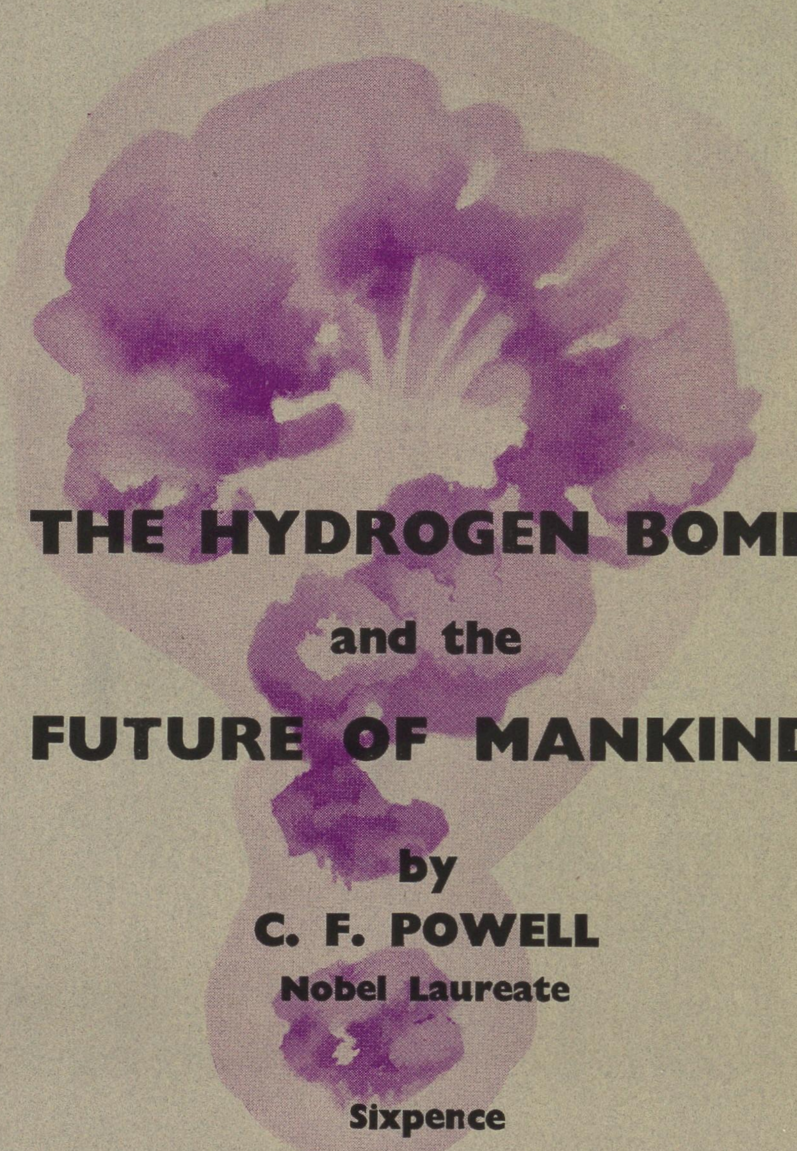

THE HYDROGEN BOMB

and the

FUTURE OF MANKIND

by

C. F. POWELL

Nobel Laureate

Sixpence

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Mrs. D. Smithers, Chairman of the L.C.S. Education Committee, presided and other speakers were the Rev. Dr. D. Soper, M.A., Ph.D., the well-known leader of the Methodist Church, and Mr. D. G. Arnott, B.Sc., a hospital physicist working with radio-active isotopes.

There were 850 people present, most of whom were delegates from Co-operative organisations, Trade Union and Labour Party branches.

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WE are passing through times of great moment in the history of mankind. On the one hand, in the event of a war between the great powers involving modern methods of mass destruction, there is the possibility of a catastrophe for the human race; on the other, the prospect of a great increase in human welfare following the widespread application, in a peaceful world, of the tremendous new forces which have been liberated by science. It is the dilemma of our times that with these two alternatives before them—of measureless disaster or of great abundance—the nations seem unable to grasp that which we all desire. As if in a nightmare, we seem to see them slipping slowly towards catastrophe.

It is the purpose of this meeting to contribute to the general understanding of these great issues of our time. My main theme will be that the only escape from our present difficulties is through an international agreement on atomic energy; that such an agreement can be realised, is urgently necessary, and that we should do all we can to promote it.

I want also to tell you something of the nature of atomic and hydrogen bombs and of their effects in war; and of the advances which could be expected to follow from the applications of atomic energy for peaceful purposes:—

If I appear to speak coolly and dispassionately about things upon which depend the lives of many hundreds of millions of human beings, you will, I hope, understand that it is because I shall serve you best only if I speak without heat and avoid any partisan approach. I shall try to give you, without prejudice, a clear statement of the facts as far as I know them, and of reasonable conjectures where there is no authoritative published information. We are in a situation of great difficulty and danger in which it is very important to create a serious and informed body of public opinion, all over the world, in favour of an early negotiated settlement between the powers. Such a body of public opinion must, if it is to be effective, embrace people with conflicting opinions on almost all other issues, but who can be united on this.

In one or two places, I shall say a brief word or two on technical matters because it is important for the argument. Perhaps I need not apologise for doing so because, for good or for ill, atomic energy is going to transform human life, and it is therefore not out of place for us all to make a small effort to understand it.

