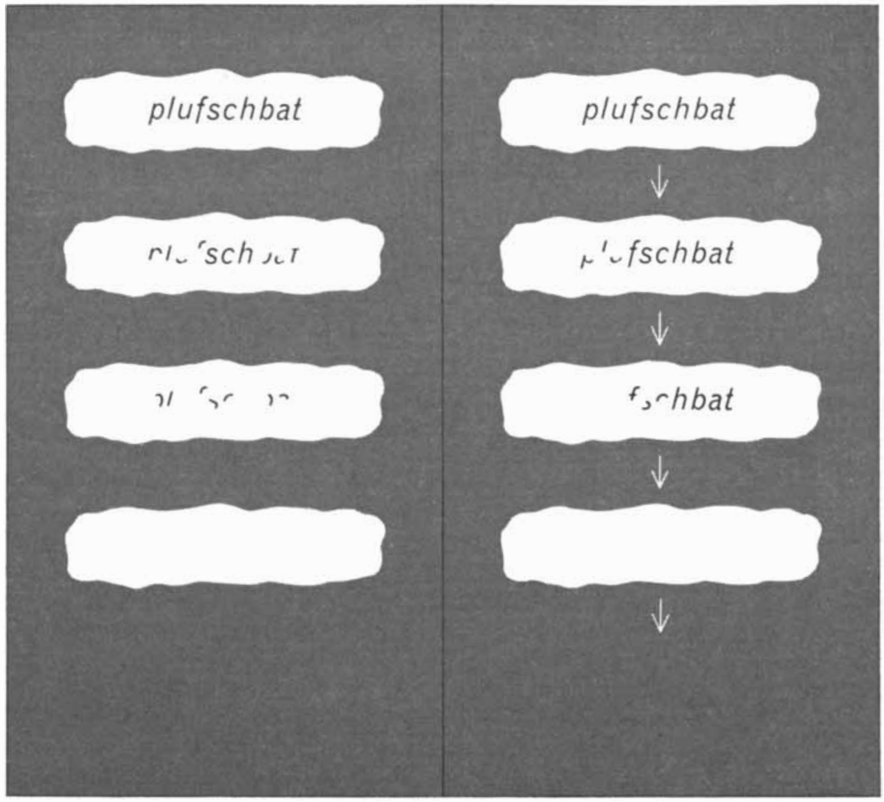
By far the most intriguing method of control reported to us (again by most of the children) was based on naming the items in the picture. That is, if while the child is looking at the picture, he names, labels, rehearses or otherwise actively attends to the items, he will not have an image. After several children mentioned this spontaneously, we examined it more explicitly. In viewing some pictures a child would be asked to name each part; for other pictures the experimenter named the parts but the child was not asked to do so. We found a clear difference: no image or only a poor, brief image would form of those pictures for which the child had named the parts.

We have not yet been able to pursue



SUBJECT WAS TIMED as he inspected the picture; he was also watched to see whether he examined every part of it. After the picture was removed from view he reported to the experimenter what (if anything) he saw on the blank easel. His words were recorded.

this finding further. It seems to imply at one level that eidetic children retain information either in the form of an image or in the form of a verbal memory or another kind of memory more similar to that in adults. The children do not seem to be able to do both at once. This can help to explain an earlier finding of ours. In one screening test, after an eidetic child had completed a description of his eidetic image and had said it had faded completely, he was asked to describe the stimulus from memory. Noneidetic children who had no images at all were also asked to describe the stimulus from memory. We expected the eidetic child to have a far superior memory, because he had had the opportunity to view not only the picture but also his enduring image, but we found that eidetic children were only slightly better than the others, and in some cases no better at all. It was as if the eidetic child paid no attention to his image in organizing his memory. Interpreting this behavior in the light of the later observations, it seems that if an eidetic child wishes to get an image, he can pay no attention to the picture in composing his memory, because trying to do so interferes with the image. The child asked to produce images sacrifices the memory. I shall return to this point. Let me note that here again we can make a distinction between the visual character and the memory character of the child's report, suggesting that the visual nature of eidetic imagery has some validity.



QUALITY OF EIDETIC IMAGES (reconstructed from verbal reports) varied from child to child. At left is the range of image completeness (of a nonsense word) for all the children with eidetic ability. Each reconstruction characterizes a different child most of the time. At right is the sequence of fading of all eidetic images. A perfect "image" is used as a model.

Can an eidetic child prolong his image or bring it back after it has disappeared? Does he have any control over its disappearance? Can he change the size or orientation of his image, or move it to another surface? The answer to each of these questions is in general negative. Few eidetic children seem to have any control over the images once they are formed.

The group of eidetic children we studied differed substantially among themselves with respect to the quality of their images. For example, the child with the most enduring images consistently reported them as lasting 10 minutes or more. Some eidetic children had good images that lasted no more than a minute. There was also variation among children in the completeness of the image, particularly for nonpictorial material such as printed letters. Some children could regularly see in their image all the letters of a very long nonsense word. Other children could see only some of the letters, still others just a few letter fragments. There were eidetic children who could get images of pictures easily but could rarely see any print in an image. What is interesting about this is that the pattern of fading for a particular eidetic child seems to reproduce the spectrum of image completeness of the group as a whole [*see illustration above*]. All the eidetic children reported that their images ended in the same manner each time, the image fading part by part in a comparatively independent fashion. As a good image begins to fade, first some fragments disappear and then more of them go until just a gray streak is left and finally nothing remains. The parallel between completeness and fading suggests that the mechanism responsible for the completeness of an eidetic image is similar to the one for its subsequent fading.

None of our eidetic children maintained that he could by any action prolong his image. One girl reported the ability to bring an image back after it had faded. She was asked to do this over periods of several weeks and reported being able to do so.

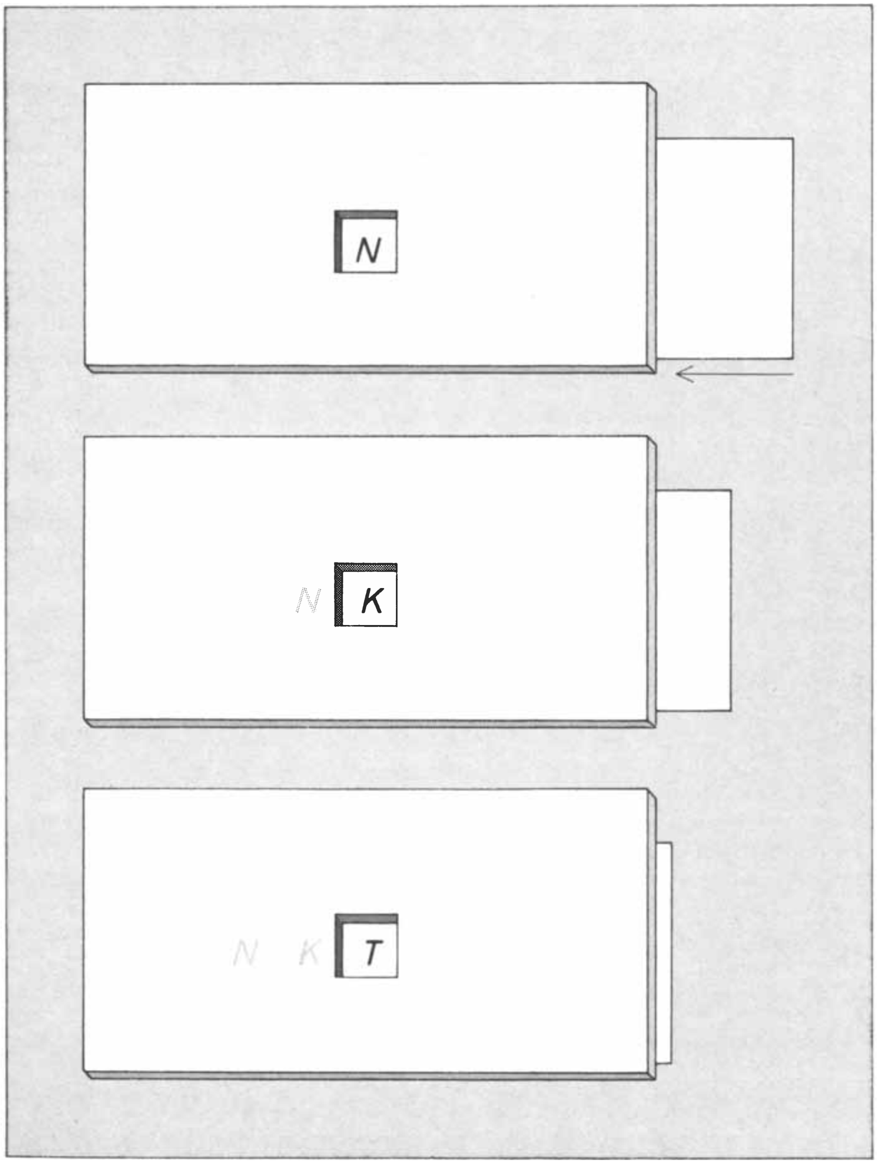
We explored somewhat more fully whether the eidetic child can move his image or change its size or orientation. The apparent size of an afterimage varies with the distance of the surface on which the image is projected (an effect known as Emmert's law). No such effect can be tested with eidetic imagery because the eidetic child cannot move his image off the original surface without losing it. The image could be moved over the surface, but nearly all the children said that when they tried moving the image over the edge, it "falls off." Only the girl who was able to bring her images back could move her image off the surface. (She said she could move it anywhere and even turn it upside down.) With this one exception the image seems to be related in specific ways to the picture that produced it. It has the same size, orientation and shape. It moves on its "own" surface but not into space or onto a "foreign" surface.

We had used pictures selected to be interesting to children in our screening procedures, because the older studies suggested that these elicited better eidetic images. We were also most interested in images of letters and how much information was maintained in these images. This was significant in its own right and also because eidetic imagery might facilitate or hinder reading. Although all the eidetic children were able to develop images of print (we used long nonsense words, strings of digits or misspelled words), these images were in general poorer than images of pictures. They were less complete and distinct, and did not last as long. The quality of the image did not differ according to the kind of printed material. The duration of exposure also seemed to be irrelevant. An eidetic child with only a partial image of print would not get a better one if he looked longer.

One procedure we followed was to show a subject letters or digits one at a time through a small viewing window in a screen. The most striking result was the nearly uniform statement by the children that as each new item appeared in the window they moved their image of the preceding one along the surface to the left [*see illustration below*]. When the image of the first letter exposed reached the left margin of the surface, it would (if it had not yet faded with the passage of time) "fall off" the edge and disappear. Note again the visual character of this description given by nearly every eidetic child.

Regardless of whether the child scanned a group of letters from left to right or from right to left, the items seen last exerted a strong effect. This was clearly due to the fact that the images of the first items scanned were fading before the last ones were scanned. Since in a task of this kind the first items viewed would normally be remembered better, the finding again seems to indicate that the children are seeing something rather than just remembering it.

We were disappointed in how few letters (or digits) can be maintained in a visual image. For a relatively good eidetic child an average of only about eight of 10 letters (one presented every three seconds) remained in an image after the 30 seconds of total exposure, and this held only under optimum conditions. A few of the children could probably have done better had we given them more letters, but for most of the children items of this kind do not persist in images for nearly as long as parts of pictures. Although we did not try to use a page of printed words as a stimulus, it was clear that none of the children would have had an eidetic image of even part of it.



SEQUENCE OF LETTERS appeared one at a time in an aperture of a screen as children who had previously displayed eidetic ability watched. They reported that the image they formed of a letter (*gray letter*) moved to the left as a new letter appeared in the window.

In an attempt to learn the amount of information retained in an image, we tried two tests utilizing pictorial items. For one test we designed a "rogues' gallery," showing a group of letters and a series of digits in conjunction with the shoulders and head of the "wanted" man [*see illustration on opposite page*]. Only four of the eidetic children could develop an image of even part of the gallery, and these images were so incomplete that the children were unable to report much information. None of the children felt he could have maintained better images with longer exposures. (The exposure time was about three seconds per rogue.)

In the second test montages made up of familiar objects were presented to the children. The montages were in pairs, one member of the pair rather closely resembling the other [*see illustration on page 38*]. We expected (and showed) that from memory alone children and adults often tended to confuse which element belonged in which picture of the pair, assuming that they could remember all the elements to start with. An eidetic child, however, if he could have a good image of both members of a pair, should have no trouble describing them accurately. Unfortunately when first one and then the other montage was shown to the eidetic group, only one child was able to maintain an image of the two pictures side by side. Several children could retain images of the second montage shown, but the first image would disappear. None of the eidetic children could report any more detail or accurate positioning of detail than noneidetic children could.

We therefore have been unable to determine how much information an eidetic image can contain, because eidetic children do not achieve satisfactory images of either high-information stimuli or even simple nonpictorial stimuli. One

"ROGUES' GALLERY" STIMULUS was designed to provide a basis for estimating the amount of information contained in an eidetic image. In addition to the name and the number associated with a rogue there are binary dimensions that could be used descriptively, for example the presence or absence of hair or a hat. The rogues (together with 20 others) were shown as a group to the children.

reason for the poor response to letters may have been the tendency to name them, which we already know interferes with the formation of a good image. These results are somewhat in contrast with the seemingly better images from complex but cohesive pictures.

We have also tried to elicit eidetic imagery with a few three-dimensional objects. Three of the eight children so tested reported images of everyday objects, at which they looked for 30 seconds. They were able to move their images and reported that they had clear three-dimensional qualities. The children were also shown the visual illusion known as the Necker cube, a line figure that spontaneously reverses in apparent depth [*see top illustration on next page*]. During the 30 seconds of scanning time all the children reported reversals of depth; only three (the same three mentioned above) could report reversals in their image. The number of reversals in the image was about four per 30 seconds compared with seven per 30 seconds during the viewing of the drawing of the cube. Since (barring deliberate faking) a report of a reversal requires a three-dimensional view, a few of the eidetic children seem to be capable of forming three-dimensional eidetic images. A reversal also requires a visual experience. There is nothing in the memory of a Necker cube that would cause its orientation to alternate.

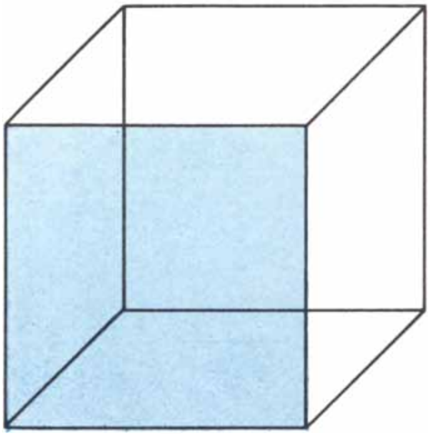
At several points in this article I have raised the question of whether eidetic imagery could merely be vivid memory. This is a crucial aspect of the research. Some criticisms of the earlier studies of eidetic imagery focused on the lack of evidence that the eidetic children were reporting a visual image rather than just describing their memory of the stimulus. Whereas many incredibly detailed reports of eidetic images have been described in these studies, there is no reason to doubt that some children may have superb memories and be quite capable of the same feats from memory alone.

I believe that resting the case for eidetic imagery on the fidelity of reports is the wrong approach. Our own evidence suggests that the amount of detail an eidetic child can report from his image is in general not phenomenally good (although we have had some amazing exceptions). I see no reason to assert that an eidetic image has to be complete or contain all the content of the original stimulus, or that it must last long enough to enable the eidetic child to describe all the content before it fades.

If we are not to depend on the criterion of accuracy, then what does differentiate eidetic images from other kinds of images or from memory? The only distinction with respect to other images is in their location. Afterimages seem to be the result of differential adaptation of retinal receptors and neural units. The image, once formed, is "burned on" the retina and cannot be moved in relation to the retina. Moreover, during the formation of an afterimage reasonably stable fixation is required to produce the differential adaptation. The likelihood of an afterimage's being produced should thus vary inversely with the amount of scanning during inspection and with the degree to which the image itself can be scanned once it is formed. Since in all our work with eidetic images we demand scanning during inspection of the stimulus and check further to be sure the child moves his eyes during his report of his image, it seems almost certain that this image cannot simply be retinal in origin.

We still leave open the possibility that an eidetic image is not an image at all. The child may not be seeing anything in front of his eyes. It is always possible that these children are trying to fool us when they say they see the image; that our questions effectively structure their answers to be as if they saw images; that since they think we want them to talk about images, they do; that they are so suggestible they "think" they see images even if they do not, or that the distinction between seeing and remembering is so difficult for a child (let alone an adult) that he is innocently confused. All of these are possible explanations and are likely to be true for perhaps one or two children most of the time and for many of the children occasionally.

Still, sufficient evidence is available to support the argument that these are images that are visual in nature and not dependent on memory in any way (except perhaps negatively). Whereas this argument cannot be settled to the degree we would wish, let me repeat some of the observations or comments that support the visual character of eidetic imagery: (1) An eidetic child can remember parts of the picture he cannot see in his image, and he says he did not have an image of those parts because he did not look at them long enough. (2) A conscious attempt to label the content of the stimulus interferes with the formation of an image. (3) Nearly all the eidetic children report the same pattern of fading in their images, even though that is only one of a number of possible sequences. (4) When asked to move their image from one surface to another, eidetic children report spontaneously that when it reaches the edge it falls off. (5) When the child forms an image of letters exposed individually in a window, he moves his image to the left as a new letter appears in the window. Furthermore, when the image reaches the edge of the



VISUAL ILLUSION was presented to children to explore their ability to form three-dimensional images. The area of the cube in color can appear as a front surface or as a rear surface, producing (in some children's images) a reversal in the cube's orientation.

surface, it too falls off. (6) Children are most capable of seeing details that they scanned most recently, a result contrary to normal organization in memory. (7) At least some of the eidetic children are able to develop three-dimensional images. This was particularly true with the Necker cube, for which reversals cannot be the result of anything other than a visual three-dimensional image.

This list should be longer, and there are certainly a large number of other observations that could be made to help verify the distinction proposed here. At present this represents the nature and amount of evidence we have.

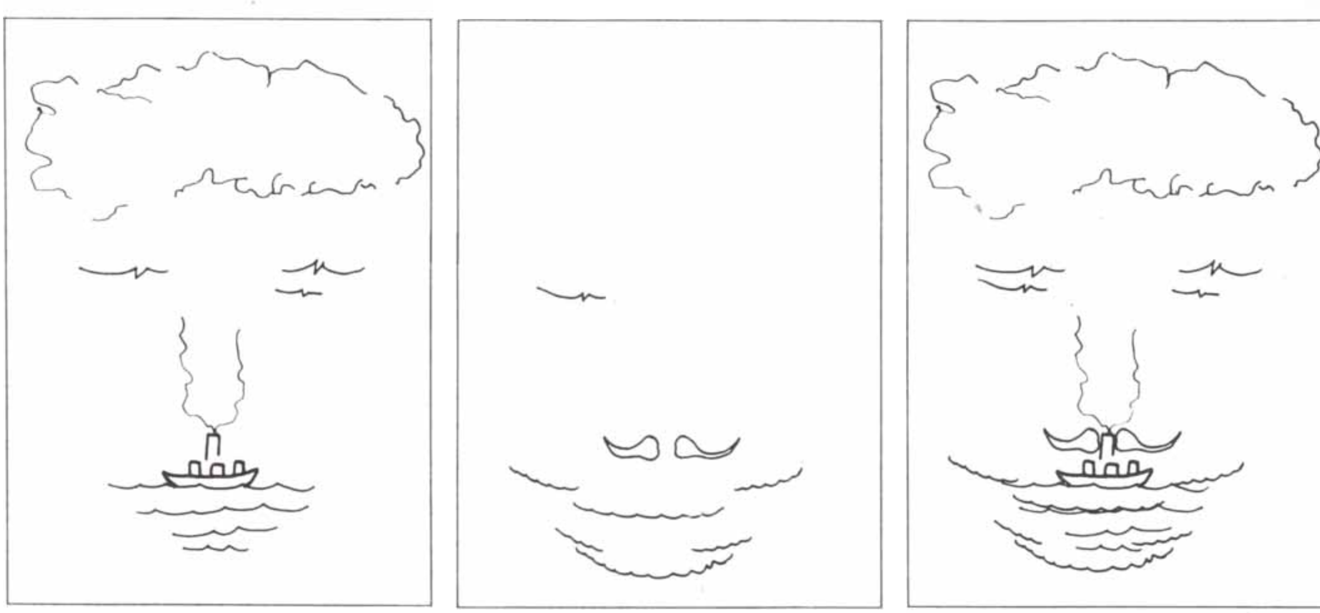
We have tried only one direct test of the visual character of eidetic imagery. This has been very difficult to work out, and our first step is only a beginning. We wanted a test for the screening of eidetic imagery that did not depend on verbal facility and could not be biased by memory. The best solution we have found so far is to use a sequence of pictures that together form another picture [*see illustration below*]. The first picture shown to the child is designed in such a way that, although it is cohesive in its own right, if it is superimposed on a second picture, a third picture (a face) is formed by the combination. Assuming that the combination picture is unpredictable from either picture alone, the only way the eidetic child could know what the combination is would be if he could superimpose one picture on the other visually. If he viewed the pictures separately, this could be accomplished only by maintaining an image of the first picture long enough to superimpose it on the second one.

We have given this test to 20 eidetic children. Only four (who were among the best four in other criteria as well) were able to "see" the combination face picture. The reaction of one child was quite impressive to us. After developing a good image of the first picture, he superimposed his eidetic image of it on the second and at first persisted in reporting the various separate elements of each picture. Suddenly, with obvious surprise, he reported the composite face and exclaimed that the experimenter was pretty "tricky" to have fooled him that way.

Although a few adults appear able to see the outline of the face in the first picture alone, children do not seem able to. Nevertheless, many more versions of the test need to be tried. It is a stringent test, since not only does it require a fairly complete image of the first picture lasting long enough for it to be superimposed on a second picture but also it assumes that the first image will not be erased and can be lined up with the second picture. The instance mentioned above seems to be one where an initially poor alignment stood in the way of a meaningful result. The child suddenly saw the composite after nearly a minute of viewing, when presumably he achieved a better alignment of image and picture.

This test cannot be faked, nor does it depend on memory or on any distinction between memory and imagery. All the child has to do is describe what he can see when the second picture is presented. The test could in fact be used with very young and preverbal children (and could be adapted for animals, if anyone thought they might be eidetic).

Much more work needs to be done with eidetic imagery. We know very little about eidetic children as individuals and have only an inkling of what their imagery is like, but the shunning of an interesting psychological phenomenon for 35 years should be ended. Imagery is an important characteristic of many cognitive tasks, and it should be further opened to serious scientific investigation.



RECOGNITION TEST posed the problem of visually superimposing an image of a picture on another picture. The eidetic children first were shown the picture at left; it was then removed and the middle picture was exposed to view. Some children then "saw" a face. At right is the picture formed by combining the other two pictures. None of the children saw a face in the picture at left.

In hope of doing each other some good

Oriented NMR, a game

The following chemicals are offered for sale:

Butyl p-(p-Ethoxyphenyloxycarbonyl)phenyl Carbonate (EASTMAN 10482)
p-(p-Ethoxyphenylazo)phenyl Hexanoate (EASTMAN 10537)
p-(p-Ethoxyphenylazo)phenyl Undecylenate (EASTMAN 10541)
p-[(p-Methoxybenzylidene)amino]phenyl Acetate (EASTMAN 9966)
p-[(p-Methoxybenzylidene)amino]phenyl Benzoate (EASTMAN 10604)

Many thoroughly likeable people educated along paths different from yours distrust and deplore "chemicals."

What is the purpose of these chemicals?

Is it to frustrate the natural order of life on the planet? No.

Is it to clean clothes faster or drive engines faster? No.

Is it to prevent rust, or cure illness, or force more milk from cows? No.

The purpose of these chemicals is to add a dimension to nuclear magnetic resonance.

Nuclear magnetic resonance was once a game which had for its object the confirmation of one's suspicions about the structure of a molecule in solution from the way its protons (or other nuclei of odd atomic number or odd atomic weight) resonate under the combined influence of a strong magnetic field and r.f. irradiation.

Now NMR is taught to smart sophomores. Since ambitious industrial laboratories must do it or be considered backward, they have to be able to prove that NMR is done for more than the pleasure of the practitioner. Chemists unafraid of playing games have lately had to take up a more advanced form of NMR. Here the molecules under study are held in the grip of a special kind of solvent which orients them to the magnetic field. This vastly complicates the resonance spectrum. Protons formerly indistinguishable because their differences in position are blurred by random motion no longer appear identical when the randomness diminishes. Now angles and relative distances within the molecule can be calculated. With one of the intramolecular distances independently measured by some other technique, such as electron diffraction, the complete molecular construction is bared—provided there are no more than about eight protons in the molecule. If there are many more, it gets a little tough in the present state of the game to adjust the player's preconception of the configuration to the observed spectrum. X-ray diffraction data must have looked just as formidable to the brave workers who first hacked at organic architecture in the solid state.

This game, too, will quit being a game when the present players will have robbed it of intrigue and moved on to something more challenging. Meanwhile a "Bibliography on Liquid Crystals in NMR" is available from Eastman Kodak Company, Eastman Organic Chemicals, Rochester, N.Y. 14650. The orienting nematic liquid-crystal compounds named at left form eutectic mixtures with desirably low ("semi-") melting points in the thirties instead of the seventies as for the individual compounds (Angew. Chem., Intern. Ed., 6:*450 (1967)). They can be ordered from the familiar distributors of Eastman laboratory chemicals: B&A, CURTIN, FISHER, HOWE & FRENCH, NORTH-STRONG, SARGENT-WELCH, VAN WATERS & ROGERS, or WILL.*

Outpost on the Front Range

70% of the American people are jammed onto 1% of the land. If inhabitants of the other 99% like it that way, it's easy to see why. Nevertheless, we are finding a welcome around Windsor, Colorado to match the beauty of the Front Range of the Rockies. We are putting up a plant there, our first U.S. photographic manufacturing plant away from Rochester, N.Y., which is now just on the edge of Megalopolis.

Several dozen supervisory people are coming out from Rochester to get the new factory going. "Doer" types—they and their families. Conditioned to ask how they can lend a hand to whatever needs doing locally. By and by, about 900 of the thousand or so people working there will have been hired locally. Whether they will have come in from half a mile away or from 2,000 miles away is up to them. Whatever their origin or ancestry, they ought to be doer types themselves who insist on living and working in a place no less pleasant than the Front Range was before we arrived. More prosperous but no less pleasant.

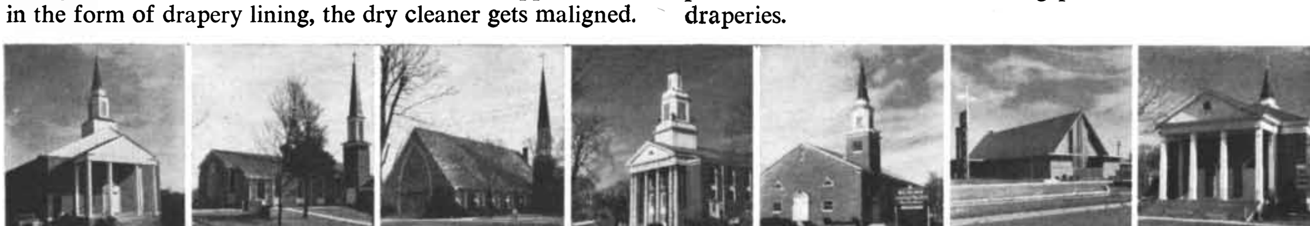
We can no more allow the neighbors in Colorado to regret their cordiality than we can slough off our responsibilities in Megalopolis. There is now more to business than good products, smart R & D, and a silky public relations department.

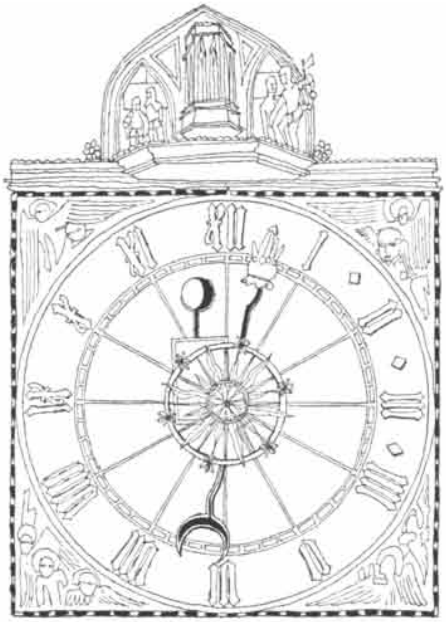
Sunlight-resistant draperies

It was in Kingsport, Tenn. nearly 50 years ago that we first tried manufacturing in thinly populated country. That operation, undertaken to supply raw materials for photographic film, by and by became one of the four U.S. sources of acetate fiber. Mankind had covered its nakedness with cellulose long before learning how to acetylate but appreciated the psychic lift from the look and the feel that textile designers achieved with cellulose acetate. As acetate became basic to civilization, prosperity brightened the East Tennessee hills.

Both shiny and dull types of acetate were demanded. Dullness was attained with titanium dioxide, a compound which under certain sunny conditions catalyzes oxidation by the air of H_2O to H_2O_2. The peroxide in turn attacks the ether linkages in cellulose acetate. If the dull acetate happens to be in the form of drapery lining, the dry cleaner gets maligned.

Lately some of the scientific talent now peopling the hills has disclosed through U.S. Patent No. 3,274,014 that by including in the yarn-spinning solution a compound like zinc ethyl phosphate, it is possible to have very cheerful draperies that are as good as plain cotton sateen at resisting sunlight deterioration and much better at standing up to heat degradation from ducts and radiators. You might save a few dollars in the long run by dropping a postcard to Eastman Chemical Products, Inc., Home Furnishings Merchandising, 260 Madison Avenue, New York City 10016, asking what brands of draperies use ESTRON SLR® Acetate. To provide trustworthy, practical, statistically sound evidence on how much longer to expect them to last by virtue of the invention, we have been permitted to embellish seven Kingsport churches with such draperies.





SCIENCE AND

Russian Science Policy

The U.S.S.R. employs at least as many professionally trained workers in research and development as the U.S. does, according to a study of Russian science policy soon to be published by the Organization for Economic Cooperation and Development. Indeed, one authority quoted in the OECD report estimates that the U.S.S.R. employs more engineers in R. and D. (close to 600,000) than the U.S. employs scientists and engineers combined (500,000). Between 1955 and 1965 both the U.S. and the U.S.S.R. doubled the proportion of their gross national product invested in R. and D. from 1.5 percent to about 3 percent. The OECD report concludes, however, that Russian scientific productivity per man still lags behind that in the U.S.

The U.S.S.R. is only now beginning to create institutions comparable to the industrial research laboratories that perform such a large fraction (some 70 percent) of all R. and D. in the U.S. In the U.S.S.R. responsibility for conducting research is divided between the Academy of Sciences (together with academies in the various republics) and government ministries. In 1965 the "academy system" controlled 958 scientific establishments employing 74,000 scientists. The "ministerial system" controlled almost exactly four times as many establishments and scientific workers. In addition, 221,800 scientists and engineers were employed as teachers in 754 institutions of higher education.

Research is coordinated by three bodies: the State Committee for Science and Technology, the State Planning Committee (Gosplan) and the Academy of Sciences. It appears that the influence of the State Committee and the Academy has been declining and the influence of the Gosplan has been increasing. Last year the first deputy chairman of the State Committee argued forcefully for a crash program to raise the annual investment in R. and D. from 10 to 15 percent per year to 20 to 25 percent in the five-year period 1971–1975. He presented data showing that the return on science expenditure was 1.49 rubles per year per ruble invested, whereas in the economy at large the return was only .39 ruble per ruble. Gosplan officials countered with figures showing that the return on major R. and D. projects was only .74 ruble per year and that the results often fell short of expectations.

According to Russian sources, the U.S.S.R. devotes 10 to 12 percent of its total R. and D. budget to fundamental research, or about the same percentage as in the U.S. In the U.S.S.R. development absorbs about 50 percent, compared with 66 percent in the U.S. The remainder of both budgets is devoted to applied research, a category falling between research on one hand and development on the other. The U.S.S.R. has recently allowed large industrial combines to establish their own research laboratories, on the American model, and is encouraging industry to work more closely with the universities and with combines that do engineering research on a project basis. The goal is to make research in the U.S.S.R. more innovative.

The Service Economy

Since World War II the U.S. has become a "service economy," in which for the first time in history more people are engaged in providing services for other people than are engaged in growing or making things. It was in 1957 that more than half of the American working population came to be employed by organizations that provide services rather than in agriculture or by organizations that produce tangible goods. In a new book, *The Service Economy,* Victor R. Fuchs of the National Bureau of Economic Research examines the implications of this watershed in the human condition.

Fuchs points out that since 1947 nearly all the net increase in U.S. employment has occurred in service institutions such as schools, banks, hospitals, retail stores, research institutions, government agencies and the like. As a matter of fact, the increase in employment in education between 1950 and 1960 was greater than the total employment in the steel, copper and aluminum industries in either year. This growth is laid largely to a slower increase in productivity in services than there was in production. Mechanization and other improvements in producing industries have allowed manpower to be diverted to the service sector just as increasing affluence has created more demand for services.

Comparing the service sector with industry, Fuchs points out that the service sector tends to provide opportunities for small firms and nonprofit organizations, countering industry's trend to giant corporations. Since less physical labor is involved, women and older workers can compete more readily for service jobs. The advent of a service economy also reverses the trend toward depersonalization that came with mass production, since service workers are often closely related to their work and have opportunities to exercise personal skill. Gross national product, the traditional tool with which to study productivity and economic growth, may be less effective in a service-dominated economy, Fuchs thinks. Output is difficult to measure in services (and is not measured at all in do-it-yourself activities), and so new measures of economic welfare may be required to supplement the G.N.P.

Gut Learning

Animals can learn to control voluntarily such supposedly involuntary visceral responses as heart rate, blood pressure, stomach activity and kidney function. This finding, the result of a series of experiments conducted by Neal E. Miller and his colleagues at Rockefeller University, has profound implications for theories of learning and psychosomatic medicine and could lead to methods for treating human psychophysiological disorders.

It has long been assumed that reason and the voluntary responses of skeletal muscles are superior functions and that emotion and the glandular and visceral functions are involuntary and inferior. Similarly, learning theorists have distinguished between classical conditioning (for autonomic responses) and what is variously called instrumental learning or operant conditioning (for voluntary behavior). In classical conditioning one "reinforces" a response (such as salivation) with a stimulus (such as food) that already elicits the desired response. In instrumental learning any reward can reinforce any immediately preceding response. Instrumental learning is therefore far more generally applicable and can be used to promote a wide range of behavior. Miller suspected that there is in fact only one kind of learning and set out to show that visceral responses could be learned through instrumental training. His results are reported in *Science*.

With Alfredo Carmona, Miller induced salivation in thirsty dogs by rewarding increased salivation with water. (The water had previously been shown to have no appreciable effect on spontaneous salivation.) In order to show that this was not a result of classical conditioning, they reversed the experiment and trained dogs to salivate less frequently. In order to rule out any voluntary, skeletal-muscle effect, Miller and Jay Trowill learned to block an animal's motor-nerve endings with the drug curare. Using as a reward first the direct electrical stimulation of "pleasure" areas of the brain and then the absence of a mild electric shock, Miller and Leo V. DiCara were able to train curare-paralyzed animals both to speed up and to slow down their heart rate, to relax and contract the intestinal muscles, to constrict blood vessels in one ear while dilating vessels in the other ear and similarly to control stomach contractions, urine formation, blood pressure and other responses.

Experimental difficulties make it harder to demonstrate the learning of visceral responses in humans than in animals, but Miller believes "in this respect [humans] are as smart as rats." Several investigators have provided evidence that they are indeed. Most recently a Harvard Medical School group has reported in *Science* that volunteers can be led to modify their blood pressure through feedback and reinforcement. Each "success" (a rise in pressure for some, a decrease for others) was signaled by a flashing light; the reward, after 20 flashes, was a glimpse of a nude pinup picture. Most of the volunteers later indicated that they had had no control over the flashing light and did not in fact know what physiological function was being measured, and so they presumably were not exerting skeletal-muscle control. The investigators, David Shapiro, Bernard Tursky, Elliot Gershon and Melvin Stern, suggest that their technique may be of value in treating hypertension.

The Rain in Space

The same group of investigators that recently detected microwave radiation from ammonia molecules in the direction of the galactic center ("Science and the Citizen," February) has now found similar evidence for the presence of water in three regions of interstellar space. The group (which consists of Albert C. Cheung, David M. Rank, Charles H. Townes, Douglas D. Thornton and William J. Welch, all of the University of California at Berkeley) reports its latest findings in *Nature*.

The search for microwave radio signals characteristic of emission from water molecules was carried out with the 20-foot radio telescope at the university's Radio Astronomy Observatory near Hat Creek. The telltale radiation, at a wavelength of 1.35 centimeters, was recorded from three different directions. One source, in the constellation of Sagittarius near the direction of the galactic center, appears to coincide with a source of strong radiation from ammonia molecules, although, the investigators point out, "there is reason to believe the two molecular species may not be closely associated." Emission from water molecules was also picked up from the direction of the Orion nebula and from the direction of a radio-emitting hydrogen region designated W49. No ammonia emission was detected from either of these two regions.

The Berkeley group attributes the observed radiation to water molecules "because its frequency coincides very closely to that found for H_2O in the laboratory, and no other known atomic or molecular species can explain the observations." The possibility that water in the earth's atmosphere could produce the observed radiation was eliminated as a possible source for several reasons.

The observed radiation is surprisingly strong, which suggests that the water is present in "rather special regions of higher than normal excitation." The investigators estimate that in the case of the radiation from the Orion nebula "the actual microwave brightness temperature of the source would have to be at least as high as a few hundred degrees, and in W49 at least as great as 1,000 degrees." They add that the actual temperatures may be much higher if these sources are smaller than their estimated angular size or if they are "optically thin." The high intensity and the narrowness of the spectral lines observed suggest that inside the sources "thermal equilibrium does not occur and that there may even be maser action."

Tough Concrete

Treatment of concrete with a liquid monomer that is then polymerized and hardened by ionizing radiation produces a material that is far stronger and more durable than untreated concrete, according to a report by the U.S. Atomic Energy Commission and the Bureau of Reclamation of the U.S. Department of the Interior. The favored technique has been to soak ordinary hardened concrete in the monomer and then to expose the concrete for several hours to radiation consisting of gamma rays from cobalt 60. The most satisfactory monomer yet found is methyl methacrylate. The experimenters have also worked with other monomers, have achieved polymerization by a thermal-catalytic process rather than by radiation and are investigating the possibility of including the monomer in the original mix.

Comparing the concrete-polymer with untreated concrete in a number of tests, the experimenters found increases of 285 percent in compressive strength, 292 percent in tensile strength, a decrease to negligible amounts in the permeability of the material to water (with a consequent gain of more than 300 percent in resistance to damage from freezing and thawing) and reduction of corrosion by brines and distilled water to negligible amounts. A cost comparison, using as an index the ratio of the finished-unit cost of a material to its strength, showed that concrete-polymer is superior to steel, aluminum, concrete alone and plastic alone in compression, better than concrete alone or plastic alone but second to steel and aluminum in tension and much better than concrete alone in durability.

Dead Galaxies

A crucial observational value in deciding among different cosmological models of the universe is the mean density of matter. The amount of mass distributed throughout space in ordinary galaxies is inadequate by a factor of about 40 to produce a finite universe; if there is no matter except for what is observable, the universe must be infinite. This has led P. J. E. Peebles and R. B. Partridge of Princeton University to propose that the universe may contain many "dead galaxies"—galaxies become so dim that only the nearest would be visible.

Peebles suggests that such galaxies, uniformly distributed in space, could account for puzzling absorption lines found in the spectra of many of the most remote quasi-stellar objects. One such object is PKS 0237–23. The light emitted by PKS 0237–23 shows a red shift indicating that the object is receding at more than 80 percent of the velocity of light. Thus the Lyman-alpha line of hydrogen, which originates in the far ultraviolet at a wavelength of 1,216 angstroms, is observed at a wavelength of 3,928 angstroms, at the edge of the visible spectrum. The value of the red shift is defined as the line displacement divided by the undisplaced wavelength (2,712 ÷ 1,216), or 2.22. An analysis of more than 40 absorption lines in the spectrum of PKS 0237–23 was recently made by John N. Bahcall, Jesse L. Greenstein and Wallace L. W. Sargent of the California Institute of Technology, who found that 28 of the lines exhibit five distinctive red shifts: 2.20, 1.67, 1.66, 1.51 and 1.36. They proposed that the absorbing material could be either in clouds surrounding the quasi-stellar object or in interstellar gas contained within galaxies in the line of sight between the quasi-stellar object and the solar system. On the basis of counts of ordinary galaxies it seems unlikely that there are enough in the line of sight, and also below the threshold of visibility, to produce the absorption lines. This might seem to leave clouds near the object as the only explanation. Peebles proposes, however, that if one introduces the hypothesis that the universe contains many randomly distributed dead galaxies, it is quite likely that several will lie in the line of sight to distant quasi-stellar objects.

The Knappers of Çakmak

The only living men who make tools by flaking flint are usually believed to be a few primitive tribesmen who still follow the customs of their forebears and a handful of specialized craftsmen who fashion the flints needed for surviving flintlock firearms. During recent archaeological work in Turkey, Jacques Bordaz of the University of Montreal found this belief to be in error: flintknappers in the Turkish village of Çakmak produce 500 tons of flint blades every year, enough to provide fresh cutting edges for all the threshing sledges in rural Turkey.

Writing in *Natural History*, Bordaz

relates that Turkish wheat-growers like to separate the grain from the stalk, as other Middle Eastern farmers have done for thousands of years, not by flailing or trampling but by dragging a sledge over sheaves spread on a threshing floor. Made out of a pair of joined planks, each sledge has 600 to 800 slots chiseled into its bottom face and a blade of flint a little less than two inches long is set on edge in each slot. The thresher stands on the sledge, guiding the horse or yoke of oxen that drags the sledge around the threshing floor so that the flints chop up the straw and free the grains from the chaff.

The knappers of Çakmak, each of whom can turn out 500 pounds of blades a day from locally quarried nodules of flint, may have helped Bordaz to find the answer to a question that has long puzzled students of Paleolithic tools. How were the long, delicate parallel-edged flakes that are characteristic of Upper Paleolithic blade industries detached from the "core" piece? One way would be direct percussion: striking the core with a hammerstone. Many scholars believe, however, that direct percussion is too crude a technique and visualize the use of a punch made of antler, bone or wood. With a punch the knapper either could have pushed sharply against the core (a process called pressure-flaking) or could have tapped the punch with his hammerstone (a process called indirect percussion). Thousands of flakes, cores and hammerstones have been found at Upper Paleolithic sites but no punches. There is good reason for their absence if Paleolithic knappers used the Çakmak technique. Letting the hammer fall directly on the flint core, the Turks detach a perfect blade three to five inches long with almost every stroke.

Good Grief

Grief, the intensely painful response to the severance of a close personal relationship, may have originated with evolutionary pressures imposed on the individual by the exigencies of group survival. James R. Averill of the University of California at Berkeley, who advances this hypothesis in *Psychological Bulletin,* notes that the behavior associated with normal grief seldom varies. He delineates three stages of grief. There is first a period of shock or disbelief when the bereaved person tends to deny the reality of his loss and continues to behave much as before. This stage is followed by one of despondency. It is marked by mental anguish, withdrawal from others, an inability to concentrate on work or to start new activities and also by somatic complaints, including wakefulness and loss of appetite. Finally, there is a period of recovery when the individual accommodates to his loss.

Averill points out that grieflike reactions have often been observed in apes and monkeys. An example he cites is that following the death of her infant a female gorilla or rhesus monkey may continue to carry the body for days, as if denying the reality of the infant's death.

The behavior associated with grief is in some respects paradoxical, Averill says. The inability to initiate new actions hinders a break with the past; withdrawal prevents the establishment of a new relationship. Since this behavior seems calculated to prolong rather than to alleviate suffering (and also to impede the reproduction of the species), it is hard to see what adaptive value it could have. He argues that this difficulty is eliminated if one considers the function grief might serve in the kind of group that higher primates form, namely one held together by attachments between individual members. The maintenance of the interpersonal bonds on which the group critically depends would not necessarily be ensured by incentives such as sexual attraction or pleasure derived from play or mutual grooming. Once such activities had been satiated there would be little reason for an individual to remain with the others. A more effective mechanism for promoting group cohesiveness would be a reaction of extreme psychological and physiological stress felt both by an isolated animal and by individuals in the group responding to its loss. This is the role Averill assigns to grief.

Gnathostomulidology

A phylum is a major unit of biological classification: the phylum Chordata, for example, includes all animals with hollow dorsal nerve cords from the sea squirt to man. One might suppose that among them the animal kingdom's 27 phyla could embrace any new species that might be discovered. Yet a 28th animal phylum has recently been established. Named the phylum Gnathostomulida, it comprises several genera of marine worms whose existence in specialized coastal habitats went virtually unnoticed until the late 1950's.

Although the first gnathostomulid species was observed in the Baltic in 1928, the report was not published until 1956. Thereafter other species were found in the Mediterranean, the Indian Ocean, the North Sea, the White Sea, the Red Sea, the Caribbean and, most recently, in Atlantic coastal waters from Maine to North Carolina. Reporting on these discoveries in *Science,* R. J. Riedl of the University of North Carolina notes that the new phylum now includes 10 genera and 43 species. Riedl expects that other new species will be found in all the silty shallows of the earth.

Pointing out that the last phylum established before the discovery of the gnathostomulids—the phylum Pogonophora—was also required by the discovery of previously unnoticed marine invertebrates, Riedl attributes the new species' long anonymity to three factors. First, they are delicate organisms, are often less than half a millimeter in length and are recognizable only when they are alive. Second, they attach themselves strongly to the silts in which they live and are difficult to extract. Third, they can survive under stagnant conditions that leave their surroundings partially or wholly without oxygen. As a result investigators in the past have either chosen not to collect samples of these odorous and presumably lifeless silts or have discarded them long before conditions were bad enough to make the worms emerge and so reveal themselves.

The Random Lawn Mower

Anyone who has mowed a lawn has probably dreamed that someone would design an automatic mower but then has dismissed the dream on the ground that the geometrical patterns of mowing would call for an impossibly sophisticated guidance system. A firm near Buffalo has solved the problem by designing an automatic lawn mower that cuts in a random pattern. The battery-operated Mowbot, made by Mowbot, Inc., of Tonawanda, N.Y., is deflected from borders and fixed objects by a buried wire that emits a signal that can be detected by the machine's electronic sensors. The sensor that receives the signal turns the mower away from the border at an angle that differs from the angle of approach. If the mower comes in contact with an unwired object, such as a toy or an infant, it turns itself off and must be restarted.

The Mowbot runs for about three hours on a single charge. In that time it can cover about 7,000 square feet of lawn. Although three hours is twice or three times as long as a man would need to cover the same amount of ground, the machine has nothing better to do.

By 1978, cars will be less of a smog

Some people think of the twenties as the golden age of motoring. They have a point.

We drove on wiggly roads instead of turnpikes. Fifty miles an hour was heady stuff. Cars were reasonably reliable but still slightly adventurous. And there weren't many of them. Who cared if they smoked a bit? The blue vapors floated up to the blue sky and disappeared. Or seemed to.

By the fifties, things were different. There were twice as many cars. And a new word had entered our vocabulary. Smog. The car's contribution to this phenomenon had become a problem to be taken very seriously. Rightly so.

By 1978, there will be six times as many cars on American roads as there were in the late twenties. Will the exhaust problem be six times worse? The answer from Jersey's affiliate, Esso Research, is a resounding no. Here are a few incontrovertible facts.

Air pollution from cars has reached its zenith. We have now passed the turning point. Despite the car population explosion, total exhaust emissions will go down this year—further down in 1970—and further and further down in all successive years.

problem than they were in 1928.

By the early eighties, the unburned gasoline exuded by each car will be less than half an ounce a day. Little more than you need to fill a cigarette lighter.

Credit for this encouraging news must go equally to oil industry scientists, automotive engineers and intelligent lawmakers. But Jersey can justly claim a major role.

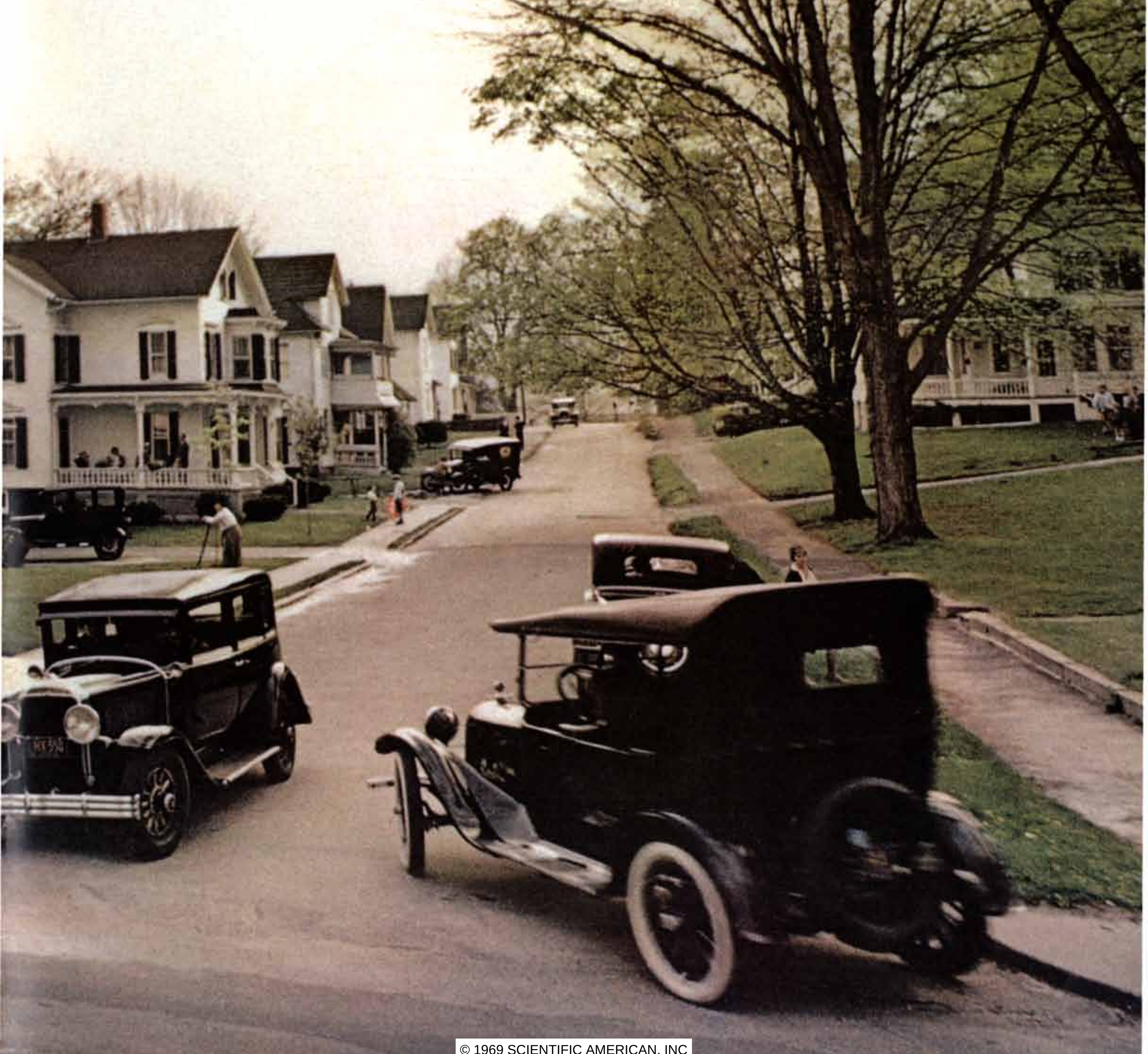
Esso Research scientists have worked with car experts to design fuels and lubricants that help cut unburned gasoline vapors and carbon monoxide to a minimum.

They have built a simple device that can reduce evaporation from your gas tank and carburetor by 95 per cent.

And they are now studying catalysts and other systems that will actually change pollutants into nonpollutants.

Ten years from now, we may well look back on the 1960's as the not-so-golden age of smog.

Standard Oil Company (New Jersey)



FIFTY-TON CARRIER made of steel and concrete is used at the Oak Ridge National Laboratory to transport synthetic elements. In this case californium that has been made in the laboratory's high-flux isotope reactor is being moved from the reactor to the facility where the material is processed for shipment to users. The carrier has a capacity of one gram of californium, which represents large-scale production of this synthetic element. The concrete in the carrier shields against the intense radioactivity of the element.

THE SYNTHETIC ELEMENTS: IV

Three earlier articles in this magazine described the synthesis of elements through element 103. Recent investigations suggest the possibility of extending the list to element 114 and beyond

by Glenn T. Seaborg and Justin L. Bloom

This series of articles, dating from 1950, has recorded the discovery of the synthetic elements, which are made in the laboratory, in nuclear reactors or in nuclear explosions rather than being found in nature. All but four of them are transuranium elements, meaning that they are heavier than uranium, which is the heaviest natural element. By April of 1963, when the third article was published, 11 transuranium elements had been prepared; they extended through element 103, lawrencium. There has been increasingly good evidence for element 104 and inconclusive evidence for element 105 in the past six years. Our primary purpose in this article is to summarize recent work giving rise to the exciting prospect that the list of elements can be extended far beyond what had been thought possible.

