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The Future of Atomic Energy

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On a July day in 1945 the newspapers of Albuquerque, New Mexico, reported that local residents had seen an early morning flash of light and had felt earth tremors due to a mysterious explosion. It was suggested that an Army munitions dump near Alamogordo had blown up, but no further news appeared.

A few hundred observers scattered through the hillsides around a New Mexico valley, however, had witnessed the birth of a new era. Three weeks later when two Japanese cities felt in succession the devastating effects of similar blasts the whole world knew that a new era had come.

As these blasts brought to an abrupt end the most devastating war in history, men all over the world knew that another war must never occur if civilization were to survive. Fifty years of scientific exploration in the field of atomic physics had culminated in a stupendous achievement which placed the world at the crossroads in the field of international relations.

It is not my purpose here to speak of the military application of atomic energy—about the atomic bomb itself or the problems of international control which it has raised. I am going to discuss the possible peacetime uses of atomic energy. But I want to make it clear at the outset that all the peacetime uses we can now foresee—valuable as they may be—are as nothing compared to the terrible military significance. If it were necessary for the world to forego forever all peacetime uses of nuclear energy in order to insure that it would never again be used in war, the world would be getting a tremendous bargain. Fortunately, I do not believe that this will be necessary. International control of atomic weapons **can** be achieved without sacrificing all of its peacetime benefits.

It is worth while, therefore, to examine just what these peacetime benefits may be and in what ways they may benefit our lives.

Even this is a large order for a brief discussion, for the peacetime uses of this great discovery are many and varied—and are to a large extent still unpredictable.

For example, one of the great fields of usefulness of atomic energy might be called its indirect uses—the production of radiations and radioactive materials for scientific and medical purposes. No one can possibly predict what great new discoveries these new tools for research will make possible. Some great new additions to our knowledge are already in sight—others will appear in wholly unexpected areas as the years go by. The radioactive by-products of atomic piles are now available for research purposes to scientists in this country and abroad. A whole new realm of scientific exploration is opening up.

But I shall not discuss these indirect uses of atomic energy. Let us consider only the direct non-military use of atomic energy itself. Here is a great new source of power which man can now control for his own use. How big a source is it? How soon can it come into use? How cheap will it be? Where and how can it be effectively used? How soon, in short, will it put the coal and oil and gas companies out of business?

Our answers to these questions must of course be based on our **present** knowledge. There is no use speculating about what radically new discoveries in science may bring. Let us examine these questions on the basis of what is now known—assuming only the normal processes of engineering development and improvement in techniques.

First, let us review a few facts.*

As is well known, a certain type of uranium atom (U-235) can be split in two, and this process releases a relatively large amount of energy. This splitting can

*** All of the information used in this paper has been previously published. Some will be found in Millikan's book THE ELECTRON (1947 edition, Chap. XVI). The rest is in the Smyth Report or in the reports of the technical committee of the U. N. Atomic Energy Commission.**

be made to occur spontaneously, at a controlled rate, in a so-called chain-reacting pile, or reactor. The energy is then recoverable in the form of heat.

When one **pound** of U-235 is consumed in this way the heat produced is equal to that produced by the burning of about 1500 **tons** of coal. Since the entire annual coal consumption of the United States is about 600 million tons, we see that the same amount of heat could be produced by only 200 tons of U-235.

If this heat could be converted by a steam engine into electrical power at 10 per cent overall efficiency, one pound of U-235 would deliver 125 kilowatts for a year. A 100,000 kilowatt generator then would use less than one-half ton of U-235 fuel per year, though the same plant would use 800,000 tons of coal per year. All the electrical power used in the whole country could be produced by consuming about 100 tons of U-235 per year.

This will illustrate, I think, the enormous concentration of energy in atomic nuclei which can be released by the fission process in a chain reaction. A new source of energy of tremendous potentialities indeed!