THE SCIENTIFIC AGE

But before coming to my main theme, let me first try and show the significance of our times against the broad perspective of world history, for this will help towards an understanding of the present situation and difficulties.

Our present dangers and opportunities appear as the result of a great scientific discovery—the release of energy from atomic sources—which has followed from 50 years of research and investigation. But this great advance in the powers at our disposal is not accidental. It is a necessary consequence of an approach, relatively new in human history, to the problem of how to win knowledge and control from nature by consciously setting out to find it. The development of this new method—the scientific method—is the great distinguishing feature of our times.

There have been great discoveries and technical innovations in the past which led to radical changes in human society; but until civilisations were established about 5,000 years ago such discoveries were few and far between. Such an innovation was the discovery of the ability to generate and use fire. We do not know when this was first done, but some authorities put it at more than 100,000 years ago. The discovery of fire must have been of enormous importance for the early communities. It made possible the cooking of materials which without it could not be eaten, and thus increased the food supply of the early settlements of people. It made possible, in the course of time, the smelting of metals, and thereby called into existence new tools and the great range of consequences which followed from their use.

In a limited sense, the whole history of humanity might be regarded as a consequence of the discovery of fire, and its supreme significance was very early recognised and celebrated in the legends of many primitive peoples. *The great discoveries with which we are concerned to-day, and their consequences which we can at the moment only most dimly discern, follow from the discoveries of the past; but in their implications for human life, they far surpass anything which has gone before.*

The slow rate of technical advance, in the period before civilisation, is illustrated by the fact that tens of thousands of years elapsed between the discovery of fire, on the one hand, and the smelting of iron, which it made possible, on the other; the first iron, and the improved tools made of it, came into use only about 4,000 years ago. But as men began to live more and more in larger and relatively stable communities, there was a great increase in the diversity of the arts and crafts; and accumulated skills and experience were transmitted from one generation to the next. In spite of these features of civilisation, the tempo of advance was still very leisurely compared with our modern societies. Innovation came, for the most part, from casual observations and accidents, and not from any deep enquiry into the nature of things. But a great change was at hand.

In this country, about three hundred years ago, Francis Bacon propounded a new philosophy to the effect that in order to solve the pressing practical problems of the time it was not sufficient to read what had been written by ancient writers like Aristotle. It was necessary, for the advancement of mankind, not to rely on authority but to study things, to try for oneself—and thus to find out new things, and new ways of doing things, by experiment. In the 50 years which followed, there was great support for Bacon's views, both here and in other countries of Europe and learned societies were established to give practical effect to the new spirit of enquiry. Important successes, such as Newton's discovery of the universal law of gravitation, were achieved, but the principal advantages of the new experimental critical method were made apparent only with the " Industrial Revolution " which, at the end of the eighteenth and the beginning of the nineteenth century, turned England from a predominantly agricultural country into a great industrial workshop.

Since the middle of the last century, we have witnessed in ever-increasing degree, the application of scientific method to an ever-wider range of human affairs. It is, however, a development which is still very far from being complete. And this method of winning new knowledge is so much more effective than anything which has gone before that technical innovations follow one another more and more rapidly, and in an unending stream. During the lifetime of many of us here there have been discovered, to name only a few things, the electron and X-rays, wireless telegraphy and television, the internal-combustion engine and the gas-turbine, the motor car and the aeroplane, radioactivity, atomic power and the hydrogen bomb. Any one of them, in early times, would have made notable a particular century.

The essential point for us here is that we have entered an entirely new epoch of human history which is characterised by ceaseless technical innovation, with all the perplexities and opportunities which are thus created. We have to see to it that the development of the hydrogen bomb does not mark the end of an epoch but a beginning. And any attempt to anticipate, in very general terms, the future course of events must allow for the possibility of new discoveries and innovations. Only about six years elapsed between the discovery of nuclear fission in 1939 and explosion of the first atomic bomb in 1945, and this was followed, less than ten years later by the hydrogen bomb, which is about a thousand times more powerful.

THE ATOMIC BOMB

A few simple analogies may help to make clear the great change which has been brought about by the development of the hydrogen bomb as distinct from ordinary atomic bombs.

To-day, most of the heat and energy employed in industry, or in our homes, is got by burning things. We raise steam for the turbines in our electrical generating stations by burning coal; in our homes we light the gas. In either case, the heat results from a *re-arrangement* of the different kinds of atoms of which everything in the world is composed —not by changing them. When coal burns in a fire, for example, the atoms of carbon in the coal unite with the atoms of oxygen in the air to form a gas called carbon dioxide, and heat is given out in the process. And this combination, as we call it, of the carbon and oxygen atoms, can only take place at a certain temperature such as we can produce with a fire-lighter. It is quite safe to leave the coal in a cool cellar without fear of it catching alight.

Now practically all the chemical processes in industry involve such re-arrangements of atoms similar to the example of the burning coal. Sometimes we get energy by building up atoms together, sometimes by splitting up substances into their component atoms. And, speaking very generally, such processes always give us about the same amount of energy from a given amount of fuel, whatever the form in which the energy appears. Suppose, for example, we light the gas and boil a kettle; we then get a definite amount of energy from the steady burning of a certain quantity of gas. If, however, we turn on the gas and wait a few seconds before applying the match, the gas " pops." In this case the combustion has taken place explosively, but the amount of energy produced from the combustion is just about the same as if the gas had been burnt quietly. And this holds good for other fuels and explosives. You get about the same amount of energy by burning a ton of coal in a furnace, as from exploding the same weight of T.N.T.