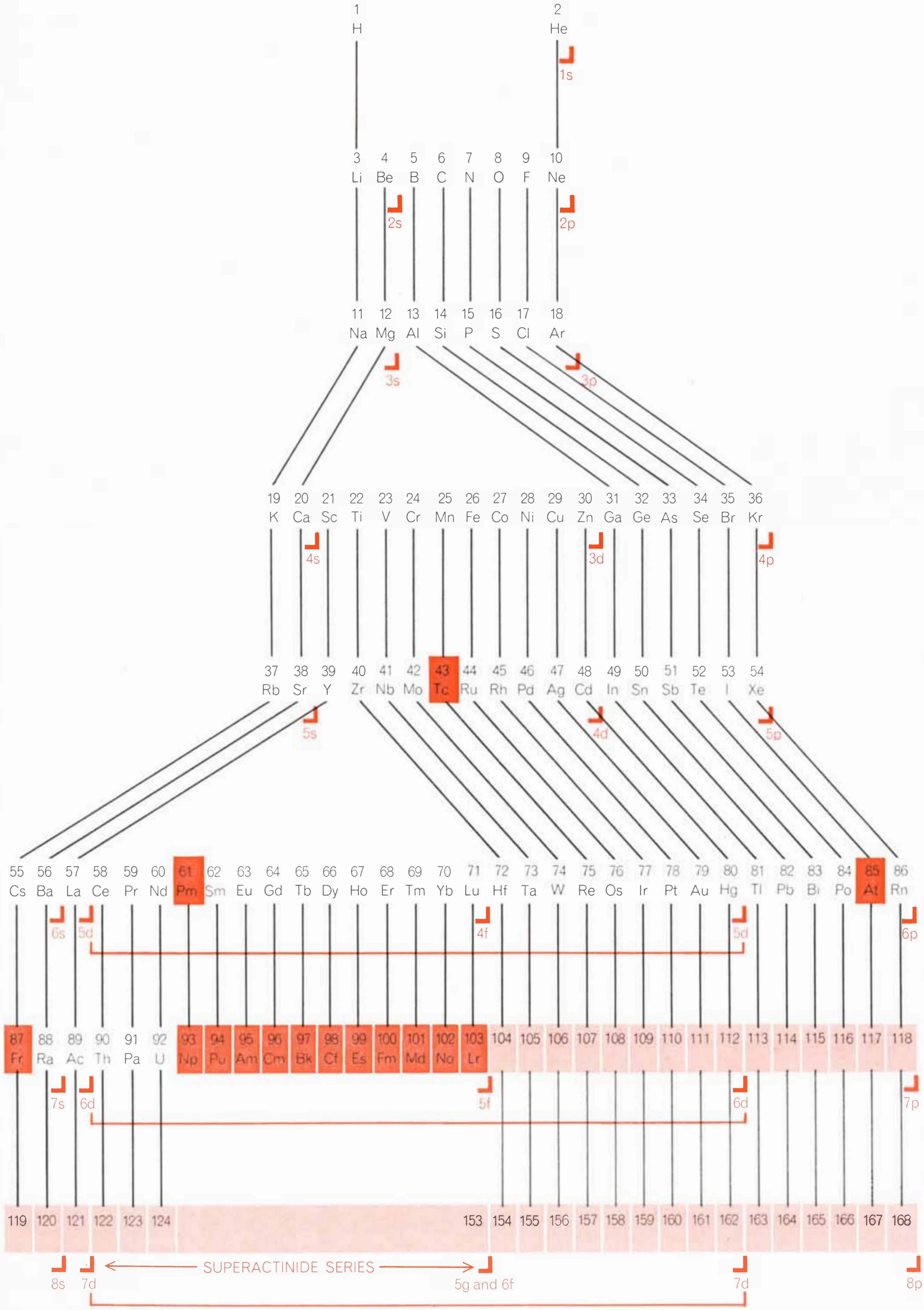
The reader will find it helpful to keep in mind a few fundamental facts. The chemical properties of an element are determined by the number of electrons in the electron cloud surrounding the nucleus of each of its atoms, and this number in turn is determined by the number of positive charges, or protons, in the nucleus. The atomic number of an element is the number of protons: hydrogen has one, helium two, uranium 92 and so on. The elements are traditionally arranged in the periodic table, which shows the similarities in their chemical properties [*see illustration on next page*].

Although an element is characterized by the number of protons in the nucleus, the number of chargeless particles, or neutrons, associated with a given number of protons varies. As a result an element can exist in various species—isotopes—that differ in weight and stability but not significantly in chemical properties. The sum of the protons and neutrons of a nuclear species is the mass number of the species. Uranium 238, for example, has the 92 protons characteristic of the element and 146 neutrons; the isotope can be written ^{238}U or, more formally, $^{238}_{92}U$. Most isotopes are not stable, and as a result they tend to decay into other isotopes or elements by beta radiation (the emission of positive or negative electrons by nuclear particles), alpha radiation (the emission of alpha particles, which consist of two protons and two neutrons) or spontaneous fission. Other types of radioactive decay can also occur. The creation of a new heavy element is essentially the reverse of a decay process: one can, for example, add protons to the nucleus of an existing element, driving them into the nucleus with the help of a particle accelerator such as a cyclotron or a linear accelerator. Another method is to add one or more neutrons to an existing nucleus, raising the mass number by the number of neutrons added. By a radioactive decay process a neutron within the nucleus can then emit an electron, thereby becoming a proton and raising the atomic number by one. The neutrons can be obtained from an accelerator, a nuclear reactor or a nuclear explosion. Since they are chargeless, they enter the positively charged nucleus of the target element easily and do not need to be accelerated to high energy.

A useful concept in foreseeing the nature of the transuranium elements and in recognizing them when they are encountered has been the family-like relation of a number of the elements that was predicted by one of us (Seaborg) in 1944. The relation arises from the disposition of electrons around a nucleus in a series of shells and subshells, which are really a simplified physical representation of quantum-mechanical energy levels [*see illustration on page 59*]. The prediction was that the elements from element 90 through element 103 would behave much like the series of rare-earth elements from 58 through 71, which had been named the lanthanide series because they have chemical properties similar to those of the immediately preceding element, lanthanum (element 57). By analogy the series through element 103, including the transuranium elements, was called the actinide series after actinium (element 89), which immediately precedes the first element in this series (thorium).

The Transuranium Elements

Up to the time of the third article in this series the rate of discovery of transuranium elements had been high, roughly one new element every two years. It is not surprising that such a rate could not be maintained, since each step forward has required more and more complex apparatus and methods to increase the number of protons in the nucleus, while at the same time the stability of the nuclei produced has decreased, making them difficult to observe and identify. Nonetheless, heavy synthetic elements are a subject of livelier interest than ever because of advances in the theory of nuclear stability, which have given rise to the possibility of synthetic elements beyond the dreams of early workers in the field. Concurrently great progress has been made in manufacturing in quantity the unstable elements through element 98, in enlarging knowledge of their properties and in finding worthwhile applications for them. The heightened interest in work on the heavier synthetic elements is indicated by the fact that this field is no longer virtually the exclusive province of investigators in the U.S. The U.S.S.R. has a cyclotron laboratory at Dubna, under

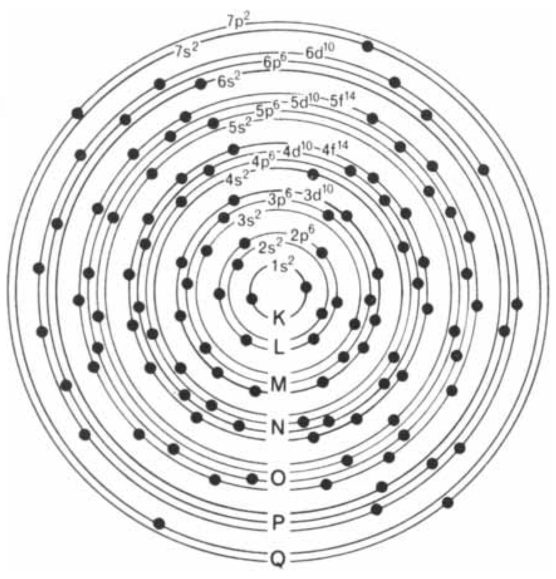


1 H
2 He
1s
3 Li 4 Be 5 B 6 C 7 N 8 O 9 F 10 Ne
2s
2p
11 Na 12 Mg 13 Al 14 Si 15 P 16 S 17 Cl 18 Ar
3s
3p
19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr 25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn 31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr
4s
3d
4p
37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo 43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd 49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe
5s
4d
5p
55 Cs 56 Ba 57 La 58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu 72 Hf 73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt 79 Au 80 Hg 81 Tl 82 Pb 83 Bi 84 Po 85 At 86 Rn
6s
5d
4f
5d
6p
87 Fr 88 Ra 89 Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No 103 Lr 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118
7s
6d
5f
6d
7p
119 120 121 122 123 124 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168
8s
7d
SUPERACTINIDE SERIES
5g and 6f
7d
8p

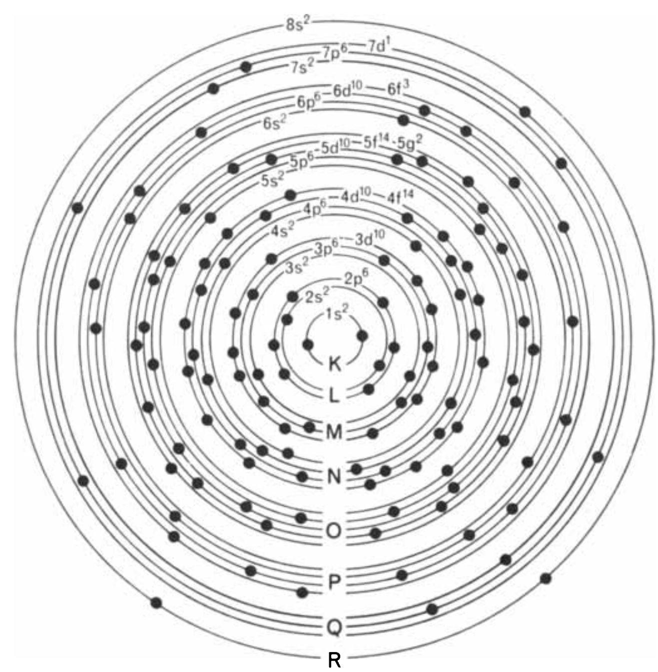
the direction of Georgii N. Flerov, that is even larger than the facilities devoted to the synthesis of heavy elements at the Lawrence Radiation Laboratory of the University of California at Berkeley. (The Berkeley laboratory has been the site of the discovery of nine of the 11 commonly recognized transuranium elements and continues to be the leading American laboratory engaged in the pursuit of new elements.) Workers in other countries are also making significant contributions, particularly to the theoretical aspects of the subject.

In 1950 the first article in this series reported that the elements through atomic number 97, berkelium, were known, and a periodic table accompanying the article gave implied positions for additional elements up to atomic number 118, which was predicted to be a noble gas homologous with radon. The precise positions the undiscovered elements would occupy in the periodic table were not given, although the table did show the potential existence of electron subshells through element 118. The second article, in 1956, noted that elements through 101, mendelevium, had been discovered, and the accompanying periodic table showed positions for elements through 106, as well as electron subshells through element 118. The 1963 article reported the addition of elements 102 and 103 to the known elements, and the periodic table showed specific locations for the elements through 118.

Now, with increased courage based on new information, we present an expanded periodic table of what may be surprising dimensions. The table [*opposite page*] extends the periodic arrangement of the elements beyond the actinide series (elements 90 through 103) far into what we designate the transactinide region: the elements following 103. The most striking feature of this arrangement is the addition of another family-like inner transition series starting at about atomic number 122 and extending through atomic number 153. We call this grouping the superactinide series, because of its rough analogy to the lanthanide and actinide series, but we hasten to point out that each element of this series does not correspond to an actinide (or a lanthanide) element on a one-to-one basis. This could hardly be the case, because the superactinide series is postulated to contain 32 elements, whereas the lanthanide and actinide series each contain 14 elements. Following the superactinide series, elements 154 through 168 are shown as being homologous with elements 104 through



ELEMENT 114



ELEMENT 126

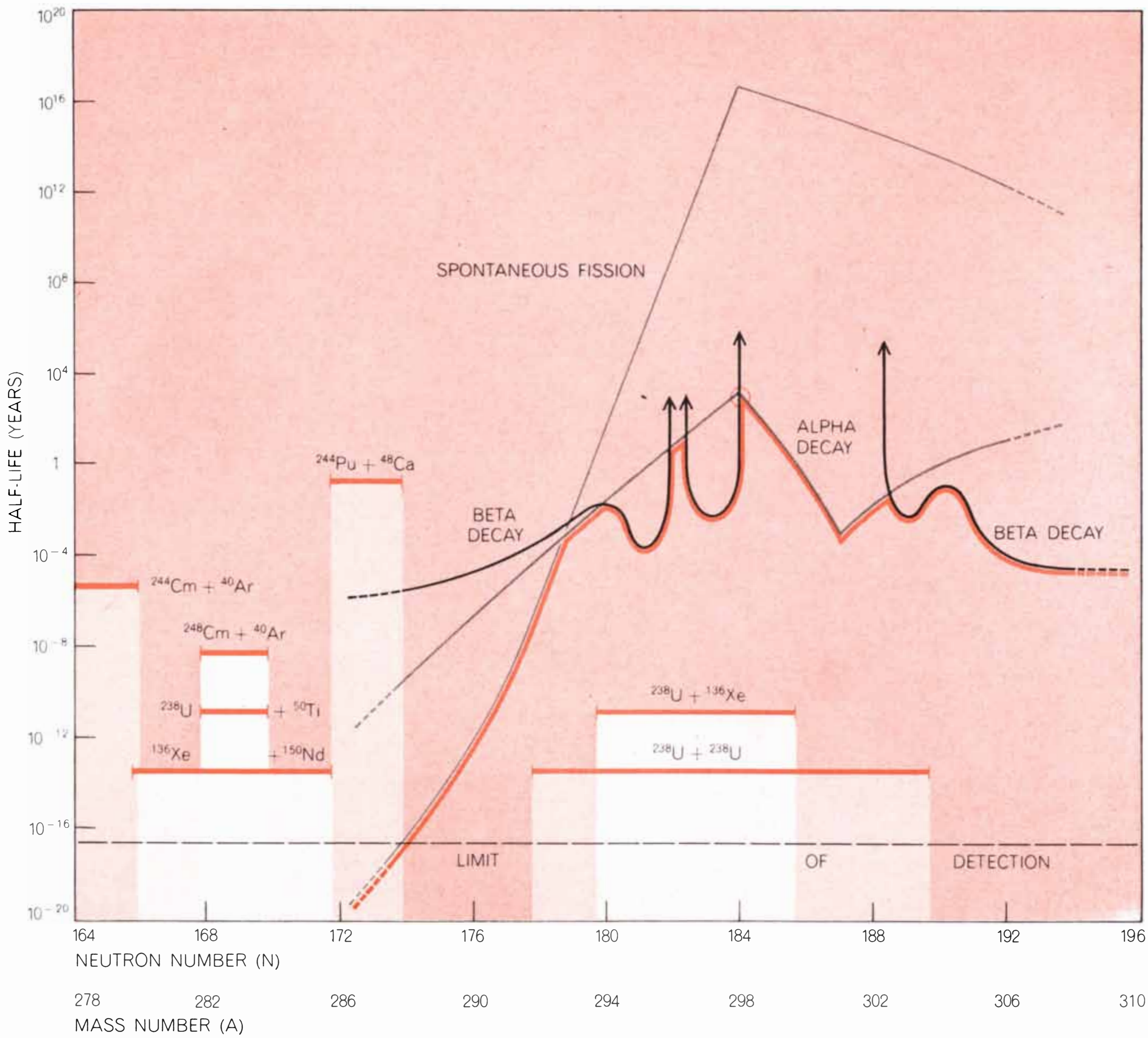
THE PERIODIC TABLE on the opposite page presents the 103 commonly recognized natural and synthetic elements together with hypothetical positions for additional elements through element 168. The 15 definitely known synthetic elements are indicated by solidly colored rectangles. Lightly colored rectangles indicate in general the synthetic elements not yet discovered, although elements 104 and 105 have been reported. Most elements in each horizontal row differ from one another in chemical properties. The lines running from top to bottom connect elements of similar chemical properties. Above the symbol for each element is its atomic number: the number of positive charges in its nucleus or the number of electrons bound by them. In each horizontal row the colored brackets designated *1s, 2s, 2p* and so on denote the filling of subshells of electrons, and it is largely the number of electrons in the outer shell that determines the chemical properties. The electron-shell structures predicted for the undiscovered superheavy elements 114 and 126 are given in the schematic drawings on this page. In X-ray terminology the shells are designated *K* through *R*; in spectrographic terminology they are *1* through *8*. The spectrographic subshells are *s, p, d, f* and, in the case of element 126, also *g*. The maximum number of electrons (*dots*) in any *s* subshell is two, in any *p* subshell six, in any *d* subshell 10, in any *f* subshell 14 and in any *g* subshell 18. For each subshell the number of electrons is indicated by a superscript figure. In most elements all the inner subshells are filled, and electrons add to the outer shell with increasing atomic number. In the "lanthanide" rare-earth elements (numbers 58 through 71) the number of *5d* and *6s* electrons remains approximately the same and electrons in successive elements are added to the inner *4f* subshell. The transuranium elements through lawrencium, element 103, are part of another group of rare earths, the "actinides," in which the inner *5f* subshell fills up. This table presents for the first time a similar "superactinide" series, predicted to run from about element 122 through element 153, and formed by the filling of new *5g* and *6f* inner subshells. Electron shell *8* is also new.

118, with element 168 occupying the position of a noble gas, although since it would be too heavy to be a gas it might better be termed a noble liquid.

If this hypothetical extension of the periodic table seems brash, consider that serious experimental efforts are being made to produce element 114 and its neighbors and that a search for element 110 in nature has been under way for almost a year. We shall discuss these intriguing matters in more detail farther along in this article. For the moment we ask the reader to accept the proposition that the thought being given to what the periodic table might look like, in regions heretofore considered beyond experimental verification, is much more than idle speculation.

Elements 101 to 105

We should first like to bring the reader up to date on the experimental results concerning those scarce elements with atomic numbers immediately beyond 100, elements whose quantities, incredible though it may seem, are measured in terms of the individual atoms produced. Element 101, mendelevium, in the form of the isotope ^{256}Md, was first synthesized at Berkeley in 1955 on a one-atom-at-a-time basis. In recent years several additional isotopes of mendelevium have been prepared, the most important one being ^{258}Md, which has the surprisingly long half-life of two months. It has been produced in what must be considered a large quantity—10,000 atoms—by the bombardment of an isotope of einsteinium with ions of helium. It is therefore quite likely that eventually enough mendelevium can be made so that some of its bulk properties can be measured. The isotope ^{256}Md,

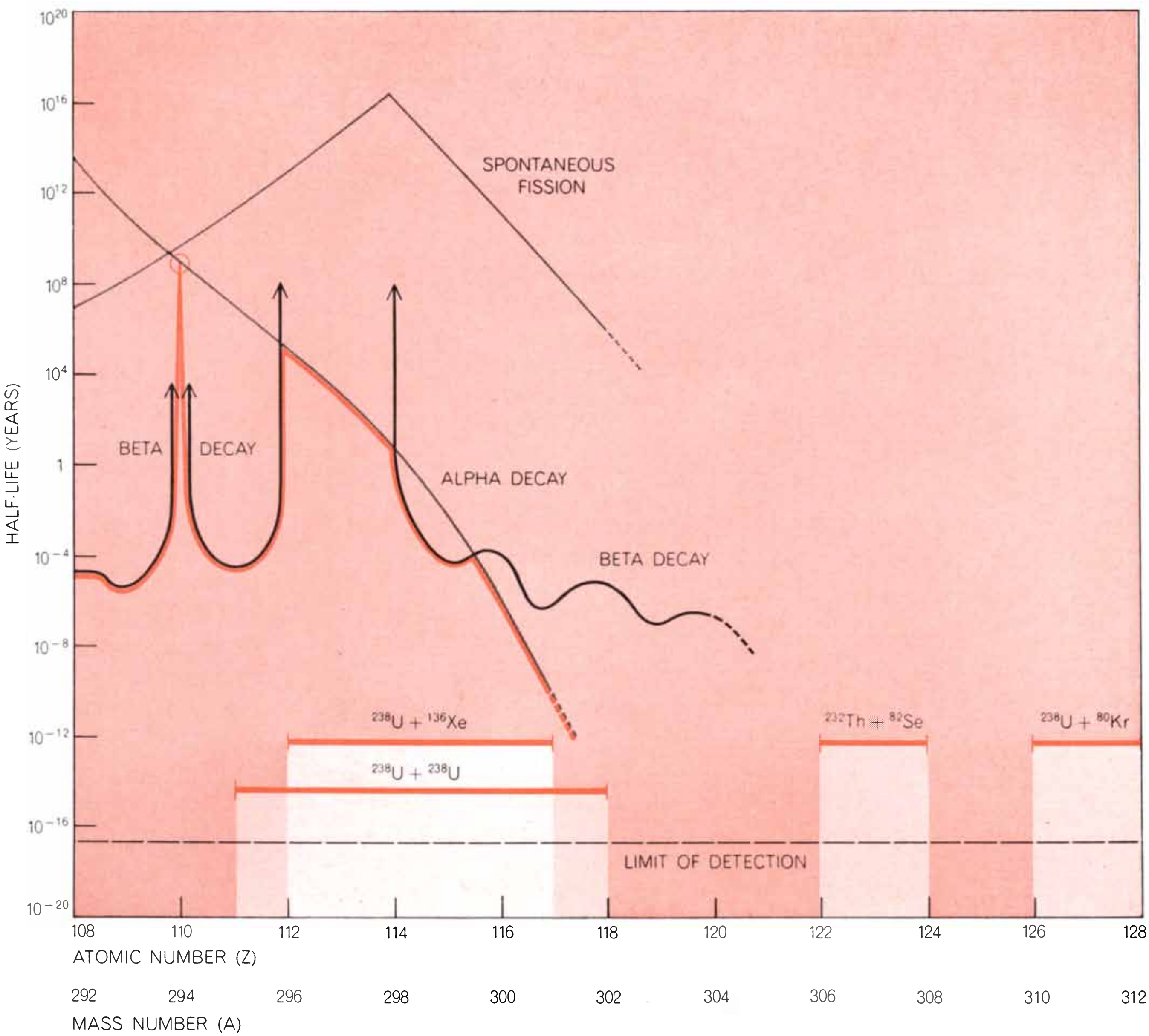


HYPOTHETICAL ELEMENT 114, predicted to have exceptional stability, is represented in terms of the half-lives predicted for three types of decay. Atomic number is constant at 114; different isotopes are indicated by the different neutron numbers. The controlling method of decay changes as shown by the colored curve, with the most stable isotope, ^{298}114, indicated by a circle. The horizontal bars, which are related only to the horizontal scales, show the range of mass numbers that could be created by various nuclear reactions, such as the bombardment of curium 244 with argon ions. The uranium-uranium reaction appears to offer the best possibility for reaching the predicted region of exceptional stability centered around mass number 298 and neutron number 184.

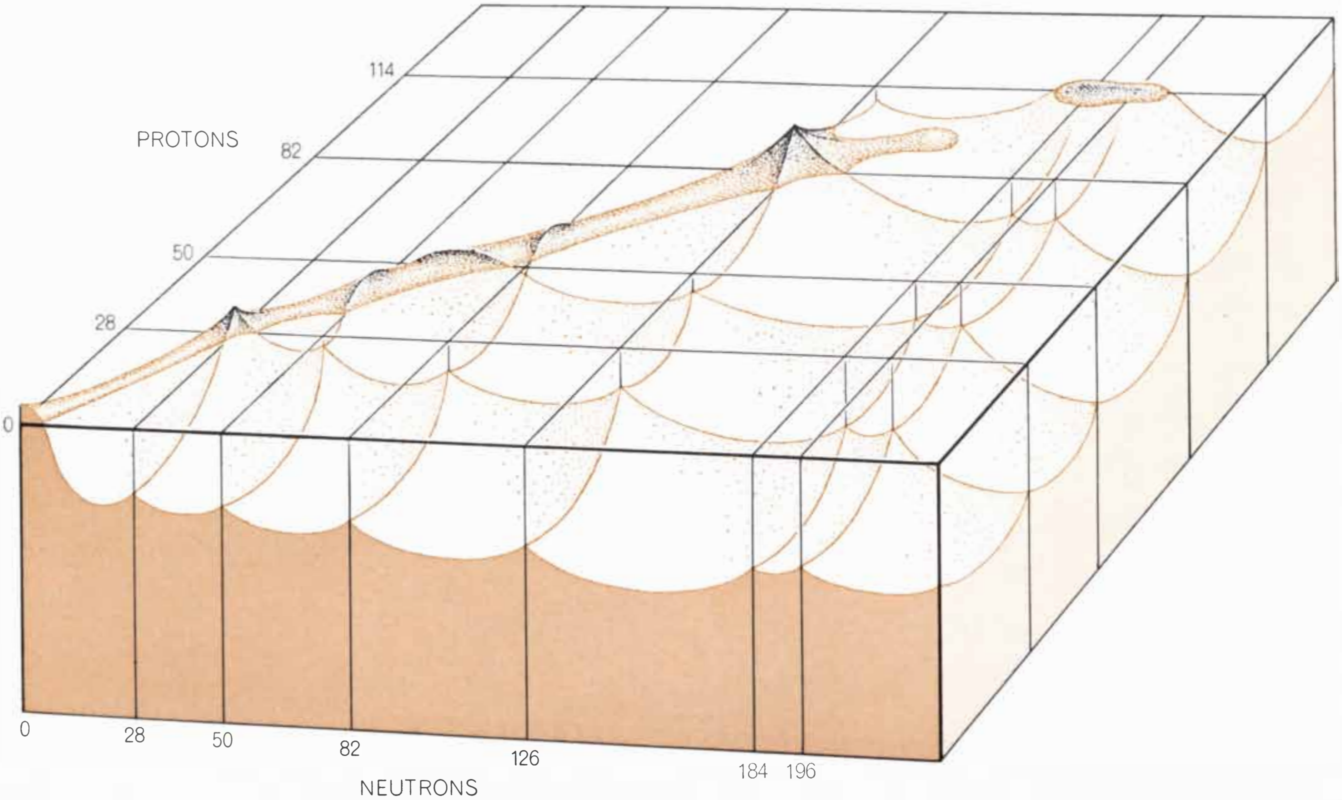
which has a half-life of 77 minutes, has been used by chemists at the Lawrence Radiation Laboratory to elucidate some of the chemical properties of the element in aqueous solution. The findings concern the oxidation state of the element. (Most chemists now use the term "oxidation" to signify the removal or neutralization of an element's electrons; "oxidation state" is a somewhat more rigorous term for what is also called the valence of an element.) It turns out that mendelevium possesses, in addition to the tripositive (III) oxidation state characteristic of the actinide series of elements, a moderately stable dipositive (II) oxidation state.

The 1963 article of this series presented details of the method employed at Berkeley in 1958 by Albert Ghiorso and his colleagues to synthesize element 102. The isotope $^{254}102$ was identified through the fact that its daughter, an isotope of fermium, ^{250}Fm, formed by alpha-particle decay, was observed and chemically identified. The half-life of $^{254}102$ was reported on the basis of another set of experiments to be about three seconds, but later work at both Dubna and Berkeley has demonstrated that this short-lived activity was due to another isotope, $^{252}102$, also produced in the 1958 experiments. The actual half-life of $^{254}102$ is now known to be about a minute.

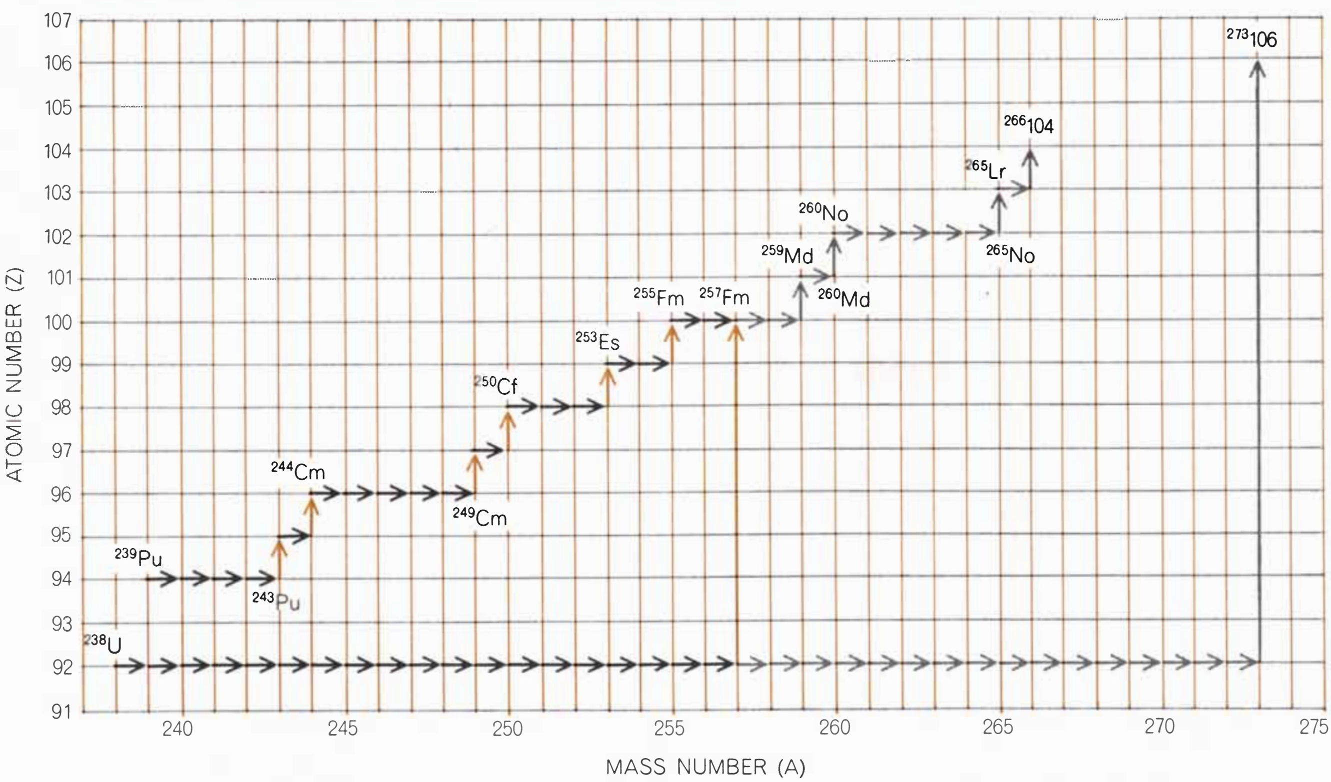
More important than the resolution of this complexity has been the discovery at Dubna and Berkeley of several other isotopes of element 102. Most of them have half-lives of more than three seconds, enabling radiochemists to delineate the chemistry of this exotic element by means of some remarkable experiments. For example, using the three-minute $^{255}102$ isotope Jaromir Maly,



HALF-LIFE PREDICTIONS are shown for various superheavy elements, represented by the atomic numbers at bottom, with the number of neutrons held constant at 184, as indicated by the difference between the atomic number and the mass number in each case. The lowest curve at any given mass number or atomic number depicts the controlling method of decay, which is the shortest half-life. The controlling mode of decay changes in the manner shown by the colored curve, with the most stable isotope, $^{294}110$, indicated by a circle. The horizontal bars, which again relate only to the horizontal scales, indicate typical nuclear reactions that might be employed to produce nuclei with 184 neutrons. Only the uranium-uranium reaction appears to approach the area of highest stability.



NUCLEAR STABILITY is depicted in a scheme that shows regions of known or predicted stability as land masses in a sea of instability representing forms of decay. Grid lines show "magic" numbers of protons or neutrons giving rise to exceptional stability. Doubly magic region at 82 protons and 126 neutrons is shown by a mountain; a predicted doubly magic but less stable region at 114 protons and 184 neutrons, by a hill. Ridges depict areas of enhanced stability due to a single magic number. Submerged ridges show isotopes that are unstable but more stable than nearby ones because of increased stability afforded by closed shells of nucleons in nucleus.



NEUTRON-CAPTURE PROCESSES resulting in the formation of heavy elements are indicated. Chain from plutonium 239 to fermium 257 has been achieved in high-flux reactors; predicted path beyond ^{257}Fm is shown in gray. Vertical segments of line represent beta decay, which can occur at several points because the target element must be irradiated for a long time. Chain from uranium 238 represents neutron captures in uranium exposed to neutrons from underground nuclear explosions. No time for beta decay is available during irradiation. After the explosion beta decay can occur at any mass number of uranium that has been produced, as shown at ^{257}U. Predicted path beyond ^{257}U is gray; undiscovered isotope ^{273}106 as an end product indicates the large number of possibilities.

Torbjorn Sikkeland, Robert J. Silva and Ghiorso demonstrated at Berkeley in 1967 that the (II) oxidation state of element 102 is very stable in aqueous solution. This behavior indicates that as the end of the actinide series is approached the (II) oxidation state is stabilized, just as it is for the homologous lanthanide element ytterbium (element 70) and as predicted some 20 years ago. It should be pointed out, however, that the ease of reduction to the (II) state, the observation of the (II) oxidation in mendelevium and recent indications that the (II) state can be observed as early in the actinide series as californium (element 98) all indicate a greater stability of the (II) state in the heavy actinide elements than is the case with the lanthanide elements.

The honor of naming a new element usually goes to the discoverer, but after the name "nobelium" (symbol No) had been accepted for element 102 by the International Union of Pure and Applied Chemistry on the basis of a Swedish proposal, the Swedish work was found to be erroneous. In 1967, however, the Berkeley group that had discovered element 102 offered to relinquish its right to name the element and proposed that nobelium be accepted.

Following the discovery of lawrencium, element 103, at Berkeley in 1961 in the form of an eight-second radioactivity (^{257}Lr, ^{258}Lr or ^{259}Lr), the Dubna workers found in 1965 a longer-lived lawrencium isotope, ^{256}Lr, with a half-life of 35 seconds. In a series of dramatic experiments at Berkeley last year Ghiorso and his associates were able to use a few atoms of this isotope (about five atoms per experiment) to elucidate the oxidation behavior of lawrencium. Their technique was solvent extraction: working with extreme rapidity and dexterity, they extracted lawrencium ions from a buffered aqueous solution into an organic solvent, completing each extraction in about 30 seconds. They found that lawrencium behaves differently from dipositive nobelium and more like the tripositive elements earlier in the actinide series, as shown by the fact that tripositive ions extract into the organic phase whereas dipositive ions do not. This behavior had been predicted.

Attempts to produce and identify elements 104 and 105 have been made at both Dubna and Berkeley. In 1964 Flerov and his co-workers published results obtained by bombarding plutonium 242 with neon ions to cause a nuclear reaction that was postulated to produce an isotope of element 104, namely ^{260}104. The half-life of the product isotope was measured as being about .3 second, with decay occurring only by spontaneous fission, a nonspecific mechanism that does not characterize an isotope with a precisely measurable and therefore clearly identifying energy as in alpha-particle decay. In 1966 Ivo Zvara and his colleagues in the Russian group reported experiments aimed at separating the .3-second isotope from the other materials present by a technique based on the premise that element 104 would be the first transactinide element and hence would have properties similar to those of hafnium, below which it would fall in the periodic table. The Russian workers thought they had succeeded, but the opportunities for ambiguity in this work are so numerous that certainty is not yet within reach. The Berkeley investigators have been unable to confirm the Russian results. On the other hand, they have recently obtained proof that one of the activities formed in bombardments of californium 249 with carbon ions is ^{257}104, an alpha-particle emitter with a half-life of about three seconds, whose daughter was identified as the previously known isotope nobelium 253. Thus ^{257}104 is the first isotope of element 104 with definitely known properties.

More ephemeral is the work done by the Russian investigators on element 105. After bombarding americium 243 with ions of neon they found two alpha-particle emitters with half-lives of less than three seconds that they believed could be attributed to ^{260}105 and ^{261}105. Again, experiments by Ghiorso and his group failed to confirm these results. A measure of the difficulties encountered in this kind of investigation is that the rate of production in the Dubna cyclotron is only one atom for each 20 hours of bombardment.

Superheavy Elements

In order to set forth the considerations giving rise to the possibility of identifying elements far beyond the region of atomic number 100 we must briefly review the theories of nuclear structure (as distinct from electronic structure) that have led to the optimism about superheavy elements. The story began about 20 years ago, when Maria Goeppert Mayer at the University of Chicago and O. P. L. Haxel, J. Hans D. Jensen and Hans E. Suess of the University of Heidelberg began to develop a "shell" model of the nucleus that consisted of particles moving in a field of nuclear force. The collection of particles (neutrons and protons) was shown to be particularly stable when the nucleus contained a "magic" number of neutrons or protons. The stable structure could be regarded as shells, or spherical orbits, whose capacity for nuclear particles is filled; it is analogous to the filled electron shells of the noble gases. Magic numbers of neutrons (N) or protons (Z) are generally recognized as being 2, 8, 20, 28, 50 and 82 in the elements below uranium in the periodic table. The magic number $N = 126$ is also significant in this region, as can be seen in the special stability of lead 208 ($^{208}_{82}$Pb, or $Z = 82$ and $N = 126$), which has a doubly magic nucleus. The shell theory has evolved through many stages, to the point where the potential of single nucleons (protons or neutrons) in a deformed (nonspherical) nuclear field can be calculated by using "Nilsson orbitals," a method developed by the Swedish physicist Sven Gösta Nilsson.

Further conceptual assistance has come from the charged liquid-drop model of the nucleus first put forward by Niels Bohr and John A. Wheeler. This model assumes for a stable nucleus a spherical, or liquid-drop, form brought about by a balance between the inwardly directed force of surface tension and the outwardly directed force of repulsion among the positively charged protons. The model has been developed further to help in predicting the stability of heavy nuclei with respect to spontaneous fission and other modes of decay. In the extension of the liquid-drop model formulated by W. D. Myers and W. J. Swiatecki of the Lawrence Radiation Laboratory the potential energy of the nucleus is a function of neutron number, atomic number and nuclear shape. The nuclei of most isotopes, including those of the lanthanide and actinide elements, have somewhat deformed shapes, for example ellipsoids, but the nuclei of isotopes whose shells are filled or nearly filled are spherical. In the absence of filled shells all superheavy elements would decay instantaneously by spontaneous fission to isotopes with medium atomic numbers located near the middle of the periodic table.

Exciting calculations made recently by Nilsson, Swiatecki, V. M. Strutinskii and others working in several countries (using the liquid-drop model, the Nilsson orbitals and patterns known from the lanthanide and actinide regions) establish the possibility of closed nuclear shells in the region of superheavy elements. The resistance of such nuclei to decay by spontaneous fission means that their rate of decay by the emission of alpha and beta particles becomes important. Estimates of stability with respect to these modes of decay have been made at Berkeley by Nilsson and his co-worker Chin Fu Tsang.

Such theoretical calculations suggest the existence of closed nucleon shells at $Z = 114$ and $N = 184$ that exhibit great resistance to decay by spontaneous fission. Fortunately the nucleus with 114 protons and 184 neutrons ($^{298}114$) is situated near the bottom of the potential-energy valley of stability, that is, it resists decay by beta-particle emission and is doubly magic just as lead 208 is. A less stable closed shell had been computed to exist at $Z = 126$ (or $Z = 124$), but there are recent indications that this is not likely. More hopeful are the calculations by Tsang pointing to a closed shell at $N = 196$. Although $Z = 164$ may represent a hypothetical point of stability, this possibility has not been investigated in any detail.

Enhancing the prospects for the actual synthesis and identification of superheavy nuclei is the fact that the doubly magic nucleus $^{298}114$ is at the center of a rather large island of stability in a sea of spontaneous fission [*see top illustration on page 62*]. Stability against decay by spontaneous fission is highest at the center, and instability increases as the edges of the region are reached. The trends predicted by Nilsson, Tsang, Swiatecki and others for spontaneous-fission, alpha-decay and beta-decay half-lives in the region of interest are shown in the accompanying illustrations [*pages 60 and 61*]. The numbers may be substantially in error, but even if the actual values are lower than indicated by many factors of 10, any nuclei that have the appropriate atomic number and mass number should still be observable. The doubly magic nucleus $^{298}114$, for example, is predicted to have a spontaneous-fission half-life of 10^{16} years and an alpha-decay half-life of 1,000 years and to be stable against beta decay. Half-lives as short as nanoseconds (billionths of a second) are discernible with the instruments now used in the detection of new elements, so that there is quite a margin for error in employing the predictions to select a region for experimental study.

It appears from the predictions that maximum stability should be found at 110 protons and 184 neutrons ($^{294}110$), an isotope that might have a half-life of as long as 100 million years for decay by both spontaneous fission and alpha-particle emission, and that is possibly

NUCLEAR REACTOR at Oak Ridge National Laboratory produces heavy actinide elements up to and including fermium. The reactor pressure vessel is in the pool of water at top. At bottom is a storage pool in which cores that have been irradiated in the reactor are kept until they have cooled. The glow, which is also seen on the cover of this issue, is produced by Cerenkov radiation from the cores. At top right is a carrier vessel used to transfer radioactive material. This facility is the high-flux isotope reactor.

stable against decay by beta-particle emission. A half-life of a few times 100 million years is enough to allow an isotope to survive and still be present on the earth (as in the case of uranium 235, which has a half-life of 700 million years), provided that it was initially present as a result of the cosmic nuclear reactions that led to the creation of the solar system. Consultation of the periodic table will show that element 110 is a homologue of platinum and should have chemical properties similar to those of that precious metal. Therefore searches have been made for element 110 and its neighboring elements in naturally occurring platinum and other metals and ores by workers in a number of laboratories.

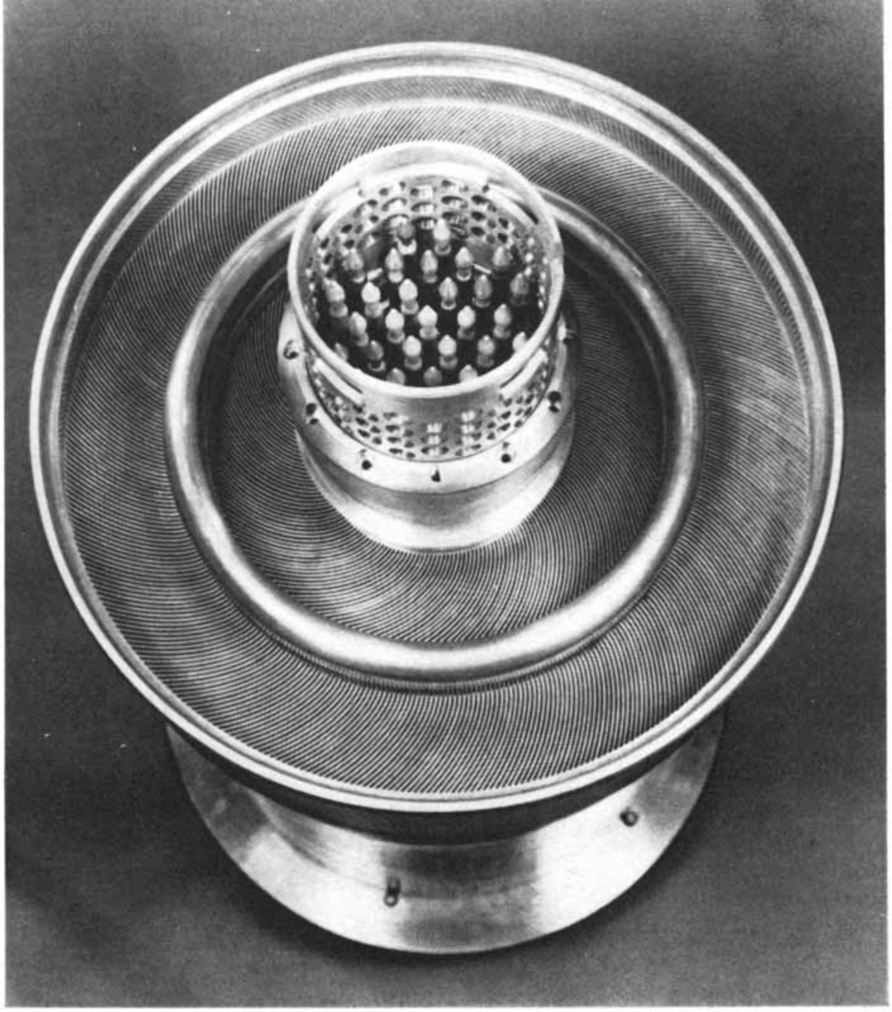
Synthesizing Superheavy Elements

Indications are that the superheavy elements can be created only by bombarding target nuclei with sufficiently energetic projectiles consisting of heavy ions. Many experimental difficulties will have to be overcome. The yield of the desired product nuclei is predicted to be very small because the overwhelming proportion of the nuclear reactions lead to fission rather than to synthesis through amalgamation of the projectile and the target nucleus. The currently available target nuclei and projectiles lead to neutron-deficient nuclei that lie outside the island of stability. Projectile ions that will soon be available with the required energy should lead to nuclei that are just barely within the island and therefore will have half-lives so short as to make them difficult to detect. To reach the center of the island may require the construction of new accelerators or the modification of existing ones in order to furnish the heavy and energetic ions needed.

A reaction that is relatively easy to produce involves bombarding an isotope of curium ($^{248}_{96}Cm$) with argon ions ($^{40}_{18}Ar$) to produce $^{284}114$. (The mass number of 284 is only illustrative, since a range of mass numbers from 282 to 284 can be expected as the number of neutrons emitted varies.) The curium target and the argon projectile at the required intensity and energy are available. The desired atomic number of 114 is achieved, but the neutron number is only 170 ($284 - 114 = 170$), apparently placing the nucleus in the sea of spontaneous fission and making it unobservable. This reaction has been attempted at Berkeley, but no identifiable products have been formed.

Thus a nucleus with additional neutrons is required. Illustrative of the best that might be done in the near future is a reaction like that in which an isotope of plutonium (^{244}Pu) is bombarded with ions of calcium ($^{48}_{20}Ca$) to yield $^{288}114$, which is a nucleus with 174 neutrons and so is at the edge of the predicted island of stability. This reaction uses ingredients that are fairly rich in neutrons. The isotope ^{244}Pu is a relatively rare material, but it will soon be available in sufficient quantity as the result of intensive neutron irradiation of ^{239}Pu. The projectile isotope, ^{48}Ca, presents other problems: it occurs in nature to the extent of less than .2 percent of the calcium isotopes, so that enrichment procedures will be needed to raise it to a much higher proportion. Moreover, it is difficult to vaporize and ionize for acceleration. Other neutron-rich isotopes of interest as projectiles include nickel 64 and titanium 50, but they present some of the same problems as calcium 48. Flerov has attempted to form element 114 by bombarding uranium and plutonium isotopes with ^{50}Ti but has not met with success. All in all, it is apparently not possible to get to the center or close to the center of the island of stability by means of reactions that employ a heavy-element target and moderately heavy accelerated ions.

Perhaps the only way to provide the required ratio of neutrons to protons will be to use as ingredients target nuclei such as the very neutron-rich uranium 238 ($^{238}_{92}U$) and projectile ions of such elements as uranium or xenon to yield $^{298}114$ and other products. The reasoning is that if an unstable, excited nucleus could be produced by the interaction or fusion of a uranium ion with uranium (probably the best reaction to attempt) or a xenon ion with uranium, it would promptly decay by fission to relatively stable products. To accomplish the uranium-uranium reaction would require uranium ions accelerated to about 1.5 billion electron volts. Each



CORE ASSEMBLY of the high-flux isotope reactor includes 31 "target bundles" (*center*) that are loaded with material to be bombarded with neutrons. A standard loading is 300 grams of plutonium 242. The entire fuel assembly contains a total of 9.4 kilograms of uranium 235. Outer element contains 369 curved plates and is 17⅛ inches in diameter.

ion must be multiply charged to a high degree by the removal of orbital electrons so that it can be accelerated in a machine of reasonable size. No machines are currently available in either the U.S. or the U.S.S.R. that are capable of accelerating such heavy ions to sufficiently high energies, but suitable machines can be built or existing ones modified, with essentially no limit on the atomic number of the accelerated ions.

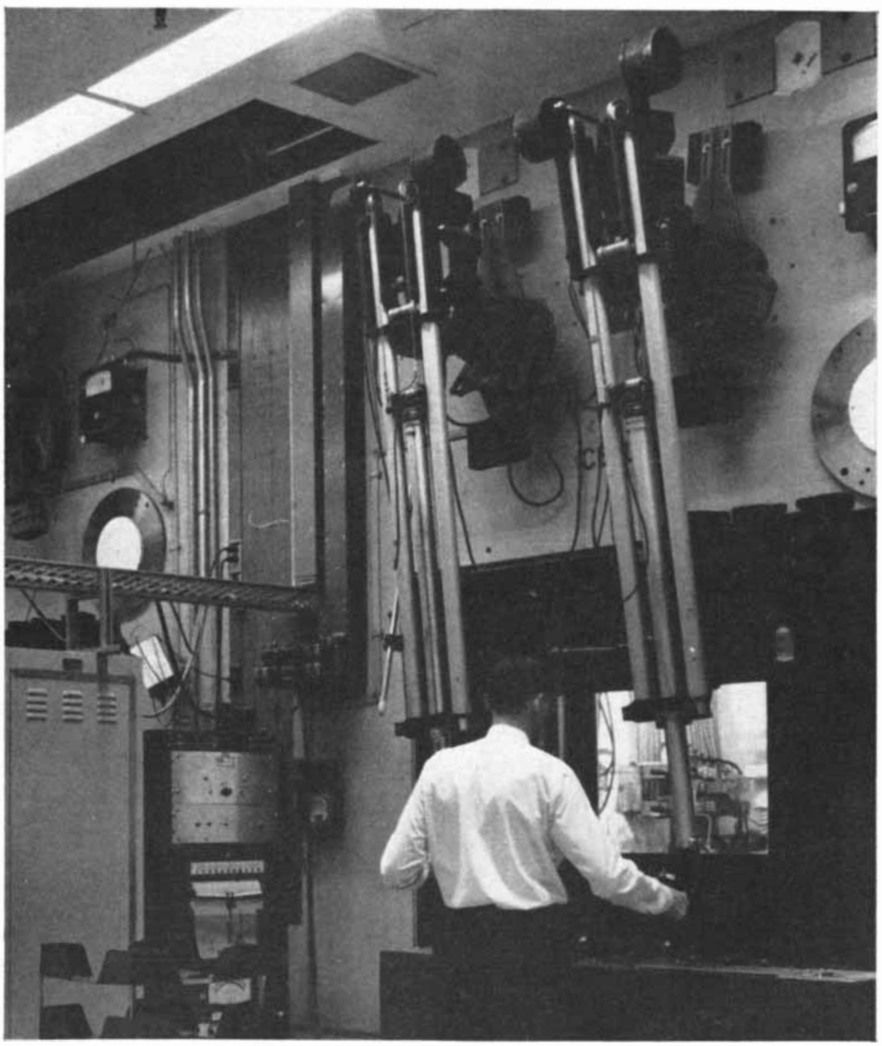
Chemical Properties

So far we have dwelt on the nuclear constitution of the superheavy elements. The chemical properties of an element, however, depend almost entirely on the arrangement of electrons outside the nucleus. The transuranium elements known or predicted until recently have electrons arranged in seven shells, numbered 1, 2, 3, 4, 5, 6 and 7, reading from the nucleus outward. The shells are further subdivided into subshells designated *s*, *p*, *d* and *f*. Entering the realm of superheavy elements introduces for the first time a shell 8 and a subshell *g* [*see illustration at right on page* 59].

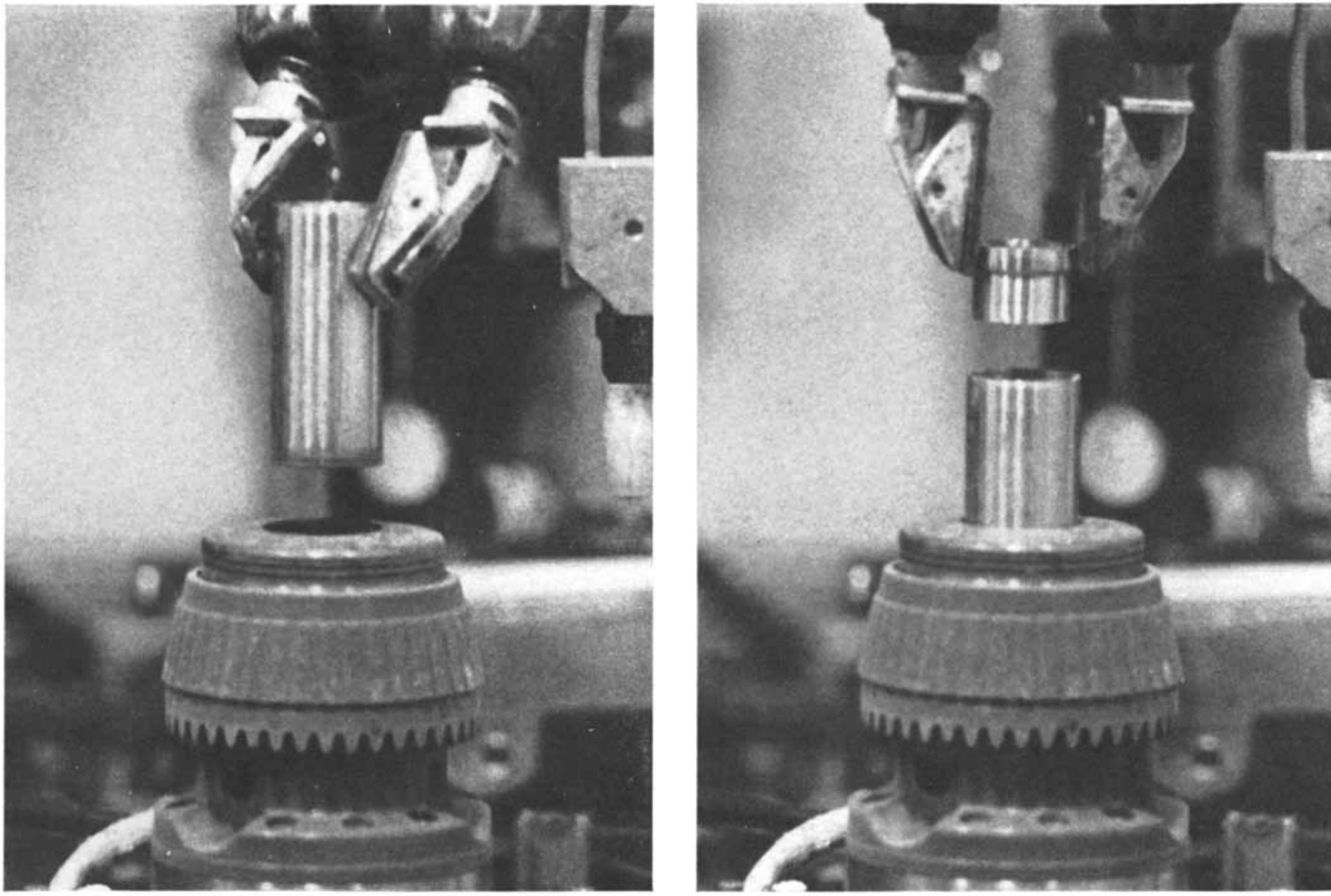
Now that we have explained our optimism about the possibility of forming superheavy elements we must give some justification for assigning them to places in the periodic table and hence for predicting their chemical properties. By way of background, one can observe from the periodic table that the lanthanide series of elements, cerium through lutecium, is a transition series formed by the sequential filling of a 14-member inner electron subshell, the 4*f* shell. This is why the chemical properties of the lanthanides are similar. In analogous fashion the actinide series is formed by the filling of the inner 5*f* subshell, with each element being somewhat similar in its properties to its lower lanthanide homologue. The 14-member actinide series is completed with element 103.

