problem, practically all of which has been borne by the USA has been concentrated on the development of an atomic bomb. Considertions of security make it impossible to disclose many of the details of this work but, in what follows, some indication is given of the share in it which has been carried out in Britain. Before doing this, however, it may be worth summarizing the nature of the problems relating to the use of fission, either to produce a violent explosion or to liberate atomic energy under controlled conditions, as they appeared when the work was organized, with a new sense of its urgency and importance, at the beginning of the war.

It was generally accepted that a chain reaction might be obtained in uranium which would yield enormous amounts of energy. This, on a basis of equal weights, would be millions of times greater than that produced by the combustion of coal or oil. But it was realised that, if this chain reaction was to be divergent and self-sustaining, certain critical conditions must be satisfied. In the first place the system as a whole must be of such a size that there was not too great a probability that neutrons, produced in the fission process, would escape from the system and so be unable to take any further part in the chain process. Secondly the system must not contain more than a limited amount of material that would absorb neutrons and, in this way again, remove their chance of contributing to the divergent fission chain reaction. Thirdly, the fact was appreciated that, if the reaction was not to "run away", it was essential to make use of neutrons of very low energy in the individual steps of the chain process. Only then would it be possible to introduce methods which would allow the rate of development of the process to be controlled. The neutrons produced when fission occurs have very high energies but this is dissipated as a result of elastic collisions with the neclei of other atoms that may be present. Professor Joliot and his co-workers in Paris, Professor Fermi and other physicists in the USA and Professor Sir George Thomson and his colleagues in London were giving thought to the possibility of using a mixture of uranium and some suitable "slowing-down" medium arranged in such a way that the fast neutrons produced by fission would lose their energy by elastic collisions before initiating further fission in the uranium. A suitable "slowing-down" medium must, above all, not have any large probability of capturing a neutron and its atoms should be of as small mass as possible in order to get the maximum rate of loss of energy in the neutrons through elastic collisions. The most suitable materials to fulfil both these conditions were "heavy hydrogen" or its compound "heavy water", helium, beryllium and carbon.

At the beginning of 1940 Dr Frisch and Professor Peierls, of Birmingham University, and Professor Sir James Chadwick, of Liverpool University, independently called attention to the possibility of producing a military weapon of unprecedented power. They pointed out that the slow neutron chain reaction would not produce explosive effects much greater than those obtained with ordinary explosive but that if a chain reaction with fast neutrons could be realised the explosive effects might be enormous. It was realised that ordinary uranium would not be suitable, for even if a fast chain reaction could be realised with it a very large quantity of metal would be required. On the other hand, the isotope U-235, if it could be separated, offered great possibilities. It seemed that the amount required to make a bomb would not be very large, certainly between one and one hundred kilograms, and rough calculations of the energy released showed that the explosion of such a bomb might be equivalent to many thousands of tons of TNT.

The explosion of an atomic bomb is very different in its mechanism from the ordinary chemical explosion for it can occur only if the quantity of U-235 is greater than a certain critical amount. This is because the reaction depends on the conservation of the neutrons produced in the fissions. In a block of pure, or nearly pure, U-235 the neutrons will either be absorbed in the mass of metal, producing new fissions, or they will escape into the outer air, thus being wasted and useless for propagating the reaction. The proportion of neutrons which escape can be reduced by increasing the size of the block of metal, since the production of neutrons is a volume effect and will therefore increase more rapidly with size than the loss by escape, which is a surface effect. If follows that if the explosion is possible it will require a certain minimum amount of material, which is called the critical size. The chain reaction will develop so fully that an explosion occurs only if the quantity of U-235 is greater than this critical amount. Quantities less than this are quite stable and perfectly safe. On the other hand, if the amount of material exceeds the critical size it is unstable and a reaction will develop and multiply itself with enormous rapidity, resulting in an explosion of unprecedented violence. Thus all that is necessary to detonate a bomb of U-235 is to bring together two pieces each less than the critical size but which when in contact form an amount exceeding it.

If an appreciable fraction of the atoms in a mass of U-235 undergo fission within a very short time the amount of energy liberated will be so great that the mass will attain a temperature of many million degrees and a pressure of many millions of atmospheres. It will consequently expand with very great rapidity. As the density of the mass decreases the neutrons can escape more easily from it, and the chain reaction will come to an end. In order to release an appreciable fraction of the available energy, it is therefore necessary that the reaction should develop so rapidly that a substantial part of the material can react before the system has time to fly apart. The neutrons produced in the fission process are fast enough to fulfil this condition (but not if they are slowed down by artificial means as mentioned in the paragraphs above).

The interval of time between the beginning and the end of the nuclear reaction is exceedingly brief. In this interval the mass will have expanded so much that the nuclear reaction breaks off, owing to the escape of neutrons. During this interval a substantial part of the mass of U-235 should undergo fission, releasing a large amount of energy. If only one pound of U-235 is affected this release of energy will be as much as from 8,000 tons of TNT.

THE REALISATION OF THE ATOMIC BOMB. BRITISH ACTIVITIES AND ORGANIZATION

(a) *Professor Sir George Thomson's Committee*

A committee of scientists, with Professor Sir George Thomson as chairman, was set up in April, 1949, orginally under the Air Ministry and later under the Ministry of Aircraft Production. This committee was instructed to examine the whole problem, to co-ordinate work in progress and to report, as soon as possible, whether the possibilities of producing atomic bombs during this war, and their military effect, were sufficient to justify the necessary diversion of effort for this purpose.

The first step to be taken was to establish the nuclear data on which depended the possibility of an atomic bomb and which determined its size. This work had already begun at Liverpool early in 1940 under Professor Sir James Chadwick and it was now pushed on more rapidly with Drs Frisch and Rotblat as his senior collaborators. As the work developed and further problems appeared, it was extended to the Cavendish Laboratory, Cambridge, under Drs Feather and Bretscher. This also had the advantage of providing an insurance against possible interruption from the effects of enemy bombing, to which the Liverpool laboratory was somewhat exposed. The many theoretical aspects of the problem were investigated by Professor Peierls, assisted by Dr Fuchs and others. They used the experimental data provided by Liverpool and Cambridge to calculate the critical size of the bomb, they examined the mechanics of the reaction, and calculated the amount of energy likely to be released in an atomic explosion, studying the conditions for increasing the amount.

This was clearly only one side of the problem for it would not have been of immediate practical use to show that an atomic bomb was feasible provided that a certain quantity of U-235 were available unless it could also be shown that there was a reasonable possibility of separating such a quantity of U-235 from ordinary uranium and in a reasonable time. This aspect of the problem was also considered by the Committee. In the early stages of the work not much actual experiment could be done owing to the scarcity of men and of facilities, but one method of separation was examined at Liverpool and shown to be unpromising. There are of course several methods available for separating isotopes on a laboratory scale. These were examined very carefully by the Committee, having in mind that it was essential to select and concentrate on what was likely to be the most economical method, owing to the fact that the manpower and industrial resources of Britain were already wholly engaged on production for immediate war needs. The Committee came to the conclusion that the gaseous diffusion method was by far the most promising for large scale production. It is based on physical principles which have long been fully understood and which are easily amenable to calculation, and it seemed likely to make fewer demands for highly-skilled precision work.

Research on this method of separation was taken up by a team of workers under the direction of Dr F. E. Simon in the Clarendon laboratory, Oxford. They were aided on the theoretical aspects by Professor Peierls and his group, and on the chemical side by Professor W. N. Haworth and a group of men under his direction in the Chemistry Department, Birmingham University. The Metropolitan-Vickers Electrical Company and Imperial Chemical Industries Ltd.

were consulted on the many technical questions which were involved. Some experimental work on the diffusion method was also started at Imperial College, London University.

By the early summer of 1941, the Committee decided that the feasibility of a military weapon based on atomic energy was definitely established and that this weapon had unprecedented powers of destruction, that a method of producing the amounts of material required was in view, and that a fair estimate of the industrial effort needed to accomplish the project could be given. Accordingly, the Committee drew up a report dated July 15, 1941, which summarized its findings and which made recommendations for the prosecution of the project on a large scale. By agreement between the Minister of Aircraft Production and the Lord President of the Council, this report was referred to the Scientific Advisory Committee of the War Cabinet of which Lord Hankey was the Chairman.

It is proper at this point to consider in general terms what had been done and what remained to be done. The experiments on the nuclear properties of uranium had confirmed that ordinary uranium itself would be useless for the purpose of an atomic bomb and that it would be necessary to use the isotope U-235 which is present in ordinary uranium only to the extent of 0·7 per cent. They had further shown that if pure or nearly pure U-235 were available in sufficient bulk a chain reaction could develop which would result in an explosion of extreme violence. The data which had been obtained were sufficient to give an estimate of the amount of U-235 required, but this estimate was very rough and the critical size was known only to a factor of three. The theoretical work had confirmed the early result that the amount of energy released in an atomic explosion would be very large compared with the effect of ordinary bombs. Calculations had been made on the effect of "tampers" and on the best size of bomb. The method of assembly of the material for use as a weapon and the method of fusing had been considered, but no experiments had been made. On the problem of production of this material, U-235, it had been decided to concentrate on the gaseous diffusion method, and research and development on some aspects had shown considerable promise. A scheme had been put forward by Dr Simon and Professor Peierls which had proceeded to the first stage of design. Leading experts of industrial firms had been consulted who had agreed that it should be possible to build a satisfactory plant, although difficulties were to be anticipated. Estimates were given for the cost of a plant to provide adequate quantities of U-235 and for the time required to build it.

In short, the Committee was completely convinced that an atomic bomb depending on the fission of U-235 was feasible and that its effect would be comparable with that of some thousands of tons of TNT and that a method of separation of U-235 from ordinary uranium could be realized on a large scale, so that sufficient quantities of the material could be obtained. Admittedly, a great deal of work remained to be done on all aspects of the project. More precise nuclear data were required so that, for example, the critical size could be estimated with better precision; some points needed confirmation; methods of assembly and of fusing of the material had to be thoroughly examined. The main problem, however, was the design and construction of a plant for the production of the material, and this most essential part of the project was only in its early stages.

A different but important aspect of the application of the fission of uranium was also reviewed by the Committee. This was the possibility, mentioned in a previous section of this statement, of finding conditions under which a mixture of uranium and some suitable "slowing-down" medium might give a neutron chain reaction in which the release of energy was obtained in a controlled way. This work was being carried out at Cambridge by Drs Halban and Kowarski.

These two French physicists had been sent by Professor Joliot to this country at the time of the fall of France in June, 1940. They brought with them the 165 litres of "heavy water"—practically the whole world stock of this material—which the French Government had bought from the Norsk Hydro Company just before the invasion of Norway. Drs Halban and Kowarski were instructed by Professor Joliot to make every effort to get in England the necessary facilities to enable them to carry out, with the co-operation of the British Government, and in the joint interest of the Allies, a crucial experiment which had been planned in Paris and for which the "heavy water" had been acquired. Facilities were provided at the Cavendish Laboratory, Cambridge, and, by December, 1940, they produced strong evidence that, in a system composed of uranium oxide (as actually used) or uranium metal with "heavy water" as the slowing-down medium, a divergent slow neutron fission chain reaction would be realised if the system were of sufficient size. It seemed likely that, if uranium metal were used, this critical size would involve not more than a few tons of "heavy water".

The Committee concluded that this work had great potential interest for power production but that this particular application was not likely to be developed in time for use in the war. It was, however, recognized that the slow neutron work had a bearing on the military project, for the plutonium which would be produced in such a system could be extracted chemically and might be capable of use in an atomic bomb instead of U-235. The difficulties in the way of building a slow neutron system seemed to be prohibitive at that time. In order to produce the quantities of plutonium which it was guessed, from analogy with U-235, might be required for a bomb, many tons of uranium and many tons of heavy water would have been necessary. The latter practically would have demanded a major industrial effort.

During this period, April, 1940—July, 1941, similar problems were occupying the minds of American scientists. Contact was maintained partly by the transmission of reports through the normal scientific liaison machine and partly by visits in both directions by scientists on general scientific missions. Professor Bainbridge, of the National Defence Research Committee of America (NDRC), was in England in April, 1941, and Professor Lauritsen (NDRC), was in England in July of the same year on general scientific matters. Both were invited to attend meetings of Sir George Thomson's Committee.

(b) Directorate of the Tube Alloys, D. S. I. R.

The Scientific Advisory Committee of the War Cabinet, of which Lord Hankey was the Chairman, endorsed the view of Sir George Thomson's Committee on the importance of the atomic bomb, with the result that Mr Churchill, who had been kept informed on the developments by Lord Cherwell, asked Sir John Anderson, in September, 1941, to undertake personal responsibility for the supervision of this project as one of great urgency and secrecy. To advise him he set up, under his chairmanship, a Consultative Council of which the members were the Chairman of the Scientific Advisory Committee of the War Cabinet (Lord Hankey and later Mr R. A. Butler), the President of the Royal Society (Sir Henry Dale), the Secretary of the Department of Scientific and Industrial Research (Sir Edward Appleton) and Lord Cherwell. To endure continuity the Minister of Aircraft Production. Lord Brabazon of Tara, served on this Council at the beginning.

The direction of the work was entrusted to a new Division of the

Department of Scientific and Industrial Research and thus fell under the general administrative charge of Sir Edward Appleton as Secretary of the Department. It was known, for reasons of security, as the Directorate of Tube Alloys. Mr W. A. Akers was, at Sir John Anderson's request, released by the Board of Imperial Chemical Industries, Ltd., to act as Director, with direct access to the Minister on all questions of policy. Mr Akers had, as his deputy and principal assistant, Mr M. W. Perrin, who was also lent by ICI. Mr Akers was advised by a Technical Committee, under his chairmanship, composed of the scientists who were directing the different sections of the work and some others. The original members were Professor Sir James Chadwick, Professor Peierls and Drs Halban, Simon and Slade, with Mr Perrin as secretary. Later it was joined by Sir Charles Darwin and Professors Cockcroft, Oliphant and Feather.

(c) Visit of U. S. Mission to Britain, November, 1941.

In November, 1941, at the time when the new T. A. (Tube Alloys) organisation was set up, an American mission, composed of Professors Pegram and Urey, of Columbia University, came to this country to study the experimental and theoretical work which had been done on the T. A. project, to learn our ideas for future work and to agree on arrangements for complete and rapid interchange of information. They visited all the establishments where T. A. work was in progress and took part in a meeting of the new T. A. Technical Committee at which progress was reviewed and new programmes discussed.

(d) Visit of British T. A. Mission to USA, February—April, 1941

Under the new organisation a great extension of the scale of work, both in university and industrial laboratories, was started. In the USA also a greatly intensified T. A. effort had followed the return of Professors Pegram and Urey from England. A mission composed of Mr Akers, Dr Halban, Professor Peierls and Dr Simon visited America at the beginning of 1942 to ensure that the programmes planned for the UK were co-ordinated as efficiently as possible with the American work.

Every section of the American programme was examined in detail and it was already clear that the new American T. A. organisation intended to make the fullest use of the enormous resources available in the universities and in industry.

(e) British T. A. Programme

It was clear in 1942 that, even though granted very high priority, the scale upon which T. A. research and development could be undertaken in the UK must be far smaller than in America. A large proportion of the qualified physicists was occupied in other urgent war work and the industrial resources of Britain were engaged, at that time, in war production to a much greater extent than was the case in the USA.

Consequently it was necessary to limit the field of T. A. investigation. Broadly the programmes chosen were:

Determination of essential nuclear physical data.

Theoretical investigations into the chain reaction in an atomic bomb, the dimensions and design of a bomb and its blast effect.

The gaseous diffusion U-235 separation process. This included theoretical and experimental research on the process, the design and construction of prototype machines, the manufacture of materials needed, studies on materials of construction, etc.

Investigation of slow neutron divergent systems, especially with "heavy water" as the slowing-down medium.

The manufacture of uranium metal for the slow neutron systems or "piles".

The manufacture of "heavy water".

(i) Location of Work—Experimental Determination of Nuclear Physical Data

The research teams at Liverpool and Cambridge Universities were considerably strengthened and small programmes were started at Bristol and Manchester Universities.

Professor Sir James Chadwick exercised general supervision over all this work.

Slow Neutron Systems

This work continued at Cambridge under Drs Halban and Kowarski with the collaboration of Dr Bretscher.

Theoretical Investigations into Chain Reaction, etc.

Professor Peierls and his team continued their studies at Birmingham, with collaboration, on special problems, with Professor Dirac of Cambridge.

Later, when Professor Peierls moved to USA, Dr A. H. Wilson led this group.

The Gaseous Diffusion Process[14]*—University Research*

The experimental work was under the general direction of Dr Simon. His extended team at the Clarendon Laboratory had, as leaders, Mr Arms and Drs Kurti and Kuhn. The theoretical study of the process remained in the hands of Professor Peierls and his group at Birmingham. Also at Birmingham University Professor Haworth, who had been active in T. A. from the days of the Thomson Committee, had a group working on a number of chemical problems connected with the diffusion project.

Research and Development in Industrial Establishments

The Metropolitan-Vickers Electrical Co. Ltd. accepted a contract for the design and construction of certain prototype machines embodying the principles worked out by Dr Simon and Professor Peierls. The successful construction of these machines was a considerable technical achievement in view of the novel features contained in them. They were later abandoned in favour of a simpler design which offered certain advantages in operation.

Imperial Chemical Industries Ltd (ICI) were entrusted with the contract for the development of the diffusion plant as a whole, and the work was carried out by the Billingham Division of that company. This programme was a very extensive one as it covered everything involved in the design of a complete plant, including the working out of flow-sheets, research on materials of construction and the development of new types of valves, instruments, etc., to meet novel conditions.

In this work they were assisted by the Metals Division of ICI, which studied various manufacturing processes. ICI Metals Ltd. had, as sub-contractors, Percy Lund Humphries and Co. Ltd. and the Sun Engraving Co. Ltd., co-ordinated by Dr Banks whose services were made available by the Printing and Allied Trades Research Association. Metallisation Ltd. also made a valuable contribution to this section of the work. Processes for the manufacture of the many special chemicals required were worked out by

[14]The Gaseous Diffusion Process—This process, which is based on a phenomenon called Thermal Diffusion, is the most powerful method for separation of isotopes. It was invented by a German physicist, R. Clusius in 1939, and its study was immediately taken up in the USA, England and France. By this method, Chlorine 35 can be separated from Chlorine 37 completely in course of a few hours, a feat which defied the skill of experimenters for over 40 years. The process requires high columns and enormous quantities of refrigerating material.

the General Chemicals Division of ICI assisted by the Dyestuffs Division. The Mond Nickel Co. Ltd., under a separate contract, made a very successful investigation of certain metallurgical problems.

Although some of these research programmes will be carried on a little longer, largely in order to establish optimum conditions, ICI Billingham Division has been able to close down the main programme after producing flow-sheets and designs for diffusion plants operating over a fairly wide range of conditions. In broad outline the plant is, of course, similar to the American diffusion plant now in operation, but it embodies certain novel features.

The manufacture of Uranium Metal

ICI (General Chemicals) Ltd. undertook the manufacture of uranium metal and succeeded in developing a satisfactory method. The conversion of the metal into rods, as required for a "pile", was tackled by ICI Metals Division. It soon became apparent that many problems required study in connection with the physical, metallurgical and chemical properties of the metal. Research on these points was undertaken by the National Physical Laboratory, Dr Simon at Oxford with a sub-group at Birmingham, the British Non-Ferrous Metals Research Association, Dr Orowan at Cambridge and the Alkali Division of ICI.

Heavy Water

ICI Billingham Division, which had some experience in the separation of "heavy water" on a laboratory scale, was asked to prepare a scheme for the production of this material on a large scale. After examining various methods they reported that the most suitable process to adopt in this country, if speed of construction and certainty of operation were paramount, was the electrolytic process incorporating the vapour phase catalytic exchange principle introduced by Professor Taylor of Princeton University, USA. Flow-sheets and designs were prepared for a plant in which the exchange system was of a novel design believed to be simpler and more efficient than any of those hitherto used or suggested.

Electro-Magnetic Method

Through the interchange of information we were aware of the remarkable development work which was being carried on at the University of California under Professor E. O. Lawrence, with the object of converting the mass spectrograph, used for the separation of isotope in minute quantities, into a large-scale production apparatus. But it was decided not to start any corresponding research in this country as the physicist most suitable for this work, Professor Oliphant of Birmingham, was engaged in other urgent war work.

In July, 1943 it was possible to release him from that work so that it was decided to start a research programme at Birmingham on this method. Before work had really started Professor Oliphant visited America in connection with discussion on a closer integration of British and American T. A. efforts, in which it was agreed, as described below, that the most efficient course to follow, in the joint interest, was for Professor Oliphant and most of his team to move to USA. The British electro-magnetic programme was therefore abandoned

After Professor Oliphant's return to this country in March, 1945 it was decided to arrange for research to be started on some of the electrical engineering problems involved in this type of plant. With this object research contracts have been placed with the British Thomson-Houston Company, the General Electric Company and Metropolitan-Vickers Electrical Company. In addition the first and last of these companies had already given considerable assistance by lending to the British T. A. organisation the services of Dr J. R. Wilkinson, Dr T. E. Allibone and other physicists and engineers.

(*ii*) *Co-ordination of Programmes*

It will be seen, from the account of the diffusion plant research project, that many university and industrial teams were concerned, so that proper co-ordination of the work became an important matter. The same applied to the work on the production of uranium metal and its metallurgy. It was also evident that some of the chemical research carried out for one project would be of interest in connection with another. To ensure satisfactory co-ordination of the work certain committees and panels were set up.

The diffusion work was dealt with by the Diffusion Project Committee reporting to the T. A. Technical Committee.

The members of this Diffusion Committee were:

Mr W. A. Akers, Director T.A. (D.S.I.R.)—(*Chairman*).
Major K. Gordon (later Dr. G. I. Higson), ICI, Billingham Division—*Dy. Chairman*.

Dr F. E. Simon, Oxford University.
Mr H. S. Arms, Oxford University.
Professor R. Peierls (later Dr A. H. Wilson), Birmingham University.
Mr J. D. Brown, ICI, Billingham Division.
Dr J. B. Harding, ICI, Billingham Division.
Mr C. F. Kearton, ICI, Billingham Division.
Mr S. Labrow, ICI, Billingham Division.
Mr J. R. Park, ICI, Billingham Division.
Mr N. Elce, Metropolitan-Vikers Electrical Co.
Mr H. Smethurst, Metropolitan-Vickers Electrical Co.
Mr M. J. S. Clapham, ICI, Metals Division.
Mr S. S. Smith, ICI, Metals Division.
Mr M. W. Perrin, T.A. Directorate (D.S.I.R.)—*Secretary*.

The chemical research was co-ordinated by a panel reporting to the T.A. Technical Committee. The constitution of this Panel was:

Professor W. N. Haworth, Birmingham University—*Chairman*.
Dr R. E. Slade, ICI.—*Vice-Chairman*.
Dr F. E. Simon, Oxford University.
Dr J. P. Baxter, ICI, General Chemical Division.
Dr J. Ferguson, ICI, Alkali Division.
Mr J. R. Park, ICI, Billingham Division.
Mr M. W. Perrin, T.A. Directorate (D.S.I.R.)—*Secretary*.

Uranium metal production and metallurgical matters were handled by a Metal Panel, whose members were:

Mr E. Colbeck, ICI, Alkali Division—*Chairman*.
Dr W. O. Alexander, ICI, Metals Division.
Dr N. P. Allen, National Physical Laboratory.
Mr G. L. Bailey, British Non-Ferrous Metals Research Association.
Dr A. M. Roberts, ICI, General Chemicals Division.
Dr F. E. Simon, Oxford University.
Mr D. C. G. Gattiker, T.A. Directorate (D.S.I.R.)—*Secretary*.

(iii) Research Contracts Patents

The contracts under which research is carried on in university laboratories contain clauses reserving exclusively to the Government all discoveries, inventions and other results arising from the work. In the case of researches carried on by industrial firms all results, inventions and developments in detail applicable within the T. A. field become exclusively the property of the Government. Where an invention is also usable outside the T. A. field provision has been made whereby its use outside the field can be made available to industry. It is within the discretion of the Government to decide whether or not a particular use is within or without the field. Questions relating to inventions and patents are dealt with by a small Patents committee composed of:

Mr. A. Blok, D.S.I.R.—*Chairman*.
Mr. W. A. Akers, Director T.A. (D.S.I.R.).
Mr. M. W. Perrin, T.A. Directorate (D.S.I.R.).

(f) Joint British-Canadian-American Slow-Neutron Project in Canada

Towards the end of 1942 it was decided that the slow-neutron research in progress at Cambridge would proceed more quickly and efficiently if it were transferred to a place geographically nearer to Chicago where the corresponding American work was being carried out.

A proposal was made to the Canadian Government that a joint British-Canadian research establishment should be set up in Canada, to work in close touch with the American group. The Canadian Government welcomed the suggestion,with the result that, at the beginning of 1943, a large research establishment was set up in Montreal under the general direction of the National Research Council of Canada.

Practically the whole of the Cambridge group, under Dr. Halban, was moved to Montreal, where the research staff was rapidly augmented by many Canadian scientists, several new recruits from the United Kingdom and a certain number from the United States. The laboratory was at first directed by Dr Halban. He resigned this position early in 1944 and professor J. D. Cockcroft was appointed to succeed him.

During the Spring of 1944 the Americans joined actively in that project which now became a joint British-Canadian-American enterprise. Its scope was enlarged and in 1944 a site was selected on the Ottawa river, near Petawawa, Ontario, for the construction of a pilot scale "pile" using "heavy water", supplied by the US Government, as the slowing-down medium.

This joint enterprise in Canada has been described more fully in statements issued by the Canadian Government. It represents a great contribution, both in men and money, by that Government to the development of this new branch of science and its application.

(g) *Transfer of British T. A. Research Groups to USA.*

In August, 1943, Sir John Anderson visited America and discussed with the US authorities the means by which the co-operation between the two countries might best be placed upon a more formal basis. Further discussions took place subsequently between President Roosevelt and Mr. Churchill which led to the setting up of a Combined Policy Committee in Washington.

Professor Sir James Chadwick who was appointed Scientific Adviser to the British members of this committee examined, with those responsible for the scientific and technical direction of the American project, the question whether there were any further steps which could be taken, in the pooling of scientific and technical effort, which would accelerate the production of atomic bombs in the USA.

As a result of these discussions it was decided to move to America a large number of the scientists working in England on T. A. in order that they might work in the appropriate American groups.

At this time Professor Bohr escaped from Denmark and the British Government appointed him as an adviser on scientific matters. His scientific advice on the T. A. project has been available both in this country and in the United States to the two Governments.

Professor Oliphant and his team from Birmingham University were moved to Berkeley to work with Professor Lawrence's group engaged in research on the electro-magnetic isotope separation project. They were joined by other physicists from Britain including Professor Massey of University College, London, Dr T. E. Allibone and Dr K. J. R. Wilkinson who worked partly at Berkeley and partly at the electro-magnetic separation plant itself. Dr Emeleus of Imperial College, London, Dr J. P. Baxter and others wre transferred to the electro-magnetic plant. Dr. Frisch from the Liverpool nuclear physics group and Dr. Bretscher from the corresponding Cambridge section, together with some members of their teams, were moved into the great American T. A. research establishment at Los Alamos, which is described in American statements on the project. They were joined, at that time or later, by a number of other

British scientists including Professor Peierls and Dr Penney, of Imperial College, London University. Professor Sir Geoffrey Taylor also paid several visits to this establishment.

The effect of these transfers, and others which were made to the Montreal project, was to close down entirely all work in the UK on the electro-magnetic process and to reduce almost to nothing the nuclear physical research. Nevertheless there is no doubt that this was the proper course to follow in the light of the decision which had been taken to give the highest priority to the production, in the shortest possible time, of an atomic bomb for use in this war.

1.3.7 THE ATOM BOMB*

On August 6, 1945, the American made atom bomb exploded over the Japanese city of Hiroshima and blasted to atoms Japan's iron will to fight to the last. More important than this spectacular incident was the fact that it signified the advent of the Atomic Age, and the unfathomable future for mankind to which it may lead.

On the other hand, apart from its frightfulness, the story of evolution of atom bomb is a scientific romance of the most absorbing type. It represents the greatest co-operative effort for a single purpose of a great State and of its scientists and technicians so far known to history.

The origin of our story can be traced to several discoveries made in laboratories within the last thirty years. The most important are:

(1) Transmutation of Elements,
(2) Equivalence of Mass and Energy.

The idea of 'Transmutation of Elements' has been familiar since medieval times, when the alchemists dreamt of converting base metals to gold. Needless to add that the claims often made in medieval and even in modern times have been found to be uniformly false, and modern science has told us clearly why transmutation was not possible, with the aid of appliances available till recently. Science has proved that the world is made up of 92 different elements, each element having a distinct personality of its own. It was no more possible to convert one element to another than it is possible to convert Jinnah to Gandhi.

But let us seek to find out what is the cause of the distinct personality of the elements. It has been found that the atom consists of two distinct parts, namely

(1) the heart or the core of the atom which in scientific language is called the nucleus, and
(2) the outer shell of electrons.

The nucleus contains all the mass and a positive charge equal to

*Full text of a lecture before the Royal Asiatic Society of Bengal, Calcutta, on Jan. 11, 1946 on the occasion of the Bicentenary of the Birth of Sir William Jones: Sci & Cult, **17**, 645, 1946, an integral number of unit charges. The electrons are minute bodies, almost without mass, but having negative charge. It has been found that it is these electrons which determine the chemical and physical properties or what we may call 'the personality of the atom'.

But the passivity of the nucleus is only apparent, for the number of the electrons, and their movements which give rise to physical and chemical properties are ultimately determined by it. The nucleus is somewhat like the 'party-boss' which remains in the background and apparently allows its followers freedom to fight and wrangle in any way they like, but actually determining every one of their steps. Hence if we change the properties of any atom, we must reach the nucleus, just as if we wish a political party to behave in a different way, we must approach the party-boss.

This is not an easy task; for ordinary chemical and physical methods at the disposal of the earlier chemists and physicists touch only the outer fringe of electrons. The nucleus, like the party-boss, is a tougher problem. He cannot be touched by ordinary methods. But a way was found by Lord Rutherford in 1919. It consists in subjecting the atom to bombardment by high energy α-particles which are obtained from radium-like bodies, and have terrific energy of the order of millions of volts. Even here we can push the analogy of the political party. Like the party-boss, the nucleus belongs to a higher caste than the electron and can be approached only by one of its own caste. Such are the α-particles which form the nucleus of the helium atom, the nucleus of the hydrogen atom or what we call the proton. But they are usually repelled by the nucleus, and if they have to make any impression on the nucleus, they must be endowed with tremendous energy measureable in millions of electron volts. The α-particle is obtained in Nature from naturally radioactive bodies like radium. If we wish to impart to the proton the same order of energy, we must use the cyclotron, the Van de Graaf generator, and other million volt generators which have been invented only after the First World War.

When the nucleus was attacked with these new appliances, it was found that its composition was relatively simple, for it was found to consist of two fundamental elements: (1) the proton, and (2) the neutron.

The proton is the nucleus of hydrogen, i.e. hydrogen minus its electron. It can be easily prepared by robbing the H-atom of its electron and then accelerating it through high voltage apparatus. It has a positive charge and the mass of H-atom.

The neutron is a new fundamental particle which is obtained when light elements are bombarded intensively by protons or α-particles. It has slightly larger mass than that of the H-particle, and it has the further advantage that, having no charge, it can enter all nuclei. Hence if we have a good supply of neutrons, we can easily smuggle the neutron into the citadel of the nucleus and watch what happens.

But this is a very difficult technical process. To have a sufficient supply of neutrons, we must have specially designed apparatus producing high speed particles having million volts of energy, or an abundant supply of radium which is an expensive material. By 1934, first class physical laboratories over many parts of the world had equipped themselves with neutron generators.

In 1934, Fermi, an Italian physicist, who had at his disposal a large quantity of radium, tried to solve an age-old problem with the aid of these new techniques. Why are the number of elements limited by the number 92 ? Why have we no element beyond 92 ? Can we not, by smuggling the neutrons into the nuclei of atoms, produce elements beyond 92—the so-called transuranic elements ?

He tried the experiment and found that when the 92nd element U is bombarded by neutrons, a minute fraction of the uranium mass develops new types of chemical properties. He concluded, rather hastily as it seems now, that elements 93, 94, 95, 96 were being produced. But these conclusions were challenged. These elements are not known on the earth; their properties were only matters of guess, and chemists hotly contested the claims of Fermi. Subsequent events proved they were right, but some claims of Fermi appear to have been genuine, *viz.*, the formation of elements 93 and 94, which are now known as neptunium and plutonium. The last is used as the main charge in atom bombs. I heard the story in America that when Fermi produced element 94, he approached Mussolini and sought his permission to christen the new element after him as Mussolinium, but the Duce refused to lend his name to the new element, as he understood it to be unstable.

Fermi was awarded a Nobel Prize in physics in 1939 for his discoveries, went to Stockholm in 1939 to receive the Prize, and, instead of returning to Rome, ran away to the hospitable shores of USA. It was said that he was afraid of persecution, as his wife had some little percentage of Jewish blood in her. This closes the first chapter.

Fission of the Uranium Nucleus

The second chapter opens with the entry of Otto Hahn and his collaborateurs in the field. Otto Hahn, a former pupil of Lord Rutherford, is a noted chemist who had specialized in radioactive elements. He was director of the Kaiser Wilhelm Institute in Chemistry in Berlin-Dahlem. By a series of extremely careful and painstaking experiments for which German scientists are famous, he and his co-workers cleared up the whole mystery of Fermi's transuranic elements. He proved that when uranium was bombarded with neutrons, one of the elements produced was undoubtedly barium which is element No. 56, and he very soon proved that some new types of the inert gas xenon, No. 54, and other elements from 50 to 57 were being produced.

This was a most revolutionary announcement, for uranium is element No. 92, and if on its bombardment with neutrons barium and elements near about 50 are produced, there is only one conclusion; that the nucleus of uranium is broken up into two nearly equal fragments by neutron bombardment. This point of view was very thoroughly proved by Hahn and his collaborateurs, amongst whom may be mentioned Lise Meitner, a woman scientist of nearly 60, who had been Hahn's lifelong collaborateur, Frisch, and many others. Some of these scientists had various proportions of Jewish blood in them and had shortly to leave the country owing to the Nazi race policy.

But why does the fission take place at all ?

This question was immediately asked, for uranium is a very stable nucleus and, though radioactive, its activity is feeble. The impact of neutrons alone was not in itself sufficient to break it up. Further it was soon shown that even very slow neutrons can break up uranium. No other element except uranium and elements 91 and 90 showed any susceptibility to fission. There is, therefore, some latent instability in the nucleus of uranium. The introduction of the neutron acts merely like a trigger—in fact, it is like the throwing of a lighted match box in a magazine of gunpowder.

Conversion of Mass to Energy

A great discovery made by Einstein in 1905, as a byproduct of his theory of relativity, forms the cornerstone for all calculations of nuclear energetics. Einstein had proved with purely mathematical arguments the equivalence of mass and energy. This theorem was regarded with scepticism for a long time; for which two physical quantities can be more unlike than mass and energy ? Mass is the quantity of matter contained in a body and energy is the capacity of matter to do work, on account of its motion. Energy can be manifest in the form of light, electricity, heat or in the form of chemical reactions, but ultimately these different forms of energy can all be reduced to motion and can be made to perform work. But how can inert matter itself be regarded as a form of energy ?

Einstein's law said that $E = mc^2$
i.e. a gram of inert matter is equal to 9×10^{20} ergs. This is equal to 2×10^{13} calories, or 2×10^{10} kilocalories, and can be obtained only by burning 2,500 tons of coal. Fancy somebody suggesting that a small cube of coal, each side measuring $\frac{1}{2}''$, contains as much energy as can be obtained by burning 5 train-loads of coal. Is not the deduction fantastic ? But in spite of its paradoxical nature the logic of Einstein's mathematics was inexorable.

Let us now see how Einstein's law is applied to explain the energetics of nuclear reactions. When we hit one nucleus A by another nucleus B, generally new products are formed, say C and D. If we work out the energetics of nuclear reactions, we find that the masses of A and B added together are somewhat different from those of C and D. This violates the time honoured principle of the law of conservation of mass, which says that mass can neither be destroyed nor created. But in nuclear reactions, some mass apparently disappears, thus violating the conservation of mass law. But Einstein's law says that there has been no violation, only the missing mass has been converted to energy. Let us now examine from this standpoint the particular features of fission-energetics.

The mass of the uranium-nucleus, as well as the masses of the fission products have been accurately determined, or at least can be obtained with tolerable accuracy from certain theoretical considerations where they are not available. It has been found that the mass of the uranium nucleus is larger than the combined masses of the products of decomposition by about a one-fifth of the mass of the proton, or 1/1000 the mass of the U-nucleus. What happens to this mass ? This must be liberated in the form of energy. This deduction was put to experimental test and was found to be correct.

This laboratory discovery was of tremendous importance for the science of energetics, for by this method we obtain from fission of 1 gm of uranium-matter as much energy as is obtained by burning 2·5 tons of coal, or one pound of uranium will give us as much energy as 1000 tons of coal. It is far shorter of the Einstein-maximum of 2,500 tons, but still it is 10-million times larger than the ordinary methods of energy-production by the burning of coal.

