Atomic Energy

Eugene P. Wigner
Palmer Physical Laboratory, Princeton University

THE YEARS THAT HAVE PASSED since the discovery of the nuclear chain reaction have not damped our high expectations in the future usefulness of atomic energy for peaceful pursuits. They have, furthermore, helped us to recognize, in addition to the size of this giant, his special skills. However, they have also helped us to realize, perhaps more clearly than we first did, that much hard and persevering work will be necessary before any of the benefits of atomic energy will be really ours.

During the period of abundance of the sources of energy which are now in use there will be two ways in which atomic energy can prove its significance. It may compete with our current sources of fossil energy and, second, it may open up new fields. As to the former, our industrial and even our everyday life has adapted itself to the possibilities of chemical fuels to a degree of which we are rarely conscious. The transition to a new source of energy would involve a re-orientation of many methods of manufacturing and also cause a shift in the character of many of the commodities and services which industry can make available. It will not be easy, therefore, for atomic energy to woo away very much territory from the chemical fuels in the near future. Even if it did, its success along this line would be quite comparable with the success of the turbine—which is great, but not decisive for the over-all economic or social life.

"Atomic Energy" was one of the addresses delivered at the Symposium on Sources of Energy, held in Washington, D. C., on September 15, during the Centennial Celebration of the AAAS.

TABLE 1

Source	Coal	Oil	Atomic energy	Solar energy
Energy available in U.S.A. 10^{15} kcal	18,000	25 high-grade 300 low-grade	100 high-grade ores 3×10^{10} very low-grade ores and rocks	20,000 per year
Consumption per year	3.6	2.5 high-grade 0.5 low-grade	?	
Investment per/kw power plant	$110		$250	
Investment for producing 1 kjoule fuel/sec		$110 from high-grade $150 from low-grade sources		

Real success will therefore come to atomic energy in the near future only on the second path—by the discovery of new needs which atomic energy is able to satisfy better than existing sources can, by opening up new possibilities which it would be difficult or even impossible to realize with the sources of energy which are now in use. This task atomic energy has not yet achieved or even tackled. In fact, research on nuclear energy has to be so sheltered and separated from other industrial and economic problems that it will require extraordinarily keen vision to discover those needs which it is particularly suited to satisfy.

Some time hence, when the currently used sources of energy will near exhaustion, the situation will be different. Then nuclear energy may become the savior of our abundant life. But even then, nuclear energy will not be the only one in the field; it will have to compete at least with solar energy, of which there is an immense abundance.

Table 1,[1] which I am sure you have seen before in this or another form but the contents of which are well

[1] The following publications were used to obtain the figures of Table 1: (a) "Geochemische Verteilungsgesetze der Elemente," by V. M. Goldschmidt. Norske Videnskaps Akademi i Oslo, Mat. Naturv. Klasse, 1937; (b) "Power and Fuel Data," by Gale Young, December 1945 (unpublished); (c) "Nuclear Power," Scientific Information Transmitted to the United Nations Atomic Energy Commission by the United States Representative, Vol. IV, September 1946 (by C. A. Thomas, *et al.*). Also "Non-Military Uses of Atomic Energy," by C. A. Thomas. *Chem. eng. News*, 1946, **24**, 2480, and "Atomic Energy: Its Future in Power Production," by J. B. Condliffe, *et al.* *Chem. Eng.*, 1946, **53**, 125; (d) "The New Power," by Gale Young. Chap. 4 in *One world or none.* New York: McGraw-Hill, 1946; (e) "Natural Gas, Coal, Oil Shale as Sources of Liquid Fuels," by E. V. Murphree. *Oil and Gas J.*, April 1948.

kept in mind, illustrates this situation. It gives, for the different energy resources—coal, oil, atomic energy, and sunshine—the magnitude of the reserves and the yearly consumption. With respect to coal we have enough for 5,000 years at the present consumption. The situation with respect to oil is more precarious. As to atomic energy, you see that there is not too much of it in the form of high-grade ores. The supply in low-grade ores is practically inexhaustible. The magnitude of the solar energy is obviously great.

