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THE WORLD' SOURCES OF ENERGY

by

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THE RADIO CLUB OF AMERICA

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LLOYD V. BERKNER

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Introduction

I am greatly honored to have this opportunity to speak to this distinguished club this evening. The radio profession is one that encourages its members to graduate from the ranks of the amateur to the ranks of the professional. It is honorable to be both amateur and professional at once. I suspect that a fair share of the members of the Radio Club of America are occupying this dual role. As professionals, we have a job to do in the field of electronics, communications or industry. As amateurs, we are free to follow our curiosities wherever they may lead. This dual status has been responsible for the position of the radio amateur in the van-guard of many areas of modern scientific discovery.

Amateurs are not content to look at one scene too long, when a whole universe remains to be explored. Tonight, I would speak of a fascinating field closely related to and deeply involving electronics. This is the field of nuclear energy, or more broadly, just of energy.

So that we can better understand the place that will be occupied by controlled nuclear power, let me briefly look at our world from an energy point of view.

That energy is fundamental to man's existence is hardly necessary to emphasize. Aside from the energy needed for food and a minimum of warmth that is common to all biology, it is energy under man's control that forms the very basis of his civilization. In his quest for better living, and for time to follow intellectual pursuits, which are the bases of civilization, man first used slaves, both human and animal, as his principal energy-source. Then man learned to use the wind to sail his ships, and a little waterpower to grind his flour. But until two centuries ago, this was about the limit. The man without slaves, or without the favor of a court that had slaves, was poor indeed.

The industrial revolution and with it, the revolution in our civilized habits was started by James Watt, who with his steam engine contrived to make controlled energy abundant. With the coming of simple electrical transmission of energy over great distances by fixed conductors, the first stage of the industrial revolution was complete. Each man, woman, and child in the United States now has the equivalent of 200 slaves at his disposal. Energy has made each of us a king in contrast to the miserable situation of our forebears.

This change has not been a slow evolution. It has been, rather, a sudden revolution. Man's written history is but 300 generations old. So close are we to the beginning of civilization that about 7% of all men born throughout history are still living. Power in substantial quantities under man's control goes back only 6 or at the most 7 generations. Yet we routinely accept the mechanical slaves that power gives us as though they had always been present. What then are the sources of power that provide these slaves?

Our energy sources can be classified in a number of ways, but for convenience we shall consider them under four categories:

1. Mechanical momentum of the solar system
2. Natural disintegration of heavy elements
3. The thermo-nuclear reactions of the sun
4. Controlled chain-reactions of heavy elements in nuclear reactors

The first three of these sources have been used under control by man to some extent since the

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EDITOR'S NOTE: The author, now President of Associated Universities, Inc. has had an outstanding professional career. 1925-1927, engineer-in-charge of Radio Station WLB-WGMS, Minneapolis, Minn.; 1928 with first Byrd Antarctic Expedition as radio engineer representing National Bureau of Standards; 1930-1941, director of research engineering and lecturer; 1941-1946, active duty as officer in U.S. Navy; 1946-1947, First Executive Secretary, Research and Development, Board of Defense; 1947 to present, director of research and consultant.

beginning of civilization. But the fourth is entirely new in our experience and has been created entirely synthetically by man within the last decade. Moreover, the last three sources named are the direct result of the conversion of mass to energy by radioactive disintegration or integration of certain elements. The mechanical momentum of the solar system, according to modern physics, was also derived from energy produced by nuclear reactions during the formation of the universe. So we see that all of our energy is derived from the conversion of matter to energy through one intermediate process or another. Going still deeper, one would like to believe that matter and energy are just perturbations on "nothing", but in our present state of science we certainly can't as yet prove this.

The Mechanical Energy of the Solar System

The mechanical momentum of the Earth is very large, but we use very little of it under controlled conditions. In its revolution around the sun, for example, the change in the potential energy of the Earth from aphelion to perihelion is of the order of 10^{18} Hiroshima A-bombs. Moreover, our best measurements of time indicate that the rotational period of the Earth is slowing down by about 1/1000th second per century. This corresponds to a decrease in the kinetic energy of rotation at a rate of 1,500,000 megawatts -- continuously day after day, year after year. This energy is dissipated through the tides and the ocean currents, for an independent estimate of the energies involved in these huge flows of ocean waters has given a figure of the same order as that computed from the diminishing rotational period of the Earth. We believe that the Earth once rotated a revolution each four hours, but this energy loss has slowed it to its present daily period. We could mention other mechanical sources of energy, such as the drunken, irregular wobbling of the Earth's axis known as "nutation", caused by lunar and solar attraction on the equatorial bulge of the Earth, or variations smaller than the "nutation", which are probably due to the transfer of varying amounts of ice and snow mass from one pole to the other between the seasons. But we have tapped almost none of this energy source since we do not know how to proceed efficiently.

The Heat of the Earth's Crust

The natural disintegration of the heavy elements, such as radium and uranium, replenishes the heat of the Earth's crust at a rate that now exceeds the outward conduction of original heat in the Earth's core. We use very little of this energy. The steam wells at Larderello, Italy produce some 250 megawatts. The famous "blow-hole" at Wairaki, New Zealand that emits through an 18 inch orifice steam said to be at 175 pounds pressure and superheated to 1200°F is about to be harnessed. We could speak of space-heating from hot springs, such as those, that make possible the year-round greenhouses at Circle Hotsprings, Alaska on the Artic Circle. But obvious limitations have prevented production of more than a negligible amount of power from the heat of the Earth's crust.