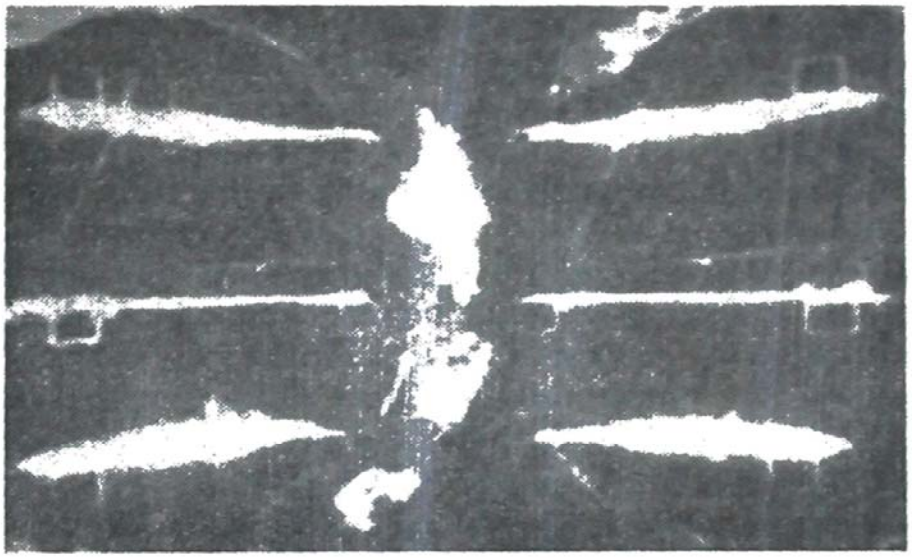


Fig. 1
[Photograph showing heavy fission particles recoiling in opposite directions from uranium film under neutron bombardment. From the nature and length of tracks, the energy of the fragments was calculated and Einstein's law was verified.]

Let us illustrate the case by a concrete example.

In 1938, England required, for running her factories, nearly 40,000 million units of electrical energy, and this she obtained by burning 25 million tons of coal, dug from her mines, distributed over her grid stations, and burnt there as fuel to produce the steam that ran the turbines which energized the generators of electricity, which through the grid transmission line, was brought to the door of the consumer. Now the new discovery signifies that if we take a cube of uranium oxide, measuring a yard each side, and subject it to fission-process, it will give us all the energy which England derives from the combustion of 20 million tons of coal. If the discovery could be turned to practical technics, coal mining for power-generation would no longer be necessary.

Is not, therefore, the discovery revolutionary ? But it is more than that for the experiment proves that uranium metal is a far more potent explosive than gunpowder, trinitrotoluene, ammonium nitrate or other chemicals which have been invented by the ingenuity of ancient and modern chemists, including Nobel. A two-ton bomb filled with trinitrotoluene releases 3×10^5 kilo calories of energy and can blast houses within 200 yds. of the explosion. A two-ton U-bomb will release 10^7 times more energy and will blast an area of 20 miles radius. But can this idea be practically realized ?

Probably nobody would have thought of pursuing the idea but for the outbreak of the Global War. We find in May, 1939, a few months before the outbreak of the war, certain German scientists discussing seriously the possibility of utilizing uranium fission for the creation of energy, and perhaps they were thinking of the atom-bomb as well. But, as subsequent events showed, the German Government committed two capital blunders. They allowed free publication of the news of uranium fission, and they turned some of their best scientific workers on this subject, amongst them some of the collaborateurs of Hahn, out of the country. It was part of their doctrine of racial superiority of Germans. Seldom has any country paid a greater price for such arrogance.*

How America was roused to 'Atom-activity'

It appears from Smythe's report that though the news of the discovery of uranium fission had spread amongst the British, French and American physicists, and some very valuable experiments were carried out in support of Hahn's work, the American physicists never seriously entertained the idea of turning fission energy for making a machine of destruction. It was the German refugee professors, Lise Meitner, Frisch and others, who after their expulsion from Germany conveyed the news to the great physicist Niels Bohr in Copenhagen, who shortly afterwards went to the USA as a visiting professor at Princeton. Bohr made a most significant contribution to the subject; he proved that it was not the abundant isotope U^{238}, but the far rarer isotope U^{235} (occurring in the proportion of 1 : 140) which is most sensitive to fission. Secondly, in a joint work done in the USA with his student Wheeler, he cleared up the mechanism of the fission-process and hinted at the possibility of creation of other nuclei by

*The only parallel, but a very faint one, is the expulsion of Spanish and Portuguese Jews in the sixteenth century by His Most Christian Majesty Philip II of Spain, on the score of their religion. These Jews found hospitable asylum in Holland, Germany and other countries and contributed in no small measure to their rapid industrial and colonial organization. A batch was received by the Sultan of Turkey who exclaimed, "Allah must have mercifully confused the brains of the infidels, for otherwise how could they commit the folly of turning out such fine stuff out of their country." We can make the same remarks over the obituaries of German Nazism and Italian Fascism.

artificial methods which would prove equally or far more susceptible to fission.

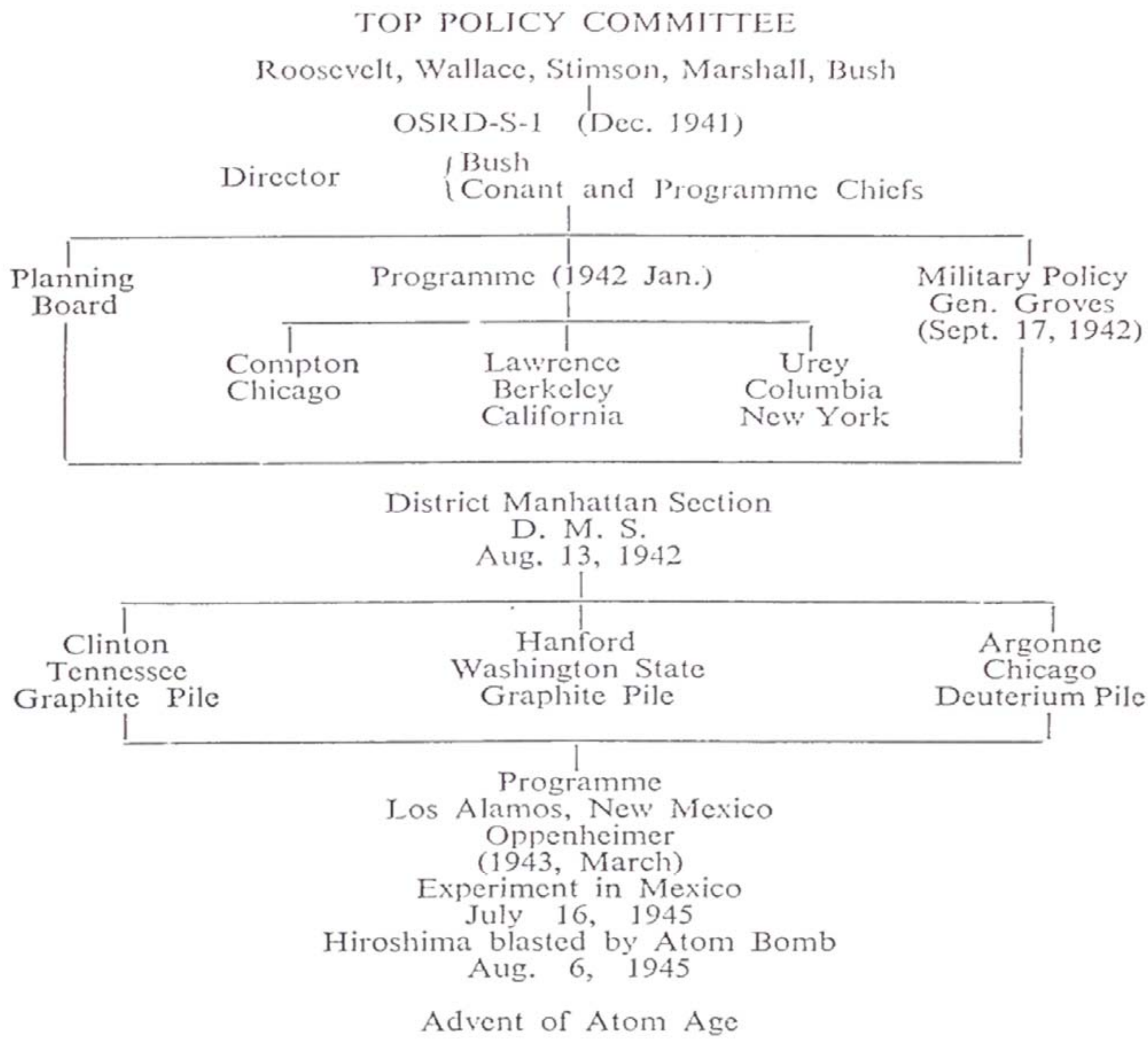
After the war broke out, three German refugee professors, Szillard, Wigner and Teller, and the Italian Fermi, who were conscious of the potency of the new discovery, began to agitate for the control of publication of research work on U-fission, and also for the sponsoring of a generous scheme of exploitation of the discovery for war purpose by the Government of USA, but they appeared not to meet with any response from the general body of US scientists. These men then enlisted the support of Einstein who wrote a personal letter to President Roosevelt recommending the measure for his serious consideration. The President appointed a Uranium Committee under the NDRC to investigate the claims of the discovery. It appears that the report of the Committee was not at first very favourable, but things brightened up when a Reviewing Committee under Professor A. H. Compton, Dean of the Faculty of Science of Chicago and a famous physicist, was set up by the National Academy of Sciences. This Committee whole-heartedly recommended for the war-time exploration of the discovery, and the President accepted its findings by entrusting the work to the OSRD under Vannevar Bush. The progress of the work is illustrated in the following charts:

CHART I

CALENDAR OF EVENTS

Discovery of U-fission in Germany by Otto Hahn ..	January, 1939
German scientists discuss possibility of using fission energy	May, 1939
Niels Bohr spreads news to USA and interests American physicists	June, 1939
German refugee scientists Szillard, Wigner, Teller, Weisskopf and Italian refugee Fermi agitate for Government action on utilization of fission energy and on their suggestion, Einstein writes personally to Roosevelt	July, 1939
President forms Advisory Committee on Uranium under NDRC	
NRDC's Reports First adverse	November, 1939
Second encouraging	April, 1940
Reviewing Committee of Nat. Acad. Sc. under A. H. Compton recommends serious government action	May, 1941

CHART II



Pilot Plant Work by Programme Chiefs

The most important objective before the programme chiefs was: (1) The separation of U^{235} from U^{238},(2) The preparation of plutonium.

The element uranium is fairly well distributed over the whole world, but it consists of three isotopes having the weights 234, 235, 238, of which 238 constitutes more than 99 per cent of the natural element. But this is relatively inert for fission. It is the isotope 235, occurring in the proportion of 1 in 140, which is active. If the uranium bomb is to be active, it must be composed entirely or at least to a large measure of U^{235}.

But this separation is not an easy task, for the chemical and physical properties of 235 and 238 are identical, and they cannot be separated by ordinary chemical methods. Special methods had to be used, involving enormous layout in machinery and power. The difficulty of the task may be gauged from the fact that Aston who first tried in 1906 to separate Ne^{20} from Ne^{22} spent ten years in this task, but without any success. Subsequently, however, several methods of dealing with this difficult task have been found. These are:

(1) Thermal diffusion, (2) Gaseous diffusion,
(3) Centrifugation, and (4) Electromagnetics.

Though the principles of the four methods have been well known for some time, none of them had, however, been used for any large scale separation of heavy isotopes. In 1940 the electromagnetic method alone had been used by Nier to separate a few micrograms of U^{235}. The OSRD-S-1 executive committee, therefore, decided to attempt all the four methods simultaneously, expecting that at least one and perhaps more of the methods may turn out to be practicable. It was a very courageous decision; for we require a few kilograms of the material, and the scale of operations over that of Nier has to be multiplied by a factor of 10^9, i.e. a thousand million times.

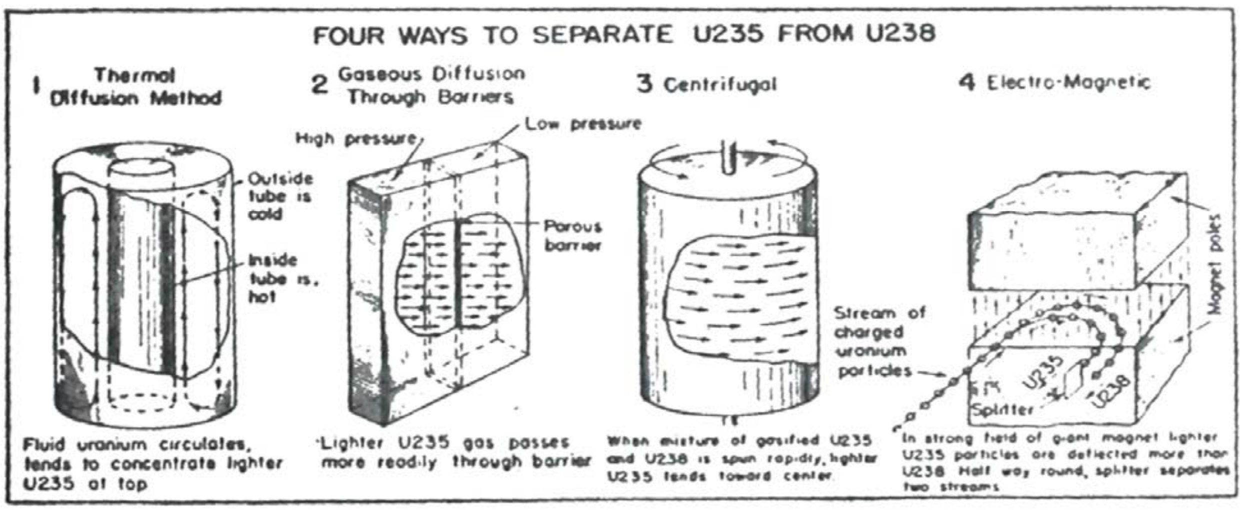


Fig. 2

Thermal Diffusion.—The thermal diffusion method which, according to a report by Urey, is the most powerful one was discovered by R. Clusius of Munich as late as 1938, and was used to separate gases of different weights by allowing the gas to flow between a hot inner cylinder, generally a wire, and a cold outer cylinder. The lighter gas tended to concentrate near the top of the hot surface and the heavier gas at the bottom as illustrated in the figure.

This method is primarily applicable only to gases, and to a slight extent to substances in solution. By using long columns, Clusius had achieved the complete separation of Cl^{35} from Cl^{37}, Ne^{22} from Ne^{20} and so on. This method requires an enormous outlay in cooling agents like liquid air or liquid carbon dioxide.

It is understood that uranium was used in the form of uranium hexafluoride UF_6 which, though a solid at ordinary temperatures and highly reactive, becomes a gas at 150°C. It is not stated whether this gas or UBr_6 was used.

Gaseous Diffusion.—The method of gaseous diffusion was proposed first by Lord Rayleigh and tried by Aston and Hertz, in which the gas is allowed to pass through a porous barrier. The lighter gas atoms tend to pass through the barrier more easily than the heavier ones as shown in the second diagram.

Centrifugation.—The third method, that of the ultracentrifuge, was invented by the Svedborg of Sweden and developed in USA. by Beams. The gas is spun at a high speed in a container. Due to the very high centrifugal forces developed, the heavier isotope is thrown towards the periphery of the container. The lighter fraction concentrates near the centre. In these three methods a direct separation of the two isotopes of uranium is not actually obtained, but a step by step small enrichment in U^{235} isotope in one fraction is obtained. A number of steps of the enrichment process are undertaken, the number of steps being determined by the percentage purity of U^{235} desired.

The actual attempt to separate U^{235} in quantity by all these methods was undertaken under Professor Urey, who was the programme chief and worked at Columbia University and later near Oak Ridge in Tennessee, and developed into a gigantic effort costing initially over 2 million dollars. Firms like the Westinghouse, the General Electric Companies, and the Du Pont du Nemours co-operated in solving the problems involved.

Electromagnetics.—The mass-spectrographic method of isotope to separate U^{235} was developed mostly at Berkeley under the direction of Lawrence as the programme chief, in which was employed a giant electro-magnet and uranium ion currents of many amperes in strength. The stupendousness of the undertaking can be imagined from the fact that even in1940 Nier had used the mass spectrograph to separate only a few micrograms of U^{235}. The power requirements in such an undertaking were enormous and 8 to 9 million dollars were spent in this project. In this connection mention may be made of another electromagnectic device invented and developed during this war, which

has also been fruitful in this investigation. R. R. Wilson, its inventor, **has used a** modification of the 'Klystron' principle to heavy uranium **ions,** and it is called by the deliberately chosen misleading title '**Isotron**'.

These preliminary experiments, under grants by the OSRD, were carried out at various institutions, some of the important centres being Columbia and California Universities, at a cost of several million dollars. The final conclusion that was arrived at was that mass-production of U^{235} of the order of kilograms was difficult and very costly, but could be done in a year's or more time.

The Pile.—In the meantime interesting work had been done by Fermi and Segre, two refugee Italian scientists, and by others who showed that the U^{238} isotope, when it captured a slow neutron, changed in two steps into a hitherto unknown element Pu^{239}. It was pointed out that this element Pu^{239} could be also susceptible to fission by slow neutrons and could be used in a chain reaction like U^{235}. A group of research physicists, under Compton (programme chief), concentrated their efforts to find a suitable method for large scale prodution of Pu^{239}. This was all the more desirable since Pu^{239} being a different element could be separated by simple chemical means and could compare favourably with the complicated mass-spectrographic separation of U^{235}. The efforts of the Chicago group resulted in 1942

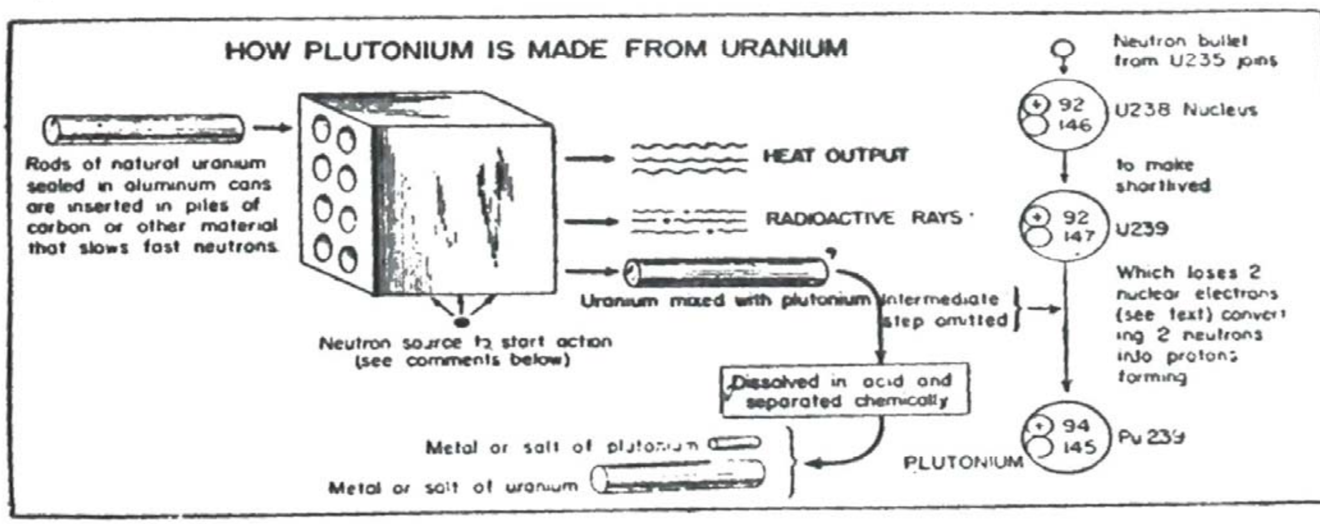


Fig. 3

in the graphite pile. It consisted of about 6 tons of *pure* uranium and about 12 tons of *pure* graphite arranged in the shape of a spheroid or cube.

Uranium was arranged in lumps of a few cm in diameter in the matrix of graphite. Any neutron released by the fission of U^{235} would be slowed down by collisions with the carbon nuclei in the graphite matrix. Some of the slow neutrons would in turn cause further fission of U^{235} in the neighbouring lumps in the matrix. A fraction of these neutrons can be captured by U^{238} isotope forming U^{239} which will give rise to plutonium after two successive β-distintegrations. Another fraction of the neutrons will of course be lost due to escape from the surface of the pile and by capture by the nuclei of other chemical elements present as impurities in carbon and uranium. Once started, such a pile will be self sustaining, since U^{235} is giving the neutron on fission and will continue to 'burn' until all the U^{235} and the Pu have been 'consumed'. The rate of energy generation depends on the number of fissions per second which is of the same order of magnitude as the number of plutonium atoms generated.

Thus for one gramme of plutonium 8×10^{27} erg of energy is released.

This energy goes to heat up the whole pile which has to be cooled by circulation of water or other coolants. The first pile was made at Chicago and operated successfully for the first time in December, 1942. It was a modest effort with 6 tons of uranium and with a power generation of 1 watt. Immediately after the success of the first pile, a much larger pile with a much larger amount of uranium was attempted at Clinton in the Tennessee Valley, operating at a level of 100 to 1000 kilowatts. Still later an even larger pile was built at Hanford in Washington State with a power level over 100,000 kilowatts and using the water of the Columbia river as a coolant. It was this last pile at Hanford that gave plutonium in large enough quantities that later went to the manufacture of the atom bombs in the self-sustaining graphite piles at Hanford for the production of plutonium.

From Pilot Plant to Manufacture

After the programme chiefs had demonstrated the possibility of large scale manufacture of U^{235} and Pu^{239} the functions of the planning board were taken over by the Army, and Major General Groves was placed in charge of the project which came to be known as the DSM-project (Development of Substitute Materials), and it was placed under a section of Army Engineers known under the code name of Manhattan District. Huge industrial plants were erected at three newly created cities at Clinton near Oakridge, Tennessee, Hanford in the State of Washington, with the co-operation of such great American industrial firms as Du Pont du Nemours, Westinghouse, General

Electric Co., Stone and Webster Engineering Corporation, and others, too numerous to mention and at Los Alamos, New Mexico. A pilot graphite-pile which could produce about 10 grammes of Pu^{239} a day and generated nearly 2,000 kW power continuously was built at Clinton, Tennessee. At the same time they built at Hanford, Washington, a graphite pile to produce a kilogram or more of Pu^{239} per day, which produced a continuous power of 200,000 kW. To dissipate this huge amount of energy, the whole flow of the Columbia river was used as the coolant. The large pile used hundreds of tons of uranium and graphite, all exceptionally pure. The production of pure uranium is a problem of first class dimensions. In 1939, even 20 grammes of pure uranium was unobtainable, because the chemistry of uranium is difficult and traces of impurity are difficult to eliminate. The chemistry of plutonium is another problem. Its properties were matters of speculation, one school holding that it resembled a transitional element, something like osmium, and the name eka-osmium has sometimes been given to it. The second school held that with $_{89}Ac$ a second rare earth group started which makes plutonium to be very similar in its properties to uranium, or rather to samarium. Now separation of rare earth elements is a very difficult job, but services of the chemists who have specialized in this line were obtained, and methods of separation were worked out, and then translated to industrial scale.

The magnitude of the operations can be obtained from the following figures.

The worker in the laboratory had worked with a few micrograms of uranium^{235} and plutonium^{239}. The programme chiefs had produced about $\frac{1}{10}$ gm of each in their pilot plant experiments which cost several million dollars. The large scale engineering works at Clinton and Hanford produced about a kilogram per day of these previous atoms.

When the production of sufficient explosive atoms was fairly on the way, another station was opened at Los Alamos in the New Mexican Desert, under programme chief Dr Oppenheimer, peace-time professor of theoretical physics in the University of California. Here the atom bomb was finally assembled and tried. The details of mechanism of assembly and control of detonation are not, however, disclosed. According to one version, there is a critical size for detonation, so that ordinarily the pieces are kept apart, and by a robot mechanism, they are brought together at the desired moment, and fired by neutrons obtained from radium-beryllium mixture.

The final testing took place on a steel tower in the deserts of New Mexico on July 16, 1945. Here the precious material was mounted in the early hours of the day and detonated by a robot mechanism at 5-30 A.M. in the presence of Army chiefs and scientific programme chiefs and workers, stationed at safe distances. As the world knows, the explosion went off as calculated. It is described as follows in Smythe's report:

"Two minutes before the scheduled firing time, all persons lay face down with their feet pointing towards the explosion. As the remaining time was called from the loudspeaker from the 10,000-yard control station there was complete awesome silence. Dr. Conant said he had never imagined seconds could be so long. Most of the individuals in accordance with orders shielded their eyes in one way or another.

"The time signals, 'minus 20 minutes, minus fifteen minutes', and on and on increased the tension to the breaking point as the group in the control room which included Dr. Oppenheimer and General Farrell held their breaths, all praying with the intensity of the moment which will live for ever with each man who was there. At 'minus 45 seconds', robot mechanism took over and from that point on the whole great complicated mass of intricate mechanism was in operation without human control. Stationed at a reserve switch, however, was a soldier scientist ready to attempt to stop the explosion should the order be issued. The order never came.

"At the appointed time there was a blinding flash lighting up the whole area brighter than the brightest daylight. A mountain range three miles from the observation point stood out in bold relief. Then came a tremendous sustained roar and a heavy presure wave which knocked down two men outside the control center. Immediately thereafter, a huge multi-coloured surging cloud boiled to an altitude of over 40,000 feet. Clouds in its path disappeared. Soon the shifting substratosphere winds dispersed the now grey mass.

"The test was over, the project a success.

"The steel tower had been entirely vaporized. Where the tower had stood, there was a huge sloping crate. Dazed but relieved at the success of their tests, the scientists promptly marshalled their forces to estimate the strength of America's new weapon."

The Advent of the Atomic Age and After

The advent of the atomic age has brought fresh problems to an already sorely tried world. What will it lead to—One Power World or One World?

According to *Nature*, the well-known London scientific weekly, "Great Britain, the USA, and Canada hold (in the atomic bomb) a weapon with which they can dominate the world."

This view is perefectly correct, but it is not probably realized that the atom bomb cannot be prepared by any individual or private institution as chemical bombs could be prepared in old days by revolutionaries working in small underground chambers. Nay it is even impossible for small sovereign nations, or technically undeveloped sovereign countries, to undertake the making of atomic bombs even on a modest scale, for the demand on power, chemicals, and technical personnel for undertaking such a job is immense. For example, the total electrical energy which is now being produced in India and the raw materials and technical knowledge available are hardly sufficient for the making of more than one or two atom bombs in a year. Only sovereign countries, having ample resources in power, technical knowledge, and requisite raw material can undertake manufacture of atom bombs in the laboratory.

According to Vannevar Bush, it will take a country satisfying the above conditions three to five years, before it can successfully prepare atom bombs. Others would bring down the period to two years.

Claims have been made that new types of atom bombs are on the way. Since nuclear physics went underground during the war, and it has not yet come up to the surface, it is difficult to judge about these claims. But some may be evidently disposed of—the fission process converts only $\frac{1}{100}$ of mass to energy. Will it even be possible to convert the whole mass to energy? If it could be done, we shall have a super atom bomb.

For this purpose, we require 'Anti-matter' or matter in which the nucleus is negatively charged, consisting of negatively charged protons and antineutrons, with outer shells of positrons. The existence of such matter has been rendered probable on theroetical grounds, and from astrophysical explorations of the world, but such matter has not yet been produced. Klein argues that cosmic ray phenomena are due to the injection of such matter into our atomisphere, and he has made a plausible case for his argument. But the production of such matter in the laboratory still appears to be a distant dream.

We may easily discount other large claims, but "Science is frontierless, and Genius are found in all climates."

The fact remains, as Prof. Urey, one of the programme chiefs, says, that more deadly atom bombs are being made and a number of these at the command of the power-intoxicated military can wipe out all large centres of population. In the USA, a gigantic struggle appears to be going on at the moment between scientists and a section of the military, between upholders of the idea of One World and One Power World.

But would Anglo-America who fought for the extirpation of Nazism in Germany and Fascism in Italy and Japan adopt the very same doctrines for their future guidance? Who would have their soul, Christ or anti-Christ?

1.3.8 INDUSTRIAL UTILIZATION OF ATOMIC POWER IN INDIA*

In an article published in *Science and Culture* a couple of years ago, attention was drawn to the desirability of supplementing the fuel resources of India by more direct methods of harnessing solar energy.

The existing world resources in coal and mineral oil, it was pointed out, were the result of utilization of solar energy by the photosynthetic activity of green plants growing in earlier geological ages, which has been stored as transformed plant and animal remains. It was suggested that in view of the impending exhaustion of these fuel resources, more attention should be given to the cultivation of land and sea vegetations, and of their utilization as sources of fuel and power, and also for the development of methods of transformation of solar radiation to electricity, by means of photoelectric cells with high efficiency of transformation. Since the article was written, the dropping of atomic bombs on two Japanese cities has revealed the possibility of utilizing atomic energy for generation of useful power. It is interesting to note that in utilizing atomic power, man is using the same process as is used in the sun, for the apparently inexhaustable production of radiant energy.

Leaving aside the question of utilization of nuclear fission for military purposes, in which we are not interested and whose logical pursuit by the rival power groups will mean the destruction of the present form of civilization, we propose in the present article to discuss the question how far atomic energy can be utilized for industrial purposes, what will be the economics of using of atomic fuel as compared to those of using coal and oil, and what are the world resources in fissionable metals compared to the known resources in coal and oil. We shall then use the information so gathered to discuss the feasibility of using atomic energy for industrial purposes in India. The reason for this enquiry is well-known. India's resources in coal, so far as is known at present, is limited. There is a consensus of opinion amongst experts, that the available high grade coal seams should be reserved for metallurgical purposes only. Our known oil resources are also negligible, and we have to depend mainly on foreign supplies to meet

* Sci & Cult, **13**, 86 and 134, 1947. (unsigned)

our ever increasing requirements in oil. Our utilization of hydro-electric power is increasing, but there is a limit to our water power resources, and there are wide tracts including desert areas, where water power is not available.

On the other hand India has a potential source of atomic power in the rich and extensive deposits of thorium containing monazite sands, principally in Travancore, but also in the east coast districts of Madras, in Tinneveli and Waltair. Estimates of the total quantity of such deposits vary widely, as well of their contents of thorium. As a mean of different estimates we can take it to be 3 to 4 million tons, with an average thorium content of 8 to 10 per cent.

Nuclear fission.—As introduction to the subject of atomic energy, we shall begin with a short account of the nuclear fission process, how the energy is released during fission, and of the principle of atomic reactor. As is well known, each atom consists of an inner dense core, the nucleus and an outer distribution of electrons, in a volume large compared to the dimension of the nucleus. The nucleus is made up of a chemical combination of two kinds of fundamental particles, protons and neutrons, which are approximately of the same mass; while the proton carries a unit of positive charge, the neutron is uncharged. The force of attraction between the nuclear particles, like the gravitational attraction and unlike ordinary chemical forces, is not of electrical origin; it only acts at extremely short distances, of the order of 10^{-13} cm which is the order ot nuclear diameter. The atomic diameter on the other hand is of the order of 10^{-8} cm. A nucleus is characterised by the total number A of nucleons (neutrons and protons) contained in it, of which Z are protons. In an atom with nuclear charge Z, there are Z outer electrons, which go to make the atom neutral. Thus the chemical properties of an atom depned upon Z, which is called the atomic number. Coal and oil which are used for fuel purposes are made up of carbon and hydrogen atoms, which can, under special conditions, be made to combine with oxygen to produce carbon dioxide and water. A large amount of chemical potential energy is released during such a process, and appears as heat, which can be used to drive heat engines to produce mechanical and electrical power. During a chemical combination there is a rearrangement of the outer valency electrons of the combining atoms, which go to form a common shell round the two nuclei with their inner electron shells. The energy released during such combination, as will be shown, is small compared to that involved in a nuclear combination. But in each case the principle of equivalence of mass and energy, first clearly enunciated by Einstein holds, *viz.*, that interaction between particles involving release of energy is always accompanied by a loss of mass $\triangle M$ of the interacting particles, such that if W is the amount of energy released, then $W=\triangle M.c^2$ where c is the velocity of light. For example one pound of the 235 isotope of Uranium during fission will give up as much heat as the combustion of 1500 tons of coal. The chemical energy released during combustion is so small that it does not produce any measurable change in the total mass of the reacting particles, while the 1 lb of U 235 loses one part in thousand of its weight. This gives us an idea of the order of magnitude of energy changes involved in atomic and nuclear reactions.

Bethe has shown that the energy of stars, including the sun, is produced by the combination, in their hot interior, of the fundamental particles protons and neutrons into heavier nuclei, like deuteron (containing one proton and one neutron) and helium nucleus (containing two protons and two neutrons). The difference in the sum of the masses of the combining particles before and after combination is proportional to the energy released. We are justified in saying that the stellar temperature, in spite of loss of energy by intense radiation, is kept up by the nuclear fire maintained at the core of each star.

The energy of fission, which is utilized in atomic piles, depends not on the synthesis, but on the breakdown of the unstable nuclei of heavy atoms at the end of the periodic table, like uranium and thorium, following their combinations with neutrons. The latter being uncharged, can very easily enter into the nuclei of different atoms; the energy released by such nuclear combinations find expression as gamma-radiation or by the emission of electrons, neutrons and other charged light particles. The maximum release of energy however takes place when the uranium nucleus breaks up into two particles of comparable masses, *e.g.*, Barium and Krypton which fly apart, due to electrical repulsion between the charges on the fission particles. It is found that the sum of the masses of the particles into which an excited Uranium nucleus breaks up is less by one part in thousand than that of the parent nucleus and hence this process is accompanied by a large release of energy.

Uranium atom, which carries a positive charge $Z=92$, has two principal isotopes with $A=235$, and 238. Bohr predicted from theoretical considerations, that it is the lighter nucleus 235, present as 1 part in 138 in Uranium metal, which breaks up under absorption of both slow and fast neutrons. The 238 isotope can absorb neutrons of intermediate velocity without fission; the combined nucleus so formed does not break up, but behaves as a radioactive element which after successive emission of two electrons, gives rise to a new atom Plutonium (A=239, Z=94) which is fissionable under further neutron absorption. Thorium (A=232, Z=90) can also be made to break up under fast neutron absorption, at a very slow rate, and in addition can also give rise to an isotope of the element Uranium (A=233, Z=92) with fissionable properties like Plutonium. The utilization of Thorium as fuel in atomic pile will depend on the production of this new element from Thorium. The circumstance that certain atomic nuclei can be made to break up with large release of energy is not enough to justify their utilization as atomic fuel. The reaction must be self-propagatory. A consideration of how a coal fire is maintained will illustrate the point. By an initial application of external heat to a pile of coal, combustion with oxygen can be made to proceed at such a rate that the heat generated will be sufficient to activate fresh coal particles to enter into combination with oxygen. Of the total heat generated in the body of the fire, a part will be radiated across the surface. Therefore it will not do to have too small a volume of coal, then too much heat will be radiated away, its temperature will cool down and combustion cannot be maintained. In the case of the atomic pile, neutron plays a role analogous to that of oxygen. The difference is, that it is a very expensive process to continually supply the pile with neutrons generated outside the pile. But fortunately during the process of fission, each nucleus emits 2-3 neutrons and these neutrons if they can be made to be absorbed by other fissionable nuclei, will make the reaction self-sustaining and thus a reactor pile can be maintained. The limited supply of neutron produced in an atomic pile, introduces an essential difference in its working compared to that of a coal fire. In the latter the supply of oxygen is practically unlimited, the rate of combustion and therefore the heat developed can be controlled by limiting the access of oxygen; further the presence of oxidisable impurities in the coal, which use up a part of the oxygen supply without generating much heat, does not interfere with the maintenance of the fire. The atomic pile must have also a certain volume in order to reduce the amount of neutron which leak away across its boundary surface, in comparison to that produced in the volume, and further all impurities which like boron and some of the rare earth elements very readily absorb neutrons and do not contribute to the maintenance of the fission reaction, must be rigidly excluded. In the purified uranium metal, a purity of one part in ten million in respect of such contaminants is specified. The conditions therefore necessary for the setting up of a self-reacting atomic pile are

(*i*) To isolate and purify a sufficient quantity of fissionable material like U 235 or Pu 239.

(*ii*) To determine from calculation or otherwise, the critical volume of the metal beyond which the fission process once started will be self-maintained. This will be so when the number of neutrons released throughout the volume by nuclear fission is larger than the number lost by absorption in impurities and by escape from the boundary surface of the pile.

Under such conditions, if we assume that a pair of neutrons are emitted during each fission and the neutrons so produced are utilized for fresh fission production, then the rate of fission will increase as 2, 2^2, 2^3 in a geometric progression. Since the velocity of the neutrons produced during fission is of the order of 10^9 cm per sec, the time between successive generations in which the number of neutrons is doubled is of the order of 10^{-8} sec; an extremely large number of fission will take place in a millionth of a second, resulting in the generation of intense heat and pressure, so that the material explodes violently and an intense compressional wave of tremendous destructive power is propagated. This is the process utilized in the making of atomic bombs. For this purpose it is only necessary to divide the bomb into two parts, each of less than the critical volume, but when the two are brought together, the fission process takes place in it at an explosive rate.

The process taking place in such fast reactors can be controlled by the introduction of bars of neutron absorbing materials at critical points in the reactor pile. The making of such a pile is very expensive, as it entails the very costly separation and purification of the metals U 235 or Pu 239, and the control is very difficult. Construction of such piles is proposed where the limitation of size of a pile is essential.

