beliefs does not imply that there is no truth or that it cannot be found. It implies only that it has not been found. The situation is not very different from the situation in art: it is probably impossible to prove that one composer is a great musician and another is not, that one novelist is a great writer, and another is not. Yet, I shall continue to hold very strong convictions on the value of their respective works; and I shall not regard them as matters of taste but of esthetic truth. Analogously, I hold moral values to be matters of moral truth. Science will help somewhat—it will clear the underbrush—but reason and faith cannot be dispensed with, if we wish to map a transcendent road.

Peaceful Uses of Atomic Energy

A British scientist summarizes the results of the second Geneva Conference of the United Nations.

John Cockcroft

I have been given the difficult task of surveying the work of this conference, and using the wealth of new information, to look once again into the crystal ball and try to predict the course of peaceful development of atomic energy in the world. If we take as a yardstick the rapid progress during the last three years, I am sure you will not expect me to claim any great clarity of vision beyond the next five years.

The three years since the previous conference have been notable for the coming into operation of the world's first large-scale nuclear power stations at Calder Hall, Shippingport, and recently in Siberia. This has been of great importance, since we have thereby begun to acquire practical operating experience of nuclear power. This has provided us with experience on the operating characteristics of such stations, and much new information about their technology is being obtained to supplement the earlier small-scale experiments in research reactors.

Power Reactor Experience

Our first impressions have been that these nuclear power stations have been docile and well-behaved. They can generate electricity for months on end until some minor fault develops. The most usual faults have been the faults of conventional components which require the normal amount of maintenance. There has been a surprisingly small number of defective fuel elements. Fuel elements rely on their sheathing to prevent corrosion of the fissile material by the coolant, which can then lead to leakage of radioactive fission products into the coolant stream. Therefore a very high degree of integrity of the fuel elements is required.

The operators have reported good experience over the first two years of operation, with failure rates of only three or four per year in 10,000 fuel elements. Reactors using metallic fuel expect to achieve a burn-up of at least 3000 megawatt days per ton, so that 1 ton of uranium will do the work of 10,000 tons of coal. Reactors using uranium oxide fuel expect over three times longer burn-up (10,000 megawatt days per ton), and indeed good irradiation stability of small samples has been reported up to 25,000 megawatt days per ton. Our experience of burn-up of *full-scale* fuel elements is now nearly halfway towards the target. Accelerated experience will be gained in the future by increasing the enrichment of the fuel. A continuing large technological effort will need to be devoted to these problems.

The nuclear power stations so far built in the world have been either dual-purpose power stations or demonstration power stations, and they would not be economical as commercial power stations. Nevertheless the experience of their operation has been invaluable in preparing the way for the next generation, which in most cases will be fully commercial nuclear power stations, with credits for plutonium based on its real value for civil purposes.

Three Types of Stations

Three main types of second-generation full-scale power stations have been described to us: first, the graphite-moderated, gas-cooled reactors; second, the pressurized and boiling-water reactors; and third, the heavy-water-moderated reactors. The capital costs per kilowatt of the first of the commercial nuclear power stations have been very much reduced below those of Calder Hall and Shippingport but are still over twice those of coal- or oil-fired stations. The papers presented to the conference show, however, that capital costs are likely to continue to fall appreciably during the next decade. The capital costs of U.K. nuclear power stations will fall a further 20 percent by 1962 as the output goes up from 300 to 500 megawatts, and a further fall of at least 10 percent, resulting from straightforward engineering developments and increase of output, is forecast in a U.K. paper.

The boiling-water-reactor power stations seem to be growing in favor as a result of the good performance of the reactor experiments. Because of their low system pressure and small size and comparative simplicity, they may achieve very low capital costs in the next five years.

Sir John Cockcroft is director of the United Kingdom Atomic Energy Research Establishment, Harwell. This article was presented as an evening lecture on 12 Sept. 1958 during the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1–13 Sept. 1958. It is reprinted from the November 1958 issue of *Atom*, the monthly information bulletin of the United Kingdom Atomic Energy Authority.