Although exceedingly complex and voluminous calculations are involved, it is possible in principle to predict the electronic structures of the actinide elements and of the undiscovered transactinide elements. Computers now make such calculations feasible, and they have been carried out at the Los Alamos Scientific Laboratory for elements with atomic numbers as high as 132. The calculations show that elements 104 to 112 are formed by the filling of the 6*d* subshell, which makes them homologous in chemical properties with the elements hafnium through mercury. Elements 113 through 118 result from the filling of the 7*p* subshell and are thus similar to the elements thallium through radon. It is of much interest here that element 114, which we have mentioned so often, proves to be homologous with that very stable element lead; it can therefore be called "eka-lead," using the terminology of Dmitri Mendeleev, the originator of the periodic table, to denote an undiscovered element in a periodic column, or family, that should have properties similar to those of the preceding members of the family. Element 119 should be an alkali metal, element 120 an alkali earth and element 121 similar in properties to actinium and lanthanum.

One of us (Seaborg), and also the Russian chemist Vitalii I. Goldanskii and others, has speculated for some years that another inner transition series of elements, somewhat like the lanthanide and actinide series, should begin in the vicinity of element 120. Quantum theory indicated that this series would be formed by the addition of 18 electrons to an inner 5*g* subshell or 14 electrons to a 6*f* subshell, but the order of filling these shells could not be predicted until the Los Alamos computer techniques became available. The calculations now suggest that after the addition of some electrons to the 7*d* and 6*f* subshells the filling of the 5*g* subshell takes place in an orderly manner. It is reasonable to expect that this would be followed by the filling of the inner 6*f* subshell, leading to an inner transition series of 32 elements, ending with element 153. The lower members of the series, perhaps through element 124, might be generally homologous with the lower members of the actinide series. Throughout the series, however, the correlation would be indistinct, although the tripositive (III) oxidation state might be the distinctive one. Since the difference in energy levels of successive electrons is very small, this series of superactinide elements will exhibit multiple, barely distinguishable oxidation states, leading to quite complicated chemistry.



CONTROL ROOM of the facility used for processing transuranium elements at Oak Ridge includes a number of stations where machinery for handling highly radioactive elements can be operated by remote control. A "cell" for such manipulations is behind the window.



INSIDE A CELL at the transuranium facility a mechanical hand puts into a welding chuck (*left*) a cylinder used for shipping curium. After the curium, amounting normally to five grams per shipment, has been put in the cylinder a cap is inserted in the top of the cylinder (*right*). The cap is then welded on by the electrode at right and the cylinder is packed in heavy shielding for shipment.

After the completion of the superactinide series the addition of electrons to the remaining positions in the 7*d* subshell would form elements 154 through 162 (eka-104 through eka-112). Filling the 8*p* shell of six electrons would result in elements 163 through 168. Note that element 164, a possible point of high nuclear stability, is an eka-114 or eka-eka-lead. Thus the known or predicted centers of nuclear stability at tin (element 50), lead (element 82), element 114 and element 164 are members of the same column or family of the periodic table. This is a curious kinship, because the principles that determine nuclear stability are apparently not related to those that determine electronic structure, which governs an element's position in the periodic table.

If the superheavy elements can be produced and are as stable as predictions indicate they will be, proof of their existence will require the use of chemical techniques as well as methods of nuclear detection. The chemical separations must be designed on the basis of some guidance as to the nature of the element sought, and so predictions (such as we have given here) of the chemistry of the new elements may well become imperative.

A Few Applications

Although the principal reason for the efforts to produce known heavy elements and to synthesize new ones is to increase knowledge of fundamental natural laws, the work has led to practical applications of the heavy elements on an unanticipated scale. Apart from the well-known function of plutonium as a source of energy in nuclear explosives and nuclear reactors, other isotopes of the actinide series are becoming useful. For example, the isotope plutonium 238, which emits alpha particles and is formed by neutron irradiation of neptunium 237 (a by-product of power-reactor operation), is being produced in large quantities in the U.S. for use as a heat source in auxiliary electric power systems, primarily for satellites and space probes. Future uses of this isotope may lie in providing power for cardiac pacemakers and perhaps ultimately in implanted artificial hearts. Requirements for plutonium 238 over the next two or three decades may amount to tons of this isotope. The isotope curium 244 also may find substantial uses in space missions.

One of the more esoteric applications of the heavy elements was effected in 1967, when the spacecraft *Surveyor V* landed on the moon and conducted a chemical analysis of the lunar surface by means of an alpha-scattering technique. The source of the alpha particles was curium 242. Alpha particles of a small amount of einsteinium 254 served as energy standards for the detection equipment.

The isotope americium 241, formed by beta-particle decay of the plutonium 241 present in plutonium produced in reactors, is available in kilogram quantities and is used in a host of applications. They include fluid-density gauges, aircraft fuel and oil gauges, thickness gauges and distance-sensing devices—all of which make use of the gamma ray that is emitted as part of the isotope's decay process. The isotope californium 252, which constitutes the most intense compact source of neutrons known, will soon be available in gram quantities. It will find use in such fields as radiotherapy for cancer, neutron radiography and neutron-activation analysis.

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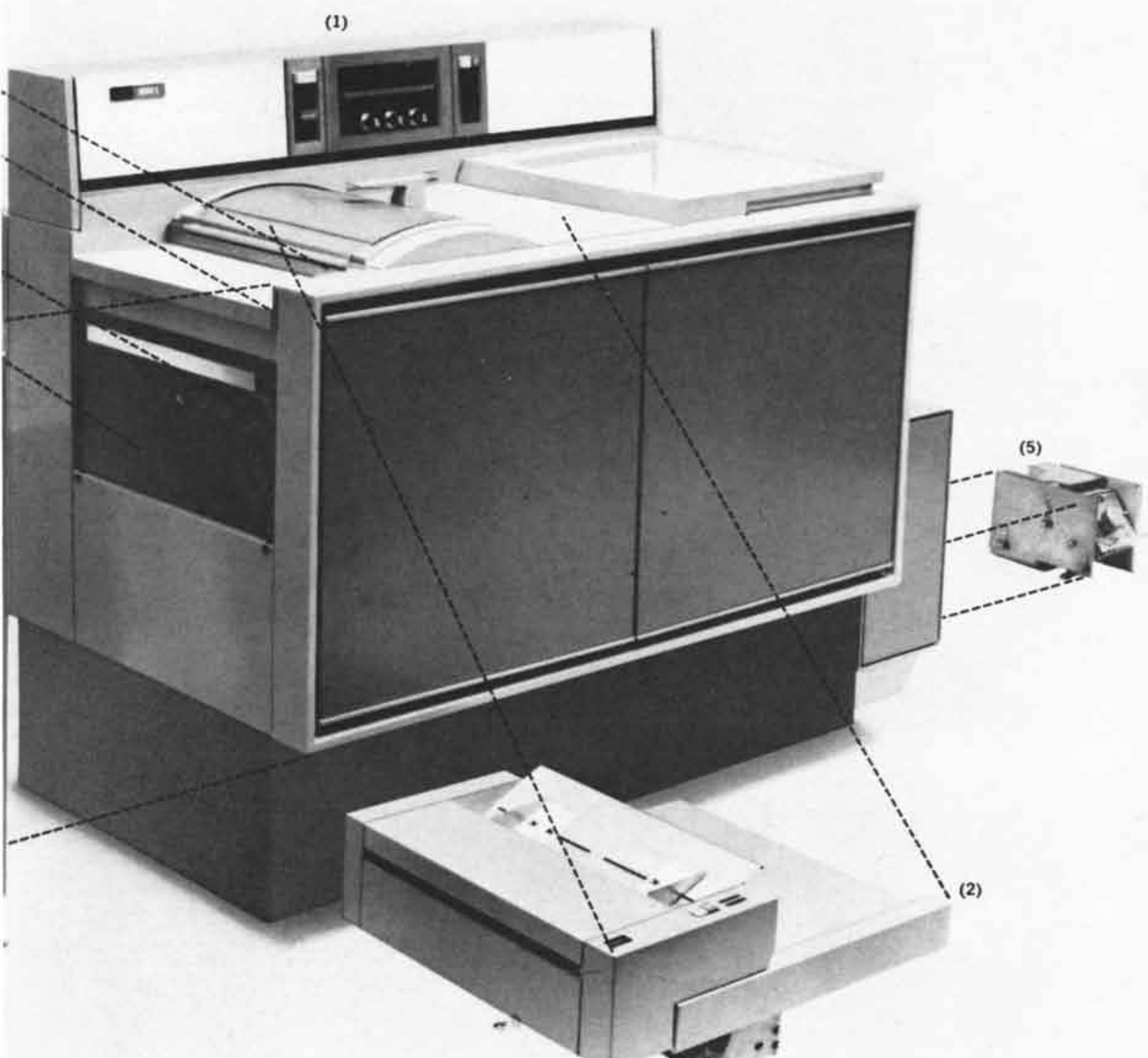


Stone Tools and Human Behavior

Statistical analysis of the implements found at Paleolithic sites can identify the groups of tools that were used for various kinds of jobs. These groupings suggest how early man's life was organized

by Sally R. Binford and Lewis R. Binford

The main evidence for almost the entire span of human prehistory consists of stone tools. Over the more than three million years of the Pleistocene epoch hunting and gathering peoples left behind them millions of such tools, ranging from crudely fractured pebbles to delicately flaked pieces of flint. Modern students of these objects are attempting to understand their various functions, and much of current prehistoric research is concerned with developing methods for achieving this understanding.

For many years prehistorians devoted almost all their efforts to establishing cultural sequences in order to determine what happened when. Chronologies have been established for many parts of the Old World, both on the basis of stratigraphy and with the aid of more modern techniques such as radioisotope dating and pollen analysis. Although many details of cultural sequences remain to be worked out, the broad outlines are known well enough for prehistoric archaeologists to address themselves to a different range of questions, not so much what happened when as what differences in stone tools made at the same time mean.

Traditionally differences in assemblages of stone tools from the same general period were thought to signify different cultures. Whereas the term "culture" was never very clearly defined, it most often meant distinct groups of people with characteristic ways of doing things, and frequently it was also taken to mean different ethnic affiliations for the men responsible for the tools. Such formulations cannot readily be tested and so are scientifically unsatisfactory. If we were to examine the debris left behind by people living today, we would find that differences in such material could most often be explained by differences in human activities. For example, the kinds of archaeological remains that would be left by a modern kitchen would differ markedly from those left by miners. This variation in archaeological remains is to be understood in terms of function—what activities were carried out at functionally different locations—and not in terms of "kitchen cultures" or "mining cultures."

The example is extreme, but it serves to illustrate a basic difference between the assumptions underlying our research and those on which the more traditional prehistory is based. The obvious fact that human beings can put different locations to different uses leads us to the concept of settlement type and settlement system, the framework that seems most appropriate for interpreting prehistoric stone-tool assemblages. In what follows we are restating, and in some respects slightly modifying, some useful formulations put forward by Philip L. Wagner of Simon Fraser University in British Columbia.

All known groups of hunter-gatherers live in societies composed of local groups that can be internally organized in various ways; invariably the local group is partitioned into subgroups that function to carry out different tasks. Sex and age are the characteristics that most frequently apply in the formation of subgroups: the subgroups are generally composed of individuals of the same age or sex who cooperate in a work force. For example, young male adults often cooperate in hunting, and women work together in collecting plant material and preparing food. At times a larger local group breaks up along different lines to form reproductive-residence units, and these family subgroups tend to be more permanent and self-sustaining than the work groups.

Although we have no idea how prehistoric human groups were socially partitioned, it seems reasonable to assume that these societies were organized flexibly and included both family and work groups. If the assumption is correct, we would expect this organization to be reflected in differences both between stone-tool assemblages at a given site and between assemblages at different sites.

Geographical variations would arise because not all the activities of a given society are conducted in one place. The ways that game, useful plants, appropriate living sites and the raw materials for tool manufacture are distributed in the environment will directly affect where subgroups of a society perform different activities. One site might be a favorable place for young male hunters to kill and partly butcher animals; another might be a more appropriate place for women and children to gather and process plants. Both work locations might be some distance from the group's main living site. One would expect the composition of the tool assemblages at various locations to be determined by the kinds of tasks performed and by the size and composition of the group performing them.

Temporal variations can also be expected between assemblages of stone tools, for several reasons. The availability of plants and animals in the course of the year is a primary factor; it varies as a result of the reproductive cycles of the plants and animals. The society itself varies in an annual cycle; the ways the members of a society are organized and how they cooperate at different times of the year change with their activities at different seasons. Moreover, any society must solve integrative problems as a result of the maturation of the young, the death of some members, relations with other groups and so on. The behavioral modifications prompted by such considerations will be reflected in the society's use of a territory.

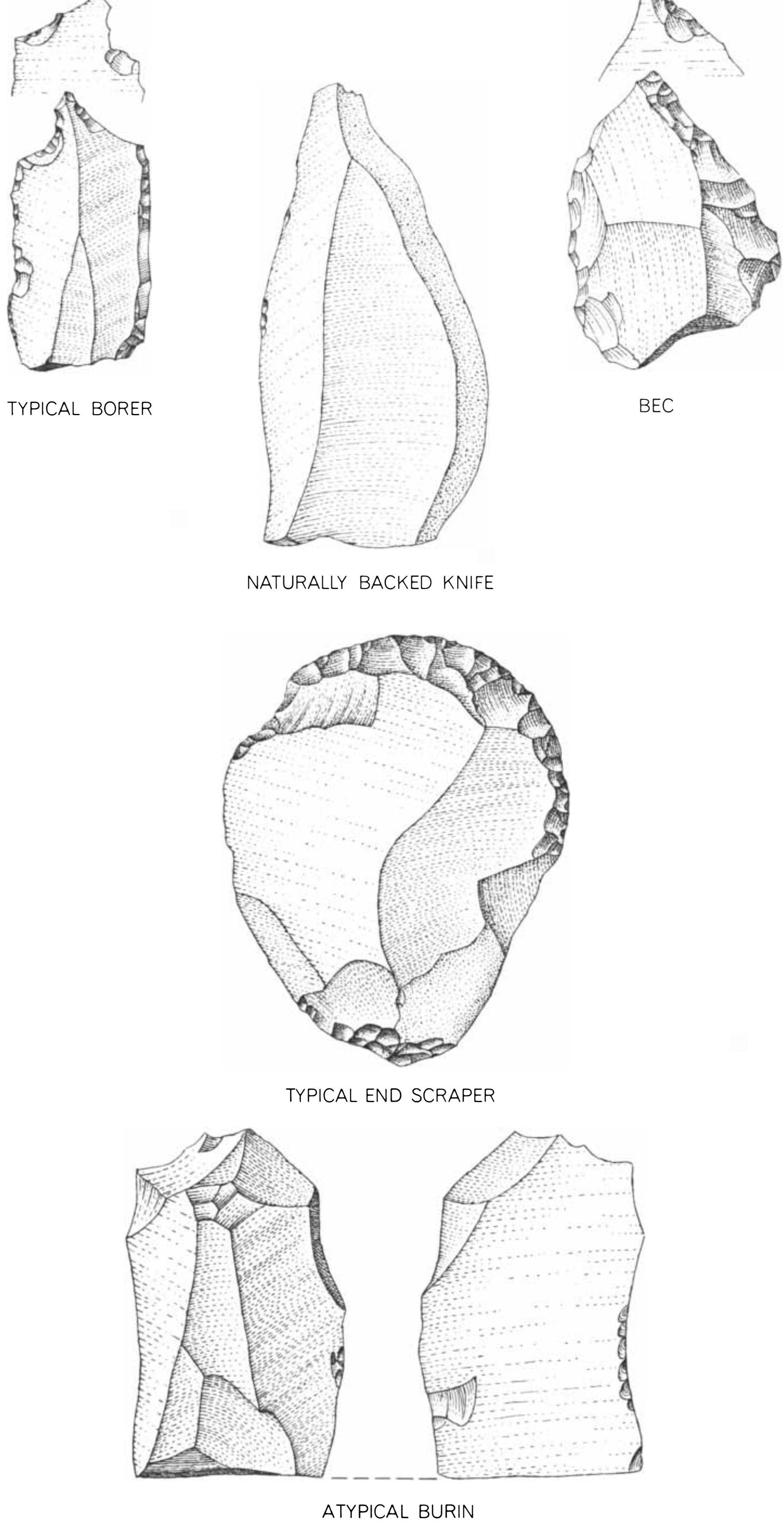
In addition to these factors that can affect the archaeological material left behind by a society, there are other determinants that profoundly modify site utilization. It is the kinds of site used for different activities and the way these specialized locations are related that are respectively termed settlement type and settlement system.

In technologically simple societies we can distinguish two broad classes of activities: extraction and maintenance. Extraction involves the direct procurement of foods, fuels and raw materials for tools. Maintenance activities consist in the preparation and distribution of foods and fuels already on hand and in the processing of raw materials into tools. Since the distribution of resources in the environment is not necessarily related to the distribution of sites providing adequate living space and safety, we would not expect extraction and maintenance activities to be conducted in the same places.

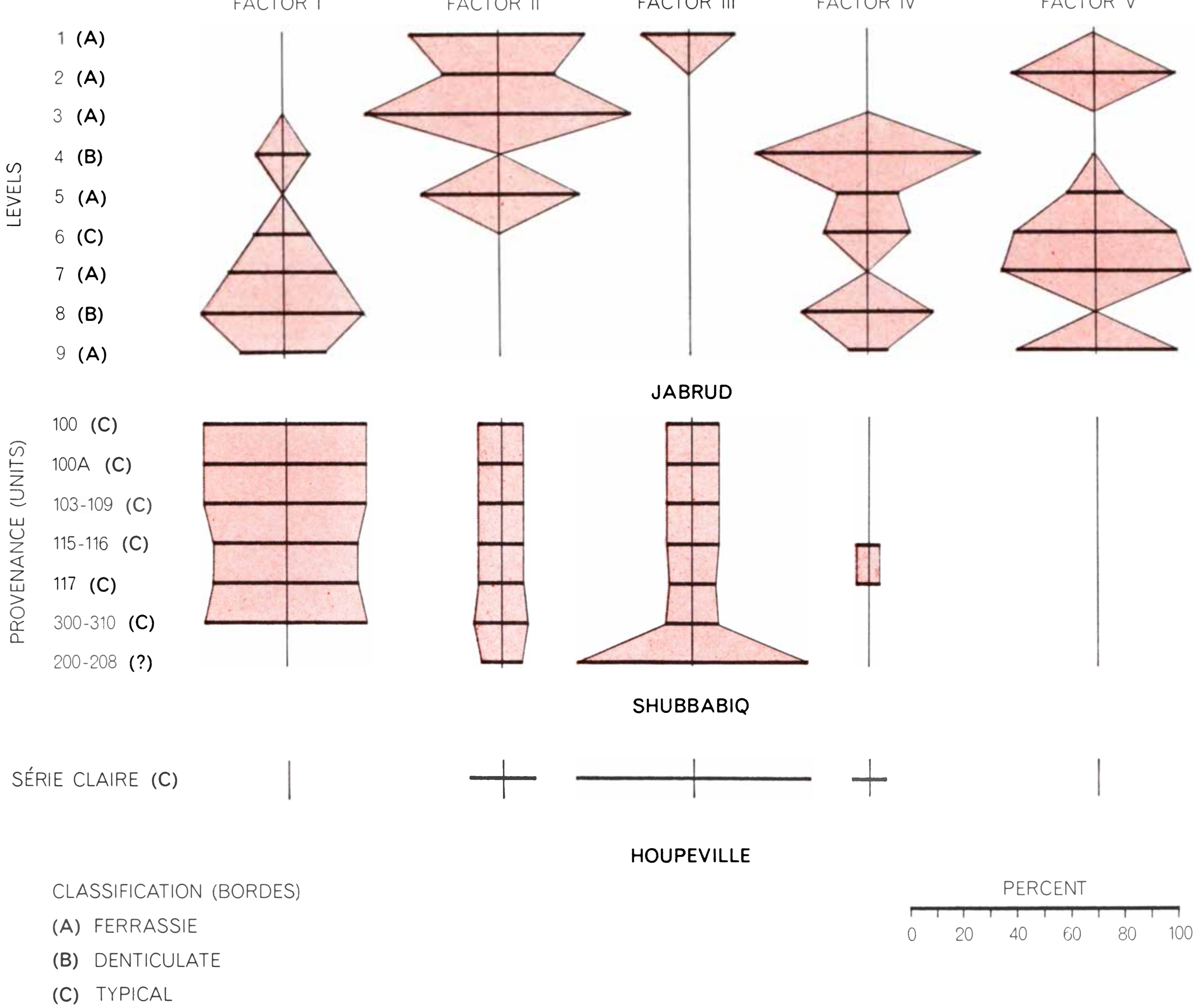
Base camps are chosen primarily for living space, protection from the elements and central location with respect to resources. We would expect the archaeological assemblages of base camps to reflect maintenance activities: the preparation and consumption of food and the manufacture of tools for use in other less permanent sites.

Another settlement type would be a work camp, a site occupied while smaller social units were carrying out extractive tasks. Archaeologically these would appear as kill sites, collecting stations and quarries for extracting flint to be used in toolmaking. The archaeological assemblages from these sites should be dominated by the tools used in the specific extractive tasks. If a work camp were occupied for a rather long period and by a fairly large subgroup, we would anticipate that some maintenance activities would also be reflected in the archaeological remains.

It is the way these two general classes of camps are used by any society that defines the settlement system. If a hunting-gathering society were relatively sedentary, we would expect the tools at the base camp to exhibit little seasonal variation because the base camp would have been occupied for most of the year. Under some conditions, however, we would expect to find more than one kind of base camp for a society. If the organization of



FIVE CLASSES OF STONE TOOLS predominate in the largest of the five groups, or factors, revealed by the authors' analyses. Of the 40 classes of tools subjected to multivariate analysis, 16 appear in this cluster, named Factor I. Few of the classes seem suited to hunting or heavy work; they were probably base-camp items for making other tools of wood or bone.



RELATIVE SIGNIFICANCE of the five factors identified in the tool assemblages from three Mousterian sites is indicated by the percentage of total variation attributable to each factor in each sample analyzed. Every sample but one bears the name (*key, bottom left*) by which the French archaeologist François Bordes characterizes the entire assemblage. The homogeneity of the samples from the Mugharet es-Shubbabiq cave site in Israel (*center*) is in sharp contrast to the heterogeneity of the samples from the Jabrud rock-shelter in Syria (*top*). The authors suggest that the cave was a base camp but that the rock-shelter was only a work camp, occupied at different times by work parties with different objectives. The Houpeville assemblage (*bottom*) is not like either of the others.

the society changes during the year, perhaps consisting of larger groups during the summer months and dispersing into smaller family units during the lean winter months, there would be more than one kind of base camp, and each would have its distinct seasonal characteristics.

The work camps would display even greater variation; each camp would be occupied for a shorter time, and the activities conducted there would be more specifically related to the resources being exploited. One must also consider how easy or how difficult it was to transport the exploited resource. If a party of hunters killed some big animals or a large number of smaller animals, the entire group might assemble at the kill site not only to eat but also to process the large quantities of game for future consumption. In such a work camp we would expect to find many of the kinds of tools used for food processing, even though the tasks undertaken would be less diverse than those at a base camp.

The extent to which maintenance tasks are undertaken at work camps will also be directly related to the distance between work camp and base camp. If the two are close together, we would not find much evidence of maintenance activities at the work camp. As the distance between work camp and base camp increases, however, the work-camp assemblage of tools would reflect an increase in maintenance activities. This leads us to suggest a third type of settlement: the transient camp. At such a location we would find only the most minimal evidence of maintenance activities, such as might be undertaken by a traveling group in the course of an overnight stay.

We have outlined here the settlement system of technologically simple hunter-gatherers. Although the system is not taken directly from any one specific living group, it does describe the generalized kind of settlement system that ethnographers have documented for people at this level of sociocultural complexity. In order to assess the relevance of such a settlement system for hunter-gatherers in the Paleolithic period it was necessary first to relate stone tools to hu-

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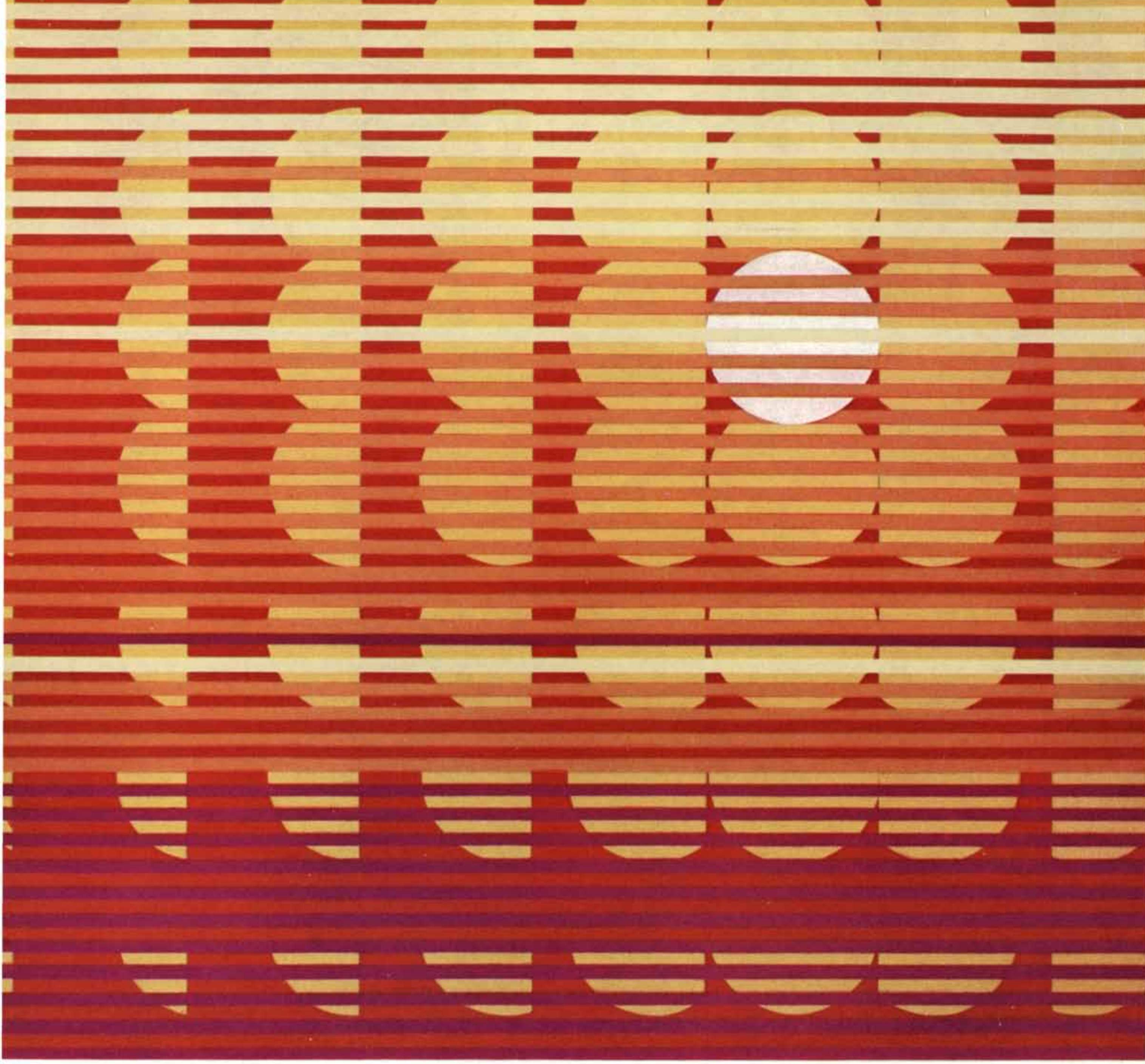

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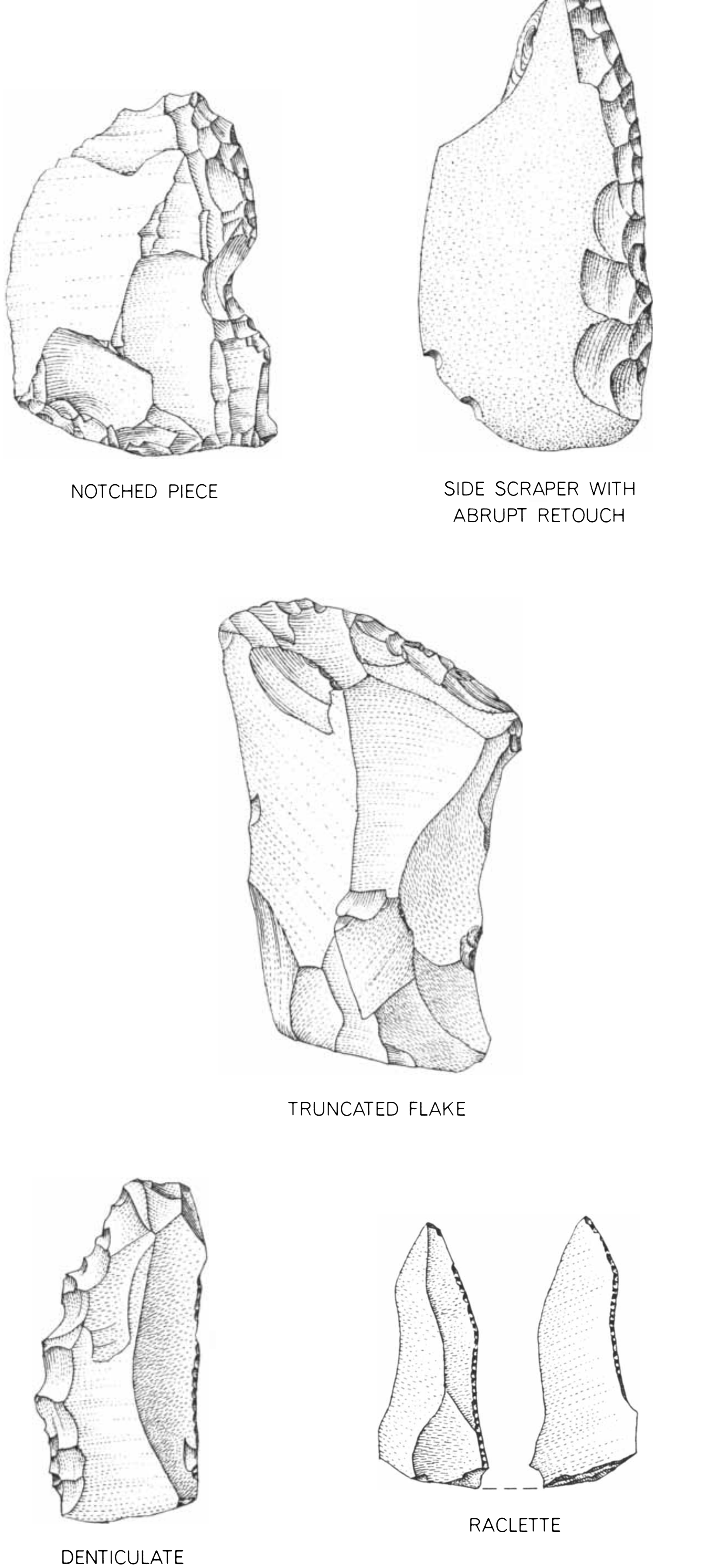
man activities and then to determine how these tools were distributed at different types of site.

The kind of analysis we carried out might well have been impossible without the basic work on the classification of stone tools done by François Bordes of the University of Bordeaux. The archaeological taxonomy devised by Bordes for the Middle Paleolithic has become a widely accepted standard, so that it is now possible for prehistorians working with Middle Paleolithic materials from different parts of the world to describe the stone tools they excavate in identical and repeatable terms.

In addition to compiling a type list of Mousterian, or Middle Paleolithic, tools, Bordes has offered convincing arguments against the "index fossil" approach to the analysis of stone tools. This approach, borrowed from paleontology, assigns a high diagnostic value to the disappearance of an old tool form or the appearance of a new one; such changes are assumed to indicate key cultural events. Bordes has insisted on describing assemblages of tools in their entirety without any a priori assumption that some tools have greater cultural significance than others. This radical departure in classification, combined with highly refined excavation techniques, provides a sound scientific basis on which much current prehistoric research rests.

According to what has become known as *la méthode Bordes,* stone artifacts are classified according to explicitly stated attributes of morphology and technique of manufacture. The population of stone tools from a site (the assemblage) is then described graphically, and the relative frequencies of different kinds of stone tools from various sites can be compared. Such a statistical technique, which deals with a single class of variables, is quite appropriate for the description of assemblages of stone tools. The explanation of multiple similarities and differences, however, requires different statistical techniques.

The factors determining the range and form of activities conducted by any group at any site may vary in terms of many possible "causes" in various combinations. The more obvious among these might be seasonally regulated phenomena affecting the distribution of game, environmental conditions, the ethnic composition of the group, the size and structure of the group regardless of ethnic affiliation and so on. Other determinants of activities might be the particular situation of the group with respect to



UNIDENTIFIED TOOL KIT, with five predominant classes of artifacts, comprises Factor IV. The tasks for which it was intended are not known. Bordes has suggested, however, that denticulates (*bottom left*) may have been utilized for the processing of plant materials.

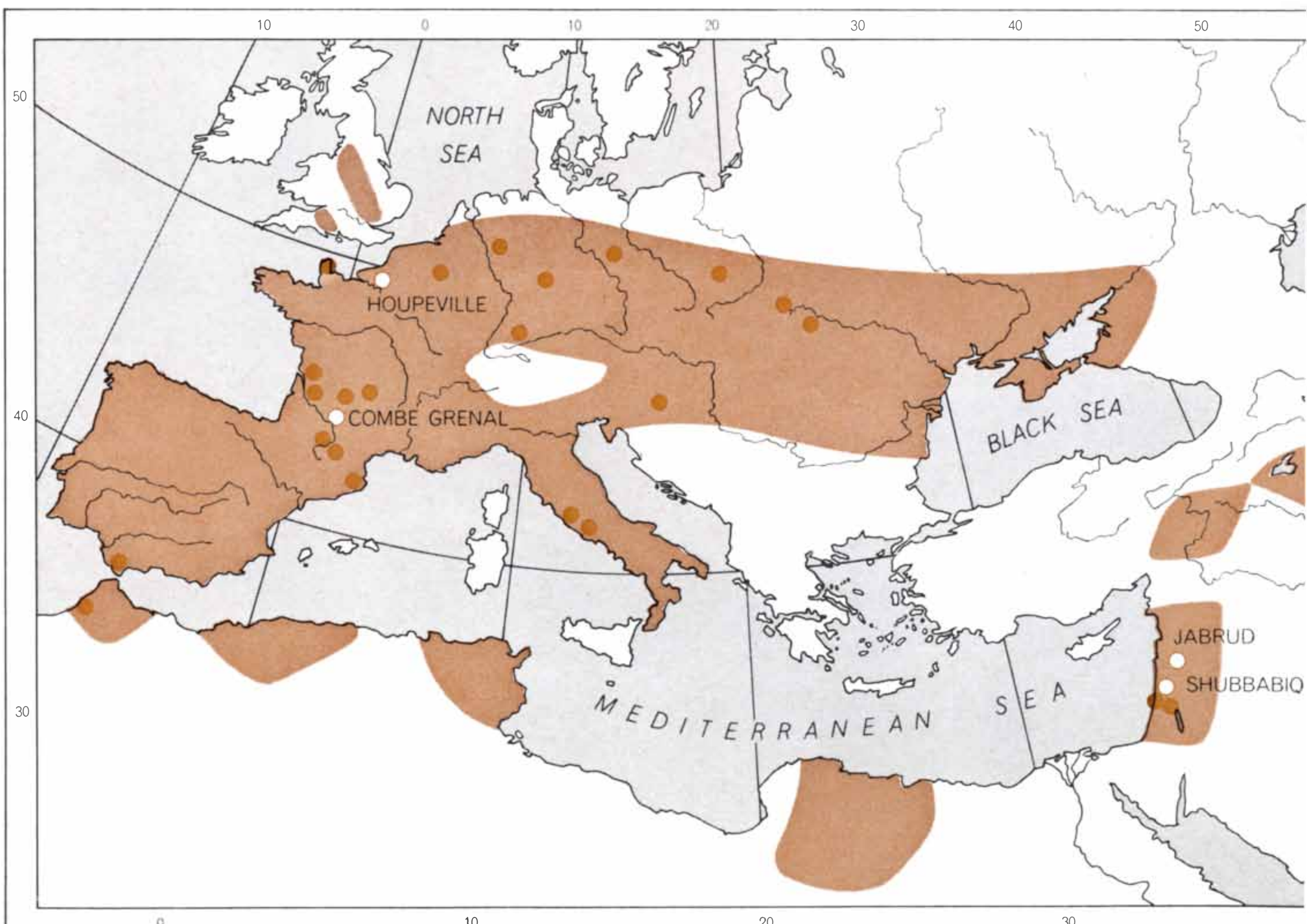
food, shelter, the supply of tools or the availability of raw materials. In short, the "causes" of assemblage variation are separate activities, each of which is related to the physical and social environment and to the others.

Given this frame of reference, the summary description of frequencies of tool types in an assemblage, which is the end product of Bordes's method, represents a blending of activity units and their determinants. We needed to partition assemblages into groups of tools that reflect activities. To use a chemical analogy, the end product of Bordes's method of describing the entire assemblage is a compound; we hoped to isolate smaller units, analogous to the constituent elements of a compound, that would represent activities. In our view variation in assemblage composition is directly related to the form, nature and spatial arrangement of the activities in which the tools were used.

Since the settlement-system model we had in mind is based on ethnographic examples, we wanted to ensure that the archaeological materials we analyzed were made by men whose psychological capacities were not radically different from our own. The Mousterian, a culture complex named after the site of Le Moustier in the Dordogne, dates from about 100,000 to 35,000 B.C. Mousterian tools are known from western Europe, the Near East, North Africa and even central China. Where human remains have been discovered in association with Mousterian tools they are the remains of Neanderthal man. Once considered to be a species separate from ourselves, Neanderthal man is generally accepted today as a historical subspecies of fully modern man. A great deal of archaeological evidence collected in recent years strongly suggests that the behavioral capacities of Neanderthal man were not markedly different from our own.

The Mousterian assemblages we chose for our analysis came from two sites in the Near East and one in northern France. One of us had excavated a cave site in Israel (Mugharet es-Shubbabiq, near Lake Tiberias) and had analyzed the stone tools found there in Bordes's laboratory and under his supervision. We also used assemblages that had been excavated in the 1930's by Alfred Rust at Jabrud, a rock-shelter near Damascus in Syria; this material had been studied and reclassified by Bordes. The French material came from the open-air site of Houpeville and had been excavated and analyzed by Bordes. We chose these samples because they represented three kinds of site, but more important because they had all been classified by Bordes. This meant that extraneous variation due to the vagaries of classification was eliminated.

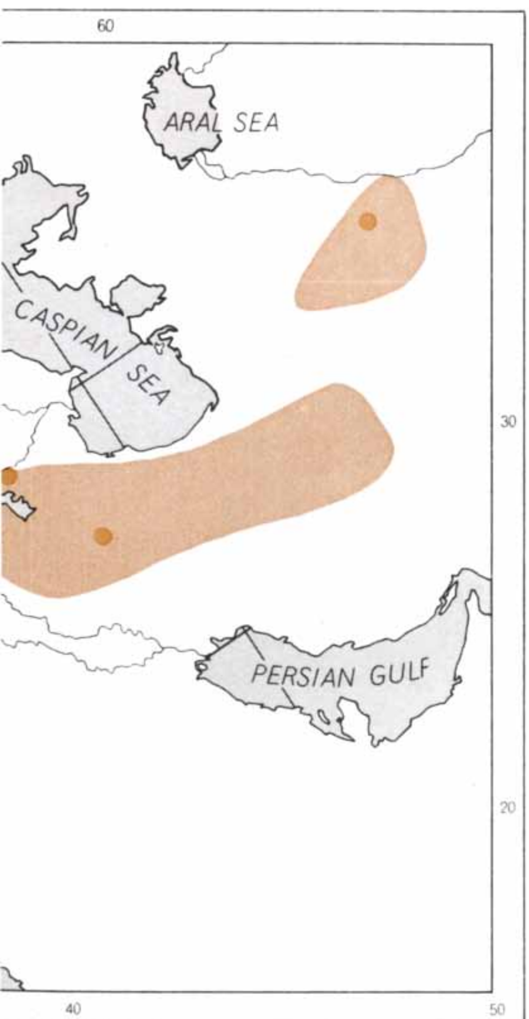
To describe the two Near Eastern sites briefly, Shubbabiq is a large cave located in a narrow, deep valley that is dry for most of the year. The cave mouth faces east and its floor covers nearly 350 square meters, with slightly less than 300 meters well exposed to natural light. Un-



STONE TOOLS of the Mousterian tradition are found throughout Europe and also in the Near East. They were made from 100,000 to 35,000 years ago and are associated in many instances with the remains of Neanderthal man (*colored dots*). The authors' statistical

fortunately the Mousterian deposits in the main part of the cave had been destroyed by more recent inhabitants. Five of the samples from Shubbabiq used in our study came from deposits in the rear of the cave. The sixth, Unit 200–208, was a small deposit outside the cave entrance. The Syrian site, Jabrud Shelter I, is long and narrow. Like Shubbabiq, it faces east, and because it is more open it is much more exposed to the elements. Located on the edge of the Anti-Lebanon range, it looks down on the floor of a valley. At the time of the occupations that interested us the shelter had about 178 square meters of floor space. Rust excavated a trench some 23 meters long and three meters wide along the shelter's back wall. The shelter yielded many layers of Mousterian tools, but only the upper nine strata contained assemblages that could be compared with those from Shubbabiq.

Our study sought to answer three questions. First, does the composition of the total assemblage from any occupation level correspond to any single human activity, or does information summarized in a single class of variables obscure the fact that each assemblage represents an assortment of activities? Second, is there any regularity in the composition of assemblages at a single location that can be interpreted in terms of regular patterns of human behavior? Third, is there some kind of directional change over a period of time in assemblages from a single location that suggests evolutionary changes in human behavior?



analyses utilized tools from two sites in the Near East and two in Europe (*open circles*).

The statistical analysis of a single class of variables is termed univariate analysis. Multivariate statistical analysis allows one to calculate the measure of dependence among many classes of variables in several ways. Because we needed to determine the measure of dependence relating every one of some 40 classes of tools found in varying percentages in 17 different assemblages from three sites to every one of the remaining 39 classes, we faced a staggering burden of calculations. Such a job could not have been undertaken before the advent of high-speed computers. Factor analysis, which has been applied in areas as unrelated as geology and sociology, seemed the most appropriate method. Our analysis was run at the University of Chicago's Institute for Computer Research, with the aid of a modification of a University of California program for factor analysis (Mesa 83) and an IBM 7090 computer.

The factor analysis showed that in our samples the different classes of Mousterian artifacts formed five distinct clusters. The most inclusive of the five—Factor I—consists of 16 types of tools. Within this grouping the tools showing the highest measure of mutual dependence are, to use Bordes's taxonomic terminology, the "typical borer," the "typical end scraper," the "bec" (a small, beaked flake), the "atypical burin" (an incising tool) and the "naturally backed knife" [*see illustration on page 71*]. None of these tools is well suited to hunting or to heavy-duty butchering, but most are well designed for cutting and incising wood or bone. (The end scraper seems best adapted to working hides.) On these grounds we interpret Factor I as representing activities conducted at a base camp.

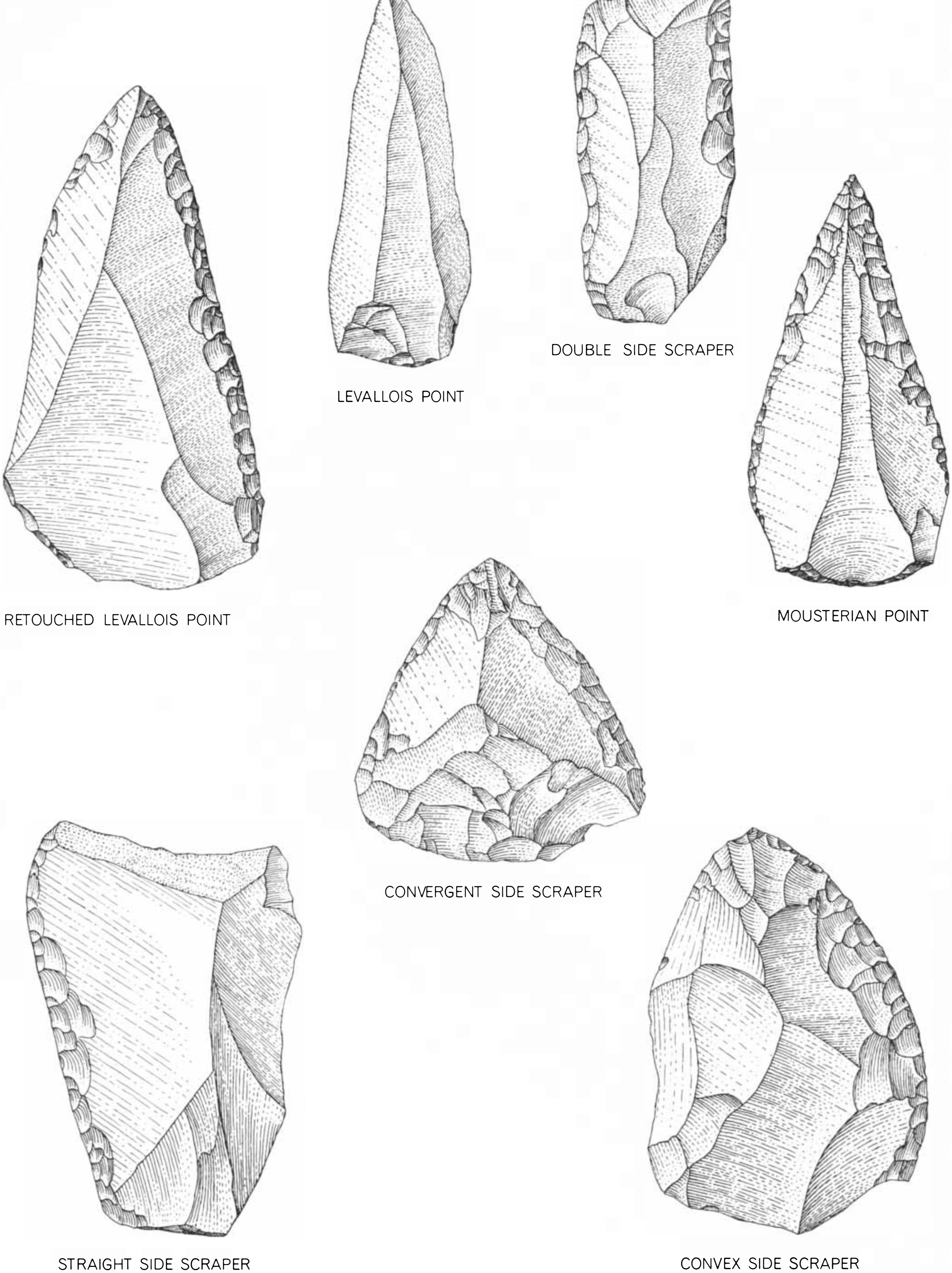
The next grouping produced by the factor analysis we interpret as a kit of related tools for hunting and butchering. The tools in this group—Factor II—are of 12 types. Three varieties of spear point are dominant; in Bordes's terminology they are the "plain Levallois point," the "retouched Levallois point" and the "Mousterian point." Side scrapers of four classes are the other tools that show the highest measure of mutual dependence: the "simple straight," the "simple convex," the "convergent" and the "double" side scraper [*see illustration on next page*].

In Factor III the main diagnostic tools are cutting implements. They include the "typical backed knife," the "naturally backed knife" (also found in Factor I), "typical" and "atypical" Levallois flakes, "unretouched blades" and "end-notched pieces" [*see illustration on page 81*]. With the exception of the end-notched pieces all these tools appear to be implements for fine cutting. Their stratigraphic association with evidence of fire suggests that Factor III is a tool kit for the preparation of food.

Factor IV is distinctive. Its characteristic tools are "denticulates" (flakes with at least one toothed edge), "notched pieces," "side scrapers with abrupt retouch," "raclettes" (small flakes with at least one delicately retouched edge) and "truncated flakes." We find it difficult even to guess at the function of this factor. Bordes has suggested that some of these tools were employed in the processing of plant materials.

The tools with the highest measure of mutual dependence in Factor V are "elongated Mousterian points," "disks," "scrapers made on the ventral surfaces of flakes," "typical burins" (as opposed to the atypical burin in Factor I) and "unretouched blades" (which are also found in Factor III). The fact that there is only one kind of point and one kind of scraper among the diagnostic implements suggests that Factor V is a hunting and butchering tool kit that is more specialized than the one represented by Factor II.

What answers does the existence of five groups of statistically interdependent artifacts among Mousterian assemblages give to the three questions we raised? In response to the first question we can show that neither at Shubbabiq nor at Jabrud does the total assemblage correspond to any single human activity. The degree to which individual factors account for the variation between assemblages can be expressed in percentages [*see illustration on page 72*]. To consider the Shubbabiq findings first, the percentages make it plain that, with the exception of a group of tools in Unit 200–208, the assemblages as a whole are internally quite consistent. The major part of the variation is accounted for by



POINTS AND SCRAPERS outnumber other kinds of tools among the 12 classes comprising the second-largest factor. The seven predominant classes in the assemblage are illustrated. Factor II is evidently an assemblage suited to hunting and butchering animals. This illustration and the others of Mousterian tools are based on original drawings by Pierre Laurent of the University of Bordeaux.

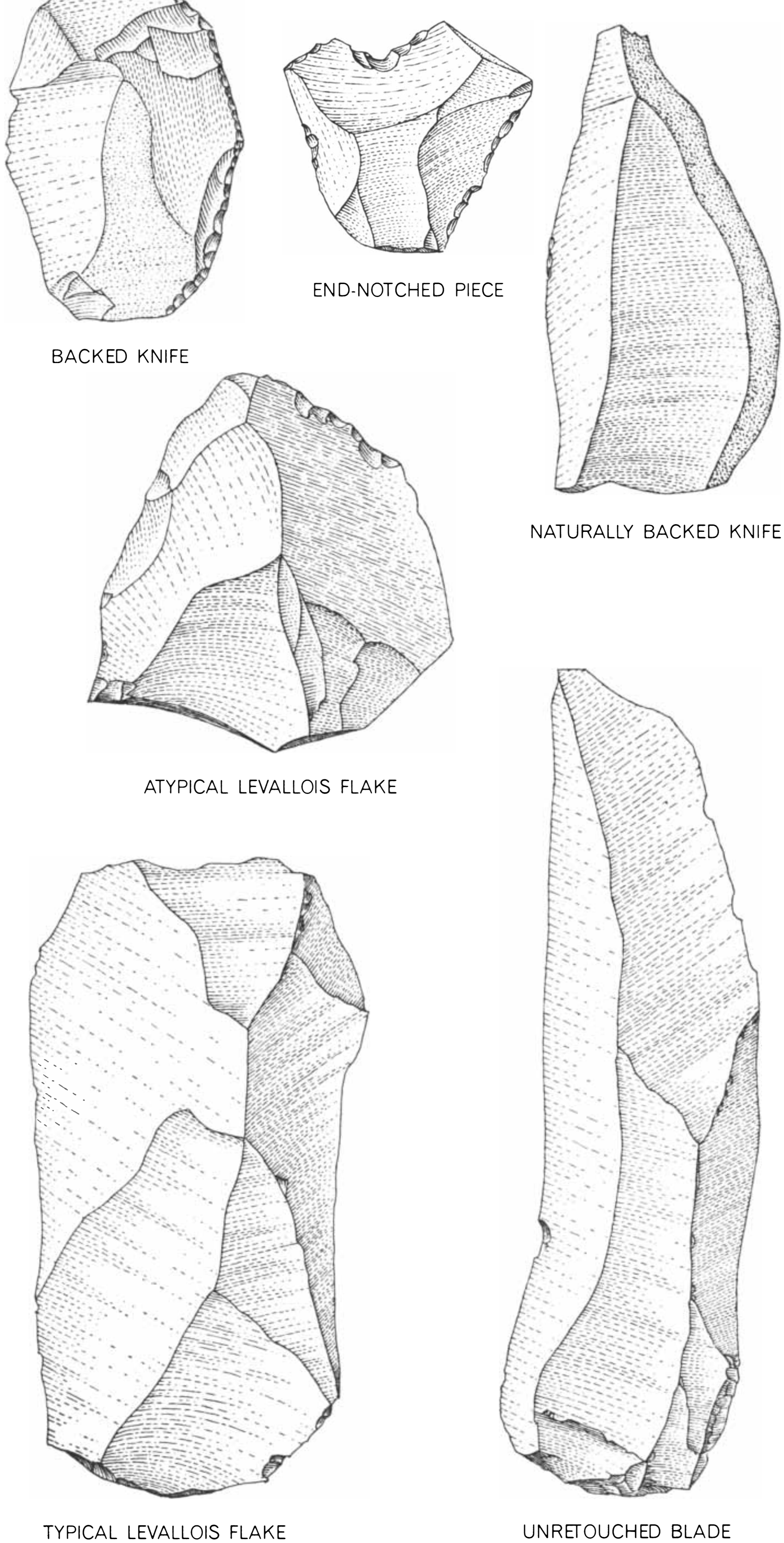
Factor I, the base-camp grouping; the remainder is shared between Factor II, the all-purpose hunting and butchering tool kit, and Factor III, the food-preparation cluster. The distinctive denticulate factor—Factor IV—appears in only two samples and represents less than 10 percent of the variability in each.

As we have mentioned, Unit 200–208 consists of tools from the deposit outside the cave mouth. Three small accumulations of ash—evidence of fires—were also found in the deposits. It seems more than coincidence that the tool grouping dominating this unit is the one associated with food preparation. In any event, the consistent homogeneity of the other excavation units at Shubbabiq suggests that the cave served the same purpose throughout its occupancy, a finding that also answers our second question. Although the occupation of the cave may have spanned a considerable period of time, the regularity of the factors suggests a similar regularity in the behavior of the occupants.