Slow neutron reactors.—Both U 235 and Pu 239 have much larger absorption capacity for slow neutrons of thermal velocities, than for fast neutrons. The great advantage of using thermal neutrons is that the reaction proceeds at a comparatively slow rate and is therefore more amenable to control. At the same time the fissionable material can be largely diluted with other materials which have negligible absorption for slow neutrons, *e.g.*, with U 238; i.e. in place of the costly isotope Ú 235, natural Uranium metal can be used, which considerably reduces the cost of the pile but produces consequent increase in its critical size. Further it involves the introduction of a foreign substance called moderator, collision with which will reduce the velocity of the fast neutrons generated during fission to thermal velocities. It is a well-known law of elastic collision, that the transference of energy between two colliding particles is a maximum, when they are of the same mass. Thus the specifications required to be fulfilled by a moderator are (*i*) its mass be as near as possible as that of the neutron, (*ii*) it has no appreciable absorption coefficient for neutron, and it can be obtained in a state of high purity in large quantities. Water otherwise ideal cannot be used, as hydrogen has a high absorption for slow neutrons. Heavy water is next best but very costly to prepare; it has been successfully used in the USA and Canada. Its use materially reduces the size of the atomic pile. The best all-round material available is graphite. Owing to the inevitable but finite loss of neutron by absorption, the multiplication factor k, i.e. the ratio of the number of neutrons produced by fission to the number of free neutrons present in it at a given time is not much greater than one. As the condition for maintenance of a chain reaction is $k > 1$, the critical size of a slow chain reactor is therefore large, and several tons of uranium and graphite are required for a pile. The uranium metal is distributed as cylindrical rods or in lumps in a lattice of graphite, so that fast neutrons produced in one metal lump is slowed down to thermal velocity in the intervening graphite material, before they enter into another lump of metal. Though the ideal shape of a lattice is spherical, for convenience of manipulation it is made of cylindrical shape.

Once a chain reaction starts in a pile, new processes are put into operation, and special measures have to be taken to cope with them. For every gramme of fissionable metal 0·999 grammes of new elements are formed, some of them or their decay products have high absorption for neutrons, and if they are allowed to remain too long in the pile, they may reduce its activity or even stop the nuclear chain reaction; so it is necessary to remove from time to time the uranium or other fissionable material from the pile and to decontaminate it by chemical means, i.e. to remove the fission products from the fissionable material. The fission products are radioactive isotopes of known metals, and so far 75 radioisotopes have been prepared from them, in varying quantities and several of them are finding important biological, chemical and medical applications. In addition to these fission products, a new fissionable material Plutonium is produced. This element is separated and utilized for enriching new atomic piles or for purposes of making atomic bombs. Due to the intense radiations generated during fission and by the radioactive fission products which are extremely dangerous to handle, all the chemical operations have to be carried through distance control processes across five feet barriers of protecting concrete shields. Behind these shields are also recording instruments installed for indication of neutron flux at different portions of the pile and for automatic insertion of control rods.

Controls and Safeguards: (*i*) Some effective means have to be found to prevent the fission reaction multiplying too rapidly, which might lead to the development of high temperature and pressure leading to the eventual destruction of the pile. This is controlled by placing cadmium or boron rods, which absorb slow neutrons very largely, at suitable positions in the pile, which when inserted will absorb a fraction of the neutrons generated and thus damp down the rate of fission production.

(*ii*) The heat developed in the pile must be removed by circulation of suitable coolants; possible methods are by circulation of water, gases, gases under pressure and by liquid metals, all of which must have low neutron absorption; they must be physically and chemically stable when subject to intense radiation, they must not corrode or erode the material of the pile they come in contact with. The heat if removed at sufficiently high temperature may be utilized for driving heat engines. It must be realized that the only way at present known by which atomic energy of fission can be utilized is by way of the heat energy to which it is transformed. As is known the efficiency of heat engines increases with the temperature at which heat is received from the source. At present the highest possible temperature at which a gas turbine can work is 700—800°C, and it is still an unsolved problem of atomic pile engineering, to devise a cooling arrangement by which the heat generated in the pile can be removed at this temperature. We shall refer to this problem later.

(*iii*) The type of engine to be selected will also be conditioned by the special hazards which accompany the working of an atomic pile, *viz.*, the release of enormous quantities of gamma rays and neutrons. A chain reacting pile producing sufficient heat to generate 100,000 h.p. would simultaneously emit radiation equivalent approximately to 500×10^6 gm of radium. In order to provide sufficient biological protection from neutron, etc. five feet thick concrete shielding surrounding the pile unit will be required. Even a low power reactor will require 50 to 100 tons of shielding material. This puts a limit to the construction of a portable low power pile unit.

Hanford Pile.—In Smyth's report the working of four atomic piles has been described. Of these, the one built at Hanford, has been made the basis of plans for future development of atomic piles for power generation purpose. The pile is built of graphite blocks with a lattice structure, for insertion and removal of cylindrical rods of uranium and of neutron absorber. The utility of such arrangement for removal and purification of uranium rods has been described before, as well as the instruments which indicate and control the neutron flux in the pile at different points.

The coolant used is pure river water, which is circulated through aluminium tubes enclosing the uranium rods. The latter are also encased in aluminium jackets to prevent their oxidation by water. The temperature of the circulating water is kept below 100° to prevent the oxidation of the aluminium pipes and jackets. Aluminium was selected because of its low neutron absorption and high thermal conduction. After circulation through the pile the cooling water is kept in a reservoir for some time in order to get rid of the radioactivity induced in it. The heat thus removed by the coolant cannot be employed usefully as source of heat in a thermal engine, unless its temperature is raised considerably over 100°C.

The Hanford pile was we believe used for the production of Plutonium required for manufacture of atom bombs. It was after the termination of war with Japan that attention was directed to investigations on nonmilitary applications of atomic energy. Future schemes for the utilization of heat developed in an atomic pile will depend on the finding of suitable coolants which in addition of other desirable properties will be able to transfer heat to the working substance of a turbine at the highest temperature at which the latter can work, *viz.*, 700—800°C. Amongst the proposals which have been made are (*i*) that coolant, which may be an inert gas, will be made to circulate in a closed circuit to prevent the discharge of fission products into the atmosphere.

(*ii*) There will be a thermal exchanger in which the heat will be transferred from the coolant to the working substance, which circulates in a closed secondary circuit. The working substance which may be steam, vaporized mercury or hot gas will be used to drive a turbine. In spite of present limitations, atomic fuels offer certain possibilities for future improvement over ordinary fuels. For example there is no theoretical limit to the high temperature which can be obtained, with the consequent increase in thermodynamic efficiency, except the ability of the materials of construction to withstand working at such high temperatures.

Economics of Nuclear Power Plants.—A group of engineers belonging to the Clinton Laboratories and the Monsanto Chemical Co. were requested by the Baruch Committee on Atomic Energy to prepare a report on the cost of nuclear power based on information at present available. The model taken was a modified Hanford Plant, about whose working design and operation, information is available. In such a study the commercial plant was considered to differ from the Hanford pile in two important respects.

(*a*) The operating temperature was assumed to be high enough to supply power.

(*b*) All plutonium formed was assumed to be recovered, only for later consumption in the pile. No such plant has yet been built and no insurmountable difficulty stands in the way, but still extensive research and development problem will be required to be solved as they arise. The complete nuclear plant will contain not only the pile itself; but all the auxiliary equipment and installations needed to operate a continuous thermal plant. It is estimated that an atomic fuel plant, producing 75,000 kW, could be built in a normal locality in the eastern USA for approximately $25,000,000. On the assumption that the plant would operate at 100% of capacity, and interest charges on the investment would be 3%, the plant could produce power at 0·8 cent per kW hour. A coal power plant would under the same condition cost $10,000,000. The operating cost will depend on the cost of coal; assuming it to be butiminous coal, of 13,600 BTU, delivered at $57·00 per ton to the furnace of a power plant in the eastern USA, the cost of power production, under the same assumptions of operating capacity and interest charges, per kW-hour would come to 0·65 cent. Equality of operating costs between coal power plants and nuclear power plants would be reached if the coal cost is over $10 per ton. It is thus seen that substitution of a power pile for a standard coal one will involve no saving. The large capital investment of atomic fuel required to reach critical size, the chemical processing, the shielding, the remote controls, the insurance against hazards, and the waste disposal problems, add considerably to the cost of operation. If only atomic fuel becomes considerably cheaper than the equivalent amount of coal, will there be favourable competition. Again the cost of fuel is only about one-fifth of the total cost of producing electricity for domestic purposes, where coal is easily available. The cost of distribution of electricity is much more and this cost is not affected at all by the substitution of atomic power for fuel. In other words if atomic fuels could be obtained absolutely free, the maximum possible saving would be only 20%. On the other hand if one paid twice as much for atomic fuel as for coal, the cost of delivering electricity would be increased only by about 20%. In certain large-scale industrial operations the fuel costs may represent more than one-fifth of the total cost of electricity produced.

But economic considerations do not alone determine developments of this kind. In isolated regions where transportation is difficult, one does not count the cost involved. The present radius of useful distribution of electricity is somewhere around 200 to 300 miles. In inaccessible territories, without any hydraulic power available, power piles could be advantageously distributed and may find their first applications. Similarly in large units of transportation, where bulky shielding could be installed—as in large ships, atomic fuel might be used for many trips round the world without refuelling.

Piles can be used for heating as well as for power. Industrial and domestic heating constitute an additional promising field for the peace-time use of atomic fission. Power piles may be used for the distillation of water from the sea. Many uses of distilled water so obtained, in areas situated near the sea, can be envisaged.

Sources of Fissionable Material—Uranium.—According to pre-war statistics, the amount of high grade uranium is limited. Valuable deposits are found in Belgian Congo and Northern Canada. Lower grade deposits are found in Colorado, Czechoslovakia and other scattered regions. Uranium is derived not only from uranium ores, but in many cases it is or might be derived as by-product of ores of other metals, mainly vanadium.

It appears from such pre-war information that the world supply of high grade uranium is entirely inadequate to supply the world's power and heat requirements even for a few years; the supply of extremely low grade ores would theoretically exceed the heat available in the world's total coal and oil reserves. Attention is therefore being directed to the possibility of utilizing low grade uranium ore for extraction purposes.

Thorium.—The other natural fissionable material is thorium. But "thorium by itself or in combination with any other natural material except uranium, cannot maintain a chain reaction. Without uranium, chain reaction is not possible, but with fairly substantial quantity of uranium to begin with and suitably large quantity of thorium, chain reaction can be established to manufacture material which is an atom explosive, and which can also be used to maintain other chain reaction".

The statement quoted above is of importance to us in India, on the feasibility of constructing atomic pile from local supply of atomic fuel. This country so far as is known has no large sources of high grade uranium ore; on the other hand, there are extensive deposits of thorium containing minerals.

Power Piles in India

We have seen that due to the high cost of producing suitable fissionable materials, and of construction of safe chain reacting piles, it is not possible even in the USA to generate atomic power to compete economically at the present stage of development, with coal and oil power plants. The question may be asked whether under such conditions it is worth while considering plans for the erection of atomic piles in India for power generation purposes. In the introduction we have stated our reasons for the desirability of planning for such an end.

Assuming that it is desirable to erect and run atomic power plants in India, we may consider different ways in which this aim may be realized. Here again we shall get some suggestions if we consider how thermal and hydroelectric power plants are obtained and maintained in this country. Here two factors are involved, *viz.*, the source of power, either fuel or water supply, and the machinery which generate mechanical and electrical power from them. There are three different ways in which the desired object can be carried out, *viz.*, (*i*) both the fuel and machinery can be imported from abroad; included in this category are the heavy diesel engines, oil burning power plants and motor vehicles.

(*ii*) The fuel and water supply can be procured locally, but the machinery is imported from abroad: coal burning power plants, steam and electric locomotives and hydroelectric power generators.

(*iii*) Both fuel and machinery are of local production. So far as is known to us only low h.p. electric and oil engines are manufactured in this country. The latter however use mostly imported fuel. It is not a matter of congratulation to us that after a century of use of imported locomotives, plans have been only recently sanctioned for the manufacture of a limited number of locomotives in railway workshops in this country.

A similar classification may be made of different methods of establishing atomic power plants in India. They are (*i*) to import both atomic fuel and atomic pile with the necessary heat engines from abroad. Such a plan does not appear to be feasible, as it is difficult to conceive how in these days of international rivalry in the use of atomic power for war purposes, any country producing atomic fuel will be prepared to supply it to a foreign country. Such fuels if supplied will be denatured, i.e. its content of U 235 or Pu 239 is made so low compared to that of the dilutant U 238, that while still retaining its utility as atomic fuel, it is not suited for atomic warfare purposes. It has been suggested however that from such fuel, by means of long complicated processes of thermal diffusion or by magnetic separation, the fissionable material may be separated and used for war purposes.

(*ii*) To chemically process the atomic fuel from local supply of uranium and thorium ores, and use it in atomic pile machinery imported from abroad. At the same time to proceed with the training of the staff required for the control and maintenance of the machinery employed, and for the processing of the fissionable and moderator materials. This plan was suggested by a foreign expert with whom the problem was discussed. In his view, even an industrially advanced country like Great Britain finds it very difficult to manufacture such machinery; so it would be better if for the present India concentrated on the processing of her fissionable materials, which she could use for barter, for procuring the necessary machinery, with countries manufacturing atomic piles.

(*iii*) India will not only produce and purify her own fissionable materials, but also build her own atomic piles, importing, so far it is necessary, component parts of machinery, constructional materials and detecting and controlling instruments.

We may consider (*ii*) as an intermediate step in the achievement of our final aim as given in (*iii*). We can now proceed with the discussion of our resources in materials, in scientific and industrial personnel, and of measures which have to be taken to realise our final aim. It may be stated at once that no immediate sensational results should be expected, and that we should be prepared for long range planning and development.

Raw Material—Uranium.—We have seen that no chain reacting pile can be worked without using a large quantity of uranium as starter. According to present information, ores containing high percentage of uranium oxides, like pitch-blende, of amounts required to start a pile, are not available in this country. As in other countries, there is a fairly wide distribution of low grade ores as in pegmatitic rocks. Sometimes it occurs in association with metals which are of economic value. It has been mentioned previously that in many countries uranium is associated with vanadium. We have in this country one of the richest deposits of iron vanadium ores (average content of samples V_2O_5 0·8 to 4 %, Fe 50 to 60 %, TiO_2 4—20 %) and isolated observations have revealed traces of radioactivity in some of the mineral specimens. According to *Chem. and Eng. News* (24, 2930, 1946) an almost inexhaustible deposit of titanium has been discovered in Arkanas, USA. Samples taken from such deposits show a thorium content of 0·5 % and of uranium of 0·1 %. It is expected that the source may make USA independent in the. development of atomic energy. If vanadium oxides and vanadium steel is manufactured from our Indian ores, then it may be possible to extract uranium, as bye-product from the residues, comparatively cheaply. It is also reported that small concentration of uranium is associated with thorium in monazite. It is expected that the proposed survey of uranium bearing rocks by the Geological Survey will disclose new deposits of uranium bearing rocks.

Thorium.—India contains probably the richest deposit of thorium in monazite sands. Unfortunately most of the deposits occur in Travancore, whose Dewan is trying to proclaim the independent status of the State. It has been suggested that the proposal is finding backing from certain interested powers, and the occurrence of monazite deposits may have some bearing on this. A resolution is reported to have been adopted by the Atomic Research Committee last February, drawing attention of the Central Government to the concession granted by the Travancore State to some British firms for the export and processing of thorium bearing minerals. The Committee has stressed the desirability of limiting the export in bulk of such minerals or of thorium metals obtained from them. It is to be hoped that better counsel will prevail, and Travancore will decide to remain in the Indian Union*.

Graphite.—Both India and Ceylon possess rich deposits of graphite. In the USA graphite rods used as moderators are prepared from petroleum coke. Whether the mineral graphite will reach the same degree of purity remains to be tested.

Chemical Processing.—After the supply of required quantities of uranium and thorium ores has been assured, the next step is to proceed with the extraction of the metals and for their purification to the required degree. The cost of extraction and purification will represent one of the limiting factors in the economic utilization of atomic fuel at competitive prices. In the USA as a result of teamwork between scientists and industrial concerns, the cost of manufacture of pure uranium metal was reduced from $1,000 to $22 per lb. We are relatively backward in our experiences of methods of separation and extraction of rare metal (which till now included uranium and thorium), and of the metallurgy of nonferrous metals. According to our information, the only place where investigations on the separations of rare earth metals is being carried out, is in the inorganic department of the University College of Science, Calcutta. There was a boom in the study of physical chemistry in most of the Indian Universities, and a consequent neglect of inorganic chemistry. The National Chemical Laboratory and the inorganic laboratories of Universities should be invited to cooperate in such investigations. Chemical Engineering of a high order, at present not available in this country, will be required to utilize the methods worked out in the laboratories for the manufacture at competitive prices of pure metal from the ores.

Thorium as fuel for Atomic Reactors.—Probably in some of the countries like the USA and the United Kingdom, data have already been collected relating to the conditions under which a reactor started with uranium metal can be subsequently maintained by thorium, and how in such piles, analogous to the production of Plutonium from Uranium, a fissionable metal U_{233} is synthesized from Thorium. It is essential that similar fundamental investigations should be encouraged in this country. We should not be dependent on foreign countries, for the supply if at all possible, of such data. Absence

*Since this article was sent to the Press information has been received that the Travancore State has decided to join the Indian Union under certain defined conditions, whose implications require further elucidation.

of such knowledge will hamper our bargaining power in the barter of thorium metal for atomic pile machinery.

The physical investigations will be aimed at collection of experimental and theoretical absorption coefficient data for neutrons of different velocities, in uranium and thorium metal and in the moderators. For such purpose experimental piles require to be constructed in which the critical size, effect on the neutron production factor of the distribution of fissionable metals and moderators, can be studied. Such information gathered in countries where atomic piles are working, are not published for security reasons. For such investigations large neutron supply sources are indispensable, and will require the aid of cyclotrons and high voltage electrostatic generators.

Along with such investigations, the medical hazards associated with the generation of intense ionizing radiations in the atomic piles should be investigated, and protective measures devised. The fission products are themselves very radioactive, and are being utilized as tracer elements in many biological and chemical investigations and for curative treatments. Similar work can also be started in this country.

Atomic Research in India.—We will now consider what steps have been already taken in this country to advance atomic research. Towards the end of 1945, the President of the Council of Scientific and Industrial Research appointed an Atomic Energy Committee with the following terms of reference : (*i*) to explore the availability of raw materials capable of generating atomic power, (*ii*) to suggest ways and means of harnessing the materials for production of atomic energy and (*iii*) to keep in touch with similar organizations functioning in other countries and to make suggestion for the coordination of the work of this Committee on international basis.

The Committee included amongst others Prof H. J. Bhabha (Chairman), Prof M. N. Saha, Mr. D. N. Wadia, Mineral Adviser to the Central Government, and Sir S. S. Bhatnagar, Director, Scientific and Industrial Research. The Committee has met twice since its appointment, in May 1946 and February 1947. From the beginning the Committee was anxious to secure the cooperation of the Travancore State and it appointed a sub-committee for this purpose. It also appointed another sub-committee to draw up concrete proposals for a geological and physicochemical survey of uranium bearing minerals in India. A member of the Geological Survey of

India, who has been deputed to study methods used for such surveys in Canada and the United States, has been co-opted a member of this sub-committee which has however, due to the frequent absence of this member, not so far been able to meet. The survey proposed to be undertaken appears to be too vast to be carried out by a single member of the Geological Survey. We suggest that efforts should be made to enlist the cooperation of institutions and universities, where similar work is being done, including the setting up of portable Geiger Müller counters, which are considered to be indispensable for field survey of radioactive rocks and minerals.

Having thus dealt with the questions relating to the survey of 'raw materials capable of generating energy', the Committee which now became known as the Atomic Research Committee, "considered the general problem of atomic research in India, and made the following general recommendations for the period immediately ahead, till the period is reached when the development work on the release of atomic energy can be started."

(1) The universities should be encouraged to give elementary instruction in the theory and the experimental technique of atomic physics as far as possible.

(2) The existing centres of atomic research, *viz.*, the Palit Laboratory of the University College of Science, Calcutta, the Bose Research Institute and the Tata Institute of Fundamental Research should be strengthened.

(3) The Tata Institute of Fundamental Research should be made the centre for all large scale programmes of atomic research in future.

The Committee also recommended the payment of certain initial grants to the three Institutes mentioned under (2), and also a capital grant for the establishment of a Betatron capable of producing electrons of energies up to 2×10^8 eV, to the Tata Institute. It was expected that with such high energy electrons, it would be possible to produce under laboratory conditions, the fundamental particle mesotron and to study its properties. The Chairman announced that during his contemplated tour to Europe and America, he proposed to visit the laboratories and industrial firms engaged in the development of high energy charged particle accelerators. At the second meeting he presented a report of his visit abroad, based on which, the Committee decided to postpone decision on the purchase of such machinery, pending clarification of the situation regarding the performance of different types of accelerators, all of which are in the development stage.

It will be seen that so far not much work has been done by the Committee on the utilization of Atomic Energy. For one thing the Committee meets too seldom, resulting in a lack of continuity in their deliberations and in their effort to initiate new schemes. So far no concrete proposals have been considered by the Committee on the development work and investigation necessary 'for the harnessing of materials for production of atomic energy.' In the effort to secure the cooperation of the Travancore Government for the reservation of thorium containing minerals, sufficient attention has not been given to the more important problem of research and development work necessary for the construction of a Uranium reactor pile. Unless this problem is solved, and also the next one of finding how far thorium can replace uranium in such pile, there cannot be any question of utilizing thorium solely as fuel in atomic reactors.

Recently however an important decision has been taken by the Government of India, to replace the Atomic Research Committee which functions under the Board of Scientific and Industrial Research by a Board of Research on Atomic Energy. This board will be directly under the control of the Council of Scientific and Industrial Research, and will be entrusted with the carrying out of the following main functions.

(*a*) To plan, finance and carry out Atomic research and development throughout India.

(*b*) To explore the availability of raw materials connected with the generation of atomic energy and to advise Government on the control, utilization and export of such raw materials in India.

(*c*) To provide the machinery for cooperation in matters of atomic energy, research and development with the corresponding bodies, and to advise Government on any agreements with foreign powers that may be necessary for this purpose.

(*d*) To appoint Committees and take all other steps in furtherance of the aim of developing atomic research and energy to the fullest extent in India.

It has also been agreed with the consent of the Travancore Government, to set up a Joint Committee for research and development of atomic energy from Travancore minerals. This Committee will consist of nine members, of whom six will be from the Atomic Research Board, and three will represent the Travancore State. We do not know how this Committee will function in view of the recent attitude of the Travancore Government.

We suggest that when the Atomic Research Board meets it will consider the desirability of setting up two Committees, one on Atomic Research and the other on Atomic Energy utilization. The functions of the first named Committee will be to deal with investigations on fundamental problems of nuclear physics and cosmic radiation. The function of the Second Committee will be to deal with investigations on utilization of nuclear energy. In the present article we are interested in the work of the Second Committee, which we suggest should carry on its work through three sub-committees for the present.

(*i*) A geological and physicochemical sub-committee for the survey of rocks and minerals containing fissionable metals and for the determination of uranium and thorium in them. The majority of such rocks will be of low uranium content, and amongst them special attention should be directed to those which are either being at present utilized or can be utilized for the metallurgical extraction of a main constituent of industrial importance. It will also survey deposits of high grade graphites.

(*ii*) A chemical processing sub-committee whose function will be (*a*) to investigate methods for the recovery of uranium from waste products of metallurgical processes mentioned in the previous para; (*b*) to investigate and develop methods of using crude oxides of uranium and thorium as starting materials, for the production of the corresponding metals in the required grade of purity. Similar investigations on purification of graphite will be undertaken.

(*iii*) A sub-committee for investigations of the physical process underlying the construction of a uranium reactor pile, and of the recording instruments used in them. The aim of this sub-committee will be the erection of an experimental uranium reactor pile.

Another investigation to be undertaken by the sub-committee will deal with the fission of thorium by fast neutrons and the production of new elements from thorium by slow neutron absorption, which are fissionable under slow neutron absorption. While a great deal of information is available on the production of fissionable elements like Neptunium and Plutonium from U^{238} very little is known about similar products Pa_{91}^{233} and U_{92}^{233} from Thorium. Probably such informations are being kept back for security reasons.

As positive results from investigations initiated by the different sub-committees accumulate, it will be necessary to widen the scope of investigations taken up by them: "Basic nuclear reactions and the theory of nuclear fission belong to the field of physics, but detailed study of problems of construction of an atomic reactor for power production include major contributions from chemistry, chemical engineering, metallurgy, electrical and mechanical engineering".

It will be necessary for the Board from time to time to suggest to the University Grants Committee and to the Higher Technical Education Committee, to introduce and finance new courses of study in subjects which are connected with the construction of atomic reactors, and also to invite the cooperation of a much larger number of universities and research institutions in the developmental work. At present only three research laboratories are associated with this work.

For comparison we give an account of the newly created Atomic Energy Commission in the USA to show how seriously and energetically the problem is being considered there. Atomic piles have been started or are under construction in other countries like Canada, England, Sweden, France, but information available regarding them are not so detailed.

The USA Commission consists of five members with D.E. Lilienthal as Chairman. They are responsible for the formulation of Government policy on atomic energy. Its function will be 'assuring national defense and security (and directing) the development of atomic energy in such a way as to improve public welfare, increase the standard of living, strengthen free competition in private enterprise and promote world peace.' The work of the Commission will be carried through five regional organizations.

(1) Clinton Laboratories at Oakridge, worked by Monsanto Chemical Co., for Power pile and Radiobiology.

(2) Hanford Engineering Works, Pasco, Washington, worked by GE Co. Several designs of piles for generation of electric power are being tried. The Company will also operate power plant laboratory at Schenechtady for study of nuclear power production and ship propulsion.

(3) National Laboratory on Long Island to be operated by a corporation of *nine Universities* in the New York area. Will be engaged in broad field of research.

(4) Los Alamos Laboratory, where military applications are under investigation, including biological effects of radiation, power development and atomic weapons.

(5) Argonne National Laboratory at Chicago: research on power plants, biological problems, medical application, chemistry of fissionable materials and their properties. *Twnty-five midwest universities* cooperate in the Argonne laboratory. In addition more than a score of contracts has been let to universities and research institutions in orde to foster private research in medicine, chemistry, metallurgy, ceramics and all phases of nuclear physics.

From what has been discussed above, it is clear that plans for utilization of atomic fuel for industrial purposes in India must be long range ones. It will require the provision of new equipments and introduction of new courses in nuclear physics and electronics in our universities; cooperation between them on large scale research programmes, introduction of specialized courses in chemical and electrical engineering in technological institutions and development of new metallurgical and power engineering industries. Without raising the level of industrial efficiency of the country, utilization of atomic energy for industrial purposes by means of local agencies will not be possible. Whether it will be possible to use locally processed atomic fuel on imported atomic pile machinery, will depend on how the international relations develop during the next ten years.

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1.3.9 RELEASE OF ATOMIC ENERGY*

SINCE the dropping of the atom bomb with its devastatingly destructive effect upon the unfortunate cities of Hiroshima and Nagasaki, the human mind has been overtaken with a bewildering perplexity as to its possible future application and development. Three influences have been at work over it, the politicians and the military leaders of the various States who have found in it a weapon of warfare which has eclipsed beyond imagination all the destructive devices of men, the scientists who foresee therein a new fascinating field of investigation for harnessing Nature's power to human welfare, and the common people who view it as an awful menace to society, civilization and the world at large. The final shape which this release of atomic energy will give to human destiny will depend, therefore, on the dominance of any of these influences over the others. If the politicians and military leaders can have their way and enforce the cooperation of the scientists taking advantage of the usually inert public opinion which seldom effectively asserts or can assert itself, then the prospect is obviously very grim. Though only the USA are now in possession of the means and the methods of production of atomic bomb, there is, however, no secrecy about the knowledge on which it is based. In fact, the fundamental physical principles relating to it were discovered mostly by the scientists of other countries. The successful application of these principles to the production of atom bomb in the USA might be attributed primarily to her immense industrial capacity, better opportunity for investigation in comparatively peaceful surroundings more or less beyond the range of enemy attack, superior organization of high level scientific research and willing cooperation of many eminent foreign scientists some of whom were expelled from the Continental Europe, or escaped from the concentration camps of Hitler and Mussolini, and above all to the unstinted and unlimited financial support from the State. But there is no likelihood that this production of atomic bomb will ever remain confined to the USA alone. Scientists and competent authorities on the subject are of opinion that other countries might as well in no distant date be able to compete with the USA in this respect, provided the requisite scientific personnel, industrial and financial resources be available. And with this end in view preparations have already been set afoot in all the great sovereign

*Sci & Cult, **13**, 167, 1947. (Unsigned editorial)

States of the world today. This conceptual competition sooner or later is bound to end in a practical race in atomic armament among the nations with what disastrous effect upon the society and civilization is dreadful to contemplate. Nay, further progress in scientific research may lead to the development of cheaper methods for the production of atom bombs and even of weapons more powerful and deadlier than the latter. The humanity is thus faced with an unprecedented peril: and the situation becomes darker still when it is remembered that the scientists have failed till now to discover any protection or defence against this diabolical device of human destruction. All attempts by the United Nations to avert this peril have yet led to no fruitful results as can be gathered from their discussion, which has rather disclosed to the dismay and despair of common man a more or less insuperable barrier of distrust, jealousy and suspicion among the big powers. The scientists too cannot shirk their responsibility in this grave affair as they themselves were major partners in the production of the atom bomb. They have raised a Frankenstein and are now at a loss how to bring him under submission. It is little consolation to the common man, now groaning under the dreadful effect of a terrific world war fought for the avowed object of freedom from fear, want and disease but which has resulted simply in intensifying and magnifying the latter, when pictures of future peace, prosperity and progress are presented to him in abundance, in season and out of season, by the scientists and State authorities in their august gatherings and conferences; for common men have had too bitter experiences of the past to be encouraged by any such promises for future.

It cannot be gainsaid that scientists in every country have become the willing and obliging tools at the hands of their State authorities for the purpose of war. This has undoubtedly contributed a great deal to the development of science and its organization. As one of the earliest instances of this, mention may be made here of the birth of the National Academy of Sciences in the USA during the days of civil war when President Lincoln sought the active help of the scientists. During the world war of 1914-18, there was a large mobilization fo scientific personnel; but the most efficient pooling and organization of scientific resources and personnel were brought about during the last global war in the UK, the USSR and particularly in the USA. In the last-named country the organization, known as Office of Scientific Research and Development (O.S.R.D.) was established through the initiative of President Roosevelt under the Directorship of Vanuevar

Bush. The manufacture of the dreadful atom bomb was the outcome of this organization.

The power and energy thus released from nature by the devoted work of the scientists have only been utilized and usurped by the political authorities for their own ends, with results which have served ultimately to multiply human sufferings and human misery rather than contributing to human welfare. Search for truth and the extension of the boundary of human knowledge for the service of humanity which form the primary objective of science, are thus prostituted for infamous and ignoble ends. No better illustration of this can be quoted than the explosion of the atom bomb; and no greater vile or criminal application of a great and magnificent scientific discovery could have ever possibly been made. This has rudely shaken the conscience of the scientists today and they are gradually becoming alive to their responsibility. Though the results of scientific researches are calculated to advance the march of civilization and improve the conditions of living and amenities of life, the scientists, since the late nineties, have been the melancholy observers of what man has made of the fruits of their devoted studies. While the average standard of living has gone up to a great extent, individual and collective greed for power and gain, as a result of maldistribution of profit and wealth, both among individuals as well as among different nations, a state of perpetual conflict and competition among the various rival groups has been the order of the day all over the world. The world is thus dominated today by limited groups of men with power and wealth. Many are forced to lead today a life of misery, suffering and shame, so that a few may live with pleasure, plenty and power. For, the common man has seen no better luck in life than the presence of heavy army and police boots coupled with the scarcity of common necessities of life. The abuse of power, thus derived from the application of science, has now reached its limit in the manufacture and dropping of atom bombs; and, unless checked in time this may ultimately lead to the extinction of modern civilization. Scientists have now realized their own responsibility in this development and are now bent upon devising ways and means for effectively dealing with the situation. This is illustrated by the following quotation from Arthur H. Compton:

> "The world-wide growth of science and technology is the main line of the rapid evolution of man into a social being whose community is the world. . . . We now have before us the clear choice between adjusting the pattern of our society on a world basis so that wars cannot come again, or, of following the outworn tradition of national self-defence, which if carried through to its logical conclusion, must result in catastrophic conflicts."

We may also refer here to that eloquent letter of Albert Einstein which we had the privilege to publish on the cover of our August issue.*

We have before us the first of a series of packets which the Association of Scientists for Atomic Education through its Committee for Foreign Correspondence propose to send out to all countries of the world. In the present connotation of the term, the Association will have 'political' work so far as they will attempt to bring about agreement amongst the nations' representatives at the UNO educating public opinion and mobilizing that opinion for 'political' pressure. The Committee has been sponsored by more than a score of eminent scientists, most of whom once worked whole-heartedly in the atom bomb projects in one or the other of the three US stations. By an appeal broadcast to the nation by Albert Einstein on behalf of the Association, a fund has been created for the Einstein Emergency Committee of Atomic Scientists, and financial assistance from this Committee has enabled the first mentioned Committee to function. The letter sent with the packet states:

"The work of the Committee is directed toward creation of sufficient confidence among the nations to permit the operation of an international system of atomic energy control. This confidence has been seriously undermined by the events of the past months. People of other nations may find much in the policy of the United States which is disturbing, particularly in view of the military demonstrations by our Government of the power of the atomic bomb, and of the continued manufacture of atomic weapons. As a result, national isolationism may become dangerously strengthened everywhere just when a rapid extension of international cooperation on an unprecedented scale is essential to peace.

"Scientists of all lands have a unique opportunity and responsibility to contribute toward international cooperation. Natural scientists in particular have developed a rich tradition of international fraternity, and we must all take specific steps to renew and strengthen this tradition and to widen its foundations. The Committee hopes that by this letter, and by the sending of regular information on developments in this country on atomic energy control, you will be convinced of the sincere support of American scientists in our common fight for world peace and true international understanding. It is toward this goal that this letter is being sent to you and to other scientists all over the world. We urge you to publicize as widely as possible the contents of this letter and of the other material which you will receive. In exchange, we should like your permission to make public any suggestions and criticisms you may propose."

A Federation of American Scientists has been formed to meet the increasingly apparent responsibility of scientists for promoting the welfare of mankind and the achievement of a world state. Their direct contribution to the present power of unlimited destruction has raised the problem to a head for the scientists' immediate concern.

*Reprinted on page 454.

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AUGUST
1947

EMERGENCY COMMITTEE *of* ATOMIC SCIENTISTS

INCORPORATED

ROOM 28, 90 NASSAU STREET
PRINCETON, NEW JERSEY

April [illegible], 1947

Dear Friend:

I write to you for help at the suggestion of a friend.

Through the release of atomic energy, our generation has brought into the world the most revolutionary force since prehistoric man's discovery of fire. This basic power of the universe cannot be fitted into the outmoded concept of narrow nationalisms. For there is no secret and there is no defense; there is no possibility of control except through the aroused understanding and insistence of the peoples of the world.

We scientists recognize our inescapable responsibility to carry to our fellow citizens an understanding of the simple facts of atomic energy and their implications for society. In this lie our only security and our only hope—we believe that an informed citizenry will act for life and not for death.

We need $1,000,000 for this great educational task. Sustained by faith in man's ability to control his destiny through the exercise of reason, we have pledged all our strength and our knowledge to this work. I do not hesitate to call upon you to help.

Faithfully yours,

A. Einstein

Editors' Note:

The above letter has been sent to Prof. M. N. Saha and we are reproducing it with the belief that our readers will be prompted by this appeal to contribute their mite to this task. Suggestions and remittances will be gratefully welcome. As an interim arrangement, collections may be sent earmarked "Einstein's Appeal Fund" to the Treasurer, Indian Science News Association, 92, Upper Circular Road, Calcutta 9.

Kind permission to use the above space for reproducing the letter has been given by ADAIR, DUTT & CO., LTD., BALMER LAWRIE & CO. LTD. and SCIENTIFIC INSTRUMENT CO. LTD. *We owe our heartfelt thanks to them for their prompt and generous response.*

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Science and scientists have thus come to be very directly and intimately involved in matters of policy affecting the general welfare and world peace. Scientists must accept immediate individual and social responsibilities and should prepare to discharge them. Science has never known sectional boundaries and as members of an international fraternity we consider that it is time Indian scientists took upon themselves the task of organizing an actively aware body like the Federation of American Scientists. The nature and ambit of our work will be much wider. At the begining much spadework has to be done by sponsoring immediate educational work both among fellow scientists and the common people. For such a scientists' organization as suggested above we may have in common the following 4 aims:

1. To study, in consideration of the broad responsibility of the scientists today, the implications of any scientific developments which may involve hazards to enduring peace and the safety of mankind.
2. To counteract misinformation with scientific facts and, especially, to disseminate those facts necessary for intelligent conclusions concerning the social implications of new knowledge in science.
3. To safeguard the spirit of free inquiry and free interchange of information without which science cannot flourish.
4. To promote those public policies which will secure the benefits of science to the general welfare.

Science does not mince matters and some of us may be complacent that as scientists we have developed 'social awareness' and we are directing our energy and study to social welfare. But the execution of the policy underlying the directive must also be taken by them who know what a scientific result means and how it can be brought to fruition. It is time that scientists took a stronger stand and control the group, distinguished as 'politicals', who are now shaping or shattering the society. Civilization, which is the product of scientific efforts, is challenged today. Hence it is the primary duty of the scientists to exert their best efforts for safeguarding and maintaining the civilization.

1.3.10 ON THE ORIGIN OF PRIMARY COSMIC RAYS*

1. The older ideas about the origin of primary cosmic radiation, e.g. Millikan's matter annihilation hypothesis, and Klein's matter antimatter collision hypothesis, have been disproved by the recent American work, of which we had an account from Dr. B. Peters (1950). These investigations have shown that 80% of the particles are protons, 19% are α particles, and 1% are stripped heavier particles. This abundance of stripped nuclei is taken by some to be the same as the relative cosmic abundance of nuclei in the universe, which we obtain from astrophysical studies (Brown, 1949). This view appears to be rather premature, because many of the stars, whose spectra have been used to give us cosmic relative abundances, do not belong to typical groups, but belong to selected ones. The percentages of electrons and photons amongst cosmic ray particles are negligible (Rossi, 1949).