POWER FROM THE ATOM

The great change which came about when we began to be able to get power from the atom was that, in effect, we discovered a new fuel—or a new explosive—which gave us about a million times as much energy—weight for weight—as the ordinary fuels like coal. This was brought about because we were able to change atoms—and, in particular, the innermost structure of atoms called the atomic nuclei. Whereas ordinary chemical processes, like burning, leave atoms unchanged, and only cause their re-arrangement in different combinations, the new processes led to a radical transformation of the individual atoms—to their disintegration; and the yields of energy were very much bigger than anything of which we had previously any experience; weight for weight, a million times more. Let us glance for a moment at the implication of this figure:

Let us suppose that in a raid on Germany during the course of the last war, the weight of high-explosive bombs dropped by 2,000 bombers was about 20,000 tons. The weight of the charge of an atomic bomb of equal explosive power would be about 40 lbs.—an amount of uranium about the size of a grape-fruit, which I should have some little difficulty in supporting. The first two atomic bombs which were dropped in Hiroshima and Nagasaki in 1945 are said to have had an explosive power of just about this amount—20,000 tons. According to Japanese authorities, they resulted in the death or injury of about a third of a million people.

Now the ordinary atomic bomb, although of such tremendous destructive power, did not go right outside conventional military thinking. Its effect was similar, in some respects to that of a very large raid with ordinary bombs; and it was difficult, for the following reason, to increase greatly the size of such bombs. An ordinary explosive, for industrial or military purposes, must not be too unstable. It must be possible to transport it, even under difficult circumstances, without fear of it exploding prematurely. At the desired instant, the main charge is set off by means of a detonator, a small quantity of a suitable substance of which the explosion sets off the main charge. And there is no limit in principle to the size of the main charge which can thus be ignited.

The ordinary atomic bomb works quite differently. The charge consists of blocks of uranium or plutonium metal of special types which have the peculiarity that they explode spontaneously if they are made to exceed a certain size—a so-called " critical size." The explosion is therefore brought about by driving suddenly together two or more pieces each of which, separately, is less than the critical size, but which together exceed it. The size of an ordinary atomic explosion cannot therefore be less than that corresponding to a block of the critical size; and it cannot be very much greater, because, for technical reasons, it is difficult to make large the number of component pieces to be driven together. So the explosion, whilst very great compared with an ordinary high explosive bomb, is limited.

THE HYDROGEN BOMB

The limitation to the size of the explosion which can be brought about with the ordinary atomic bombs has now been removed by the development of a completely new device called the thermo-nuclear or hydrogen bomb. This works in the following way.

We have seen that an ordinary explosive depends upon a detonator which, at the desired moment, produces a small violent disturbance of the main charge, sufficient to set it off. Now it has been known for about 20 years that some compounds of the lightest atoms which occur in nature, notably hydrogen and lithium, could be made to explode if they could be raised to a sufficiently high temperature. It was recognised that there would be a great release of energy through the coming together—the fusion—of their atomic nuclei. Such processes are known to occur in the central regions of hot stars, such as our sun, where the temperatures are about 20 million degrees centigrade; they are known as thermo-nuclear reactions; " nuclear " because, unlike ordinary chemical changes, they involve the atomic nuclei, and " thermo " because they proceed only as a result of great temperatures. It is these thermo-nuclear processes, and the release of energy which they produce within the sun, which maintains the heat and light continuously emitted by the sun, and which therefore makes possible all life on earth.

When the possibility of a " thermo-nuclear " explosion, using light atoms, was first realised, it seemed unlikely that it would be produced in practice, because there appeared to be no way of generating the necessary high temperatures. The highest temperatures produced on earth by conventional methods are about 30,000 degrees centigrade, and to produce a thermo-nuclear reaction required a temperature at least a thousand times greater.

With the development of the atomic bomb, however, it was recognised that for a very short interval of time temperatures occur at the centre of the bomb which are much greater than those at the centre of the sun. The possibility therefore became apparent that if an atomic bomb were surrounded with a mass of substance composed of suitable atoms of hydrogen, or of hydrogen and lithium, a thermo-nuclear reaction might occur. An ordinary explosive is set off with a detonator; the ordinary atomic bomb was to be the detonator of the hydrogen bomb.

As we all know, these anticipations have now been realised. There is no authoritative statement on the history of the developments which led to the production of the hydrogen bomb, or of what it is constituted. According to plausible accounts by responsible American journalists, however, the first American attempts were made by surrounding an atomic bomb with different kinds of hydrogen. This attempt was partially successful, and a device of this kind was exploded at Eniwetok, an island in the Pacific, in 1952. In 1953, however, a great explosion was produced in Siberia which employed a compound of lithium and heavy hydrogen, called lithium deuteride, as the main charge. It appears that the Americans found traces of lithium or beryllium in the atmosphere at great altitudes. There were great advantages in the new method, and the Americans detonated a similar device about nine months after the Russian explosion.