Energy from the Sun

The vast majority of our energy comes directly or indirectly from the thermonuclear reactions of the sun. The H - He nuclear cycle heats the sun. In this reaction, the nuclei of hydrogen are synthesized to form helium through the intermediate formation and destruction of nitrogen using carbon as a catalyst. We must remember that such thermonuclear reactions are not uncommon, for we have some 10^9 such thermo-reactors as suns in our galaxy, and according to Britain's Astronomer Royal, there are more than 10^8 galaxies, giving a grand total of perhaps 10^{17} known thermonuclear reactors in our universe.

While our own sun is a very average sun, being neither very big or very small, to us its radiated energy is very great. The Earth intercepts only some 4 or 5 parts in ten billion of the total radiated (4.55×10^{-10}).[1] Nevertheless, the total energy received by the Earth arrives at the rate of 4.14×10^{16} cal/sec or 1.73×10^{14} kw out of the total of 3.8×10^{23} kw radiated from the sun. Sometimes I think our 30 megawatt nuclear reactor at Brookhaven is pretty big, but it would take 6 billion such reactors to equal the power supplied to the Earth by the sun. We must not forget that at midday in mid-summer at Brookhaven, the power from the sun received over 5 or 10 acres is the same as that generated by the Brookhaven reactor.

How well do we use the sun's energy?

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[1] The Earth receives energy at a rate of about 1.94 calories per minute per square centimeter or about a watt per 7.4 square centimeters projected toward the sun. The average rate at which a particular area on the Earth's surface receives energy will be something under 1/6 of this depending on the latitude, season, and atmospheric absorption.

Direct Use of Solar Energy

Very little of it is used directly. And there is good reason. Storage of any substantial amount of energy is very difficult with techniques that we now know, and heat storage and heat transfer with small temperature differences are very inefficient. No doubt, direct utilization will increase somewhat with time, but from what we know of the specific and latent heats of convenient materials, it is doubtful that direct utilization can ever be important in relation to the gross amounts of energy needed for industry, commerce, and ordinary living. On the other hand, there is some possibility that inorganic chemical reactions can be found that will permit more efficient absorption and storage of the sun's energy in inorganic chemicals from which the energy can be obtained for controlled release at higher temperatures. Very little has been done to concentrate the sun's energy using large but perhaps inexpensive lenses to focus the energy for production of such reactions. Likewise, we may yet perfect a heat pump that can concentrate heat energy at useful temperatures and in quantities significantly greater than it uses. But while, at the moment, there are many attractive avenues for research and development, direct utilization of the sun's energy remains both unimportant and difficult to assess for future consequence.

Solar Energy in the Atmosphere

About one third of the solar energy incident on the Earth is stored in the atmosphere and given up in the form of atmospheric circulation or in rainfall. In the neighborhood of 1.6×10^7 tons of water per second are involved. We recall that about 560 calories or more than 2 BTU are required to vaporize a gram of water. Thus a gallon of water requires the heat equivalent of a pound of coal to vaporize it without any increase in its temperature.

Energy from the sun evaporates water near the equator. This vapor is circulated toward the poles where it is condensed, giving up the heat of one pound of coal for each gallon condensed. The heat transferred to the poles in water vapor is equivalent to an extra day of polar sunlight for each inch of precipitation that is condensed in the polar regions. This is not an insignificant proportion of the total heat received at the poles. Thus the atmosphere is a huge heat engine with heat absorption by evaporation at the equator, heat transfer through transport of water vapor, and heat radiation from the cold areas at the poles. It is probably the only large heat engine that uses a radiator as the condenser! But this engine produces circulation that provides mechanical energy of the wind, and lifts huge quantities of water to the plateaus. This water flows to the sea in rivers to provide substantial useable energy in the form of water power. But the supply of water power is limited to the water that falls on areas substantially above sea level. This provides potentially about 500,000 megawatts of useable power of which less than 15% is developed. It is interesting to observe that potential water power is distributed 42% in Africa, 23% in Asia, 10% in Europe, 10% in South America, 4.5% in the United States, with 7.5% in remaining North America and 3% in island areas. But the total potentially available water power is only about one third the present U.S. demand alone and is well behind the total world demand for energy.

We have not yet learned to use very effectively energy directly from the wind. We can estimate that various wind driven devices produce an average of 40 megawatts of power, but this is the output of a single small nuclear reactor. After all, this is less than one third the power used to drive electric fans to produce small winds in our homes, offices, and factories.

Solar Energy from Organic Chemicals

The vast supply of our energy from the sun is derived from chemical storage of that energy. This supply is available in two forms:

1. Fossil fuels stored in the earth, such as coal, oil, gas, lignite and peat, and

2. Biological forms currently growing or even cultivated deliberately for chemical storage of energy currently received, such as wood, crops, or "chlorella" that I will mention in a moment.

Chemical storage involves an indothermic reaction during the growth of the biological forms, where the sun provides the energy. Chlorophyll, or similar chemicals, make possible the vital reaction known as photo-synthesis. The energy can be obtained at any later time through exothermic chemical reactions, usually burning. While chemically stored, the energy can be chemically transferred into any convenient form and is easily transported and retained more or less indefinitely for controlled use.