2. At present there are three theories about the origin of primary cosmic rays. The first theory is that the cosmic rays extend over the whole universe comprising all the galaxies. The second theory is that the cosmic rays we get are of galactic origin, and are confined within our galaxy, but this does not mean that there are no cosmic rays in other galaxies. Every galaxy besides our own may have its local system of cosmic rays. The third theory is that they are produced by the varying magnetic field of the sun and are confined within a few light years of the sun. If this view be correct, they cannot be called cosmic rays at all, because every star will have its own system of cosmic rays which is confined within a few light years of that particular star. (Richtmeyer and Teller, 1948.)

3. As regards the first theory the main argument against it is that the energy of cosmic rays, as has been found by Millikan and Regener and confirmed later by others, is of the same order as the total amount of the star-light within the visible region. This introduces the following difficulty: Supposing we place ourselves in the space between two galaxies which are generally a million light years apart, then the star-light intensity will be very much reduced, but the cosmic ray energy will remain the same and may be of the same order as the total mass-energy in the whole space. This will mean that a good part of the total energy of the universe is in cosmic rays. Though there is no compelling agrument against such an exigency, most physicists

*Proc. Int. Conf. on Primary Cosmic Rad.—TIFR Bombay, 1951.

are unwilling to accept such an extreme view and think that cosmic rays do not extend over the whole universe. (This argument is due to Richtmeyer and Teller).

4. Let us consider the third view that cosmic rays are of solar origin. It has been found (Forbush *et al*, 1949) that a few solar flares, but not all, are accompanied by changes in the cosmic rays intensity on the earth. The time-lag between the flare and the increase of cosmic ray intensity has been found to be about two hours. This has been sought to be explained as being due to the creation of a sort of tunnel by the magnetic field of the sun which gives cosmic rays favourable intervals to pass through. This is as yet a mere hypothesis and has not been clearly worked out; and so, on the whole the evidence that the cosmic rays are accelerated by the sun during the time of solar disturbance and are confined by the permanent magnetic field of the sun within a few light years about it seems to be very unsatisfactory. We must add to that some facts that have come to light recently. The first is that new experiments (Pomerantz, 1950) have shown that the general magnetic field of the sun either does not exist or is very weak. So the probability that cosmic rays come from the sun and the sun's magnetic field confines them to its neighbourhood appears to be receding. Another argument against this view is that though a theory of acceleration due to the variable field has been worked out (Swann, 1934), the effect of the conductivity of the upper layers of the sun is seldom taken into account. We can have large fields, only if there is no conductivity in the upper layers of the sun which is certainly not the case. Some other theories of the solar origin of cosmic rays (Menzel and Salisbury, 1947, MacMillan, 1950) appear to be too speculative for any comment.

Further, if the finding of the American workers that stripped Ne^{20} nuclei form a good percentage of the heavier component of primary rays be correct, it is difficult to see how they can originate in the sun. For neither the Fraunhofer spectrum of the sun, nor the flash spectrum has revealed a single line of Ne or Ne^{+}, though a good many of them are in the visible range, and 'we are compelled to think that neither Ne nor Ne^{+} is a normal constituent of the sun's atmosphere' (Sitterly, 1939). This argument may also be used against the hypothesis that cosmic rays are due to some acceleration process on the surface of magnetic stars, for neon lines are not found in the atmospheres of the stars forming the main sequence or of magnetic stars. They are found only in a few dwarf A and B stars which are styled peculiar, and in novae and planetary nebulae, which are supposed to be due to internal explosion of stars (Merril and Adams, 1943).

5. Rossi (1949) states categorically (p. 108) that electrons and photons are totally absent from primary cosmic radiation. If subsequent observations confirm this finding, its significance cannot be ignored in any theory about the origin of primary cosmic rays. For it is very probable, nay almost certain, that any process which gives birth to primary cosmic rays will also give rise to electrons and any process which accelerates positively charged particles to high energy will also accelerate electrons almost to the same energy. The reader may refer to the solar emission theory or the theories mentioned in §6. Why then do high energy electrons fail to appear as a component of primary cosmic radiation?

Foenberg and Primakoff (1947) have found that when electrons collide with thermal photons, they may suffer inverse Compton effect and lose energy to the photons. Making plausible assumptions about the number of thermal photons in the intra-solar space, and the intra-galactic space, they find that the number of collisions is insufficient to diminish the energy of electrons to any signification extent, in a straight passage through these systems, but the loss is quite significant. if the electrons have a cruising time of 10^8 light years through the intra-galactic space.

This is quite possible if the primary cosmic rays (and along with them high energy electrons) originate in the galaxy and are retained in the galaxy by the kind of magnetic field described in §4. On the other hand, protons and heavier particles will escape this fate. This is also an argument against the solar emission theory, for it is clear that electrons excited to high energies by the Swann-process cannot undergo sufficient number of encounters to lose all energy within a few light years of the sun.

6. We have now to examine the second view that primary cosmic rays are generated within our local galaxy, and are confined within the galaxy by some mechanism. The first question to be examined in this connection is—what happens to a primary cosmic ray proton as it cruises through the galaxy?

An average primary cosmic ray proton has been found to have the mean free path 70 gm/cm² in our atmosphere. Using the relation $N\sigma=1$, the cross section of interaction of the proton with the constituents of the atmosphere is found to be $\sigma=2{\cdot}6\times10^{-26}$cm² per nucleon (Fermi). The order of magnitude is in agreement with the recent experiments carried out at the Radiation Laboratory, Berkeley.

The mean free path of a cosmic ray proton within the galaxy is therefore $\lambda = 1/n\sigma$, where n is the density of nucleons in the galaxy. Recent studies of the galaxy have shown that the space within the galaxy is strewn with clouds of extensive dimensions consisting of gases, and dust particles, 90% of the gas is H, for which Stromgren gives the density to be 10 per cc, the density of the other particles being negligible. The density outside the clouds is given as 0·1 particles of H per cc. We have therefore $\lambda = 4 \times 10^{24}$ cm within the clouds, and $\lambda = 4 \times 10^{26}$ cm in the intra-galactic space containing no clouds. Both these lengths are larger than the dimensions of the galaxy, which is lens-shaped and is estimated to have a dimaeter of 10^5 light years ($\sim 10^{23}$ cm) and a thickness of 2×10^4 light years ($\sim 2 \times 10^{22}$cm). Hence primary cosmic rays will be leaving the galaxy, unless they are retained by some force.

From the relation $E = 300\ Hr$, it is easy to see that a field of $10^{-13}P$ extending throughout the intra-galactic space is able to retain the highest energy cosmic rays within the galaxy. The many hypotheses about the existence of such a field are examined. Apart from speculations, there appears to be actual physical evidence in support of the existence of magnetic fields, co-extensive with the clouds, from the discovery of polarization of continuous light from distant stars, with electric vector perpendicular to the plane of the galaxy (Hall and Hiltner). But determination of the magnitude, extent, and location of the field will take some time. But it is clear that the fields are patchy and confined probably to the interstellar clouds.

The life of billion-volt protons will be λ/c seconds, i.e. 4 million years within clouds, and 400 million years outside them. As the average radius of clouds has been found to be 60 light years, a proton, even when passing through a cloud, spends a very small fraction of its life within clouds—it cruises round the Milky Way a number of times before it comes into collision with another proton or a heavier nucleus.

The effect of collision of a cosmic ray proton with a nucleon is to produce (1) a spray of mesons which ultimately transforms into electrons, photons, and neutrons, and in such an encounter, the proton disappears. (2) A small fraction of the collisions results in the production of secondary protons and neutrons, the last ultimately decomposing into protons and electrons, but the energy of these protons will be much smaller. If we identify them with X-particles of

Conversi (1950), the average energy appears to be half a billion volts. When the energy of protons falls to low values, ionisation and radiation losses begin to mount up (Sengupta, 1942).

If the cosmic rays are to maintain their present stay-level, we must look for two processes happening in nature:

(1) A continuous or discontinuous supply of fresh protons (injection process).

(2) Acceleration of these fresh protons, if they are lacking in the requisite energy, and of old protons whose energy has undergone great diminution, to the energies observed (acceleration process).

7. We shall first take (2), *viz*. the acceleration process. The various suggestions for the acceleration process are:

(*a*) That the primary protons and other heavy particles get accelerated either on the surface of magnetic stars, on account of the variation of these fields, or in the intra-galactic space, through changes in the localized magneticfields of clouds.

The first suggestion due to Babcock (1948) has not been fully worked out yet, but the same objections which have been raised against the solar theory apply here too. The second suggestion is too vague for any comment.

(*b*) That there are separations of charges in regions of the galactic space, which lead to the existence of large electrostatic fields. The charged particles get their energy as they pass through these fields.

The original of these theories is that proposed by C. T. R. Wilson who suggested that cosmic rays might be identical with electrons which acquire energies of the order of 10^9ev as they pass between opposite ends of a charged cloud (hypothesis of run-away electrons). Recently this theory has been revived by Hoyle (1947), but he has not indicated how this separation of charges takes place in space. Altogether the suggestion is too vague, and our experience of the stellar worlds tells us that extensive e.s. fields do not exist anywhere except in the atmosphere of a few stars which are not typical like T-Scorpii; even in these cases, the fields appear to be fluctuating (Underhill, 1948), rather than unidirectional.

(*c*) That the protons suffer collisions with moving intragalactic clouds, and gain or lose energy, the gains predominating, the net gain being given by the law $\delta\omega = B^2\omega$ where $B = v/c$, v being the velocity of drift of the clouds (Fermi Process).

This process has been introduced by Fermi (1948), but he has shown that protons must have an initial energy of 250 Mev, in order that they can take advantage of the process. So we must have a mechanism by which protons are being continuously produced, with a threshold energy of 250 Mev. For heavier nuclei, the threshold energy should be 250 Mev $\times A$.

8. Let us now consider the "Injection Process".

The only hypothesis worthy of consideration at the present moment for the injection of protons is the supernova hypothesis, which is described in some detail.

A supernova explosion is a very unique and rare phenomenon. It happens once in three hundred years per galaxy, i.e. the frequency of occurrence is 10 per year. In our own galaxy, only three supernova outbursts have taken place within historical times, *viz.* in 1054 A.D., 1572 A.D., and 1604 A.D. (The last two are known as Tycho's and Kepler's stars respectively on account of the attention which they received from these founders of modern astronomy.) The supernova of 1054 A.D. was noted by the Chinese and Japanese astronomers, and its remnants are now traced to the Crab Nebula.

It has been found that the light curves of all supernovae form a unique pattern with steep rise to a flat maximum, where it stays for about 20 days. The total amount of energy emitted during the explosion in the visual range is about 10^{48}-10^{49} ergs during the active stage, equivalent at its maximum to 600 million suns. The spectrum consists of a number of broad bands showing that gases are rushing out at speeds of 5,000 to 6,000 km/sec at the time of the explosion. Baade and Zwicky calculate that the total energy of explosion is about 10^{53}-10^{54} ergs, made up of visible and ultraviolet radiation, energy of the out-rushing gases, energy of ionisation etc. This forms about 1 % of the total mass energy of the star which flashed out as a supernova. In the explosion which causes the supernova, it appears that nearly 1 % of the mass energy of the pre-supernova star is converted into the energy of explosion. The features of supernova explosion bear a considerable resemblance to the explosions of atom bombs as described by Taylor and others (1950).

There is some evidence that the supernova outburst happens to stars which are hydrogen-poor like V-Sagittari, i.e. have consumed all their hydrogen in the ordinary Bethe Carbon-Cycle process for maintaining the normal energy-flow. A stage is reached when on account of the almost complete consumption of hydrogen, the star collapses to small dimensions, enormous pressures and temperatures are developed. Under these pressures, giant nuclei having atomic numbers $A \sim 10^6$ may be formed. There comes a stage when on account of high temperature, these giant nuclei undergo multifission. Applying the Bohr-Wheeler formula, Ter Haar (1949) has calculated the energy imparted to the fission fragments per nucleus as follows:

A	10^2	$3 \cdot 10^2$	$5 \cdot 10^2$	10^3	10^4	10^5	10^6
E in Mev	$3 \cdot 10^2$	$8 \cdot 10^3$	$2 \cdot 10^3$	$4 \cdot 10^3$	$2 \cdot 10^5$	10^7	$4 \cdot 10^8$
E/A in Mev	3	8/3	4	4	20	100	400

After fission has started at one place, a shock wave is propagated throughout the whole star, and on account of the high temperatures prevailing within the shock region thermonuclear reactions set in, and shatter the whole, leaving little or no residue.

It is seen from the above table that the energy of the fission particles may amount to 0·3 Bev per nucleon. If some of these particles succeed in escaping through the surrounding nebulosity, they may form the injection wanted in the Fermi process.

It may be noted that the occurrence of multiple charged particles amongst primary cosmic rays was predicted by Vallarta (1938), and Cernuschi (1939), the latter assigning the production of such particles to supernova outbursts.

Discussion

F. Perrin: It was mentioned that in the case of supernovae, 1% of the total mass energy is released. What is the source of the initial energy?

M. N. Saha: The supernova, as it is now understood, is caused by gravitational contraction of a star in a certain stage of its evolution, as a result of which the centre of the star would consist of nuclei alone (the atoms being stripped of their electrons by the extreme conditions of temperature and pressure). These nuclei lead to the formation of giant composite nuclei consisting of $\sim 10^6$ nucleons. The charge of these giant nuclei is dependent on the number of nucleons constituting the nuclei, but in certain cases it amounts to a quarter of the total number of nucleons. The fission occurring in these giant nuclei is the probable cause of the supernovae and the enormous energy release.

P. M. S. Blackett: The energy release in supernovae alone cannot account for the enormous energies encountered in primary cosmic rays. Thus this energy can only be the initial injection energy, which is the minimum energy required for the Fermi acceleration mechanism to come into operation.

R. E. Peierls: It is difficult to believe that a giant nucleus consisting of 10^6 nuclei could have a charge of as much as $1/4 \times 10^6$. Recent calculations by Teller *et al* indicate that the nucleons will mostly be neutrons and that the charge will be negligible.

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1.3.11 PEACEFUL UTILIZATION OF ATOMIC ENERGY ON INTERNATIONAL LEVEL*

ON December 8, 1953, President Dwight D. Eisenhower accepted the invitation of the Secretary General of the United Nations to address the General Assembly. He delivered his speech in the Assembly Hall before a gathering presided over by the President of the General Assembly, Madame Vijayalaxmi Pandit.

In his speech, President Eisenhower outlined an international four-point plan for devoting atomic resources to peaceful purposes. The four points are**:

(1) Opening up a new channel for peaceful discussion and initiate at least a new approach to the many diffiucult problems that must be solved in both private and public conversation if the world is to shake off the inertia imposed by fear and is to make positive progress toward peace.

(2) To allow all peoples of all nations to see that in this enlightened age, the great powers of the earth, both of the East and of the West, are interested in human aspirations first rather than in building up the armaments of war.

These two points are in general terms. The more concrete proposals are given in Nos. 3 and 4.

(3) To begin to diminish the potential destructive power of the world's atomic stock-pile.

(4) To encourage world-wide investigations into the most effective peacetime uses of fissionable material and with the certainty that they had all the material needed for the conduct of all experiments that were appropriate.

Let us explain Nos. 3 and 4. It is well known that since 1942 the United States of America made a great effort in order to utilise energy locked in the uranium nuclei for evolving an atom bomb, as an aid to the fighting power of the Allied forces, against Nazi Germany and her allies. At a cost of 2.000 million dollars they evolved this terrible instrument of destruction and it was used on the two cities of Japan *viz.*, Hirosima and Nagasaki. The destruction caused by these bombs was sufficient to bring proud Japan into submission. The atom bomb made the world conscious of a new terrible weapon of destruction. After 1945, the United States of America strengthened its atomic energy programme not only on the peaceful side, but

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**The order given is our own. The President's order of the points are first No 4), second No 3), third No 2), and fourth No 1).

mainly also for the evolution of new types of atomic weapons of far greater destructive power.

It is now well known that 3 types of atomic weapons have been developed:

(1) Fission bomb composed of U^{235} and Pu^{239};

(2) Fusion bomb or Hydrogen bomb;

(3) Cobalt bomb.

1. The principle of Fission bomb is that when the lump of $Uranium^{235}$ or Pu^{239} exceeds a certain minimum weight which is estimated to be between 10 and 20 kilograms, it becomes explosive and the total amount of energy released exceeds 20,000 tons of TNT. In practice, smaller lumps of U^{235} or $Plutonium^{239}$ which are below the size for explosion are brought together at the critical moment when they release their nuclear energy with explosive violence. There is thus a limit to the explosive power of the fission bomb. It is estimated that it can cause complete destruction within the radius of one kilometre and the affected area where the partial destruction of life and property can take place has a radius of 5 to 6 km.

2. The principle of fusion bomb is quite different. The nuclei of light elements, hydrogen, deuterium (heavy hydrogen), tritium (tri-hydrogen), lithium are allowed to be brought together and fuse into helium nuclei. This reaction can take place only at a temperature of the order of 100 million degrees. The fusion bomb is made of a core which contains lumps of $Uranium^{235}$ or $Plutonium^{239}$ like an ordinary fission bomb which is surrounded by the outer jacket of solid compounds containing Hydrogen, Lithium, Tritium or Deuterium (Thermo-nuclear process). Lithium Hydride would be an ideal substance. The explosion of the fission bomb raises the temperature of the core to 100 million degrees. At that temperature the fusion of the light elements into helium takes place freely releasing further large quantities of energy.

It is estimated that the total energy released is 20 to 25 times larger than that of the fission bomb, but actually there is no theoretical limit. It is supposed, though it is not officially admitted by the USA, that a fusion bomb was actually tried at the Pacific Ocean island group of *Eniwetok* and the island at the centre of the explosion with an area of 3 miles $\times$ 2 miles completely disappeared without leaving any trace. On August 12, it was given out that Russia had also exploded a fusion bomb and this was officially admitted by Soviet Russia on August 20, 1953.

3. *Cobalt bomb*—The Cobalt bomb is essentially a fission bomb within a cobalt jacket. When the fission bomb is exploded, a large number of neutrons are released which are captured by the cobalt nuclei of weight 59, to form the radioactive cobalt isotope of atomic weight 60. This isotope gives out strong gamma rays and has a disintegration half-life of 5 years. The heat generated by the atom bomb vaporises the cobalt which later settles down over a large area as radioactive dust. This radioactive dust in sufficient quantities can destory all life in the area over which it is spread. It is calculated that a few thousand tons of radioactive cobalt dust spread uniformly over the Earth can effectively kill every living plant or animal in the world. It is not known that the Cobalt bomb has yet been tried anywhere.

These are the terrible weapons of destruction which President Eisenhower had in mind while giving his address before the UNO. It is known that the United States of America, United Kingdom and Soviet Russia have by now huge stockpiles of U^{235} and Pu^{239}, which are the raw materials for three kinds of bombs. The total energy locked up in the stockpile material is, according to our calculation, equivalent to the total energy output of the world for several years in the shape of electrical energy and other varieties. This dangerous stockpile can be used for mutual destruction by the 'Two Atomic Colossi', as President Eisenhower plainly speaks out, and if they choose to start the 3rd World War the achievements of civilisation over thousands of years may completely disappear. The great cities are the most vulnerable to these attacks. It will take one or two fusion bombs to wipe out the existence of the great cities like London, New York, Chicago, Washington, Tokyo, Calcutta, Moscow, Leningrad and Paris and as far as known, there is no way of preventing such wholesale destruction once the bomb is dropped. The radar organisation may beat off some attacks, but if one or two leaks in through the defence, the destruction will be complete. A few hundred Cobalt bomb can effectively destroy all life in a country. President Eisenhower speaks with full knowledge of this dire consequence of the next world war and has made a very noble gesture, worthy of the best traditions of the great country he leads, but it is rather regrettable that no other country except Soviet Russia has taken cognisance of this gesture. Probably conversations have been carried on also with England and France. He has made definite proposals in order to give effect to Point Nos. 3 and 4. These proposals are:

"The Governments principally involved, to the extent permitted by elementary prudence, to begin now and continue to make joint contributions from their stockpiles of normal uranium and fissionable materials to an *International Atomic Energy Agency*. We would expect that such an agency would be set up under the aegis of the United Nations. The ratios of contributions, the procedures and other details would properly be within the scope of private conversations I have referred to earlier."

If major powers of the world accept President Eisenhower's proposals, a proportion of the fission materials which have been collected by the USA, Soviet Russia and Great Britain would be made over to the Central Pool of the International Atomic Energy Agency for peaceful utilisation.

The President says that the Atomic Energy Agency could be made responsible for the impounding, storage and protection of the contributed fissionable and other materials.

In order that these materials may not be used by hostile powers, he wants that the scientists will devise certain other conditions under which such a bank of fissionable material could be made over to the Agency.

In other words, he suggests that differences between nations should be settled by conversations, and the dangerous stockpile of fissile material should be utilized for peaceful purposes. This is a new and noble approach to 'International Problems'.

His next point is that the more important responsibility of this Atomic Energy Agency would be to devise methods whereby this fissionable material would be allocated to serve the peaceful pursuits of mankind. Experts would be mobilised to apply atomic energy to the needs of agriculture, medicine, and other peaceful activities. *A special purpose would be to provide sufficient electrical energy in the power-starved areas of the world.* It is now well-known that the power plants run by atomic energy are undergoing trials in the USA, as well as United Kindgom, but they have not yet reached the final stage when they can compete economically with steam or hydroelectric power. A large amount of research is necessary before this is possible.

It appears that if the power plant is of very large capacity, of the order of one million kilowatts, it can even now be considered economic in a region where ordinary power plants are very expensive. President Eisenhower's point No. 4 invites co-operation of scientists of all countries in the technical problems which must be solved before fissionable materials could be utilised for power development. The address also indicates that the scientists of all countries would be allowed to utilise atomic techniques for researches in agriculture, medicine and other peaceful activities. It can also be used for fundamental researches, for in spite of the money which has been spent so far, it is well known that the fundamental laws of the nucleus have not yet been discovered.*

In our opinion the President has made a very noble and far-reaching suggestion, but unfortunately the Government of this country have not yet expressed any opinion on it. The UNESCO in its last session at Delhi has actually requested the Government to study the implications of the President's gesture and give a suitable reply.

We suggest that the Government of India would convene a meeting of the select persons of this country conversant with and interested in the latest developments in Atomic Energy to advise them as to how to draft a reply to the President's reply. This meeting should advise the Government on these points:

(*a*) How far the scientists of this country engaged in fundamental investigations on nuclear physics, and chemistry, on biology and medicine would be benefitted if the President of USA's wishes were to be accepted in a practical form by the UNO.

(*b*) How far the Industrialisation of India would be accelerated if one or two atomic energy power plants of about half to one million kilowatt capacity were to be established in the power-hungry areas of India like Madras, Bombay and Rajasthan.

*On January 7, 1953, Einstein, Oppenheimer and certain other eminent scientists issued a statement that in spite of expenditure amounting to several billion dollars on Nuclear Science no first-rate work of fundamental science has yet come out after the discovery of nuclear fission in 1938 by Hahn in Germany. The results of application of tracer technique to biology have been very disappointing.

The eminent scientists have not told the world what in their opinion, is the cause of this disappointing record. It appears largely to be due to "Secrecy", preventing cross-fertilisation of the brains of creative personalities, a process which has been mainly responsible for the spectacular advances in fundamental sciences since 1900, and due to the fact that investigators over major parts of the world have been deprived of the means of investigation which Nuclear Science has placed at the disposal of a few fortunate people. The President's suggestions, if carried into effect, is expected to break down secrecy, and make available the new materials for research and development all over the world. One need not insist removal of secrecy from weapon development and industrial application, as even in ordinary technological processes, these items are regarded as "Secret".

We gather from literature that great efforts are being made in the USA, as well as the UK for turning atomic energy into industrial energy, but the processes are not yet economic unless the plants have a capacity of about one million kilowatt capacity. Researches in progress are expected to yield good results in a few years. The Indian scientists ought to be familiar with these researches, and should try to participate in them.

But the technical problem of utilizing a power load of one million kilowatt capacity is a tremendous one. It slightly exceeds the total power in the industrial belt of Calcutta. We have to find out use for such large blocks of energy in the area where the plant will be installed. Further, all that we can expect to have from the International Atomic Energy Agency is a Nuclear Power Reactor, and sufficient fissile material to run them. There must be sufficient number of Indian technicians who should be capable of handling the plant. The planning of the distribution lines, handling of the load in accordance with industries to be planned have to be taken in hand. But there can be no doubt that such a plant will be of very great help in the power-hungry areas of Madras, Bombay and Rajasthan and will help in the development of industries in these regions, where lack of fuel is at present a great handicap for the installation of thermal plants, and there are not sufficient hydroelectric resources, which can be cheaply turned to power.

1.3.12 ORGANISATION OF ATOMIC ENERGY WORK*

1. Introduction

THE world-wide press propaganda about secrecy in 'Atomic Energy Work' has produced a general impression that all such work in the USA and other countries are carried out by a set of super-scientists called 'Atomic Scientists' working behind an iron-curtain of secrecy under the strict supervision of the security police or the military. An examination of the atomic energy organisations in different countries except Soviet Russia about which we know nothing, however, shows that this impression gives a grossly exaggerated picture of the actual facts.

First, let us remark that there is no such distinct class as Atomic Scientists. The so-called Atomic Scientists are nothing but ordinary physicists, chemists, mathematicians, biologists and engineers who, since the discovery of the importance of atomic energy, have applied their minds to some aspect of this subject and have been busy with its development, and by virtue of their achievements and experience have been entrusted with special duties in a statewise organisation for the development of atomic energy in the nation's interest. Actually a huge number of scientists is employed in the work and organisation has taken a definite pattern. Let us take for example the case of USA, the country which spends a huge amount on atomic energy, and has developed it more than any other nation and is supposed to have organised '*Secrecy*' with the zeal of inquisitors of the Roman Catholic Church.

2. Organisation in USA

The organisation of atomic energy work in the USA is shown in the following chart:

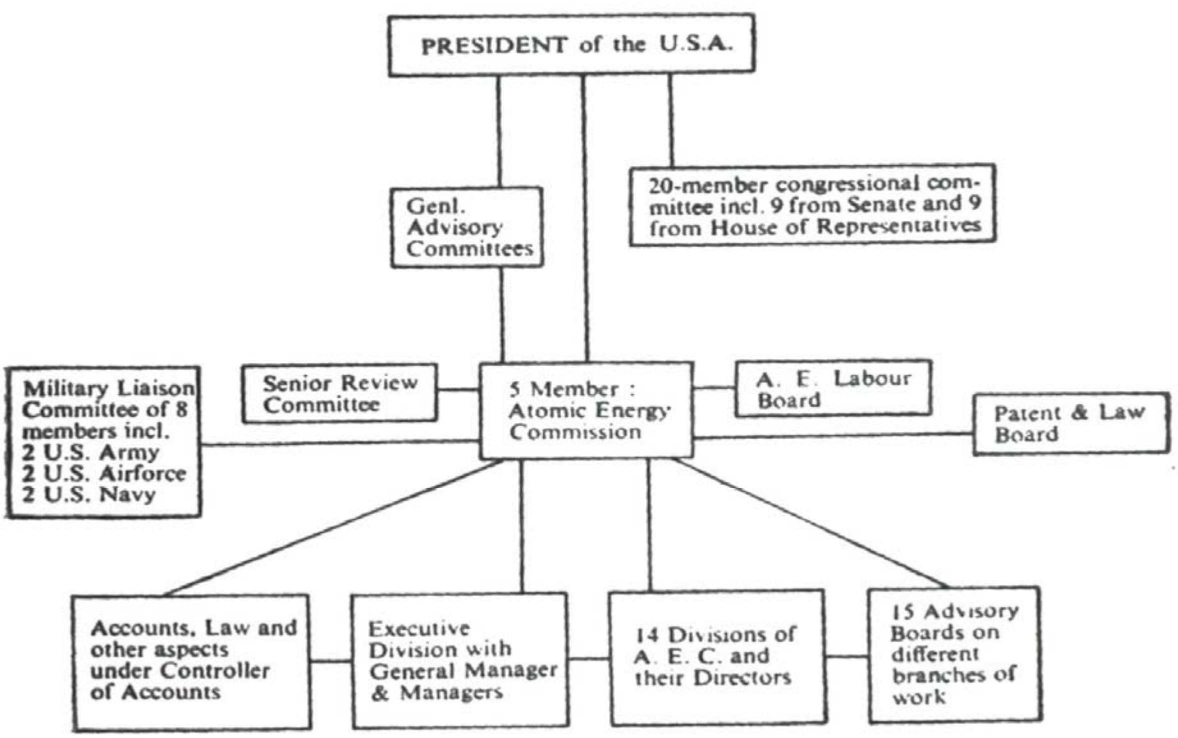
At the head is the 'President of the Republic' who reserves to himself all powers; he gives directives for policy, but his actual interference is confined to very important matters *e.g.*, the decision whether an atom bomb was to be dropped on the Japanese cities was taken by the President. The policy is laid down by a 20-member congressional committee of both houses. As they are politicians, they are guided in their deliberations by a General Advisory Committee consisting of nine eminent scientists. The composition of the General

*Sci & Cult **19**. 368, 1954.

Advisory Committee for 1952 is shown below:

1. Dr. J. R. Oppenheimer—*Inst. Adv. Studies, Princeton, N.J.*
2. ,, J. B. Connant—*President, Harvard University.*
3. ,, Buckley—*Bell Telephone Laboratories, Director of Research.*
4. ,, DuBridge—*California Institute of Technology.*
5. ,, Libby—*Prof. of Chemistry, University of Chicago.*
6. ,, Murphree—*Std. Oil Dev. Co.*
7. ,, Rabi—*Prof. of Physics, Columbia University.*
8. ,, Neumann—*Prof. of Mathematics, Inst. Adv. Studies, Princeton.*
9. ,, Whitman—*Research & Development Board, Defence Dept.*
10. ,, Dodson—*Chemistry Division, Brookhaven National Laboratory.*

Each member is appointed for a 3-year term except for the Defence Department representative. The USA is a democratic country and its power lies not in supermen, but in the general intelligence of the people. Consistent with that idea, nobody is allowed to enjoy power for an unlimited period.



One-third of the members retire every year to ensure continuity of the Committee. An analysis of the personnel shows that it consists of Professors of Physics, Chemistry and Mathematics, university administrators not necessarily experts on atomic energy. This is the body which lays down the policy under directives from the President, for the AEC, which is the executive body. The congressional committee determines how successful the AEC, has been in carrying out the allotted programme of work, and also recommends allocation of funds.

The executive work is entrusted to the Atomic Energy Commission composed of 5 members including a Chairman appointed by the President of the USA. Each of the members of the AEC including the Chairman is appointed for 3 years and no member has yet been immediately reappointed on his retirement although there have been instances of reappointment after a gap of sometime. To ensure continuity not more than two members are retired at one time. The members of the AEC in 1952 were:

1. Gordon Dean, *Chairman*
2. T. Keith Glennan.
3. T. E. Murray.
4. H. D. Smythe.
5. E. M. Zuckert.

An analysis shows that the members are University Professors, Directors of Research Laboratories of large firms, and Engineers who have large experience of development projects in industry and administration.

Under the US Atomic Energy Commission Act, certain amount of work of the organisations working for atomic energy have to be kept as secret. This is determined by the Senior Reviewing Committee which is composed of *three university scientists* and *one Government scientist*. We give below the names of the four members of this Committee for 1952:

1. Dr. Johnson—*Prof. of Chemistry, University of Chicago.*
2. ,, Kellog—*Los Alamos Station, AEC.*
3. ,, Libby—*Prof. of Chemistry, University of Chicago.*
4. ,, Thornton—*Prof. of Physics, University of California.*

They determine what work of the AEC should be withheld from public knowledge according to the rules of the AEC, the law of the country, the directives given by the President and the policy formulated by the General Advisory Board. It should be noted that two of the four are chemists, one is a military engineer and one is a physicist. It is mostly chemical or engineering processes which are kept secret.

Besides these main committees, there are fifteen other advisory committees consisting of more than 200 members who report to the Atomic Energy Commission. An analysis of the membership shows that they include many important scientists and engineers, from Universities and Industry who can conceivably help or contribute in any way to the AEC programme. Some of them also undertake in their own institutions schemes of work formulated or allocted by the advisory boards. They also discuss and make suggestions regarding that particular aspect of the work of the AEC covered by the respective boards.

3. Classification of Work

The work of the Atomic Energy Commission may be classified under the following headings:

(*a*) Procurement of minerals, fabrication into metals.

(*b*) Their processing into fissile materials (U^{235}, Pu^{239}).

(*c*) Problems of application of atomic energy to produce industrial power (long range work).

(*d*) Weapons development and testing (short range work).

(*e*) Peaceful applications of atomic energy, fundamental research, and development of machinery and instruments.

Only the USA, Soviet Russia and Britain are working on all these objectives.

All other nations, including France, Norway and Holland are working only on (*a*) and (*e*).

A vast number of organisations has been set up under the AEC to carry out the programmes, but they are not always the direct administrative charge of the AEC.

All programmes under (*a*) and (*b*) are directly under the AEC, though sometimes a number of industrial firms are associated under special contract.

Programmes under (*c*) are carried out generally in co-operation with industrial firms who have specialized on the subject.

Programmes under (*d*) are carried out in co-operation with the defence forces, army, navy and air-force.

Programmes under (*e*) are carried out mostly in association with universities, or groups of universities, other institutes of university rank, research organisations etc.

(a) Procurement of minerals and processing into metals

The major supplies of uranium ores had been from Haut-Katanga, situated in the south-eastern part of Belgian Congo, and from Canada. The AEC also made an extensive exploration of possible uranium ores in US. By 1951 the domestic production increased to a point that US became second amongst free nations in the mining and processing of uranium ores. Important uranium deposits have also been found in Australia and South Africa and these are being handled jointly by USA, UK and Australia.

(b) Production of Fissile Materials

Immense efforts have been employed for the production of fissile material by the USAEC. Some of the places where these works are carried out are mentioned here.

(*i*) The production of fissile material and processing are carried out at Oak Ridge, Tennessee, original cost $500 m enlarged at a cost $200 m.

(*ii*) The second U^{235} Gaseous Diffusion plant at Paducah, Kentucky, is in operation at $500 m.

(*iii*) Aiken, South Carolina—New $900 m plant for U^{235} preparation by diffusion (p. 15, *Vol. 1, No. 1, A.S.N.*), is also in operation.

(*iv*) Handford, Washington (originally under contract to G.E.C. now with DuPont)—$200 m more for Pu production is being spent on the $350 m Handford works (p. 15, *Vol. 1, No. 1, A.S.N.*). Mammoth reactors use liquid coolant and U as the fuel.

(*v*) Portsmouth, Ohio—A fifth fissile material producing plant is in the Ohio valley using gaseous diffusion plants at a cost of $1,200 m and power required 4,00,000 K.W. (p. 288, *Vol. 1, No. 6, A.S.N.* and p. 117, Vol. 2, *No. 2, A.S.N.*).

(*vi*) Savannah River Project—Details are absent.

(c) Conversion of Atomic Energy to Industrial Energy.

(*i*) National Reactor Testing Station at Arco, Idaho:

Experimental breeder reactors is in operation this year producing about 100 K.W. of power (p. 15, *Vol. 1, No. 1, A.S.N.*). Estimated cost of the breeder is $3·3 m (p. 16, *Vol. 1, No. 1, A.S.N.*) excluding the cost of fissionable materials and moderators.

(*ii*) A material testing reactor has been set up to determine the effects of continuous and heavy neutron bombardment on the physical properties of various materials—to be utilised in later reactor designs, to test such elements as coolant tubes, structural support, moderators, fuel rods and neutron reflector or radiation shields (p. 289, *Vol.* 1, *No.* 6, *A.S.N*). Estimated cost is $18 m fort he material testing reactor (p. 16, *Vol.* 1, *No.* 1, *A.S.N.*).

(*iii*) A prototype reactor suitable for submarine propulsion is under construction at (p. 288, *Vol.* 1, *No.* 6, *A.S.N.*) an estimated cost $26 m (p. 16, *Vol.* 1, *No.* 1, *A.S.N.* and p. 371, *Vol.* 2, *No.* 6, *A.S.N.*).

(*iv*) Useful electric power from atomic energy was produced for the first time from the Arco breeder reactor. Liquid metal was used to extract heat from the breeder and to drive a turbine which generated 100 K.W. of electric power (p. 151, *Vol.* 1, *No.* 4, *A.S.N.*). A chemical plant for recovery of fissionable material from used reactor fuel (p. 373, *Vol.* 2, *No.* 6, *A.S.N.*) has been set up.

(*v*) North American Aviation Inc.—(p. 151, *No.* 4, *A.S.N.*). Research on industrial and aviation applications of nuclear science on contract with AEC operates piles with natural water and heavy water cooling systems on low cost basis.

(*d*) *Weapons Development Stations are:*

(*i*) Los Alamos Station—This is the station for atomic weapon development and testing. Naturally not much is known of its activity. Apart from these stations there are the testing sites at Nevada, Eniwetok in the Pacific and other places operated by the AEC and the defence services.

(*ii*) Fulton, Illinois—29 million dollar plant has been built for processing and assembling explosive cores of atomic weapons.

Also in association with Illinois Institute of Technology and Armour Research Foundation the development of industrial power and breeding are carried out.

(*iii*) Knoll's Atomic Power Laboratory—Schenectady, carries out experiments on submarine intermediate reactors using liquid metal coolant instead of water (p. 289, *Vol. 2, No. 6, A.S.N.*).

A cobalt (60) source rated at 3,400 curies, equal to twice the world's supply of Ra, is used to test the effect of radiation on materials to be used in an atomic power plant for submarine. The source costs $20,000 whereas equivalent Ra source would cost $138 m (p. 188, *Vol. 2, No. 3, A.S.N.*). The G.E. Co. is carrying on works for the second nuclear powered submarine (The first called 'Nautilus' is now undergoing tests by the US Navy).