Fuel Costs

Fuel costs are the second important component of over-all costs and range from 20 to 40 percent of the unit cost, depending on whether natural uranium or near-natural uranium or more highly enriched fuel is used. The graphite-moderated and heavy-water-moderated reactors will have the lowest fuel costs. Nuclear fuel costs for gas-cooled, graphite-moderated reactors have been given to us as about 2 mills. The Canadians believe that for heavy-water reactors these costs can be brought down to 1 mill. Fuel costs for light-water-moderated reactors have been reported to be about 3 mills. These are to be compared with conventional fuel costs ranging from about 3.3 mills in low-fuel-cost areas in the U.S. to 8 mills in European countries using imported coal. So nuclear fuel costs should in all cases be lower than conventional fuel costs.

The over-all economy of nuclear power stations depends greatly on the capital charges, the load factor, and the fuel costs in a particular country. High load factors are essential to counteract the present high capital costs. A United Kingdom Electrical Authority lecturer has told us that the first group of nuclear power stations could run continuously if there were no technical reason preventing this. The economic forecasts have, however, adopted the conservative figure of a 75-percent load factor. On this assumption, the 500-megawatt power station to be completed in 1962 is expected to achieve parity with coal-fired stations in areas in Britain away from coal fields. On the basis of our experience so far, these power stations seem likely to achieve an appreciably higher load factor, while fuel costs are likely to fall as burn-up increases with the development of our technology and as uranium prices fall, so forecasts may be conservative.

Parity Dates

By the late 1960's, as the installed capacity of nuclear power stations grows, the available load factor will fall. By that time, however, this is likely to be more than compensated for by further reduction of capital costs of the order of 20 to 30 percent, resulting from higher temperatures of operation and higher ratings associated with a switch to ceramic fuels. Nuclear power costs in Britain are therefore expected to fall well below conventional costs by late 1960's.

The date of achieving parity will be later in countries such as the U.S. where hydroelectric and stations using low-cost coal or natural gas can generate power at 4 mills. We have been told that stations started in the U.S. in the late 1960's should achieve parity.

In Italy, the World Bank study for the Societa Elettronucleare Nazionale nuclear power station has shown that, with the assumed 14-percent capital charges, nuclear power would be about 10 percent more costly than power from oil, and that there is little economic difference between the various types. India has reported that the first 150-megawatt power station to be built in India could achieve parity. We see therefore that the date for achieving parity ranges from 1963 to 1973, depending on the circumstances of individual countries. This date will determine the rate at which large-scale installations of nuclear power stations will develop. The Organisation for European Economic Co-operation predicts that Western Europe will have an installed nuclear capacity of 10,000 megawatts by 1965. The U.S. has predicted 1300 megawatts by 1963; the U.S.S.R. 2000 megawatts by the early 1960's. All of this might add up to an installation of about 15,000 megawatts between 1965 and 1970.

There is general agreement that by 1975 most new high-output power stations will be nuclear.

Underdeveloped Countries

H. J. Bhabha, in his evening discourse, has dealt with the need for atomic energy in underdeveloped countries, taking as his definition countries where per capita income is low. Since India comes very low in the table of per capita income, it comes in this category. Indian power requirements are doubling every six or seven years, and Dr. Bhabha considers that nuclear power stations would be competitive now and may have an installed capacity of 500 megawatts by 1965. Japan seems to be in a similar situation and predicts 750 megawatts by 1965. The growth of nuclear power in other underdeveloped countries will depend on their indigenous fuel supplies and on the available loads, and on the state of technological development. It will be hard for nuclear power to compete with diesel power where power requirements are less than 30 megawatts, and load factors are low. It should be remembered that technicians are scarcer than graduates in many countries, and they are crucial to this development. I agree with our president [H. J. Bhabha] that nuclear power will not perform miracles in underdeveloped countries.

By the late 1960's new, third-generation types of stations may be coming into service. We have had reports of operational experience with their precursors, the reactor experiments. The organic-liquid-moderated reactor experiment has shown that this reactor is likely to be simple to operate because of its low system pressure and its noncorrosive, nonradioactive coolant. The previously unknown cost of replacement of the moderator required by radiation breakdown seems to be about 1 mill per kilowatt-hour. The Oak Ridge experience on the aqueous homogeneous reactor shows good progress in overcoming the difficult compatibility problems, but the stability of the fluid fuel is still a crucial point. The sodium-graphite reactor experiment will provide important information on sodium technology and on metallic fuel elements operating at high temperatures. The high-temperature, gas-cooled reactor projects, for which all-ceramic fuels are used, may well be important for propulsion as well as for land use by the end of the 1960's. A high-temperature, gas-cooled reactor experiment seems likely to be built in Britain as a collaborative European project.