There are three points in Table 1 which I want to emphasize particularly. First, the total amount of coal under the ground in the United States has somewhat less heat content than the United States receives as sunshine during a single year. The over-all situation for the whole earth is even worse. Paradoxical as it may sound, the sunshine which falls on an acre of land during a single year would have, in the form of coal, a value of about $5,000. Second, if we look a little further ahead than a few hundred years, the chemical sources of energy are surely insufficient, and some of the new sources of energy will have to be utilized. Only two such sources are now known: nuclear energy from low-grade ores and solar energy. The question to which of these belongs the future will probably be decided by the relative convenience with which these two sources of power can be utilized and by the magnitude of the effort needed to exploit low-grade ores, on the one hand, and to concentrate solar energy, on the other. The last point which I wish to make is that oil or gasoline consumption is, in spite of the higher price of this fuel, almost as great as that of coal. This shows that the price of fuel is not always the decisive consideration; its adaptability and concentration are often more important.

The figures of our table clearly show that coal and oil cannot remain very long the predominant fuels. Nuclear energy may eventually replace them, but the above figures do not do more than to leave this possibility open. As for the present, a number of independent studies show, first, that nuclear energy is on the verge of competing with coal and, second, that a cheapening of power may have a stimulating influence on our economy, which could go far beyond the direct benefits calculable on a dollar-and-cent basis. The stimulating influence on more backward countries may be even greater.[2]

[2] Cf. in particular the Special Papers of the Cowles Commission, "Nuclear Fission as a Source of Power," by John R. Menke, and "Economic Aspects of Atomic Power," by Jacob Marschak, Sam H. Schurr, and Philip Sporn. Chicago: Univ. Chicago Press, 1947. Also, "Some Economic Implications of Atomic Energy," by Walter Isard. *Quart. J. Econ.*, 1948, **72**, 202. I am also personally indebted to Prof. Marschak, Dr. Schurr, and their collaborators for communicating to me a vast amount of unpublished material.

My personal impression would be that the emphasis on the stimulation of economic life is perhaps somewhat exaggerated. A similar and even more intense stimulation could be expected from the easier availability of many other types of goods—for instance, ingredients of housing. On the other hand, it seems to me that most price estimates disregard the ability of a stationary power plant, which uses the raw materials uranium and thorium not only to furnish heat and electricity but also to manufacture a pure fissionable material which is bound to occupy the role of a high-grade fuel (such as gasoline). The investment cost for nuclear energy, given in the last row, which militates so strongly against the economic attractiveness of nuclear energy, should be compared, therefore, not with the investment cost of a stationary power plant but with the joint investment costs of a power plant plus an oil refinery. This would improve considerably the economic attractiveness of atomic energy, while the first point I made would tend to decrease the importance of energy sources in general for our present economy. Perhaps even more important than these factors, which can be reduced to a dollar-and-cent basis, will be the relative convenience and safety with which the different types of plants can be operated. The full impact of the enormously dangerous radioactivity accompanying all nuclear energy operations is being felt increasingly, and the need of training a large number of people in new techniques involves an additional investment, the magnitude of which is difficult to estimate.

Let me now go over somewhat to the technical side, and, although this has been done on many occasions before, describe once more the broad features of the arrangements in which uranium can be used for the generation of energy.

Just as a single log cannot burn in our fireplace, in a similar way there is a minimum amount of uranium which is necessary to produce power. This minimum amount is called the critical amount. Once this critical amount is assembled in the so-called reactor space, it undergoes fission, and the energy of the fission fragments is converted into heat. This heat can be transferred by means of a heat transfer medium, which circulates through the reactor space, to a conventional heat engine.

Nothing could be simpler in principle than this, and there are only two problems which are not encountered in conventional engineering. These are the limitations of the heat transfer medium to substances which do not stop the chain reaction and the need to surround most of the equipment with a tight and thick shield. This shield has to protect the environment from the deadly radiation of the reactor and of the heat transfer medium which becomes radioactive within it.