(*e*) *Fundamental Researches are carried out at*

(*i*) School of Reactor Technology for Engineers at Oak Ridge—Low Power Reactor submerged in a pool 40 ft. by 20 ft. and 20 ft. deep costs $250,000 excluding fissile materials and moderator. Pool and building alone cost $2,00,000. Max. power is 10 K.W. Max. neutron flux is 10 neutrons per sq. cm. per sec. Water serves as shield. The purpose of the reactor is research and training (p. 43 *of Vol. 2, No. 2, A.S.N.*).

(*ii*) Experimental homogeneous reactor at Oak Ridge National Laboratory with a power 1,000 K.W.—Reactor was switched to gas turbine generator and about 150 K.W. of electricity was generated. A single solution served as moderator and coolant. Cost of building etc. $1 m—Cost of research and development $ 3 m (p. 318, *Vol 2, No. 5, A.S.N.*).

(*iii*) A new cyclotron at Oak Ridge which will open a new field of basic research in nuclear physics to accelerate heavy particles as nitrogen ion, to 25 MEV. These accelerated nitrogen ions may combine with oxygen, carbon etc., to produce flourine, sodium, aluminium etc. The machine's estimated cost is $1,40,000 (p. 372, *Vol. 2, No. 6, A.S.N.*). There is also an older 63 inch cyclotron (p. 278, *Vol. 1, No. 6, A.S.N.*).

(*iv*) Brookhaven National Laboratory run by Associated Universities of the USA (13 participating Institutions and AEC) has many research equipment including Pile, Cyclotron, Cosmotron, etc. It is one of the largest and best equipped laboratories in the world and is jointly managed by AEC and associated Universities with major funds from AEC.

(*v*) Radiation Laboratory, Berkeley—University of California laboratories, financed and operated under AEC contracts but managed by the University of California work on chemical, medical, physical and technological problems. Initiated and developed the E.M. separation of isotopes. A 6 BeV synchrotron called bevatron is undergoing trials.

(*vi*) Argonne Laboratories near Chicago (associated with the Institute of Nuclear Studies, Chicago)—Biological aspects of nuclear radiations on plant hormones, controlled growth etc. are studied (p. 279, *Vol.* 1, *No.* 6, *A.S.N.*). Also an experimental heavy water and uranium pile designed to generate 300 K.W. is in operation for experimental purposes. Pile researches and researches on neutron beams are being carried out.

(*vii*) Stanford Research Institute under the Stanford University. Work is done on the problems of the use of fission products as sterilizers of food, drug, for radiography, production of chemicals, flourescent lights and new types of luminiscent paints and tubes (p. 16, *Vol.* 1, *No.* 1, *A.S.N.*). There is also one BeV linear accelerator nearly completed.

4. Review

The analysis of the work shows that sections (*a*) and (*b*) *i.e.*, procurement of minerals, production of fissile materials and (*d*) weapons development are entirely under the AEC.

(*c*) Utilization of Atomic energy for industrial concerns is a long range work, but how long will it take to harness atomic energy to industry. Experts in the development of Nuclear Reactors like Dr. Goodlet, Deputy Chief Engineer, AERE, Harwell, UK, and Dr. G. L. Weil, Assistant Director, Division of Reactor Development, AEC believe that it will take a considerable time and many millions of pounds (sterling) before nuclear energy can be harnessed economically for industrial power. One U.S. expert estimates that it will take 20 to 25 years in the U.S. before this is done. (*Nucleonics, Feb.* 1953, p. 9, and *April* 1953, p. 12—*Editorial, Nuclear Power.*)

(*d*) *Fundamental Research Works.*—The analysis shows how the Universities, Research Institutions and Industrial Organisations are drawn into atomic energy work in various aspects of it. In fact by far the greater part of the atomic energy work is conducted by these organisations with the Atomic Energy Commission acting as the central pool of information and funds and responsible for the overall programme of work. They are also entrusted with much short range work viz., the production and utilization of radioactive substances in the nuclear reactor and their wide use in various fields of science and technology including the production of the radioactive substance known as plutonium and uranium (233) for atom bombs or for experimental research on production of power or for breeding. The development stage is entrusted to organisations under AEC under secrecy. This short range aim is already being progressively achieved by the various countries of the world such as the USA, UK, USSR, France, Canada, Holland, Norway and others. Even the achievement of this limited goal requires extensive development and dissemination of this technology to the widest extent.

5. Budget

The total budget of the Atomic Energy Commission sanctioned by the Congress for 1953 was 1·137 billion dollars *i.e.*, about five hundred crores of rupees *i.e.*, it exceeds the budget of India by hundred crores of rupees. The break-up of the budget for the year 1953 is given below (*Nucleonics*, 1952, July):

Project or item	*Amount allowed*	*Decrease*
Operations		
Source and fissionable materials ..	$315,900,000	$25,600,000
Weapons	208,000,000	20,000,000
Reactor development	70,000,000	22,400,000
Physical research	33,100,000	10,000,000
Biology and medicine	23,285,000	1,314,500
Community operations	1,800,000	1,000,000
Program direction and administration ..	30,000,000	5,400,000
Stores and inventories	202,000	3,000,000
Special reactor materials	2,780,500	2,780,500
Other special materials	1,018,500	1,018,500
Working capital	700,000	--
Unliquidated obligations	22,200,000	
Total operating obligations ..	708,986,500	92,513,500
Plant and Equipment		
Source and fissionable materials ..	300,826,000	10,574,000
Weapons	27,500,000	27,500,000
Reactor development	20,400,000	23,700,000
Physical research	1,000,000	4,985,000
Biology and medicine	515,000	--
Community facilities	1,500,000	4,000,000
Equipment not included in construction projects	20,000,000	11,000,000
Total plant and equipment obligations	371,741,000	81,759,000
Cash to liquidate prior contract authority	57,000,000	--
Grand total obligations	1,137,727,500	174,272,500

This does not appear to be the whole budget. Testing of atomic weapons appears to come separately under Army and Navy budgets. According to President Eisenhower, so far about 45 atomic explosions have been carried out, including one or two fusion bomb explosions.

It is difficult to estimate the total number of scientific and technical personnel employed by the AEC. It is learnt from "Major Activities in the AEC Programmes" published by the AEC July 1952, that the AEC of America has entered into 652 contracts (May 31, 1952) for unclassified research on different aspects of atomic energy with scientific workers of universities and resesrch organisations all over USA under the categories: Chemistry—116, Metallurgy 51, Physics—94, Mathematics—1, Biology—160, Biophysics 23, Medicine—152, Raw Materials Research 13, Reactor development—42. The total number of workers directly on the pay-roll of the A.E.C. is estimated at over 11,000.

6. Atomic Energy Organisation in other countries

Though the fundamental discoveries in Atomic Energy were made mainly in Germany, England, France and other countries of Western Europe, the practical application of these discoveries to the making of the Atom Bomb was carried out mostly in the USA and Canada during the years of the war by a great State effort which was directed to a large extent by foreign refugee scientists, and scientists of friendly countries as American scientists had not much knowledge of it. On account of such co-operative efforts, and huge expenditure amounting to 2,000 million dollars, development work which normally would have taken at least 50 years, were carried out in 5 years. According to the Smythe report which gave an account of these efforts, the development work was mostly confined to the PILE and production of sufficient quantities of fissionable material like U^{235}, Pu^{239} for the making of atom bombs, and use of atom bombs. The planned development of atomic energy for peaceful work started only a year after the termination of the war, but in this attempt, very great difficulties were created for other countries on account of the craze for secrecy and monopoly, developed by the USA in post-war years.

The U.S.A. wanted:

(1) to keep the knowledge of all technical processes evolved during the war to herself, also tried,

(2) to acquire monopolistic rights over sources of raw materials used in atomic energy all over the world, *e.g.*, the uraniferous mines in Belgian Congo, in South Africa, and in Latin American countries,

(3) to prevent the export of special instrument and apparatus developed for the A.E. work,
(4) to exercise a strict control over all publications from atomic energy laboratories of the USA,
(5) to keep a strict watch on their own atomic energy personnel, and attract foreign personnel to their own country, so as to deny their availability to other countries.

The MacMahon Act was passed by the Senate in 1947 to give effect to this mentality. The USA had not been successful in her efforts, but she had produced a state of tension which has been felt not only by Soviet Russia, but by the West European countries as well. (See *Atomic Science News*, July, 1953, p. 350—article by Dr. Skinner.)

Ever since the intentions of the USA were known, these countries determined to break the monolpoly. Some have been successful in varying degrees.

For example, it is apparent that Britain has discovered all the secret chemical processes and technical operations which the Americans had tried to hide from her and some people think she is ahead of the USA in several respects. England has been carrying on investigation in all the five lines mentioned previously and hence her pattern of organisation is quite similar to that of the USA, though the headings are different. The budget is not given out, but it has once been said that where the USA spends one dollar, the UK spends 10 cents. This may be a good approximation.

Atomic Energy Organisation in France: France, whose condition was not much better than that of India in 1947, now claims to have achieved the second stage in "Atomic Autonomy" which is expected to be achieved in a fifteen year plan, of which six years have passed. She has adopted only programmes (*a*) and (*e*), and do not appear to have any plan yet for industrial utiliasation of atomic energy or for weapon development.

How have the French achieved so much inspite of American obstruction?

First by making a great national effort in which the knowledge and skill of all the available scientists of the country—Physicists, Chemists, Geologists, Technologists and Engineers were utilised for the objective. *Evidently, if such co-operation is to be achieved, there can be no Iron curtain of "Secrecy" within the nation.* There can be no development of atomic energy without development of an atomic instruments industry, and of associated chemical and metallurgical industries.

The French Atomic Energy Commission is working with a singular lack of "Secrecy".

The French AEC frankly and openly disavowed "Secrecy" both inside and outside. In fact, the first Chairman of the Commission, Prof. Joliot Curie, is a professed communist, and he was appointed as Chairman by General de Gaulle, his opposite in political views. Later Joliot Curie was removed at Ametrican instigation, but not before he had completed the organisation and set the whole machinery of Atomic Energy work going. Moreover, his removal from the headship appears to be merely an eyewash, for he is still Professor in the College de France, and nerarly all atomic energy workers in France are either his pupils, friends or co-workers. They publish everything and all are welcome to see their "Plants" and they give almost every information asked for except probably a few chemical processes.

7. Secrecy

One of the most unhappy features of Atomic Energy Work in many countries is the 'Secrecy', with which a certain class of operations have to be carried out. It has been imposed by the politicians and the military and nobody but these classes seems to be happy about it.

We learn from an article in *Nucleonics*, 1950, Feb., p. 18 that even USA realised as early as 1946 the importance of free access to information by the scientists as can be seen from the statement incorporated in the Atomic Energy Act of 1946 where it says "that the dissemination of scientific and technical information relating to atomic energy should be permitted and encouraged so as to provide that free interchange of ideas and criticisms which is essential in scientific progress". The USA publishes its budget, allocations, names, locations and objectives of its plants. These appear as regular festures in the relevant journals *e.g.*, the *Nucleonics*.

The publications of the AEC (USA) are so numerous that all countries without exception find it difficult to keep pace with them. The AEC (USA) publishes all declassified (once secret, now made public) documents and Nuclear Science Abstracts giving information about all unclassified work (work which has never been considered secret) done under them.

The publication of Government plans and programmes evokes a good deal of public discussions. It is important to note that both the UK Govt. and the US Govt, invite such discussions and are not afraid to face criticisms. These always help the Govts. to correct their mistakes and to change or modify their plans so as to operate more efficiently and for broader and clearer goals. Evidences of such criticisms can be found in each issue of *Atomic Scientists News* (Published by Tayler & Francis Ltd., Red Lion Court, London E.G. 4) and *Nucleonics* (A McGraw Hill publication, USA).

Field where "Secrecy" is adopted. : "Secrecy" is exercised only in certain chemical and technological operations, in weapon development, and in publications of results of "Atomic Explosions". Even this secrecy, which is imposed upon them by the MacMohan Act, is not liked by responsible atomic energy officials and scientists, for example, Mr. Gordon Dean once Chairman of the AEC says (*A.S.N.* 1953, March, p. 258): "Such extensive secrecy as we now have will almost certainly hamper progress, if it has not begun to do already".

The British have kept a show of secrecy to please the Americans. In the early stages, according to an article by Sir G.P. Thomson, F.R.S. (*A.S.N.*, Vol. 2, No. 6, p. 439) every British physicist, chemist and other scientists of note were taken into confidence. The British Government has published the names, locations, and objectives of all their Atomic Energy plants, and all publications of a purely scientific nature are allowed to be published. It is well known that almost all their eminent physicists, chemists and geologists who can be helpful are consulted even in so called "secret work".

Secrecy has defeated its very purpose : It appears from the avove review, that 'secrecy' has defeated its very purpose for inspite of 'Secrecy' countries like UK, USSR, have been able to discover almost all the processes for production of fissile materials and for their peaceful use.

The production of UK in fissile materials is of course smaller, than that of USA and that of France is still negilgible because they cannot spend sufficient money and have not the huge industrial resources of USA. But the USA is nervous that the USSR has overtaken her completely both in research and production and can give an eye for an eye and a tooth for a tooth.

What is then the point of maintaining "Secrecy" in the peaceful application of Atomic Energy? President Eisenhower's speech commented in our editorial calls for 'Liquidation of Secrecy' as far as peaceful utilisation of Atomic Energy is concerned.

Secrecy is in fact doing gerat harm to the progress of Nuclear Science, for inspite of expenditure in this line on a scale unheard of in the annals of Science, no fundamental discovery equal in its importance to the discovery of fission by Hahn in 1939 which was made with the aid of very simple apparatus has yet been made. History of progress of science tells us that the greatest discoveries in science have come from open exchange of information on an international scale, which leads to cross-fertilization of the human brain, and provocation of new fruitful ideas, some times from unexpected quarters. This has been prevented by "Secrecy". Nations are spending huge amounts of money for the discovery of the same process, which could be diverted for better purpose if open inter-change of scientific information was allowed. It was a good sign of the times that persons in 'Authority' are now conscious of the evil effects of "Secrecy".

1.3.13 PEACEFUL USES OF ATOMIC ENERGY*

I have ventured to raise this debate in the hope that the representatives of the people who guide the destinies of our nation may take a more braver and enduring interest in the development of atomic energy in this country, for, its peaceful application, if properly done, is going to change human life very profoundly. What is atomic energy? Atomic energy is a kind of new fire. It will give us energy in a way which is very different from the older forms of energy. It will give us a source of inexhaustible energy which can be transported to any locality, deserts, mountains, oceans, not excepted, and it can transform human life. It can, if properly applied, revolutionise the arts, sciences and industry, and it will cause as great a revolution in human life as the discovery of fire nearly six thousand years ago which raised mankind above the animal level. But at the present time, we are not very much aware of the beneficial aspects of the utilization of atomic energy. We think more or less about its evil effects. The two atom bombs which were dropped on the two Japanese cities nearly nine years ago have produced unfortunately a great tension in the international life. This tension in growing daily. We know that this tension is due to the atomic armament race on the part of the great powers of the world. The United States of America which was the first in the field had developed since 1942 an extensive and elaborate atomic energy programme. They cost nearly two billion dollars annually. It is a little more than the whole budget of India and the States combined, and it amounts to about two per cent of their national budget. The USSR started late, but their development since 1948 on atomic energy, and programme, the details of which are not very much known, is supposed to vie in dimension with the American programme. Unfortunately, this stock-piling of fissile material has produced very great unrest in the world. There was about 200 years ago a great king, Louis XIV. He got a new gun manufactured, which was better than those existing those days. Then he inscribed on the new gun the words, "logic of peace". With that logic, he tried to bring into subservience the other countries of the world. We know what was the effect. The same kind of atomic laws are being applied by certain nations of the world now to coerce the less fortunate nations into subservience. I think the effect of this logic too will be no better

*Loksabha Debate on May 10, 1954, Vol 5, 7007, 1954.

than that of Louis XIV. It is now estimated that the United States has got enough fissile material for the making of 6,000 bombs. Each one of them, if properly dropped on centres of population, could wipe out almost the entire cities. It is not known how much Soviet Russia has got, but it is supposed to be 300, by authorities who claim to know the inner facts. But the rate of production of Soviet Russia is said to be higher than that of America. That is not exactly the point now, but the very stock-piling of this dangerous material has produced alarm throughout the whole world. The question which is uppermost in the minds of the people is this. Is any of the great powers using this dangerous material to end civilization, or will better sense prevail and the different nations will utilise this stock-pile of material for peaceful purposes? It has been pointed out by great authorities that the development of atomic bomb by two rival groups has somewhat obviated the dangers. The situation is similar to that of gas warfare at the end of the first world war. Gas warfare was perfected during the second world war, but people knew that if any party used gas warfare, the retaliation would be so swift and so great, that both the belligerent parties refrained from using gas warfare. We therefore think that no atomic warfare is probable in the near future. We can therefore ask ourselves what will be the peaceful application of atomic energy which will transform human life? We are aware that a good deal of our backwardness is due to the fact that we have not been able to utilise energy. We have not been able to produce much power which we can apply to develop the resources of this country and increase the productivity in every field.

I shall just give an example. This country, like the countries in medieval times, still depends upon manpower and animal power. We use about 90 units per head and as regards electrical and steam power, probably our total *per capita* production is about 60 or 70 units at the present time. So, our total *per capita* energy will not be more than, 140 or 150 units. Compared to this, the great countries of the west like Soviet Russia, and above all, the United States of America, produce every year about two to three thousand units of energy *per capita*. That is the reason why those countries have achieved so much economic prosperity. The *per capita* income of India is about Rs. 260; that of America is about twenty or thirty times higher than this. The income of other countries falls in between these two. So, if we have to solve this problem of poverty, problem of malnutrition, the problem of giving plenty to all our brothers and sisters, the Government must have a plan for the development of energy in this country and for utilisation of that energy, to develop the natural resources of the country. Unfortunately, our power is not so great. We have very limited supplies of coal and if we utilise all the coal in the way that America does, it will not last more than a few decades. Our hydro-electric power is also very limited, and excepting a few parts of India—the eastern parts, the Himalayan regions, Mysore and to a certain extent, Trivancore-Cochin—the remaining parts of India are power-hungry. It is very difficult to develop the natural resources of this country. There are five iron ores in the Salem district of Madras but these cannot be developed because we have no power. There are great mineral deposits in Rajputana. They cannot be developed because there is no hydro-electric power there. Whatever can be developed from the Chambal is very small and coal has to be hauled over long distances and it does no become a paying proposition. In all these parts, if atomic energy can be developed it will prove a great blessing.

Every country in the world has beocme conscious of this great fact and every country is trying to develop atomic energy, each in its own way. But, there has been a very great difficulty. America has been first in the fleld and, taking advantage of her great position, she has tried to corner all the raw materials—uranium and thorium and the moderating minerals like purified graphite, beryllium and heavy water. Unfortunately, very few contries of the world have got these resources. And as a matter of fact, after the termination of the war, America parted company with her former friends like the United Kingdom. France and other conutries and put a ban on the export of atomic materials, on the export of knowledge. You know what has happened as a consequence. The other countries of the world have been at a great disadvantage to utilise atomic energy. Let us take the example of England itself. England's great prosperity is due to her possession of coal deposits. But, she feels that, at the present rate of consumption her coal deposits would be exhausted after about a hundred years. Therefore, they made very great attempts to explore the possibilities of atomic power and they have succeeded to a large extent. They say that without American aid, depending upon their own expert knowledge, they have developed atomic energy plants and they think that in a few years power would be provided by atomic reactors.

But, other countries have not been fortunate like England. England has got a great Empire—even minus India—and she has been able to discover large deposits of uranium in different parts of that Empire. She has taken all this uranium to her own courntry. They have erected very huge plants and have been able to have a stock-pile of uranium out of which they have been able to set up numerous reactors, which are the first stage for the development of atomic energy. They confidently claim that in a few years they will have economic atomic energy plants. I may say that atomic energy plants are at present nowhere economic propositions, just as the steam engine, when it was discovered, was not an economic proposition at all. To produce one unit of power-one unit of energy one had to spend nearly ten lb of coal. Now, it has been reduced to one lb. Similarly, atomic energy electricity will cost about 10 or 20 times more than ordinary electricity, But, experiments are in progress, in England and America, which will greatly bring down this margin. At the present time, atomic energy can only be used in those regions where cost is of no account for example in making an atom bomb or in running submarines or even aeroplanes. Though England has been successfull in solving her atomic energy problems to a great extent this has not been the case with other countries. For example take France. It is a long way behind, though after a terrible effort extending over a period of six or seven years, they now say that, without the aid of America or any other country who would not sell uranium for any amount of money or other atomic materials for any amount of money, they have been able to get everything within their own Empire and have been able to set up three or four reactors. They now say that they have achieved atomic autonomy and it will be possible for them to run their industries with the aid of atomic energy in ten or twenty years. This is very great importance to France because France had been handicapped on account of her poor resources of energy. She has no coal practically and she depends only on hydro-electric power. Though she has got the finest iron ores in the Lorraine region, she has to depend upon German coal for the development of her iron and steel industry.

The other European countries are in a very bad condition I was in Sweden in 1946-47. I talked with some of my Swedish friends. They were all alive to the possibilities of atomic energy but they said they could not get uranium for any amount of money. They tried to explore their own uranium ores, which contianed only a very small part, scarcely 0.1 or 0.2 per cent. We find that by this time Sweden has not been able to put up an atomic reactor.

The only other European country which has been able to do so, is a joint enterprise by Holland and Norway. Holland had a great Empire and she could scrape sufficient uranium before she quitted Indonesia, and she had enough uranium for a nuclear reactor. On the other hand, Norway had not uranium but she had the moderating material, chiefly heavy water. They have combined and been able to have a nuclear reactor.

Other countries, the Latin-American countries are still a long way behind. Therefore, we see that most of the countries of the world are not able to take advantage of this discovery.

In this debate, I wish to invite the attention of the House to the excellent suggestions which have been made out by President Eisenhower on December 8th, before the General Assembly of the United Nations Organisation in a meeting which was presided over by Shrimati Vijaya Lakshmi Pandit. In this debate he made a suggestion for easing war tension by making a very geneorus gesture. We have got a stock-pile of this dangerous material. It is not our intention to utilise it for war purposes. He formulated four points. I have put them in a different form.

(1) Opening of a new channel for peaceful discussion and to initiate at least a new approach to the many different problems that must be solved in both private and public conversation if the world is to shake off the inertia imposed by fear and is to make positive progress towards peace. This is in general terms.

The second is also like that. To allow all people, of all nations to see that in this enlightened age, the Great Powers of the earth both of the East and of the West are interested in human aspirations first rather than in building up the armaments of war. This is also in general terms.

But the more pointed and concrete proposals are given in the next resolution. To begin to diminish the potential destructive power of the world's atomic stock-pile, I have just now told you that America has got a stock-pile for about 6,000 atom bombs and Russia has got a stock-pile of probably lesser amount. Britains stock-pile is probably far inferior to that possessed by these two nations. We have been told that the hydrogen bomb is far more dangerous. It may, in fact be made nearly 600 times more dangerous. But the hydrogen bomb can not work without the atom bomb. When the atom bomb acts as a detonator, it sends the hydrogen bomb into action. Some stock-pile of uranium is a fundamental thing, which we require, the other things are not very difficult. If this stock-pile, which is already there, is made for peaceful purposes, it can solve the power requirements of the world for a few years and that will be a great blessing. President Eisenhower's third proposal is to begin to diminish the potential destructive power of the world's atomic stock-piling. Then, the fourth resolution is to encourage worldwide investigations into the most effective peace time uses of fissionable material and with the certainty that they had all the material needed for the conduct of all experiments that were appropriate. These two were the main proposals. He has also told us how to take advantage of the proposals. He makes the proposal that "the Governments principally involved, to the extent permitted by elementary prudence, to begin now and continue to make joint contributions from their stock-piles of normal uranium and fissionable material in an international atomic energy agency. We would expect that such an agency would be set up under the aegis of the United Nations. The ratios of contribution, the procedures and other details would probably be within the scope of private conversations I have referred to earlier". This is a proposal for making an international pool where uranium and other materials would be contributed by the USA and by Russia, and out of this, the other countries should be allowed to take such amount of materials as will be necessary for their own experiments. For example, India has got an Atomic Energy Commission and five years ago we had announced that we were going to set up a nuclear reactor within five years. This is 1954 and nuclear reactor has not been set up. We are in the same condition as Sweden. Though we have got thorium, we have not got sufficient stocks of uranium and we have not been able to get together 30 tons of uranium and about 100 tons of pure graphite, which are necessary for setting up a nuclear reactor. I do not know how long it will take us to make good this proposal. It may take us to set up a nuclear reactor, but if there is an international pool like this from which we can draw up the necessary material, it will be possible for us to set up a nuclear reactor within a very short time. We all welcome the creation of the international pool of fissionable materials. It will enable small nations as well as backward nations like ourselves and China to draw upon this international pool and set up a reactor and set on these experiments which will be necessary before atomic energy becomes a practical proposition. I hope that our Government will weigh the proposals of President Eisenhower very carefully and will lend to it all its support. I have talked with several of the political groups and it may be that they smell something very rotten in these proposals, but I do not see why we should take a very gloomy view from the very beginning. Even if we get a gift of fissionable materials, is it possible for us to utilise them properly for the good of the country ? If atomic energy is really to be useful, we cannot depend upon foreign countries. You know they would not part with their knowledge. You have read of the prosecutions of spies and so on. We have to develop all the knowledge in this country; we have to develop our own personnel. Have we got a proper organisation for all that ? We have not got. I would insist upon our Government that they make our atomic energy work more broad-based they spend more money upon it and train up a band of personnel which will be able to take advantage of this offer by the United States and other countries, if it comes at all. If this International agency does not come into existence, we have to depend upon our own efforts and I do not think it is impossible for us to develop atomic energy if we harness all the talents in the country and spend a sufficient amount of money for the development of atomic energy. I would just remind the House that this new discovery is almost like the discovery of knowledge of ancient classics which brought on the renaissance in Europe, and if we have to take advantage of this discovery, we must make sufficient efforts. As I have told you, America spends about two billion dollars; England spends about one-tenth of that; and it is said that France which has got no weapon development in its programme, spends one-tenth of that. While America spends one dollar, England spends 10 cents, and France spends about one cent. The French expenditure would be from Rs. 10 to Rs. 20 crores. If we have to develop atomic energy in this country, we have to spend about Rs. 10 crores to start with, and this is worth spending on account of the great promise which it holds for solving the problems of poverty, malnutrition and disease in this country. At the present time, we are spending about Rs. 3 crores on scientific research. If this organisation is to come into existence, we must have a bigger organisation than the present Council of Scientific and Industrial Research has got. Therefore, the Atomic Energy Commission, which you have got now, has to be scrapped and we must start our work on a broad basis. First of all, there should be no secrecy. If you read our Atomic Energy Act, you find that it does not tell us what to do, but it simply tells us what is not to be done. We shall not export neptunium, we shall not do this, we shall not do that and so on. I would ask our honourable friends on the Treasury Bench to read the Atomic Energy Acts of England and America and see how broad-based they are. They of course, have secrecy, but the Act deals with how new work has to be organised properly and how the money, which will be devoted for this purpose, has to be spent judiciously, how the efforts of the scientific talents of the country have to be harnessed in one scientific effort. There is a common prejudice that atomic scientists are a special class by themselves. It is a great fallacy; it is an illusion. There has been no atomic scientist to start with. The atomic scientists have been ordinary chemists, ordinary physicists, biologists and others. When this great discovery came, they turned their minds to the discovery and tried to find out how to utilise that for the different purposes. So, the atomic energy scientist is not a new race that has come into existence. But if we utilise the scientific talents available in this country then we can have an atomic energy organisation which will be as fruitful, which can develop atomic energy as successfully as any other country in the world. We have got raw materials scattered all over the country; we have got unravelled deposits of thorium in Travancore; we have got uranium here and there; but we have got a very poor prospecting organisation. I think we are utilising the services only of 40 or 50 men and all of them are not geologists. Prof. Joliot Curie, who was Chairman of the Atomic Energy Commission in France, and started this work, told me that he had employed about two hundred fully qualified geologists and under them he had trained another about four or five thousand men to explore not only all the regions of France, but also French colonies like Madagascar, Morocco, and the result of this great effort is found in the French success in building up three or four nuclear reactors. I think if we have to get all the uranium in our country and process them, we must make as big and mighty effort as that.

I would therefore, suggest, that Government should convene a meeting of the selected persons of this country who are conversant with and interested in the latest developments of atomic energy to advise them as to how to draft a reply to the President's proposals. This meeting should also advise Government on this point.

How far the scientists of this country engaged in fundamental investigations of nuclear physics, chemistry, biology and medicine would to benefited if the President of the United States' wishes were to be accepted in a practical form by the United Nations Organisation; second how far the industrialisation of India would be accelerated if one or two atomic energy power plants of about half to one million capacity were to be established in the power-hungry areas of India like the South, except Mysore, parts of Rajasthan and Central India.

I think, Sir, I have spoken sufficiently about the way in which the organisation has to be set up and we should reply to President Eisenhower's proposal. Let me conclude by saying that development of atomic energy in this country holds out a very great future and as far as I know our scientific colleagues of this country are capable of shouldering this great task. It now is for the Government and our youngmen—I have spent one generation and a half in training younger generations to undertake this work, and I know that if our young scientists are entrusted with this great task they can deliver the goods. I would, therefore, request Government to make our atomic energy establishment more broad-used than it has been so far and to expel all ideas of secrecy from the new Atomic Energy Act.

1.3.14 FUTURE OF ATOMIC ENERGY IN INDIA*

I need hardly remind this assembly of real politicians that the atom has dominated World Politics since 1945, when the first three atom-bombs were exploded. The Atom Bomb and the Hydrogen Bomb have been so much on the headlines of daily papers that the far more important significance of the great discovery of Nuclear Fission has been missed. I am going to tell you about that: how the Atom is going to dominate, within probably a generation, the industrial and technical life of the world.

It is well-known to you that there is a great disparity in the standard of living in the different countries of the world, as is illustrated in Table I, which represents the per capita income per year in different parts (valid for the year 1949) of the world.

I have taken the average standard to be proportional to the per capita income. The table shows that the highest standard has been attained in the USA. Next in order come several West European countries. India and Pakistan do not stand exactly at the bottom, but even Mexico, Turkey, and some South American countries have reached a better standard. What is the cause of this enormous disparity ?

It is because production of all goods essential for life viz., food, and industrial products are very much less, in the backward countries, where, in addition, education, sanitation and transport are very poorly developed. The common people have very few comforts in life. A few figures may be given.

India has a population of 360 millions, USA has 160 millions. India produces barely one million tons of iron and steel, while USA produces over 100 million tons. The per capita consumption of iron and steel in USA is over 1200 lb, all of which is produced in the USA. The per capita consumption in India is 12 lb of which only 7 lb are produced in India, the rest comes from abroad. As iron and steel are essential key materials, their poor supply embarasses a lot of other national activities, viz. housing, transport, machinery, industry, defence etc. The same sad picture may be given of every other key industries and others dependent on them viz., basic chemicals, aluminium, coal-tar industries, machineries etc.

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*A talk by Prof. M. N. Saha to a group of Members of the Parliament and other distinguished guests presided over by the Hon'ble Prime Minister of India at his residence on September 28, 1954: Sci. & Cult., **20**, 208, 1954.

TABLE I

PER CAPITA NATIONAL INCOME (1949) OF SOME COUNTRIES

Name of Country	Per capita annual income in dollars	% to USA level
USA	1,453	100·0
Canada	870	59·9
New Zealand	856	58·9
Switzerland	849	58·4
Great Britain	773	53·2
Denmark	689	47·4
Norway	587	40·4
Belgium	582	40·1
France	482	33·2
Ireland	420	28·9
Israel	389	26·8
Czechoslovakia	371	25·5
Argentina	346	22·8
Russia	308	21·2
E. Germany	300	20·6
Poland	300	20·6
Roumania	280	19·2
Hungary	269	18·5
Bulgaria	150	10·3
Lebanon	125	8·6
Egypt	100	6·9
Syria	100	6·9
Iraq	85	5·8
Ceylon	66	4·6
India	57	3·9
Pakistan	51	3·5
Saudi Arabia	40	2·8
Burma	36	2·5
Siam	36	2·5
China	27	1·8

Why is production so poor in India ? There are many factors, but the main factor is that power-production which is the key to all industrial production is extremely meagre in India compared to other countries is illustrated in Table II taken from Putnam's 'Energy Sources in Future'.

The unit of energy used here is a million British Thermal Units which is equal to 300 kilowatt hours.

The USA consumes a tremendous amount of energy viz., 67 units per capita in a year to maintain her production, transportation and other activities. The consumption of other countries varies in a graduated way. The lowest figure in Table II is that of India viz., 0·7. The figure will be somewhat larger according to my calculations,

TABLE II

Year	Country	Annual input per capita millions of Btu	Aggregate efficiency of the energy system %	Annual output per capita millions of Btu	Tons of bituminous coal equivalent to annual output per capita
1947	United States	232	29	67	2·6
1945	United Kingdom	132	24	29	101
1939	Germany	110	19	21	0·8
1950	U.S.S.R.	62	26	16	0·6
1947	World	41	22	9	0·3
1949	France	36	21	8	0·3
1941	Argentina	29	21	6	0·2
1945	Japan	20	13	3	0·1
1945	India	11	6	0·7	0·03

because Putnam does not take into account energy produced by human and animal labour, which is negligible for USA, but add considerably to India's total. India's consumption of 0·7 units is nearly a hundredth part of the American figure, or 1/60th of the American figure if we take human and animal labour into account. But there are countries lower in the scale than India—viz., China, the countries of the Near East, some countries of Africa, etc.

Table I and Table II put the whole problem in a nut-shell. The highly industrialized countries produce a tremendous amount of energy, and their production is proportionately far larger in every respect. The backward countries are unable to do so, and their production is little removed from that in medieval times, because as in medieval times they continue to depend mainly on human and animal labour. But is it possible for the highly industrialized nations to maintain their sources of energy-supply, and their rate of production in future ? On the other side, is it possible for the backward nations to exploit and develop their energy sources, so that they can raise their production to the level of industrialized countries ?

Sources of Energy Supply

To answer these two questions, we have to examine critically the sources of energy supply. They are, in order of priority of utilisation:

Human and animal labour.

Burning of wood and farm products.

Natural sources like solar radiation, wind power and power of running water.

Combustion of coal to feed steam engines, steam turnbines for generating electrical power, machinery for domestic use.
Combustion of petrol to give motive power to auto-engines.
Harnessing of running water to produce electrical power.

Atomic Power

In medieval and modern times, almost all human activities depended on human and animal labour, on the burning of wood, and farm products, and to a slight extent on wind-power, as in plying sailing boats, or wind-mills and primitive methods of use of running water (water-wheel). There was not much difference in the standard of level of different countries.

The discovery of the steam engines in 1780, changed all this. The working capacity of mankind was increased a good many times by making use of the energy locked up in coal. Human and animal labour yielded place to steam engines, and steam turbines which energised machinery producing electrical power. It became possible to handle large volumes of power, transport the power over long distances. The effect was a silent, but very profound revolution of human life: home and cottage industry was substituted by the factory, artisans by labourers, tools by machineries, horse transportation by railroads and feudal societies dependent on trade and agriculture were replaced by groups handling finance and labour separately.

The industrial revolution has not yet reached its climax. The invention of the internal combustion engine, use of petrol, development of electrical power from coal, as well as from running water, has given fresh supplies of industrial power, which are transforming human life at a rate never reached before in human history.

Let us first see how America produces such a huge quantity of energy by the use of coal, petrol, gas and water power: She uses 4 tons of coal, per year per head, two-ton equivalent in coal of petrol and gas and 200 kWh from water power. The corresponding figures for India are 1/10 ton of coal, very slight or negligible amounts of petrol and gas, and very little from water power.

The anxiety of USA is—can she continue to keep up consuming her energy-sources at such a lavish and increasing rate ? The anxiety of India is how to produce more energy from coal and hydro-electric and other sources, so that she can increase her production and raise the standard of living to a decent level. Every other country has its own anxiety, and each has taken stock of its position.

Britain now produces 200 m tons of coal to run her highly industrialized structure. Her stocks of coal are being depleted, she has no water power to fall back upon and her mining labour is unwilling to descend to pits. She feels that within the next 5 years, she must replace by other fuel, 20 million tons of coal, and ultimately coal, as an important source of chemicals, should be *wholly* replaced by other fuels.

Belgium has nearly finished all her coal; she is now mining coal from a depth of 4,000 ft and raising for 1 ton of coal 20 tons of water. Her industrial fabric is power-starved.

France and Italy have poor or almost no coal-reserves. Even with the maximum development of water-power, they are power-starved in a modern world.

Coal and petrol have so far provided 90% of energy for industrial production. Production of energy by water-power barely amounts to 7% of the total, though in certain countries like Norway, Switzerland, Sweden and Canada, it gives the bulk of energy. But other countries have not such ample reserves of water-power. They have to depend on coal, internally produced or exported from other countries.

Let us now scan the position of India. According to the Geological Survey of India, India has altogether 60 billion tons of coal, against USA's 3,000 billions and China's 1,500 billions, within the first 1,000 ft of earth's surface. Of these barely 1/3 is economically recoverable.

How long will this coal last? The present rate of consumption in India is 36 million tons per annum only, while USA's consumption with 44% of India's population is 500 million tons. If within the next few years, India wants to raise her industrial production 10 times, consumption of coal would have to be raised nearly 10 times, and at that rate, we shall finish all our coal within about 50 years. Our water-power resources are meagre, and most of it are in the Himalayan regions, not directly within our influence. So the problem of supply of energy is a very acute one for us. China, with her far larger resources of coal, is in a much better position, to undertake industrialization.

The whole world, excepting a few favoured countries is facing an era of "Acute Energy Famine".

In this juncture, the discovery of 'Atomic Power' raises new hope. Let me explain, in simple words, the process.