Fuel Cycles

We have heard a number of interesting papers on fuel cycles. It seems clear that with the general trend to the use of uranium oxide fuels, most reactors built after 1965, with the possible exception of the heavy-water reactors, will require some enrichment. The graphite-moderated reactors will require only modest enrichment, of the order of 1 percent uranium-235. The light-water-moderated reactors will require enrichment ranging up to 3 percent uranium-235.

The enrichment can be provided either by using uranium-235 from diffusion plants or by using plutonium from earlier reactors. Thereafter the reactors could operate on a natural or slightly enriched uranium feed by recycling plutonium, using this in the form of oxide mixed with uranium oxide. We have heard of promising technological work on recycling and of the limitations imposed by the accumulation of higher isotopes such as plutonium-242. One of our speakers has predicted that by the time nuclear energy is producing 20 percent of world power we shall need to invest about 5 percent of the capital for nuclear power programs in diffusion plants to provide the initial charges of uranium of low enrichment.

An alternative fuel cycle involves feeding the plutonium to reactors of the fast breeder type; this will have a positive gain factor for plutonium. The advantage of this would be that, in the long term, we should achieve a much better utilization of world uranium supplies. The superabundance of uranium which is forecast for the next two decades has shown that this is not an urgent problem. We can therefore take time to develop the difficult technology of fast reactors in a thorough manner. We have heard reports at this conference on the results obtained with experimental fast reactors; from their operation we have gained a great deal of knowledge about the physics, kinetics, and stability of these reactors which has been important in the design of the higher power reactor experiments which will come into commission during the next two years. Already, however, prototype fast-reactor power stations of 50- to 200-megawatt electrical output are being constructed and designed. The rate of installation of fast reactors will depend, first, on our experience with the reactor experiments and second, on the rate at which plutonium becomes available from thermal reactors. Fast reactors are unlikely to contribute much to world power before the 1970's.

Thorium possesses considerable advantages as a fuel for thermal reactors, but a large investment of uranium-235 or plutonium is required to start the thorium cycle. We have had a description of the Indian Point 275-megawatt (electrical) nuclear power station, which will be the first full-scale reactor to use the thorium cycle. Thorium may well be coming into use by the late 1960's, especially since large supplies will be available as a by-product of uranium mining.

Uranium and Thorium Supplies

We have heard from Jesse Johnson that his 1955 forecasts of uranium and thorium supplies have been more than realized. He has told us that on the basis of current production costs we could obtain supplies of at least 40,000 tons a year of uranium oxide at prices of between $8 and $10 a pound. The ore reserves in South Africa, Canada, the United States, and France are likely to contain at least 2 million tons of uranium, and on the basis of present geological data and the experience of the last ten years, an additional 2 million tons is likely to be available. These forecasts are two to four times higher than those made in 1955. If we guess that reserves in the U.S.S.R., China, and other countries are of the same order, the world reserves of high-grade ore are likely to be of the order of 10 million tons of uranium. The supplies of uranium in lower concentrations in shales and phosphorites are said to be unlimited. We have also heard that in addition to deposits of thorium in India, important deposits of thorium have been found in Canada at Blind River, where the ore contains one part of thorium to two parts of uranium oxide. World thorium reserves seem likely to be at least 500,000 tons.

At the 30 percent burn-up which might be achieved by breeding, 10 million tons of uranium are equivalent to 10^{13} tons of coal; this is three times the world's estimated coal reserves. We are likely to have developed fusion power long before we run out of uranium.