TWO ESSENTIAL POINTS

Although some of the details in such reports may be questioned, there seems now to be no doubt about two essential points. First, that it is possible to detonate a main charge consisting of the lightest atoms found in nature. Secondly, that whilst the substance of the main charge does not occur in nature in an immediately usable form, so that there is no possibility of an uncontrolled thermo-nuclear reaction being initiated which would destroy the globe, the substance can be prepared in substantial quantities relatively cheaply as compared with the special uranium and plutonium required in the atomic bomb. Thirdly, that in such thermo-nuclear reactions, there is no limit to the size of the explosion which it is possible, in principle, to produce. The limit to which the ordinary atomic bomb is subject is thereby removed.

The consequences of these developments are very profound: Whereas the atomic bombs dropped on Japan were equivalent to about twenty thousand tons of T.N.T., a hydrogen bomb has already been exploded which was equivalent to 20 million tons. Whereas an ordinary atomic bomb was equivalent to a heavy raid by about 2,000 aircraft, each carrying ten tons of bombs, a hydrogen bomb has already been exploded which was equivalent to 1,000 such raids. The figure for the destructive power of this bomb—20 million tons—is 15 times greater than the total weight of bombs dropped on Germany during the last war by all Allied aircraft put together, namely 1,300,000 tons; it is about 100 times the

total weight of bombs dropped by German aircraft on British cities during the same period, which I put at not more than about 200,000 tons.

There is a legend in Greek mythology that Prometheus stole fire from the Gods for the service of man, and for his effrontery was chained to a rock for eternity where his vital organs were perpetually torn by vultures only to be perpetually renewed. It is our generation which has dared to snatch from nature the secret of an immeasurably more potent fire seen against which the very lighting is a shadow. It is only our collective wisdom and intelligence which can save us all from torments immeasurably worse than those which Prometheus had to endure.

THE CONSEQUENCES OF A GENERAL WAR WITH ATOMIC WEAPONS

Before trying to estimate the effects which would be likely to follow from a general war with atomic weapons, there are two features of the present situation which it is important to emphasise.

First, it appears that it is well within the capacity of any state able to produce an ordinary atomic bomb to proceed to the cheap hydrogen bomb. In a sense, the ordinary bomb is already out of date, for its explosive power can be greatly increased by surrounding it with a main charge of lithium and hydrogen which can be relatively easily produced. In a military sense, it is wasteful, therefore, to use ordinary atomic bombs; they can serve as the detonator to make a much greater explosion, the additional cost being relatively small compared with the effect produced.

It is also important to estimate how many atomic bombs have been produced already, because that gives us an idea of how many hydrogen bombs may be available to the great powers in the near future. There are, of course, no published figures, but plausible estimates suggest that the United States "stock-pile" is about 4,000 atomic bombs, with an annual production rate of several hundreds, whilst the U.S.S.R., has about 1,000. These numbers may each be wrong by a factor of two or three or more, but that will not change the general picture appreciably.

The essential point is that each of the two groups of powers already equipped with hydrogen bombs has, or will soon have, a sufficient number to destroy the main centres of population and industry of the other. A stage has already been reached, or is being rapidly approached, when a general conflict will result in the common ruin of the contending forces, for neither is able to protect its own cities. It is a little difficult to see what advantage there can be in increasing stocks beyond such a point.

It is, I think, unnecessary to emphasise that countries with a high density of population, and an elaborate and sensitive economic and social organisation, such as our own and some other states of Western Europe, are particularly vulnerable to attacks by hydrogen bombs. The explosive power of the largest hydrogen bombs detonated hitherto, said to be about 20 million tons, is such that they could destroy completely the largest cities.

The effect produced by the early atomic bombs exploded at Hiroshima, allow us to estimate the range of destruction of hydrogen bombs. The radius of complete destruction of a 20 million-ton bomb due to blast alone is about 7 miles; the corresponding area of destruction is about 200 square miles. But on a clear day, widespread and extensive fires would be produced by the heat flash at much greater distances from the centre of the explosion. These fires would be fanned by a great wind rushing in from all sides to take the place of the mass of heated air rising, as in a chimney, from the immediate centre of the explosion. To the immediately destructive effect of the blast from the bomb would therefore be added that due to widespread and devastating fires.

It appears almost certain that a well-directed hydrogen bomb could cause the almost complete destruction of the fabric and the population of any city on earth, whether Moscow, London or New York. *Two bursts of total explosive power* 40,000 *tons killed* 100,000 *people and destroyed most of the buildings of Hiroshima and Nagasaki. We are considering the effects of bombs a thousand times more powerful.*

It is now known that in addition to the immediate effects on the target area, a hydrogen bomb can also, if detonated near the ground, cause the production of great masses of radioactive dust which contaminate wide areas as it is distributed by the winds. This radioactivity can be lethal to all living matter in parts of the area of descent, several thousand square miles unless extensive measures of protection are taken—to human beings, animals and vegetation.

" BROKEN-BACKED " WARFARE

In view of these effects, it is not surprising that the aftermath of an attack with hydrogen weapons on this country has been described as a period of " broken-backed " warfare, and as " a struggle for survival of the grimmest kind." It is, of course, very difficult to assess the full consequences of a situation which is widely different from anything the world has ever known, but I think it must be assumed that a relative few well directed hydrogen bombs on this country, say 10 or 20, would make ordinary organised social life impossible.

It is not only the immediately destructive effects of the bombs, and the complete dislocation of our ports and transport system, which have to be considered. Many secondary effects must follow from the mounting level of radioactivity, the debilitation of the population from radiation, lack of food and shelter, the multiplication of diseases and many other consequences which we cannot at present foresee.