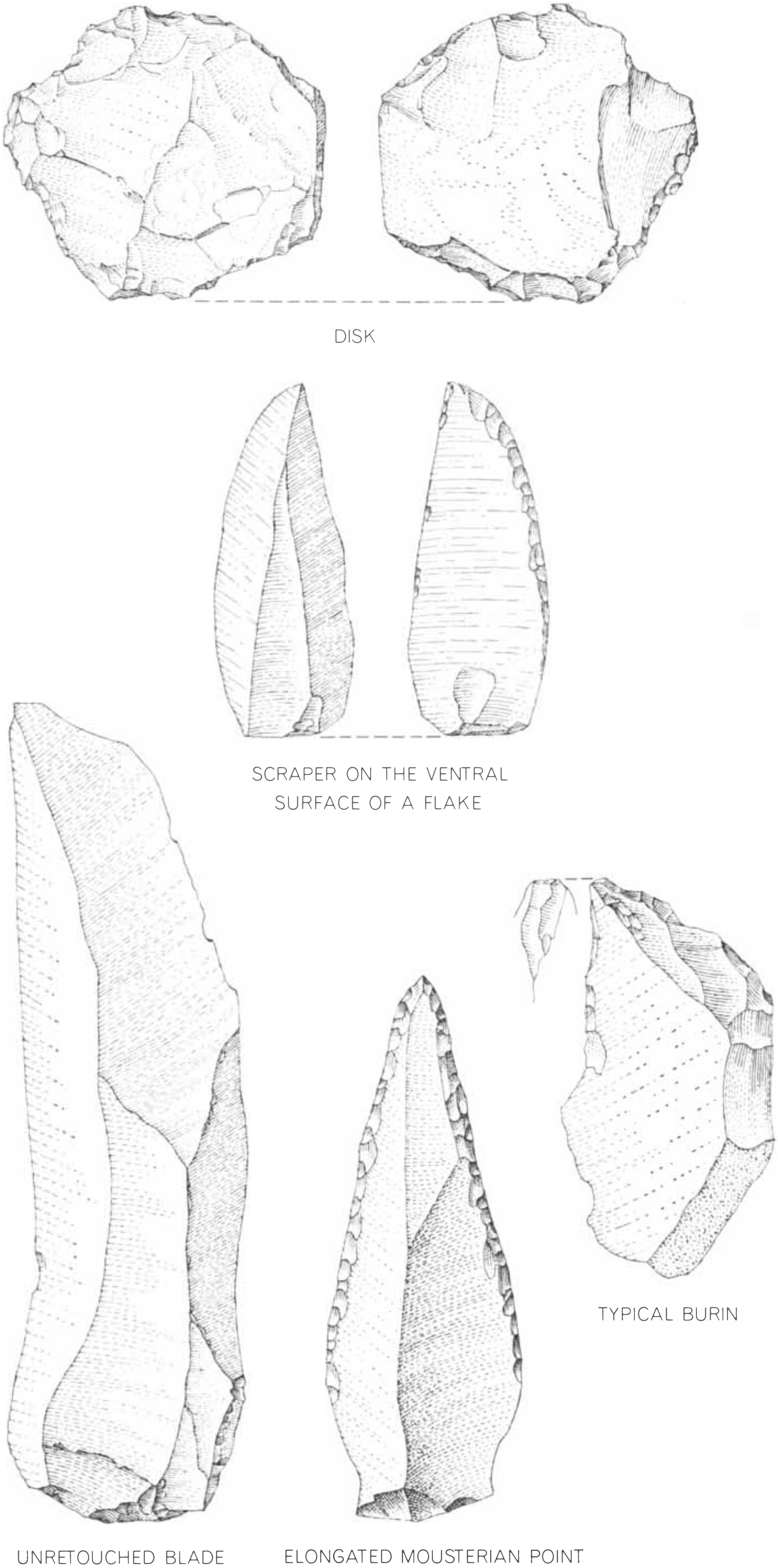
The percentages of variability accounted for at the Jabrud rock-shelter suggest in turn that Jabrud served repeatedly as a work camp where hunting was the principal activity. Evidently the valley the shelter overlooks was rich in game. The animal bones collected during the original excavation of the site have been lost, but recent work at the same site by Ralph S. Solecki of Columbia University indicates that the valley once abounded in horses—herd animals that were frequently killed by Paleolithic hunters.

The Jabrud findings also provide an answer to our third question. The decreasing importance of Factor V—the specialized hunting tool kit—and its replacement by the more generalized hunting equipment of Factor II suggests directional changes in the behavior of Jabrud's inhabitants. The same is true of the steady decline and eventual disappearance of the base-camp maintenance tools represented by Factor I.

Some of the data from Jabrud even provide a hint of a division of labor by sex in the Middle Paleolithic. The tools characteristic of Factor IV are quite consistently made of kinds of flint that are available in the immediate vicinity of the site, whereas the hunting tools tend to be made of flint from sources farther away. If, in accordance with Bordes's suggestion, the denticulates were used primarily to process plant materials, the expedient fashioning of denticulates out of raw materials on the spot coincides nicely with the fact that



TOOLS FOR FINE CUTTING are the predominant implements of Factor III. An exception (*top middle*) belongs to the class of end-notched pieces. Their association with hearths suggests that the knives, blades and flakes of Factor III were used for food preparation.



MORE HUNTING TOOLS are found in Factor V; the five predominant classes are illustrated. The presence of only one class of points and one of scrapers suggests, however, that Factor V reflects specialized hunting rather than the general hunting implied by Factor II.

among living hunter-gatherers women are responsible for the collecting and processing of plant materials.

Recent advances in understanding of the minimum number of persons needed to maintain a self-sustaining human social unit provides additional evidence in favor of our view that Jabrud served as a work camp and that Shubbabiq was a base camp. William W. Howells of Harvard University has suggested that a self-sustaining group must number between 20 and 24 individuals. (He does not imply that the group would necessarily remain together during the entire year.) Taking Howells' estimate as a starting point, we can propose that any base camp where a group could live at full strength must include enough space for the daily activities of 20 to 24 people over a period of several months. Raoul Naroll of the State University of New York at Buffalo suggests that the minimum amount of sheltered space required by an individual is some 10 square meters. On this basis the 178 square meters of floor space in the Jabrud shelter could not have accommodated more than 18 individuals. Shubbabiq cave has enough sheltered floor space for 25 to 30 individuals. Taken together with the differences in the composition of the tool assemblages at the two sites, this leads us to conclude that the sites are basically different types of settlement within a differentiated settlement system.

The tools from Houpeville, called the *Série Claire,* has a totally different geographical context. Since Houpeville is an open-air site and the only one in the study, we feel that an attempt to draw conclusions about its function would be almost meaningless. The *Série Claire* sample nonetheless offers a further demonstration of the power of multivariate analysis. When calculated by univariate statistics, the total configuration of the Houpeville assemblage strongly resembles that of Shubbabiq, that is, the summarized statistics of frequencies of tool types are very similar. When subjected to factor analysis, however, the assemblages from the two sites look quite different. Factors I and V are missing altogether at Houpeville; Factor III, the cluster of food-preparation implements that constitutes a minor percentage of the variability at Shubbabiq, is the major component of the *Série Claire.*

Although we found the results of this factor analysis provocative, it was quite clear that many of our specific interpretations of the factors could not be tested

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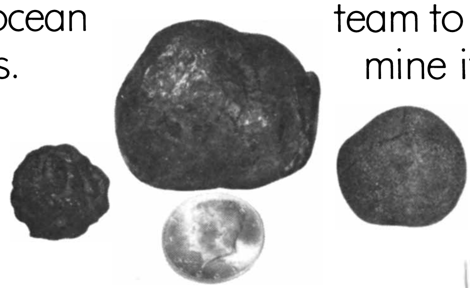

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on the basis of such limited data. We felt it essential to add other classes of information to the analysis: animal bones, pollen counts (as checks on climatic inferences) and the distribution of other traces of man (such as hearths) within each occupation level. Such data were available from the site of Combe Grenal, a deeply stratified rock-shelter in the Dordogne region of France excavated by Bordes. They are undoubtedly the finest and most complete Mousterian data in the world. Soil analysis has been done of all the deposits; animal bones are well preserved; pollen profiles have been made for all the 55 Mousterian occupation levels. The sophisticated excavation techniques used at Combe Grenal make it possible to reconstruct the relation of each tool at the site to other tools, to hearths and to clusters of animal bones. We were thus delighted when Bordes graciously volunteered to allow us to analyze his findings.

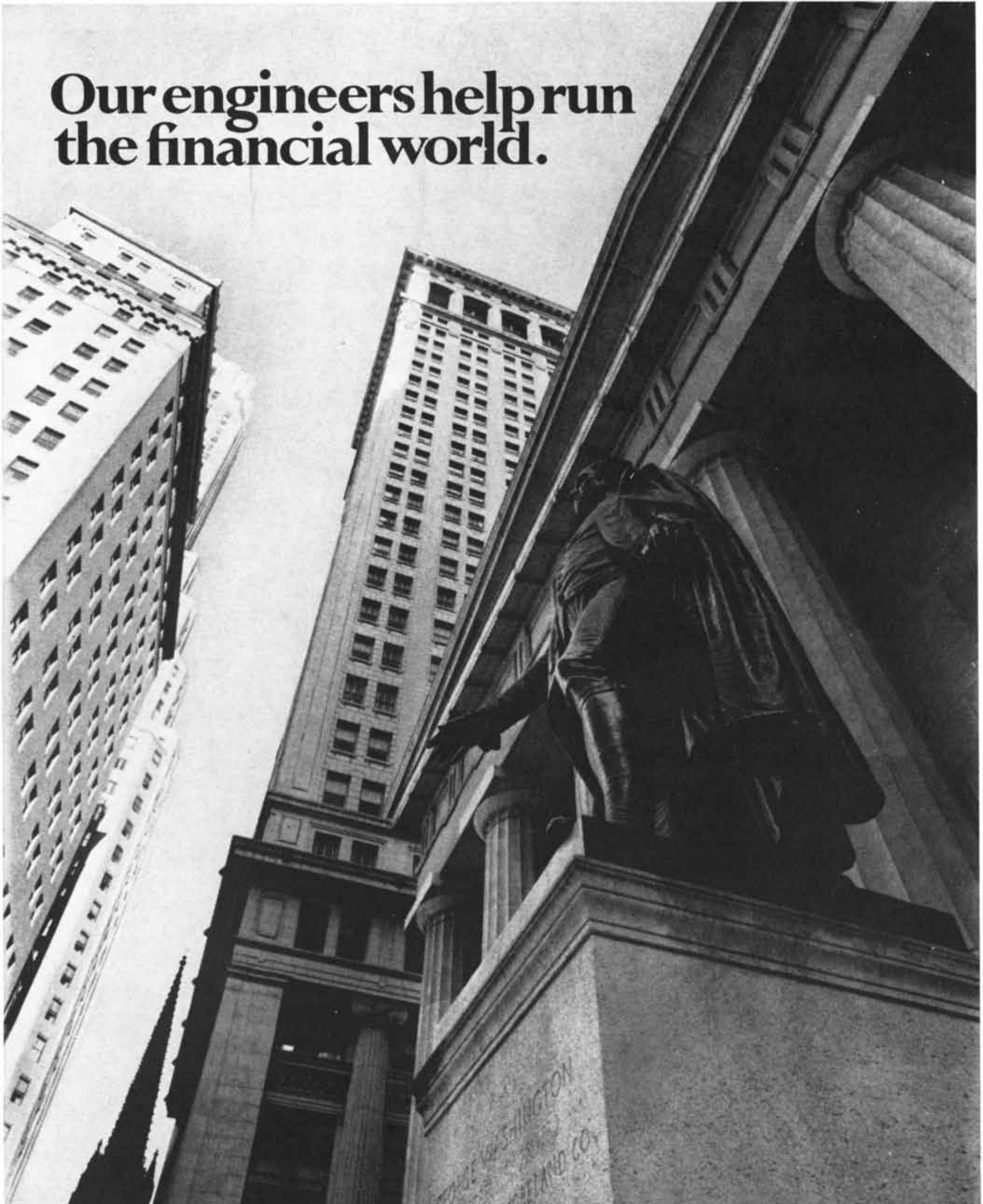
Our analysis of the Combe Grenal data has occupied the past eight months. (It has been made possible by a grant from the National Science Foundation.) While the work is far from complete, results of a preliminary factor analysis can be summarized here. First, the larger and more complete sample has shown a far wider range of variability than the smaller samples from the Near East have. The tool assemblages in all the Mousterian levels thus far analyzed—41 in number—consist of two or more factors. The factor analysis produced a total of 14 distinct tool groupings, in contrast to the five factors in the Near Eastern sites. In comparing the Combe Grenal analysis with that of the material from the Near East we note some gratifying consistencies. Such a replication of results with independent data from another region suggests that we have managed to isolate tool groupings that have genuine behavioral significance.

In attempting to relate clusters of tool types to environmental variables such as climate (measured by pollen and sediment studies) and game (as shown by animal bones) we have found no simple, direct form of correlation. There is, however, a nonrandom distribution of the frequency with which a given factor appears in levels that are representative of different environments. It appears that major shifts in climate, sufficient to cause shifts in the distribution of plants and animals, did precipitate a series of adaptive readjustments among the inhabitants of Combe Grenal.

Our present work on the material from Combe Grenal has led us to propose a series of refinements in interpretation. It is clear, for example, that the portability of game played a significant role in determining whether an animal was butchered where it was killed or after it was carried back to the site. We are now reclassifying the bones from that site by categories based on size, as well as by anatomical parts represented, and this should provide information that is not currently discernible. Whether an animal is an upland or a valley form and whether it occurs as one of a herd or as an individual is also evidently significant. We suggest that the behavior of the animals hunted had a profound effect on the degree of preparation for the hunt and on the size and composition of the hunting groups.

It should be stressed that the findings presented here are our own and not Bordes's. As a matter of fact, discussions of our interpretations with Bordes are usually lively and sometimes heated, although they are always useful. We all agree that Combe Grenal contains so much information in terms of so many different and independent classes of data that many kinds of hypothesis can be tested. Indeed, a procedure that requires the testing and retesting of every interpretation against independent classes of data could be the most significant outcome of our work.

If one goal of prehistory is the accurate description of past patterns of life, certainly it is the job of the archaeologist to explain the variability he observes. Explanation, however, involves the formulation and testing of hypotheses rather than the mere assertion of the meaning of differences and similarities. Many traditionalists speak of "reading the archaeological record," asserting that facts speak for themselves and expressing a deep mistrust of theory. Facts never speak for themselves, and archaeological facts are no more articulate than those of physics or chemistry. It is time for prehistory to deal with the data according to sound scientific procedure. Migrations and invasions, man's innate desire to improve himself, the relation of leisure time to fine arts and philosophy—these and other unilluminating clichés continue to appear in the literature of prehistory with appalling frequency. Prehistory will surely prove a more fruitful field of study when man is considered as one component of an ecosystem—a culture-bearing component, to be sure, but one whose behavior is rationally determined.



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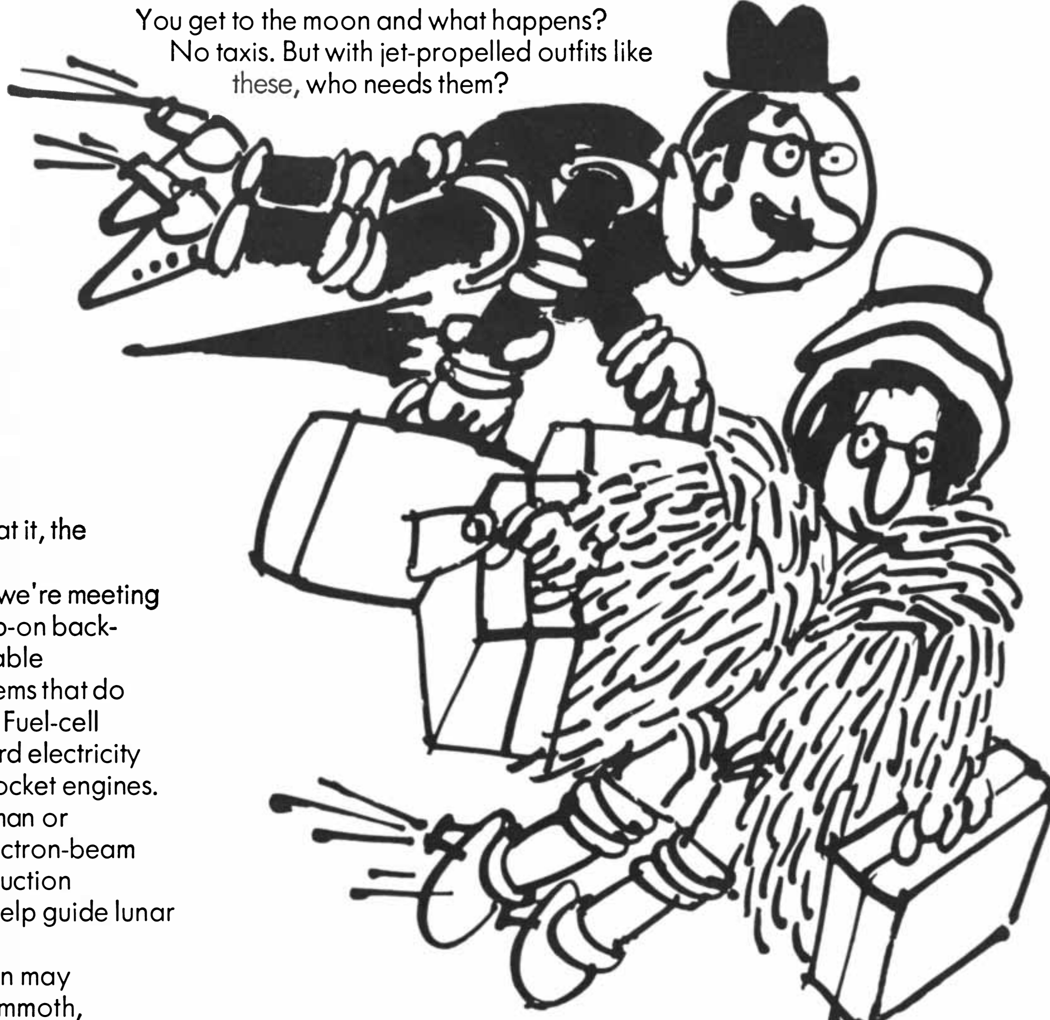

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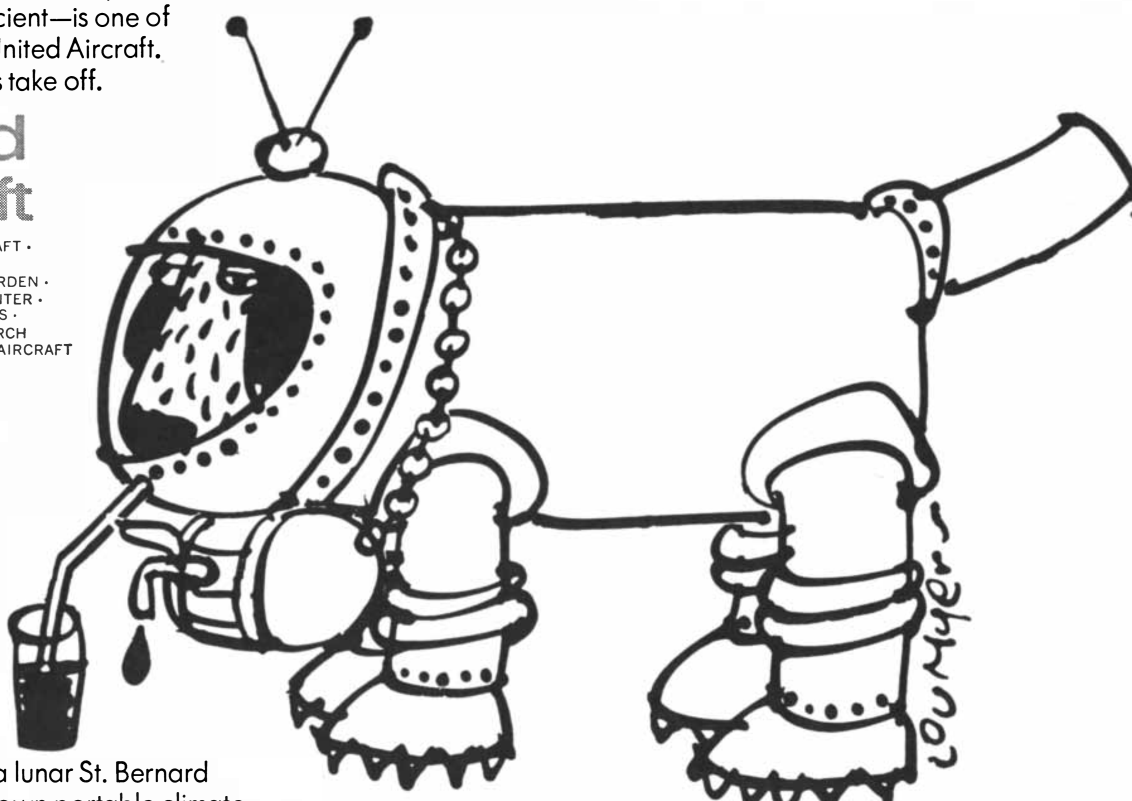


To survive in space, even a lunar St. Bernard will need his own portable climate.

Soil Pollutants and Soil Animals

How is the ecological system of the small invertebrates that live in the soil (and play such a key role in its character) affected by the introduction of pesticides?

by Clive A. Edwards

Few people are aware of the vast numbers of small invertebrate animals that live in the first few inches below the surface of the soil. Yet the soil's structure, its fertility and even its formation greatly depend on these invertebrates. Into their shallow but ubiquitous environment modern agriculture now injects huge quantities of potent new substances: chemical pesticides. How do these substances and other pollutants affect the complex, interrelated world of the soil animals? This question has been taken up by our research group at the Rothamsted Experimental Station in England.

Soil animals, which belong mainly to three invertebrate phyla, vary greatly in size and form. The largest of them, the earthworm, is the best-known member of the phylum Annelida. Some earthworms can grow to a length of six feet, and the earthworm population in an acre of average pasture in the Temperate Zone may weigh 500 kilograms, or about as much as a steer. At the other end of the scale, the smallest soil animals are the microscopic Protozoa. The rest of this extensive fauna, which ranges through the roundworms of the phylum Nematoda, the enchytraeid worms (another group of annelids) and species representative of almost every class in the phylum Arthropoda, are intermediate in size. The soil under one square meter of ground can contain as many as a million arthropods, and these are greatly outnumbered by the nematodes and the protozoans. The biomass, or weight of living matter, of all the soil animals (exclusive of microorganisms) in such an area can total as much as 500 grams, or roughly a pound. The smallest and largest organisms—the protozoans and the large invertebrates such as earthworms—contribute the most to this biomass.

Some soil animals spend much of their lives at depths in the soil greater than 12 inches, but the majority are found within the top three inches [*see illustration on page 90*]. They are not distributed uniformly throughout the soil but are grouped in large or small aggregates; the patterns of distribution vary from species to species. The animals also migrate vertically in response to seasonal changes in the environment.

Many members of the soil-animal community live by disintegrating and digesting plant residues, breaking the debris down into its organic and inorganic constituents and working the end products into the soil structure. The most important of these soil-conditioning animals are the earthworms, their relatives the enchytraeid worms and representatives of several arthropod classes: wood lice (crustaceans), millipedes (myriapods), oribatid mites (arachnids) and several insects, particularly springtails, termites and the larvae of beetles and flies. In places where only a few of these animals are present the soil is usually of poor structure and contains distinct layers of undecomposed organic matter near the surface [*see illustration on page 91*]. Soil that contains few invertebrate animals or none still produces crops if it is well tilled and artificially fertilized (although in fact the process of cultivation tends to reduce the number of soil animals). If there were no invertebrate populations in woodland soils, however, the process of soil formation would be very slow or would stop altogether, with drastic ultimate effects on the soil's fertility.

Not all soil animals are beneficial. Some beetle and fly larvae are serious crop pests. Other arthropods (among them millipedes, several mites and the tiny, primitive, centipede-like symphylids) occasionally damage crops. Still others (spiders, centipedes and parasitic mites) prey on their fellow soil animals. Because their prey includes both beneficial species and pests, however, it is difficult to assess their net effect on soil fertility.

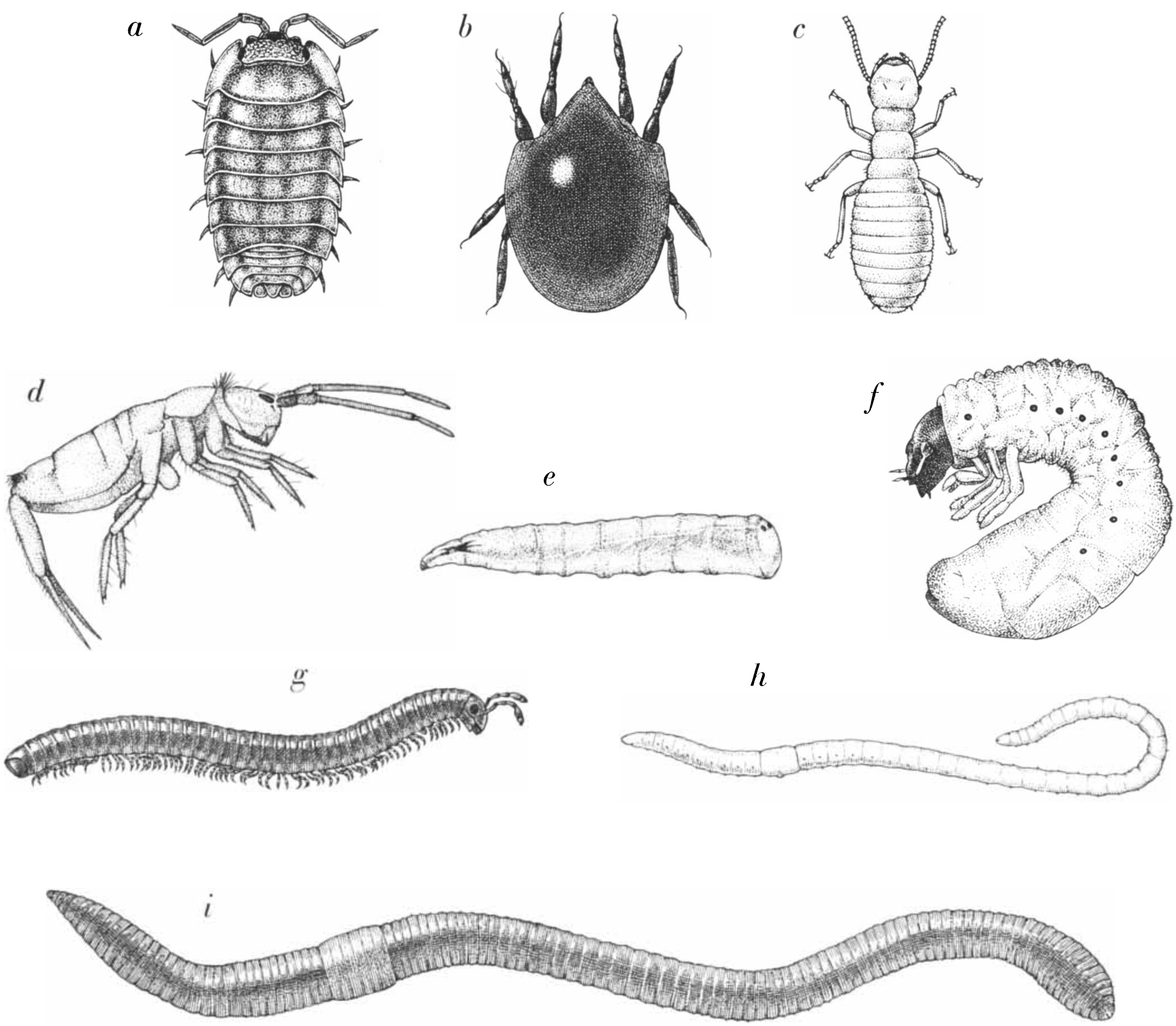
The most important soil pollutants are the large quantities of insecticides, fumigants and herbicides that are used on crops and timberlands. Some are applied directly to the ground, but even when the chemicals are applied to foliage some residues eventually reach the soil, either as direct runoff from the leaves or when plant remains that contain them fall to the ground and are mixed with the soil. Because many pesticides (particularly the chlorinated hydrocarbons such as DDT) have a high degree of chemical stability, these chemicals and their residues remain in the soil for a long time.

At Rothamsted during the past six years my colleagues and I have investigated the reactions of soil animals to most of the insecticides that could be expected eventually to reach the soil because of their mode of application. We found the effects were least severe when (for example as a result of aerial spraying) the chemical reached the surface of the soil but did not become mixed with it through cultivation. Such surface residues are much less persistent than chemicals that have been incorporated into the soil, and they kill only those soil animals that pass part of their lives on the surface.

When the insecticide is mixed with the soil by cultivation, it reaches many more soil animals. Indeed, the more efficient the cultivation and the better the incorporation, the longer the chemical will persist and the larger the number of soil animals that will be killed. It is virtually impossible, however, to mix the discrete particles of insecticide evenly through the soil. Therefore the smaller the animal, the smaller the proportion of its living space that will be contaminated and the better its chance of survival.

Soil animals differ widely in their susceptibility to the many different kinds of insecticide that reach the soil. One chemical may completely eliminate a particular species whereas another leaves the species unaffected. Moreover, many species are either susceptible or resistant to all of a wide range of insecticides that differ considerably from one another in chemical structure, activity and persistence. We found, for example, that many different insecticides are lethal to four particularly susceptible groups of animals in the soil populations: predatory mites, pauropods (another of the primitive, centipede-like arthropods), springtails of the isotomid family and the larvae of flies. On the other hand, most of the other families of springtails and all symphylids have considerable immunity to many insecticides, and earthworms and enchytraeid worms are also unaffected by most of these chemicals.

Insecticides persist in the soil from a few days to many years. Whether the chemical disappears slowly or quickly from the soil, the soil-animal populations usually remain changed for many months after the last residues have vanished. The duration of such an ecological upset depends both on the persistence of the chemical and on its absolute toxicity. This was best illustrated when we observed springtails recolonizing soil areas that had been treated with pesticides that differed in two characteristics. Dichloropropane-dichloropropene (D-D) was the least persistent chemical applied, but it was also the most toxic. It eliminated the springtail population completely in the 30 days after treatment, by which time the last trace of D-D had dissipated. The first evidence of springtail recolonization did not appear until 90 more days had passed, and almost two years were required for the springtail population to return to its original size. In contrast, simazin (a herbicide), which is a far more persistent



NINE SOIL-DWELLING ANIMALS are the chief consumers of plant debris and are primarily responsible for the fertility of the soil. Seven of them belong to the phylum Arthropoda; they are the wood louse, a crustacean (*a*); the oribatid mite, an arachnid (*b*); a termite (*c*), a springtail (*d*), a fly larva (*e*) and a beetle larva (*f*), all insects, and a millipede, a myriapod (*g*). The other two are worms of the phylum Annelida, an enchytraeid worm (*h*) and the common earthworm (*i*), the largest animal in the community.

compound but is less toxic to soil animals, eliminated only 70 percent of the springtail population in 30 days. Its last residues did not disappear until five months later, but by then the springtail population had regained 90 percent of its initial numbers [*see top illustration on page 92*].

It is nevertheless the more persistent insecticides rather than the more toxic ones that have the most drastic influence on the numbers of soil animals. This is probably because most of these animals encounter the chemicals as they move around through cracks and crevices in the soil; a transient insecticide will disappear before many animals have accumulated a lethal dose. Agriculturists currently favor insecticides that persist for less than one growing season. It is significant that these chemicals have not been as successful as the more persistent insecticides in controlling the soil pests at which they are aimed nor have they affected the soil-animal community as drastically.

The relationship between the amount of insecticide applied and the number of soil animals killed is not directly proportional but more nearly logarithmic: a dose 10 times greater may kill only twice as many animals. Thus it is not surprising that with a persistent insecticide repeated annual applications have little more effect than a single dose. The soil community lives in a state of dynamic equilibrium and shows marked seasonal changes in numbers; the influence of a persistent insecticide is therefore greatest in the fall and the spring, when the populations of soil animals are at their peak.

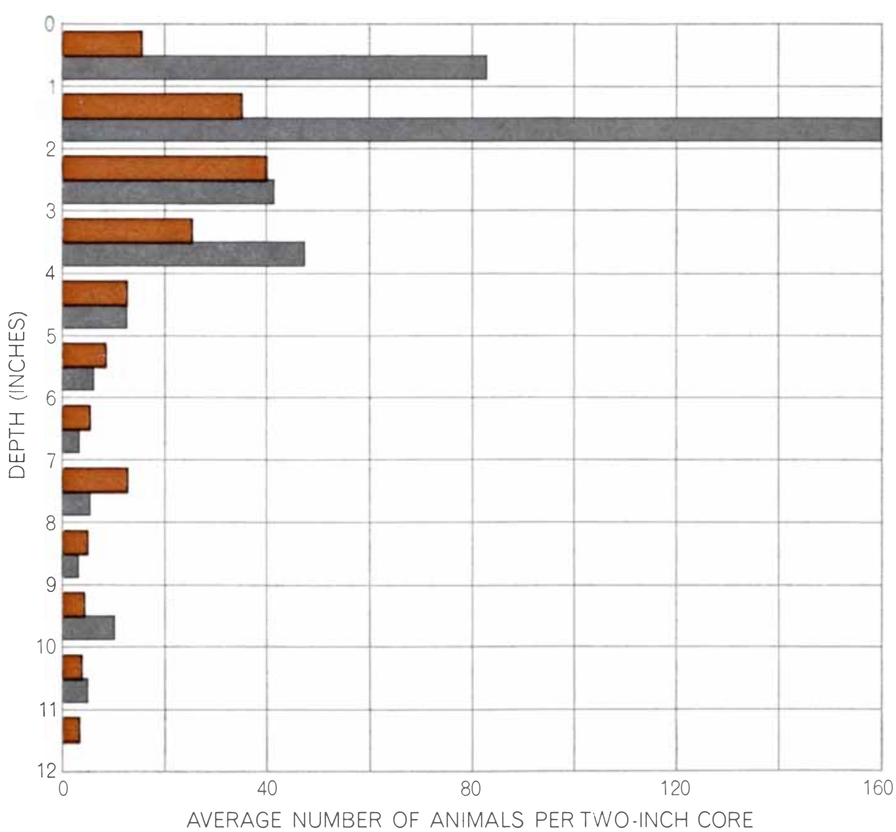
Fumigants, as distinct from insecticides, are injected directly into the soil in the form of a gas, with the aim of controlling harmful microorganisms and other pests. At the same time they kill almost all the soil animals in the treated area because the toxic gases can penetrate the smallest crevices in the soil and are lethal to most organisms. Fumigants are relatively transient, however: they persist for a few weeks at most. They also seldom penetrate the soil to a depth of more than 12 inches. Arthropods such as diplurans (a primitive wingless order of insects) and symphylids spend much of their time deeper in the subsoil; after the last traces of a fumigant have vanished they may return and recolonize the soil from below. Our experiments have shown that animals such as springtails (which may be carried into the fumigated area by air currents) and fly larvae (which may hatch from eggs already laid in the soil) can recolonize the sterile area from above faster than others can by migration from the subsoil. The animals that first recolonize the soil multiply rapidly and soon become more numerous than they would be in untreated soil. This increase is temporary; the numbers of these pioneers decrease as other species gradually return. Nevertheless, the process is slow. Even after two years there may still be fewer species of animals in a fumigated soil than in an unfumigated one.

Herbicides are a group of chemicals that have only limited direct effects on the soil community. Some herbicidal compounds can kill soil animals on contact, but more often their influence is indirect. The weeds that herbicides destroy are an important food source for certain invertebrates; these soil animals feed on the growing roots of the weeds or digest their decaying remains. Once the weeds are gone the populations of soil animals dependent on them usually decrease.

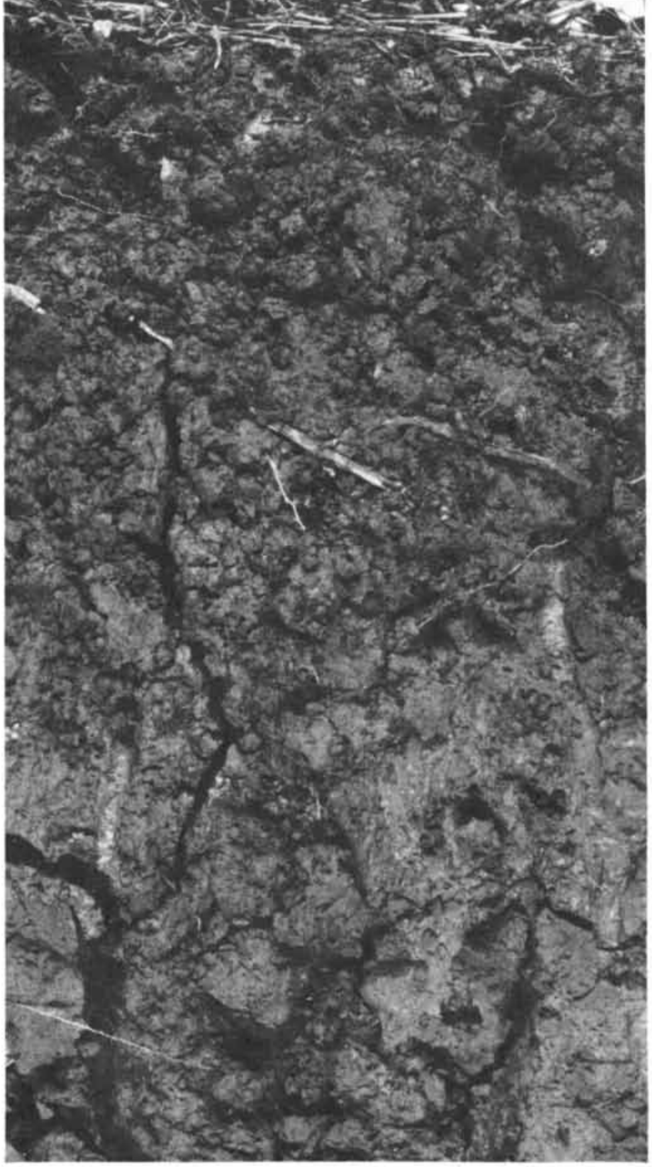
We tested many herbicides for their direct effects on the number of soil animals. Only DNOC (4,6-dinitro-ortho-cresol) and simazin (which is the more toxic of the two) significantly reduced the populations. Even with these herbicides a decrease in numbers usually did not persist beyond the time the chemicals remained in the soil. Clearly herbicides do not constitute a serious hazard to the soil community.

Another of our enterprises at Rothamsted has been a study of the effects of ionizing radiation on soil animals. Such studies in the past have been concentrated on a few orders of insects; the usual objective has been to use gamma rays or X rays to kill insect pests (notably beetles) that feed on stored produce or to sterilize certain insects before releasing them to interfere with the species' breeding cycle in the wild. The main objective of our work was to measure the resistance of soil animals to radioactive contamination such as might result from fallout or from the improper disposal of radioactive waste. A secondary aim was to determine the amount of gamma radiation needed to produce a soil free of animals for experimental purposes.

We have now recorded the effects of different doses of gamma radiation both on individual soil animals and on populations in soil, including in our studies



VERTICAL DISTRIBUTION of soil animals in a pasture (*black*) and a tilled field (*color*) was determined at Rothamsted Experimental Station in England by counting the numbers of animals contained in cores of soil two inches in diameter and 12 inches long. Pasture soil harbored the larger population, but in both areas most animals were near the surface.

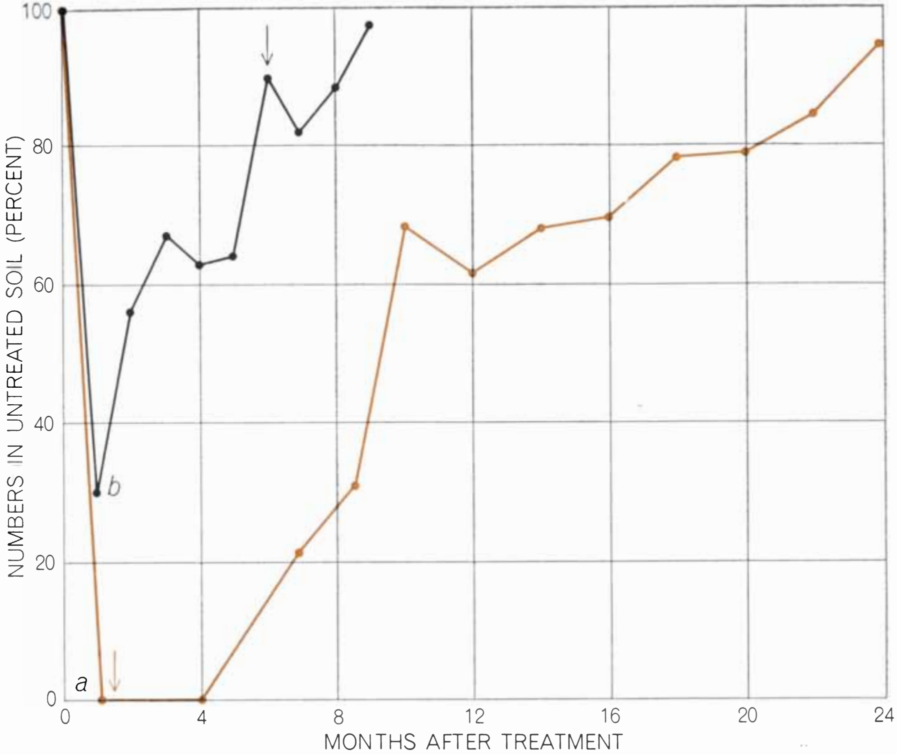



GOOD AND POOR SOILS are seen in foot-deep profiles. The good soil (*left*) is in an orchard with a large population of earthworms. The poor soil (*right*) is also in an orchard; the earthworms there, however, were killed by copper residues from spraying. In the good soil undecomposed plant debris is largely confined to the surface. In the poor soil it has collected in a thick black layer (*top*).

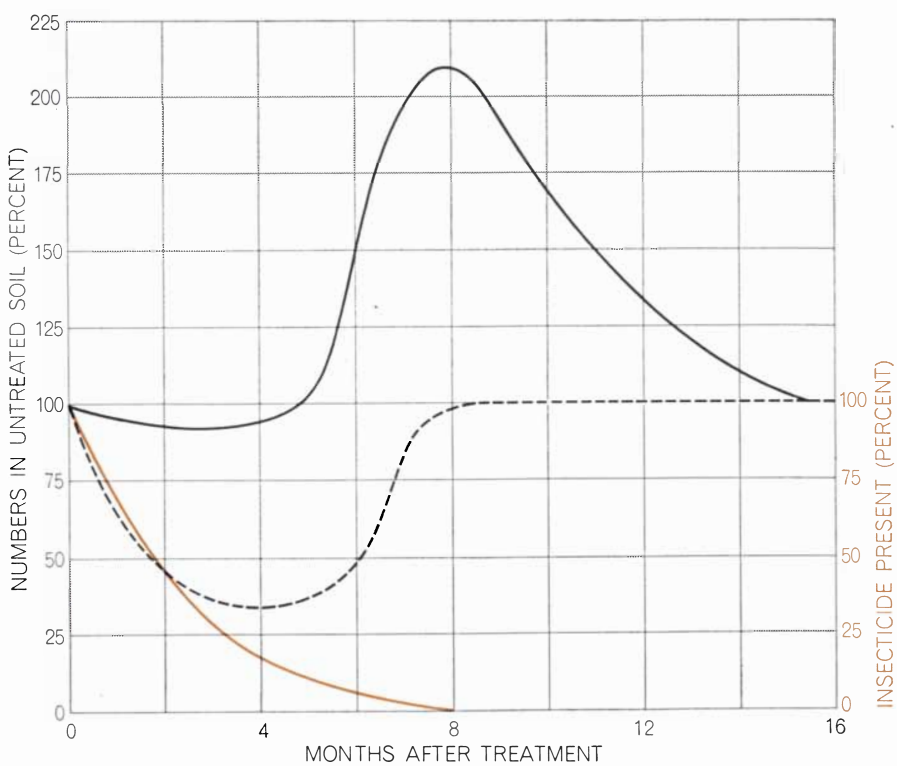
most of the animals that are members of the soil community. Although these animals varied greatly in their susceptibility to radiation, most could survive doses of several thousand rads (a rad is a dose amounting to 100 ergs per gram of the recipient's body weight). For humans the median lethal dose—an exposure that kills half of those who receive it—is only 400 rads. Soil animals, however, are much more susceptible to gamma radiation than are the soil microflora. Populations of fungi and bacteria recover in a few weeks from doses in excess of 200,000 rads, whereas such exposures eliminate some soil animals for months and even years.

There appears to be little or no correlation between the susceptibility of soil animals to radiation and their taxonomic position. Different species within a given order or family often had a greater range of sensitivities than did representatives of different orders or classes. The most striking correlation we found was between an animal's susceptibility and its activity level: the greater its mobility, the smaller the dose of radiation needed to kill it. Very active animals—centipedes, wood lice, symphylids, parasitic mites and surface-living springtails—die much sooner after being irradiated than the more sluggish, deep-living springtails and oribatid mites. After exposure to a 200,000-rad dose the median lethal time (the time by which half of the exposed population is dead) ranges from less than a day for wood lice to nearly a month for oribatid mites. When the dose is reduced to 10,000 rads, the median lethal time for wood lice rises to 11 days and for oribatid mites to about 70 days. When exposed to these doses of radiation, animals that are moderately active, such as earthworms, nematodes and the larvae of flies and beetles, die after periods intermediate between those for wood lice and oribatid mites.

Radiation kills soil animals much more slowly than insecticides do. A proportion of the animals exposed to a dose of radiation above their minimum lethal dose die in less than a week, but those that escape this initial damage take much longer to die. Some of the longer-lived invertebrates survived for several months before succumbing to the lower doses of



PERSISTENCE AND TOXICITY of a pesticide affect its performance. The springtail population of one test plot (*color*) was reduced to zero in 30 days (*a*) by an application of D-D, an insecticide of great toxicity but short persistence. By then the last residues of D-D had disappeared (*colored arrow*). The plot remained free of springtails for 90 days more, and the numbers of the recolonizers did not approach the pretreatment level for 21 months more. Another plot was treated with simazin, a less toxic but more persistent chemical. Although its residues persisted for six months (*black arrow*), the springtail population never fell below 30 percent of its original level (*b*) and was back to normal within nine months.



UPSET OF EQUILIBRIUM between the numbers of predators and prey occurs when application of an insecticide kills many of the predatory mites in a test plot (*broken line*). The springtail population, the mites' prey (*solid line*), was scarcely affected. Soon after the number of mites fell to a minimum four months later, the number of springtails began to rise sharply. As the chemical continued to break down (*colored line*), the number of mites gradually returned to normal. The springtails, however, took longer to return to normal.

radiation tested in our experiments. This makes it difficult to express the radiation susceptibility of soil-animal populations, as distinct from individuals, in terms of median lethal doses (as is common with insecticides). The total number of animals in the soil was greatly reduced even by the lower doses of radiation we administered; a 10,000-rad dose, for example, killed a large percentage of the animals in a soil. To kill all the animals took a dose as large as 200,000 rads, and even then a few animals survived for as long as three months [*see illustration on page* 97].

The most valuable of all the soil invertebrates to man is probably the earthworm; these animals break down much of the plant debris reaching the soil and also turn over the soil and aerate it. Accordingly pesticide residues in soils that appreciably reduce the numbers of earthworms are a particularly serious matter. Fortunately earthworms are not susceptible to many insecticides. Of all the insecticides we have tested only chlordane, heptachlor, phorate and carbaryl seriously decreased populations of earthworms. None of the chlorinated hydrocarbons other than chlordane or heptachlor affected them even when large doses were applied. Although organophosphorus insecticides other than phorate sometimes reduced earthworm numbers slightly, the populations soon recovered from these chemicals, which were comparatively transient.

A more important aspect of soil pollution with chlorinated hydrocarbons is that earthworms can concentrate these chemicals from the soil into their fatty tissues. We have found aldrin and dieldrin residues in the bodies of earthworms at a concentration as much as 10 times higher than in the surrounding soil. Other workers have substantiated these results and have shown similar concentration into tissues of heptachlor, heptachlorepoxide and DDT. Such uptake of persistent insecticides has more than academic interest; earthworms provide food for such animals as birds and moles, which themselves can concentrate these insecticides in their bodies. Hence earthworms, as a lower link in a food chain, may be an important source of undesirable chemical residues in higher animals. Fortunately we have found no such concentration of the organophosphorus insecticides (which are replacing chlorinated hydrocarbons for many agricultural purposes) in earthworms.

The ecological implications of the effects of pollutants on populations of soil invertebrates are significant. One of

What women like about the Rover 2000 Automatic

We cannot say we designed the Rover exclusively for ladies any more than we designed it exclusively for gentlemen. But the fact is ladies like it. Admittedly, some of the things they see in the Rover may seem trivial to menfolk, but to ladies little things mean a lot.

Opening and closing.

Long fingernailed ladies need not worry about breaking their nails when they open the door—the push buttons on the doors are twice as long as normal.

Stepping in and stepping out.

No big deal really. It's just simpler because the floor is four inches below the door sill and the doors open w-i-d-e.

Room—with a view.

Once seated, there is a great amount of room for leggy legs. A lot of headroom, too. The view from all windows is excellent and uninterrupted. A lady can see exactly where the right fender is going without having to guess.

Seating arrangements.

The two front bucket seats can be adjusted to the contours of any female shape. They go forwards and backwards, adjust from English upright to chaise longue. Although all four seats tend to hug their occupants, we suspect that ladies really love them because of the smell and feel of English leather.

Big wheel.

The steering wheel is larger than is usual, which makes it easy to turn and ladies like that. It can be moved up or down. When the car is still, the steering is a little stiff; just stiff enough to remind the driver to look behind before pulling into traffic.

Shifting and handling.

Some ladies don't like shifting and with the Rover automatic transmission, they don't have to. And, if they want to—well then, it can be just as manual as they please. The car handles effortlessly; holds the road like a leech. It's a snap to park—not just because it's shorter and narrower than Detroit's finest but also because it turns circles inside them and most other cars. Yes, even a VW.

Bric a brac.

Two huge padded bins beneath the dashboard can hold an arsenal of cosmetics and packages. Even jumbo purses. Both bins lock. Above them is a generous shelf with a clingy rubber surface that stops things like earrings and sunglasses from sliding around.

Easy to read.

The speedometer is the ribbon type, unmistakably clear to read and placed so as to reduce the difficulty of refocusing when glancing from road to speedo and back. The switches are clearly marked and shaped so you can recognise them, even by feel. No two next to each other are shaped alike. A bold red brake light on the dash tells a lady: (1) the handbrake is on or, (2) the level of the braking fluid is low. High beams can be flashed, with headlights on or off, by flicking a lever on the steering column.

The quiet type.

The Rover is quiet inside save for the engine's reassuring purr. Thick wall-to-wall carpeting absorbs lots of noise. There is, however, a loud built-in sound which ladies with children appreciate—the loud click behind the driver's ear when someone unlocks a rear door from inside. The trunk is doubly carpeted, and the spare wheel has a cover to keep the luggage clean.

Out of gas?

Nothing to worry her pretty head. A reserve fuel tank switch on the dash gives her an extra thirty miles or so to find a gas station.

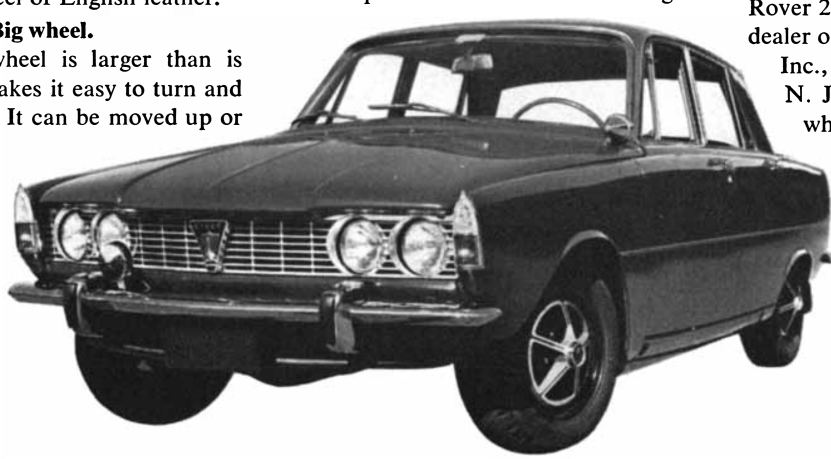
About those dents.

Say someone biffs the Rover in a parking lot, what then? It's a relatively simple garage task to remove the dented panel and replace it—Rover's nineteen body panels are simply bolted on. It's even possible, at some expense, to get a spare set of panels in another color.

Know more.

If you want to know more about the Rover 2000 Automatic ask your Rover dealer or write: British Leyland Motors Inc., Willow Tree Road, Leonia, N. J. 07605. (We'll even tell you what men like about it.)

BRITISH LEYLAND ROVER



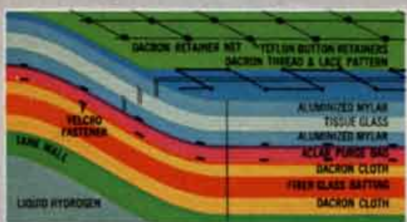
Heard about the Roverseas Delivery Plan? The same money it costs to buy a new Rover over here may buy you a new Rover in England and cover your transatlantic air fare, too.

Achieving critical cooling ...anywhere

• Multilayered "blanket" of ultra-thin sheets can insulate cryogenic propellants for long space trips. • Turbine fog is turned from nuisance to cooling agent in new air-cycle system. • Solid cryogens in tandem will work to refrigerate infrared detectors over year-long space missions. • Wind tunnel and computer help to solve unique high-heat problems for USAF's Mach 3+ SR-71.

The interplay of heating and cooling vitally affects the performance—and the life—of materials, fuels, instruments, and controls. Some of Lockheed's advanced ways of beating the heat with insulation and cooling techniques are briefly described here.

Thinning down a heat barrier. As space missions grow longer in time, the effectiveness of protective insulation for liquid cryogen propellants will become ever more crucial. Yet such insulation systems, while being highly reliable, should be ultra-thin and ultra-light so that they consume little of the spacecraft's precious allotments of volume and weight.



"Blanket" for insulating liquid cryogen propellants.

For exotic applications, therefore, Lockheed has developed an exceptionally thin, light, high-performance laminated system in which a multiple number of 0.00015-in.-thick aluminized plastic radiation shields and 0.0006-in.-thick fiber-glass paper separators are sandwiched in layers.