Nuclear Propulsion of Shipping

The technical feasibility of the nuclear propulsion of shipping has been abundantly demonstrated by the voyages of the U.S. submarine *Nautilus,* culminating in the remarkable voyage underneath the polar icecap. The pressurized-water reactor used to develop steam for its propulsion has proved to be highly reliable. We have heard of the first approaches to commercial nuclear propulsion. The *N.S. Savannah,* a combined passenger-cargo ship coming into commission in 1960, will use a pressurized-water reactor developing 22,000 shaft horsepower. The pressurized-water propulsion unit seems likely to achieve fuel costs, based on U.S. prices, about equal to those for fuel oil. Present capital costs are, however, three to four times higher than conventional capital costs, and a drastic reduction of these costs is necessary before parity with conventional propulsion is achieved. The United States expects to build a nuclear tanker with a boiling-water reactor for propulsion by 1962. Since this type of reactor appears to have lower capital costs than the pressurized-water reactor, this should help to bridge the gap, though operating costs will still be well above conventional costs. It seems likely that we will have to wait five years or more before we will know whether truly commercial nuclear propulsion is a feasibility.

However, there is one immediate application which would be impossible without nuclear power. The opening up of the 6000-mile seaway north of Russia has had to wait for the practically unlimited endurance of the nuclear-propulsion unit, and we have heard details of the icebreaker "Lenin," which is due to be commissioned in 1959. Three pressurized water reactors will provide 44,000 shaft horsepower for propulsion.

In contrast to the hopeful outlook for marine applications, commercial nuclear aircraft propulsion seems much further away.

Fusion Reactors

In his presidential address to the last conference, H. J. Bhabha said he predicted that a method would be found for liberating nuclear fusion energy in a controlled manner within the next two decades. The papers presented to this conference on fusion research have shown that remarkable progress is being made in this field on a very broad front. Most workers have in view the long-term objective of attaining "temperatures" of 50 to 100 million degrees in a mixture of deuterium and tritium gas. This should make it possible to reach the "break-even point" at which the energy release from fusion reactions in a mixture of deuterium and tritium gas would equal the energy input. The long-term goal is to go well beyond the 100 million degrees—to use the deuteron-deuteron reaction and eliminate the dependence on lithium as a source material for tritium.

Although we have been using the word *temperature* as a measure of our progress, we should remember that it is not strictly applicable to these very complex hot plasmas. We have also to remember that the electron temperatures are often very different from the deuteron temperatures, and that it is the latter which are important for our objective.

We have had reports from several laboratories that "temperatures" up to several million degrees have already been achieved in deuterium gas, with prospects of going considerably beyond this in the future. It is necessary, of course, to be able to hold these high temperatures for a sufficiently long time for an appreciable proportion of the deuterium to be burnt. Thus, at a temperature of 50 million degrees in a deuterium-tritium mixture and with gas densities of about 0.001 atmosphere, only 1 percent of the deuterium would be fused in 0.1 second.

The containment of this high-temperature gas depends in all cases on the use of magnetic fields, the so-called "magnetic bottle." The containment also depends on our being able to maintain this hot, tenuous plasma, generating and radiating energy at a great rate, in a stable configuration not subject to violent oscillations or eruptive processes leading to loss of energy.

Two Approaches

Two main lines of attack on the fusion reactor have been described to us. The first is the pinched high current discharge method, used in the ZETA and other tori, the Stellarator, and the straight discharge tubes. The stability of the plasma depends critically on the relation between the magnetic fields produced by the circulating current and the additional magnetic fields applied to produce containment and stability. In ZETA, containment is not well understood, and we do not yet know how far we will be able to maintain containment as energy input is increased. We have heard that other torus devices can lose large amounts of energy by runaway electrons escaping to the walls of the tube, and that the production of a quiescent plasma is the crucial problem.

In the torus devices the plasma is heated in various ways: by resistive heating, by shock-wave heating, or by radio-frequency methods. "Temperatures" have so far been measured by Doppler broadening of highly ionized impurity atoms or by even more indirect methods. It seems that deuteron temperatures of several millions of degrees may have been reached but that electron temperatures are much lower.

The second class of fusion device, known as the "mirror machine," also contains the plasma in a "magnetic bottle," but the plasma is heated in a different way. In the Pyrotron, the first of the mirror machines, the plasma has been heated by using pulsating magnetic fields acting like magnetic pistons—to compress the plasma—and electron temperatures of about 10 million degrees have been reported. In the Oak Ridge D.C.X. machine, a plasma is formed by passing intense beams of high-velocity molecular ions into a chamber where the molecules pass through a powerful carbon arc and are split up into neutral and charged hydrogen atoms. The neutral atoms leave the plasma, and the charged atoms are trapped in the magnetic bottle and form a hot plasma. The progress of this method will depend critically on producing several amperes of molecular ions and on keeping the loss of energy from the plasma low; the method will be watched with great interest. The U.S.S.R. OGRA machine which has just been completed will work on a similar principle, but the molecular ions are to be split up by impact with the atoms already there in the course of a long spiral path to and fro between the magnetic mirrors. These mirror machines also will depend for their success on being able to maintain a quiescent plasma.