Taking into account that atomic bombs equivalent to about 40,000 tons of T.N.T. caused 100,000 deaths at Hiroshima and Nagasaki, it is a reasonable conjecture that 20 hydrogen bombs of the greatest power, equivalent to, say, 500 million tons of T.N.T., dropped on this country in the conditions of a general war, would lead to the destruction of most of the population. What is quite certain is that such a war would produce such radical changes that for the survivors our present life would appear to have been like a pleasant but entirely remote dream. Over large areas, the very landscape, and the animal and vegetable life subsisting on it, would have been transformed. Not one of those who survived would have escaped the most bitter bereavement and the loss of everything they held dear; and the biological effects of radiation would be still to come for many generations. It would indeed be an example of the sins of the fathers being visited on the children unto the third and fourth generation. On the morrow of such a war, it would be a poor consolation to the pathetic remnant of our country that we had been able to reduce other lands to a similar condition of ruin.

I ought to emphasise that in making the above appraisal I have tried to take a restrained view and to avoid any tendency to over-estimate the outcome of atomic attack. I have also assumed that no cobalt bombs would be employed. It appears that it would be a relatively simple operation to enclose a hydrogen bomb in a container of the common metal cobalt which is rendered radioactive under the action of the radiation—the neutrons—produced in an atomic explosion. A number of authorities have pointed out that the explosion of a relatively few of these bombs would produce such a great amount of radioactivity that wherever they were exploded, the material would be rapidly dispersed over the globe by the winds, and would render all forms of life impossible. **It has been said that to manufacture and employ such bombs would be the act of a madman. But there have been madmen in high places before, and a war with hydrogen weapons, without cobalt bombs, is also madness.**

THE INSTABILITY OF THE PRESENT SITUATION

At the present time, only two of the major powers possess hydrogen weapons, but it appears certain that any state able to produce ordinary atomic bombs will be able to convert them into hydrogen bombs soon afterwards. The number of states equipped with the weapon is therefore likely to increase, and so also the difficulties of a general settlement and the dangers of political accidents and miscalculations. The growing instability of the relations between the powers will also be made worse by improvements in the methods of delivering atomic and hydrogen weapons.

At the moment, we think of attacks by manned aircraft carrying hydrogen bombs; and as a defence, of their interception by fighters, and by projectiles from the air and the ground, which seek out and destroy the attacker. But it is quite certain that the time is rapidly approaching when rockets of various forms, possibly piloted, or directed automatically to their targets, will be produced with ranges of thousands of miles.

Any realistic forecast must take account of a very rapid technical development in this field as in that of nuclear energy and atomic bombs. It is said that even in 1944, some of the German V-weapons could be directed on to their target by radio, and the " off-line " error at a range of more than 100 miles was only about half a mile. At a range of 1,000 miles, the corresponding error would be only 5 miles, which is sufficiently accurate for the delivery of a hydrogen bomb against a large city.

In view of its military importance great efforts have certainly already been made to develop long-range rockets; and we must anticipate that they will come into operation in the course of a few years. There seems to be no serious possibility, at the moment, of developing methods of intercepting such projectiles, which would fly at great altitudes, virtually outside the atmosphere.

These considerations suggest that in the course of a few years—and in the absence of war, and of an agreement between the powers—we shall reach a situation in which several of the major powers will be equipped with hydrogen bombs in sufficient numbers to destroy completely the main centres of population and industry of their enemies; that they will be in a position to deliver these bombs, without warning, by high-speed projectiles from launching sites invulnerable to attack. We should then have reached the position of " push-button " warfare, where statesmen will know that they can utterly destroy an enemy in the course of half an hour, and that their own country will suffer the same fate immediately afterwards. This is, of course, not a prospect for the immediate future, but it is not an unreasonable forecast on the basis of present developments and tendencies. Once again, it may be emphasised that it is a view necessarily limited by present ideas which takes no account of really new developments.

THE PEACEFUL APPLICATIONS OF ATOMIC ENERGY

Before considering the steps already taken to reach agreement between the powers, let us now glance briefly at the other aspect of our situation. After trying to assess the fearful horrors of atomic warfare, we can, with a feeling of relief, turn to the great positive advantages which could follow a reduction of present international tensions, and the application of our scientific resources to peaceful ends.

Even now, when most of our effort on research is directed to war, and only a small fraction to peaceful ends, notable advances in the applications of atomic energy have been made in the last few years in such fields as medicine and power production. There would be almost unlimited possibilities if we spent as much on peace as we do on war.

As examples of peaceful applications of atomic energy, we now begin to use the radioactive substances from the atomic piles—the prototypes of the power-stations of the future—in our hospitals and research institutions; they can be employed in a number of ways in the diagnosis and treatment of disease, and they begin to take the place of our X-ray tubes. A whole new science is growing up which employs them to trace out what happens in biological processes and which gives us a detailed insight which was previously impossible.

The knowledge thus gained will certainly be of great importance in many branches of medicine. Illustrations of this kind could be multiplied, but it is in the field of power production that the most striking applications have been made.

You will know that a small station of 5,000 kilowatts, using atomic fuel is already in use in the U.S.S.R., and that a larger station of 50,000 kilowatts will come into operation in this country in a year or two. These will be followed by a rapid development, so that within 10 years we shall have 10 or more stations with a total capacity of 2 million kilowatts, and in less than 50 years most of our power will come from such stations.