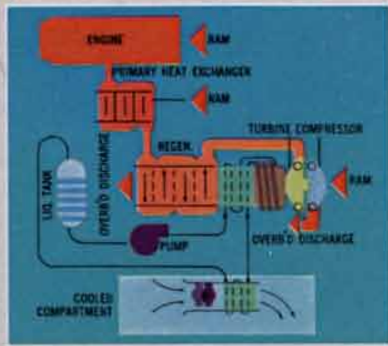
The resulting multilayered "blanket" has proved to be the most formidable heat barrier yet devised for shielding hypercold propellants like liquid hydrogen, oxygen and fluorine. And it promises to see many other space uses; for example, keeping instruments, optics, sensors, antennas and other equipment at optimum temperatures.

Harnessing an unwelcome fog. Present-day aircraft using air-cycle cooling systems can be plagued by internal fog when operating in humid climates. Dense amounts of vapor, discharged from cooling turbines, create unfavorable humidity for instruments and an actual clouding up of cabins. Unfortunately, so-called fog separators often cannot relieve the condition.

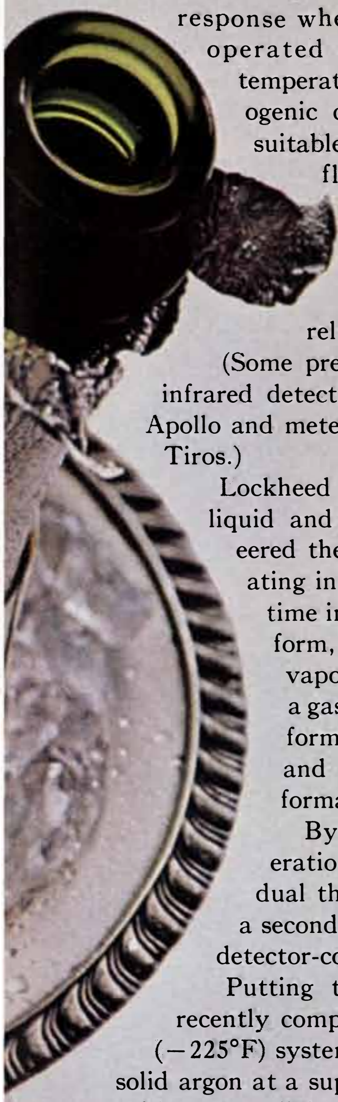
To beat this problem, Lockheed has put the trouble-making fog to good use in a unique Indirect Air-Cycle Cooling System. Instead of extracting the moisture and draining it overboard as waste, the Lockheed system intercepts the fog and reevaporates it. This process acts to reduce the temperature of an indirect coolant; the coolant, in turn, is plumbed to other locations for local cooling of occupied spaces or heat-generating equipment.

The Lockheed system thus performs three constructive

operations: It blocks visible fog from the cabin, utilizes the vapor's inherent cooling capacity, and prevents subfreezing fog from icing up the elements downstream of the turbine.



System uses turbine-generated fog to help cool remote areas of aircraft.



Refrigerating the refrigerants. Infrared detectors, critical sensors for spectral measurement and scanning devices used in space, show their best sensitivity and response when operated at temperatures below −279°F. This makes cryogenic cooling a necessity. But devising a suitable refrigeration system for long-time flights means solving a many-sided problem: The system must have low weight, volume, and power consumption...and the volatile, delicate cryogens must last and work reliably throughout the mission.

(Some present, typical applications for cooled infrared detectors are on such major programs as Apollo and meteorological satellites like Nimbus and Tiros.)

Lockheed scientists, after extensive research on liquid and solid cryogen characteristics, pioneered the use of cryogenic solids for refrigerating infrared detectors during long spans of time in space. The reason is basic: In liquid form, a cryogen has a given latent heat of vaporization—or phase transformation to a gaseous state. The same cryogen in solid form, however, has much higher density and a higher latent heat of phase transformation.

By applying solids in an advanced refrigeration concept, Lockheed has developed a dual thermal-protection technique in which a secondary solid cryogen guards the primary detector-cooler.

Putting these principles to work, Lockheed recently completed a solid-cryogen carbon dioxide (−225°F) system which acts as thermal protector for solid argon at a supercold temperature of −369°F. This refrigerator efficiently cools an infrared detector, with its heat load of 17 milliwatts, for a full year. And other year-or-more systems under development include those of comparatively light weight and low volume that use a solid neon primary coolant at a near-absolute-zero temperature of −432°F.

Controlling high-speed heats. The U.S. Air Force's special-purpose SR-71 endures harsh temperature cycles —from below −60°F to above +630°F—and flies reliably for long periods at searing Mach 3+ speeds. Every material and component in the aircraft must withstand environments hotter by far than ever experienced before in steady-state flight. And when Lockheed's Skunk Works started the SR-71 design, many of the complex thermodynamic problems had no precedents.

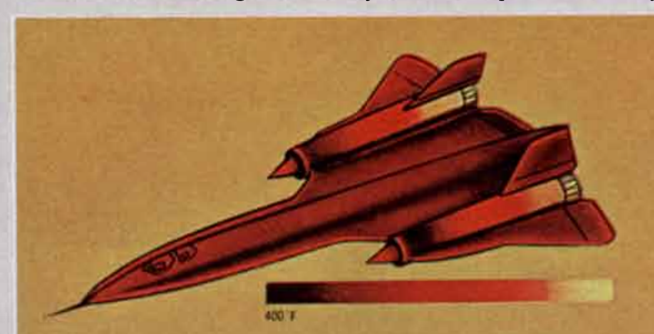
All aspects of internal and external thermodynamics were probed in the developmental studies—every tool was used from the straight-forward experimental approach in the wind tunnel to the complex analytical approach utilizing the maximum capability of the modern computer.

Wind tunnel coefficients helped project the external environment: High skin temperatures and stagnation ram air above 630°F. Because temperatures would be above aluminum alloy limits, titanium alloys were used for all skins and structure. A special high-emissivity black paint was applied to increase radiative heat loss and to help reduce skin temperatures. And, since the external skin is also the fuel tank skin, Lockheed created a unique tank sealant that would tolerate both severe flexing in flight and severe heat levels.

Accurate prediction of fuel temperature rise during high-speed flight was a must. Not only would the hydraulic and constant-speed drive systems be cooled by fuel but, for the first known time in an aircraft, fuel would serve as a direct heat sink for environmental control. The cooling performance gained through this bold approach provides a habitable cockpit atmosphere.

In the fuel tanks themselves, all equipment—pumps, vents, valves, switches, and wires—had to survive high-temperature operation as the tanks emptied. Furthermore, to prevent spontaneous ignition of vapor in the tanks, Lockheed also developed a fail-safe nitrogen inerting and pressurization system.

The hottest spots are the engine, its inlet system, and the nacelle. The engine inlet system is exposed entirely


Temperature profile of the SR-71 at Mach 3+ speeds.

to stagnation air temperatures above 630°F. Within the nacelle, the engine generates even higher temperatures. In addition to using all external radiation available, the engine is cooled sufficiently during prolonged missions by passing the inlet cowl's low-energy boundary layer air between the engine exterior and the nacelle skin.

The varied SR-71 cooling techniques have proved thoroughly effective. A typical example: Many high-precision components—servo valves, actuators, electrical connectors, and others—operate reliably in the engine inlet and nacelle at temperatures that remain, during long flights, far above normally destructive values.

The activities mentioned here are only a few of Lockheed's projects in environmental controls. If you are an engineer or scientist interested in this field of work, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California 91503. An equal opportunity employer.

the most consistent effects was that some species of mites and many species of springtails multiplied to numbers far greater than those in untreated soil. These increases were invariably accompanied by a considerable reduction in the numbers of predatory mites (in particular certain rhodacarid and gamasid mites). In one long-term experiment at Rothamsted we observed the fluctuation in numbers of predators and prey over a five-year period following a single application of DDT to the experimental area. The populations of predatory mites gradually fell during the course of the experiment (in spite of seasonal recoveries) until after four years there were less than 5 percent of the numbers found in untreated soil. With each decline in mites the population of springtails increased sharply, and with each recovery of mites the springtail population decreased. At one point, just before the mite population fell to its lowest level, the number of springtails had increased to more than 400 percent of the population in untreated soil.

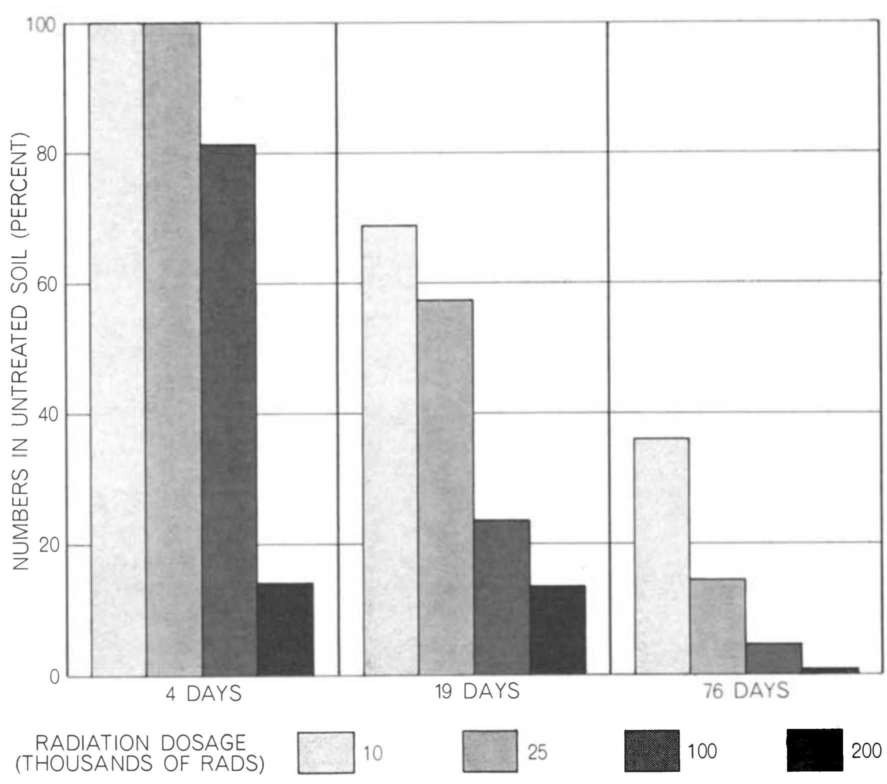
Although such increases in the springtail population usually did not occur after the soil was treated with other chlorinated hydrocarbons, they did so consistently after applications of DDT in many different experiments. Not only our group but also J. G. Sheals of the British Museum (Natural History) and Christiaan van de Bund of the Netherlands Plant Protection Service have confirmed that the numbers of a particular springtail species (*Folsomia candida*) increase when the numbers of a species of predatory mite (*Rhodacarellus silesiacus*) are reduced by DDT applied to soil. Laboratory experiments show that this mite readily preys on these springtails.

When the less persistent organophosphorus insecticides are applied to soil, the numbers of both springtails and mites commonly increase. In nine out of 12 randomly selected experiments testing the effects of organophosphorus insecticides on soil-animal populations, either the population of springtails or the population of oribatid or trombidiform mites or populations of all three increased, whereas populations of predatory mites decreased. These consistent increases in numbers are good evidence that the populations of these mites and springtails are usually limited more by predator pressure than by a shortage of available food; when their principal predators are removed, they multiply rapidly.

Increased numbers of the smaller soil animals after pesticide treatment may often compensate for the loss of larger invertebrates that play a role in breaking down decaying plant material or other organic matter in soil. In an experiment in which we buried leaves in nylon-mesh bags that excluded earthworms we found that after nine months 73 percent of the leaf material had disappeared in untreated soil, 90 percent had broken down in DDT-treated soil and only 43 percent had done so in aldrin-treated soil. These figures corresponded closely with the numbers of springtails present.

In the same experiment we observed the changes in soil-animal numbers caused by a single dose of DDT and aldrin in terms of functional animal groups [*see illustration on next page*]. As one might expect, both insecticides greatly reduced the biomass of pests. Predators were reduced to about half their normal biomass, whereas the arthropods whose main role is to break down decaying organic matter actually increased in biomass after the DDT treatment (although their total weight was considerably reduced by the aldrin). The increases in numbers and in biomass of the smaller soil animals that occur after treatment of the soil with organophosphorus insecticides can more than make up for the death of other invertebrates that assist soil formation.

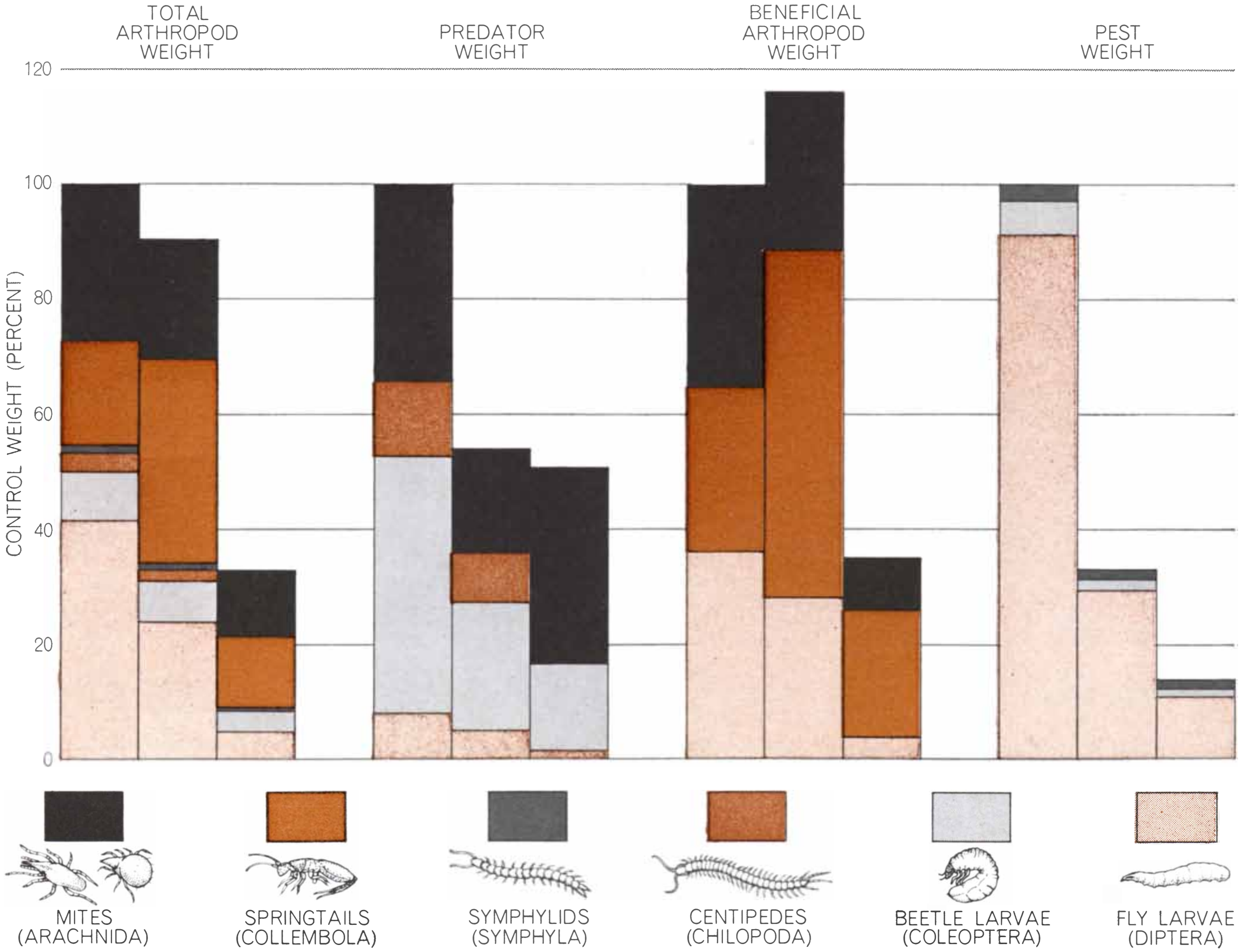
Ecologists who have studied interrelationships between predators and prey have shown that changes in the numbers of the predators usually lag behind those of the prey both when the numbers are increasing and when they are decreasing. There was not much evidence of this in our experiments with DDT, which decreased the numbers of rhodacarid mites and increased those of isotomid springtails. This may be because our samples were taken every two months and thus were not adequate to show a small difference in phase. Similar predator-v.-prey curves, plotted from data obtained from our experiments testing organophosphorus insecticides in soil, clearly demonstrate such a time lag [*see bottom illustration on page 92*]. The numbers of predatory mites usually approached the numbers found in untreated soil at about the time that the last traces of the insecticide (in this experiment chlorfenvinphos) disappeared, but the springtails did not begin to multiply beyond the numbers found in untreated soil until shortly before the mites had reached minimum numbers. This seems to be a consistent pattern, although most organophosphorus insecticides are less persistent than chlorfenvinphos.



LETHAL EFFECTS of gamma radiation were studied by exposing soil-animal populations to increasingly severe doses. The animals proved quite hardy, surviving doses 20 or more times larger than 400 rads, the median lethal dose for humans. The largest doses killed quickest but did not kill all animals. Four days after exposure (*left*) 18 percent of animals receiving a 100,000-rad dose were dead, compared with 88 percent of those receiving twice that dose. After 76 days (*right*), however, the numbers were 95 and 99.9 percent respectively.

A similar increase in the numbers of springtails occurred in some of our experiments that examined the effects of gamma radiation on soil populations. Predatory mites, which are very susceptible to radiation, were greatly reduced in numbers by small doses such as 5,000 rads, an exposure that does not kill the more sluggish species of springtail in deeper soil. A few weeks after it was irradiated soil exposed to a dose of 5,000 rads contained fewer predatory mites and many more springtails than untreated soil. This demonstrates the similarity of the ecological effects of quite different kinds of pollutants on soil-invertebrate populations. The reason certain groups of animals are susceptible to certain pollutants is related to the pollutants' mode of action. Predatory mites are probably more vulnerable to pesticides than other soil animals because their greater mobility exposes them to a larger dose of the chemical as they move through the soil, whereas radiation is probably lethal to these active mites because of interference with some metabolic pathway.

Pollutants consistently decrease not only the number of individuals within the population of each species of soil animal but also the number of species of animals present in the soil. In one of our experiments aldrin was applied to a plowed field and in another it was applied to a pasture. A census of control areas in the two fields showed that even before the pesticide was applied the plowed field harbored only 66 species of soil animals, or less than half the number in the unplowed pasture (which contained 148 species). The application of aldrin reduced the number of species in the pasture considerably, but its effect on the animals in the plowed field was proportionately less, so that ultimately the numbers in both fields after aldrin treatment did not differ greatly. The pesticide had certainly brought about a great reduction in the number of species in the pasture, but in the other field plowing had by itself reduced them nearly as much. Therefore it is extremely doubtful that the change produced by the aldrin was significant in terms of soil fertility, particularly because some of the remaining species of soil animals may have increased in numbers. In any case, after the aldrin residues had disappeared many of the eliminated species



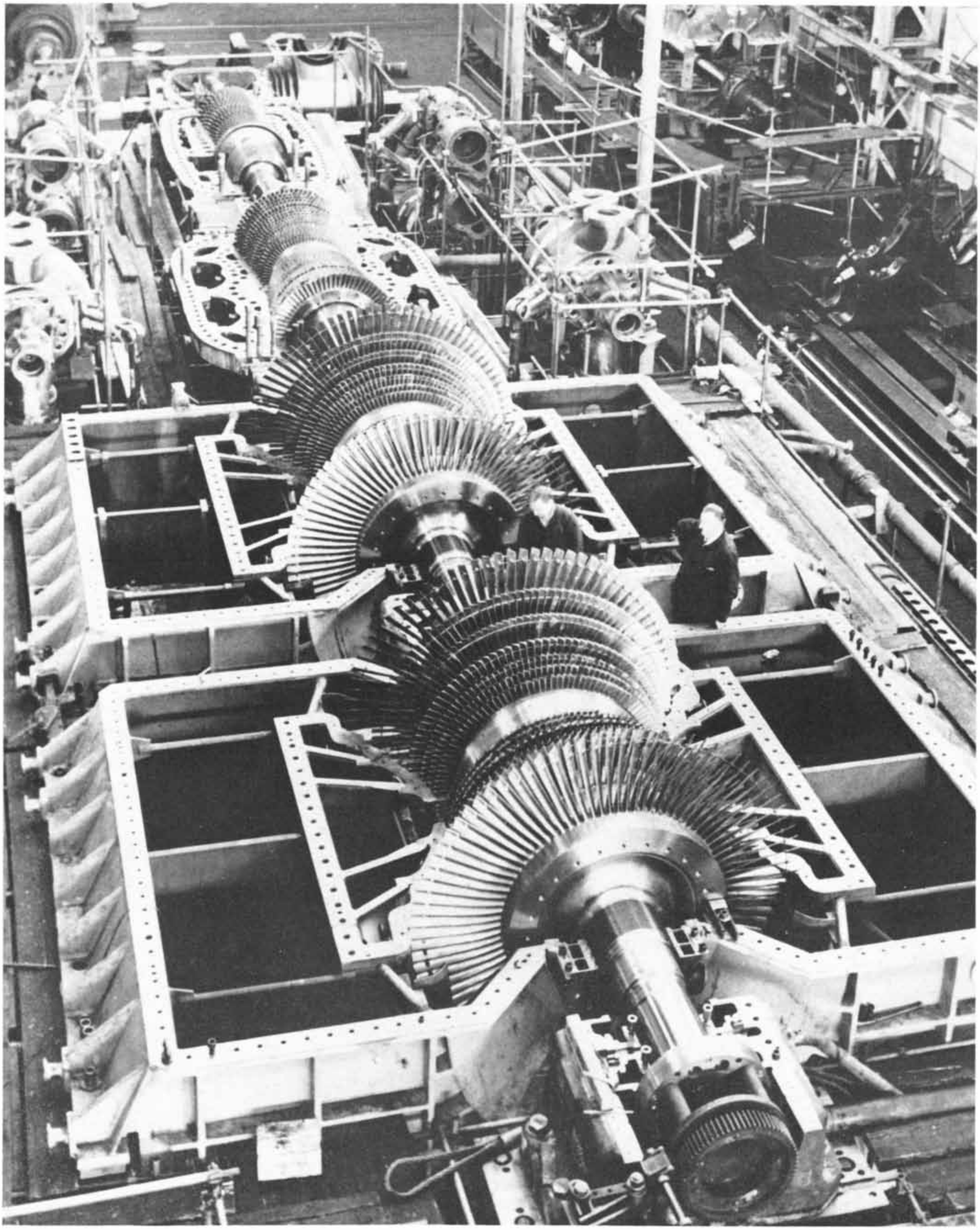
EFFECT OF INSECTICIDES on various kinds of soil animals was studied over a period of a year. Each set of columns shows the average weight of the animals listed in the key (*bottom*), expressed as a percentage of the whole, in untreated soil (*left column*) and in soils treated with standard doses of DDT (*middle column*) and aldrin (*right column*). The first set of columns shows the effect of each insecticide on all six animals. Aldrin has produced a 70 percent overall kill and has completely eliminated centipedes. DDT, lower in toxicity, appears even less toxic than it is because the weight of springtails in DDT-treated soil has doubled. The next set of columns explains the springtail upsurge: although the overall effects of DDT and aldrin on soil predators were almost identical, DDT evidently killed more of the mites that prey on springtails, reducing the pressure of predation. The third set of columns shows the result: the total weight of beneficial arthropods in the DDT-treated area is 15 percent above normal. The last set of columns shows that, as pesticides, both chemicals were quite effective against fly and beetle larvae but less so against symphylids.

recolonized the treated areas, or species new to these areas were introduced, although it was sometimes several seasons after the insecticide residues disappeared before the diversity of species was as great as it had been before treatment.

Although we can speculate on the long-term ecological effects of pollutants, we cannot precisely determine the ultimate consequence of much reduced numbers of soil animals until we fill gaps in our knowledge of the various roles played by the different species of invertebrates in the soil. Two things, however, are clear. First, even the most drastic effects of pollution cannot persist for more than a few years after the last traces of the pollutant have disappeared. Second, even the more persistent insecticides are gradually degraded.

In tilled soils any contribution the soil animals make to fertility can be replaced by mechanical cultivation and the addition of fertilizers. There are indications that in the future crops may be grown in soils without mechanical cultivation. This practice is now common in Britain, and it is growing increasingly so in the U.S. If such practice becomes widespread, soil animals may become more important in turning over and aerating arable land. There is evidence from workers such as Herbert T. Streu of Rutgers University that soil animals influence the quality of pasture, being detrimental to some species of grasses and encouraging the growth of others, but these are long-term effects and five to 10 years may pass before significant changes in floral composition are established. Current agricultural trends are to put arable land into pasture for a few years at most, so that in this situation the soil-animal community is again probably not very important.

Only in forest and woodland soils is it likely that pollutants are a potential hazard, in that they may slow down the processes of soil formation and maintenance of soil fertility. The most important pollutants in woodlands are pesticides, and the largest quantity of such pollutants comes from indiscriminate aerial spraying to control forest pests and diseases; it seems essential that such practices should be limited or abolished. Thus it appears that although pollutants may cause extensive ecological changes in the soil and hence should be eliminated wherever possible, their effects are currently much less serious than the similar pollution of oceans, lakes and streams that threatens a wide range of aquatic organisms.



ANATOMY OF A STEAM TURBINE is exposed in the shops of Brown, Boveri & Company Limited near Zurich. When connected to an electric generator, this turboset, as it is called, is capable of producing 320 megawatts of electricity, equivalent to approximately 400,000 horsepower. It thus ranks among the larger sets built with a single shaft. Steam enters the turboset at a pressure of 2,640 pounds per square inch and a temperature of 977 degrees Fahrenheit. After passing through the high-pressure turbine, located at the extreme rear, the steam is reheated to 977 degrees and then enters a double-flow intermediate-pressure turbine, located in the housing next in line. The steam emerges from this unit divided into two streams and passes, without further reheating, into two double-flow low-pressure turbines, which are located in the large boxlike housings in the foreground. This division of flow is needed to accommodate the thousandfold expansion in volume that takes place as the steam travels through the turbine from inlet to outlet.

STEAM TURBINES

These efficient machines are the principal means of converting the heat energy released by fossil and nuclear fuels into the kinetic energy needed to drive power generators and large ships

by Walter Hossli

The steam turbine ranks with the internal-combustion engine as one of the major achievements of mechanical engineering in the 19th century. Steadily increased in size, reliability and efficiency, steam turbines now account for more than 75 percent of the electric power generated in the world (most of the rest is hydroelectric) and propel most of the biggest and fastest ships. Between 15 and 20 percent of the fossil fuel consumed in the U.S. and western Europe—and essentially all the fuel now consumed in nuclear power plants—has only one purpose: to evaporate and superheat water that then passes through a steam turbine. For all their size and ubiquity steam turbines are among the least understood products of the mechanical age; they are seldom located where they can be seen by the public and the complexities of their design are familiar only to specialists. It took the recent failure of the turbines in the new Cunard liner *Queen Elizabeth 2* to remind people not only that these great machines exist but also that their design and construction is an exercise in high technology.

In principle a steam turbine is simplicity itself. It is a pinwheel driven by high-pressure steam rather than by air. It basically consists of a rotor from which project several rows of closely spaced buckets, or blades. Between each row of moving blades there is a row of fixed blades that project inward from a circumferential housing. The fixed blades are carefully shaped to direct the flow of steam against the moving blades at an angle and a velocity that will maximize the conversion of the steam's heat energy into the kinetic energy of rotary motion. Because the steam's temperature, pressure and volume change continuously as it progresses through the turbine, each row of blades has a slightly different length, and in certain parts of the turbine the twist of the blade is usually varied along the length of the blade, from root to tip. At the inlet of the turbine the blades are stubby, with little or no twist; at the outlet the blades are much longer and the twist is pronounced.

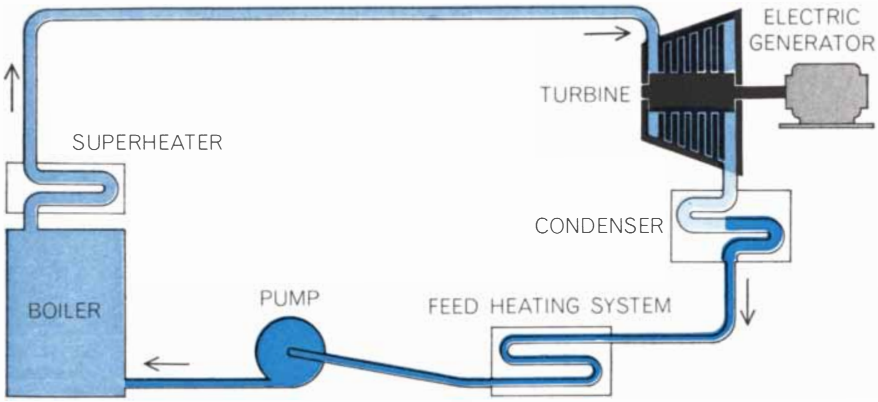
In a typical modern power plant steam leaves the boiler, after being superheated, at a pressure of 2,500 pounds per square inch and a temperature of 1,000 degrees Fahrenheit [*see illustration on page 103*]. As it enters the high-pressure turbine (the first unit in a cascade of three or four, usually working on a single shaft) a pound of steam occupies about .3 cubic foot. A short time later, when it leaves the low-pressure turbine (the last unit in the cascade), a pound of steam occupies more than 300 cubic feet, a thousandfold expansion.

The steam enters the high-pressure turbine at a velocity of about 150 feet per second and is immediately accelerated by expansion in the first row of fixed blades. In the low-pressure turbine, steam velocity and blade velocities can exceed 1.5 times the velocity of sound under the existing steam conditions. When the steam finally leaves the low-pressure turbine, its velocity is about 600 to 1,000 feet per second. Thus the turbine engineer must design "airfoils" (more accurately blade profiles) able to operate efficiently over a range of velocities roughly equivalent to the range encountered by the designers of a supersonic airplane.

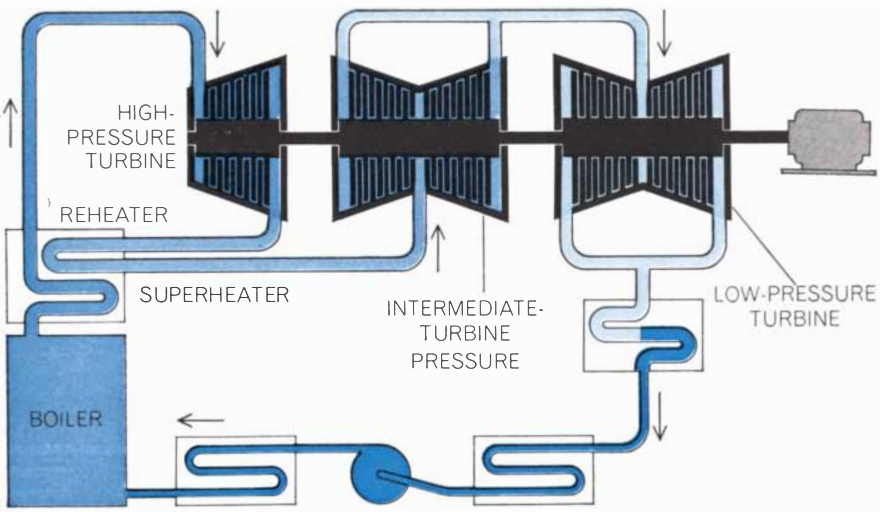
It is now 85 years since the British engineer Charles A. Parsons conceived the modern steam turbine and energetically began pushing its practical application. In an age commonly regarded as ultraconservative the steam turbine was developed and put to large-scale use with remarkable speed—a speed not equaled later by its descendant, the aircraft gas turbine, in an age thought to be much more receptive to innovation. Parsons demonstrated his first steam turbine in 1884. Seven years later he saw the value of adding a condenser to exploit the turbine's distinctive capacity for utilizing the energy of low-pressure steam down to a near-vacuum. That same year, 1891, the first steam turbines were harnessed to generate electricity.

In 1897 Parsons installed a 2,100-horsepower turbine in the *Turbinia*, a vessel of 44 tons, and astonished the British Admiralty by driving it at 34 knots through a parade of warships in a naval review at Spithead. The fastest ship yet built, the *Turbinia* easily outraced the entire fleet, which was equipped with conventional reciprocating steam engines. By 1904 the Admiralty had installed one of Parsons' turbines in a cruiser, the *Amethyst*, and a year later decided to abandon reciprocating engines and put Parsons turbines of 23,000 horsepower in the new *Dreadnought* class of battleships and turbines of 41,000 horsepower in the 28-knot *Invincible* class of cruisers. In 1907 the Cunard line launched the *Lusitania* and the *Mauretania*, each equipped with Parsons turbines developing 70,000 horsepower. Nearly twice as powerful as the largest reciprocating engines ever employed for ship propulsion, the turbines drove the two Cunard liners at a record speed of 25 knots. Only 16 years had elapsed since Parsons had thought to add a condenser to a turbine of a few hundred horsepower.

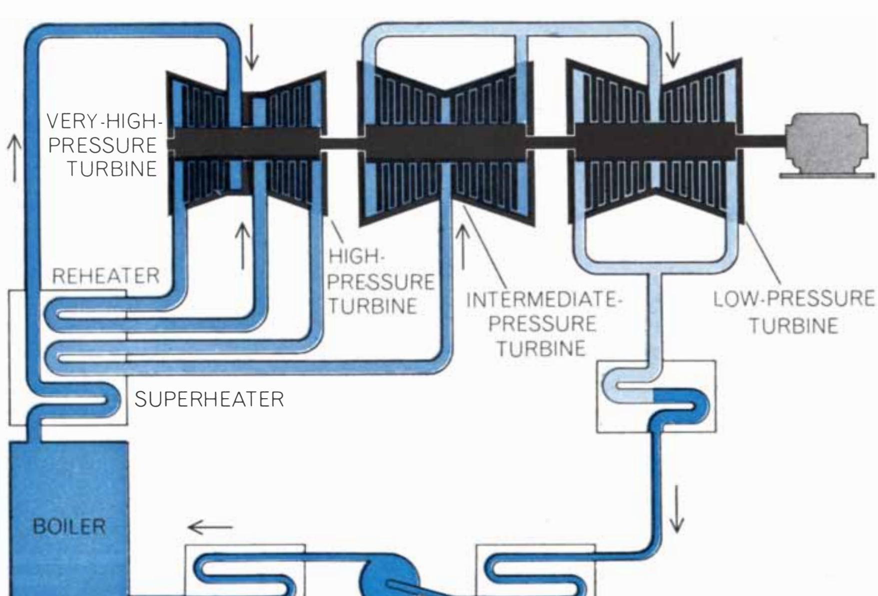
His accomplishments made such an impact on the British that they were recounted in much detail in the famous 11th edition of the *Encyclopaedia Britannica*, published in 1910–1911. (The same edition does not mention Einstein's special theory of relativity, published in



SIMPLE TURBOGENERATOR is used where power demand is light or fuel is cheap. Steam passes through a single turbine. Steam pressure is limited to about 1,500 pounds per square inch, output to 100 megawatts. Maximum thermal efficiency is around 37 percent.



SINGLE-REHEAT TURBOSET is usually preferred when the demand for power exceeds 100 megawatts and fuel costs make a thermal efficiency above 40 percent desirable. After steam leaves the high-pressure turbine it is reheated and returned to the double-flow intermediate-pressure turbine. From there it passes to the double-flow low-pressure turbine.



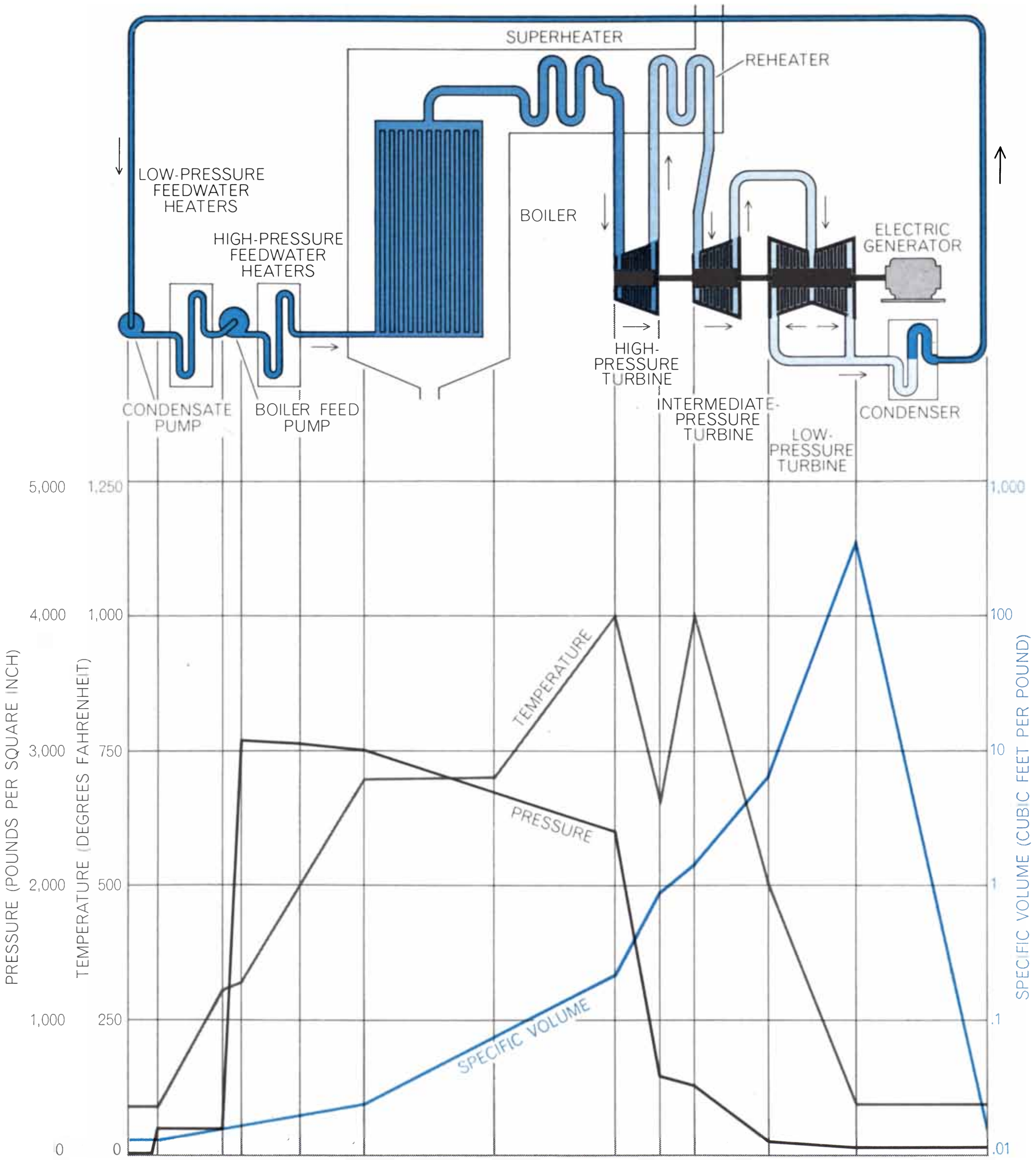
DOUBLE-REHEAT TURBOSET provides the highest power output and the highest efficiency, around 47 percent. In all three systems feedwater is heated by steam bled from the turbines. Cooling water for the condensers often comes from a nearby river, lake or ocean.

1905, or Planck's concept of the quantum of energy, published five years earlier.) The author of the entry on steam turbines has no hesitancy in describing "the invention of the steam turbine [as] the most important step in steam engineering since the time of Watt."

Steam turbines for ship propulsion have not grown very much since the days of the *Lusitania*. The turbines of the *Queen Elizabeth 2* are designed to produce 110,000 horsepower. Turbines of only 40,000 horsepower enable the largest tankers, vessels of more than 300,000 tons, to travel at 13 knots. The biggest increase in turbine size has been in the field of electric-power generation, and the end of this evolutionary trend is not in sight. In 1900 the first steam turbine used for power generation in continental Europe had a rating of 250 kilowatts; it was built by Brown, Boveri & Company Limited of Switzerland, the firm with which I am affiliated. (For purposes of comparing electric-power turbines and marine turbines, one kilowatt is about 1.3 horsepower.) Brown, Boveri is now building for the Tennessee Valley Authority the world's two largest steam turbine sets; each will have an output of 1,300,000 kilowatts, or 1,300 megawatts [*see illustrations on page 107*]. Our projections show that well before the end of the century single units of 2,000 megawatts will be required for the most efficient generation of power.

For propulsion of big ships and power generation, where large unit output and maximum efficiency are essential, the steam turbine is unchallenged. Diesel engines have a comparable efficiency but the largest units so far built are limited to about 30,000 kilowatts. Gas turbines go up to 100,000 kilowatts, but their efficiency is somewhat lower. At the other end of the size range, steam is again being considered as a power medium for automobiles; it remains to be seen, however, whether turbines or piston units will be more successful. The incentive is a reduction in air pollution. Nearly complete combustion can be achieved when fuel is used to fire a boiler instead of being burned in the cylinder of an engine.

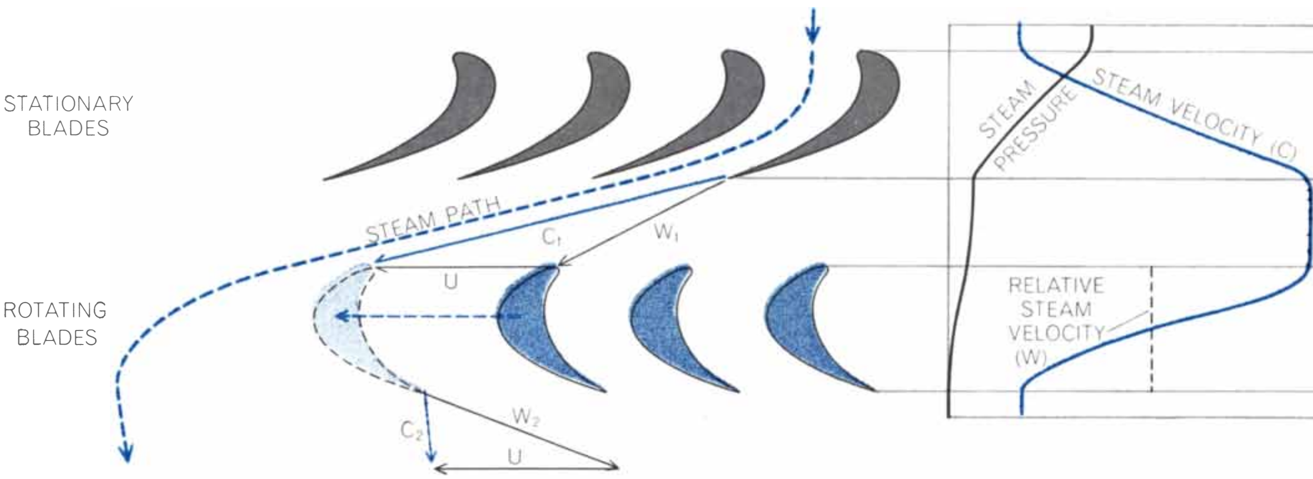
Present-day applications of land-based steam turbines are by no means limited to electric-power production. In many industrial plants, such as refineries, sugar mills, paper mills and chemical plants, low-pressure steam is needed in large quantities for process purposes. Instead of producing this steam directly in a low-pressure boiler it is advantageous to install a high-pressure boiler at little extra cost and to drop the steam to the desired level by expanding it through a "back pressure" turbine whose outlet pressure corresponds to the pressure needed for process steam. (If steam at two pressures is desired, a second turbine can be installed ahead of the back-pressure turbine so that steam can be withdrawn between the two units as well as after the second.) When this is done, electric power can be produced as a by-product at almost no cost. In most cases, of course, an external power supply is needed to handle fluctuating electric loads. It is also common in industry to use steam turbines as a direct power source for rotating machinery, such as compressors, blowers and pumps. All told, the worldwide demand for steam turbines requires the production of units whose annual combined output exceeds 50,000 megawatts, or 65 million horsepower.

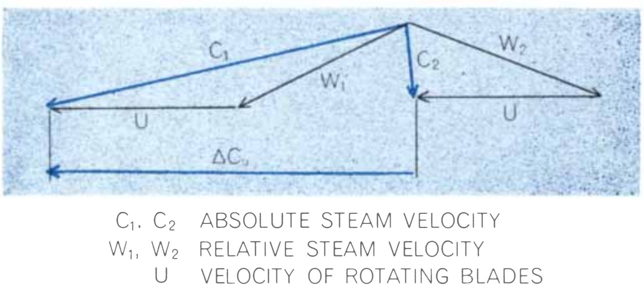


STEAM TEMPERATURE, PRESSURE AND VOLUME are the critical factors in the design of a steam power plant. The curves show how these three factors vary throughout a typical system. Pressure is highest at the exit of the feedwater pump leading to the boiler. At the entrance to the high-pressure turbine the pressure has dropped somewhat to around 2,400 pounds per square inch. Thereafter it falls rapidly as it passes through the turbine cascade. The steam temperature is raised to 1,000 degrees F. in the superheater and again in the reheater, finally plunging to about 80 degrees F. as it leaves the low-pressure turbine. The specific volume of the steam (*color*) varies over the greatest range and is therefore plotted on a logarithmic scale. At the inlet to the high-pressure turbine one pound of steam occupies about .3 cubic foot. When the steam leaves the turbine cascade, it occupies about 300 cubic feet.

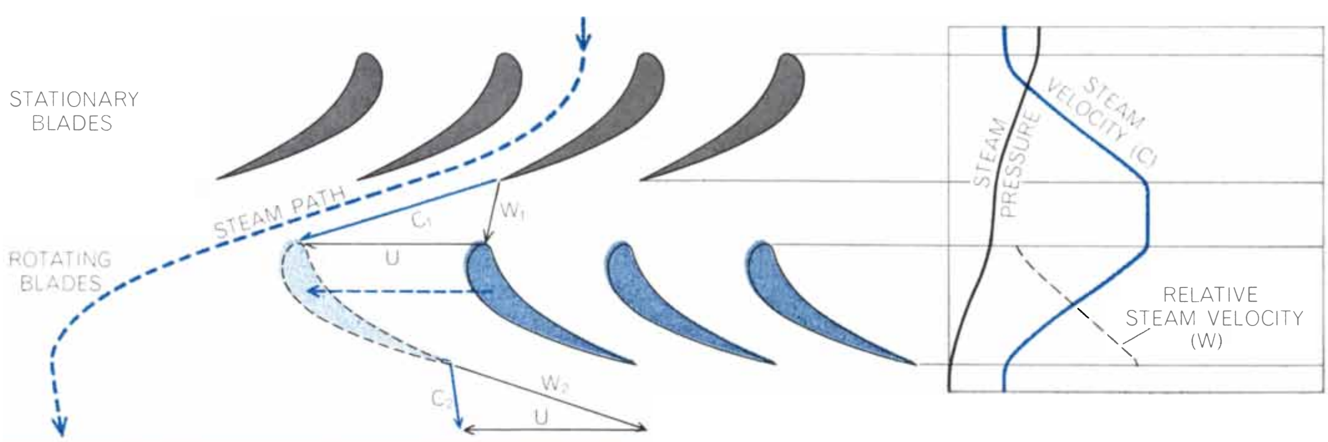
The development of practical steam engines occupied many minds in the 18th and 19th centuries. The first successful steam engine had been introduced in 1698 by Thomas Savery. It was a crude affair in which steam was condensed alternately in two chambers, creating a vacuum that could be used to draw water from mines. In 1705 Thomas Newcomen built the first practical steam engine with a piston. In 1763 James Watt began making his contributions, and in 1781 he was the first to patent methods for converting the reciprocating motion of a piston steam engine to rotary motion. With this advance the steam engine finally became a versatile prime mover. By 1804 Richard Trevithick had built the first steam-driven locomotive.

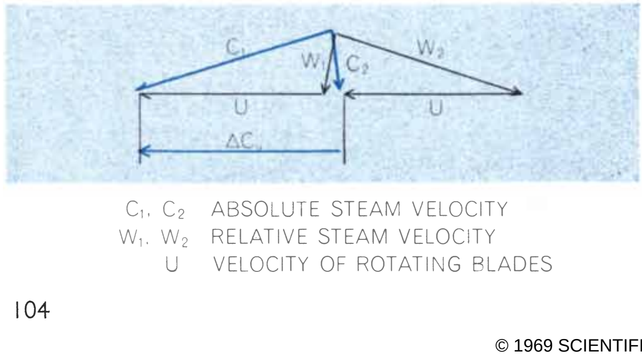
During the remainder of the 19th century piston steam engines were steadily improved. Many inventors, however, saw the advantages that would result if steam could be used directly to produce rotary motion by means of some kind of turbine. Many devices were built in crude imitation of waterwheels. It remained for Parsons to recognize that what was needed was a device with many rows of buckets in which a small amount of the steam's kinetic energy would be extracted with high efficiency at each of many successive stages. Whereas the piston steam engine exploited only the pressure and temperature of steam as it came from a boiler,





IMPULSE BLADING is one of two general methods for extracting kinetic energy from steam in a turbine. In the stationary blades steam is accelerated to a velocity (C_1) about twice that of the moving blades (U). Velocity is obtained at the expense of pressure (*curves at right*). The moving blades extract kinetic energy from the fast-moving steam, so that it leaves with essentially no tangential component of velocity (C_2). In passing through one row of fixed blades and one row of moving blades, called a stage, the amount of energy transferred to the rotor is proportional to the change in absolute steam velocity, ΔC_u (*diagram at left*).



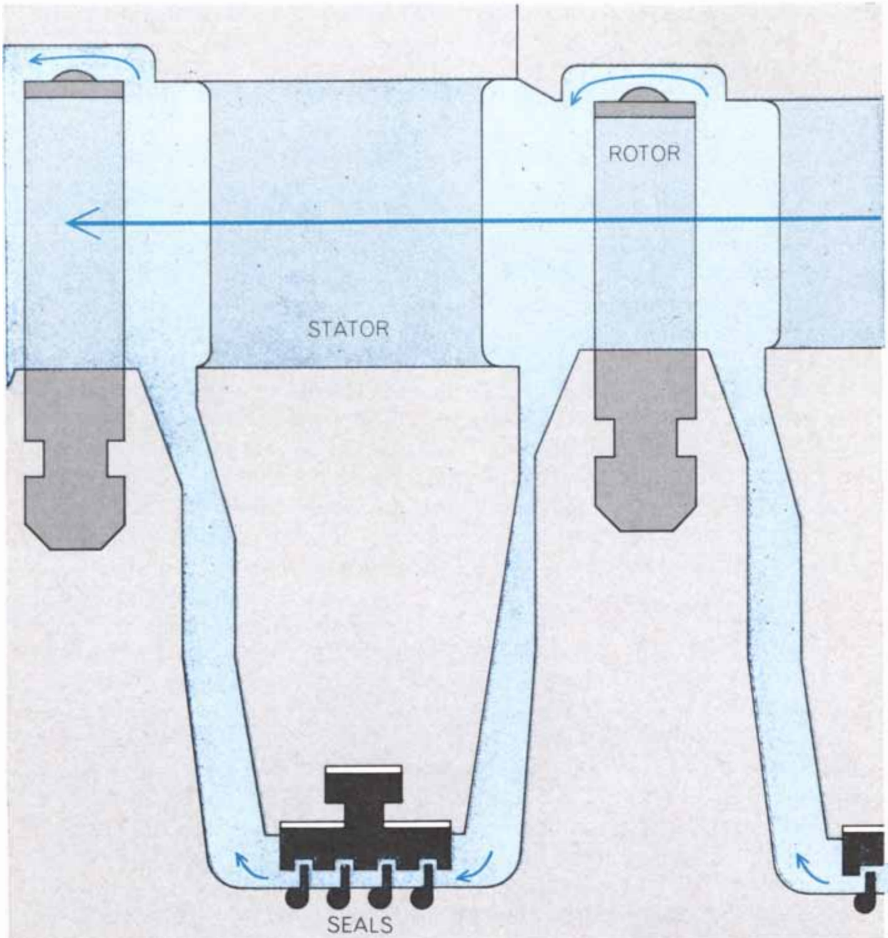


REACTION BLADING is the other concept used in steam turbine design. Here the pressure drop per stage is equally divided between fixed and moving blades (*curves at right*). In the fixed blades steam is accelerated to a velocity (C_1) only slightly greater than that of the moving blades (U). Continued expansion of the steam in the moving blades provides thrust and gives the steam a relative velocity (W_2) equal and opposite to its former absolute velocity (C_1). In reaction blading the energy, ΔC_u, transferred to the rotor in a single stage (*diagram at left*) is only about half that transferred by impulse blading. Efficiencies, however, are comparable.

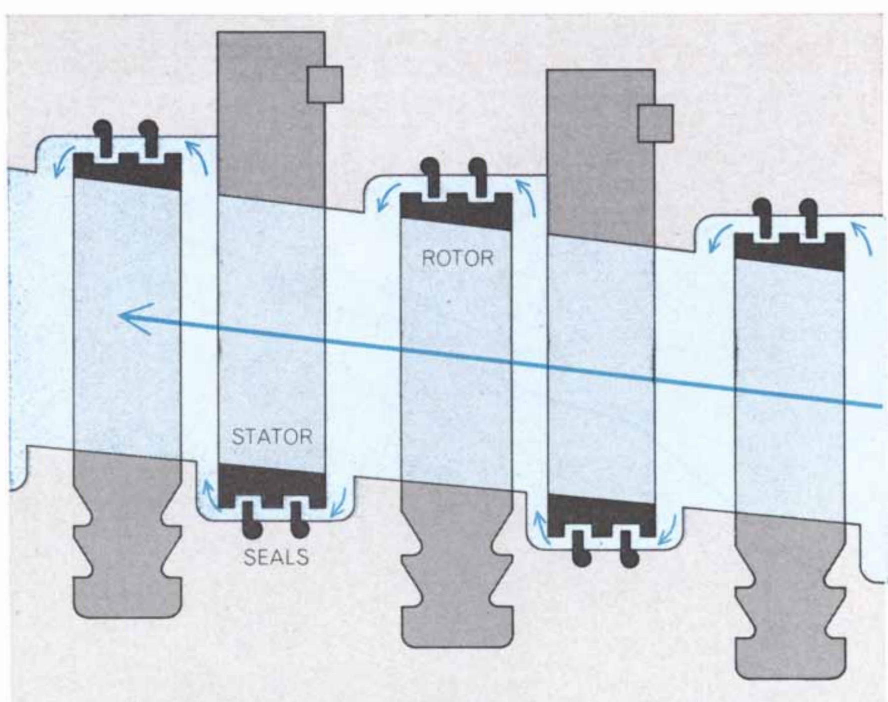
the steam turbine used some of the pressure to create high-velocity jets, whose energy was then absorbed by the rotating blades.