The energy which can be liberated from uranium is about 3,000,000 times greater than that contained in the same mass of coal. The ratio is 10,000,000 if we add to the weight of coal the weight of oxygen which it needs for burning. This establishes the most important characteristic of uranium as a fuel: it is practically weightless. This is, of course, not true of the whole power-generating equipment. In particular, the weight of the shield in many, if not most, cases overbalances the saving in fuel weight. This is particularly true in small engines and when refueling is easy. A serious disadvantage of the nuclear fuel is, furthermore, that any accident which breaks the shield is likely to liberate a vast amount of radioactivity and thus develop into a calamity much beyond the calamity which may result from an accident in the operation of the conventional sources of power.

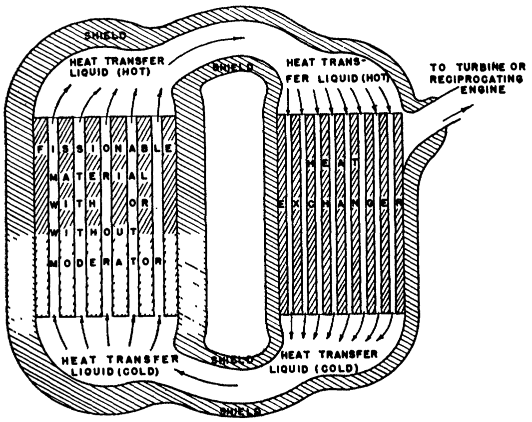

FIG. 1

Primarily, nuclear energy appears as the kinetic energy of fission fragments. The velocity of these corresponds to a temperature of about 600,000,000,000° C, and one feels that it is a pity to degrade this high temperature to a pittance of a couple of thousand degrees. For this reason, a good deal of thought has been spent on methods for a direct utilization of the energy of fission. Electric, electromagnetic, thermoelectric, and chemical methods have been discussed in some detail.[3] To date, none of these methods has proved attractive, and it is at least temporarily conceded that the fission energy will have to be converted into heat at a tractable temperature before it is further utilized. For land-based power plants, in which the rejected heat can be easily discarded at a few hundred degrees, this is not a major disadvantage, since the efficiency in this case is already close to its optimal value if the prime heat is delivered above 1,000°. However, the need for converting the energy of the fission fragments into heat becomes more of a drawback if one tries to exploit the most outstanding feature of nuclear energy—its enormous concentration.

Figs. 1 and 2 show the by now conventional arrangements to generate power and thus illustrate what I have previously called the competitive uses of nuclear energy. In the arrangement of Fig. 1 the heat transfer medium first traverses the fissionable material through a number of channels, gathering up the heat generated, and then flows to a heat exchanger. In this heat exchanger the heat of the primary coolant is transferred to another medium which, in its turn drives a turbine or a reciprocating engine. In the arrangement of Fig. 2 the primary coolant drives the turbine directly. This arrangement has fewer parts, but a larger shield than the former, and a turbine which is, because of the radioactivity of the primary coolant, inaccessible. It is not yet possible to say with certainty which of the two arrangements is more advantageous and under what conditions.

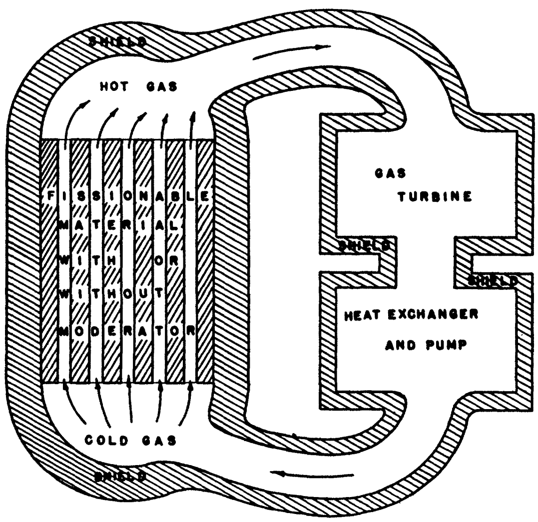

FIG. 2

The time scale for the development of nuclear energy on a substantial scale naturally comes up at this point, but it is a question most difficult to answer. Our uncertainty concerning this point not only has its origin in our inability to answer several technical and scientific questions, but is caused, to an equal degree, by the circumstance that the answer is bound to depend on the strength of our desire to see nuclear energy prove itself soon, on our courage, and on our confidence in our technical judgment and foresight.