Already very important technical advances have been made, so that it is probable that all the uranium and thorium found in nature can be made available as fuel, instead of only about 1 per cent. of the uranium which had at one time seemed possible. This will greatly increase our power reserves, for the known uranium and thorium deposits should be sufficient to supply all the world's estimated power requirements for more than a thousand years, even without any major technical innovations.

But such a list of the positive contributions from atomic energy would appear as a poor compensation for our present dangers and anxieties if they were the only advantages we might expect to enjoy. In this sense, such an account is quite misleading. It always takes time for the full implications of a great discovery to be made clear and to be applied.

The discovery of fire made possible the smelting of metals, but it was tens of thousands of years before bronze, and later iron, were extracted from their ores. When a new discovery is made, it is first applied to those immediately pressing problems for which it provides an obvious solution, and only later are its deeper potentialities realised. When the internal combustion engine was first developed, for example, it was fixed to a carriage in place of the horse, and only later was it realised that it made possible sustained flight with machines heavier than air—the aeroplane.

Similarly to-day, we are proposing to employ our atomic furnaces to generate steam, or other vapours, with which to drive the turbines in our electrical power stations. Only later shall we discover new possibilities which are still quite outside the range of our present speculations. An example of a great potential development which, for the moment, we don't see how to realise, occurs in connection with the hydrogen bomb:

The same uranium or plutonium metal which forms the charge of an atomic bomb can also be the fuel for our atomic power-stations; we can use it for the one purpose or the other But we cannot yet use for peaceful purposes the thermo-nuclear reactions which operate to produce the explosion of a hydrogen bomb.

"TERRIBLY FIERCE CREATURE"

As the Japanese physicist Yukawa has said "We have to learn to domesticate this terribly fierce creature." If we could find out how to master it, we should be able to produce almost unlimited power; for, as we have seen, the forms of lithium and hydrogen on which it is based are present in enormously greater quantities over the earth's surface than the rare uranium and thorium. The amount of fuel for our atomic power stations would then be virtually unlimited.

It is a difficult problem because it is not easy to see how we could make a furnace hot enough for the thermo-nuclear reactions to occur. We shall certainly have to solve the problem in a new way, and it may take the united efforts of scientists all over the world for a good many years to do it. But, in view of the great prize which it represents, we shall certainly do it one day.

How great is the prize can be illustrated in terms of the figures I quoted above. Hydrogen bombs have already been exploded which were equivalent to 20 million tons of high explosive. If successfully harnessed for peaceful purposes, the same amount of material would give as much *useful power as is got to-day by burning 20 million tons of coal. The material of 12 such bombs would give us as much power as to-day costs us the labour of all the miners of this country for one year. That is a measure of the prize before us.*

And with unlimited power at our disposal, a whole range of problems with which people have concerned themselves in the last few years would simply disappear. The problem of supplying food for a rapidly expanding population appears in an entirely different light, for example, if unlimited supplies of power are availabe for irrigation and other purposes. Over large surfaces of the earth, now desert or entirely unproductive, water alone is sufficient to bring fertility. We should then be able to make the desert blossom with the rose.

But any forecasts which we can make at the present time are necessarily limited by our present horizons, and even our most daring speculations will be proved to be poor and restricted compared with the reality. We see how far, in a single generation the most fanciful anticipations, like those of Jules Verne and H. G. Wells, have been surpassed. This will always be so, for nature is infinitely richer in content than the most brilliant imagination.

When we have learned to make use of some of the great potentialities of what I may call the " atomic fire," we shall surely find that the science fiction of to-day, with its journeys in space-ships through the solar system, and its visitation of other planets, was also only a pale reflection of the reality to come. It will be seen to have failed not through being too imaginative, but because it was necessarily limited by the horizons of our own time. A novelist, like anyone else, cannot anticipate great discoveries and innovations; they are great precisely because they are really new, and therefore completely outside the range of the conventional ideas of their time.

In assessing these positive advantages, I have concentrated on developments particularly related to atomic energy. Though of great importance, this is still only a narrow sector of modern science; and it is on science as a whole, and on our wisdom and wise use of it, that our possibilities of human advancement depend. But I have perhaps said enough to give you some indication of the great possibilities which open out before us as an alternative to destruction and war. It remains for me to describe some of the difficulties which have hitherto stood in the way of an agreement between the great powers on the subject of atomic energy. This is the key to the problem of avoiding our present dangers and seizing the advantages.

NEGOTIATIONS FOR AGREEMENT BETWEEN THE GREAT POWERS

Very soon after the explosion of the first atomic bombs, negotiations began between the great powers on questions related to the international control of atomic weapons and atomic energy and, in one form or another, they have continued ever since. In the early days, the discussions took place in the U.N. Atomic Energy Commission, and the general problems of disarmament were dealt with in the Disarmament Commission. In January, 1952, the commissions were merged so that the two problems were no longer separated.

In order to understand the background to the negotiations, it is important to recognise the three following features of the relations between the powers:—

First, that in the early days, the U.S.A. had a monopoly of atomic weapons, which was broken by the U.S.S.R. in 1949:

Secondly, that the U.S.S.R. and its allies have a preponderance in manpower and in the more conventional weapons:

And thirdly, that the U.S.A. and its allies have an assured majority in the U.N.O. and in all its commissions.