Early in the turbine's history two concepts of blade arrangement were developed, each with its champions. Parsons favored what became known as reaction blading. Some of his competitors adopted impulse blading [*see illustrations on opposite page*]. In the reaction turbine the fixed blades and the moving blades that constitute one stage are practically identical in design and function; each accounts for about half of the pressure drop that is converted to kinetic energy in the entire stage. In the fixed blades the pressure is harnessed to increase the velocity of the steam so that it slightly exceeds the velocity of the moving blades in the direction of rotation. In the moving blades the pressure drop is again used to accelerate the steam but at the same time to turn it around (with respect to the blades), so that its absolute tangential velocity is almost zero as it enters the next bank of stationary blades. Thus thrust is imparted to the moving blades as the steam's absolute tangential velocity is reduced from slightly above blade speed to approximately zero. An imaginary observer moving with the steam could not tell whether he was passing through the fixed blades or the moving ones. As he approached either type of blade it would appear to be nearly motionless, but as he traveled in the channel between blades his velocity would increase steadily until he reached their trailing edges, which would then seem to be receding rapidly.

In the impulse turbine the fixed blades are quite different in shape from the moving ones because their job is to accelerate the steam until its velocity in the direction of rotation is about twice that of the moving blades. The moving blades are designed to absorb this impulse and to transfer it to the rotor in the form of kinetic energy. In this arrangement most of the pressure drop in each complete stage takes place in the fixed blades; the pressure drop through the moving blades is only sufficient to maintain the forward flow of steam. The amount of energy transferred to the rotor in each stage is proportional to the change in absolute steam velocity in the direction of rotation. This is the value labeled ΔC_u in the illustrations on the opposite page. It turns out that the value is about twice as high for impulse blading as it is for reaction blading. This means, in turn, that an impulse turbine will need fewer stages for the same pow-



DIAPHRAGM TURBINE provides effective seals (*black*) in turbines with impulse blading, where the complete expansion of steam per stage occurs in the stator, or fixed, blades. This design allows seals to be placed on as small a diameter as possible. The moving blades are usually covered by a circumferential shroud, which may also carry seals (*not shown*).



DRUM TURBINE offers the simplest arrangement of seals (*black*) when reaction blading is used. Seals on rotor and stator blades can be identical because the pressure drop across them is equal. Also the seals can be simpler than those needed for impulse blading.

er output than a reaction turbine; the efficiency, however, will be about the same for both types.

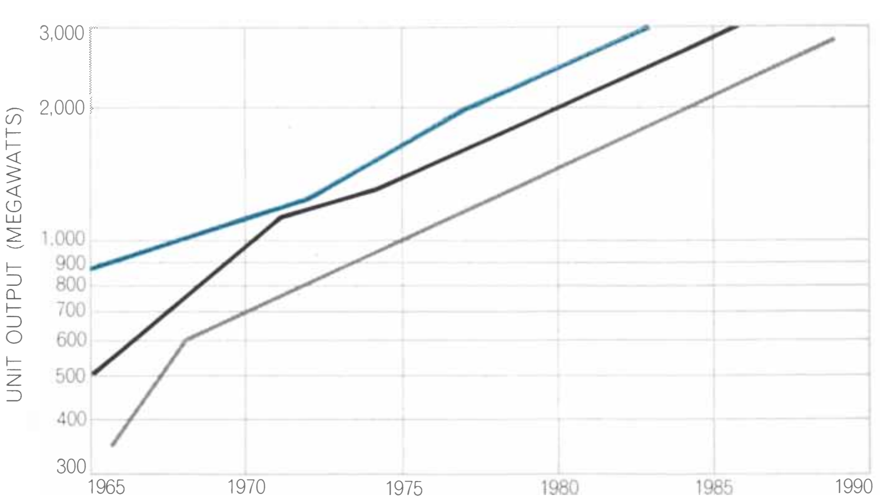
This being the case, one would expect impulse blading to have carried the day. Not so. As often happens in engineering, a design that seems clearly superior can present secondary problems of such magnitude that the choice between the alternatives becomes very nearly equal. In turbine design one of the major secondary problems is providing seals to keep the steam from leaking through the narrow spaces between the rotor and the stator. In impulse blading the complete expansion in each stage takes place in the fixed blades. It is thus desirable to place the seals on as small a diameter as possible. This has led to a turbine design known as the diaphragm type [*see top illustration on preceding page*]. Because the pressure differential is large the diaphragm needs considerable space in the axial direction. Therefore the width of the fixed blade must be made larger than it would otherwise have to be. A circumferential shroud is often placed around each ring of moving blades.

In reaction blading the pressure drop per stage is less than it is in impulse blading; moreover, it is divided equally between fixed and moving blades. Thus both blades can be fitted with similar seals, and the seals need not be as effective as those needed on the fixed blades in impulse blading. The result is a drum turbine [*see bottom illustration on preceding page*]. Another advantage of the reaction turbine is that the stationary and moving blades in each stage can have the same shape, which simplifies design and yields manufacturing economies.

For more than 50 years these two kinds of turbine, the diaphragm turbine and the drum turbine, have been in competition without either type's demonstrating a distinctive advantage. Along the way the advocates of the two designs have moved somewhat away from pure reaction or pure impulse blading to adopt various compromise arrangements.

The efficiency that can be attained at each stage in a large modern turbine is quite remarkable: more than 90 percent. For large units with reheat systems an overall turbine efficiency of about 88 percent can be achieved. This is not the net thermal efficiency of the steam turbine as a heat engine, however. For this calculation one must introduce the limitations on the theoretical efficiency of heat engines first described in 1824 by Nicolas Léonard Sadi Carnot, who recognized that heat does work only as it passes from a higher temperature to a lower one. Specifically the efficiency is 1 minus the fraction "final temperature"/"initial temperature," both values being expressed on the Kelvin, or absolute, scale. If the working fluid is initially at 1,000 degrees F. (811 degrees K.) and is finally at 100 degrees F. (311 degrees K.), the maximum theoretical efficiency is about 60 per cent $[(1 - 311/811) \times 100]$. Because the inherent properties of a steam cycle do not allow the heat input to take place at a constant upper temperature, the theoretical maximum efficiency is not 60 percent but closer to 53 percent. Thus the actual thermal efficiencies achieved with large reheat-steam turbines is .88 (the turbine efficiency) times 53, or somewhat better than 46 percent.

Today the chief point of competition among rival turbine manufacturers is not efficiency, since all guarantee comparable performance, but the capital cost of the unit. As units have become steadily larger the cost per megawatt of capacity has dropped substantially because of economies inherent in size. For example, a turbine of 125 megawatts, which was considered large 15 years ago, weighed about 2.64 tons per megawatt. The 1,300-megawatt turbine Brown, Boveri is building for the TVA will weigh less than half that amount per megawatt. The cost per megawatt is roughly proportional to weight.

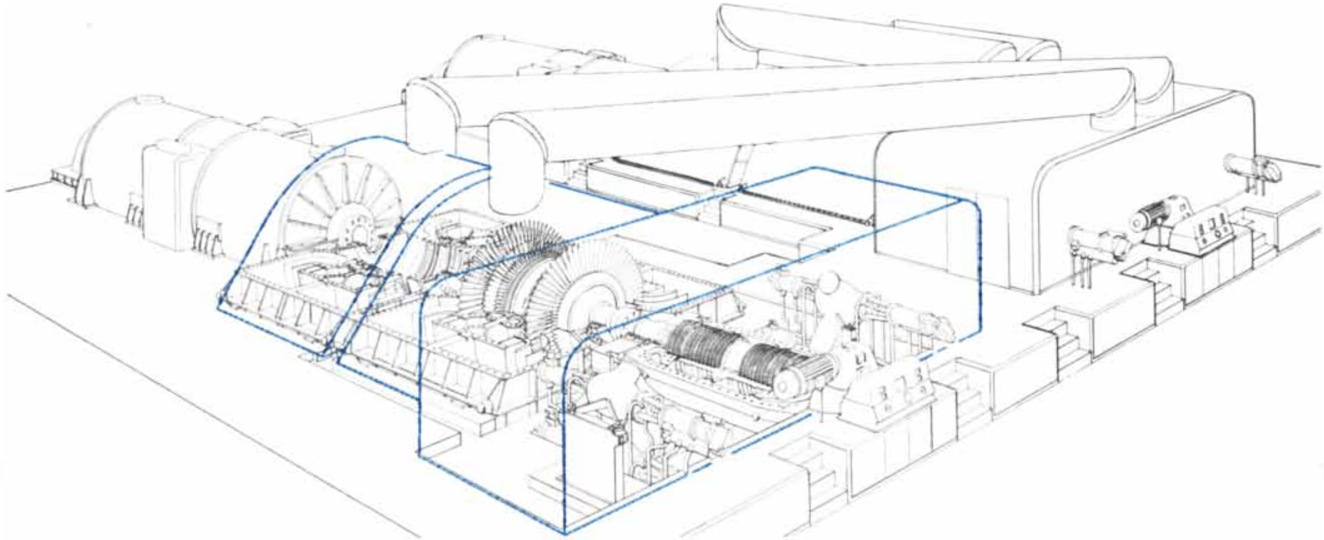


PROJECTION OF TURBINE SIZES, made by Brown, Boveri, reflects the fact that U.S. nuclear power plants (*top curve*) run larger than U.S. fossil-fuel plants (*middle curve*) and that both are larger than fossil-fuel plants contemplated in Britain (*bottom curve*).

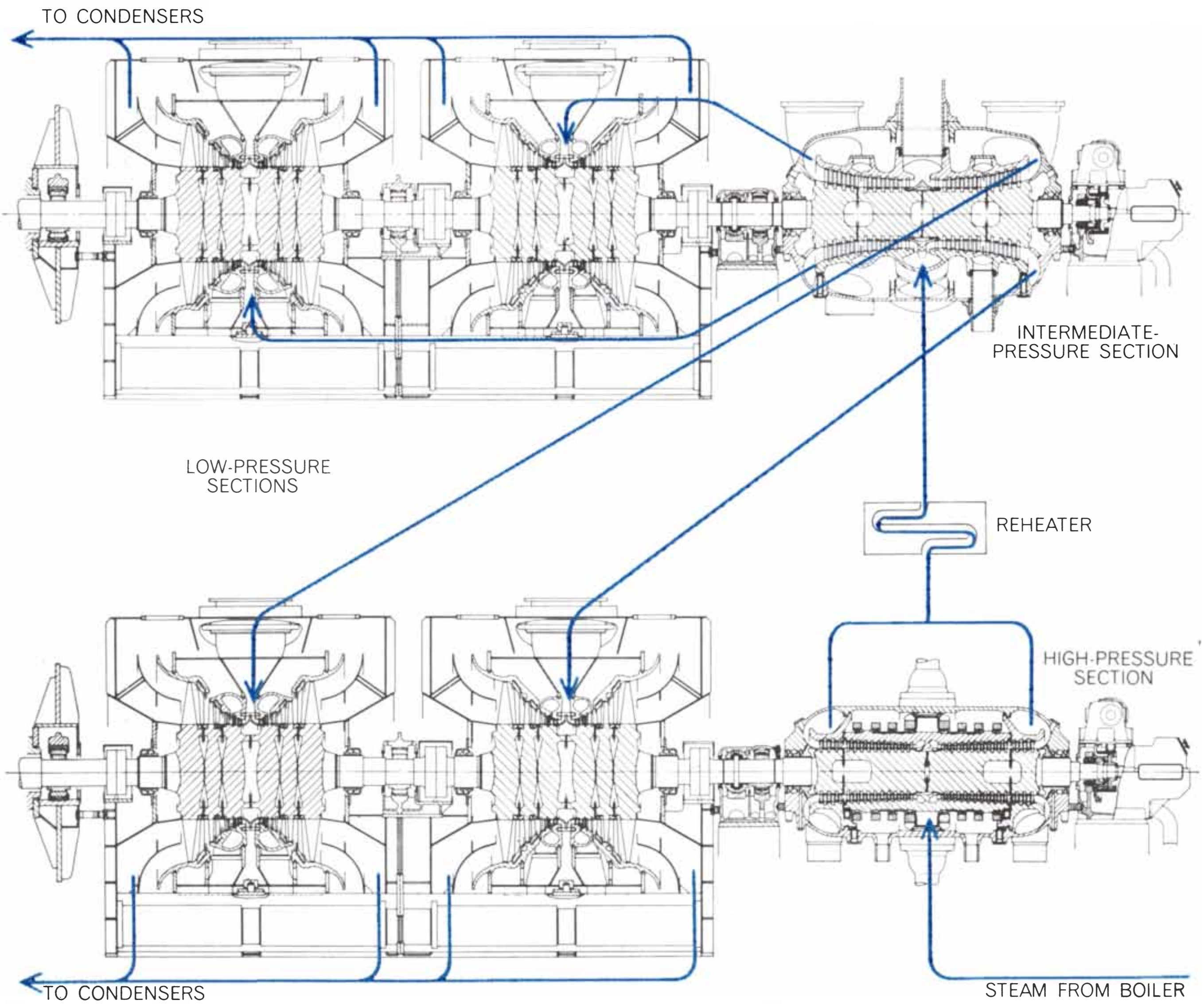
In the first 50 years of the steam turbine's history (roughly 1890 to 1940) turbine design was guided mainly by the intuition and ingenuity of engineers who were never far from the shop floor. Today, with the sharp increase in power density and the use of steam at higher pressures and temperatures, turbine progress depends increasingly on scientific understanding and the skillful application of new problem-solving tools such as the electronic computer. The design of a modern turbine requires the solution of difficult problems in aerodynamics, applied mathematics, metallurgy, stress, vibration and the physical behavior of steam, together with attention to many manufacturing problems (such as the production of complex blade contours at reasonable cost, the setting of permissible tolerances and size limitations imposed by transportation).

Rather than discuss such problems as they apply to the turbine as a whole I shall speak only of the design of the moving blades used in the last stage at the low-pressure end of the turbine. These are the longest blades in the turbine, hence the blades with the highest tip speed and the most acute vibrational problems. They are also the blades most subject to erosion from water droplets, which tend to appear as the steam approaches the turbine exit just before entering the condenser.

In designing such blades aerodynamic calculations reach a complexity exceeding that met in other sections of the turbine, where pressures are higher and flow patterns somewhat simpler. In passing through the low-pressure turbine the volume of steam expands about 100 times, with the result that the path of the steam has a strong radial component in addition to its forward component. The calculations must therefore deal with steam flow in three dimensions. An equilibrium condition must be maintained between the centrifugal forces that throw the steam outward and the distribution of radial pressure. In a very poor design the moving blades will tend to act as a compressor. The solution to this complicated flow problem involves



A 1,300-MEGAWATT TURBOSET, now being built by Brown, Boveri, will be the largest unit in operation when it is delivered to the TVA in 1971. It is described as a cross-compound unit, indicating that the steam travels sequentially through turbines of different sizes located on two different shafts (*see flow scheme below*). The turboset will run on steam produced by burning of fossil fuel.



FLOW PLAN OF TVA TURBOSET shows how the steam is conducted through a double-flow high-pressure turbine, a double-flow intermediate-pressure turbine and finally four double-flow low-pressure turbines, all mounted on two shafts turning at 3,600 revolutions per minute. Steam enters the turboset at 3,500 pounds per square inch and 1,000 degrees F. Before passing to the intermediate-pressure turbines the steam is reheated to the same temperature. The flow of steam is 4,000 tons per hour, or 1.1 tons per second.

differential equations that can be solved only with a large-capacity computer.

The results of these initial calculations provide the designer with a preliminary concept of the blade cascade, indicating the number of stages and the inlet and outlet angles of the blades in each stage. The next step is to design blades with high efficiency from root to tip. Toward this end the designer chooses profiles whose characteristics are known either from calculation or actual measurement. Even near the root, where the steam flow is subsonic, existing blade profiles may be unsatisfactory; new profiles must then be developed and evaluated. In the outer third of the blade, where the flow passes from subsonic to supersonic, things become more difficult. In calculating the line where sonic velocity is reached, mathematical equations tend to become unstable, meaning that they fail to provide a reasonable result. One must then use a combination of empirical and analytical methods. The critical passage from subsonic to supersonic velocity, known as the sonic line, must be verified by experiments in a water tank or in a rotating cascade in which the fluid is air.

In the supersonic region calculation becomes simpler again. Good methods exist for predicting the location of regions, called Mach lines, where minor disturbances will cause sudden but small changes in steam velocity and pressure. One can also compute shock lines: the lines along which high-compression waves will develop. Water-tank methods, in which water passes swiftly between model blades, provide an excellent visual representation of flow patterns and shock waves [*see top illustration on opposite page*]. Under suitable conditions flowing water behaves like a supersonic flow of air or steam. From such studies, with the help of scaling laws, one can readily determine the supersonic flow pattern as well as the sonic line. The results can be checked by passing air through a rotating cascade of blades and using optical methods to disclose the flow patterns. A critical comparison of the three methods—mathematical analysis, water-tank flow and airflow in a cascade—enables the designer to make a sound prediction of actual steam-flow conditions. In this way the aerodynamic side of the problem can be solved.

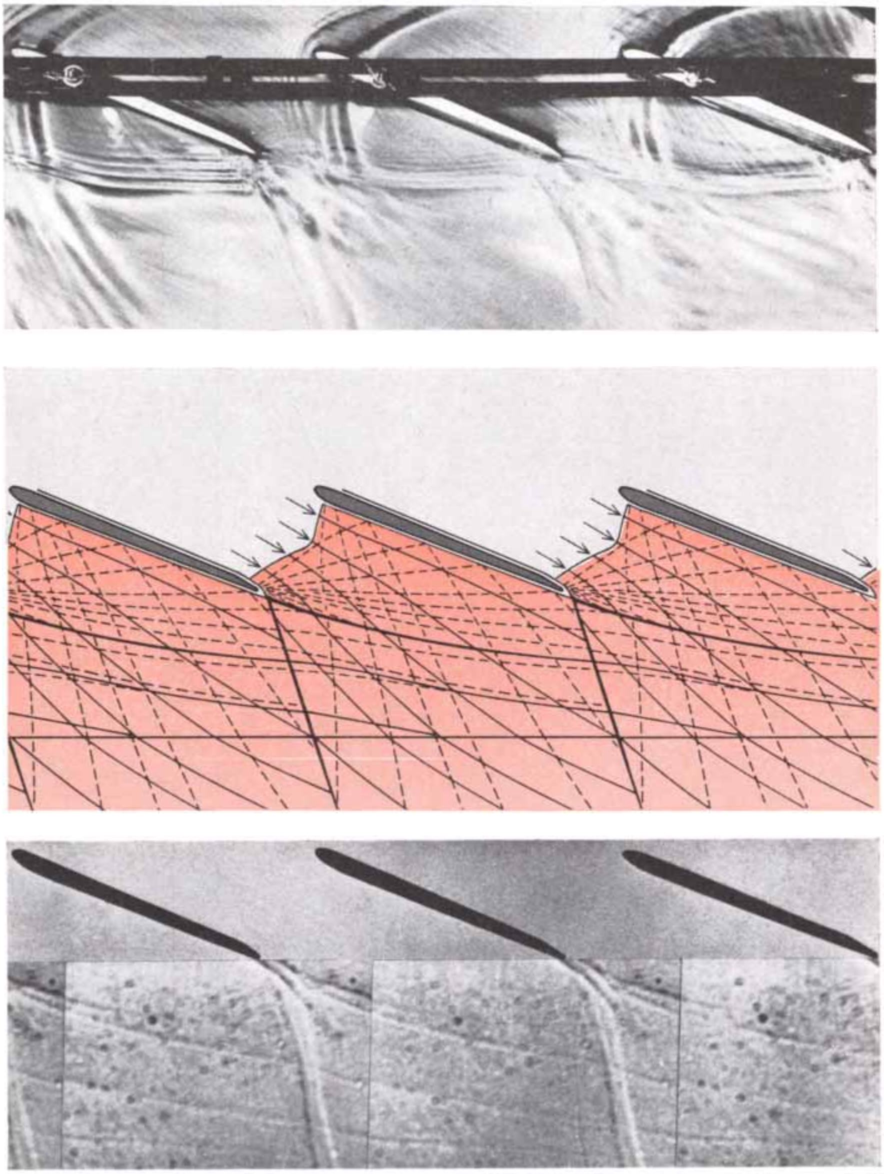
The designer is now ready to sketch a preliminary configuration for the blades in the last stage of the low-pressure turbine. Because they are highly twisted these blades are subject to unusual stresses. Under centrifugal force a last-stage blade may untwist more than seven angular degrees. To keep material stresses under control the positioning of the centers of gravity in various sections of the blade and also of the centers of inertia is very important.

Not the least of the engineer's problems is to design a root that will hold the blade in the rotor against a centrifugal force of more than 250 tons. The space available for transmitting this force to the rotor body is very limited. Tiny strain gauges and polarized-light studies of transparent plastic models provide information about stress distribution, and sample roots are stressed to destruction. Such tests can shed light on the rupture mechanism and indicate the safety factor expected when the blade is run at normal speed.

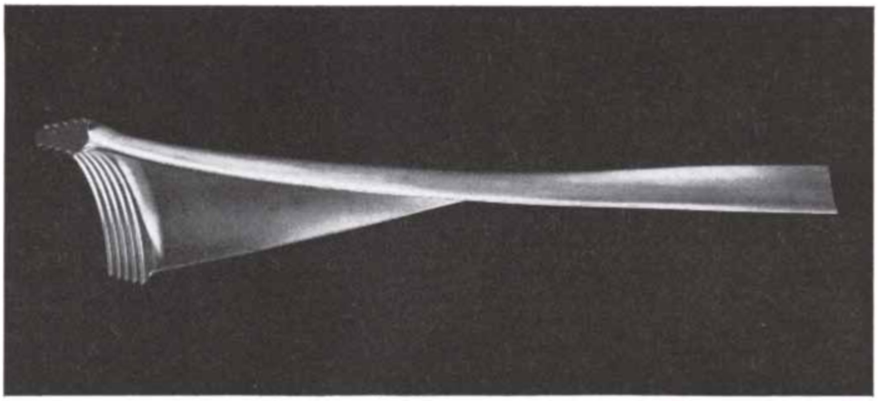
Vibration can be particularly troublesome in long blades. The failure of blades in the turbines of the *Queen Elizabeth 2* has been traced to vibrations at resonance frequencies, attributable to faulty design. In designing the last-stage blades one must calculate resonance frequencies and where the nodal points will occur. The calculation method accounts for centrifugal and torsional frequencies as well as for their coupled effect. The calculated values must then be verified by static and rotational tests; close agreement is usually obtained between calculation and experiment [*see illustration on next page*].

Even these tests are not sufficient. The distribution of steam pressure and velocity acting on the blade may vary considerably with the load, so that additional tests must be made. This is usually done in a test turbine scaled down from a complete low-pressure turbine. One can study how the last-stage blading is influenced by stages preceding the last stage under varying load conditions and also examine the back effects produced by the exit diffuser. Reliability of the last-stage blade is so important that further tests are run on turbines in commercial operation. Tiny strain gauges are attached to the blade, and their measurements are transmitted by radio.

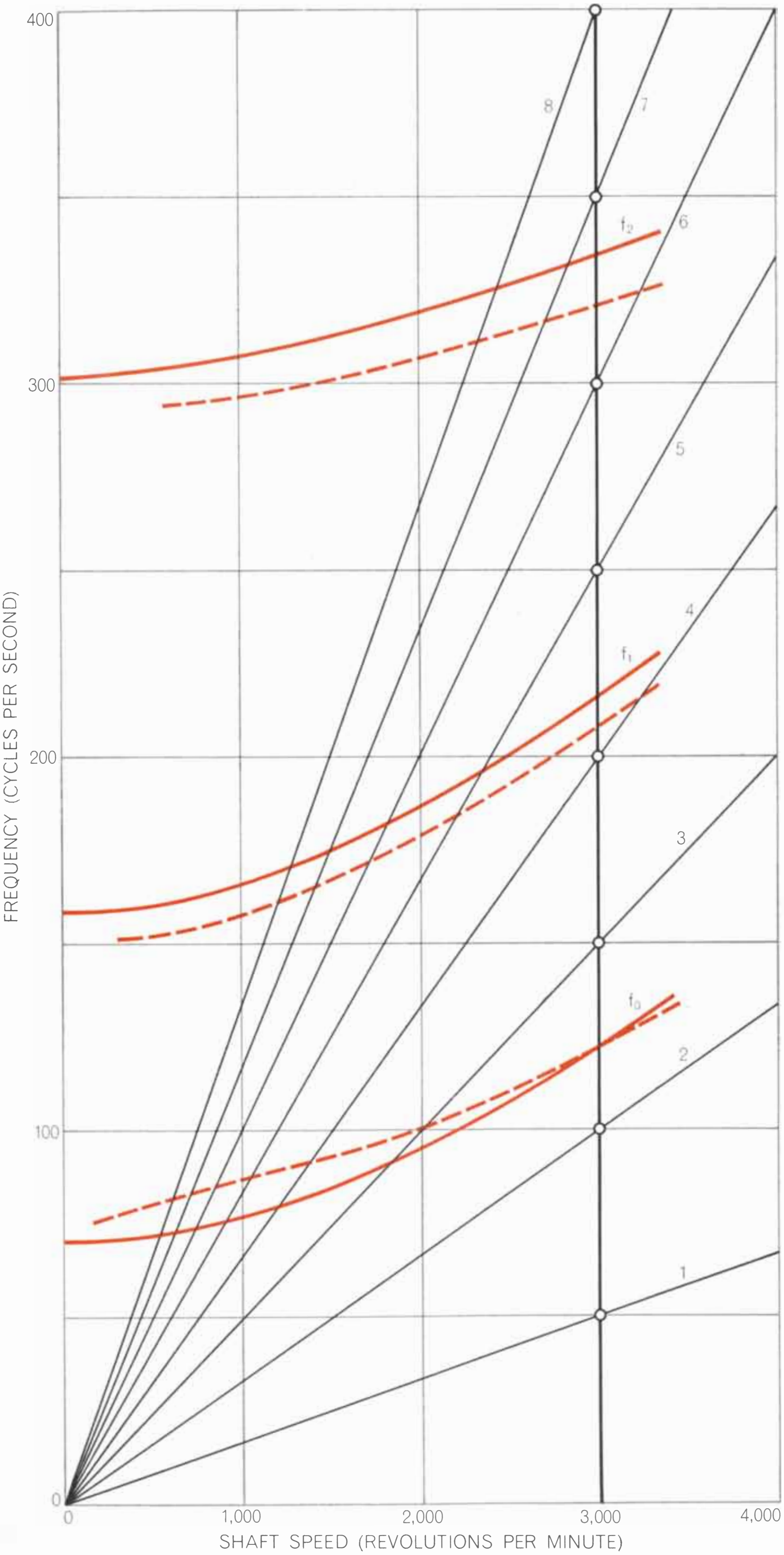
In addition to determining resonance frequencies up to the sixth or seventh mode of vibration, it is necessary to check carefully still higher modes in a range near the exciting frequencies produced by the stationary blades. There are evidently flow disturbances, similar to wakes, behind each stationary blade that are capable of inducing resonances characteristic of a vibrating plate. Fortunately this phenomenon is nearly independent of centrifugal effects, so that stationary tests are sufficient. Laser holography has recently been used to re-



TURBINE-BLADE CHARACTERISTICS can be studied in three general ways: by water-tank analogy (*top*), by direct calculation (*middle*) and by airflow tests in a rotating cascade (*bottom*). It can be seen that the three methods give comparable results. These particular studies show patterns of transonic flow when blades are traveling at 1.4 times the speed of sound in air. In the middle picture the area tinted in color denotes supersonic flow.



TYPICAL LAST-STAGE BLADE is 95 centimeters (37.5 inches) long, excluding the root. When installed and running, the tip of the blade will travel at 600 meters per second, or 1.6 times the speed of sound in steam under the conditions existing in the turbine's last stage.



RESONANCE FREQUENCIES of last-stage blades can now be calculated with good accuracy. The slanting lines (*1 through 8*) are potential exciting frequencies. Conditions to be avoided (*open dots*) occur where these lines intersect the vertical line at the normal shaft speed, here 3,000 revolutions per minute. The solid lines in color (f_0, f_1, f_2) are resonant frequencies of the blade as obtained by calculation. The broken lines are measured values.

cord the vibration pattern in such tests.

The metallurgical requirements for a last-stage blade are, as one might expect, demanding. The steel should have a high yield point combined with good ductility in order to withstand high centrifugal stresses. It should resist fatigue as well as erosion and chemical- and stress-corrosion. (In normal operation one can expect small quantities of corrosive chemicals to be entrained occasionally in the steam.) The steel should also have high damping characteristics to minimize vibration. Finally, the steel should lend itself to machining or forging; more exotic means of shaping a blade are usually very costly.

If the steel itself does not possess sufficient resistance to erosion, the blade can be hardened or surfaced with an erosion-resistant hard alloy such as Stellite. Much study has been devoted to the mechanism by which wet steam causes erosion. Because the steam passing through the low-pressure turbine is wet, drops of water tend to collect on the trailing edge of the stationary blades. The drops are then torn away by the passing steam and hurled against the moving blades, producing tiny pits. The designer's task is to see that pitting does not impair the efficiency and reliability of last-stage blades over the 20-year minimum lifetime expected of a steam turbine. Blades in the high-pressure turbine, where the temperatures are highest, are virtually free from erosion.

I have described in some detail the development of last-stage blades not only because their design involves a representative range of engineering problems but also because they place one of the limits on the size to which individual turbine sets can grow. For maximum economy high-pressure, intermediate-pressure and low-pressure turbines should be arranged in a single line. The more steam per hour that enters the high-pressure end of the set, the larger the blades required at the low-pressure end to handle the much expanded volume of steam. "Half-speed" turbines (1,800 revolutions per minute instead of 3,600) have been introduced to provide large output in a single turbine set, but their weight and cost, megawatt for megawatt, are higher than those for full-speed turbines. To hold costs in line, therefore, it is imperative for manufacturers to learn to design full-speed turbines with larger low-pressure last stages than any built so far. These larger units will be needed to meet the growing demand for electric power at a steadily reduced cost per kilowatt-hour.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HORNS AND ANTLERS

They are commonly believed to be rather alike but in actuality they are quite different. Among other differences, the material of horns is related to skin and the material of antlers to bone

by Walter Modell

Some years ago a curator at the New York Zoological Society received a shipment of antelopes from South Africa to which he had been looking forward eagerly. It included rare specimens that were hardly known to Americans except in crossword puzzles: the hartebeest, the eland, the waterbuck, the impala and others. When the antelopes were unloaded from the ship, the curator was stricken with shock and horror. They had all been dehorned. In order to save space and prevent injury the shipper had polled the animals' horns with a cattle dehorner, assuming that they would regrow their "antlers" after settling down in their new home. Unfortunately the shipper had made a serious zoological error, failing to distinguish between horns and antlers. All the animals in the shipment had horns, which as every dairy farmer knows do not regenerate after polling. The curator rejected the mutilated animals as being unsuitable for exhibition in a zoo, and since no one else wanted them they were slaughtered and given to the large cats, which for the first time in a long while ate as they had been brought up to eat.

The hapless animal dealer who confused horns with antlers was not particularly ignorant but was a victim of a common misapprehension. Many people and even reference books are not entirely clear on the differences between horns and antlers. The differences are fundamental and complex, and they present interesting problems in biochemistry, physiology, animal behavior and evolution.

True horns, antlers and similar cephalic adornments are found today only in five families of ungulates (animals with hooves): (1) the Rhinocerotidae (rhinoceros), characterized by one or two permanent midline nasal horns; (2) the Bovidae (cattle, sheep, goats and antelopes), characterized by a pair of symmetrical permanent horns; (3) the Antilocapridae (pronghorn antelope), which annually renew their pair of symmetrical horns; (4) the Cervidae (moose, caribou, elk and deer), which annually renew a pair of antlers, and (5) the Giraffidae (the giraffe and the okapi), whose cephalic protuberances are permanent and paired but are neither horns nor antlers.

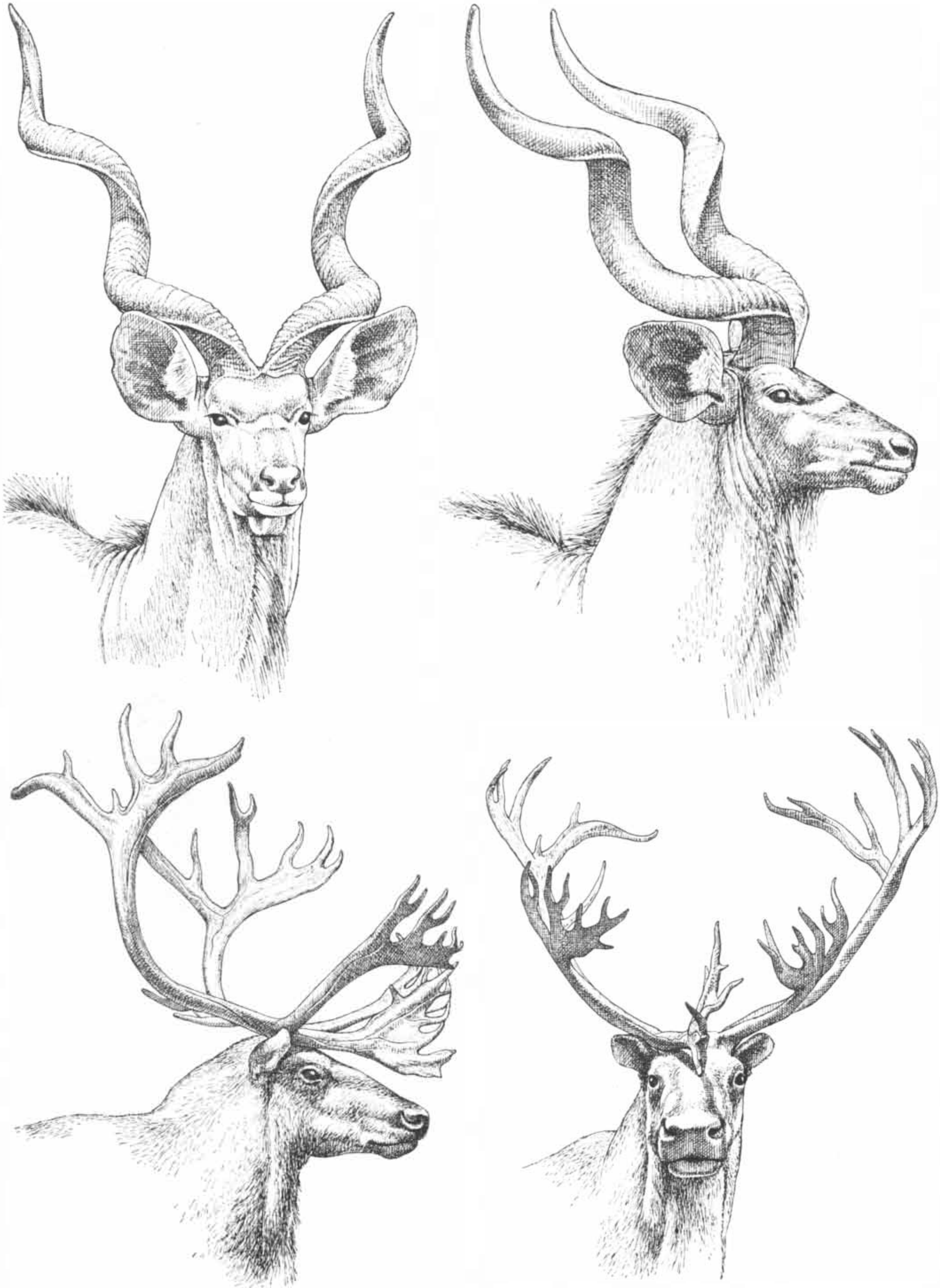
In functional terms horns make sense: they serve their possessors as effective weapons. The knobs on the giraffe's head are less understandable; borne some 18 feet above the ground, they are hardly in a position to attack anything except perhaps a low-flying airplane, and in any case they are short, blunt and cushioned with a tuft, so that they cannot inflict much damage. The function of antlers is even more mysterious; apart from giving the animal a noble appearance these headpieces have little utilitarian justification; indeed, they are an encumbrance. Antlers are too delicate to serve as weapons. When antlered animals really fight, they use their hooves and not their antlers. For several months of the year, between the annual shedding and the regrowth, the animal does without antlers and seems not to miss them at all.

The only observable function served by antlers is that during the mating season the males use them to tilt with other males in winning a harem. This unique application often ends unhappily; it is not uncommon for the two contestants to lock antlers (not horns!) so that both are immobilized and perish, and the herd loses the genes of what may well be its two best stags. As we shall see, the antler is a strange and uneconomic experiment of nature, extravagantly costly to its possessors in several ways, and it seems destined eventually to disappear.

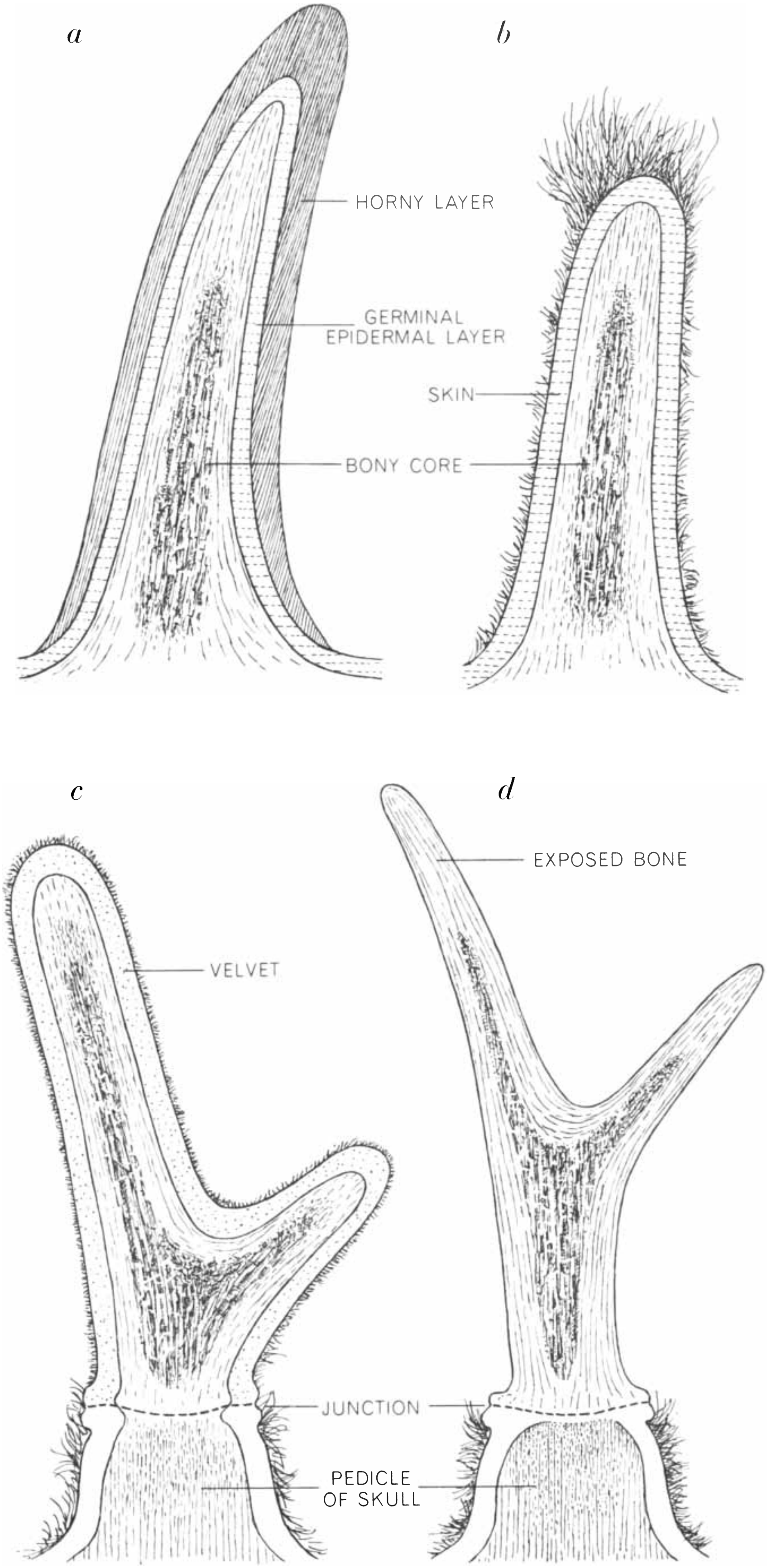
In distinguishing antlers from horns we note to begin with that they are composed of entirely different materials. Horn consists mainly of keratin, the protein that is the principal constituent of hair, nails, hooves, scales, feathers, claws and other tough structures derived from epidermal tissue. Like hair and nails, horn is not a living, sensitive tissue: it has no nerves or blood supply and hence is insensible to pain and does not bleed when it is cut. Horns grow slowly and attain their definitive size and shape by extension from their source in an epidermal layer surrounding a bony core, the *os cornu* at the base of the frontal bone of the skull, as the animal grows to adulthood. If the horny material is cut off, it is not regenerated.

Antler, in contrast, is living tissue that resembles true bones of the body in physiology, chemical composition and cellular structure. During the antler's development it is covered with a hairy skin called velvet, which has a rich supply of blood vessels and nerves. While the antler is in velvet, it bleeds profusely when injured, and the skin is sensitive to touch and pain. At this stage the antlers are not only tender but also fragile. As the season progresses the antlers become ossified, the velvet is shed and the bare tines of bone are exposed. At the end of the mating season (usually in December in temperate regions of the Northern Hemisphere) the animal sheds its antlers, and four to five months later (in April or May) it begins to grow a new set. In short, the antler is a deciduous organ that is cast off and renewed annually like the leaves of a tree.

Horns and antlers differ significantly in their architecture. Antlers, at least those sought as trophies, tend to be large, complex and ornate. Antlers are paired,



TYPICAL HORNS AND ANTLERS are shown in front and side views. At top are the horns of the kudu ram, a large antelope that is found in much of Africa. At bottom are the antlers of the caribou, which is the North American equivalent of the reindeer.



INTERNAL STRUCTURE of horns and antlers is shown for a bovine horn (*a*), the knob of a giraffe (*b*) and the antler of a deer, with its "velvet" covering (*c*) and with the bony structure exposed (*d*) after the velvet has been shed. The junction with the skull where growth begins in the spring and where the antler breaks off at the time of the annual shedding is indicated. Developing antlers have blood vessels and nerves, whereas horns entirely lack them.

although in some species they are not symmetrical. In certain animals, such as the reindeer and the moose, antlers have a winglike, palmate structure—like the palm of a hand with extended fingers. From year to year after a deer has reached maturity and until it reaches its prime each new crop of antlers becomes larger and more elaborate, adding branches and "points" that provide a measure of the animal's age and vigor. The number of points is also a measure of the magnificence of the deer; in Scotland, for example, a deer with 12 points is called a royal stag. In some species of Cervidae now extinct the antlers weighed more than the animal's entire internal skeleton. At the other extreme the tiny pudu of the Chilean Andes, a reddish deer only about a foot high, has simple pygmy antlers consisting of almost invisible spikes two or three inches long.

The horns of the Bovidae, although they too can be magnificent, are clearly structured for use rather than ornamentation. They exist as symmetrical pairs (an exception is the four-horned antelope with two symmetrical pairs) in a rich variety of forms: curved, twisting, coiled, helical and zigzag. They all end, however, in a single strong spear capable of impaling or tossing an adversary. (Testimony to the formidable power of horns as weapons has been erected outside the bullring in Madrid in the form of a statue of Sir Alexander Fleming, the discoverer of penicillin, whose wonder drug has reduced the death toll among gored matadors.) It also seems significant that in almost all species of Bovidae the female as well as the male possesses horns (although they are often smaller in the female), whereas among the Cervidae antlers are secondary sexual characteristics of the male (the only known exception being the reindeer and its identical American version, the caribou). This again suggests that the antler, unlike the horn, did not evolve primarily as a weapon of defense.

Let us examine the biological and evolutionary distinctions between horns and antlers in more detail. Horn is made up of filaments that closely resemble hair, and these filaments arise from papillae in the skin that are much like hair follicles. It is clear, however, that horn is not, as it has sometimes been said to be, simply a mass of agglutinized hair. On microscopic examination it can be seen to be made of distinct hollow filaments, whereas hair fibrils are solid. Furthermore, horns originated much earlier (probably at least 50 million years earlier) than hair, which apparently developed only after the arrival of mammals.

The simplest and most primitive horn of our day is the horn of the rhinoceros. It is made up of tubular, filamentous secretions from the skin that are cemented together to form a projection from the animal's nose. Having no bony core, the horn consists of solid keratin. As it grows it becomes cemented to the nasal bone, but if a dead rhinoceros's head is skinned, the horn often comes away with the skin, to which it is firmly attached.

In cattle and other animals of the bovid family the horns are hollow, as one can see in an antique powder horn. The horn is mounted like a shoe directly on the spikelike *os cornu,* which projects from the frontal bone of the skull. Part of the frontal sinus can often be found in the center of the *os cornu.* Horns arise from an inner epidermal layer (the *stratum germinativum*) immediately covering the *os cornu.* This layer lines the developing horn and produces its slow growth by continuing to secrete filaments. The reason a horned animal cannot regrow a polled horn is that the operation destroys the essential filament-secreting epidermal tissue.

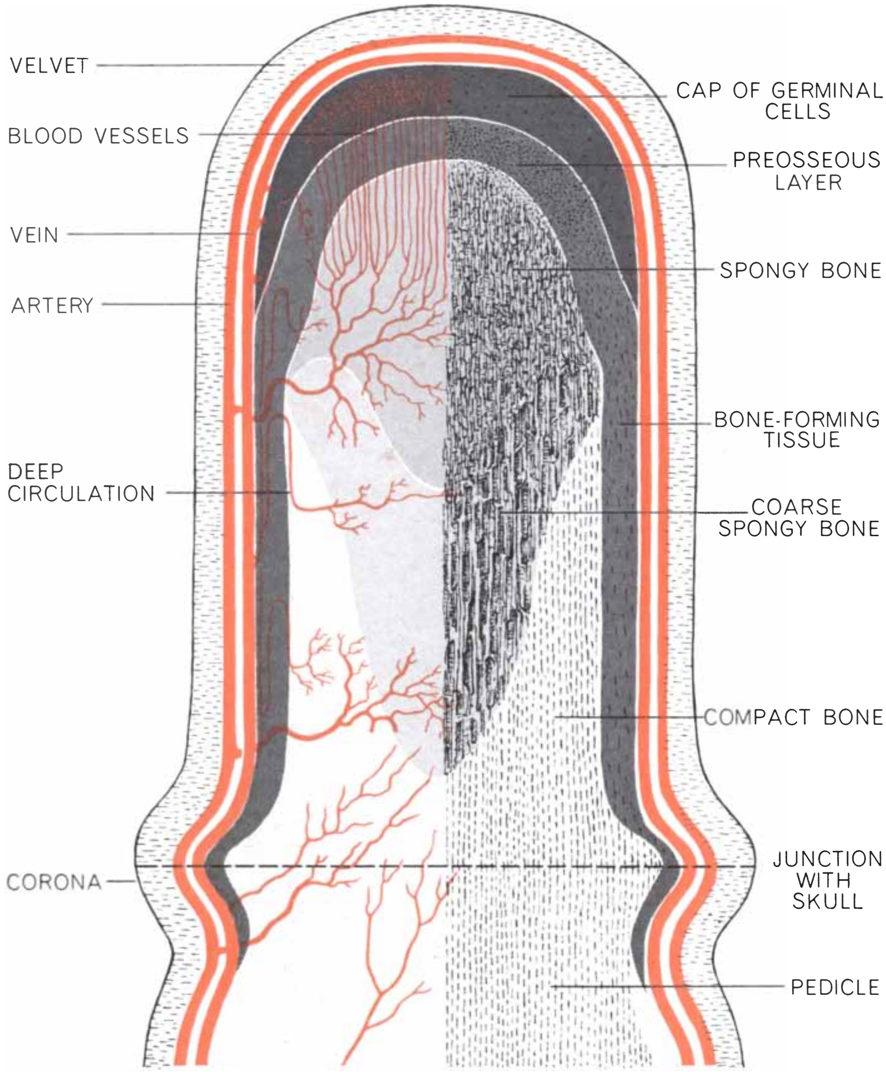
The only horned animal that sheds its horns periodically is the pronghorn antelope (*Antilocapra americana*), a native of North America that was once numerous but was almost wiped out by hunters before conservationists took measures that have effectively preserved the species. Each year the pronghorn develops a set of true horns that consist of keratin and grow on an *os cornu.* The prong is an extra spike on the horn.

This animal's annual shedding process is not even remotely related to that of antler replacement. The new horn grows while the old one is still in place and pushes the old shoe off the *os cornu* as it achieves full development, so that the animal is never without a horn. Although such an experiment is not recorded, it is probable that, if the old horn were cropped at the base, a new one would not grow. The pronghorn's horn differs from the horns typical of the Bovidae in that it is often covered with a considerable growth of hair. Yet the pronghorn antelope is so like members of the family Bovidae in all its obvious physical features that I believe it belongs in that family.

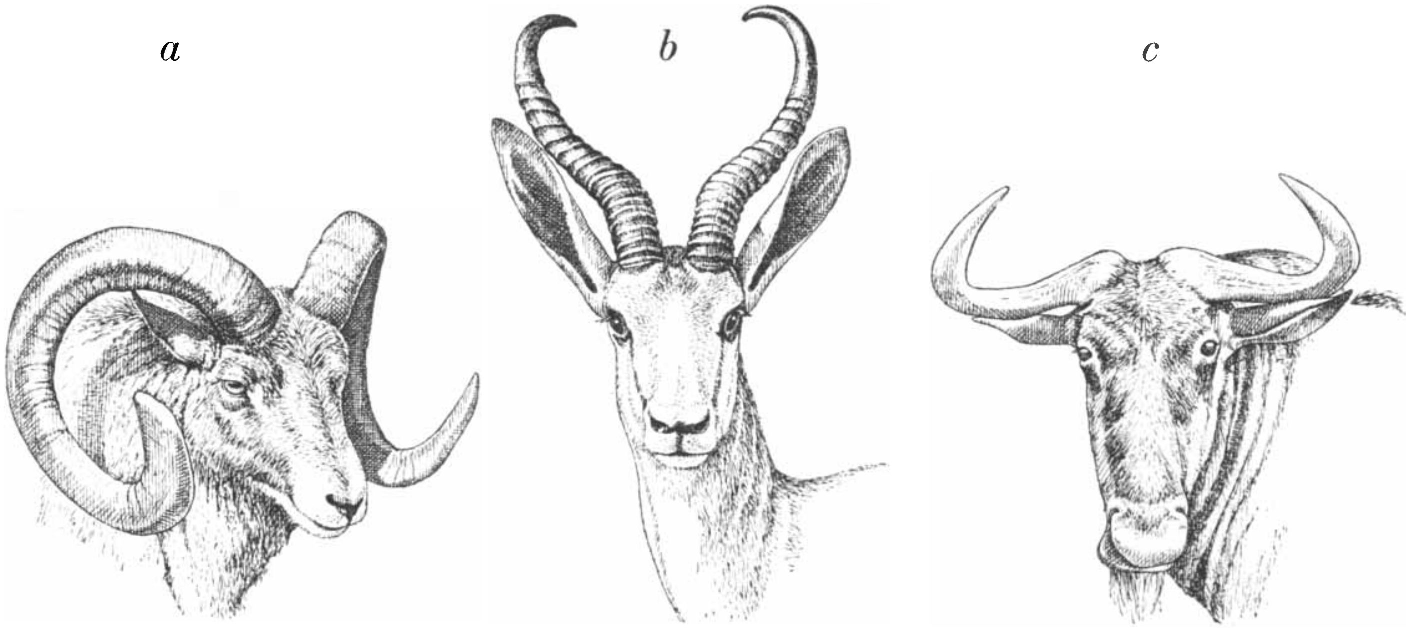
In contrast to horn, antler is a unique anatomical object. It is far and away the fastest growing postnatal bone known. My interest in this unusual tissue goes back to my days as a second-year medical student, when I began a study on seasonal changes in the elk at the laboratories of the New York Zoological Society. I showed one of my histologic sections of growing antler to my professor, James Ewing, who was then the world's outstanding student of malignant growths. On examining it under the microscope, he described the tissue, which was extraordinarily rich in mitotic figures and gave other signs of fierce growth, as a sample of malignant bone sarcoma. When I told Ewing that it was actually a slice of a normal growing antler, he urged me to pursue the study of the tissue because of its simulation of malignant growth.

Unfortunately neither I nor any other investigator since has been able to discover the nature of the mechanism that controls the exuberant growth of antler cells. Although under the microscope the actively growing antler tissue cannot be distinguished from that of malignant neoplasm of bone, it is clear that its development is under rigid control. Instead of spreading out in all directions the cells produce a sharply defined structure growing away from the head. In the course of a few months the original cells grow into a large, bony tree of great complexity. Then, at the end of the mating season, special mechanisms of the body in effect cleanly amputate this structure and it is discarded. No surgeon has yet achieved such success in removing a bone sarcoma. It is noteworthy, however, that like a malignant neoplasm the antler recurs (every year until the stag becomes very old) because a few primordial cells are left behind.

Antlers have intrigued and mystified naturalists since ancient times. Until the beginning of the 19th century they were



BLOOD SUPPLY of growing antlers is provided through the elaborate structure of arterioles and veins depicted at left. The major structural zones of the antler are shown at right.