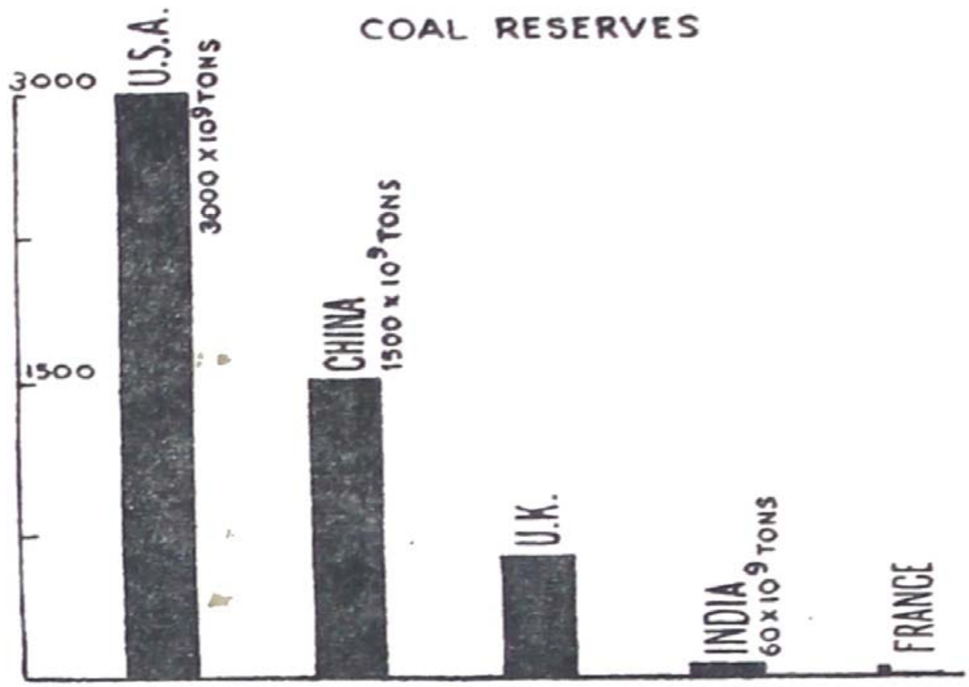

Fig 1

'Coal-power' depends on the burning of 'Coal' to carbon dioxide gas. When we burn 12 kilogram of coal which is about 12 seers in Indian weight, we obtain 96,000 kilocalories of heat. The process can be written as follows:

$$C+O_2=CO_2+96 \text{ kcal.}$$

(Here the amount of Carbon taken is 12 gm 1 calorie is the amount of heat which will heat 1 gm of water through 1°C.).

This heat is used to produce high-pressure steam in a boiler, and the high-pressure steam is made to run a steam engine directly to produce power or to run a steam-turbine, which produces electrical power: this is the usual heat-cycle. The best type of machinery gives for one kilogram of coal about 2·8 units at the highest efficiency attained which is only 30%.

Let us see the order of quantity of coal needed to run a power-station. The Electric Supply Corporation of Calcutta produces in a year roughly one billion units of electricity, for domestic use, and for running the machinery for industrial production in the Calcutta city and its suburbs. They produce this energy by burning nearly 0·35 million tons of coal per year. Actually they burn more, about half a million tons, because their machinery is not so efficient as the latest types.

Let us see how much 'Atomic Fuel' will be needed to replace this coal. For this purpose, we have to understand the process of uranium fission, which was discovered by Otto Hahn, a very famous German chemist early in 1939. This was achieved by the bombardment of the element uranium by slow neutrons.

The element uranium was so long the heaviest element known to man. It exists in two forms, having the weights 238, and 235. Natural uranium is 99·3% U-238, only ·7% U-235. It is the U-235, which is active. Otherwise, both forms have identical chemical and physical properties and can be separated only by very expensive physical methods.

The neutron is an elementary constituent of the nuclei of all atoms, the other being the proton. While the proton has electric charge, the neutron is uncharged and is heavier. A neutron is allowed to approach a heavy uranium nucleus with or without energy. The slow neutrons produce the maximum effect. Then the U-235 nucleus becomes deformed and splits up into two unequal halves A and B, as shown in figure 2.

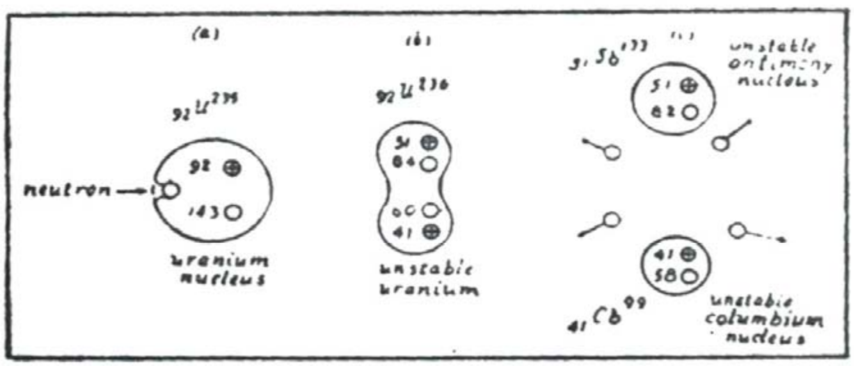

Fig. 2.

The reaction may be written as:

$$_{92}U^{235} + {}_0n^1 \longrightarrow x_1A^{y_1} + x_2B^{y_2} + (y_3)_0n^1 + Q$$

The left side shows that the neutron approaches the uranium nucleus.

The right hand side shows the products of reaction.

A is a new nucleus, with x_1 protons, and $(y_1 - x_1)$ neutrons.

B is another nucleus, with x_2 protons, and $(y_2 - x_2)$ neutrons.

We have,

$$x_1 + x_2 = 92$$
$$y_1 + y_2 + y_3 = 236$$

There is a large number of ways in which this process, called fission can take place. Both A and B are highly radioactive.

In this process, a number of neutrons y_3 evaporate and is on the average about 2·5. These are called Fission Neutrons.

The fission fragments A and B leave with great energy. We call it Q. Let me give you some idea of this quantity; for this is essential.

When a gm of U-235 splits in the way I have mentioned, the energy produced has the gigantic value of 20 million kilocalories, contrasted with 8 kilocalories we get by burning one gm of carbon. Thus this fuel process gives per gm of matter burnt 2·5 million times as much energy as the ordinary process of combustion of carbon, which is the process used for almost 90% of our energy generating machinery.

Let me bring home to you the enormous contrast between this new 'energy-producing mechanism' and the millenium-old mechanism of combustion of carbon. We remarked that the Calcutta Electric Supply Corporation has to burn $\frac{1}{2}$ million tons of coal. We can produce the same amount of energy by fissioning $\frac{1}{8}$ ton of U-235.

It seems incredible, but it is nevertheless true.

Therein lies the chief significance of the discovery of fission. It gives us a method of energy generation which will probably save the world from the impending energy-famine which is already there in some countries, but which is going to be acute for the whole world within the next 50 years on account of the rapid depletion of coal, at present, our main source of industrial energy. It will be shown presently that the fission of U-235 ensures a plentiful supply of energy for the next thousand years, so that inspite of formidable technical difficulties experiments on development of nuclear energy are worthwhile and are being undertaken by all advanced nations. But all is not plain sailing.

Hurdles in the way of Atomic Energy Development

Let us see what are the hurdles to be overcome. The various hurdles are:

(*a*) Prospecting for the Uranium Ores;
(*b*) Processing the Ores to Uranium Metal;
(*c*) Separation of U-235 from U-238;
(*d*) Design of an Atomic Furnace in which U-235 is fissioned;
(*e*) Conversion of the heat produced to useful energy;
(*f*) Breeding of U-238 to active Pu-239 and of Th-232 to active U-233.

Let us take these items one by one.

Prospecting for Uranium: First uranium ores have to be procured.

These are not very difficult matters but require a vast organisation. Uranium is not a rare metal—it is said to be ¼ as plentiful as the common metal lead. It is estimated that there are 25 million tons of uranium available in the earth's crust, which can be economically recovered. But it rarely occurs in large concentrates as in Pitchblende or Samarskite. The vast amount of it occurs dispersed in certain rocks to the extent of 0·2 to 0·3% i.e., after processing 1,000 tons of ore, one hardly gets 2 to 3 tons.

So the first item is prospecting on the widest scale for uranium. On account of the importance of the subject, every atomic-energy-minded nation is organising it on the widest scale by public instruction, propaganda and lure of rewards. Many nations have got large stock-piles by taking advantage of war conditions, and ignorance of less advanced nations.

Processing: The second item is to process the ores for the metal. Although the chemistry of uranium is well-known, many of the technological processes for the recovery and fabrication of pure uranium metal as well as other materials are well-guarded *secrets*, and has to be worked out by patient efforts by every nation.

Design of an Atomic Furnace: The third item is the construction of the Atomic Furnace or the Reactor or the Pile as it is variously called.

This takes the place of the ordinary coal furnace, or the petrol combustion chamber, but it is a far more complicated piece of machinery than a furnace. If we take a lump of natural uranium, nothing happens to it; and it can remain unaffected, as it actually does for millions of years. But all the time, the U-235 atoms in it, which constitute one part in 140, are being occasionally hit by stray neutrons from space and getting split during which time minute quantities of heat are produced. But nothing happens till another stray neutron hits another U-235 atom and these are very rare incidents. But how can one make the fission-process continuous? There are two ways of doing it. First is the way of atom-bombs. The first steps are taken by separating the active isotope (235). Suppose one U-235 nucleus is fissioned deliberately, or by a stray neutron from space. Then 2·5 neutrons are produced on the average and if the lump of U-235 is large enough these second generation neutrons, on passing through the lump fissions further nuclei of U-235; in this process further neutrous are produced and further fission takes place as illustrated in fig. 3. A chain-reaction is produced.

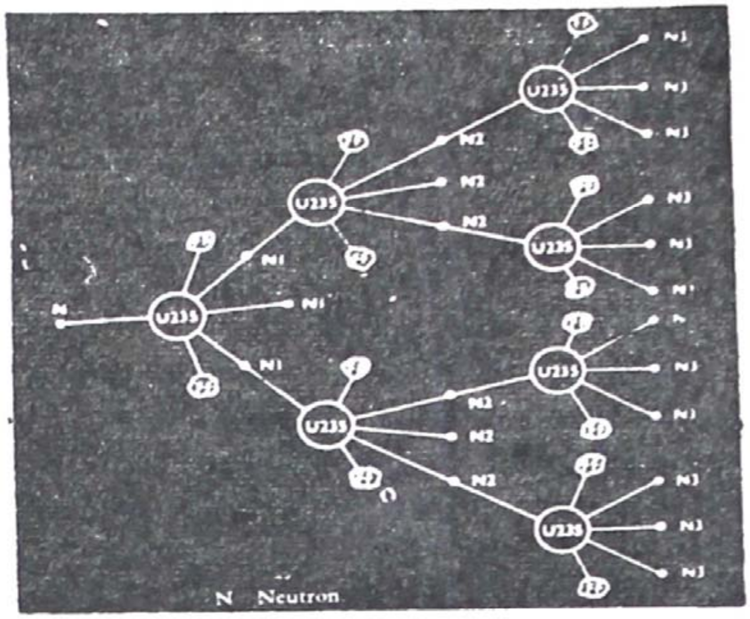

Fig. 3.

Chain-Reaction

The whole process is finished in the fraction of a second, giving rise to an explosion equivalent to that produced by 20,000 tons of TNT. But this is the way of atom-bombs.

It is not easy to isolate U-235, as it has identical chemical properties with the far more numerous U-238, and the American Government had to spend nearly 700 million dollars out of the first investment of 2000 million dollars to erect two plants for the separation of U-235. One did not work; nearly 350 million dollars were wasted. The other gave nearly 20 seers of U-235 after full 2 years' running, giving just sufficient material for the production of the Nagasaki Bomb.

The Pile or the Reactor or The Atomic Furnace

The atom bomb produces enormous amount of energy within an incredibly short time. For peaceful utilisation of energy, the furnace has to be designed differently. A form of it, known as the Graphite Reactor is shown in fig. 4.

This reactor consists of graphite blocks with a square section and hollowed inside within which are placed ordinary uranium rods, canned very carefully airtight within small aluminium containers. The graphite blocks are piled one over the other in the form of a cube, which may be 25 ft on each side. Interspaces are provided for circulation of water or gas to carry off the heat.

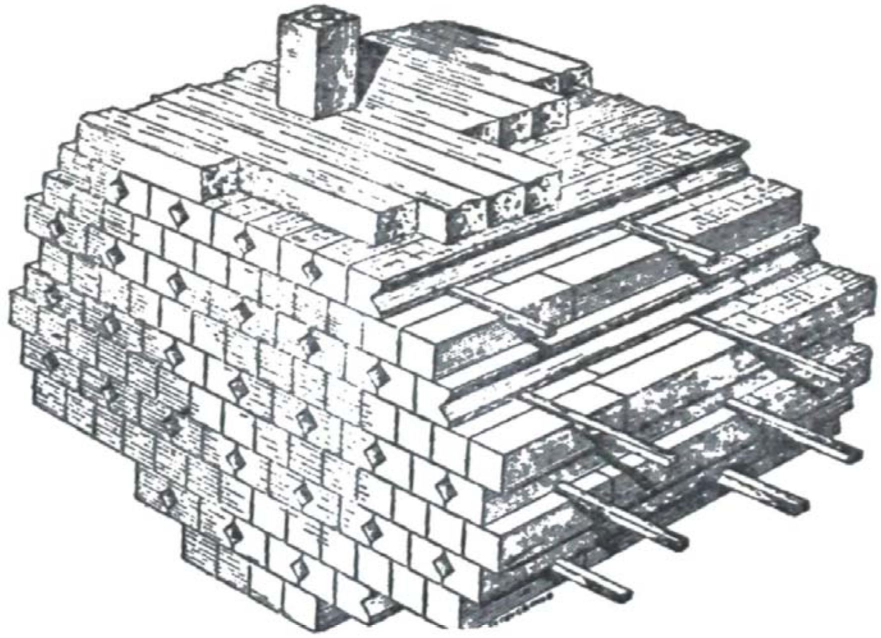

Fig. 4.

The mechanism is as follows: suppose some U-235 atoms within the aluminium can is hit by neutrons—then some energy will be produced which will be quickly converted into heat and on the average 2·5 fast neutrons will be produced. These neutrons will have to be slowed down before they can fission another U-235 atom. This is done by the graphite which is only pure carbon, through which the fast neutrons have to pass; it encounters a large quantity of carbon atoms before it comes across another U-235 nucleus, and in these encounters, its energy is reduced from million electron volts to fraction of a volt (thermal neutrons). If then the thermal neutron encounters another U-235 nucleus the latter is fissioned, fresh neutrons are produced and the chain-reaction continues.

The function of the graphite is to slow down or moderate the velocity of primary fast fission neutrons. Graphite is the moderator. There are other moderators; in fact the lighter the atom of which the moderator is composed, the better, for energy taken up by the moderator nucleus is inversely proportional to its mass and the neutron will be brought to rest in a shorter path. We have choice besides carbon of other light nuclei; but only H^2 (heavy hydrogen) and Be^9 can be used, for other light nuclei like H^1, Li^6, Li^7 will capture the fission neutrons, which will be lost for the fission reaction and He cannot be had in the solid form. In fact only heavy hydrogen, beryllium, and carbon which have small capture cross-sections can be used for moderating purpose.

In fact, heavy hydrogen has been used for moderation, in the form of heavy water which is $(H^2)_2O$. Beryllium has not been used for it is difficult to work with and is poisonous.

Reactors have been constructed using heavy water in place of graphite. They are smaller in size, and require smaller quantity of uranium. (Fig. 5).

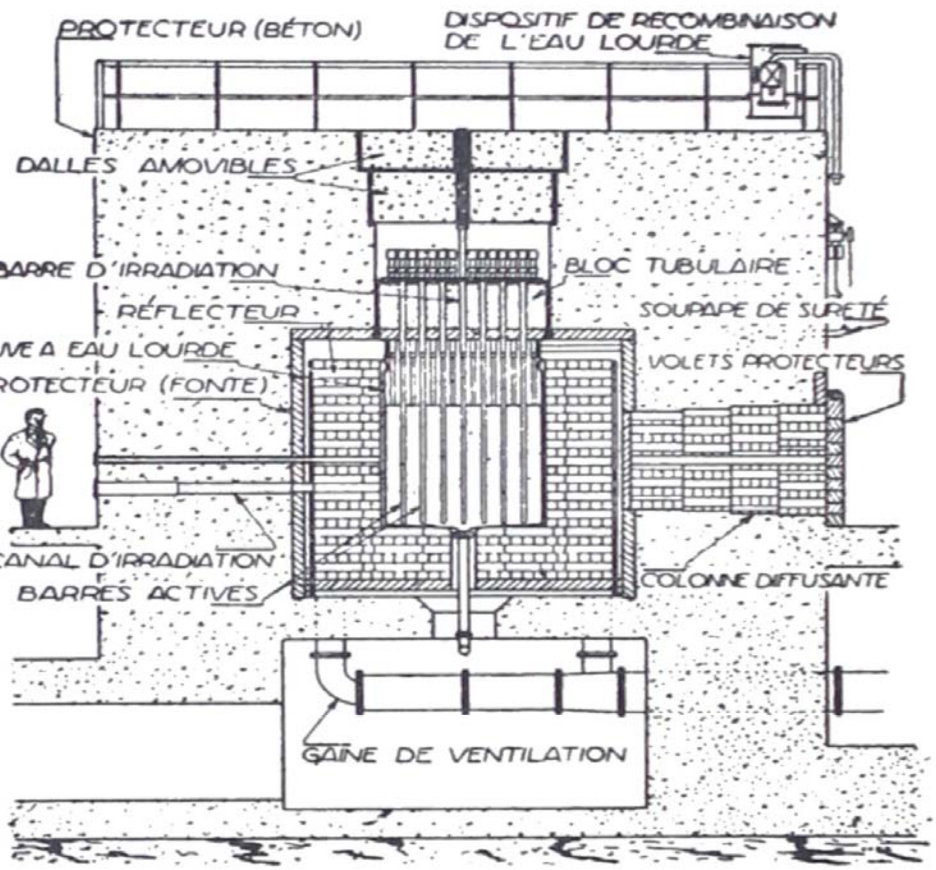

Fig. 5. Heavy Water Reactor at Saclay.

Contrast between the Coal-Furnace and the Reactor

The reactor or the atomic furnace is thus quite different in its action from an ordinary furnace, for in the latter, coal is burnt to CO_2 which escapes to air, and the heat is used to produce high pressure steam which runs a steam engine, or a turbine to produce electrical energy. The fuel has to be fed constantly.

In the reactor we have several thousand quadrillion (10^{24}) atoms of U-235 and a small fraction of them are being hit by neutrons at random. Depending on the amounts of U, and the moderator, a constant amount of heat is being produced. This must be carried off, otherwise the reactor would blow off. This is done by either simply cooling the reactor by forced air, or in the case of very big reactors by water cooling.

The heat carried off may be enormous. The Brookhaven reactor dissipates 40,000 kW of power, nearly as much power as is handled by the Delhi Electric Supply. The great Handford Piles, used for fertilising U-238 to Pu-239, another fissile material, dissipates nearly a million kilowatts, and cooling is done by diverting all the water of the Columbia river into the Piles (Fig. 6).

The heat can be converted into useful work by the usual heat-cycle i.e., producing steam and running steam engines or steam turbines with high-pressure steam (Fig. 7).

But there are other uses for the 'Pile'. One of the most important is 'Breeding'. This may be explained as follows:

"Fission" depends entirely on U-235, of which we have limited supply. In fact, if we had no U-235 in the world, there would have been no atom-bomb or atomic energy development. But in every reactor, the supply of U-235 is being constantly depleted on account of fission. So the chain-reaction will, after sometimes, come to a standstill, when the amount of U-235 falls below a certain limit. Such rods are to be thrown out into water and have to be replaced by fresh rods of U.

Necessity of Breeding

But the process of utilising U-235 cannot be allowed to go on indefinitely. For U-235 being in short supply, will be exhausted in rather short time, and we must think of replacing U-235 by some other active material. Here another reaction which takes place simultaneously comes to our rescue. Some of the inert U-238 may capture a neutron and by two jumps, it is converted into a new metal Pu-239, which is also fissionable like U-235, and can be used, either for atom-bomb making or for heat-production. An ideal reactor

$$ {}_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{92}U^{239} \xrightarrow{\beta^-} {}_{33}Np^{239} \xrightarrow{\beta^-} {}_{94}Pu^{239} $$

would be one which produces as much or more Pu-239 as the U-235 it consumes. Such reactors are called "Breeders". The great Handford Reactors or Windscale Reactor in Great Britain which are used for Plutonium production are not called "breeders", since the quantity of Pu-239 produced is smaller than the quantity of U-235 fissioned.

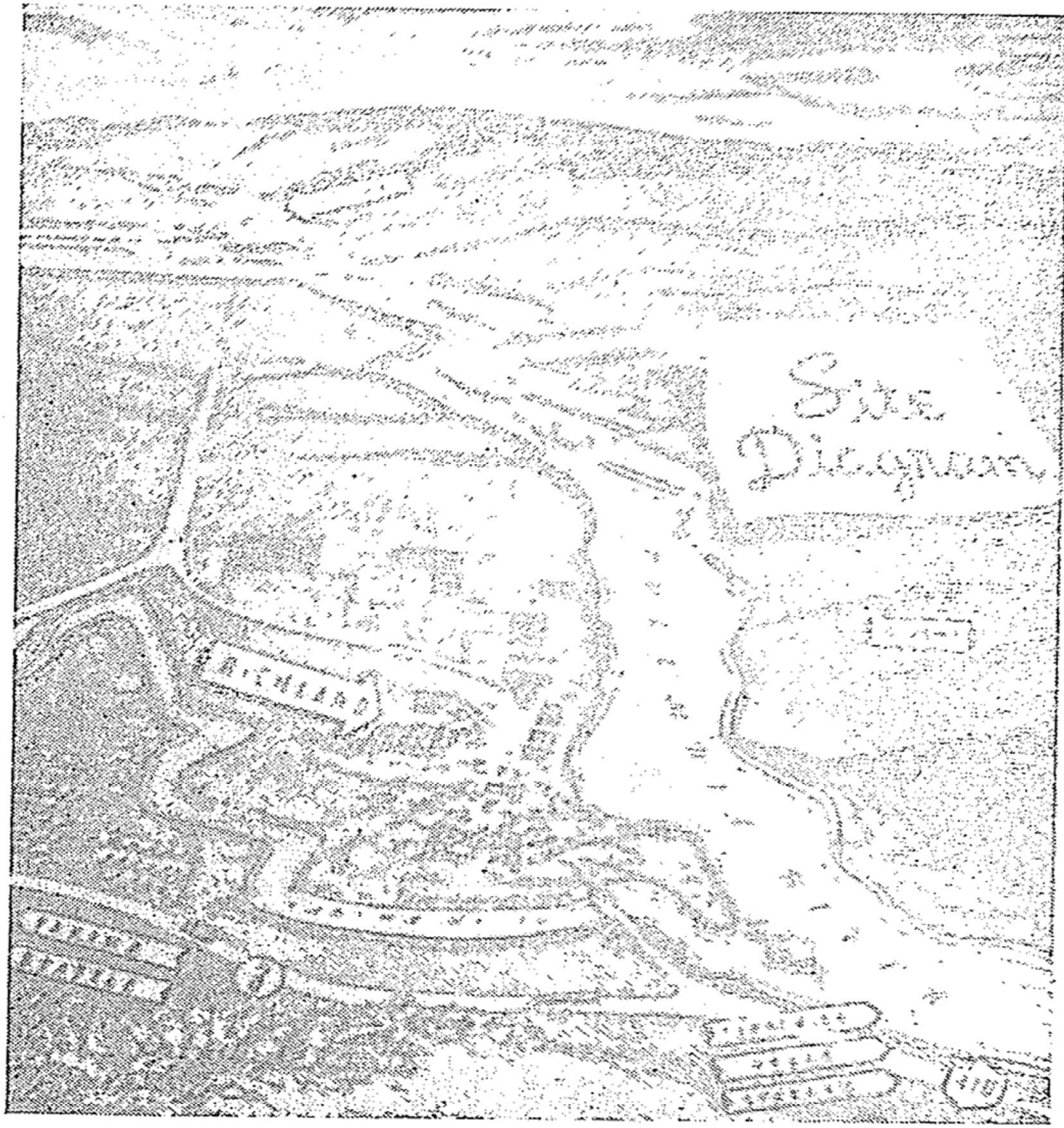

Fig. 6

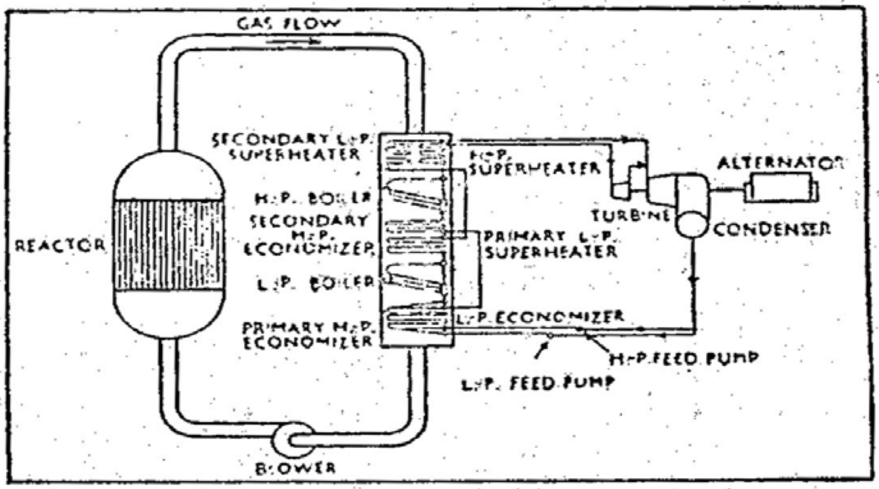

Fig. 7

The reactor at Idaho is called a breeder because here more Pu is produced than U-235 is consumed.

Besides, U-238, we can use the more plentiful element Thorium for breeding, by the following process:

$$_{90}Th^{232} + _{0}n^{1} \longrightarrow _{90}Th^{233} \xrightarrow{\beta^-} _{91}Pa^{233} \xrightarrow{\beta^-} _{92}U^{233}$$

Thorium captures a neutron, becomes Th-233. This sheds two electrons from the nucleus in succession and become U-233 which is fissionable like U-235. We can breed Th-232 into fissionable U-233, by simply exposing it to streams of neutrons. So thorium, though it cannot take the place of U-235, is a potential nuclear fuel.

We say, 'Potential' because without neutron-irradiation, thorium is valueless. We must have first a uranium-235 pile before this can be done. So uranium is the key-material.*

Different Types of Reactors

At present, many designs of Reactors are being tried to produce economic power, and breeding new fuels U-233 and Pu-239. Sir John Cockcroft, Director of the British Atomic Enery Research Establishment at Harwell in a speech before the French Chamber of Deputies in August 1954, disclosed that Britain has worked out a

*We are making this pointed remark, because some men in power in this country, have given out vaguely that we can do without uranium in atomic energy development.

reactor-programme, according to which, electrical energy to the extent of five million kilowatts will be produced within 10 years from nuclear reactors, and will substitute coal to the extent of 20 million tons per year. These stations will be put into the Electrical Grid supplying Great Britain. The cost is expected to be a penny per unit, about 50% higher than from thermal sources. His colleague, Sir Christopher Hinton, Director of Production, estimates that it will take 20 years to reach the goal.

The United States of America has already harnessed nuclear energy to run a submarine, the *Nautilus*, bearing the name of the under-water vessel in Jules Verne's novel, "20,000 Leagues under the Sea". But the power costs are nearly 10 times higher.

The present objective is to design reactors which will give energy at $\frac{1}{2}$ to $\frac{3}{4}$ pence. Then only nuclear energy may be competitive with energy from thermal or hydro-electric sources. Last year, the Atomic Energy Commission of the USA considered 80 suggestions for the design of economic Power Reactors of which 5 were chosen for experimentation and 200 million dollars were voted, for financing the experiments, which are in progress (Table III). Some of these designs are very unorthodox, for example, a reactor in which only light water and enriched fuel are used.

India and Nuclear Power

Our resources of coal, oil, and water-power are so limited that many competent persons have rightly expressed the doubt, whether it will ever be possible for us fully to exploit our natural resources, and thus raise our standard of living to a level comparable with European countries. The situation is extremely bad in south and western India where there are either no coal at all, or very poor and limited quantities are available and water-power is insufficient. Natural resources cannot be developed simply for lack of power. It will therefore be complete lack of foresight, if we do not seriously explore the possibilities of harnessing nuclear power to our needs within the next generation.

This is the light in which I read the revision of the USA Atomic Energy Act, which authorises its AEC to help private parties like universities, and industrial concerns as well as friendly nations to participate in fundamental and developmental research on Atomic Energy. They cannot function unless aided by central service to be organised by the USA—AEC.

TABLE III

	Estimated cost	Estimated completion	
1. Pressurized water reactor	85 million	1957	Westinghouse.
2. Boiling water reactor	17 million	1956	Argonne National Lab.
3. Sodium Graphite reactor	10 million	1955	North American Aviation Co.
4. Homogeneous reactor	47 million	1956-58	Long term project (ORNL)
5. Fast Breeder reactor	40 million	1958	Long term project (ANL)
Total:	199 million	5 years	

The development of nuclear power, unlike other sources of power, which can be immediately tapped and should be tapped whenever necessary or possible, is still an expensive long range one, but solid foundations for its development have to be laid without delay as has been done by USA, USSR, Canada, Great Britain and France. France has been a little behind, on account of her initial handicaps, but with the new ample sources of uranium which she has discovered within her borders, as a result of intense prospecting, there is no doubt she will soon draw level with England. Now that the MacMahon Act has been modified, so that the Atomic Energy Commission of USA is allowed to help her private industries and friendly nations in the development of atomic power, many other nations closely allied to the USA will get the advantage of USA's wonderful lead in atomic energy. For example within a year, Germany and Italy may be allowed to start atomic energy work in full force. Even backward nations may benefit. There is nothing in the way of USA setting up a Nuclear Reactor in Pakistan or any other satellite country of America within a year or two and train their physicists to its use. But such countries will have to be absolutely dependent on USA for the replacement of fuel and supply of key apparatus.

The proposals for an International Pool for fissile materials have not yet taken a definite shape.

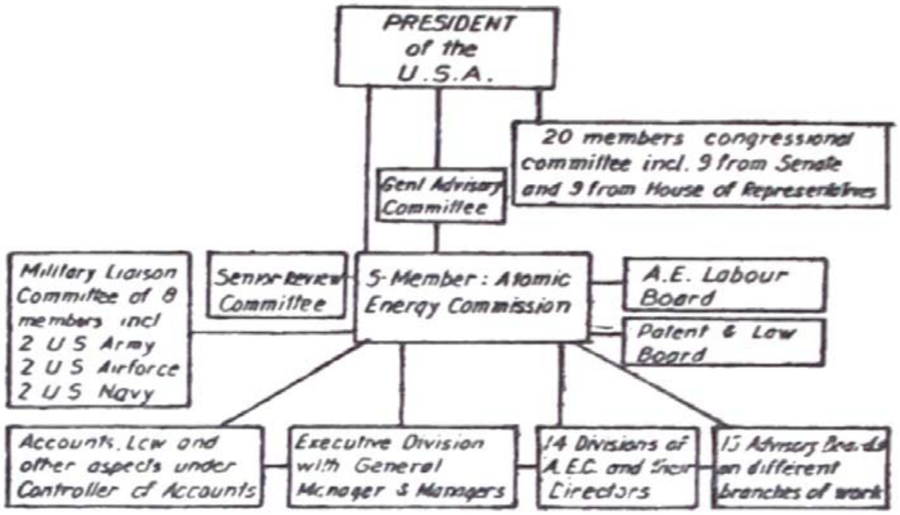

Fig. 8.

In my opinion, we ought to take advantage, if possible of the provisions of the new American Atomic Energy Act, or of the International Atomic Pool, when it comes into existence, but we should aim at, in this as in every other industry, at complete Technical Autonomy without which our hardwon Independence slides on slippery grounds. We ought to aim at Technical Autonomy particularly in Atomic Energy for its close relationship to nuclear weapons will make it hazardous for our country or any other country to be vitally dependent on any other nation.

Can we achieve technical autonomy in Atomic Energy? I think, yes and the example of France furnishes me with a stimulating example.

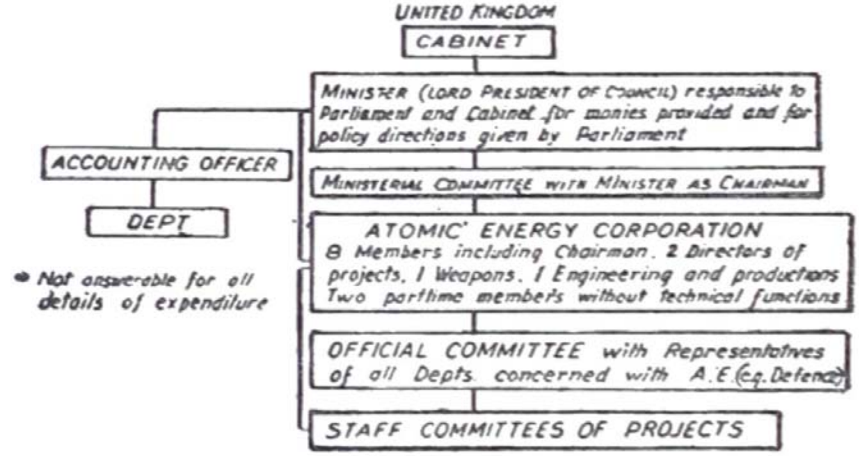

Fig. 9

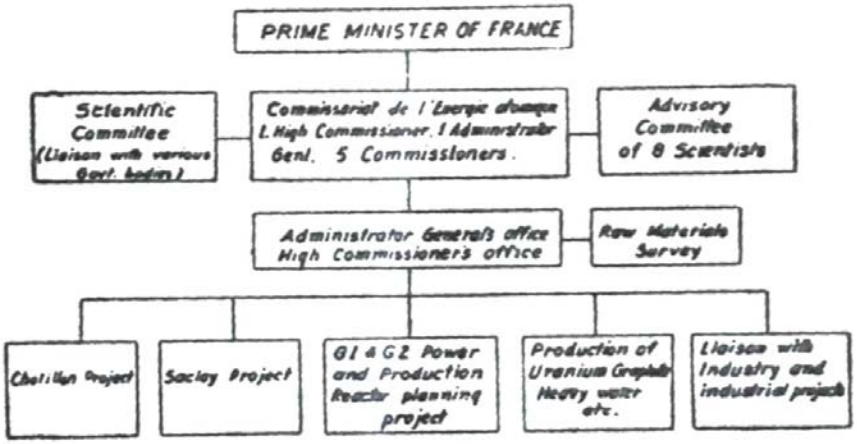

Fig. 10

France Achieves Atomic Autonomy

The writer had some inside knowledge of the situation in France when she started her Atomic Energy Programme in 1947 after five years' of World War, with General de Gaulle's Government in power. The General belonged to the extreme right, but he did not hesitate, as was done in Germany during the war with fatal consequences, to appoint Prof. Joliot Curie, well-known for his communistic leanings to the key-position as the Chief Commissioner for the development of atomic energy. The author was then in France at the invitation of Prof. Joliot Curie to attend the Rutherford Memorial Celebrations and was admitted to some knowledge of France's difficulties. The main difficulty was the absence of the fundamental nuclear fuel, *viz.*, uranium, and France's inability to procure it from outside owing to the operations of the MacMahon Act.

France's next door neighbour Belgium had plenty of it and thousand tons of rich pitch-blende was supplied by the Belgian financier Sengier out of his mines at Katanga, Congo, to the USA in 1941; but for this act there would have been no atom-bomb in America. America had secured during the war a strangle hold on Belgium, and sternly forbade her to supply even a gm of uranium ore to France or any other nation including Great Britain. The bitterness was so great that in my presence, Prof. Joliot Curie and Madame I. Curie told one outstanding American atomic scientist: "France is the birth place of Nuclear Physics; and you Americans have learnt all your science from France and Europe. Yet you are now keeping all knowledge, and raw material to yourself. But we shall demonstrate to you that we can undertake development of nuclear power even in the teeth of your opposition".

Joliot and his colleagues had amply fulfilled their brave resolution and though a few years later he was removed by the weak French Government, hopelessly dependent on Marshall Aid for her economic rehabilitation, from active participation in the work of the French AEC, I gathered in course of my recent travels in France, that the removal is but an eye-wash, because all the guidance and work are in the hands of his friends and the pupils, he and Madame I. Curie have trained and are training.

Now what has Franch achieved? Only last year, the Franch Atomic Energy Commission proudly declared that it has achieved "Atomic Autonomy". This means that she has been able to lay the foundations of a programme of nuclear power development, dependent entirely on French uranium and other French materials, and on French talents in science and technology.* She has constructed successfully two experimental piles with only French material and French design and has taken in hand the construction of two other large piles, producing power and radioactive plutonium. She hopes to finish them by the end of 1955. She has thus laid the foundations for a strong Nuclear Energy Development programme dependent eintirely upon French materials, and French personnel and I have no doubt that in course of the next two decades, she will make up, with the aid of nuclear power developed, her notorious deficiency in power-resources; for it is well-known that she has very little coal, and petroleum was still recently unknown and even all her water-power completely developed placed her in a much inferior position to Germany, who has the best and most extensive coal deposits in western Europe.