As a result of the negotiations in these U.N. Commissions, there has been a certain degree of accommodation and there is now a field of agreement between the powers. I want first to describe this common ground, and then go on to the outstanding points of difference.

INSPECTION AND VERIFICATION

There has been widespread misunderstanding about one important issue: that which may be referred to as the problem of inspection and verification. It is the elementary right of any state which, as a result of an international agreement, undertakes to limit its production of atomic weapons, or ceases to make them altogether, to be assured that the terms of the agreement are being kept by its potential enemies. Otherwise, it must feel that it is placed in a position which invites attack.

All the great powers, without exception, agree that any authority of the United Nations responsible for the control of atomic energy must have continuous and extensive rights of verification and inspection on the territory of the contributing states, so that it can detect infringements.

The problem before such an international authority has been complicated by the fact that there are now large stocks of atomic bombs owned by three powers. Any controlling authority must therefore know both the rates of production of nuclear fuel in the different countries, and the extent of existing stocks. It must call for a disclosure of existing stocks, and must be able to verify the truth of the disclosures.

The situation has also been complicated by the development of the hydrogen bomb, of which the main charge is composed of materials which are widely distributed, and of which there is a relatively plentiful supply. Insofar as it remains necessary to employ an ordinary atomic bomb to detonate the main charge of a hydrogen bomb, however, the principal problem could perhaps be solved provided the verification covered ordinary atomic bombs. Without the detonators the main charge would be useless.

Whilst the above difficulties are doubtless serious, it is reasonable to believe that it would be possible to overcome them as a result of discussions between the technical experts of the great powers, given a genuine desire to do so from all sides.

In addition to agreement on inspection and verification, the following points are also accepted by the great powers: That both atomic energy and weapons must be subject to international control. This follows because the same materials are employed for bombs and for power production; that the control must be exercised by an international personnel with unrestricted access to all mines, plants and laboratories engaged in atomic energy; that developments of atomic energy in the different countries shall be subject to a quota system and that the international authority shall organise international research.

PLAN FOR DISARMAMENT

Some progress has also been made towards an agreed plan for disarmament, to which joint Anglo-French proposals, made at a meeting of the Sub-Committee of the U.N. Disarmament Commission which met in London in May, 1954, made an important contribution. For several years, disagreements, clearly reflecting the particular strengths and weaknesses of the different states, had led to a deadlock on these issues. The United States, for example, took the position that any disarmament plan must begin with a reduction of conventional arms to a point where there is an approximate equality between the two rival groups of powers in these arms, and that any control of atomic weapons should only come afterwards. On the other hand, the Russian point of view was that any plan should begin with a ban on the production and use of atomic weapons and that disarmament in conventional weapons should take the form of a reduction in constant proportion say, one-third, of the existing forces of all states.

As a result of negotiations there has been an important degree of compromise. According to the Anglo-French proposals a general reduction in arms and the prohibition of nuclear weapons would proceed in several stages which would involve prohibition of nuclear weapons, " except for defence," and the setting up of a control organisation whose first task would be to limit military manpower and expenditure to the level of 1953. Later, and in sequence, the control organisation would enforce the first half of an agreed reduction of armaments, the manufacture of nuclear weapons would be prohibited, the agreed reduction of armaments would be completed, and, finally, nuclear and other prescribed weapons would be totally prohibited.

Some months later, at the General Assembly of U.N., the U.S.S.R. suggested that the Anglo-French proposals should be taken as a basis of a scheme for disarmament and atomic control, and put forward the draft of an " International Convention " which is closely similar in substance to the Anglo-French proposals.

In particular, this proposal of the U.S.S.R. visualises, as a first step, the carrying out by the different states of the first half of an agreed reduction of armaments, and the formation of a provisional control commission to check that such reductions are actually carried out. Secondly, after six months or a year, states are to complete the agreed measure of disarmament and, at the same time, manufacture of nuclear weapons is to be prohibited and all nuclear weapons dismantled. Finally, a permanent international body is to be formed to exercise control of the fulfilment of undertakings by inspection.

The important features of the above proposals are that they accept the ideas of a reduction of armament by stages, that they do not insist on reductions by definite fractions but by agreed quotas, and they do not demand that disarmament should start with atomic weapons.

Two other important contributions, by the U.S.A., which I shall not have time to describe adequately were, first, suggestions for the structure and functions of the control organisation of the United Nations responsible for the international control of atomic energy and secondly, a proposal by President Eisenhower, in December, 1953, for establishing atomic power stations in industrially undeveloped countries which are retarded through lack of power. Although it is no longer being actively pursued, such a plan may become the basis for future steps towards peaceful collaboration in this field.

SERIOUS DIVERGENCIES

In spite of progress towards a common view, serious divergencies have remained. They have centred round the nature and powers of the international body responsible for the control of atomic energy. It was a feature of the early American plan—the Baruch plan of 1946—that the controlling body—to be called the International Atomic Energy Development Authority—should have ownership and managerial control of practically all stages in the production and use of nuclear fuels. It was to decide when, where and to what extent operations for the production of atomic energy were to be carried out in all parts of the world. Further, the Authority was to have the power to decide when violation of rules had occurred and to administer sanctions and punishment to guilty states. In the American view, these great powers were essential to ensure adequate safeguards against infringements, and adequate inspection and verification.