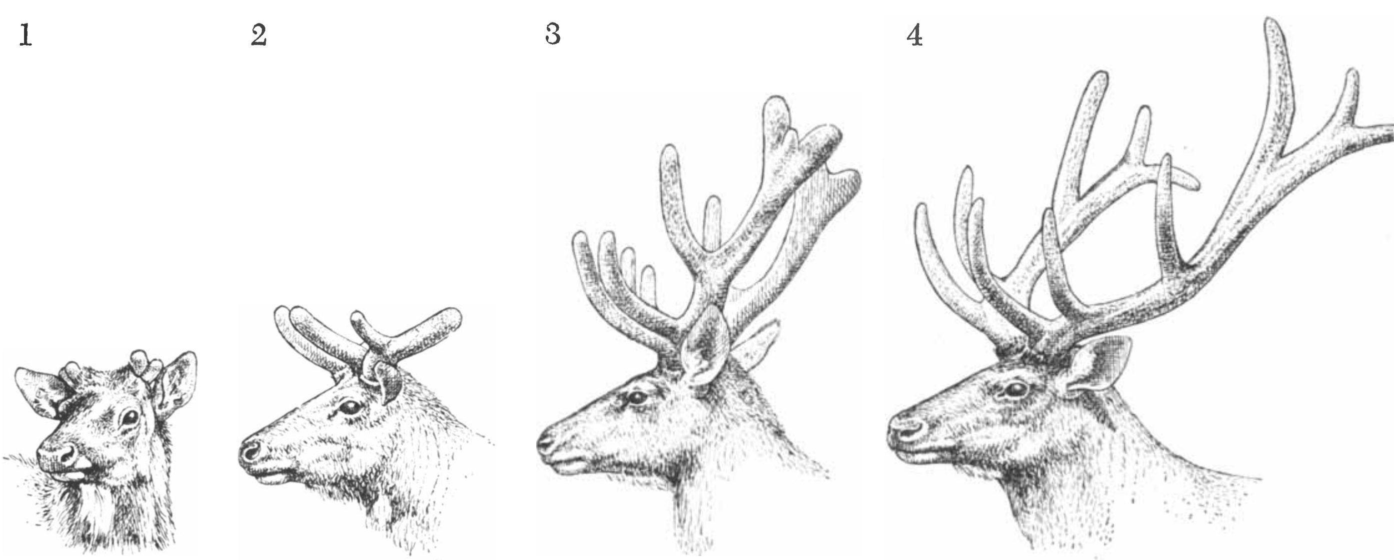


ARCHITECTURE OF HEADPIECES is suggested by five horned animals and the giraffe. The horned animals are (*a*) the mouflon, (*b*) the springbok, (*c*) the wildebeest, (*d*) the rhinoceros, whose horn is made up of tubular filaments as other horns are but, unlike

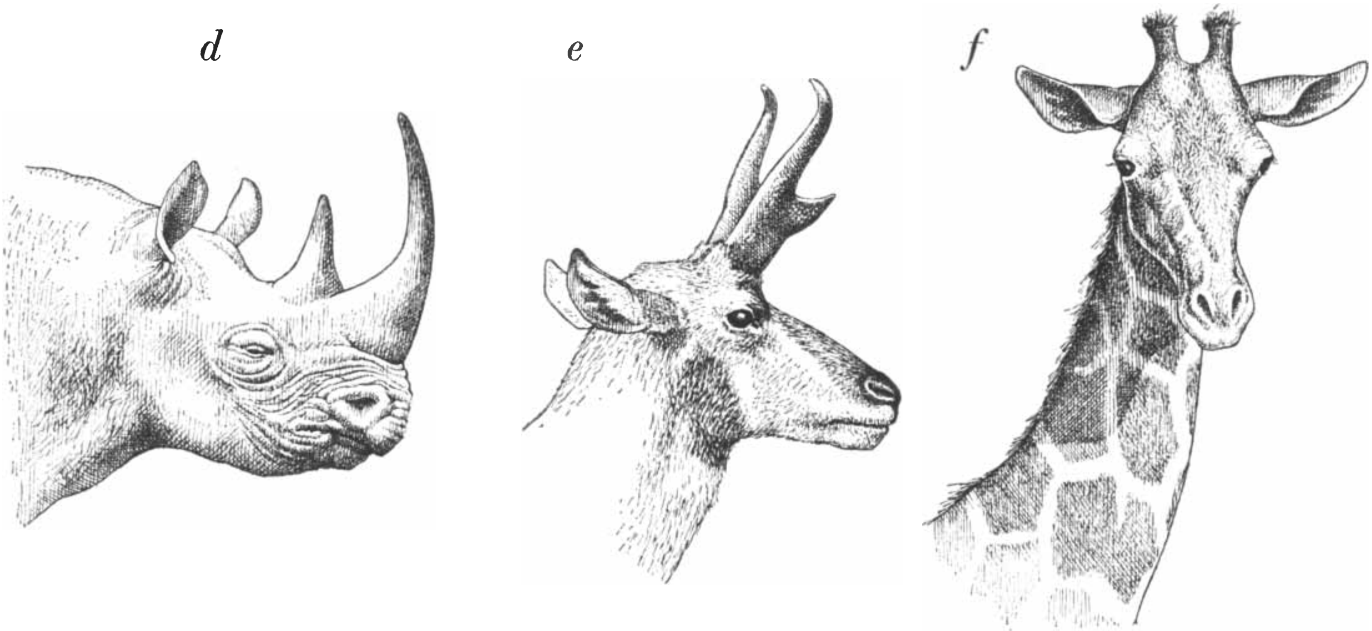
generally thought to be composed of wood; indeed, French naturalists named them *bois,* and they attached the term *écorce,* meaning bark, to the velvet that came off when the antlers matured. The discovery that they were actually bone did not come until some 19th-century investigator boiled antlers and identified gelatin in the residue.

Not all naturalists took so naïve a view as the French. Since antlers are a male characteristic, some early investigators sought to relate them to male physiology. Aristotle correctly noted: "If stags are castrated before they are old enough to have antlers, these never appear, but if castrated after they have antlers, their size never varies nor are they subject to annual change." In recent years it has been shown that injections of the male hormone testosterone can cause a castrated male deer to develop antlers. The male hormone can also stimulate a spayed female deer to produce knobs, covered with skin resembling velvet, at the sites on the skull where antlers normally grow in the male. I have observed (as have others) elderly female deer with similar knobs after menopause.

How is the antler formed? Investiga-



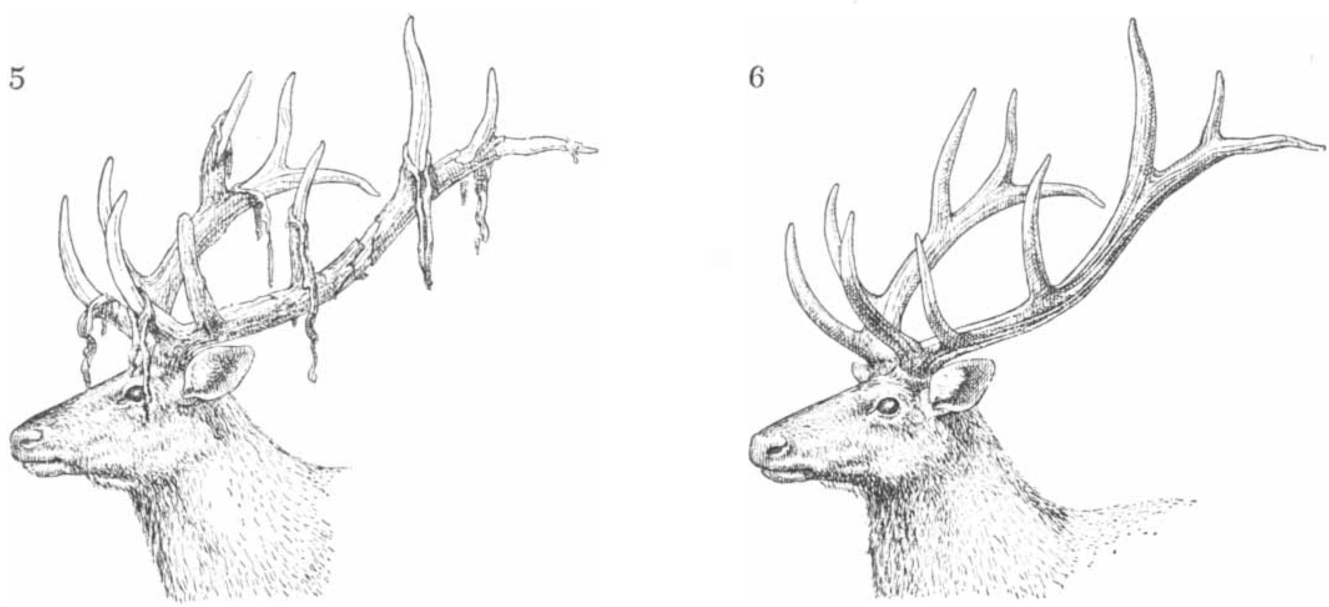
ANNUAL EVOLUTION of antlers, belonging in this case to the wapiti elk, begins (*1*) with the appearance of the velvet-covered buds of new antlers in April, about six weeks after the former antlers have been shed. Within two weeks (*2*) the characteristic branched pattern has appeared. By the end of May (*3*) the antlers are well developed and fully covered by velvet. During this



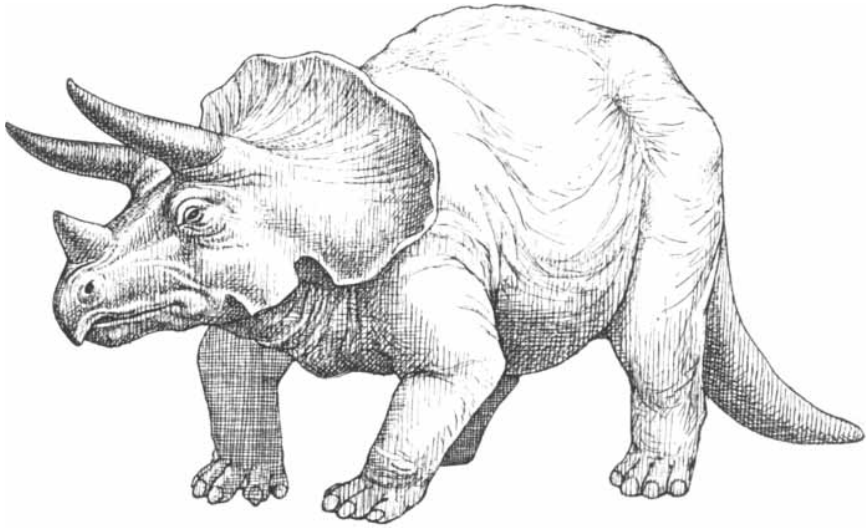
them, is solid rather than hollow and (*e*) the pronghorn antelope, which is the only horned animal with horns that are deciduous, or periodically shed. The giraffe's head (*f*) has growths that are not true horns but rather are protuberances covered with a hairy skin.

tors many years ago, using ordinary stains (hematoxylin and eosin) to study by microscope the intimate details of the growth of the tissue, concluded that antlers, like the long bones of the body, developed through an intermediate cartilage stage. I examined the microscopic details of antler development with special silver staining techniques and found that, on the contrary, the bone of antler, like the bone of the skull, is formed by direct ossification of the framework of fibrous tissue that develops first. It becomes cancellous (spongy) bone with an internal cavity that is continuous with the cavity of the skull and shares its blood supply. Curiously, unlike other spongy bone in the body, such as the sternum and the pelvis, the bone of the antler does not manufacture blood, although there is considerable blood (and a little fatty marrow) in it.

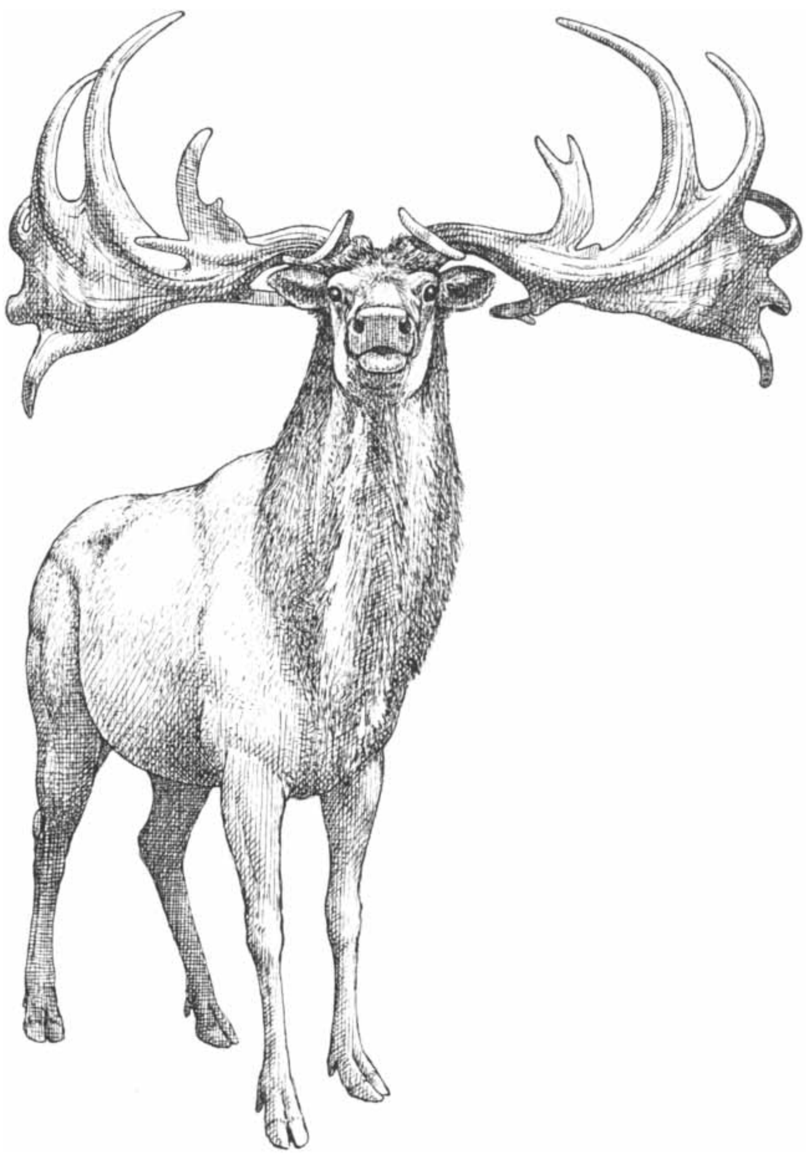
Under the influence of a hormonal rhythm the male deer begins to grow its antlers in the spring (late April or May in the U.S.). The developing antler bulges out of the velvet that covers the pedicle, a bony platform atop the frontal bone of the skull, soon after the old antler separates from it. From a few



stage the animal is careful to avoid hard objects. By August (*4*) the antlers are mature. Growth has ceased and the velvet has begun to dry at the tips. When the bony material of the antler has become fully hardened, the velvet dies (*5*) and peels off in ragged shreds. After the antlers are mature and have lost their velvet (*6*) the wapiti, which is an American elk, becomes sexually aggressive.



ANCIENT HORNED ANIMAL was *Triceratops*, a reptile with three horns and also a horny shieldlike structure. Horns apparently originated with the early large reptiles.



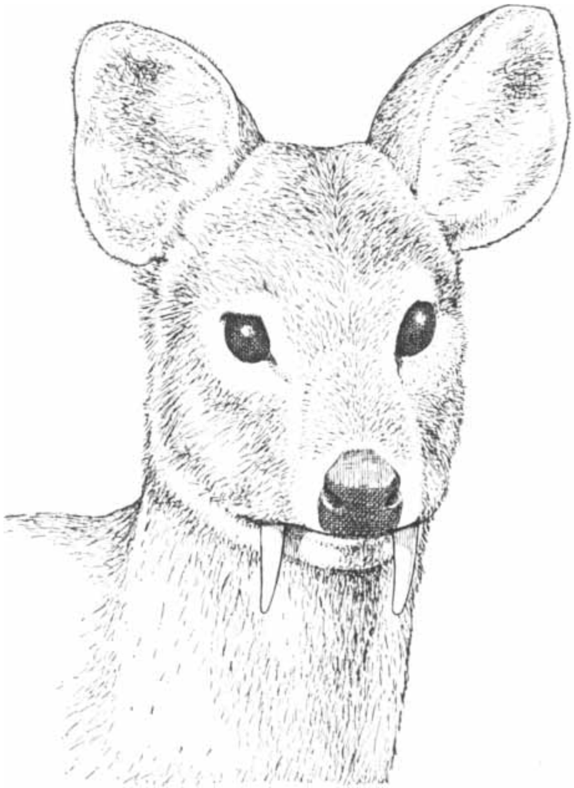
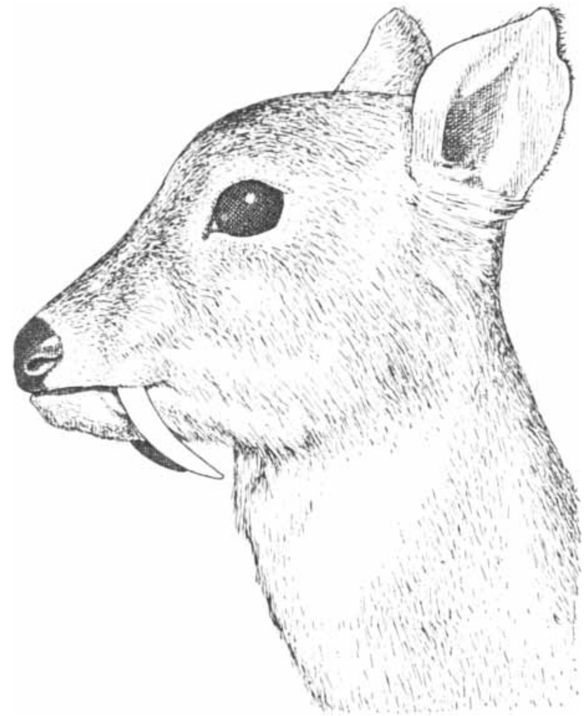
ANCIENT ANTLERED ANIMAL, much more recent than *Triceratops* but also extinct, was the giant Irish elk. Its massive antlers weighed more than its entire internal skeleton.

fibroblasts (embryonic cells) left behind when the former antler was cast a mass of fibroblasts develops below the skin, and the velvet cover grows to conform with the developing antler. The fibroblasts rapidly form the armature of the antler, much as a branch and twigs grow out of a tree. Meanwhile osteoblasts (bone-forming cells) begin to stream into this framework and to lay down the bone-forming calcium. The resulting bone has a thinner cortex and consequently is not nearly as strong as the bone of the skull, but apart from the fact that it does not form blood it is indistinguishable from the cancellous bone of the skull and other spongy bones of the skeleton.

By September the antler has grown to full size and has firmly united itself to the pedicle. The bone at the base becomes progressively denser and eventually cuts off the flow of blood from the skull to the antler's interior. Some blood is still supplied, however, by arteries coursing through the velvet covering the antler. Soon, as a result of some mechanism that has not yet been satisfactorily explained, the velvet proceeds to degenerate. It dries up and is shed by the stag, coming off in strips when the animal rubs its antlers against trees or shrubs.

At this stage the antlers have no blood supply or nerves and are insensible to painful stimuli. The bare bone and sharp tines of the antler are exposed, and for a few weeks in the fall the many-spiked antler might be usable as a weapon. It is an awkward weapon at best, however, and its development is not particularly well timed, because by that season the fawns born of the stag's preceding matings are fleet enough to escape predators and no longer need the sire's protection. As I have noted, when stags tilt with each other to gain a harem for the new mating season, the antlers may be dangerous to both adversaries. Furthermore, how is one to explain the curious fact that sometimes the harem winners are stags (called hummels) that for some unknown reason have failed to develop antlers? Could they be better fighters because they lack antlers?

The antler's implausibility as a weapon suggests that it did not actually evolve for this function. One interesting current hypothesis is that antlers serve the deer and other Cervidae as a cooling device during the summer. The velvet covering the antler provides an admirable means of radiating body heat, because of its considerable surface area and its exten-

POSSIBLE EVOLUTIONARY TREND in antlered animals may be represented by the Chinese water deer (*left*) and the musk deer (*right*), which are the only animals of the family Cervidae that do not possess antlers. The two species, however, have evolved tusks.

sive apparatus of peripheral blood vessels and sweat glands. The fact that the velvet dies at the end of the summer and the antlers are shed not long afterward lends some support to this surmise about the antler's primary reason for being. It is difficult to imagine any other plausible reason why nature should have endowed animals with an elaborate superstructure that is used only during a few weeks of the year and is discarded annually after being produced at great metabolic expense. (To the question of why females lack these radiators the supporters of the hypothesis respond that females stay in the shade.)

In the late fall some of the cement holding the base of the antler to the pedicle is resorbed, the connection weakens and the antler is cast—not as an active process but by breaking off when it happens to strike something. The break occurs neatly at the junction with the skull where the antler started to grow in the spring; there is a little bleeding, but the blood promptly clots. The process is painless. A new growth of hairy velvet (rather than the hairless, nonsweating scar tissue that forms in the normal healing of wounds) quickly covers the wound on the exposed skull, and the organs and cells involved in the formation of antler go into a dormant period, lasting from late December until the following April or May. An injection of testosterone during this period, however, can trigger antler growth.

Notwithstanding the peculiarities and apparent frivolity of antlers, they cannot really be called a freak of nature. As a headpiece they are one version, albeit an exotic one, of a phenomenon that goes back to the early history of land animals. Horns are at least 100 million years old. In the Cretaceous period there were dinosaurs and crocodile-like reptiles with horns. Some of these growths beggar the imagination of science fictionists. *Triceratops* had three horns: a huge spike rising from the nose and one above each eye. *Styracosaurus* had an upright nasal spike nearly two feet long and a neck shield with six spikes thrust out from its edges. Skull protuberances have also been found among fossils of some early mammals, notably the elephantine ungulates. The horns were formidable weapons in some early mammals, such as *Arsinoitherium,* but in others, such as *Uintatherium* and *Brontotherium,* they were blunt extensions from the skull and were probably covered with skin. By the end of the Eocene epoch some 40 million years ago the rhinoceros, its naked horn as menacing a weapon as the horns of the ancient reptiles, had begun to appear.

The rhinoceros is unusual in several ways. It is the only odd-toed animal that has a horn. The Rhinocerotidae include the only nonmythical unicorn, but several surviving species of rhinoceroses have two horns, both positioned on the midline one behind the other. The rhinoceros's horn is also exceptional in that it is solid keratin, not a hollow shoe. In prehistoric times the animal must have made considerable use of its horn as a weapon, but today the rhinoceros's massive size and armor are sufficient protection to discourage attack by its less massive contemporary competitors.

Paradoxically, in our era the horn has been the rhinoceros's undoing. For more than 1,000 years man, now the animal's principal enemy, has been hunting down the rhinoceros for its horn. In China ground rhinoceros horn has long been prized for its supposed values as an aphrodisiac and a medicine for various ailments, and in the medical markets of China and Africa today the horn is said to be worth half its weight in gold. A thriving trade is also conducted in dried rhinoceros blood and in rhinoceros hide for use as a warrior's shield. A few rhinoceroses manage to survive in Asia by keeping out of sight, and in some parts of Africa the animal is protected from hunters by law.

During the Miocene epoch, beginning

some 25 million years ago, horns and antlers developed among many species of two important families of ungulates, the Bovidae and the Cervidae. These two families are so remarkably alike in many ways that they may well have had a common ancestry. The great differences between horn and antler, however, indicate that the two forms of head appendage had different origins. The Bovidae revived the keratinous horn growth that was already a 100-million-year-old carryover from the age of reptiles. The Cervidae introduced the antler as a basically new growth. According to the available fossil record, the first antlered cervid was *Dicrocerus*, an ungulate of the early Miocene that grew a very simple antler in the form of short spikes. Because antler is so skimpily constructed that it deteriorates about twice as fast as the skull bone under ordinary exposure, it may well be that its ancient history is not as well preserved in the paleontological record as that of skull and skeletal bone. The record does show, however, that in the Pleistocene epoch antlers became common among the Cervidae and some of them grew to monstrous size. Probably the most impressive antlers of all time were borne by the great stag (*Cervus megaceros*) of the Ice Age; its pair of antlers had a spread of three meters and weighed about 70 kilograms (154 pounds)! Among the living members of the family Cervidae today all but two species have antlers. The exceptions are the Chinese water deer and the musk deer [*see illustration on preceding page*].

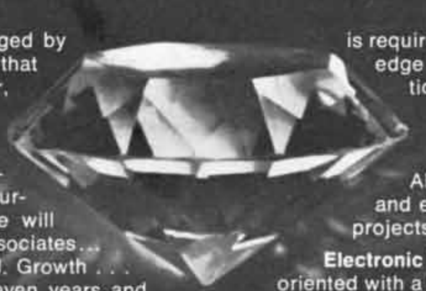
There are reasons to believe the giraffe and the okapi are closely related to the Cervidae and evolved from the same group of ancestors. The permanent knobs on the head of the giraffe and the okapi are not made of keratin; hence they are not true horns. The giraffe's knobs are formed of a bony core extending straight up from the skull and are covered with a hairy skin that gives the knobs their tufted appearance. In the okapi a bit of bare bone is exposed at the tip. The knobs of these two strange beasts seem closer to antlers than to horns and perhaps are best compared to antlers permanently in velvet.

In a curious way horns and antlers are invariably associated with certain other apparently unrelated anatomical features. Headpieces of one kind or another (horns, antlers or knobs) are possessed by virtually all even-toed ungulates with a four-chambered (or true ruminant) stomach; this includes the Bovidae, the Cervidae, the pronghorn, the giraffe and the okapi. With the single exception of the rhinoceros no odd-toed animal (which includes the horse, the ass and the zebra) has a headpiece, and headpieces are also absent in all even-toed ungulates with false ruminant, or three-chambered, stomachs (camels, llamas and others), as well as in those with a single-chambered stomach (pigs, peccaries and hippopotamuses). What connection can there be between horns or antlers and a perfect ruminant stomach and even-toed hooves? By what odd quirk of evolution did these seemingly unrelated characteristics come to be associated with one another, if indeed the association is not mere coincidence?

Be that as it may, this enigma is much less intriguing than the mystery of why antlers evolved and why they have persisted so long. The evolutionary success of horns, which have proved their value over 100 million years of trials and are now firmly incorporated in a great number of species of ungulates, is quite understandable. The antler, on the other hand, is obviously an encumbrance with a very limited, if not entirely questionable, usefulness. Perhaps the main surprise is that it has lasted for upward of 25 million years and is still retained by almost the entire family Cervidae. There is evidence, however, both in the fossil record and in the hunting history of man, that antlers as well as the antlered animals are on the decline. Their often suicidal tilts with their antlers, by killing off some of the best and strongest stags, may have played a part in this decline. The preservation of the Cervidae is now aided by the U.S. program for the protection of wildlife, but this has led to a proliferation that has made them a true pest and necessitates large-scale seasonal hunting of the animals to spare them from starvation and our forests from ruination by debarking. Overprotection of the animals, with its consequent disturbance of ecology, may not be in our interest.

It may be that in the long run natural selection can save the Cervidae by eliminating those with elaborate antlers, so that the surviving members of the family come to be like the two nonantlered species, the Chinese water deer and the musk deer. In any case, it appears that antlers, if not the antlered animals themselves, are doomed by evolution, and that the eight arboreally ornamented reindeer of Santa Claus, like the handsome unicorn, will one day become strictly a legend.

The many facets of a rewarding career.



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MEMOREX

MATHEMATICAL GAMES

An octet of problems that emphasize gamesmanship, logic and probability

by Martin Gardner

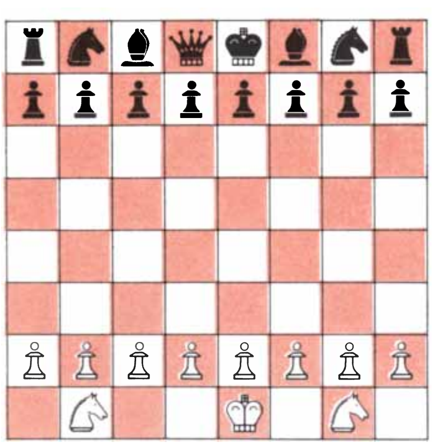
Here are eight problems to be answered, the last of them consisting of a collection of 10 "quickies." The solutions will be given next month.

1. Last January, after 10 weeks of haggling, the Vietnam peace negotiators in Paris finally decided on the shape of the conference table: a circle seating 24 people, equally spaced. Assume that place cards on such a table bear 24 different names and that on one occasion there is such confusion that the 24 negotiators take seats at random. They discover that no one is seated correctly. Regardless of how they are seated, is it always possible to rotate the table until at least two people are simultaneously opposite their place cards?

A much more difficult problem arises if just one person finds his correct seat. Will it then always be possible to rotate the table to bring at least two people simultaneously opposite their cards?

Both questions will be answered next month, although the proof for the second is too complicated to give in detail. The problem was first called to my attention by Eaton Lattman.

2. *The British Chess Magazine,* Vol. 36, No. 426, June, 1916, reported that



White to move knights and check in five

an American amateur named Frank Hopkins had invented a variation of chess, which he called "Single Check" or "One Check Wins." The game is played exactly like standard chess except that victory goes to the first player who checks (not checkmates) his opponent's king. The magazine, quoting from an article in *The Brooklyn Daily Eagle,* reported that "a suspicion that the white pieces had a sure win turned into a certainty" when U.S. grand master Frank J. Marshall one day "laconically remarked that he could 'bust' the new game." Hopkins was unconvinced until Marshall quickly won by moving *only his two white knights.* Marshall's strategy is not given, except for his opening move, nor does the account of the incident give the number of white moves before he administered the fatal check.

Since 1916 the idea of "single check" chess has occurred independently to many players. I first heard of it recently from Solomon W. Golomb, who knew it as "presto chess," a name given it by David L. Silverman after learning of the game from a 1965 reinventor. Back in the late 1940's the game had been reinvented by a group of mathematics graduate students at Princeton University. One of the students, William H. Mills (who has been at the Institute for Defense Analyses in Princeton since 1963), had discovered then what was undoubtedly Marshall's strategy: a way in which White, moving only his knights, can win on or before his fifth move. This year Mills and George Soules, a colleague at the institute, found different five-move wins involving pieces other than knights. I shall discuss them next month, but now readers are asked only to see if they can duplicate Marshall's feat by solving the problem shown in the illustration at the left. How can White, moving only his knights, check the black king in no more than five white moves?

Attempts have been made to make the game more even by imposing additional rules. Hopkins himself proposed beginning with each player's pawns on the third row instead of the second. Sidney Sackson, a New York City game inventor who told me of the 1916 reference, suggests that the winner be the first to check a specified number of times, say from five to 10, depending on how long one wants the game to last. Whether either proposal effectively destroys White's advantage I cannot say.

3. Anatol W. Holt, director of advanced systems for Applied Data Research, Inc., is a mathematician who makes a hobby of inventing games. His board game MEM, played with 32 stones of 11 colors, is a delightful strategy game based on a completely new idea involving pattern recognition. (It is currently on sale in stores and can also be ordered postpaid for $6.50 from Holt's own firm, Stelledar, Inc., 1700 Walnut Street, Philadelphia, Pa. 19103.)

A few years ago Holt devised the following word game. Two people each think of a "target word" with the same number of letters. Beginners should start with three-letter words and then go on to longer words as their skill improves. Players take turns calling out a "probe word" of the agreed length. The opponent must respond by saying whether the number of "hits" (right letter at the right position) is odd or even. The first to guess his opponent's word is the winner. To show how logical analysis can determine the word without guesswork, Holt has supplied the following example of six probe words given by one player:

Even	*Odd*
DAY	SAY
MAY	DUE
BUY	TEN

If you knew the target word and compared it letter by letter with any word on the even list, you would find that an even number of letters (zero counts as even) in each probe word would match letters at the same positions in the target word; words on the odd list would match the target word in an odd number of positions. Find the target word.

4. In *Problematical Recreations,* No. 7, a series of puzzle booklets issued annually by Litton Industries in Beverly Hills, Calif., the following problem appeared. A man places his beer glass on the bar three times to produce the set of triple rings shown at the top of the opposite page. He does it carefully, so that each circle passes through the center of the other two. The bartender thinks the area of mutual overlap (*shaded*) is less than one-fourth of the area of a circle, but the customer says it is more than one-fourth. Who is right?

The solution can be obtained the hard way by finding the area of an equilateral triangle inscribed in the shaded section and then adding the areas of the three segments of circles on each side of the triangle. A reader of this column, Tad Dunne of Willowdale in Ontario, sent me a beautiful graphical "look and see" solution that involves no geometrical formulas and almost no arithmetic, although it does make use of a repeating wallpaper pattern. Can the reader rediscover it?

5. In Grand Central Terminal in New York I saw in a store window an unusual desk calendar [*see bottom illustration on this page*]. The day was indicated simply by arranging the two cubes so that their front faces gave the date. The face of each cube bore a single digit, 0 through 9, and one could arrange the cubes so that their front faces indicated any date from 01, 02, 03, . . ., to 31.

The reader should have little difficulty determining the four digits that cannot be seen on the left cube and the three on the right cube, although it is a bit trickier than one might expect.

6. In the *Journal of Recreational Mathematics* for July, 1968, L. D. Yarbrough of Lexington, Mass., introduced a new variant on the classic problem of the knight's tour. In addition to the rule that a knight touring a chessboard cannot visit the same cell twice (except for a final reentrant move that in certain tours allows the knight to return to the starting square), the knight is also not permitted to cross its own path. (The path is taken to be a series of straight lines joining the centers of the beginning and ending squares of each leap.) The question naturally arises: What are the longest uncrossed knight's tours on square boards of various sizes?

The bottom illustration on the next page reproduces samples of the longest uncrossed tours Yarbrough found for square boards from order-3 through order-8. The order-7 tour is particularly interesting. Seldom does a reentrant tour have maximum length; this is one of the rare exceptions as well as a tour of pleasing fourfold symmetry.

The idea of uncrossed knight's tours caught the interest of Donald E. Knuth, a mathematician at the Institute for Defense Analyses who has been mentioned several times in recent columns. Knuth wrote a "backtrack" computer program that, among other things, found every possible maximum-length uncrossed knight's tour on square boards through order-8. Rotations and reflections are, as usual, not considered different. The computer found two tours for the order-3 board, five for order-4, four for order-5, one for order-6, 14 for order-7 and four for order-8 (the standard chessboard).

It is the unique tour on the 6-by-6 that is most surprising and that provides our problem. Only on the order-6 board did Yarbrough fail to find a maximum-length uncrossed tour. His tour has 16 moves, but there is one uncrossed tour on this board that has 17 moves. The reader is invited to match his wits against the computer and see if he can discover the 17-move tour.

To find the order-6 tour the computer examined 88,466 cases. The order-7 search examined 10,874,673 cases and the order-8 3,137,317,289 cases.

7. Probability theorists are fond of illustrating theorems with problems about identical objects of different colors that are taken from urns, boxes, bags and so on. Even the simplest of such problems can be confusing. Consider, for instance, the fifth of Lewis Carroll's *Pillow Problems:* "A bag contains one counter, known to be either white or black. A white counter is put in, the bag shaken, and a counter drawn out, which proves to be white. What is now the chance of drawing a white counter?"

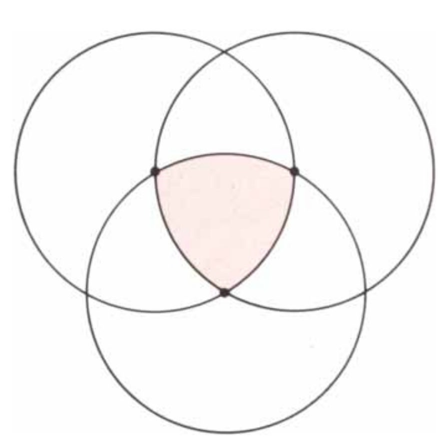
"At first sight," Carroll begins his answer, "it would appear that, as the state of the bag, *after* the operation, is necessarily identical with its state *before* it, the chance is just what it was, viz. 1/2. This, however, is an error."

Carroll goes on to show that the probability of a white counter remaining in the bag actually is 2/3. His proof is a bit long-winded. Howard Ellis, a Chicago reader, has done it differently. Let *B* and *W(1)* stand for the black or white counter that may be in the bag at the start and *W(2)* for the added white counter. After removing a white counter there are three equally likely states:

In bag	*Outside bag*
W(1)	*W(2)*
W(2)	*W(1)*
B	*W(2)*

In two of these states a white counter remains in the bag, and so the chance of drawing a white counter the second time is 2/3.

A recent problem of this kind, with an even more surprising answer, begins with a bag containing an unknown number of black counters and an unknown number of white counters. (There must be at least one of each color.) The counters are taken according to the following procedure. A counter is chosen at random and discarded. A second one is taken at random. If it is the same color as before, it too is discarded and a third is chosen. Each time the color matches that of the counter that was taken just previously, the newly taken one is discarded. When the color fails to match, the counter is replaced, the bag is shaken and another drawing is made. In other words, a counter is replaced only when a change of color occurs. It turns out that regardless of the ratio of white to black counters at the start there is a fixed probability that the final counter will be black. What is that probability?



How much of one circle is shaded?

8. And now the 10 quickies:

(1) With a seven-minute hourglass and an 11-minute hourglass, what is the simplest way to time the boiling of an egg for 15 minutes? (From Karl Fulves.)

(2) A man traveled 5,000 miles in a car with one spare tire. He rotated tires at intervals so that when the trip ended each tire had been used for the same number of miles. For how many miles was each tire used?

(3) A standard deck of 52 cards is shuffled and cut and the cut is completed. The color of the top card is noted. This card is replaced on top, the deck is cut again and the cut is completed. Once

What digits are on the cubes' hidden faces?

1.	a		
2.			b
3.	a	+	b
4.	a	+	$2b$
5.	$2a$	+	$3b$
6.	$3a$	+	$5b$
7.	$5a$	+	$8b$
8.	$8a$	+	$13b$
9.	$13a$	+	$21b$
10.	$21a$	+	$34b$
	$55a$	+	$88b$

Answer to Fibonacci problem

more the color of the top card is noted. What is the probability that the two cards noted are the same color?

(4) Find a number base other than 2 or 10 in which 121 is a perfect square.

(5) Draw six line segments of equal length to form eight equilateral triangles.

(6) Assuming that the angle cannot be trisected by compass and straightedge, prove that no number in the doubling series 1, 2, 4, 8, 16, 32, ... is a multiple of 3. (From Robert A. Weeks.)

(7) A farmer has 20 pigs, 40 cows, 60 horses. How many horses does he have if you call the cows horses? (From T. H. O'Beirne.)

(8) Translate: "He spoke from 2222-222222222 people."

(9) A Greek was born on the seventh day of 40 B.C. and died on the seventh day of A.D. 40. How many years did he live?

(10) A woman either always answers truthfully, always answers falsely or alternates true and false answers. How, in two questions, each answered by yes or no, can you determine whether she is a truther, a liar or an alternator?

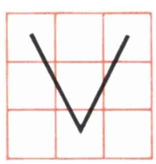
The first problem last month was to find the winning move in Fibonacci nim when the game begins with a pile of 20 counters. Since 25 is not a Fibonacci number the first player has a sure win. To determine his first move he expresses 20 as the sum of Fibonacci numbers, starting with the largest possible F-number, 13, adding the next largest possible, 5, then the next, 2. Thus $20 = 13 + 5 + 2$. Every positive integer can be expressed as a unique sum in this way. No two consecutive F-numbers will appear in the expression. An F-number is expressed by one number only: itself.

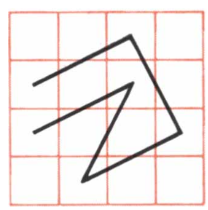
The last number, 2, is the number of counters the first player must take to win. The second player is forbidden by the rules of Fibonacci nim to take more than twice 2, and therefore he cannot reduce the pile (which now has 18 counters) to the Fibonacci number 13. Assume that he takes four counters. The pile now contains 14. This is equal to F-numbers $13 + 1$, and so the first player takes one counter. By continuing this strategy he is sure to obtain the last counter and win.

If the initial number of counters is a Fibonacci number, say 144, the second player can always win. True, the first player can take 55 counters to leave 89, the next highest F-number, but then the second player can immediately win by taking all 89 counters because 89 is less than twice 55. The first player is forced, therefore, to leave a non-Fibonacci number of counters and the second player wins by the strategy that I have just explained. (See Donald E. Knuth, *Fundamental Algorithms,* Addison-Wesley, 1968, page 493, exercise No. 37, and "Fibonacci Nim," by Michael J. Whinihan in *The Fibonacci Quarterly,* Vol. 1, No. 4, December, 1963, pages 9–13.)

To prove that the sum of the first 10 numbers in a generalized Fibonacci series is always 11 times the seventh number, call the first two numbers a and b. The 10 numbers and their sum can be represented as shown at the top of this page. The sum obviously is 11 times the seventh number. Note that the coefficients of a and b form two Fibonacci sequences.

None of the three king's-tour spelling matrices that I presented in the January column is unique. So many readers pointed out the four solutions for the Nixon matrix that I cannot list all their names. Gerald K. Schoenfeld also called attention to the three solutions for the Humphrey matrix, and two readers, Malcolm C. Holtje and Dean P. McCullough, in addition to finding the four for Nixon and three for Humphrey, were able to find eight different matrices for Johnson.


ORDER 3, LENGTH 2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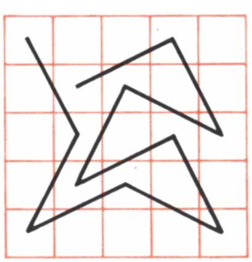
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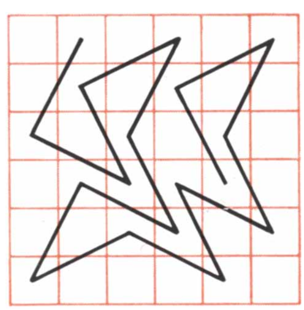
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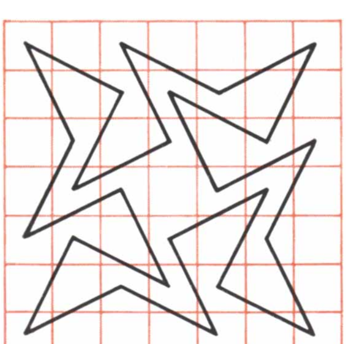
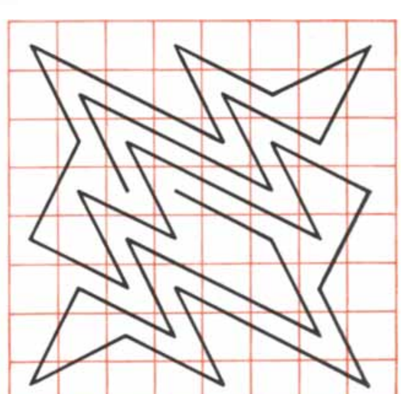

ORDER 7, LENGTH 24


ORDER 8, LENGTH 35

Try to lengthen the order-6 knight's tour

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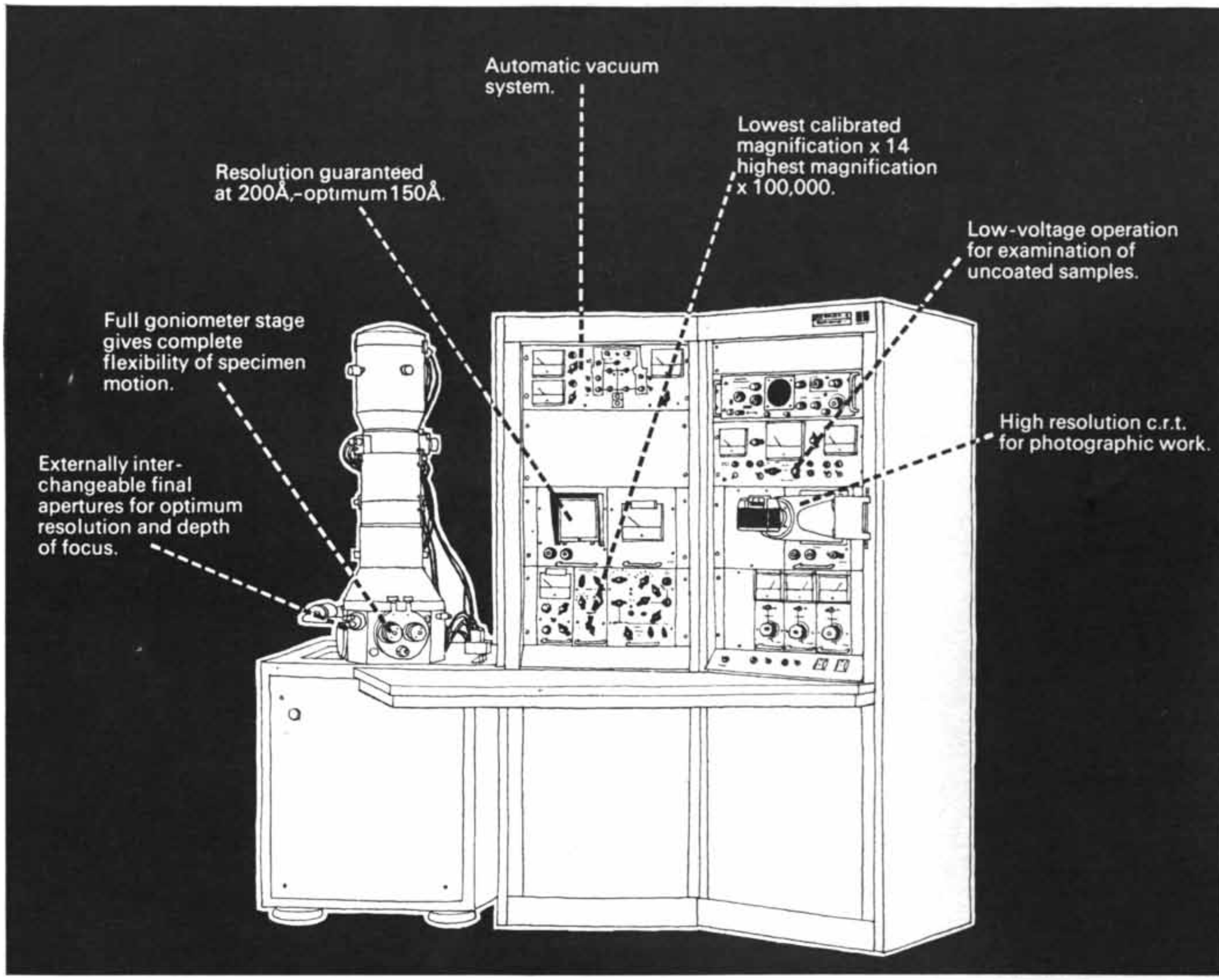

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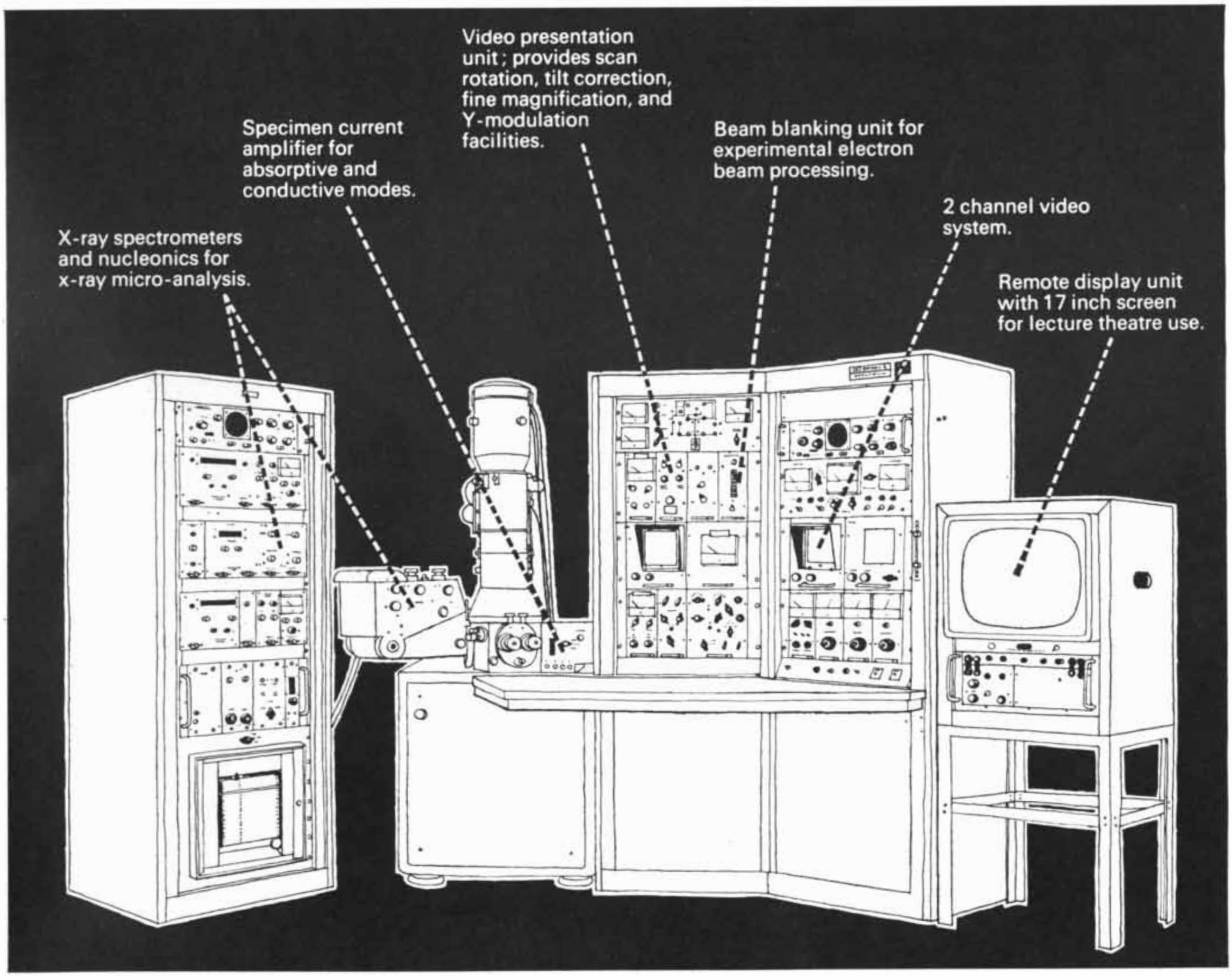

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THE AMATEUR SCIENTIST

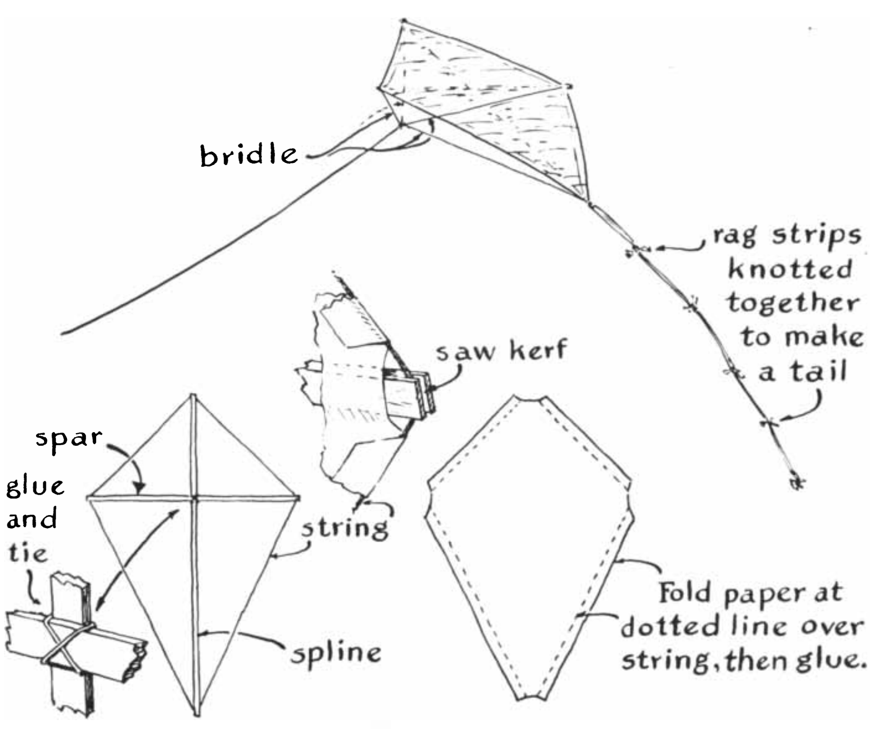
The lore and aerodynamics of making and flying kites

Conducted by C. L. Stong

Some years ago two boys offered to mow my lawn if I would help them to build and fly a kite. I agreed. The resulting kite performed so nicely that we extended the contract at the rate of one kite for one mowing and spent a memorable summer discovering the joys of designing, building and flying kites. Although one of the boys ultimately became an aeronautical engineer and the other a biochemist, their enthusiasm for kites lives on, as does mine.

What is a good kite? The answer depends on your tastes and interests. To the skillful enthusiasts of the Orient, where the sport of kite-flying predates recorded history, kites are of three kinds. The first category consists of fighting kites. A good one is so agile and sturdy that it can knock down all competitors in controlled aerial combat. The second category consists of acrobatic kites that can be made to dive, loop, perform figure eights and so on. Designs in the third category appeal primarily to the eye and ear. These kites range in form from simple diamond shapes to figures resembling birds, animals and mythological creatures including dragons up to 100 feet long. The kites are usually gaily colored and may carry bamboo pipes and other instruments that emit musical sounds.

The kites we built belong to still another category: those that reach the highest possible altitude for a given length of string, or, as aeronautical engineers would put it, kites of maximum lift-to-drag ratio. We had fun trying novel designs and contriving jobs for the kites to do, such as measuring the temperature of the air at altitudes up to a few thousand feet and making aerial photographs. We obtained much of the information we needed from the files of the U.S. Weather Bureau, which relied heavily on kites to carry meteorological instruments aloft before the advent of radiosondes, rockets and satellites. At the turn of the century the bureau operated 17 kite stations across the country and set a number of records. For example, on May 5, 1910, the uppermost unit in a train of 10 Weather Bureau kites carried a load of meteorological instruments to an altitude of 24,000 feet. Collectively the kites in the train had a sail area of 683 square feet and exerted a pull of more than 400 pounds on the nine-mile flying "string" of piano wire. The wire was paid out and drawn in by an electric winch.



Elements of a diamond kite

Our efforts were much less ambitious. Our first kite was a simple diamond formed by a pair of crossed sticks covered with paper. The spline, or vertical stick, was three feet long and the spar, or horizontal stick, was two feet long. The middle of the spar crossed the spline a foot from the top. We fastened the sticks together at the cross with a drop of glue and a binding of string. A saw kerf about a sixteenth of an inch deep was made in the ends of each stick before assembly [*see illustration at left*].

When the glue had dried, we stretched a string through these kerfs and glued the paper covering to the strings. The kite was then fitted with a bridle, which consisted of a loop of twine tied to the top and bottom of the spline on the papered side of the kite and another loop across the spar. The length of the bridle was adjusted so that the string became taut when the loops were pulled a foot from the paper at a point directly above the cross. The flying string was tied temporarily to the bridle at this point. The point at which the string is attached to the bridle determines the angle at which the air strikes the kite: the angle of attack. Kites, like the mainsail of a sailboat, perform best at angles of attack ranging from about 20 to 25 degrees, greater than the angle at which an airplane wing meets the wind because of the pronounced curvature of the paper. The exact angle of attack at which a kite performs best depends on the strength of the wind and must be determined experimentally. In general the angle must be decreased as the speed of the wind increases. The change is accomplished by shifting the string toward the top of the kite.