[3] Much of the material referred to remains unpublished. Cf., however, Marschak, Schurr, and Sporn, footnote 2.

In other words, the human element strongly enters the picture.

Disregarding this human element, M. H. L. Pryce gave a tentative answer in a most thoughtful article in a recent issue of the *Bulletin of Atomic Scientists* (1948, **4**, 245). He estimates that nuclear energy may begin to replace coal in about 30 years. The number 30 is uncertain, but it is not likely to be less than 5 or more than a few hundred.

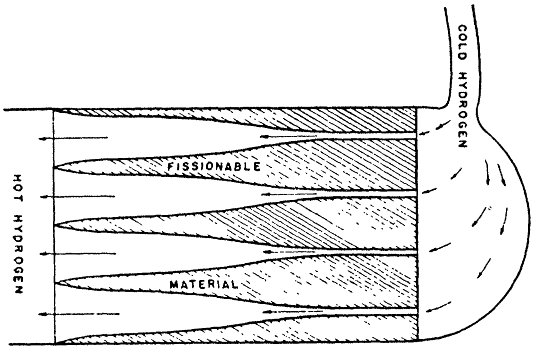

FIG. 3

Let me now go over to the more speculative uses of nuclear energy. The high concentration of nuclear energy would seem to make it the ideal fuel for providing power for transportation. As long as one considers the most conventional types of transportation—land and sea routes—the rejection of part of the energy still remains a subordinate difficulty, and it is, in fact, in powering ships, in which the problem of radioactivity can be mastered more easily, that the first application of nuclear energy may come. In long-range aircraft, flying at high altitudes, the rejection of the waste heat is already much more difficult, unless one is willing to take higher temperatures of rejection into the bargain and thus reduce thermodynamic efficiency. If one considers, finally, travel outside the gravitational sphere of the earth, the problem of the rejection of waste heat becomes dominant.

In order to escape the gravitational field of the earth, one needs about 15,000 kcal/kg of escaping material. Since the energy content of a fissionable material is more than 1,000,000 times greater than this, the energy requirement is not, in itself, prohibitive even if one assumes a relatively low efficiency, η, for the process which furnishes the needed energy. However, for an efficiency, η, the waste heat amounts to 15,000 $(1-\eta)/\eta$ kcal/kg, and unless one can dispose of this, it will surely vaporize the body of the ship. As we discussed it before, the problem of elimination of the waste heat can easily be solved on the sea; it can also be solved in the air, but if the ship is to have power also outside the atmosphere, it can keep cool only either by throwing off hot parts or by radiation. The first alternative is the one which is discussed most commonly,[4] but it has its definite limitations. Current opinion is that it may be barely sufficient to achieve the purpose: to raise a rocket off our planet. What runs out first is, characteristically, not the energy of the uranium but the hydrogen.

The second alternative, discarding the waste heat by radiation, also has clear limitations. The efficiency decreases very strongly if the time of ascent is much more than 1,000 sec. Taking this into account, one finds that, for a radiating temperature of 200° C, a radiating area of about $20(1-\eta)/\eta$ m²/kg of the vessel is needed—a practical impossibility. For a radiating temperature of 1,000° C the radiating area becomes more manageable: about $0.4(1-\eta)/\eta$ m². At this temperature of the radiator, however, the thermodynamic efficiency is necessarily rather low in any conventional heat engine. This example shows again how problems of an apparently secondary nature can push themselves in a most disappointing fashion into the center of the picture.

Breaking the gravitational prison of the earth is so challenging a problem that I wanted to say a few words about it, even though it would be clearly premature to discuss it in detail. Furthermore, it is not the direction in which nuclear energy has so far proved itself most decisively. That field is indeed an application of nuclear energy in which a new need has been discovered. It is the procurement of research facilities for biology, chemistry, and physics by radioactive tracers, by new and more intense types of radiation. Even though this subject is the last one on my list, it is at present the most important one, and it is quite possible that it will maintain this position for a long time. The subject, which has received adequate treatment on several occasions,[5] lies outside the scope of our symposium. If we could divest ourselves from our admiration of the spectacular, we might easily find that the nuclear research facilities are for the present more important than nuclear energy. The success of the research which they support is a more real and more truly human need than is the need for additional energy and power.