When the French Atomic Energy work was started, there was practically no knowledge of the existence of uranium ores in France. But the Commission engaged at one time nearly 20,000 men, only a few of them geologists, and equipped them with modern instruments. As a result of intensive prospecting, large amounts of ore, both rich and poor, have been found in places where their geological survey had not previously reported the existence of such ores. Particularly rich are the ores in the Vosges. France can now go forward confidently with her programme irrespecitve of foreign supply.

*Gordon Dean, ex-Chairman USAEC says in his "Report on the Atom" that "The French programme unlike that of US, UK and Canada has from the beginning operated in open. *Secrecy is virtually unknown*".

Those claims were proudly made by Dr. Dupuy, Director of CNRS (opposite number of Dr. S. S. Bhatnagar in France) who had been in India as member of a committee to examine the working of our national laboratories, when I saw him last on July 28, at his office at Quai du Anatole France in Paris. He further added: Our ideas about the occurrence of U-ores have entirely changed, as a result of our prospecting. I am quite sure that if you organise prospecting on a wide basis as we have done, you will get as plentiful supplies of U within the borders of India.

Administrative Organization

Description has been already given of the programme for development of Nuclear Energy which has taken a set pattern in all the countries which have taken seriously to it. No discovery is in sight which may disturb it in the near future.

From the very outset, atomic energy developments in all countries have been State undertakings, including the USA, the classical land of private enterprise, because the costs involved were too large for any big business and the responsibilities to be assumed were of too serious a nature to be entursted to big business. The USA has recently modified its Atomic Energy Act, relaxing some of the rigidities of the old Act and admitting some private enterprise, but as will be shown presently this has not materially changed the situation.

What are the orders of the budget of different countries for AE development? The following figures are for the USA:

Year	In Million Dollars
1949	621·9
1950	702·9
1951	2,032·1
1952	1,605·9
1953	4,124·6

It is said that where USA spends one dollar, Great Britain spends ten cents, France from one to two cents.

The administrative organisation which has been set up for carrying through the programme in all countries is having similar patterns. At the head is the Prime Minister or the President whoever really administers the country and can take final decisions. He should be helped by a high power committee consisting of ministers, scientists

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and technicians who will advise the Prime Minister in laying down the policy; they will also review the work done by the different bodies, under the AE Organisation and sanction the budget. There may be a parliamentary committee to stimulate interest amongst the public and review the policy, and finally sacntion the budget.

The actual work of administration should be entrusted to a Secretariat or Commissariat consisting of a Chief Secretary or Commissioner helped by two or more Deputy Secretaries. The Secretariat or Commissariat, taken together, should have administrative experience, scientific and technical knowledge, and knowledge of financial administration. The officers and employees of the commissariat or the secretariat should be whole-time workers and should have no other job. Under no circumstances, they should be allowed to have any other job.

The scientific and technical work is to be entrusted to a number of directorates viz., of Prospecting, Procurement and Processing. The directorates should cluster round a central Atomic Energy Establishment where all scientific and technical work, study, planning and developmental research will be carried out. The establishment should have a Reactor, and all divisions needed for its running, utilization and experimentation, and should have a school of reactor technology.

There should be in addition a Board of Nuclear Studies and Research to interest universities and laboratories in the work connec-

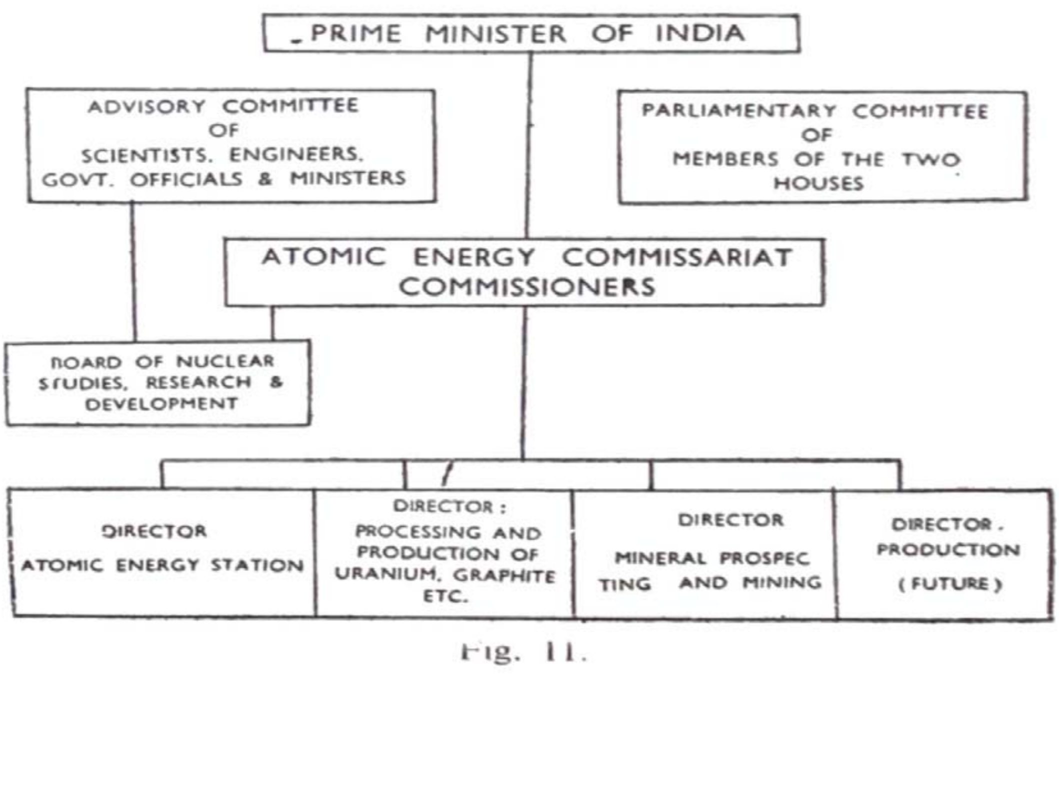

Fig. 11.

ted with nuclear energy development and fundamental research in nuclear sciences, and engineering and personnel training.

Before I conclude, I should like ot draw your attention to the lesson that German failure to make the atom-bomb or nuclear reactor can teach us and in this connection to bring to your notice some of the pitfalls that were the causes of German failure.

Why Germany failed to evolve an Atom-Bomb during World-War II?

It has remained a mystery for most people why Nazi Germany failed to evolve an Atom-Bomb during World-War II? The foremost atomic scientists were there; Otto Hahn, the discoverer of Uranium Fission, W. Heisenberg, one of the foremost of theoretical physicists; W. Bothe, whose work led to the discovery of the Neutron by Chadwick in 1932; G. Hertz, the inventor of the apparatus for separation of isotopes by the Gaseous Diffusion method, the only method which worked, and is still the basis of U-235 separation in the USA and UK; R. Clusius, the discoverer of the method of Thermal Diffusion, the other method for the separation of isotopes, and a host of other scientists of front rank. Germany had no dearth of raw materials. She had plenty of pitchblende in the famous Joachimsthal mines in occupied Czecholslovakia, lower grade ores in Eastern Germany, and plentiful Graphite in Bavaria. Germans had access to the Norwegain heavy water plants.

In fact, there were all conditions pre-requisite for the success of of such an undertaking; in fact, USA which started this work in 1940, was always nervous that Germany would be the first in the field with the Atom-Bomb. Why did it not happen?

These points were answered in a book called 'Alsos' by Dr. Samuel A. Goudsmit, author of the famous Uhlenbeck-Goudsmit hypothesis of rotating electrons. Dr Goudsmit was a Dutchamn by birth, had migrated to USA and taken the American nationality. He was sent as the scientific chief of the Alsos Mission which was a unit of scientific and medical personnel sent to Europe to find out what the Germans had been doing in scientific work in general during the war. Goudsmit's special task was to find out whether the Germans had a large Atom-Bomb plan.

From Goudsmit's book we learn that the Director of Army Scientific Research was one Dr. Mentzel who was responsible to Reichsmarshal Göring. About his qualifications Goudsmit says that

Mentzel was in reality only a second-rate chemist who had climbed to his high post through the devious channels of Nazi Parti politics. The German scientists referred to him contemptuously as the "culture sergeant" and joked about the time he had given *his one and only lecture on chemistry*. Mentzel was said to have remarked on that occasion, that he hadn ever realized, how much harder it was to deliver a scientific lecture than to make a political speech.

The next man was Dr. Schumann, who headed the Ordnance Department. About him Goudsmit writes: Schumann was actually professor of military physics at the University of Berlin, although his few publications deal only with the vibrations of piano strings—an interest derived, presumably from the fact that he was a descendant of the composer, Schumann. His colleagues, somewhat contemptuously, referred to him as Professor of Military Music. His right hand man in Nuclear Physics was Diebner.

The next important man was the President of the Bureau of Standards attached to the Ministry of Education. He bore the surprisingly non-Aryan sounding name of Abraham Esau, and while he had some knowledge of electronics, he could hardly be called a physicist. He had attained his post mainly by being an ardent Nazi. He was given the bombastic title of 'Plenipotentiary' for Nuclear Physics to the Staff Council of Reichs-Marshal Göring. The work was started at different places at the University of Leipzig and, under Diebner. Important contributions were also made at the Kaiser Wilhelm Institute at Berlin and Heidelberg, but there appears to have been little coordination, between different groups.

Allowances for Goudsmit's strong anti-German bias must be made but his facts are interesting and disclose the many errors made by the Nazi bureaucracy. I quote from Goudsmit's remarks: "Cut off from the Army and from industry, and headed by an incompetent Nazi like Esau, the academic siecntists made slow progress on the uranium problem. The true physicists could not give Esau their confidence. Unfamiliar as he was with this field of science he could not fail to provoke resentment among them by his insistence on making decisions himself. Indeed it is said that he interfered with uranium research rather than guided it".

The real work was done by Gerlach, Heisenberg and Diebner. Goudsmit continues—"Of course, Heisenberg remained the leading spirit in Germany's uranium project. Its policies regarding scientific research were entirely dominated by him; his word was not to be doubted. But the Fuhrer principle does not work very well in scientific projects, which are essentially collective endeavours and depend on the critical give and take of many minds and viewpoints. Had Heisenberg considered himself, had he been considered by his colleagues, as less the leader and more the co-worker, the German uranium project might have fared better.

"It was not until the beginning of 1944 that the scientists with the secret help of Speer, Minister of War Production, succeeded in squeezing out Esau, who became the boss of radar and radio research. He was replaced by a real, first-class physicist, Walther Gerlach, of the University of Munich. An able experimenter, Gerlach was also experienced in dealing with govenrment and army officials, as well as with *prima donna* scientists. He was acceptable to all; even his Gestapo record was favourable, in spite of some earlier clashes. He did much to bring unity among the various groups whose members had thus far been rivals.

"Inspite of administrative changes and increased importance being given to uranium project it remained comparatively insignificant but the total number of scientists working on uranium and closely allied problems was less than 100. They lacked the equipment necessary for important preliminary and basic laboratory measurements. For instance, they complained in their reports that there were no cyclotrons in Germany, whereas the United States had twenty of these important machines. They had to go to Paris to work with Joliot's cyclotron. Although half a dozen machines were planned or under construction in Germany, only the one in Heidelberg, in the physics section of the Kaiser Wilhelm Institute for Medical Research, was completed and used before the end of the war.

"They knew, of course, of the possibility of a U-235 bomb, but they considered it practically impossible to separate pure U-235. One can hardly blame them for this. Perhaps only in America could one have visualized and realized at Oak Ridge, where pure U-235 was produced by the huge combined efforts of science, engineering, industry, and the army. No such vision was apparent among the German scientists and certainly no such gigantic combination of all forces working on all fronts.

"Furthermore, the Germans never thoguht of using plutonium in the bomb, which enormously simplified the problem. The existence and probable properties of plutonium, though still unnamed, had been mentioned in scientific literature before the war, and in a few

German secret reports, but they overlooked the practical phase of this side of the problem completely.

"In fact, the whole German idea of the bomb was quite different from ours and more primitive in conception. They thought that it might eventually be possible to construct a pile in which the chain reaction went so fast that it would produce an explosion. Their bomb, that is, was merely an explosive pile and would have proved a fizz compared to the real bomb.

"It was this misconception which made the Germans believe that an energy-producing pile was the first problem to tackle. In our case it was the other way around. We discovered that it was easier to make an atomic bomb than an atomic power plant.

"Our lingering belief in the supremacy of German science makes it hard for us to accept the fact that the German physicists could have failed so utterly. There are even scientists among us who still refuse to believe that their German contemporaries could have made such blunders. For these, it is necessary to quote a few German statements which prove the facts beyond all possible doubt.

"When the greatest of modern atomic physicists, Niels Bohr, fled to Denmark in the fall of 1943, he reported that the Germans were merely thinking of an explosive pile. At that time we thought this meant simply that they had succeeded in keeping their real aims secret, even from a scientist as wise as Bohr.

"But a secret Gestapo summary, dated May of the same year, states:

"There are two technical applications of uranium fission.

"1. The Uranium Engine can be used as a motor if one succeeds in controlling the fission of atomic nuclei within certain limits.

"2. The Uranium Bomb can be realiszed if one succeeds in bombarding uranium nuclei suddenly with neutrons. The neutrons released in the fission should not be allowed to escape, but their too-large initial speed must be slowed down sufficiently so that they will again produce further fissions. The process propagates itself like an avalanche.

"Mathematical computations based on foreign data have shown that processes 1 and 2 are technically certainly possible.

"In a recent press despatch Otto Hahn is quoted as stating: "We knew that (plutonium) must exist, but we did not succeded in producing this substance."

"Heisenberg, according to the Associated Press, said that he advised the German authorities that "Atomic explosives could be produced either by the separation of uramium isotopes or by building a uranium pile". This is a typically careful satatement, which makes our scientists believe that he meant "of course" to use the pile to produce plutonium. He never thought of it; the pile itself was supposed to be the bomb."

1.3.15 ATOMIC ENERGY IN INDIA*

We have the privilege of printing in this issue the address on Atomic Energy by Prof. Meghnad Saha, member of the Parliament, before a distinguished gathering of Parliamentarians and Ministers of the India Government, presided over by the Prime Minister. Prof. Saha recently undertook a journey to Europe and America and obtained first hand knowledge of atomic energy developments in European and American countries of which he has given a full description. He has tried to make out, and we think with complete success, that the importance of atomic energy research does not lie in development of atomic missiles or the hydrogen bomb, but in the promise which it holds out for meeting the 'Energy Famine' which exists in many countries of the world, or the insatiable Energy Hunger which some highly industrialised countries have developed.

He has shown that the 'Energy Famine' already exists in different countries of the world, and nowhere in a more acute form than in India as a whole and certain States of India in particular. Energy is in short supply in France, and Italy amongst European countries, and in most of the Latin republics of South America on account of poor resources in coal which is the main source of industrial power in the world, in those countries. Even the USA and Great Britain, though they have been blessed by Nature with abundant supplies of coal, have been alarmed at the terrific rate at which their coal deposits are being depleted. Mr. Putnam, in his 'Energy Sources in the Future', thinks that in another 150-200 years, even USA and Britain will be faced with acute 'Energy Famine'.

He has laid particular stress on coal, for so far it has provided nearly 90% of the bulk of industrial power supply. We share the opinion of Prof. Saha that no other source, except atomic energy, can take the place of coal. Solar energy is mentioned in this connection, but it must be remembered that inspite of two thousand years of effort, it has not been found possible to harness solar energy effectively, except producing some toys for demonstration purposes, and no method is in sight for handling large volumes of energy produced out of solar radiation, as are required for large industrial plant as we can do with coal or atomic energy.

Prof. Saha gave a picture of the level of developments in different countries. The USA has been easily the first, due to the lead she

*Sci & Cult, **20,** 205 (1954)—unsigned editorial.

had obtained during the World War II in fundamental and developmental research. She has now entered the field of production seriously. She has a five-year programme for reactor development, the object of which is to develop electrical energy out of uranium fission at rates which would be competitive with that obtained from thermal or hydro-electric sources. Great Britain has already a ten-year programme for constructing reactors which will develop 5 million kilowatts of energy. This will replace 20 million tons of coal, and will deliver energy at 1*d* per unit. Though the rate is almost double that of electricity from thermal sources, the British leaders think that the experiment is worth trying, and they have actually undertaken the construction of industrial power reactors. The reader may read the article by Sir John Cockcroft published in Science and cuture, Nov. 1954 with profit.

It is thus clear that the leading nations of the world have accepted the position that nuclear energy alone can meet the impending 'Energy Famine' of the energy starved areas of the world and of the Energy Hunger of highly industrialized countries of the world and have taken serious steps to meet it by giving very serious attention to atomic energy development problems.

Where does India stand now ? She is one of the energy starved areas of the world.

India's total reserve of coal is only 60 billion tons, of which only 1/3 is economically exploitable against China's 1500 billion tons. This means that China has a chance of rapidly industrialising herself by developing her wonderful natural resources and raising her level to west European standards, but India has not the power-potentiality for doing so. According to Atlee, China has, since the Revolution of 1912, the first honest Government. He might have added also that the Government is very serious for industrialization as the composition of her reorganised cabinet* shows.

Of the 36 Ministries, 22 are devoted to economic reconstruction, 9 to industries, 2 to over-all planning. This shows the seriousness

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*CHAIRMAN MAO TSE-TUNG APPOINTS VICE-PREMIERS AND MINISTERS

Mao Tse-tung, Chairman of the People's Republic of China appointed on September 29 the Vice-Primiers, Ministers and Chairman of Commissions under the State Council, and the Secretary-General of the State Council in accordance with the decision of the first session of the first National People's Congress.

They are:

Vice-Premiers: Chen Yun, Lin Piao, Peng Tehhuai, Teng Hsiao-ping, Teng Tzu-hui, Ho Lung, Chen Yi, Ulanfu, Li Fu-chun and Li Hsieonien.

with which the Chinese are tackling the problem of industrialization. The importance which the Chinese Government attaches to economic and industrial reconstruction may be contrasted with the levity with which these matters are dealt by the Government of this country.

India must therefore make a serious effort at rapid industrialization, for which the most important step is to devise adequate measures at meeting the Energy Famine which exists in a very acute form. We have not tried to hide our view that so long our Government has only been playing with these two vital items of national development. Let us justify our opinion.

The Government of India appointed in 1948 an Atomic Energy Commission with the objectives:

(*a*) To survey the country for raw materials.

(*b*) To take steps to develop these materials industrially.

Hsieh Chueh-tsai, *Minister of Internal Affairs;*
Chou En-lai, *Minister of Foreign Affairs;*
Peng Teh-huai, *Minister of Defence;*
Lo Jui-ching, *Minister of Public Security;*
Shih Liang, *Minister of Justice;*
Chien-Ying, *Minister of Supervision;*
Li Fu-chun, *Chairman of the State Planning Commission;*
Po I-po, *Chairman of the National Construction Commission;*
Li Hsien-nien, *Minister of Finance;*
Chang Nai-chi, *Minister of Food;*
Tseng Shan, *Minister of Commerce;*
Yeh Chi-chuang, *Minister of Foreign Trade;*
Wang Ho-shou, *Minister of Heavy Industry;*
Huang Ching, *Minister of the First Ministry of Machine Building;*
Chao Erh-lu, *Minister of the Second Ministry of Machine Building;*
Chen Yu, *Minister of Fuel Industry;*
Lee Ssu-kwang, *Minister of Geology;*
Liu Hsiu-feng, *Minister of Building;*
Chiang Kuang-nai, *Minister of the Textile Industry;*
Chia To-fu, *Minister of Light Industry;*
Sha Chien-li, *Minister of Local Industry;*
Teng Tai-yuan, *Minister of Railways;*
Chang Po-chun, *Minister of Communications;*
Chu Hsueh-fan, *Minister of Posts and Telecommunications;*
Liao Lu-yen, *Minister of Agriculture;*
Lian Hsi, *Minister of Forestry;*
Fu Tso-yi, *Minister of Water Conservancy;*
Ma Wen-jui, *Minister of Labour;*
Shen Yen-ping, *Minister of Culture;*
Yang Hsiu-feng, *Minister of Higher Education;*
Chang Hsi-jo, *Minister of Education;*
Li Teh-chuan, *Minister of Public Health;*
Ho Lung, *Chairman of the Physical Culture and Sports Commission;*
Ulanfu, *Chairman of the Nationalities Affairs Commission;*
Ho Hsiang-ning, *Chairman of the Overseas Chinese Affairs Commission;*
Hsi Chung-hsun, *Secretary-General of the State Council.* (*The Hsinshwa News*, Sept., 29).

(*c*) To set up a nuclear reactor within 5 years.

(*d*) To promote fundamental research in laboratories.

In a debate on the 'Peaceful use of Atomic Energy' the Prime Minister admitted that the Commission has failed to achieve its objective of setting up a reactor within 1953. He did not analyse the causes, but probably these have been made known to him.

It appears to us that the Government, has either not been serious in its intentions or has not been properly advised. In every country which has taken seriously to atomic energy, the chief men to whom the work is entrusted, are whole-time workers. The American Atomic Energy Act says:

> Sec. 22 b. *No member of the Commission shall engage in any business, vocation or employment other than that of serving as a member of the Commission.*

It is well-known that none of the members of the Indian Atomic Energy Commission have been whole-time men. Each one of them has at least one whole time job, in addition to other part-time jobs of a serious nature.

Another defect of the Indian Atomic Energy Act, has been the excessive insistence on secrecy. The Indian Atomic Energy Commission publishes no budget, no account of its activities, and has not hitherto invited the cooperation of the general body of Indian scientists for this great work. Attention has been drawn to the sterilizing influence of secrecy, but though some explanations have been given, we are not at all convinced of the soundness of these arguments. We think that there should be complete disavowal of secrecy as in France.

The structure of Atomic Energy Organisation in every country is now taking a definite pattern, and on the basis of these patterns, we recommend to the Government the pattern suggested in the preceding article by Prof. M. N. Saha.

The most important unit in the development of atomic energy in every country has been the setting up of an Atomic Energy Establishment of which prototypes are found in the—

(1) British Atomic Energy Station at Harwell;

(2) The French Atomic Centre at Saclay; and

(3) The Great American National Atomic Laboratories at Brooekhaven, Argonne and Oak Ridge.

The India Government has not yet seen its way to establish any laboratory of the above type.

The objectives of such laboratories have been primarily to carry out all the developmental research for industrial power production out of nuclear sources, and to carry on fundamental research. All of them maintain one or two or more reactors, and have laboratories for processing material needed for reactors, *viz.*, uranium rods, their canning in aluminium, preparation of moderators, and a hot laboratory for processing the used-up uranium rods, *i.e.*, extracting radioactive poison and plutonium, and making them again fit for use in the reactor.

All these laboratories have elaborate equipments for fundamental research.

In recent years, the situation has somewhat changed. Atomic news is no longer very secret, except in the case of weapon development and certain metallurgical and chemical processes. The MacMahon Act of 1947 has been modified allowing the Atomic Energy Commission of USA to establish a Central Service for supply of small reactors to American Universities and to friendly nations. It is quite possible that Pakistan and other small nations friendly to USA may get reactors before India has one but they have to depend on the central service organised by the American AEC, to supply them with material and expert advice for maintaining these reactors in action.

It will help development of atomic energy in India, if negotiations are carried on for equipping the existing nuclear institutes in India with such reactors.

But India cannot, and should not allow herself to be dependent on the USA or any foreign power for the development of atomic energy within her territories. *She must aim, like France, on Atomic Autonomy*. For this purpose, a Central Atomic Energy Laboratory is needed whose aim should be:

(*a*) To organise prospecting work for Uranium and Thorium on a much vaster scale than has so far been done;

(*b*) To process the Ores to metal, and process Graphite and other moderators;

(*c*) To build Reactors out of Indian material and carry out researches on Economic Power Reactor Development; and

(*d*) To organise a Central Service for Atomic Energy work in the country.

Fundamental research may be left to the existing institutions but all of them should be organised in a well-knit, purposeful group.

We also lay down the requisites for the location of site for such a place. There are several factors in determining the location of such station. Some of them may be mentioned here:

(1) Security—It must not be in an exposed position.

(2) Power—large quantities of power of the order of 30 to 40 thousand kilowatts may be ultimately needed.

(3) Plentiful supply of good water.

(4) Nearness to industrial resources.

(5) Seclusion—away from centres of population due to (*a*) hazards and (*b*) radioactivity disposal.

(6) Communication.

Should the Government decide to establish a Central Atomic Energy Establishment, it is to be hoped that they do not make a wrong selection of site, for the success of the atomic energy enterprise will depend to a very great extent, on the proper selection of site and personnel.

The administrative machinery is not less important. We have shown that the machinery set up by the Government of India during these five years had neither the spirit nor the stature of the machineries which have been found suitable in other countries and therefore it was unable to make any progress, worth the name. The present machinery should be scrapped, and a new one should be set up, of which we give a tentative sketch (p. 520).

This new administrative machinery proposed will achieve three objectives essential for success: (1) committing the Government seriously in Atomic Energy Developments; (2) securing the cooperation of the general body of scientists—physicists, chemists, geologists, and engineers in the work of policymaking as well as in research, development and production; (3) creátion of a strong administrative staff to give effect to the policy laid down; (4) establishment of a national centre of AE reasearch and development.

The proposal is on the pattern of systems now getting a standard shape in all countries. It is now an urgent necessity that the policy of hesitancy be given up, and the old Atomic Energy Act be repealed and a new Act be brought into existence, embodying the experience of other countries.

1.3.16 ON THE CHOICE AND DESIGN OF REACTORS*

1. Introduction

As is generally known, the reactor is the atomic furnace. It is a device based on two scientific discoveries, viz.—

(*a*) Fission of certain heavy nuclei, viz. U^{235} which occurs naturally, and Pu^{239} and Th^{233} which have been made in the laboratory; and

(*b*) The principle of chain-reaction.

It is assumed that these principles are known and no attempt has been made to describe them.

Immediately after the discovery of fission, scientists of many countries realized that the discovery had pointed out to a source of energy, which had much greater potentiality than energy obtained from combustion, which was so long the mainstay of industries and transport. Scientists of many countries began to think simultaneously how this energy could be made available for useful work, and many people simultaneously thought of chain-reaction.

But the first reactor which embodied the principles (*a*) and (*b*) was completed in Chicago in the year 1942 under the direction of E. Fermi and was a graphite moderated natural uranium reactor. The success achieved encouraged the USA Government to build during the war the Oak Ridge reactor and the Handford production reactors, which yielded plutonium used for making the first atom-bombs. After the termination of the war, the USA Government organized

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* D M Bose 70th. Birthday Commemoration Volume. Trans. Bose Inst. **20**, 109, 1955: (*Received for publication on December* 27, 1954)—This is a report submitted to the conference on Atomic Energy Development held at New Delhi on November 25 and 26, 1954. Generally, such a report has to be compiled by a person who has worked on the subject, and has acquired experience and knowledge. But the reporter regrets that along with other participants of this conference, he has no experience in the handling of a reactor, because India has as yet no reactor, and no Indian, to his knowledge, has any experience of actually handling a reactor. All the information given here is derived from book-knowledge, or from knowledge obtained in course of the reporter's visits to atomic energy establishments in foreign countries. Further, it is well-known that much knowledge is still withheld by USA, USSR, and other countries. Any discussion on reactors is, therefore, bound to be rather incomplete.

a huge programme on atomic energy development including construction of different types of reactors. But they excluded even friendly nations like UK and France from active participation in the work, and by the MacMahon Act of 1946 put a ban on the export of all atomic knowledge and equipment, unless they were declassified. But nothing undeterred, Soviet Russia, England and France started their own atomic energy work, and by 1950 had achieved signal success in the construction of reactors. By 1952, even Norway and Holland were able to construct successfully heavy-water reactors, out of their own resources.

By 1950, USA (which in the present context also includes Canada) realized that the atomic monoploly sought by it was broken and that it was useless to keep back the knowledge which other nations had obtained by their own efforts and certain amount of information on the design and working of reactors was declassified.

Before proceeding further, let me give you diagrammatically, an idea of the different types of reactors. This is done in Tables I to VII.

In these tables, the reactors are classified according to moderators, and nuclear fuel used. The moderators are graphite, beryllium, heavy water or ordinary water, and there are reactors with no moderator at all. The fuel used may be natural uranium (99.3% U^{238}, 0.7% U^{235}), enriched uranium (i.e., uranium in which the proportion of the active component U^{235} is increased by artificial methods) or 100% U^{235}, Pu^{239} or Th^{233}.

2. Other methods of classification

The reactors are also classified according to their mode of action as slow or thermal, intermediate, or fast. The slow or thermal reactors are those in which the neutrons released are moedrated to thermal energy by collision with moderator-nuclei. Their action depends on the fact that it is only the slow thermal neutrons which cause effective fission of U^{235}. Not much is known of the working of intermediate or fast reactors in which moderation is more or less discarded; they use enriched uranium or pure fissile material. Information on these reactors have not been allowed to be declassified.

Reactors are also classified, according to the purpose for which they are made, as follows:

(*a*) General purpose reactors,
(*b*) Production reactors,
(*c*) Breeder reactors,
(*d*) Research reactors,
(*e*) Power reactors.

Combination of more than one purpose is possible in a reactor. The early reactors, graphite-natural uranium, or heavy-water-natural uranium, were used for general purpose, viz., for research on design of reactors, for the production of radio-isotopes either from fission or exposure to streams of neutrons. The Oak Ridge graphite-moderated reactor, built in 1943, is still used for the making of radioactive isotopes. The Hanford reactors were used for the production of plutonium which made up one of the atom-bombs dropped on Japan.

Necessity of Breeding.

Of the two isotopes of U, only U^{235} occurring in the proportion of 1 : 140, is active. But for the existence of U^{235} in Nature, there would have been no *atomic energy development* for an unpredicted number of years as the great investigator Lord Rutherford held, up to the time of his death (1937). But the proportion of U^{235} in uranium in the world is so small that unless we can find a substitute there can be no satisfactory atomic power development to serve the needs of the world for a sufficiently long period of human history. Hence, it is imperative that we replace U^{235} as fast as it is consumed by other fissile material. But no other fissile nuclei have yet been found in Nature; they have to be made artificially in the laboratory. A new fissile material Pu^{239} is formed in reactors when the more abundant nucleus U^{238} captures a neutron. When the element thorium (Th^{232}) which occurs more plentifully than U in nature captures neutrons, it leads to the formation of U^{233}, which is a third fissile material. The object has, therefore, been to devise new types of reactors called *Breeder Reactors*, in which more Pu^{239} or U^{233} is produced than U^{235} is consumed. Such reactors can be used for the conversion of U^{238} to Pu^{239} or Th^{232} to U^{033} on a large scale. The great Handford reactors constructed in the USA during the war, or the British reactors erected at Windscale in 1950 for the production of Pu^{239} should not be called 'Breeders', for they consume larger number of U^{235} atoms than the number of Pu^{239}-atoms they produce. These reactors produce from 80% to 90% Pu^{239}.

TABLE I

Natural Uranium—Graphite Reactors

Reactor	Location	Year of operation	Composition (in tons)	Power in kW	Power (kW) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
CP-1	Argonne, USA	1942	6 U, 40 U_3O_8 385C	0·1	2×10^{-3}	4×10^{6}	1·5	Thermal, Hetero.	*Nucleonics*, April, 1954
CP-2	Argonne, USA	1943	10U,42 U_3O_8 472 C	2	4×10^{-2}	1×10^{8}	2·0	Thermal, Hetero.	*Nucleonics*, April, 1954
X-10	Oak.Ridge, USA	1943	85 U, 620 C	3,800	110	5×10^{11}	5·2	Thermal, Hetero.	*Nucleonics*, April, 1954
U^{235}—Production reactors	Hanford, USA	1945	..	$\simeq10^{6}$	..	..	..	(*a*) Thermal, Hetero. (*b*) At least 4 [illegible] in operation	(*a*) Stephenson: Nuclear Engineering (p. 68). (*b*) *Nucleonics*, Dec., 1954 (p. 70)
GLEEP	Harwell, UK.	1947	12U.21 U_3O_8 505 C	100	3	3×10^{10}	..	Thermal, Hetero.	(*a*) Lenihan: Atomic Energy (p. 126) (*b*) *Harwell* (p. 95)
BEPO	Harwell, UK.	1949	40 U, 850 C	6,000	150	1×10^{12}	..	Thermal, Hetero.	Lenihan: *ibid.*, p. 101
BNL	Brookhaven, USA	1950	60 U, 700 C	28,000	470	2×10^{12}	20·0	Thermal, Hetero	*Nucleonics*, April, 1954
Windscale reactors	Windscale, UK	1950	Several thousand tons of U & graphite (C)	..	..	..	..	(*a*) Thermal, Hetero (*b*) Two in operation	Jay: Britain's Atomic Factories (p. 27)
Cumberland power reactor	Cumberland, UK	1955	..	40,000 kW (of electricity)	..	..	..	Thermal, Hetero	*Nucleonics*, June, 1953 (p. 86); Jan., 1965 (p. 7)

The first reactor in the world CP-1 was made at Chicago in 1942. It was graphite-moderated.

The other graphite-moderated reactors made in the different countries are shown in the chart with all details, viz. composition, total power, power per ton of fuel, neutron flux and costs.

The chart shows the enormous improvement in performance of this type of reactors with time. One compares the performance of CP-1 with BNL, which is used for research. The X--10 at Oak Ridge is now mostly used for production of isotopes.

Besides USA, the UK is the only country which has constructed graphite-moderated reactors- GLLEP and BEPO. GLEEP is being dismantled. BEPO is being used for research and production of isotopes. The British and French are constructing graphite-moderated power reactors for production of power. Sir John Cockcroft estimates the cost of power production to be 1d per kWh.

TABLE II

Natural Uranium—Heavy-water Reactors

Reactor	Location	Year of operation	Composition (in tons)	Power in kW	Power (kW) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
CP-3	Argonne, USA	1944	3 U, 6·5 D_2O	300	100	5×10^{11}	2·0	(*a*) Originally built for research purposes (*b*) Thermal, Hetero	*Nucleonics*, April, 1954
NRX	Chalk River, Canada	1947	10 U, 17 D_2O	30,000	3,000	2×10^{13}	10	,,	,,
ZOE	Chatillon, France	1948	3·6 UO_2, 6 D_2O	10	3	2×10^{10}	..	,,	(*a*) Lenihan: *ibid.* (P. 126) (*b*) *Physics Today*, Jan., 1951
JEEP	Kjeller, Norway	1951	2 U, 7 D_2O	300	150	1×10^{12}	..	,,	Kjeller Conference on Heavy-Water Reactors (1954)
P-2	Saclay, France	1952	3 U, 7 D_2O	1,200	360	4×10^{12}	..	(*a*) Originally built for research purposes (*b*) Thermal, Hetero	(*a*) Booklet on 'Saclay' (*b*) *Les Atomes*, April, 1953, p. 114 (*c*) Kjeller Conference Report (*d*) *Nucleonics*, Sept., 1954
SLEEP	Stockholm, Sweden	1954	U, D_2O	300	..	..	..	Like JEEP or CP-3	(*a*) Kjeller Conference Report (*b*) *Nature*, 174, 161, 1954

TABLE II—*Contd.*

Natural Uranium—Graphite Reactors

Reactor	Location	Year of operation	Composition (in tons)	Power in kW	Power (kW) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
U^{235} Production reactor	Savannah River, USA	1954 (?)	..	..	..	..	..	(*a*) Primarily used for producing materials for A or H-bombs (*b*) Usable power produced	Gordon Dean: Report on the Atom (p. 136-46)
NRU	Chalk River, Canada	1955	..	..	..	..	..	..	Nucleonics, Feb., 1953
Swiss reactor	Switzerland	..	5 U, 11 D_2O	10,000	2,000	2×10^{13}	10	At present in the design stage	Kjeller Conference Report

The first heavy-water moderated reactor CP-3 was made at Chicago in 1944.

These reactors require about $\frac{1}{5}$ to $\frac{1}{10}$th the amount of uranium required for graphite-moderated reactors, but what is gained in uranium is lost in the price of heavy-water which costs \$200 per kg. and $2\cdot10^{5}$ dollars per ton. These reactors are less bulky, easier to construct and control but rather complicated devices have to be made for the recovery of precious D_2O.

According to expert opinion, the heavy-water moderated reactors have not much of future unless the price of heavy-water, the supply of which is at present the monopoly of a single nation (Norway) can be brought down. Researches are in progress for discovery of newer methods of production of D_2O which will bring down the costs. The amount of fuel to be used is reduced drastically when the fuel is enriched.

TABLE III

Enriched Uranium Reactors with Moderators

Reactor	Location	Year of operation	Composition (in tons)	Power in kW	Power (kW) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
North American Aviation's homogeneous graphite reactor	Downey and Livermore, USA	..	3·2 kg. U_3O_8	160	40,000	1×10^{13}	1·4	(*a*) Thermal, Homo (*b*) At present in the design stage	*Nucleonics*, April, 1954
Sodium reactor experiment (SRE)	Santa Susana, USA	1956	Slightly enriched U or U^{233}+Th.	20,000	..	..	10	,,	U S A EC's 16th Semi-Annual Report
CP-3′	Argonne National Laboratory, Chicago, USA	1950	1·2kg.U+Al 6·5 D_2O	300	68,000	2×10^{12}	2	Thermal, Heteo.	*Nucleonics*, April, 1954
CP-5	Argonne National Laboratory, Chicago, USA	1953	4 kg. U+Al 7 D_2O	1,000	910,000	2×10^{13}	3	,,	*Nucleonics*, April, 1954
DIMPLE	Harwell, UK	1954	Highly enriched uranium	Low power	..	..	..	(*a*) Thermal (*b*) Used as a research reactor	*Nature*, Vol. 173, p. 825; also, Vol. 174, p. 251

The homogeneous graphite-moderated enriched uranium reactor which has been located at the atomic energy laboratory of the North American Aviation Inc., of Downey, California, USA. is a new and promising departure. Enriched U and graphite are put together as a homogeneous mixture (solid). The fuel will have to be reprocessed after 10 years (at 10^{12}/cm^2. sec. neutron flux for 2,000 h per year). It uses 3·2 kg of ($U_3^{235}O_8$). It uses, as primary coolant, D_2O, and as secondary, H_2O. The reflector is of graphite and the shield is made of steel and concrete (350 tons). As a next step, the North American Aviation Inc. are trying to develop the sodium- graphite reactor (SRE) for power production.