Diamond kites are inherently unstable and must be fitted with a tail to hold them upright. Part of the stabilizing force is provided by the weight of the tail, part by friction between the tail and the moving air and part by turbulence generated in the airstream by the tail. The last two forces are known as drag. If the kite is to fly, the downward forces must be exceeded by the lifting force that is developed by the flow of air under and over the paper covering. The tail provides stability but at the cost of lift. The amount of stability required increases with the speed of the wind. A kite that flies nicely with a short tail during a light breeze will spin out of control in a stiff wind. Yet a kite with a long tail that flies well in a stiff wind may not fly in a light breeze.

One solution to this problem is to provide the kite with a tail that consists of a series of wind cones [*see illustration on this page*]. The cones can be made by removing the bottoms from paper containers, such as paper cups or ice cream cartons. The force developed by air flowing through the cones increases with the speed of the wind and so provides optimum stability through a fairly broad range of wind speeds. Kites with light tails of this kind fly substantially higher than those with tails made of strips of cloth or bundles of paper tied at intervals along a string.

The shape of the diamond kite can be easily modified. For example, three sticks of equal length can be crossed to form a hexagon. A circular form can be made by bending bamboo into a hoop. Combinations of straight sticks and bamboo can be formed into figures of birds. All these shapes fly about equally well when they are equipped with an appropriate stabilizing tail. In the Orient complex designs are often made by stacking a series of kites closely behind one another. The kites are tied together by strings that extend from the corners of the first kite to the comparable corners of succeeding kites. The bridle is attached to the first kite of the series. Succeeding members of the series function both as kites and as the stabilizing tail.

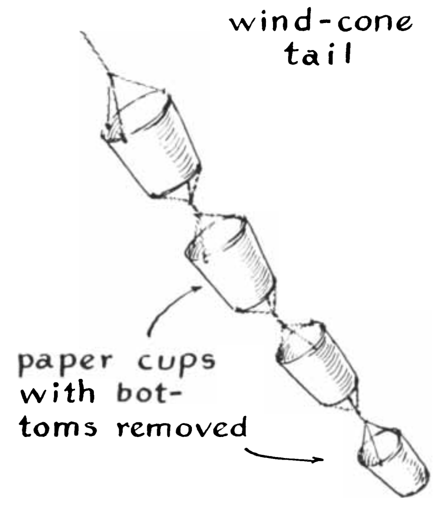
To launch a kite of any kind grasp the flying string in one hand and the bottom of the kite in the other. Incline the kite at an angle of about 25 degrees into the wind, with the paper side facing the wind, and let it go. As the kite rises pay out flying string at a rate that allows the kite to continue its ascent. If two people do the flying, let one hold the kite while the other pays out about 50 feet of string. When the string has been pulled snug, the inclined kite is tossed into the air.

The materials for kite making are readily available. Our sticks came mostly from a local lumberyard. We selected clear, straight-grained spruce 3/4 inch thick, six inches wide and six feet long and had the yard saw it into strips from 3/16 inch to 1/4 inch in width. We also made kite frames of wooden dowel stock 1/4 inch in diameter. Dowel stock is heavier than spruce, bends rather easily and is more difficult to assemble than flat sticks. On the other hand, it is available ready-made in most hardware stores.

We used nylon flying string. The breaking strength of nylon is high in proportion to its weight and thickness, and it develops less drag in the wind than other strings we tested, particularly the fuzzy cotton string known as butcher twine. Do not use piano wire for the flying string or any other material that conducts electricity. Kite-fliers have been electrocuted by electrically conducting "string" that made accidental contact with high-voltage power lines. Never fly a kite with a string that is wet or attempt to duplicate Benjamin Franklin's experiment of drawing "the electric fire" from a thunderstorm. Franklin was lucky. A European scientist who followed his instructions for performing the experiment was killed by a bolt of lightning that traveled down the wet string.

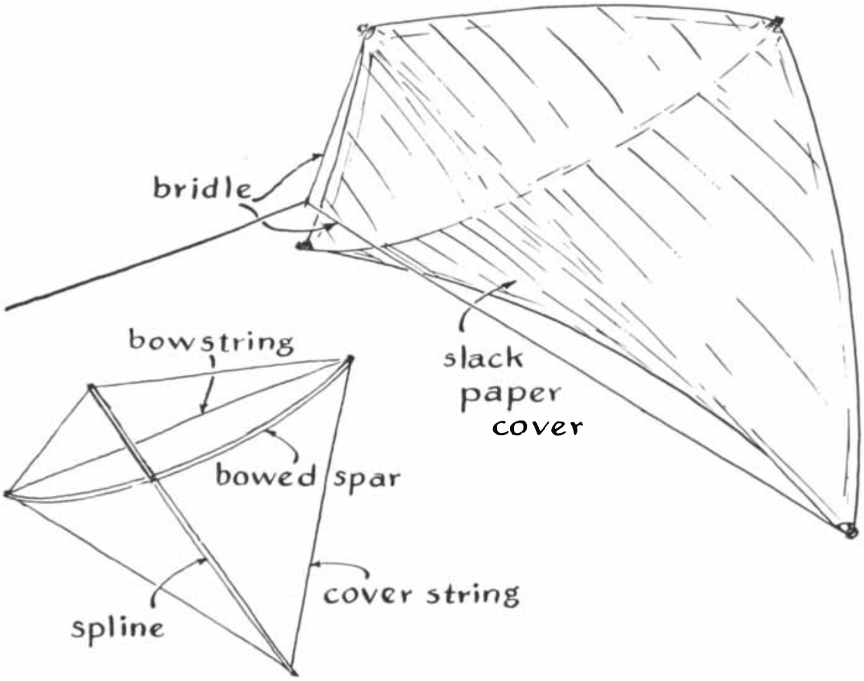
Kites up to four feet in diameter can be covered with paper, even newspaper. Light, closely woven silk is better and stronger and develops less drag, but it is expensive. The strongest and aerodynamically most efficient material is Mylar, a plastic sheet that is available from mail-order firms that cater to farmers. The sheets are used to protect grain and hay from the weather.

We next made and flew several Malay kites. Essentially they are diamond kites that achieve stabilization through their shape and therefore need no tail. They fly much higher than kites with tails and are more maneuverable. Stability is achieved by bending the spar backward with a bowstring [*see top illustration on next page*]. Stability increases with the depth of the bow. In the case of a spar two feet long the bow is typically made about four inches deep. When the kite faces squarely into the wind, the force of the wind acts equally on the left and right sides of the surface. When a puff of wind turns the kite so that one side faces more squarely into the wind than the other, the forces are unbalanced. The side facing into the wind then experiences greater force, which rotates the kite to restore the balance. Airplane wings are similarly joined to make a shallow V, known as the dihedral angle, that provides lateral stability. Again, stability is gained at some cost in lift. Malay kites of minimum bow fly higher than those of maximum bow but tend to dart back and forth, to loop and spin. Kites of maximum bow fly steadily but lower. The paper covering of Malay kites should be slack, like the sails of a boat, so that the wind can bend the surface into a uniform curve. A Malay kite has a single bridle string that is tied to the spline.



Wind-cone tail

By fitting a Malay kite with two or more flying strings and a crossed bridle the flight pattern can be controlled from the ground. Two bridle strings of equal length are tied to the top and bottom of the spline and a third string is tied to the ends of the spar. The vertical strings are separated to the left and right and tied symmetrically to the horizontal string [*see bottom illustration on next page*]. The flying strings are attached to the points at which the bridles cross. During flight the kite will drift sideways, toward the string that is pulled most, and at a speed that increases with the amount of pull on the string. At the



Configuration of a Malay kite

limit of the lateral drift the kite will loop, dive and reverse its lateral direction. The maneuver will twist the flying strings together. They can be unwound by pulling the slack string, which will cause the kite to perform the same maneuver in reverse. The art of making the kite perform other acrobatic stunts can be learned by practice.

For lifting a load such as a thermometer, a barometer or a camera we prefer the French war kite, a triangular box kite that has a pair of triangular wings [*see top illustration on opposite page*]. The framework consists of five sticks. In a design of modest size four of the sticks may be three feet long and the fifth one 14 inches long. Two of the long sticks are used for parallel splines, spaced 12 inches apart. The spar crosses the splines a foot from the top. The short stick crosses a foot below the spar and parallel to it. All of the crosses are cemented and bound with string. The completed frame is covered with paper, as in the case of a hexagon kite. The paper is then slit diagonally in the square center space bounded by the splines, the spar and the short stick. The resulting flaps of paper are folded over the adjacent wooden strips and cemented in place. The structure is now a hexagon kite with a square hole in the middle.

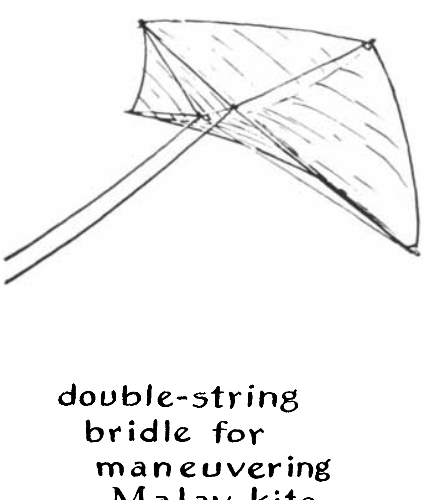
The triangular box section is made by equipping the edges of two paper strips with cover strings. Drive four nails partway into a bench top to mark a rectangle a foot wide and three feet long. Stretch a cover string snugly around the four nails and tie the ends together. Cut two strips of paper 14 inches wide and 26 inches long. Slide one of the strips under the rectangular loop of cover string and center it with respect to the nails. Fold an inch of the paper over the string at the sides and cement it in place. Cut the loop of string at the ends midway between the nails. The sides of the strip are now reinforced with strings, the ends extending from the four corners of the strip.

Slit an inch of the paper, close to the string, at the four corners and bend the edge up into one-inch flaps. Prepare the second strip in the same way. To assemble the strips to the body of the kite, first make four small holes in the paper of the body at the outer edge of the splines, where they cross the spar and the short stick. Thread the strings of the paper strips through the holes and tie them securely to the splines. Cement the one-inch flaps of the strips to the body covering. Finally, slip the remaining spline into the bands of paper, center it and cement it to the paper strips. Centering is easy if the paper strips have been marked with a right-angled crease across the middle. The kite can be suspended upside down by strings attached to the ends of the center spline while the cement dries.

Just before the kite is launched the spar is bowed and fastened with a bowstring, as in the case of a Malay kite. The bridle is attached to the center spline of the triangular section. When a French war kite of these proportions is flown in a wind of 15 miles per hour, it will lift a payload of about two ounces per square foot of sail area and will exert a pull on the flying string of about a pound per square foot.

The amount of lift a kite develops in relation to the force of drag that tends to pull it downwind—the lift-to-drag ratio—increases within limits as the width of the kite is increased in relation to its length, a proportion known as the aspect ratio. The aspect ratio of airplane wings is about seven to one; they are long and narrow. The French war kite can be regarded as a triangular box kite with triangular wings of comparatively low aspect ratio. The aspect ratio can be increased by using a spar that is longer than the splines. This improves the lift-to-drag ratio. The modification, when carried to the extreme, results in instability and also in structural weakness unless the spar is made in the form of a truss. We had great fun constructing kites of various proportions and observing their performance.

To achieve maximum altitude we would launch a kite and pay out as much flying string as it would support. When a pronounced sag developed in the flying string, we would attach a second kite and let it rise until the flying string sagged again. A third kite was then attached, and so on. The number of kites that can be flown as a train is limited only by the strength of the flying string. Occasionally the top kite of the train is caught in an updraft and lifted into a wind that blows in a direction that differs from the wind at the surface. The entire train is then carried skyward. On one occasion the upper-



Control of a Malay kite

most kite in one of our trains reached an altitude of more than a mile. The string spiraled downward so that the top kite was directly above our heads. It remained there for about an hour.

We fitted kites with various payloads that could be dropped by parachute or otherwise manipulated. For example, a parachute can be attached to the kite by a simple wire hook that has an extension to serve as a trigger for releasing the load. The trigger can be operated from the ground by placing a paper cone, called a messenger, around the kite string and letting the wind carry it up to the kite, where it strikes the trigger and releases the hook [*see bottom illustration at right*].

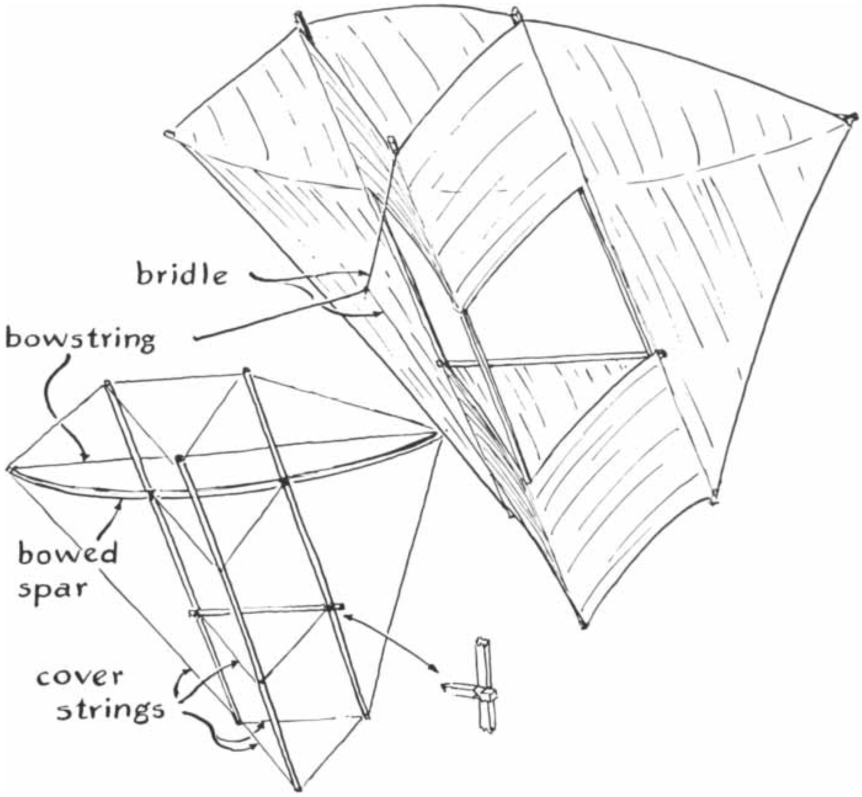
It is also possible to release loads and operate camera shutters by means of a fuse. To prepare the fuse soak ordinary cotton twine in a solution made by dissolving as much saltpeter (potassium nitrate) as possible in a cup of water. Let the string dry. When the string is lighted, it will burn without flame at about three inches per minute.

To make a photograph by this technique tie the shutter release of a camera in its closed position with a short length of fuse. Stretch a rubber band over the shutter release from the opposite side, so that it exerts an opposing pull on the release. Fasten the free end of the rubber band to a convenient point on the body of the camera.

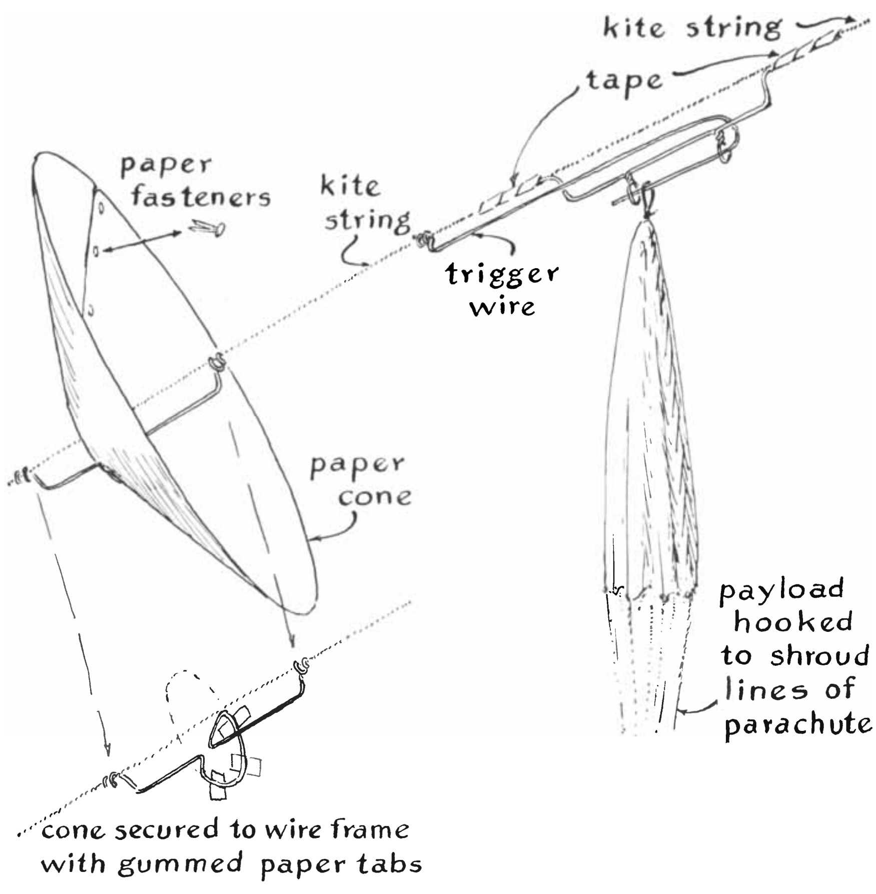
Cut a length of fuse for the desired time interval. If you want the shutter to click in 10 minutes, make the fuse about 32 inches long. Thread two inches of this length through the fuse that ties the shutter release and secure it with a knot [*see top illustration on next page*]. The shutter will operate 10 minutes after you light the free end of the 32-inch fuse. The camera can be kept pointed in any direction by fitting it with a wind vane.

The angle at which the kite meets the wind can be increased or decreased during flight by inserting in the bridle a loop of string held closed by a triggered hook or a fuse. When the loop is released, it opens, increasing the length of the bridle and so altering the angle of attack. The modern kite-flier could perform these and other operations by radio control. Versatile radio receivers that weigh less than an ounce and are capable of obeying a number of commands can be built with transistors.

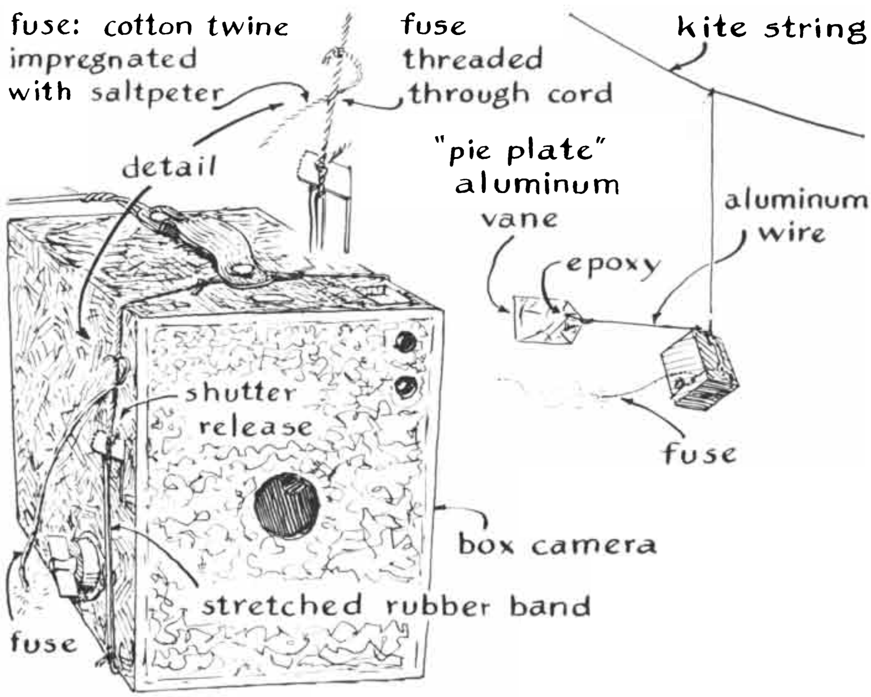
The approximate height of a kite above the ground can be determined by multiplying the length of the flying string by the trigonometric sine of the



A French war kite



Mechanism for releasing a payload

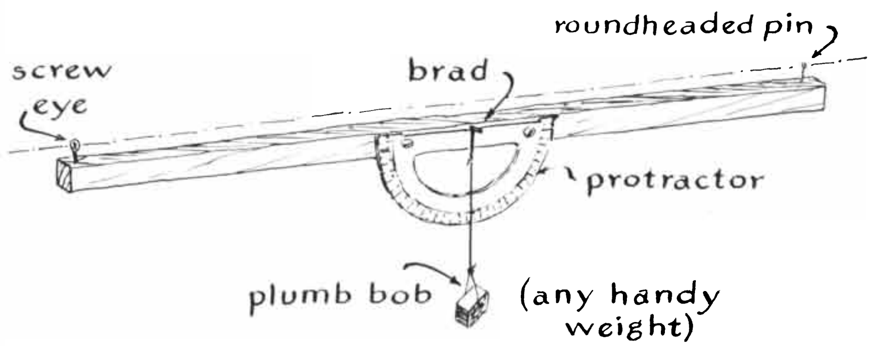


Fuse release for camera shutter

angle made between the kite, the end of the string and the point directly below the kite. We marked the string with dabs of colored paint at 100-foot intervals: red, yellow, blue, green and black through the first 500 feet, then red-red, red-yellow, red-blue and so on for the next 500 feet. Thereafter we used combinations of three colors, four colors and so on. To measure the angle we fastened a protractor and a plumb bob to a stick with a pair of sights on it [*see illustration below*]. Multiply the calculated height by .96 to correct for the error caused by sag in the flying string. For example, how high is a kite that flies at an angle of 30 degrees on a 500-foot string? The sine of 30 degrees is .5, and 500 times .5 times .96 is 240 feet.

The aerodynamic features of kites invite innovation. We made several designs, one of which gave us great satisfaction until we learned that it had been invented independently several times. It occurred to us that the lift of a kite might be improved by borrowing a trick from the designers of racing sloops. These boats have both a jib and a mainsail. Aerodynamically the jib makes only a small direct contribution to the forward motion of the boat, but by directing a jet of air at the proper angle behind the mainsail the jib increases the effectiveness of the mainsail about threefold, according to the German yacht designer Manfred Curry. The "wing slat" of high-lift airplane wings is another application of the jib principle. Why not fit a kite with a pair of jibs? We decided to do so.

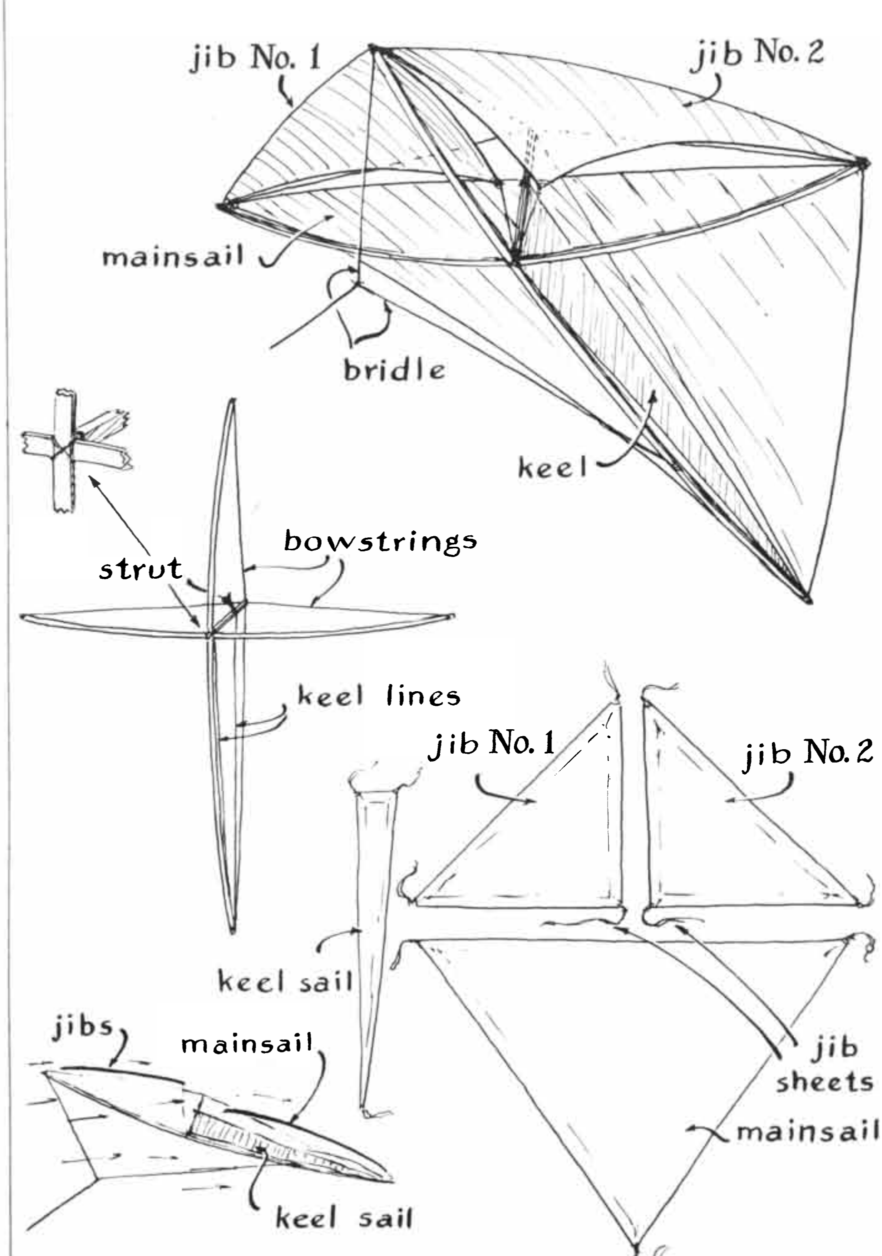
The frame of our jibbed kite resembles that of a Malay kite, consisting of a crossed spline and spar. A strut extends vertically from the cross to leeward and



Instrument for measuring angles

is braced at the outer end by a pair of bowstrings attached to the spline and spar. The sails are made of thin, closely woven nylon. A triangular keel sail resembling a pennant is tied between the strut and the bottom end of the spline [*see illustration below*]. The triangular mainsail is tied to the ends of the spar and the bottom end of the spline, and it loops over the keel. Two corners of each jib are tied to the ends of the spar and the top of the spline. The third corner of each jib is tied loosely to the cross of the frame. The jib sheets are adjusted so that air flows over the lower surfaces of the jibs and passes over the leading edge of the mainsail. As in the case of a sailboat, the optimum adjustment of the jibs varies with the strength of the wind and must be altered experimentally for maximum lift. The kite appears to develop about twice the lift of a French war kite at wind velocities up to about 12 miles per hour. We had been planning to make a series of wind-tunnel tests of the jib kite, but our memorable summer ended before the tunnel was ready, and my collaborators returned to school.

A note of caution: Always wear leather gloves when you hold a kite string, particularly if you use nylon. A running string can burn and cut your hand. Never fly a kite above the heads of a crowd or on more than 100 feet of string within a mile of an airport.



A jib kite

How to lift a giant with 20 p.s.i.

While this new Boeing 747 superjet was having its compasses calibrated, it was rotated on a gentle cushion of air. Strategically placed air casters beneath the plane lifted and suspended the 362,000-pound load, enabling engineers to swing it easily with a small tractor.

The manufacturer of this air caster transport system is Aero-Go, Inc., a young Seattle firm. The basic unit of the company's air cushion system is a donut-shaped inflatable air caster in various sizes and combinations to float specified weights. With a surprisingly low level of air input *(the 747 was lifted with a mere 20 p.s.i. pressure)* the casters work together to lift loads three inches from the ground, with a microscopic film of escaping air acting as a frictionless, stress-free bearing. The air casters offer no resistance to side or oblique motion and put virtually no stress on floors, pallets, or cargo.

Air cushion systems can find many uses around the airports of tomorrow. Palletized cargo can be moved from dock to plane with a minimum of equipment, time, noise, and cargo risk.

And airplanes themselves can be eased quietly into hangars on a layer of air—guided only by a small truck. Air-supported pallets are also being used for transport of heavy steel building materials for autos and ships.

The realm of fascinating applications for air devices is so broad that Aero-Go engineers are having trouble limiting their imaginations to priority programs. Among the more unique future projects is the designing of an enormous air track to carry a 30-million-pound dome back and forth between proposed twin stadiums.

Also on the drawing boards is a heli-barge—a large cargo-carrying barge operating on the air-cushion principle. But instead of being pulled by a tugboat, the barge would be powered by a helicopter which would land on its deck and use the air from the rotors to lift and move the barge.

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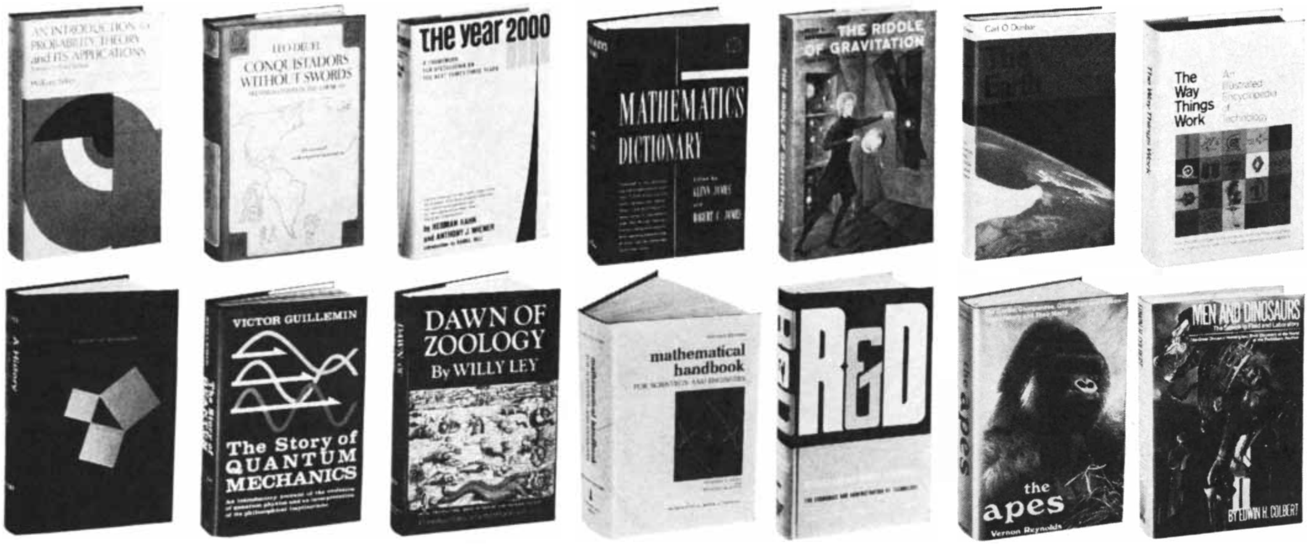

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BOOKS

The Condon report on unidentified flying objects, and other matters

by Philip Morrison

SCIENTIFIC STUDY OF UNIDENTIFIED FLYING OBJECTS, conducted by the University of Colorado under contract to the United States Air Force. Edward U. Condon, Scientific Director. Daniel S. Gillmor, Editor. Bantam Books ($1.95). More than a decade ago the political struggles that are born of the fears and the strengths of a great nuclear power were made starkly clear in a thick Government document called *In the Matter of J. Robert Oppenheimer*. That work was unrelieved tragedy; its content and its impact were fearful; even its form was austere, unified, concentrated. Once again the reader is presented with a thick official volume of genuinely dramatic interest, describing another unique episode of our times. This document, however, is diffuse, cheerful, catholic, discursively instructive and marvelously illustrated. It is no farce but rather a high and human comedy. In a curious way the two dramas overlap.

This report presents the work of able men, led by a wise physicist of high repute, who have tried to bring order to the disorderly, to make what sense they could out of rumor and hard data, out of cynical fraud and honest and courageous observation. They have succeeded brilliantly, building a monument to reason, to experiment and to intellectual patience, modesty and candor. The heart of their work is the careful study of about 60 unusual reports. Their chief data are the accounts of eyewitnesses; their main instrument is the tape recorder. The thrust of the work, however, is not psychological but physical. Each event is described, and a set of sensible hypotheses is tested against the data. Could the object have been a balloon? Then seek the data on upper-air winds. Was a strong magnetic field used to stop an automobile? Then compare the magnetic pattern of the automobile body with that introduced into other cars cold-formed by the same presses.

The most interesting cases are the ones that present photographic evidence; these have been analyzed with great penetration and alertness, mainly by William K. Hartmann, a planetary astronomer at the University of Arizona. About a quarter of the photographs show evidence of fabrication, a quarter are mistakenly identified normal phenomena, a quarter simply present too little information (point sources or mere luminous blobs), and a quarter are clear enough but lack supporting data for analysis. Only two out of 35 photographic cases remained. Both of them are events of 1950. In one "all factors . . . appear to be consistent with the assertion that an . . . object, silvery, metallic, disk-shaped, tens of meters in diameter . . . flew within sight of two witnesses" (an Oregon man and his wife). Fabrication cannot be ruled out; the position of the object in the same place below a wire in two pictures suggests that it is the small suspended model it resembles, yet photometry of the pictures argues that the object was far away, since its shadowed portion is brightened as though by the scattering of light by the intervening atmosphere. The second event, which yielded 16-millimeter film, shows two bright lights moving slowly across a noonday sky in Montana. They were not meteors (too slow) and not birds (too steady); both aircraft and balloons remain possible but not compelling fits.

So the report goes. The investigators do not contend that they have explained away every event; they are too honest for that. They nonetheless make a real try, and overall they succeed wonderfully. The whole work seems to show conclusively that there is no prima facie case for closer study; no one can think of means that at any reasonable cost would greatly increase our data on such scattered, diverse and transient events. The group tried out a few such schemes; they didn't work at all. The formal conclusion is widely known, and it seems particularly sensible and well supported: "Further extensive study of UFO's probably cannot be justified in the expectation that science will be advanced thereby." Yet if specific ideas for new work appear, let them receive consideration for support on their individual merits. No new agencies, no big plans. New evidence, better than any we now have, would be needed to change this eminently convincing view.

There are many amusing bits. "One evening . . . a most articulate gentleman told us with calm good manners . . . [in] some detail about how his wife's grandfather had immigrated to America from the Andromeda nebula." A piece of celestial foil turned out to be radar chaff, precisely identified by its makers as to lot, color and material (1145 alloy, Kerstyn lacquer, Acruanx C). It was "manufactured in Brooklyn, New York, U.S.A., and not in some remote corner of the galaxy."

There is a large and interesting section devoted to the physics of optical and radar mirages, to atmospheric electricity and ball lightning, to the surprisingly widespread use of high-altitude balloons, to problems of perception and so on. There is an outline of the prehistory of the UFO's, with a rather discouraging burden of misleading and even false citations on the part of many authors. There are 32 pages of photographs and many sketches and graphs.

One comes away edified, amused, admiring and well satisfied. The report documents how much the story is linked to the national mood of the early 1950's: the concerns of secrecy and the near-paranoia. Even the cogent report made in 1953 by a panel of distinguished physicists, headed by H. P. Robertson, sponsored by the Air Force and the Central Intelligence Agency, reflects that extraordinary atmosphere. It is sad that the CIA still insisted on censoring the old report, so that we learn of Dr. ——, and even "The —— opened the meeting." (*Never* mention the —— in print, the rule must say out there at headquarters.) Careful students will be interested to see an overlap in minor cast between the Oppenheimer hearings and the UFO report. "Foo-fighters" and the cabal called ZORC are both the expertise of one professor. It is clear that a profound mistrust both of official science, with its link to weaponry, and of the secret operations of our government suffuses the subject. UFO's are not wholly but in large measure a creature of the American scene circa 1950.

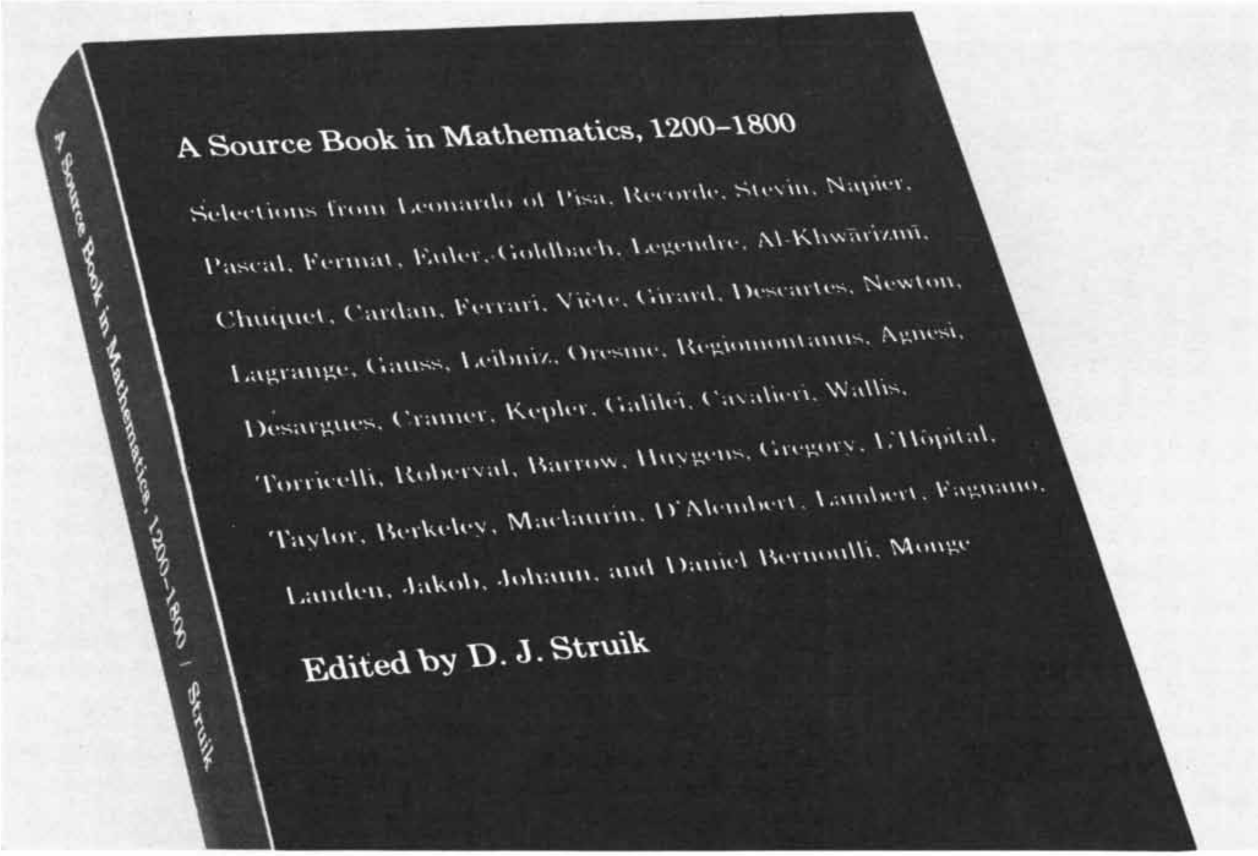
One would have welcomed a brief factual account of the scale and scope of the flying saucer "industry," which today touches even some national publications, and represents a vested interest in mystery. Condon urges that teachers not allot credit for schoolwork on currently available UFO books and articles. He has made that recommendation out of date; this report is well worth broad study at many levels. Finally, it is clear that the UFO reports should not be met by ridicule but by real interest. They are often the faint echo of science itself, men seeking order in a world made anxious not only by fancied fears but also by real ones. That among the witnesses are madmen, rascals and jokers does not single out any group. Science is the stronger for this sincere and expert effort to deal with a public concern.

The Machine as Seen at the End of the Mechanical Age, by K. G. Pontus Hultén. The Museum of Modern Art ($6.95). The text of this book is fresh enough, but the book is literally canned. That is, it is bound between Swedish tinplate covers, embossed and color-lithographed, as apt as they are durable. It is the extensive catalogue by a director of the Stockholm museum who assembled the art exhibition presented in New York in the fall of 1968. He himself observes that it is in no sense a history of the machine; rather, it is "a collection of comments on technology by artists of the Western world." It is full of interest, less for the novelty of the works illustrated and explained than for the fact that it displays so many diverse works, most of which are well known in other contexts. It begins, of course, with a Da Vinci: one design for a pseudohelicopter. Then comes one of Dürer's fantastic engravings of the cogwheel chariots for Maximilian's paper triumph. The marvelous Neuchâtel automata, real clockwork figures that draw and write, are here, and a strange drawing out of the Italian baroque depicting a street knife-sharpening machine drawn as a man with mechanical parts.

There is a Shortshanks etching of English gentry walking in steam-driven boots, and a familiar anonymous Victorian lithograph of a Mr. Golightly astride a "steam riding rocket." Nonetheless, it is the 20th century that makes the collection. Most of the newest ideas of the artists are seen to be very early: there is an *art nouveau* wax model of a double-decker automobile that could be influential today; op-art illusions, the collage and assembly of machine parts and junk, and kinetic sculpture (the example shown is standing waves in a vibrating metal rod) all began before 1920. The most dazzling concept of this period is the fantastic plan of Vladimir Tatlin for a monument to the Third International in Moscow, which was to have been a slanted steel helix 400 meters high holding four glass-walled chambers of decreasing size, the largest rotating in a year and the smallest daily. "The technical potential to build it did not exist," and even a wooden model 15 feet high was lost, although it was much praised.

The last word also appears, in the self-destructive mechanical comedies of Jean Tinguely, the still or animated tableaus of Edward Kienholz (for example "The Friendly Grey Computer," an electronic chassis in a rocking chair with a doll's legs protruding) and the reactive electronic devices of the organization Experiments in Art and Technology. Altogether this is a summarizing document of a catholic taste. The philosophical analysis of the writer will not always appeal to readers who are closer to the machine than he is.

Military and Civilian Pyrotechnics, by Herbert Ellern. Chemical Publishing Company Inc. ($15). Here is an expert's account of a living technology—up to date, coherent and personal. Pyrotechnics is much older and much more conspicuous than its present economic scale would suggest. For this author pyrotechnics can no longer be fireworks alone; he defines it as the technology of the use of the heat and other products from the mainly nonexplosive exothermic reactions of solids. The core of the industry is the safety match; the 400 or 500 billion matches made each year in the U.S. exceed by tenfold the value of all fireworks production. Matches are treated here both historically and technically, although with little attention to the purely mechanical side of their mass production. The safety match has no secret formula; its successful manufacture is based on skillful management of the process, on maintaining uniformity in the face of small changes in materials and external conditions. The key is in details such as the use of the best hide glue ("Peter Cooper Grade IIa extra with foaming properties"); other binders can form a hardened skin over the pyrotechnic material, and the match



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explodes instead of burning smoothly. Good glue solidifies quickly and reversibly on mere cooling, without need for evaporation.

The dual title goes with a rather tough-minded text, rich in references to devices with names such as the "Mark 1 Smoke Pot (HC)." The duality lies deep in the material itself: the toy percussion cap and the old-fashioned gravel-filled fireworks torpedo are made with Armstrong's mixture: potassium chlorate and red phosphorus mixed wet with a starchy binder. Mixed with ether the same stuff can be loaded into larger containers and evaporated to dryness. Then it is a "formidable antipersonnel mine" that is exploded by slight pressure. The same reaction is the ingenious basis of the safety match. There the phosphorus is in the striker and the chlorate is in the head. (It is a "most fascinating . . . solid reaction.") The subtlety of a reliable safety match is made quite clear, if only qualitatively. The fuel is the glue, there are necessary catalysts, particle size is controlled and a sintered residue is designed in.

A special chapter by an English semi-pro, Rev. Ronald Lancaster, discusses fireworks for pleasure. That industry is too small to afford much research, unlike the military side. Fireworks history is divided into periods by the materials available: first black powder alone, with movement and propulsion the aim; then the rise of chlorates and pure chemicals in general, leading to the glories of color; next the bright light given by aluminum and magnesium and finally titanium. (A high output of white light depends on high energy release and on a very refractory solid oxide.) There are formulas for all the favorite fireworks: Roman candles, sparklers, Bengal lights, fountains and stars. Potassium chlorate, metal powders and the special ions for color pretty much span the field. The great Tokyo family Marutamaya launches paper shells full of marvelous colored stars 1,000 feet into the air from mortars a yard in diameter.

Tear gas? Orthochlorobenzal malononitrile, the irritant, is made up in sugared pellets. These are embedded in a mixture of nitrocellulose, chlorate and sugar. The reaction disperses the stuff as a distressing aerosol. (Chemical Mace is a nonpyrotechnic liquid dispersion of very fine particles.) The great flashes used to illuminate the terrain for night photography from high altitude call for a mixture of atomized aluminum (uniform grains 20 microns in diameter) with perchlorate and barium nitrate. A very large flash uses 100 kilograms of the mixture and yields for some milliseconds the luminous power of a few million garden flood lamps. Somehow this work, in which intelligence enlivens a technical and even esoteric topic, is a microcosm; within it death and delight stand very close. Even so special a technology can imply an epoch.

THE GERM-FREE ANIMAL IN RESEARCH, edited by M. E. Coates. Academic Press ($11.50). Prepare a large worktable with a circular manhole in the center. Cover the table with a tent of thin polyvinyl film. Seal off the hole with a polyvinyl jacket, within which a man stands, his arms in sleeves ending in tight gloves for his hands. All interior surfaces are sterilized with a spray of dilute peracetic acid. Carefully filtered air is fed in at a slight positive pressure. That bulging transparent tent is now an isolator within which a man is free to rear and care for a colony of laboratory animals, which he must supply with carefully heat-sterilized food and water. With this ingenious, inexpensive and flexible scheme many laboratories can now raise individual animals—animals known to be a single organism, not, like ourselves, an entire ecology.

The book presents a set of papers by authors from Britain, the U.S. and the Continent reviewing the state of this particular line of mammalian research. The implications for the study of the immunological system are evident. Moreover, these animals harbor no intestinal microflora, so that the role of such important symbionts can be seen. Indeed, ruminants, which are particularly reliant on bacteria for their digestive processes, have never yet been raised germ-free beyond the milk-fed stage. Sixteen vertebrate species have been reared, from the chicken to the burro. Germ-free mice have gone through nearly 30 generations. Rats and mice outlive their conventional counterparts, even though they die mostly of conditions associated with the chronic bowel disturbance common to germ-free rodents. All four laboratory rodent species—rat, mouse, guinea pig and rabbit—"happen to be those in which coprophagy is a way of life." These four species and the quail are the only ones to have been carried through several generations.

The larger questions are still far from settled. The animals have little antibody, but they can still respond quickly to deliberate infection. Restored to the infectious world, they generally survive the shock well. Subjected to ionizing radiation, they show considerable resistance, probably because they are free

from the complications of infection once radiation has damaged the fast-growing cells of the antibody-forming system. Germ-free rats can develop spontaneous tumors, which brings up the fact that they cannot be guaranteed to be virus-free from the womb. Indeed, electron microscopy has shown virus particles within germ-free mice that look identical with the virus of mouse leukemia. Such mice can develop a spontaneous leukemia, which is judged to be viral. They inherited the alien genetic code after all.

SOIL ANIMALS, by Friedrich Schaller. The University of Michigan Press ($1.95). Charles Darwin was a pioneer in the study of the hidden life of the soil. There in the deep green lawn of Down House one can see the heavy stone that sinks decade after decade as the soil of the garden is imperceptibly churned by the random passage of earthworms. This fascinating little paperback by a German zoologist views the subject from our decade. The census of the soil is complex; it is plain that microorganisms and earthworms play a major role, but the wide variety of roundworms and springtails and members of many orders of life are now recognized to be important, particularly for the formation of that enigma, humus. The laws of scale, which suggest that animals metabolize roughly in proportion to their area, tend to favor the work of the smaller creatures over that of the large and long-lived earthworms.

The blind earthworm, like many of the soil beasts, hates light. It is especially vulnerable to ultraviolet and its skin is filled with warning light receptors (not in eyespots but all over, although they are more numerous at the front end). The blind soil predators seek their prey by being “constantly on the move, touching everything in their path . . . and putting their ‘noses’ into every crack.” Some victims develop splendid defenses, such as the pill bug, the unrelated pill millipede and the big armadillo, all converging on the same hopeful solution of rolling up into a hard-shelled ball. Most remarkable is the natural history of love among the soil animals. Scorpions lock into a dance that may last for hours, until the male, who for unknown reasons stings his mate's claw joint from time to time, plants a small winged rod into the ground. He drags his partner across the rod, a trigger springs and two drops of sperm enter the female aperture. The humble silverfish instead begins his dance by blocking his mate's way; finally he crosses her path with a few threads of web that bear a spermatophore. Rushing past, she feels the threads brush her raised abdomen and at once begins to search for the essential packet. Springtail males plant a whole garden of a hundred stalked seminal flowers. This style of transferring the genetic code is possible in the soil because it is damp there, and the sperm does not dry out. It represents a design intermediate between the external fertilization common in the waters and the true internal copulation of most animals that live in the dry air above the surface.

THE INDUS CIVILIZATION, by Sir Mortimer Wheeler. Cambridge University Press ($2.95). Large gatefold maps and plans of great clarity in this paperback edition compensate the reader for the absence of the color plates that we had in Sir Mortimer's more popular 1966 version of his unending narrative of the rise and fall of the Harappan culture. The entranced reader of this dazzle of inference will not want to do without his most up-to-date and enlarged version of the now classic story. The author still holds that it was probably the Aryan conquerors, and not solely the recurrence of floods, that brought an end to the city of Mohenjo-daro; he invokes Indra, the war god of the Rigveda, who “rends forts as age consumes a garment.” Subtle difficulties arising from carbon-14 dates are considered, and the decision is given that “the nuclear cities . . . were founded sometime before 2400 B.C. and . . . endured . . . to the eighteenth century.”

AUSTRALIAN ABORIGINAL PORTRAITS, by Charles P. Mountford. Cambridge University Press ($11.50). The author-photographer has spent many years wandering desert and strand with the original Australians. In this book he presents some 40 sensitive photographs, mostly portraits of individual men, women and children, people he has come to know. He tells us briefly about each subject's walk of life and the mood at the time of the picture. The result is beyond ethnography: it gives us a rare chance to see humanness exhibited in a cultural setting different from our own by 10,000 years. Here is a good child, there a pouting spoiled girl. Now one sees a young man, stoic face set hard 10 minutes after passage into manhood through the frightening and painful rite of circumcision. There is an artist crouched intently on the sand where he is drawing a rich ornament of concentric circles. A sequence of painted Melville Island mourners ends the collection.

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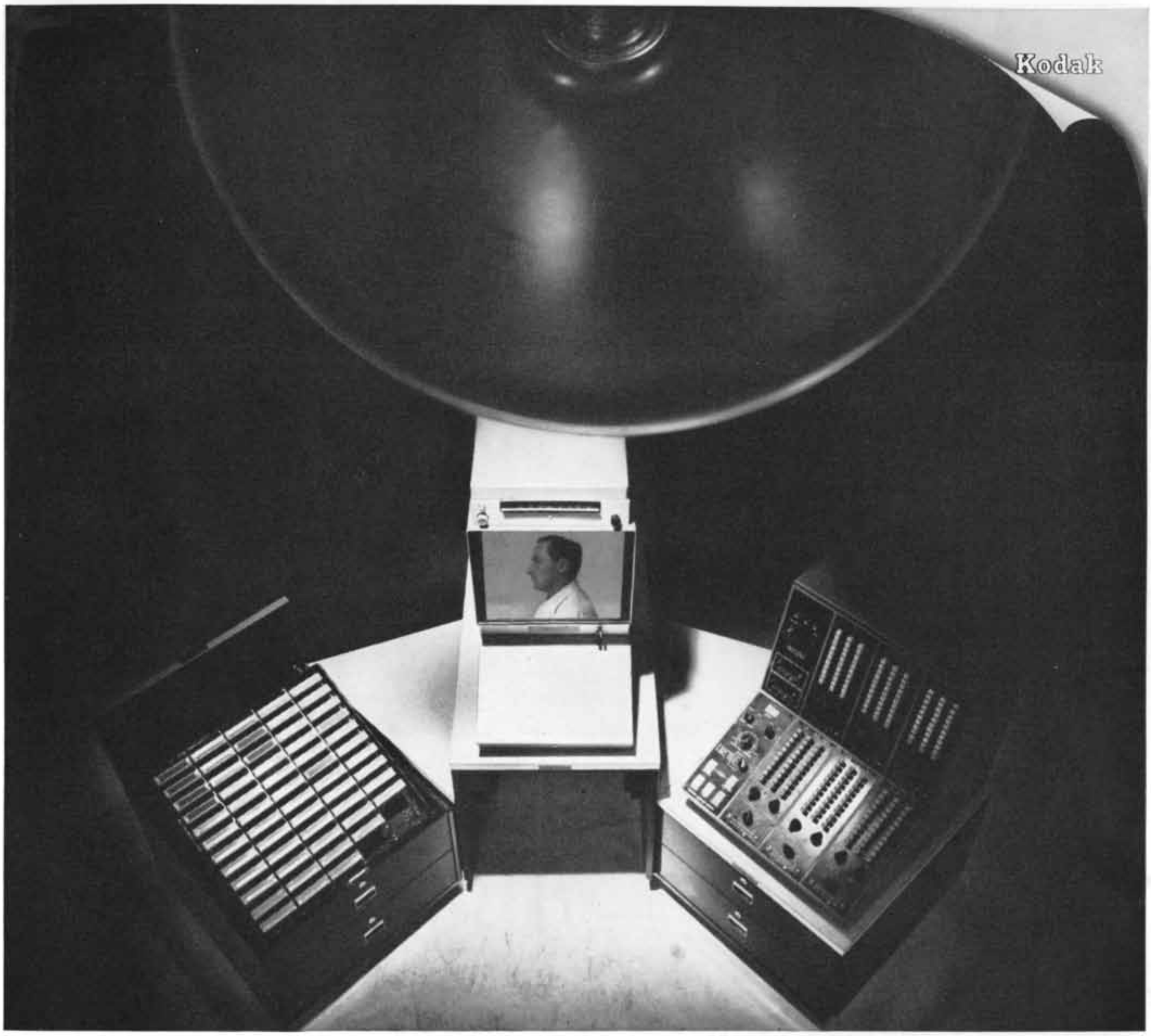

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