The Fossil Fuels

Coal represents 96% of our store of fossil fuels, with 4% in oil, lignite, shales, natural gas, and other forms. The total accessible fossil fuel reserves of the United States is between 2×10^{15} and 2×10^{16} K.W.H. depending on the degree of optimism of the estimator. Certainly the fossil fuel supply of the whole Earth is much less than the solar energy falling on the Earth in one year. So the efficiency of fossil fuel storage has been incredibly low, at most a few parts in a billion depending on how far back you care to start counting.

At present, the United States uses about 1×10^{13} K.W.H. annually including conversion loss. By conversion loss, I mean the energy required to get the fuel and make it useable. Obviously, if we expend a pound of coal to provide energy to obtain a pound of coal, the conversion loss is 100%, for we are back where we started and have gained no energy. Likewise, if we must have our energy in liquid form, such as gasoline, there is an additional heat loss if it is converted from coal. Clearly in obtaining heat from fuel, we must come out with more than we put in or the initial fuel is useless as a source of energy. Our present conversion losses are about 16%, that is one pound to obtain six. But we are now mining the coal and oil that is easy to get. In a hundred years, all the fuel that is easily accessible will be gone. The most conservative estimate indicates that a century from now the conversion loss will be above 50%, that is one pound for two. How much farther can we go with this?

Because of increased useful demand and higher conversion loss, we can estimate that the United States energy requirements in 100 years will multiply by 5 or 6, to perhaps 6×10^{13} K.W.H. per year. A few curves and some simple calculation show that our fossil fuels will be pretty well exhausted in 150 to 175 years. Those who have predicted that coal will last a thousand years have failed to appreciate the significance of conversion loss, where the billions of tons in thin seams are useless as fuel.

This is so startling that we must look at it more closely. What about the rest of the world? Unfortunately, fossil fuels are only found in the temperate zone. They have not accumulated near the equator since biology rots too quickly. Not enough biology has lived near the poles. Therefore, such fuels are available in substantial quantity only over very limited land areas. For these and other geologic and meteorological reasons, other areas of the world are generally less prolific in fossil fuel than the United States, so that their total cannot be much more than twice that of the United States. If in the next 50 years, the people of the world develop the social consciousness they appear to be acquiring, they will use up the remaining stores faster than we, for our population is only 5% of the whole.

In a philosophical sense, man was provided with easy access to a store of energy, the fossil fuels - to develop his mechanical potentialities. But these resources are extremely limited and, in the expanding economy that they encourage, can last a total of only 10 or 15 generations of civilized history. That is 3 to 5% of his time. He is given this short interlude to use his newly developed mechanical skill to acquire new and more permanent sources of useful energy. This is the task before us. Where shall we turn?

New Sources of Energy from the Sun

First, what about better use of the sun's energy? We have long burned wood, and the like, for heat. Except in the earliest heat engines such fuels have not been very important as large sources of energy, for the supply is extremely restricted. Nevertheless, it is worthwhile to push our examination of this possibility more vigorously, since the supply of the sun's energy is unbounded when measured by even the most optimistic future need. A hybrid corn plant appears among the most efficient common photosynthesizers, capturing perhaps 0.3% of the energy incident on it during the growing season. But in recent years, certain algae similar to the green scum on ponds, have been found to synthesize about 3% of the incident solar energy. These algae having the property of efficient photosynthesis are known as "chlorella". Chlorella have been cultivated experimentally by the scientists of the Carnegie Institution of Washington and pilot plants for their production have been set up experimentally by the Stanford Research Institute, and the A.D. Little Company of Cambridge.

A small tank exposed to the sun and supplied carbon dioxide and chemical fertilizer can produce several tons of chlorella per day to be dried and burned. The carbon dioxide and mineral fertilizer can be retained as residue and fed back into the process so that all basic elements appear only as catalysts in the process. Only the heat is abstracted. Fortunately, chlorella can be selected to produce either proteins or carbohydrates. Experiments up to the present have been directed primarily toward a chlorella to produce food, since some strains produce a dry weight content of as much as 50% proteins. But there appears no bar to mass production of carbohydrates for fuel in the same way. The cost is still high, but not too much higher than coal, and the work along these lines has only begun.

The whole process of photosynthesis is due for much more intensive research, particularly with the new radioactive tracers to follow the controlling factors underlying each step in the reaction. Photosynthesis may be the key to gross chemical storage of the sun's energy.

We shall learn in a moment that because of intense radioactivity reactors cannot be built in small units, to supply small mobile vehicles, for example. Certainly, nuclear energy can supply large ships, or perhaps even specialized aircraft or large railway prime-movers of a kind that we do not yet conceive. But I suspect that our cars and trucks must always use a simple chemical fuel. It is not hard to imagine this fuel in the form of alcohol derived from chlorella-like biology.

Therefore, chlorella-like biology seems promising as a future means of storage of the sun's energy in useful form and in large quantities. The efficiencies of the chlorella permit us to dream of tank farms extending over the deserts, synthesizing the sun's energy in huge quantities. But we have a long and arduous experimental row to hoe to achieve this promise. We must understand much more about biological processes, and the fundamentals of photosynthesis before we can realize success.