Fusion Prospects

Fusion reactors will aim ultimately at developing several hundred megawatts per cubic meter of plasma, so they may not be very different in size from fission reactors. It is too early to judge the relative prospects of the different approaches to fusion power, demonstrated so well in the exhibition, so much depends on experiments still to be carried out. Although neutrons emitted after the fusion of deuterium nuclei have been observed from many of the devices, the deuterons responsible have so far been mainly speeded up by direct processes. No laboratory has so far claimed what have been called "true thermonuclear reactions," though we are probably not far away from this. However, I agree with L. A. Artsimovich that this is not the important question. The origin of the neutrons will become clear enough if we can increase the temperatures in our plasmas. The important question is whether we can maintain stability in our plasmas as we feed in more and more energy, and whether we can, in due course, reach the break-even point where the energy generated by fusion equals the energy input. Peter Thonemann thinks this may well take ten years, and that even if we are successful it is likely to be at least another ten years before we know whether an economical fusion power station is practicable. I agree with this. Edward Teller's time scale is even longer.

Biological Aspects of Radioactivity

It is not to be expected that there will be any revolutionary advance in the applications of radioactive isotopes in medicine and biology. The principles of tracer work are now well established, so that now we see merely an increasing application.

Biochemistry has been revolutionized by the availability of labeled components, and with each congress much work is reported on their use in studying the dynamics of chemical reactions. Reviews of the ways in which radioactive tracers have extended knowledge in important fields, such as protein synthesis, have been given at this meeting.

Much of the now-classical work in biochemistry has been carried out with carbon-14. At the first conference, in 1955, Glascock pointed out the even greater potential value of tritium. This is borne out in the present conference, where it has been demonstrated that when tritium has been incorporated into thymidine, a specific label can be built into the nucleoproteins of cell nuclei. Tritium, with its very low-energy beta-emission, allows very precise localization by the autoradiographic technique. Already this is providing direct evidence on cell nuclear processes which formerly were merely inferred from indirect considerations.

Clinical medicine benefits in the same way from the application of radioactive tracers to problems of diagnosis and the measurement of individual body functions. The physician is no longer limited to identification of what goes in and what is excreted; he can trace intermediary metabolism in vivo by direct counting or by sampling tissues or body fluids. A notable contribution in this conference is the increasing accent on the use of shorter-lived radioactive isotopes in order to reduce the radiological dose to the subject. Ingenious, too, is the application of cyclotron-produced oxygen-15 for investigation of malfunction of the lung. The isotope pill for diagnostic purposes predicted by Willard Libby has already been demonstrated in the exhibition.

Occupational Exposure

The biological implications of nuclear energy, however, extend far beyond the hospital. Ionizing radiation is becoming one of the features of many occupations. The effect of this on occupationally exposed individuals and on the population at large has led to a great deal of experimental work, as well as to much speculation. The biological effects may be manifested within the individual's life-time, or only in his progeny as genetic effects. The recent report of the United Nations

Committee on Atomic Radiation and the work of the International Council for Radiation Protection have now provided us with sound guidance which will enable us to protect the health both of the individual worker and of the general population. It is comforting to report that at this conference we have had evidence given to us that doses of radiation received occupationally in the large government-sponsored projects are, with very few exceptions, gratifyingly low. Furthermore, we have evidence for the first time that private industry can carry out commercial operations with equally good records of exposure of personnel. We note from the retrospective survey by Court Brown and Doll that there has been no significant shortening of life in individuals exposed to doses which must have been very much larger, in the early days of the British radiological profession, and that the only major problem for that group of radiologists was cancer of the skin in the earlier workers—a hazard which we are now confident of avoiding.

Nevertheless, from the experimental data we see that shortening of life can result in animals when substantial doses are given. The effects of radiation on the induction of leukemia and other malignant diseases is now becoming much better understood.