However, there is good reason to look forward with confidence also to the more direct applications of nuclear energy. In order to be fully successful, these

[4] Cf. e.g. "Atomic Power for Airplanes and Rockets" article in the March 1947 issue of Atomic Information based on L. Alvarez's address.

[5] See, for example, (a) *Radioactive tracers in biology*, by M. D. Kamen. New York: Academic Press, 1947; (b) *The use of isotopes in medicine and biology* (Symposium Report). Madison: Univ. Wisconsin Press, 1948; (c) various articles in *Nucleonics*, 1948.

applications will require more of the undeviating interest which is so necessary for technical success but not enough of which they have received so far. They will surely receive this interest in the future, and we may hope that they will receive it from us—not only from our neighbors and children. And we may even dare to hope that the success may be so overwhelming that the first application of nuclear energy will appear just as insignificant, in comparison, as the first and still most efficient heat engine, the cannon, is in comparison with our generators of electricity and industrial power.

What Is a Map?

Eugene Van Cleef
The Ohio State University

SOME YEARS AGO ISAIAH BOWMAN, in a consideration of "Commercial Geography as a Science" involving "Reflections on Some Recent Books," propounded a conundrum as follows: "Q.—When is a map not a map? A.—When it has neither scale nor coordinates" (*Geogr. Rev.*, 1925, **15**, 285–294).

In the light of a regenerated interest in maps among both geographers and the general public, Dr. Bowman's comment has added significance today. Here and there American geographers, consciously or unconsciously, have exhibited a fault common in British circles—failure to provide either scale or coordinates, or both, for drawings which they designate as maps. There may be justification for a portrayal of a portion of the earth's surface without scale or coordinates on the grounds that the objective is not the orientation of any part of it with respect to the earth, but rather a presentation of a chart which will reveal certain general relationships within the limits of the area shown. For example, one might draw a sketch to show a road pattern or a succession of stream meanders, not with the idea of enabling the reader to measure distances or to determine the location of the respective elements upon the earth's surface, but rather for purposes of exhibiting certain characteristics of the phenomenon itself, irrespective of its relation to the earth. Such diagrams may serve their purposes admirably, but, lacking scale or coordinates, they hardly reflect the fundamental basis of a map; hence, they are not entitled to the designation *map*. If an individual wishes to apply the term *map* to these various drawings because that word is more convenient or more appealing than another but recognizes the incorrectness of so doing, he can protect himself by indicating his deliberate substitution to be a matter of convenience. This type of action can be illustrated in the case of the reciprocal use by some persons of the names Russia and USSR. They announce the fact that they mean the USSR whenever they say "Russia."

It may be trite to record the fact that man from very early times has been interested in making a graphic recording of the surface features of the earth. He recognized time and distance, and long struggled with the problem of measuring them. He was intrigued, first, by their relation to the nature of the earth as a body of some kind upon which man struggled for an existence and to the earth as a planetary body. Not long after he ventured out of sight of land or traversed considerable distances overland, he was moved to find safer ways of travel than dead reckoning or the marking of fixed reference points as momentary guide posts. As is now familiar to all of us, he ultimately solved many of these perplexing problems as he accumulated factual data relative to the nature of the earth itself, the characteristics of the solar system, and the universe in general.

Some geographers argue that many early representations of the earth showed neither scale nor coordinates yet have been designated as maps. The use of the term *map* in these instances, however, has probably been "complimentary," in the sense that the ignorance of the times was no fault of the peoples and that, had there been an adequate knowledge of the sphericity of the earth and of the measurement of distance, the fundamentals of scale and coordinates would have been brought into play. The ancients did ultimately lay the foundation for the assignment of 360° to a circle and the use of heavenly bodies to fix places upon the earth. Eratosthenes (about 275–196 B. C.) succeeded in securing some such data as we now demand as essential characteristics of maps, and used them. Ptolemy (90–168 A. D.) did likewise, but there were others who did not, either because they were unfamiliar with the work of their predecessors or had no confidence in their mathematical philosophies. The significance of the map for measurement