Energy from Nuclear Reactions

I will now turn to the most fundamental source of energy we know, i.e. the nuclear energy released in the transmutation of certain elements. There are two possibilities:

1. Disintegration of heavy elements, known as the fission process.
2. Integration of the light elements, known as the thermonuclear reaction.

The thermonuclear process is typified by the reaction that goes on in the sun; this involves the synthesis of light nuclei into heavier nuclei up toward the middle of the periodic table. We certainly do not, as yet, know how to produce such a reaction under controlled conditions. So we will turn to the conventional nuclear reactor that can maintain a high level fission process under controlled conditions.

A nuclear reactor is a device for the control of nuclear energy derived from the disintegration of heavy elements as a consequence of the chain reaction. It produces three products:

1. Heat
2. Fission products
3. Fissionable material

Let us look at a typical chain reaction. We start with uranium which in nature consists of 0.7% U-235 and 99.3% U-238. Now, the U-235 has the property that when hit by a low moving neutron, it explodes or "fishes" into several new and lighter elements generally near the middle of the periodic table. In the process of fission several high speed neutrons are given off. These neutrons can then be slowed down by a suitable "moderator" so they will be captured by several other U-235 nuclei. Each of these fission and give off several neutrons for further use. This process of successive multiplication of emitted neutrons is known as a chain reaction. The much larger quantity of U-238 is in itself not fissionable in the thermal reactor, so that if natural uranium is used, only the minute fraction that is U-235 enters in the reaction.

Obviously, we have a lot of spare neutrons in this process, since if we used them all to multiply the reaction, it would grow until, shall I say, the energy output became excessive. Fortunately, the U-238 can capture neutrons, and when it does so, a curious thing happens. The U-238 retains the neutron and becomes U-239 which promptly gives off an electron and becomes Ne-239, which ejects another electron and becomes Pu-239. And plutonium is a stable fissionable material that like U-235 can sustain a chain reaction (though this must be done in another type of reactor). Therefore, like U-235, Pu-239 is a nuclear fuel. This process of making a fuel such as Pu-239 from a non-fuel such as U-238 is known as breeding. Since each fission of U-235 gives off several neutrons, and only one is needed to maintain the reaction, the others are available for breeding purposes. This permits us to have more fuel at the end than we had at the start. Through breeding, we can burn our whole stock of uranium as nuclear fuel, by first transforming the 99.7% of U-238 to nuclear fuel in an operating reactor.

There are other possibilities for breeding, such as the breeding of thorium into U-233 that is also a nuclear fuel.

During the chain reaction and breeding process, heat is derived in large amounts. It comes from the fact that the sum of the masses of the fission products is less than the original mass. The balance of mass has gone into energy according to the famous Einstein equation

$$E = mc^2$$

The nuclear reactor to control the chain reaction consists of a number of basic elements.

1. An initial source of neutrons, usually the U-235, that "fishes" at a naturally slow but sufficient rate to start the reaction in a properly designed reactor.

2. A supply of fuel which could be U-235, U-233, or other fissionable material amounting to more than the critical minimum mass necessary to sustain reaction in the particular reactor configuration involved.

3. A moderator such as carbon or heavy water that will slow the neutrons, but not capture them. (We should observe, parenthetically, that in a fast reactor, that is one using a fuel such as plutonium that will capture fast neutrons to produce fission, no moderator is required).

4. A means of control to regulate the level of the reaction. To prevent reaction, any rod of high neutron absorbing material such as cadmium can be inserted into the fuel until the fuel mass is no longer critical. The rod is just pulled out slowly until the reaction begins and the neutron flux reaches the proper value. Additional safety rods can be arranged to drop automatically into the reactor by gravity if it gets too hot thereby shutting it down.

5. A breeder material suitably arranged to keep the efficiency high by capture of excess neutrons for production of new fuel.

6. A means of heat transfer from the reactor to regulate the reactor temperature. This may be air, or water, or any liquid that does not absorb neutrons.

7. A means of shielding to prevent neutrons from coming out and producing dangerous radioactivity in the whole surrounding area. Several feet of concrete will suffice, though any material that effectively absorbs neutrons and gamma rays will do.

There are innumerable configurations that reactors can take, depending upon the materials we use and the properties that we want. But the configuration should always be directed to high neutron efficiency. The objective must be to use every possible neutron for useful purposes in producing fission or in breeding fuel, and to waste as few as possible in shields, controls, cooling, and auxiliary devices. To keep the reaction going, an average of one neutron from each fission is captured by another fuel atom to produce the next fission. When a second neutron from each fission is captured to make a new fuel atom, our net loss of fuel is zero, since a fuel atom is made for each one burned. So our neutron efficiency might be called 100%. If we can capture more than one neutron to make fuel from each fissioned atom, the efficiency is more than 100% and we are breeding fuel faster than it is burned. Therefore, high neutron efficiency in reactor design is at a premium and the self-respecting reactor of the future should have an efficiency of more than 100%.

If the reactor breeder efficiency is over 100%, it need be supplied only with raw uranium or thorium, at a few dollars per pound. Then it supplies as much fuel as it uses, and produces some extra fuel for new reactors or other applications. Needless to say, this extra fuel is quite valuable as one of the products of the reactor, and is the first output of the reactor to be considered in reactor economy.