Genetic Effects

It is on the genetic aspects of the biological effects of radiation that this conference has broken new ground. Hitherto, the direct proportionality of gene mutation with dose of radiation has been accepted as a law which holds, irrespective of dose rate, down to the lowest accumulated dosees. W. Russell and L. B. Russell have here produced evidence for departure from linearity in the relation between mutation rate and dose for point mutations in the spermatogonia of male mice. Furthermore, they have shown that the mature egg cell of female mice is substantially less sensitive to the induction of mutations than the spermatogonia of the male. Similar results have just been reported by Carter from Harwell. These two facts will probably necessitate a complete reconsideration of the quantitative predictions of the genetic hazard.

Another gratifying feature of the genetic reports is the increasing effort devoted to study of irradiated populations. While characters determined by single genes are ideal objects of laboratory study, most of the mammalian characters of major importance—in a word, fitness—are the summation of effects of many genes. Studies of fitness of populations are thus of great significance but difficult to mount. Our lecturers are to be congratulated on initiating and carrying out such important work.

Health and Safety

A number of lecturers have discussed the problems of reactor safety. We have had reports on the important experimental work on the kinetics and stability of reactors. We have learned about the effects on reactor kinetics of the accumulation of radioxenon and the growth of plutonium in fuel. These will not produce any difficulties in operation provided the reactor instrumentation is adequate.

We have also learned a great deal from three reactor accidents which have led to partial melt-out of the reactor fuel elements. Although two of the reactors were put out of commission for a year and one was written off, no one was hurt by these accidents or received an overdose of radiation. The results of the accidents agree in a remarkable way with data presented in one of the experimental papers in showing that only a very small fraction of some of the bone-seeking isotopes escaped from the melted fuel. The disturbances due to these accidents were accordingly less than envisaged in the 1955 papers. Later generations of reactors than these early models are much better protracted by containment and instrumentation, and some papers have shown that considerable progress has been made in advanced designs of containment which are thought to be proof against the maximum credible accident. This gives us considerable reason to anticipate safe operations in the future, and we may, in due course, expect the location of plants in more populated areas.

National Organizations

We have also heard of the growth of national reactor safety and inspection organizations, analogous to those in being for the aircraft industry. They inspect designs and prescribe codes of operation to help to maintain safety. We may also need an international reactor safety panel to help smaller countries who do not have safety experts available to them.

In our legal sessions we heard that our international conventions may be required to deal with problems raised by mobile reactors, the disposal of radioactive effluents in the oceans, and any possible damages beyond national boundaries from reactor accidents.

Industrial and Research Uses of Isotopes

The multitudinous industrial uses of radioisotopes continue to increase rapidly. Libby has estimated that their use in process control, in the oil industry and other production fields, is already saving United States industry 400 million dollars a year and that the savings will soon reach the multibillion-dollar level. Topchiev has reported that the present annual savings to Soviet industry by their use amount to over a thousand million roubles. Several million meters of oil-well bores have been logged by neutron sources.

Sources of radiocobalt and of radiocesium are shortly becoming available in strengths of the order of 100,000 curies, for industrial applications. These powerful sources will be used for sterilization of hospital dressings, pharmaceutical products, and other materials where chemical sterilization is less attractive. They can be used to produce grafted polymers in which the properties of the original polymer are beneficially changed. Thus, Libby told us that a styrene-polyethylene film had been used to make an ion-exchange membrane which had much improved properties for purifying brackish water. Topchiev has reported the production of block polymers of polyethylene and polystyrene which have high strength and stability up to 250°C. Many more chemical applications are promising, and we are likely to make full use of the tens of millions of curies of radiocesium and radiocobalt which could become available as by-products of the power program.

The movement of silt in river estuaries and harbors is now being studied with the help of radioactive tracers in many parts of the world, following pioneering studies in the Thames estuary. Gold- and tritium-labeled water is being used to determine the flow of water in rivers, sewers, and underground strata. This may have important applications to the survey of water resources in underdeveloped areas, and for the control of irrigation in arid areas.

The polonium alpha-particle camera is an example of a new research tool which will make it possible to measure mass differences of 10^{13} and possibly 10^{15} grams in microtome sections of biological material. These examples of the industrial and research uses of isotopes, taken almost at random from an enormous field, can do no more than illustrate their already great and growing importance.