I said a **new** source of energy. So it is! For as far as we know the energy released by the **fission** of heavy **nuclei** has never before been tapped on a significant scale. However, nuclear energy itself is not a new thing. Nuclear energy released by another process is not only the oldest but is the primary source of energy of the universe. When very light elements, such as hydrogen, unite to form heavier ones, such as helium, great quantities of energy also are released. This process is now known to be the source of energy in the sun and all the stars. Unfortunately—or fortunately maybe—there is in sight no method for causing this type of nuclear process to take place on earth. We are limited for the present to the fission process in heavy atoms.

Now a new source of energy on earth is a tremendously significant thing in itself. Nevertheless it is well to remind ourselves that man is not yet approaching the end of his previously known energy stores. It is estimated, for example, that the known coal deposits will last at the present rate of consumption for another 4000 years. Gas and oil stores may not last that long—but new fields are being found every year.

And then there is one source of energy we have not yet begun to tap except in a small way—namely, sunlight itself. We use waterfalls and windmills, of course, and we grow trees and other plants usable for fuel. Even coal and oil are really only trapped sunlight. But if we could really use all the sunlight falling on a single piece of land 30 miles square it would be equivalent to the entire coal consumption of the United States. Here truly is a staggering and inexhaustible source of energy which we will certainly some day learn to use more effectively than we now do. At the present time, however, we do not know how to use it economically.

But to return to nuclear energy, let us ask a few practical questions. How much uranium is there in sight? What are the problems of using nuclear energy economically? How soon will nuclear power plants become available?

As to the supply of uranium, the picture is not bright. Before the war uranium was mined for various industrial uses, but especially because of its radium content. The annual production of raw uranium was only about 1000 tons a year—with known reserves totaling only 30,000 tons. But natural uranium contains only .7 per cent of the precious U-235; hence, 1000 tons of natural uranium contains only 7 tons of U-235. Seven tons a year is equivalent in heat value to 21 million tons of coal—but that is only 1/30 of our annual coal consumption. Thus if all the U-235 being mined in the world were used in this country for industrial purposes it would add only 3 per cent to the effective annual coal supply. And that assumes no other country uses any. As a matter of fact, very little uranium is actually mined in the United States, it comes mostly from Canada and the Belgian Congo. (If these had not been friendly countries there would have been no atomic bomb!)

And we also assumed that all the 7 tons of U-235 could be used for power—and none diverted to military weapons. This is hardly a reasonable assumption in the world in which we **live.**

So until great new deposits of uranium are discovered, or until economical methods for treating very low grade ores are developed, we had better not abandon our coal mines or oil fields!

Actually the picture is not quite so dark. For we know that if U-235 is consumed in a pile containing raw uranium, some of the abundant isotope, U-238, is converted by neutron bombardment into plutonium—and this is an even better fissionable material than U-235. So while we are getting power from U-235 we are also making plutonium. We can then use the plutonium and get more power—and at the same time make more plutonium. In principle, then we could, step by step, convert all of our natural uranium into plutonium. This at once multiplies our stock of fissionable material by 140, for U-238 is 140 times as abundant as U-235. And if we could use our whole 1000 tons a year of uranium, instead of only 7 tons of U-235, we would have an energy equivalent of 3 billion tons of coal a year, which is 50 per cent more than the production of the entire world before the war. And though only 30 years' supply is now in sight, new sources will surely be found and low grade deposits will be worked.

But here again we must be careful! Using all our uranium rather than only U-235 is a **possibility**—but it has not yet been proved to be practical. Certainly many years of work will be needed before we can be accomplishing this conversion into plutonium on a large scale—and many years more will be required to build up the stocks of plutonium. I am inclined to believe that 30 to 50 years will elapse before uranium can possibly become a **major** source of power, comparable, say, with present production of electrical energy.* And even this assumes that military requirements for plutonium will not take the whole output for the next few years, as they are likely to do. Furthermore, by the time uranium is likely to be a large-scale source of power our power needs will have multiplied so greatly that we will still need full-scale production of coal, oil and other existing fuels.

Does this mean that nuclear fuel is of no importance to us at all? Certainly not!

There are scores of important applications where a few thousand or a few million kilowatts of power from uranium will be of enormous importance.