The fission products, sometimes called radioactive waste, are the second principal output of the reactor. When the fuel fissions, it breaks into atomic fragments having a mass near the center of the periodic table. Caesium, barium and lanthanum are common fission products. Fission products are usually the unstable radioactive isotopes of such elements. Unfortunately, many such fission products are good neutron absorbers. So if fission products are allowed to accumulate in the reactor, they wastefully absorb neutrons, and the neutron efficiency of the reactor goes down with time. Therefore, the fuel must be frequently reprocessed to remove these products. This is a difficult procedure, since the fission products are highly radioactive. Remote control and special shielding are involved, both upon removal, and during reprocessing. The fission products or wastes are usually removed in liquid form and concentrated, for the cost of protected storage is very high, and wastes must be stored for perhaps 50,000 years to permit the radioactivity to fall below dangerous levels.

There is some hope that some substantial return can be obtained from this costly process. We recall that, at one time, radium was our only useful source of radioactivity and it cost several thousand dollars a pound. Its great cost discouraged thought of its use for other than medical purposes. If now, we can concentrate particular radioactive materials from these fission product "wastes", at a dollar or so a pound, we can afford to explore possible commercial applications for quantities of radioactive material. This exploration is going on. A large packing company is testing the effectiveness of food sterilization in radioactive fields. (Perhaps canned raw steak is around the corner.) We find that new kinds of plastics can be polymerized in a radioactive field. Special isotopes abound in these "wastes". So the removal, concentration, and storage of fission products, now a heavy cost-load on reactor operation, may yet be turned to provide a useful and profitable reactor by-product.

Now let us turn to the third and perhaps ultimately the most important reactor product, or its heat output. A pound of uranium when burned completely in a reactor produces 2.5 million K.W.H., the heat equivalent of at least 1,000,000 pounds of coal. Our present U.S. economy would burn about 200 tons of uranium annually to supply its entire fuel requirements. The problem is to transfer and transform this heat into energy in useful form, preferably electricity. There is no known way, nor may I add, even a good lead, to transformation of the energy of fission directly into electricity. Therefore, we must go through a heat cycle very similar to that used between the fire-box and the generator in the ordinary electric plant. In this analogue, the reactor is just the fire-box. It is not a simple fire-box, but a highly radioactive source on which any work is very difficult after the reactor has been operated. It is not a simple matter to overhaul the boiler, or heat exchanger that removes the heat from the reactor, since no man can go near it. The job must be done entirely by remote control. Can you imagine trying to run your furnace entirely by remote control for 30 years? It would be expensive. Yet this is the problem of heat exchange from the reactor. Obviously, we must achieve extreme simplicity of design and replacement maintenance of every element of such a unit.

At this point, we cannot avoid the subject of neutron corrosion and neutron-induced distortion. We have already said that if materials used in the reactor have large capture cross sections for neutrons, they reduce the neutron efficiency of the reactor. But in addition, when an element captures a neutron, it transmutes to another element. While our initial material may be strong, it may transmute to a weak element, or to one that makes the metallurgical structure of which it is a part very weak, or one that chemically corrodes. Likewise, when fast neutrons collide with the atoms of the crystal structure of reactor materials, they knock the atomic corners of the crystal-lattice out of place. As this process goes on, the material "grows" in size and distorts in shape. These are but a few examples of change in the character of materials that occur when they remain in reactors for long intervals. To remain reliable, the materials selected for reactor construction must meet structural performance requirements not ordinarily experienced. Designs must allow for unavoidable distortion. Therefore, entirely new structural materials and designs are coming into use because of reactor technology. And, need I add, a whole new area of structural engineering is being developed.

As in any power plant, the temperature difference across the heat exchanger should be as large as possible to permit efficient heat transfer from a moderate sized reactor. This means that the reactor must operate at the highest practical temperature, and use the most efficient methods of heat transfer at these high temperatures, to achieve reasonable efficiency. But high temperature operation of reactors introduces some new and difficult problems concerning reactor behavior that require extensive research.

In the foregoing discussion, I have tried to point out the principal general areas of reactor research and engineering that underlie the development of reactor design for power production. I have no intention of making such problems look unsurmountable, because they aren't. As in all engineering development we must classify the problems, determine the fundamental limitations, and then solve the problem with an acceptable ultimate efficiency. Research on these basic problems has evolved so rapidly that we are about ready to see some pilot plants built.

Summing up the economy of power from reactors, it works out something like this:

1. If the neutron breeder efficiency is more than 100%, we will have rather valuable fuel for sale. It is hard to value this fuel, depending on future demands for its use in bombs, or to load other reactors. Our input costs of raw uranium fuel are relatively low.

2. We have fission products that are now costly to handle and store, but may be saleable as a profitable by-product in the future.

3. The reactor and heat exchanger are a rather expensive form of fire-box and boiler. The remainder of the plant will be rather standard.

In comparing costs of reactor power with coal-generated power, it is important to remember one fundamental point. In coal generation, the cost of fuel, over the life of the plant, is very much more than the cost of the plant itself. Therefore, the amortization of the plant is a small fraction of the total cost of operation. On the other hand, since a reactor produces more fuel than it uses, the fuel cost per kilowatt is almost negligibly small, since the only fuel material that need be supplied is raw uranium or thorium in relatively inexpensive quantities. Since the reactor fuel-costs are negligible, the principal costs derive from operation and investment. As a consequence, we are permitted to think in terms of much higher investment charges for reactor-generated power than for coal-generated power. We must balance the low cost of raw uranium, and the value of the heat generated and the fuel bred in the reactor, against the high cost of the reactor and heat exchanger, the problem of maintenance, and the handling of fission products.