In opposition to the Baruch Plan, and to later American proposals which contain similar features relating to the powers of the controlling body, the U.S.S.R. has insisted that the raw materials and plant situated within a state must remain the property of that state. In effect, the U.S.S.R. has said that it cannot allow decisions governing the development of a decisive section of its potential power production to be in the hands of an international body on which it could always be outvoted on important issues, by the permanent majority of the U.S.A. and its allies.

The U.S.S.R. has also been opposed to two other features of the U.S. proposals; first, on the question of the veto and of sanctions. You will know that the decisions of the Security Council, the highest organisation of the U.N. for the maintenance of peace, are subject to what is called the unanimity rule. Its decisions can be vetoed by one of the Great Powers. This rule was inserted into the constitution because it is the function of the United Nations to preserve peace; to apply sanctions, overwhelming force, against one of the Great Powers is merely another name for a third world war.

It is generally agreed by the powers that the ordinary work of the controlling authority shall be subject to majority decision. The point of contention is that the U.S.S.R. insists that actions against a country adjudged by the controlling authority to have violated its agreements shall be subject to the veto. The U.S.A. takes the position that it should not.

Further, the U.S.A. proposes that the controlling authority shall have power to determine, on a world scale, the disposition of stocks of nuclear fuel, to close down plants and to apply punishments such as depriving plants of raw materials. The U.S.S.R. on the other hand would limit the authorities' powers to making recommendations to governments regarding production and other features of nuclear fuel and to recommending measures of prevention and restraint to the Security Council.

Briefly stated, it may be said that in the U.S. view the controlling authority should have full powers even to the application of sanctions, whereas the U.S.S.R. insists that it shall operate within the framework of the Security Council. It will be apparent to you how clearly these differences of view reflect the influence and support which the two countries can command within the U.N.

NOT AN EASY TASK

It is on the possibility of finding acceptable compromises on these issues that the solution of international tension depends. No one would suggest that it will be an easy task. But, without it, we shall all continue to live in the shadow of a catastrophe, in a situation which grows even more precarious and threatening. As you know, negotiations are currently proceeding, and a most grave responsibility rests on the representatives of Britain, France and other powers, who, standing a little apart from the two giants may be counsels of restraint and moderation contribute so greatly to the peace of the world.

A heavy responsibility rests also on those of us who have some small understanding of the great issues which are in suspense. A measure of agreement between the powers has been reached, but progress has been slow, and time is not on our side. We still do not know whether we shall advance to the happy future that is within our grasp or whether civilisation will be destroyed, so that a bruised and scattered remnant of humanity will slowly recover to begin life again in a new and strange world where our own times will be hardly remembered.

In a situation so precarious, small forces can turn the balance, and our prospects will be brighter the more people are convinced, and the more firmly and untiringly they insist, that international agreement on atomic energy can be brought about, that it is essential for our survival; and that it must be achieved in a form which respects the freedom and independence of all peoples to determine their own destinies.

Prof. C. F. POWELL, M.A., F.R.S.

CECIL FRANK POWELL, M.A., F.R.S., Melville Wills Professor of Experimental Physics University of Bristol, was born on December 5, 1903, at Tonbridge. His early education was received at the local elementary school and Judd's School from where he obtained an Open Scholarship to Sidney Sussex College, Cambridge. After graduating he carried out research under Lord Rutherford and C. T. R. Wilson on condensation phenomena.

He moved to Bristol in 1927 and worked under Professor Tyndall on gaseous ions, developing a new and accurate method of measuring their mobilities.

In 1936, he was appointed seismologist of an expedition sent to Montserrat in the West Indies to investigate volcanic activity. On his return, Powell continued the work commenced in 1935 on the construction of a Cockcroft generator for accelerating fast protons and deuterons, with the intention of producing neutrons for use in conjunction with a Wilson Chamber, in order to study neutron-proton scattering.

In 1938, however, in conjunction with W. Heitler and G. Fertel, Powell had undertaken some experiments on the cosmic radiation using photographic plates in order to record directly the tracks of the particles. He immediately recognised the value of this technique and, using the Cockcroft machine and the photographic plate, soon established, contrary to opinion held at the time, that the length of the track of a charged particle in the emulsion gave a satisfactory measure of its range.

In 1945, with Occhialini and a number of other young workers, Powell developed the technique of using photographic emulsions with increased sensitivity, which were then available, in an exploration of the cosmic radiation. As a result of Powell's contribution to our knowledge of cosmic radiation he was awarded the Hughes Medal in 1949 (in the same year as he was elected to the Fellowship of the Royal Society) and later in 1950 international recognition was given to his work when he was awarded the Nobel Prize for Physics.

During the past ten years, Powell's research school in Bristol has won world-wide renown for its experiments at great altitudes with free balloons, and for its discoveries of various types of new fundamental particles called mesons. The techniques thus developed have provided the basis for an extensive collaboration, involving physicists in more than twenty European and other Universities, for studies which are to-day at the centre of interest of fundamental physics.

Powell's interest in the social relations of science may well be summarised by a quotation from his speech at Stockholm in December 1950 on the occasion of the banquet given in honour of the Nobel Laureates:

> *"In all our work, my colleagues and I have received inspiration, even when we were least conscious of it, from those great aims of natural philosophy which were embodied in the doctrine of Utility and Progress, so clearly enunciated by my great countryman, Francis Bacon; from the view that the true end of the sciences is to lighten the burden of labour and to enrich human life."*

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