Think, for example, of ship propulsion.

Once a nuclear-powered engine has been installed on a great ship, only a few pounds of additional fuel will be required to keep it running for a year. This would seem to be one of the most promising applications —especially for naval vessels—and still more especially for submarines. Think of a fleet that could stay at sea almost indefinitely without refueling!

Let me emphasize that even this application is not yet here. A nuclear pile operating at a temperature high enough to operate steam or gas turbines has not yet been built or even designed. Probably, however, a few years would be sufficient to solve the engineering problems, so that if this project could command the manpower, the money and the uranium, one might expect a few ships, say 3 or 4, to be powered in this way in the next 10 years.

Another application has been suggested by my colleague, Dr. Pauling. A nuclear heat engine generating at 50,000 to 100,000 kilowatts, with suitable compressors and heat exchangers, could distill a million gallons a day of sea water for Southern California. For industrial and agricultural purposes this would be much better water than we now get from the Colorado River.

Think also of other places in the mountains or desert —near sources of raw materials—where industrial processing plants might well be located, except for the prohibitive coasts of bringing in coal. Think also of countries such as England where the equivalent of only a few million tons of coal would be a critical addition to a desperately short supply. And you will think of many other places where nuclear power could be a great boon—primarily because of the very small weight of fuel required.

What about costs?

Here there are two unfortunate factors. First, at present, nuclear power plants are rather expensive investments. According to a report of the U. N. Atomic Energy Commission, a plant to produce 100,000 kilowatts of power might easily cost 25 million dollars. Thus interest and depreciation costs are going to be very high.

Second, however, uranium 235 or plutonium are exceedingly expensive fuels. Raw uranium, before the war, cost only about $2.00 a pound. But one must separate out, in part at least, the U-235, and this is extremely expensive. Think of the enormous plants at Oak Ridge devoted to this purpose!

Including both plant investment and fuel costs (and neglecting vast development costs) uranium power will certainly cost much more than power from coal. Hence, the first applications must be those where low weight of fuel is more important than high costs. Engineering development can certainly bring these costs down. But it is hard to see how uranium power can ever be very cheap.

Finally, one must not minimize the magnitude of the engineering problems which remain to be solved before even **one** power-producing pile is in operation. It is true that several reactors were built during the war for experimental purposes and for the production of plutonium. It is also true that some of these reactors produce a very large amount of heat. But they were purposely designed to operate at very low temperatures and hence this heat—while it might supply running hot water to a sizable city—cannot be efficiently converted into electric power. The main engineering problem ahead is the design of a reactor to operate at a high temperature so that one can obtain a reasonable thermodynamic efficiency. This will some day be done, but the design and engineering problems are staggering. For example, many materials that we would like to use to construct the reactor would absorb so many neutrons that they would stop the chain reaction. Structural problems, thermal problems, fantastically difficult chemical problems, problems of shielding and safety appear in a staggering array. It will be many, many years before they can be solved.

Does this all present a pretty confusing picture? Unfortunately, that is the way things are—and even the picture I have presented is over-simplified. But one thing seems clear. An over-enthusiastic press—and some over-enthusiastic scientists—have created the impression that the **large scale** use of **cheap** nuclear fuel is just around the corner. The sober fact is that uranium 235, while it may be a concentrated, is not either an **abundant** nor a **cheap** source of power. If we use only U-235 there is not enough of it in the world to be very interesting. We must therefore convert U-238 to plutonium, but this is a very slow and costly process. And in any case, engineering development takes time.

The public expects great things of atomic energy and all its peacetime possibilities. And it should! But we must expect these developments to come slowly. Each step will come as a result of strenuous efforts in research, development and engineering. It took 200 years to bring the steam engine to its present stage of development! Things move faster now and only a few decades may be required for a comparable development in nuclear power.

* **J. R. Oppenheimer, in a report to the United Nations Atomic Energy Commission, is a bit more vague. He said "decades will elapse . . . ."**

This paper was given at the 54th Annual Convention of the Pacific Coast Gas Association at San Diego on September 24.