Until we try an actual operation, we cannot formulate firm or even close cost comparison figures between reactor and coal-generated power. Authorities will differ a good deal on probable cost. A few things seem sure. As long as plutonium is valuable as a bomb material, it should certainly be cheaper to make it in a reactor that sells its heat at a few mils per K.W.H. than one that sends it up a stack or down a river. Moreover, the actual cost of operation will certainly come down when we have had experience to assess what we believe to be the important sources of expense in actual operations. We first must develop some technological and operating "feel" for the problem.

Even at the present time, there are places where coal or other conventional fuel is so expensive that the reactor now could do an efficient job. I think of the Arctic regions or other fuel-starved regions as an example. There are military applications for submarines and ships, where performance cannot be measured in dollars. Here is obviously an important and suitable application that our government is pushing vigorously.

I believe we are getting very close to the time when the economy of reactors will permit them to compete effectively with coal generation. The first experimental reactors will probably not be competitive unless the fuel bred in the reactor is sold as bomb material. But, with actual operating and design experience, the cost will come down quickly, and the completely competitive reactor will very likely be put in operation in the next decade. The research program of the AEC is beginning to pay off, and we are becoming more confident of improved designs on paper, and of new materials. The next five years will certainly see a number of pilot plants operating to test a variety of reactor configurations. These scale-test operations should put us over the hump.

There is no doubt whatever that nuclear generated power will become important in the future. We have already seen that we must find new sources of power, and power from the atom is a powerful possibility. But, you ask, what about the uranium supply?

Uranium is about as common as lead. True, most of it is spread out in low grade ores. But there is an accessible uranium supply with reasonable conversion losses that is at least equal to the heat capacity of all of our coal reserves. According to reliable estimates, there are at least 100,000 tons of uranium available in the U.S. in minable ores. This is equal to 10^{16} K.W.H. if used for controlled energy release, or somewhat more than our coal reserves. Thorium is also an important element. And with improved methods of handling low grade ores and utilization of by-products in ore reduction, this may be multiplied several times. Particularly, large quantities of uranium and thorium will be produced as profitable by-products of other mining operations.[2] Also,

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[2] Uranium production from processing of phosphate fertilizers has already been significant.

such profitable by-products inevitably make new mining ventures possible.

We might remark at this point that we could afford to expend as much as the equivalent of 250 tons of coal, per pound of uranium mined and processed before the fuel conversion efficiency would drop as low as 50% earlier mentioned as a limit for coal. This would permit the processing of incredibly low grade ore.

The first nuclear plants to be built will produce power at a higher cost than coal. But, with experience and development of technical skill, this cost will undoubtedly come down to two or three mils. This is comparable to generation costs at present with coal.

We can estimate that nuclear powered plants will add to our coal generation capacity starting modestly perhaps in five years, and in significant numbers in ten years. But I seriously doubt that any nuclear plant will supercede a coal plant until that coal plant is ready to abandon. The process will be one of supplementation rather than substitution.

We said earlier that we had been given 10 or 15 generations of grace within which to find more permanent sources of energy. More than half of this is gone. But the search is on. We and our children will hear a lot about it in the future, and the availability of new sources of energy in new places will inevitably produce vast changes in our economic structure.

From The Pen of CHARLES F. JACOBS, Radio Club of America

"Uneasy lies the head that wears the crown" -- no truer words were ever spoken.

At the turn of the century Great Britain led the world in international commerce and banking. Her influence was felt in all corners of the globe and his philosophies were respected by all.

In the last decade, as you well know, the United States has replaced Great Britain as the leader in the Free World. However, when any nation accepts such leadership, they likewise have to accept the responsibilities that go with it. This is just what is happening now to the United States.

More and more of the production and financial load is being piled upon us all the time. We are also gaining leadership in international communication and transportation. This should prove to be a wonderful thing, provided we are able to train ourselves to handle the situation in the proper way.

When I say "train ourselves" I mean from now on out, more and more of our industrial leaders; bankers; statesmen and executives should be able to speak at least 2 or 3 foreign languages fluently. They will also have to better acquaint themselves with the living habits of Europeans, Asiatics, Castillians and Orientals.

All this requires time and training. The men of our armed forces during World War 1 and 2, and now, are spread all over the universe, and this should help us become a factor in international affairs.

I look forward to the time when the federal government will control and operate schools in which qualified civilians of the U.S. can take courses in international banking; diplomacy; foreign languages; communications and export customs. This would train personnel for specific government jobs, and, of course go a long way toward carrying on a systematic and scientific approach to some of the most important tasks confronting the United States for a long while to come.