Fundamental Research

We have been both entertained and instructed by our sessions on fundamental research. New giant accelerators have been described to us, and we have heard that the cosmic ray workers, flying large stacks of photographic emulsions in Comet proving trials, have been able to obtain an enormous amount of new data on the collision of protons ten thousand times more energetic than any which can be produced by the largest planned accelerators. We have also heard of the new discovery, by the orbiting satellites, of intense belts of 40-million-volt protons, 1000 kilometers or so above the earth in particular latitudes. The great question of why pions and nucleons exist, with their particular masses and particular interactions, remains totally unanswered, in spite of the wealth of new knowledge produced by the accelerators. Strange particles accumulate and now total 31. The theoreticians have a new occupation of inventing new rules and waiting to see whether the latest strange particle obeys them. Feynman has predicted that 20 years hence our successors may be convening a "Conference on the Peaceful Uses of Strange Particles."

New Tools

In the field of nuclear data we have heard that the present situation leaves no room for complacency, since present reactor technology requires much more precise information, which we shall have to work hard to obtain. To help in this, important new tools providing enormously powerful pulses of neutrons are becoming available.

In the chemical sessions we have heard of the isolation of weighable amounts of berkelium, and that the chemists look forward to going well beyond element 102, aided by expensive reactors with neutron fluxes up to 10^{16} per square centimeter per second, which they hope benevolent governments will supply in the future. The chemical effects of fission fragments appear to be much higher than anticipated, and this may have important technological consequences. There has been a rapid advance in solvent-extraction technology, and long-chain amines and long-chain derivatives of phosphoric acid have been synthesized, with highly specific activities. Such developments could have applications far outside the world of atomic energy.

We have had a rich feast—perhaps too rich—at this conference, not only from the lectures but from the exhibitions, which have enabled us to see in a few days, in an exciting visual way, work proceeding throughout the world. We have also held innumerable discussions in small groups to amplify the knowledge gained in our formal sessions. This is the classical method of cooperation in the scientific world. We will go away with a great deal to think about, and this conference, like the 1955 conference, is likely to have a profound effect on the future development of atomic energy.

Requirements for Growth of Single Human Cells

"Nonessential" amino acids, notably serine, are necessary and sufficient nutritional supplements.

Royce Z. Lockart, Jr., and Harry Eagle

A number of human cell strains serially propagated in monolayer culture have been shown to have the same nutritional requirements for growth (*1*). A minimal medium containing the essential 13 amino acids, eight vitamins, five ions, and glucose, supplemented with dialyzed serum, permitted the apparently indefinite propagation of all these cultures, with a generation time in the logarithmic phase of growth of approximately 20 to 24 hours. However, when cultures were initiated with a relatively small inoculum, and, in particular, when cloning was attempted with several cell lines by the method of Puck and Fisher (*2*), the cells failed to grow in the same minimal medium which permitted the growth of heavily seeded cultures. As is shown below, the additional factors required for the growth of these small inocula proved to be the "nonessential" amino acids, which, for the growth of heavily seeded cultures, need not be added to the medium; in many experiments serine alone sufficed.

The authors are on the staff of the Laboratory of Infectious Diseases, National Institute of Allergy and Infectious Diseases, National Institutes of Health, Bethesda, Md., in the section on experimental therapeutics. Dr. Lockart is currently a National Research Council postdoctoral fellow.

Methods

The present experiments (*3*) were carried out with four serially propagated human cell cultures: (i) the stock HeLa strain; (ii) the S3 HeLa clone isolated by Puck *et al.* (*4*); (iii) a human conjunctival culture (*5*); and (iv) the KB strain (*6*). The cultures were grown in suspension in "spinner" cultures, as described by McLimans *et al.* (*7*). With such suspension cultures, the only manipulation of the cells required in the preparation of the inoculum was that of dilution; this obviated the cellular damage incident to the dispersal of stationary monolayer cultures by Versene, trypsin, or mechanical means.

As suggested by McLimans *et al.* (*7*), the medium contained the essential amino acids and vitamins at twice, and phosphate at ten times, the usual concentrations, while calcium was omitted