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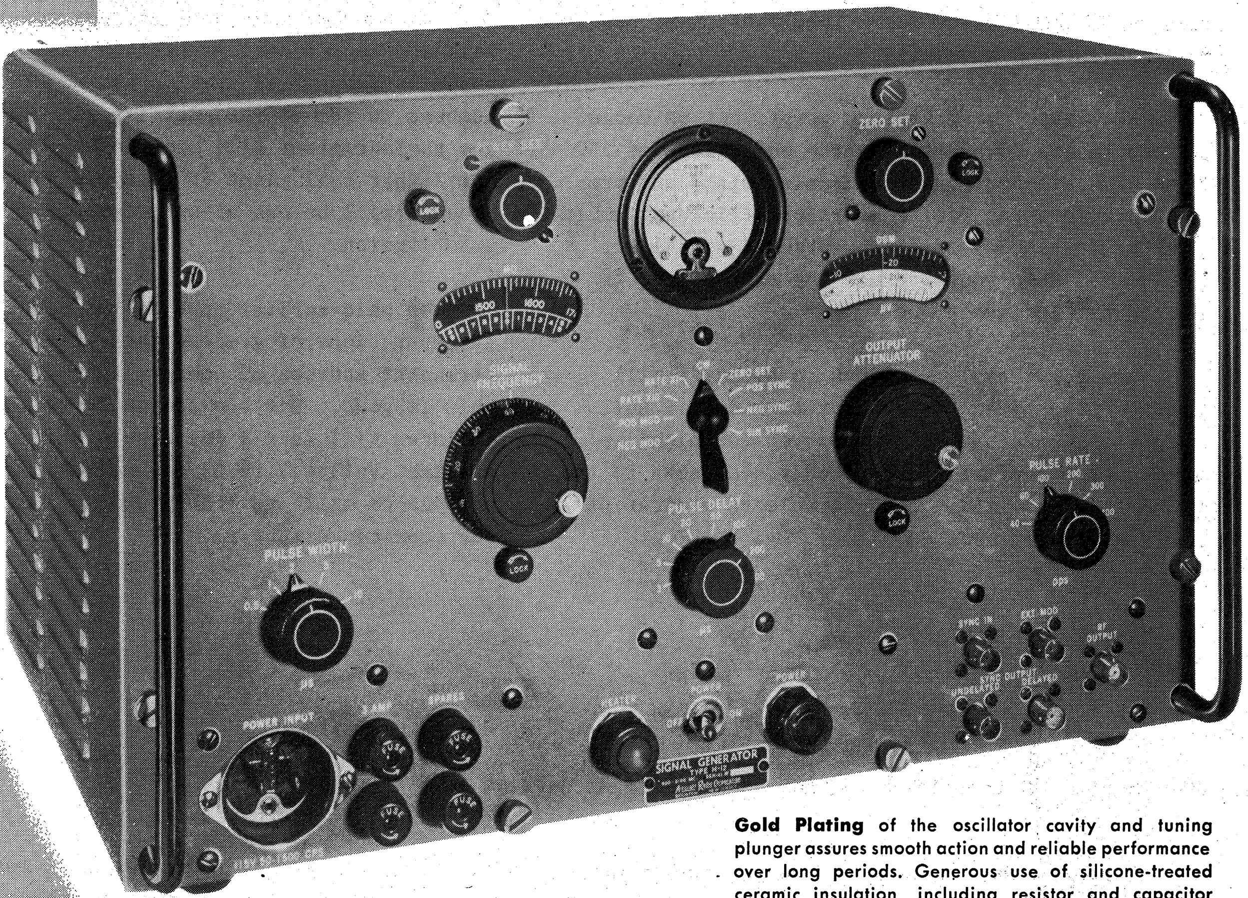

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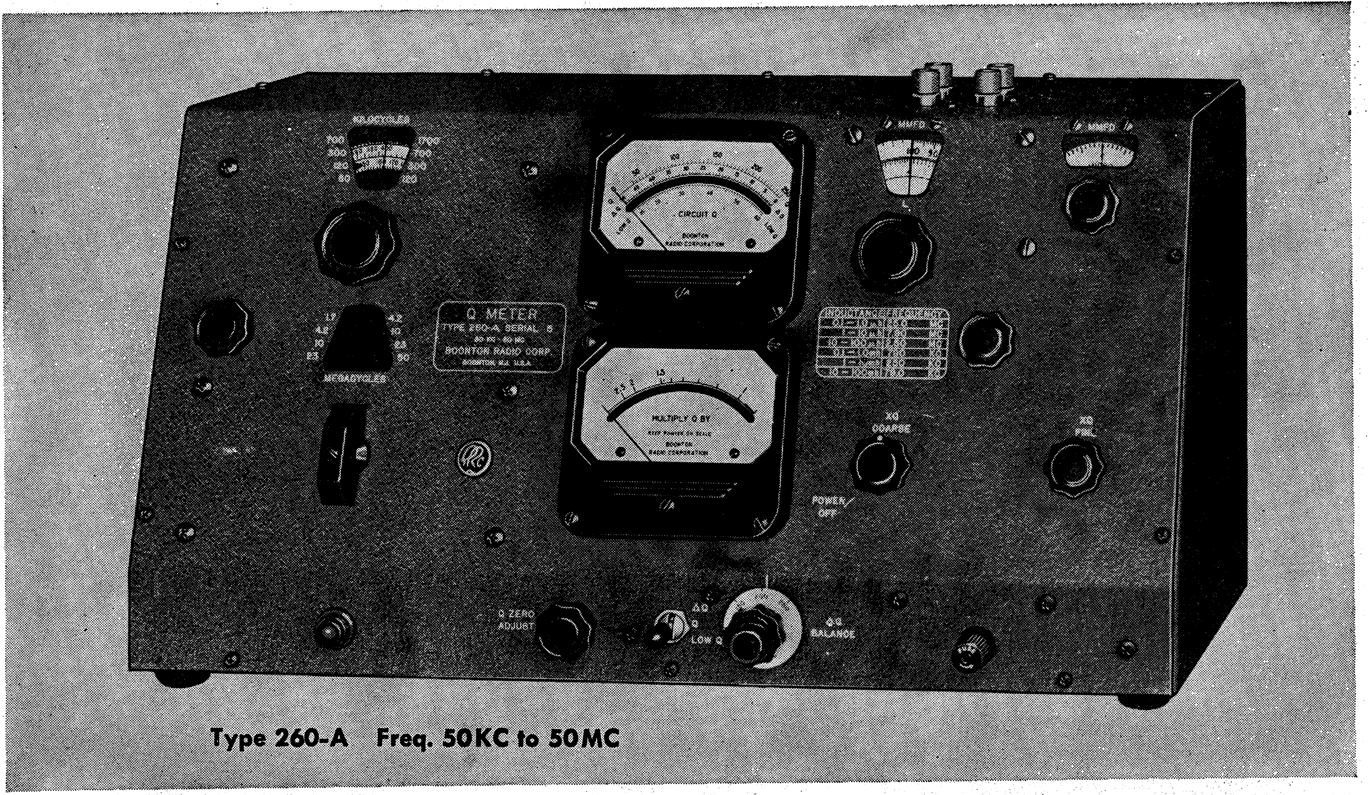

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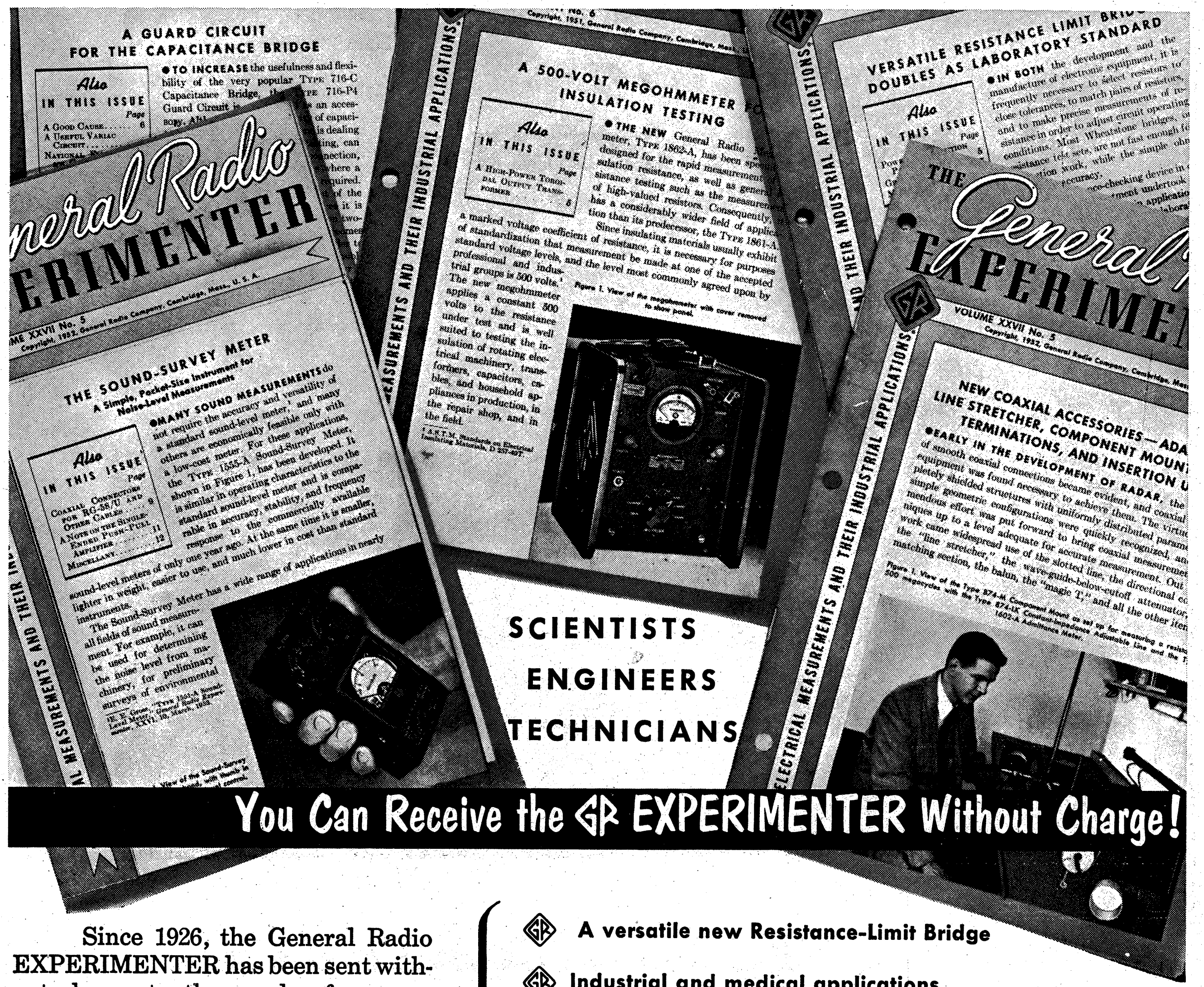

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