TABLE IV

Enriched Uranium—Light Water Reactors:

A. *Boiling-water Types*

Reactor	Location	Year of operation	Composition (in tons)	Power in kW	Power (kW) / Fuel(tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
LOPO	Los Alamos, USA	1944	0·5 kg, UO_2SO_4 (15%)	$<1 \times 10^{-3}$	..	..	..	Thermal, Homo	*Nucleonics*, April, 1954, (p. 13)
HYPO	Los Alamos, USA	1944	0·8 kg, UO_2SO_4 (15%)	6	7,000	1×10^{11}	0·5	Thermal, Homo	,,
SUPO	Los Alamos, USA	1951	0·8 kg, UO_2SO_4 (88·7%)	45	50,000	1×10^{12}	0·5	Thermal, Homo	,,
N C S R (North Carolina State College water boiler)	Raleigh, North Carolina, USA	1953	1 kg, UO_2SO_4 (80%)	50 (max)	45,000 (max)	$2 \cdot 5 \times 10^{12}$	0·5	(*a*) Thermal, Homo. First university built reactor	,,

The percentages indicated in column 4 represent the enrichment factor of U^{235}.

B. *Swimming-Pool Types*

Reactor	Location	Year of operation	Composition (in tons)	Power in kW	Power (kW) / Fuel(tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
Low Intensity Test Reactor (LITR)	Oak Ridge, USA	1950	3 kg, U (90%)	2,000	500,000	1×10^{13}	1·0	Thermal, Hetero	*Nucleonics*, April, 1954, (p. 12-13)
Bulk Shielding Facility (BSF)	Oak Ridge, USA	1951	2·5 kg, U	100	37,000	1×10^{12}	0·25	Thermal, Hetero	,,
Material Testing Reactor (MTR)	Arco, Idaho, USA	1952	4 kg, U	30,000	7,000,000	2×10^{14}	18	Thermal, Hetero	,,
Submarine Thermal Reactor No. I (Land based proto-type STR—1)	Arco, Idaho, USA	1953	..	..	..	..	..	Thermal, Hetero	(*a*) Gordon Dean: Report on the Atom (p. 136-146) (*b*) *Nucleonics*, May, 1953

TABLE IV

Enriched Uranium—Light Water Reactors:—Contd.

B. *Swimming-pool Types*

Reactor	Location	Year of operation	Composition (in tons)	Power in kW	Power (kW) / Fuel(tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
				B. *Swimming-pool Types*					
ORR	USA	1956	2·5 kg, U	5,000	1,800.000	$5 \cdot 10^{13}$	2·8	Conceptual design of a reactor of the MTR Type: *does not refer to a specific reactor project*	*Nucleonics*, April, 1954, (p. 13)
Experimental Boiling Water Reactor (EBWR)	Arco, Idaho, USA	1956	Natural U + enriched U^{235}	20,000	..	..	17·0.	At present in the design stage	USAEC's 16th Semi-Annual Report
Pressurized Water Reactor (PWR)	Shipping-port, Pa., USA	1957	15-20 U (concentration of U^{235} is 1·5—2%)	300,000	..	..	85·0	(*a*) At present in the design stage (*b*) To be used as a power reactor	USAEC.'s 16th Semi-Annual Report
Submarine Thermal Reactor No. 2 (STR—2)	U.S.S. *Nautilus* USA	..	..	..	..	..	..	At present in the design stage	*Nucleonics*, Sept., 1954, (p. 66)

These reactors have been evolved entirely in the USA They all use enriched uranium. There are two main types, *e.g.*, 'Water-Boiler' and 'Swimming Pool.'

The Water-Boiler Type: We first describe the water-boiler type, the first of which (LOPO) was made at Los Alamos in 1944. Subsequently two others were made there, the HYPO (1944) and the SUPO (1951). They use enriched uranium in the form of solutions of uranium sulphate in light water or as a slurry. The details of water-boiler types of reactors have been published in various issues of *Nucleonics*. The low-power water-boiler reactor is one of the most suitable type which can be installed in a research institute or a university, specially because of its low cost. North Carolina State College in America has installed such a reactor in its campus—the first reactor to be installed in a university.

The Swimming-Pool Type: It is an enriched uranium water-moderated, water-cooled, thermal reactor. The cost of installation of a low-power reactor of this type is the lowest. Hence they are also very suitable as university reactors. Many American universities are planning to instal one of the above two types of reactor. Fuel will be supplied by the USAEC

TABLE V

Enriched Uramium—Beryllium Reactors

Reactor	Location	Year of operation	Composition (in tons)	Power in kW	Power (kW) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
Submarine Intermediate Reactor —A (SIR—A) (land-based)	West Milton, NY., USA	..	..	..	..	..	..	Under construction now	(*a*) Gordon Dean: Report on the Atom (p. 136-46) (*b*) *Nucleonics*, Sept., 1954

Only one reactor of this types has so far been designed. It will work with neutrons of intermediate energy.

TABLE VI

No-Moderator: Fast Reactors

A. *Enriched Uranium*

Reactor	Location	Year of opera-tion tion	Composition (in tons)	Power in kW	Power (kW) / Fuel (tons)	Neutron flux	Cost (in million dellers	Remarks	Source reference
Experimental Breeder Reactor No. 1 (EBR—1)	Arco, Idaho, U S A	1951	Pure U^{235}	1,400	..	6.5×10^{14}	3.0	(*a*) Fast (*b*) To be used for development of power and breeding	(*a*) *Nucleonics*, Sept., 1952 (p.8). (*b*) 16th Semi-Annual Report, USAEC
Experimental Breeder Reactor No. 2 (EBR—2)	Arco, Indaho, U S A	1958	At first U^{235} Later on Pu^{239}	62,500	..	..	40(?)	(*a*) Fast power reactor. (*b*) At present in the design stage.	USAEC's 16ht Semi-Annual Report.
				B. *Pure Plutonium*					
CLEMENTINE	Los Alamos, U S A	1946	..	10	..	5×10^{12}	..	Fast, Hetero.	(*a*) Gordon Dean: Report on the Atom (p. 136-46). (*b*) *Stephenson:* Nuclear Engineering.
ZEPHYR	Harwell, UK	1954	..	Zero power	..	...	..	(*a*) Fast (*b*) To be used in expts. on breeding.	*Atomic Scientists Journal*, p. 273, (1954).

No moderator: These reactors use pure fuel, either pure U^{235} or Pu^{239}. They have very small sizes. The fuel is in the form of lumps separated from one another, so that no explosion may occur. They work with fast neutorns. They are used as cores in breeder reactors in which the synthetic fissionable materials Pu^{239} or U^{233} are produced from U^{238} and Th^{232} respectively by neutron capture. At least as much synthetic fuel is produced in a breeder as the amount of fuel consumed.

TABLE VII

Miscellaneous Types

Reactor	Location	Year of operation	Composition (in tons)	Power in kW	Power (kW) / Fuel (tons)	Neutron flux	Cost (in million dollars)	Remarks	Source reference
Homogeneous Reactor Expt. No. 1 (HRE – I).	Oak Ridge U S A	1951	Enriched U	1,000	..	..	1·0	(*a*) Water-boiler type. (*b*) Liquid moderator. (*c*) Thermal. Homo. (*d*) Used for the study of power possibility.	Murray: Nuclear Engineering (p. 102).
Homogeneous Reactor Expt. No. 2 (HRE—2).	Oak Ridge, U S A	1956	Enriched U	5,000	..	..	47 0(?)	(*a*) Water-boiler type. (*b*) To be used for power study.	USAEC's 16th Semi-Annual Report
British Breeder Power Reactor.	Northern Scotland.	1956	..	50,000 kW (of electricity).	..	..	..	..	*Nucleonics*, Dec., 1953, p. 70.
Homogeneous Thorium Reactor (HTR).	Oak Ridge, U S A	1959	At first, probably U^{235}, later on U^{233}.	65,000	..	..	44 0	At present in the design stage.	(*a*) USAEC's 16th Semi-Annual Report. (*b*) *Nucleonics*, Sept. 1954, p. 66.
Boiling Experiments.	Arco, Idaho, U S A	..	..	..	..	..	..	Two reactors	(*a*) USAEC's 16th Semi-Annual Report. (*b*) *Nucleonics*, Sept., 1954, p. 66.
E 443 ..	U K	..	..	..	..	..	..	At present in the design stage.	..
Submarine Intermediate Reactor – B (SIR—B).	U.S.S. *Sea Wolf* U S A	..	..	..	..	..	..	At present in the design stage.	*Nucleonics*, Sept 1954.

The USA announced in 1953, the successful operation of a breeder reactor at the Physical Laboratory at Idaho under the direction of Zinn (*Nucleonics*, Nov., 1953, p. 30). The details have not yet been declassified. It is probably a fast reactor without the use of moderators and uses an assembly of Pu^{239} -lumps of subcritical size for the production of an intense source of neutornos.

3. **General principles of reactor construction and control**

The working of the reactor depends on the 'sustenance' of the 'chain-reaction'. Suppose we have a neutron causing fission of a U^{235}-nucleus occurring in the reactor. This gives rise on the average to 2.5 fast neutrons. What happens to these as they pass through the matrix of the reactor?

Some of these are captured by U and the moderator material. Others are scattered by the nuclei of moderators and of fuels. Some escape capture beofre being slowed down, and a fraction is absorbed in the fuel. Others leak out of the reactor. The possible fates of the neutrons are listed in what is called the neutron balance sheet. After all these vicissitude, we get K slow neutrons capable of producing further fission. If $K \gg 1$, the chain-reaction is sustained, otherwise it stops. It has been shown that K depends on five factors:

$$K = \eta \epsilon p f F$$

This is known as the five-factor formula. Let us explain the significance of each term on the right-hand side.

The last factor F is due to leakage from the reactor. If the reactor were of infinite size, there would be no leakage. But as in actual practice it is of finite size, F is <1. But reactors are surrounded by a mantle of graphite or beryllium, which reflect most of the leaking neutrons back to the reactor. It is, therefore, the general custom to make calculations with an infinite reactor, *i.e.*, with $F=1$.

Let us now take the other factors one by one.

η=average number of fast neutrons emitted as a result of the capture of the primary thermal neutron by the fuel.

If we had pure U^{235} as fuel $\eta=2.1$ and not 2.5, for not all thermal neutrons captured by U^{235} cause fission, but only a fraction given by $\sigma_f/\sigma_f+\sigma_c$

where σ_f=fission cross section; σ_c=capture cross section of U^{235} producing U^{236}.

So that, $$\eta = \nu . \frac{\sigma_f}{\sigma_f + \sigma_c}$$

If it is natural uranium, we have to consider the action of the slow neutron on U^{238}. This further brings down η to 1.32. For enriched uranium, η varies between 1.32 and 2.1 becoming larger as the enrichment becomes larger.

The calculation of η is a very important item in 'Reactor Technology'. Actually it is not so simple as given above, for σ_{fission} and σ_{cap} depend on the velocity of neutrons. The full data do not seem to have been declassified.

The second factor ϵ is known as the fast fission factor, for fast neutrons also cause fission, though to a slighter extent than slow ones. ϵ is the ratio of total number of fast neutrons porduced by fissions due to neutrons of all (fast and slow) energies to the number resulting from thermal neutron fissions.

For graphite and U reactor, ϵ is taken to be 1.03. Both η and ϵ depend on the fuel-material.

p = Resonance escape probability
= Fraction of fast (fission) neutrons that escape resonance capture, mostly in U^{238}, while being slowed down. For the British reactor BEPO, $p = 0.899$

f = Thermal utilization factor
= Ratio of thermal neutrons absorbed in the fuel leading to fission to the total number of thermal neutrons absorbed by fuel, moderator and other materials and not leading to fission. For BEPO, $f = 0.889$

p and f can be varied to some extent. They are both less than unity, but for chain-reaction to proceed, should be as large as possible. Unfortunately, such changes in the relative proportion of fuel and moderator which increase p decrease f. For instance, reducing the amount of moderator increases f, but the greater relative proportion of U^{238} decreases p, and *vice versa*. The optimum arrangement should give the maximum value of the product pf.

The exact calculation of the quantities η, ϵ, p, f depends upon experimental data involving variation of different kinds of nuclear cross sections with velocity of neutrons and on the nuclear properties of reactor materials. Most of these are still classified material. Even when these fundamental data are vailable, the best working conditions will depend on the design selected, for which the values of η, ϵ, p and f have separately to be calculated therotically and verified experimentally. These involve mathematical and experimental skill of the highest order.

But when the idea of the reactor was first mooted, the values of the quantities η, ϵ, p andd f were only roughly calculated, and due to the urgency of the military situation, work on reactors started without stopping for further refinement. The early reactor work was done rather '*brutally*'.

After the termination of the war, greater attention is being paid to the determination of the four factors determining K, both theoretically and experimentally. The student of reactor technology will find an excellent summary of the declassified material in the Elements of Nuclear Reactor Theory, by Glasstone and Edlund, written under instructions from the Atomic Energy Commission of USA. There are schools of 'Reactor Technology' at Oak Ridge, USA, and Harwell, England, where instructions are given to students on reactor physics and technology. We should have such a school in India, for the last work on the design of reactors has yet to be said, and probably better knowledge of fundamental quantities and better design may save millions of dollars and develop and extend the fundamental knowledge of this science.

The published literature is confined only to the treatment of thermal reactors. The great amount of work, going on in the USA on intermediate and fast reactors which are expected to solve the problem of production of economic electrical power from nuclear energy and details of successful breeder reactors are still classified. Probably these will not be made public before other countries embark on similar enterprises.

4. Need for growth of scholarly tradition

The absence of scholarly tradition is to be very much regretted and in a recent issue of *Nucleonics*, Dr. A. Weinberg, Technical Director of the Oak Ridge National Laboratory, pleads for the growth of a scholarly tradition in nuclear development. He says (*Nucleonics*, Sept., 1954, p. 20):

'Although American work in nuclear energy now proceeds on a colossal scale, we still believe that there is a need and place for the pursuit of technology on a smaller, more leisurely and more scholarly basis than it is pursued here.'

The European countries, unable individually to cope with America in money or organization, have combined to put up a Centre Europeen pour la Recherche Nucleaire shortly called CERN for the pursuit of fundamental researches in nuclear science. The laboratory will spend much less than a single American atomic national laboratory, but that does not mean the intellecttal output will be less. Says Dr. Weingberg:

'Of the commodities necessary for establishing and nurturing the scholarly tradition, I would place money *a poor third to time and brains*.'

5. What kind of reactor India should have

In India, the greatest handicap to the development of nuclear energy is, first of all lack of a proper organization which is dealt with elsewhere. Even the few laboratories which have started work on this line are handicapped by the absence of a reactor. for this provides a source of neutrons of the order of 10^{12} to 10^{14} per cm^2 per sec, which is indispensable for the persuit of many researches on nuclear energy. It is understood that plans are being made to obtain a heavy-water moderated natural uranium reactor for our AEC, but this point should be very carefully deliberated. The heavy-water moderated reactor certainly requires far less uranium, about 1/10th of the amount for a graphite moderated reactor, as shown in Table II. but it is not realized that what we gain in the price for lesser quantity of uranium to be used, is more than made up by the price of the heavy-water needed for the purpose. America may build heavy-water reactors for they have unlimited funds, or Norway may built it for it is the only country which makes heayv-water, and their own costs of production must be much less than those at which they sell this commodity to other countries, as they are virtually monopolists. But as long as we have to purchase heavy-water from Norway, the the proposition will remain a very expensive one.

In fact in the Kjeller Conference on Heavy-Water Reactor, the British representative, Mr. Dunworth remarked:

'I think I can say that we (British) shall not actually build the plants unless heavy water is produced *much more cheaply than at present*, or at least, it is not very likely.'

Recently, it has been announced that the British Government, in co-operation with the New Zealand Government, is going to set a plant in New Zealand, where heavy-water is expected to be produced far more cheaply.

The British representative was not alone in his views. Dr. Kowarski, the inventor of the idea of heavy-water reactor, said:

'On the whole I think, however, that in spite of all those advantages, the time of heavy-water reactor for laboratory use is drawing to a close.'

The present price of heavy-water is $87 per pound. To what extent is the price to be reduced if heavy-water reactors are to be economic? This is revealed in a remark by Dr. Weinberg:

'I should like to say again that nothing that I have said or that any of other gentleman said should be construed to contradict your (Dunworth's) very well taken point that heavy-water is too expensive and in fact, I have not been authorized to say so, but I think that the United States will buy as much heavy-water as anybody can produce if he will sell it at 5 dollars per pound.'

It has been remarked that heavy-water may be produced as a by-product of the fertilizer plant to be set up at Bhakra-Nangal and we shall get heavy-water *at no price*. This is a very bad economic argument, for nothing can be produced in this world *gratis*, and when we say at no price, somebody else, in this case the Indian tax-payer, makes his invisible contribution. It is therefore suggested that we should deliberate very carefully before we fix upon the types of reactor to be built at our Atomic Energy Establishment. The merits of different types should be carefully weighed by a representative expert committee.

The days of graphite-moderated natural-uranium reactors are not yet over. In fact, as Table I shows, the design of graphite-moderated reactors has improved immensely and Sir John Cockcroft informs us that the new power reactor which Britain is putting in its electrical grid in addition to coal stations will be a *graphite-moderated reactor*. The author was told by Dr. Dupuy, Chairman of the National Centre Scientific Research in France, that France is putting up a graphite reactor for power production in the south of France, for, on account of the discovery of large quantities of U in France itself, it has been able to overcome the initial hurdle of getting quantities of uranium necessary for a graphite reactor. It appears that the American stranglehold on the Belgian uranium supply is getting loosened, and in course of the author's recent visit to Brussels, he learnt that large quantities of uranium sifficient for the construction of a graphite-moderated reactor can be had from Belgium.

6. Research reactors for India

The Need for a Research Reactor.—It is very necessary that we make a reactor by our own efforts, out of Indian material as far as psssible, but should we wait till we can achieve it? Speaking for myself, I do not foresee the time-limit when we can build up such a reactor, with our own efforts.

But should we wait so long? I think that we ought to take advantage of President Eisenhower's generous offer to help friendly nations in nuclear energy work made on December 8, 1953, which formed the the subject of a debate in our Parliament on May 11, 1954, and attempt should be made to obtain a *research reactor of the University type* which is now coming into use in American universities and research institutes for fundamental research purposes. I am told that 30 American universities have applied to thier AEC for research reactors. Since then ,the proposals have been accepted by a committee of the UNO and an International Pool for Atomic Energy has been formed. The need for such a research reactor can hardly be over-emphasized. In reseaerch on nuclear science, we require a steady source of neutrons, one of the two fundamental particles out of which all nuclei are made. The primitive source was the radium-beryllium source, which gives a flux of about 10^7 neutrons per sec, if the amount of radium is a gram. This source has the disadvantage that it has inconvenient γ-rays. A polonium-beryllium source is better and is used in the Oak Ridge School of Reactor Technology but it suffers from the defect that Po has a life of 138 days only. From the great reactors of USA, a flux of 10^{12} to 10^{14} neutrons per cm^2/sec is obtained, and I found in course of my recent visit that about 20 fundamental experiments on nuclear research are being carried out round the great Brookhaven graphite-moderated reactor.

The university type of research reactors are of two types—the water-boiler and the swimming-pool type. They are much smaller, but give easily a flux of 10^{12} neutrons per cm^2/sec. I enquired about the costs. I was told that we require about 10^5 dollars for the reactor, 2×10^5 dollars for the reactor building, and the fuel which is 90% enriched uranium has to be obtained from the American AEC. The total quantity required is 3.5 kg costing 70,000 dollars. So the total cost comes up to 3.70×10^5 dollars, nearly 2 million rupees. It is far better to get one or two reactors of this type by negotiaitons on on government level, than wait for the day when we shall have our own graphite or heavy water moderated reactor costing at lesat 3 to 4 crores of rupees.

The USA Government has recently placed 180 kg of U^{235} at the disposal of the International Pool for Atomic Energy for distribution amongst friendly nations. We should be quick to take advantage of this offer.

I have added a list of experiments (Supplement I) which have occurred to me, and which we can carry out if we have a research reactor of this type. They are fundamental topics, but research on topics needed for the design of our own reactors may also be undertaken. We shall not then have to send 3 tons of beryllium to Saclay, as proposed by Dr. Bhabha.

Let me remind you that in spite of the huge expenditure of money on research on nuclear science and technology, we are yet far from understanding the nature of interaction between nuclear particles, in and outside the nucleus. If this were known, probably much of the cumbrous technique evolved to utilize nuclear energy would have been simplified. I may explain by a historical analogy. Mankind had observed for over two millennia the motions of the planets including the sun and the moon, under the astrological belief that if we can predict their motions in advance, we would be able to predict the destinies of nations and men. The Greek astronomers tried geometrical notions to explain these motions, and for a millennium, Greeks, Arabs and Hindus played with epicycles and deferrents and all sorts of complicated curves to understand the nature of planetary motion till the thing became so complex that a scholarly Castillian king, Alphonse XIII, who was also an astronomer, remarked that if he were present at creation, he would have given God some good advice. But when Newton discovered the law of gravitational attraction in 1680, the darkness looming over these problems for thousands of years dissolved and there was light, and since then the calculation in advance of planetary positions has become exercises in algebra. We are still in the age of epicycles and deferrents as regards nuclear science, and fundamental discoveries are still to be made. Should not the Government of free and independent India aid her scientists by helping them with meney, material, men and euipment?

Supplement I

Range of research work possible with a low-power reactor

In most of these reactors the maximum thermal neutron flux inside the reactor is about 10^{12} neuts cm²/sec. A well collimated thermal flux of about 10^6 neuts/cm²/sec may be obatined outside the thermal column. The flux of 10^{12} neuts/cm²/sec is sufficient for many types of scattering and diffraction studies with slow neutrons. Possible topics of study include:

A. *Physics*

1. Diffraction and scattering study with neutrons of various single energy. Single energy is produced by the use of:

   (*a*) Mechanical velocity selector. Latest addition in this field is the '*fast-chopper*' designed by W. Selove at the Argonne National Laboratory.
   (*b*) Time of flight velocity selector or by crystal diffraction. There are designs of different types of neutron monochromators to produce these monoenergetic neutron beams.
2. Studies in the reaction thershold: Accurate determination of reaction thresholds by monoenergetic neutron beams will furnish information on the masses of unstable isotopes.
3. Yield ratios of reactions, in which a number of products are formed. This helps in the study of competitive processes in nuclear reactions, and verification of the statistical theory of nuclear reactions.
4. Study of neutron polarization, decay of neutrons, scattering of polarized neutrons by polairzed nuclei. Scattering experiments are performed to find out the law of interaction between nucleons, viz. between proton-proton, proton-neutron, neutron-neutron, proton or neutron and different nuclei.

All nuclei have spins, and formerly all experiments were performed using unpolarized beams. Recently these experiments have been revised using 100% polarized beams of neutrons, and nuclei which are 100% polarized. The results are found to be quite different from those obtained earlier with unpolarized beams.

5. Resonance absorption of neutrons leading to information regarding nuclear levels.
6. Energy level studies with isotopes produced in nuclear reactors by β-and γ-ray spectroscopy.
7. Study of reactor characteristics—distribution of neutrons; temperature effects on distribution of neutrons; study of reactor designs.

B. *Chemistry*

1. Relative yields of fission products produced in U, Th, etc. fissioned with neutrons of different energies. Also relative yields of fission products in photo-fission.

2. Activity method of analysis: such as in complex mixtures of rare earths, etc. Cross-sections of some of the constituents for neutron capture may differ considerably from those of others and hence estimation of their radioactive products gives their percentages.

3. Radiation chemistry, *i.e.*, effects of irradiation by pile radiation (neutron and γ-rays) on chemical valency, chemical binding, etc. Study of the primary effect of irradiation, *i.e.*, nature of the primary products: as for instance, whether H and OH are the primary products of the irradiation of H_2O or aqueous solutions.

4. Polymerization effect of radiation: study of the irradiation induced polymerization of gases and liquids, *e.g.* styrene, benzene and cyanide compounds.

5. In isotope separation problems, radiometric method is a very promising method for the analysis of the percentages of enriched isotopes. The relative radioactivity of the neutron capture product of the required isotope before and after separation will give the enrichment factor.

6. Use of radio-isotopes as tracers in various types of chemical problems, *e.g.*, thermal and photochemical exchange reactions (C^{14}), chemistry of detergents (S^{35}), adsorption processes study leading to better dehumidifiers (S^{35}, P^{32}, etc.), ion exhange problems in the recovery of minerals, concentration of sugar solutions etc. (Ca^{35}, Cs^{137}), crystal formation and deposition at grain boundaries (C^{14}, Fe^{35}).

C. *Metallurgy*

1. Effect on materials for reactor construction of the intense beam of neutrons in reactor.

2. Uses of radioactive isotopes as tracers in (*a*) the study of the rôle of P and S in steel making and their removal (S^{35}, P^{32}), (*b*) the the study of aging mechanism of metals, *e.g.* diffusion of C in iron (C^{14}), (*c*) absorption of Cl from salt solutions in stainless seteel (Cl^{36}), (*d*) rapid determination of Ti content in iron alloys (Ti^{51}), (*e*) study of mechanism of corrosion and surface wetting of iron by organic acids (Fe^{55}, Fe^{59}).

D. *Biology, Botany and Medicine*

1. Use of radioactive isotopes as tracers in the study of—
   (*a*) Metabolism of various elements in animal and plant systems,
   (*b*) Rôle of various carbon atoms in photosynthesis, etc.

2. Therapeutic uses of the radiations form radio-isotopes, viz. I^{131} in toxic goitre, Au^{198} in cancer therapy, P^{32} and Au^{198} in leukaemia, etc.

3. Study of the therapeutic value of pile radiations.

4. Germicidal property of radiations , *e.g.* destruction of trichinosis cycle in pork by γ-rays.

(See N.R.C. Report : *Radioisotopes, A New Chemical Tool* by G.M. Guest of Canada.)

1.3.17 ATOMIC WEAPONS, DISARMAMENT AND USE OF ATOMIC ENERGY*

THE atom has dominated world politics since 1945 when two atom bombs were dropped without warning on the unfortunate Japanese cities, Hiroshima and Nagasaki and caused destruction of life and property on a scale unknown to history. The atom bombs and hydrogen bombs have been so frequently in the headlines of daily papers that people all over the world have been fully alerted of the horrors of atomic warfare. The World Peace Assembly consisting of representatives of public opinion, has assembled here at Helsinki to protest against the use of atomic and thermo-nuclear weapons in any futeure combat between nations, to devise ways and means for the banning of manufacture and use of atomic weapons. Prof. Joliot-Curie, President of the World Peace Assembly, has so ably analysed the cold war diplomacy on atomic weapons, that it is impossible to improve on it. Let us give our own version of this diplomacy.

A great medieval king who inherited a prosperous State found that the head of his ordance department has devised a new kind of gun, which was far more powerful than those in the possession of his neighbours. He had a large number of them cast, and, proud of his possession, got inscribed on them the words "Logique Royale". He used the royal logic on a number of neighbouring countries and was responsible for a great deal of destruction and misery but was ultimately foiled in his attempt to absorb small nations into his empire. He died an old broken-hearted man with his State in complete chaos and misery. We have a similar process happening in the world today, since for the last ten years, one or other part of the world is being threatened frequently that the Atomic Logic would be unleashed on them, if they do not subscribe to the views of those in a position to use that logic.

Peaceful Utilisation of Atomic Energy

But there is another side to the question. The discovery of methods for releasing the energy of atoms is probably the greatest technical discovery since that of fire in the distant past and we are still far from reaping, even realising, the full consequences of this great discovery

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on human life. We are told that the Titan who taught mankind the use of fire was chained to a mountain for perpetual torture for the sin of having placed in the hands of men such a weapon of destruction: that is how the ancient seers looked upon the discovery of fire as full of evil potentials for human destiny. But mankind has not destroyed itself. On the other hand fire has been very beneficial to human civilisation. The use of fire has taught him arts of cooking, metallurgy etc., and ultimately it led to the invention of the power engine which brought about the Industrial Revolution, and this has developed and raised in advanced countries the standard of life to a level which could not be thought of in medieval times. The atomic revolution is expected to produce far greater revolutionary changes in the world and promote a deeper understanding of the laws of Nature including biological processes, heretofore mostly unknown.

Threat of Atomic Diplomacy

For the present, however, the constructive programme based on the use of atomic energy is threatened on account of the international tension it has produced. The threat of atomic warfare has been too often used to exert political pressure, and as our President has told us, to blackmail the weaker nations. The world has so far fortunately escaped the atomic horrors which were threatened to be unleashed on Korea, Vietnam and Taiwan. We people of India, under the guidance of our Prime Minister, Jawaharlal Nehru, have perisistently and consistently protested against the use of Atomic Diplomacy. A large number of signatures have been secured in India for the banning of atomic weapons and the maintenance of peace throughout the world. India wants to have sufficient time to use her hard-won freedom for her own benefit. India considers that actions by foreign powers to secure military bases in South-East Asia are only other phases of atomic logic. She is determined to raise these attempts to the last drop of her blood and in this matter the 370 millions of India, speak with one voice.

India would nevertheless welcome the intensification of efforts for peaceful utilisation of atomic energy by underdeveloped countries of the world. It is well known that our countries have suffered intensely from imperialistic colonialism which has exploited our resources for enriching the predatory classes, mostly of foreign origin, having no stake in the country. Like other underdeveloped countries we are very backward, as the natives were used only as "hewers of wood and drawers of water". The statesmen of all underdeveloped countries which have fortunately won their independence, have the following problems to solve. The average per capita income of the backward countries is only 60 dollars per year against 600 dollars of the most advanced nations. This is because the advanced nations are able to produce per capita ten times more goods needed for human consumption because of a vast organisation of work using modern science and technology to utilise the natural resources of their country. The first necessity is industrial energy which has been so far furnished by coal, petrol or water-power. But most of the backward countries have not sufficient power resources and they would naturally welcome any proposal that would place at their disposal a source of energy which they can harness for the work under contemplation. Proposals for the peaceful utilisation of atomic energy for these purposes have been forthcoming but they have to be examined with caution.

What is to be done with accumulated Atomic Materials?

The accumulation of materials for the manufacture of atomic weapons by USA and other countries has resulted in the creation of a situation which is known to economists as the "cycle of diminishing returns". What is to be done with the enormous stock of atomic materials produced as a result of gigantic organised efforts costing about 20 billion dollars; if they are not to be used for warfare?

For the past year and a half leaders on both sides have come to realise that this enormous atomic material should be utilised for the generation of additional industrial energy which may supplement and finally replace the usual power-producing machinery.

Experiments carried on in the USA, USSR, UK, and France have shown that electrical energy may be generated economically from special designs of nuclear reactors. At present the price of such energy is somewhat dearer than that derived from conventional machinery, viz., thermal or hydro-electric, but it is confidently asserted that time is not distant when electrical energy produced out of new designs of reactors will compete economically with the energy obtained from conventional sources. In fact both USSR, and USA have made these claims and Great Britain and France are actually engaged in working out details of nuclear reactors, which will supply up to 25 per cent of their requirements for industrial energy by 1965.

This has given a new turn to atomic politics. It was President Eisenhower who on December 11, 1953, advocated in the assembly hall of the UNO, a fourfold principle for the use of atomic energy, particularly for the benefit of the backward nations of the world, which cannot undertake industrialisation of their countries, on account of their deficiency in energy resources. Almost simultaneously the Soviet Union has also offered to help backward nations of the world in the peaceful utilisation of atomic energy. As these proposals have come from very eminent quarters, they should be very carefully examined by the World Peace Assembly.

Atomic Imperialism?

Certainly these offers consititute a ray of hope in the general gloom produced by the atomic armament race, but are the backward nations in a position to take advantage of these offers? At present only the great nations have the monopoly of atomic fuels, of atomic machinery and technical knowledge which have so far been kept as jealously guarded secrets. Therefore even if a gift of nuclear energy-producing machinery be made to underdeveloped nations, they will have to be dependent for an indefinite period on the great powers for running the power plants. Does it not threaten to impose a new kind of imperialism—which we may call Atomic Imperialism—on underdeveloped countries?

It is possible for big underdeveloped nations to overcome this dependence on great nations and achieve Atomic Autonomy in a number of years depending on their own ability to overcome their general technical backwardness. But most of the small nations have neither the resources nor the personnel to achieve Atomic Autonomy.

A central international pool of nuclear fuel, machinery and personnel has been proposed. This requires the closest scrutiny by the World Assembly for Peace.

The natural resources of atomic energy are uranium and thorium and both these materials are found widely distributed in all parts of the world. In fact the survey is very incomplete. It is generally surmised that they are almost as plentiful as lead, though all deposits may not be economically exploited. Concentration of large stocks of these materials in the hands of any single group as is happening now is not desirable. There should be an International Pool.

Atomic Warfare

Let me now turn to threats of atomic warfare. Why Atomic warfare should be banned?

Though possession of atomic weapons appears to constitute great military strength, actually it is not so. Its use constitutes a great moral sin against humanity. Its production involves immense organisation and cost, which only the biggest nations are capable of undertaking. It is effective only against great centres of population and industry, whose destruction would be an unpardonable crime against civilization. It is not so effective against countries whose population can be dispersed over vast areas.

A decision was made on December 18, 1954, by the NATO Council to base its military strategy on the use of atomic weapons. The decision is immoral because the very persons in whose interest atomic weapons are proposed to be used would be its first victims. History teaches that 'wars to end wars', 'violence to end violence' have never accomplished their objective. The consequence of the decision will be to intensify the race for atomic armaments and endanger the peace of the world. If the conflagration spreads, as it is sure to do, it will lead to sheer mass destriction.

Since retaliation is sure to follow, it will lead to paralysis completely or partial of the life of not only the combatants, but also of those who have the misfortune to come in their way. The NATO decision brings the destruction of modern civilisation within the range of technical possibilities.

What is the attitude of scientists, intellectuals and artists towards the atomic danger?

The Atom Bomb was evolved as the result of a great co-operative effort made in the USA during the years of the Second World War. Nevertheless, the scientists who were responsible for the work felt a great moral guilt in using it. It is well known that even as early as 1944, a representative committee of distinguished scientists actually participating in the atomic bomb project, under the presidentship of James Franck (Nobel-laureate), warned President Truman of the consequences of the use of the aotm bomb. They earnestly beseeched him not to use it. It is also well known that the bomb was not used to bring about the surrender of Japan for the American military leaders knew fully well that Japan was going to surrender within a few weeks, even without the atom bomb. It was only to unleash the cold war against the Soviets that the atom bomb was used.

Since 1946 the majority of the scientists of the World have been unanimous in their condemnation of the atom bomb tragedy and have warned the world against atomic danger. It is now well known that many of the eminent scientists who were engaged in the Manhatten project either retired from their war-time jobs or slackened in their efforts. The late Professor Einstein whose letter to President Roosevelt induced the latter to mobilise the industrial and technical resources of the American Continent towards the atom-effort, was incessant in his denunciation of atomic warfare. In his last years he even remarked that if he had to choose his career again, he would have preferred one of a pedlar or a plumber to that of a physicist. He was not alone in his opinion, but others expressed themselves very definitely against the manufacture of weapons of destruction and their use.

Apart from the few fire-eating generals, admirals and politicians of the McCarthy type, the world opinion of scientists, artists and intellectuals is definitely against the manuafcture and use of atomic weapons.

There is no need to dilate on the economic, social and political consequences of an atomic arms race. The atomic race in which only great and technically efficient nations can indulge, is even on them a great strain economically. It is creating bad blood, producing world-wide nervousness and preventing backward nations on whom the Charter of the United Nations Organisation had conferred the right to work out their way to a better life, to settle down, and work out schemes for the utilization of their natural resources to achieve a better life for their masses. It is time that this state of hypertension comes to an end.

Apart from the mass destruction committed on the spot—in Hiroshima, it killed outright 2,00,000 people and at Nagasaki 1,00,000 people—there have been serious after-effects which have been described in detail by Doctor Nobuo Kushano, member of the Institute for Infectious Diseases, University of Tokyo. He found as a result of 10 years' observation that the survivors suffer from haemorrahagic diatheses (vomiting, splitting of blood, haemathuria, etc.) almost complete disappearance of white corpuscles due to destruction of blood forming organs such as bone-marrow, lymph, etc., incapacitation of the organs of reproduction and a slow, painful and lingering death of a large proportion of survivors. Children subjected to the death-rays who have survived have suffered from retarded physical and mental development, and even the brain of the foetus was seriously affected.

Does the world want to see the repetition of such horrors?

Experiments on thermonuclear bombs are being carried out in the remote regions of the world. But radio-active ashes produced by such explosions have affected seriously animals and plants within hundreds of miles of explosions, and being carried by wind and water-current to distant countries, have proved dangerous to agricultural crops as well as to the fishing industry of Japan.

So those who are indulging in the testing of thermonuclear bombs, even in distant areas, cannot avoid the moral responsibility of committing a crime against humanity.

The atomic logic has been used since 1946 to frighten nations. In 1946, there was an attempt, on the part of a great political leader and a representative of a great religion, to induce the American President to use the atomic logic on communist countries. This did not materialise, probably because, as we now know from revelations made by Gordon Dean, one time Chairman of the Atomic Energy Commission of USA, there did not exist at that timet sufficient material for more than a few atom bombs. The ardour of the atomic warmongers was further chilled by the revelation on the part of certain scientists that nearly 40 thousand atom bombs would be needed to extinguish all life out of communist countries.

The history of 'Atomic war-mongering', chiefly the work of ill-informed generals, admirals and politicians, has since been variegated. It was esitmated by them that the Soviet Union would take 15 to 20 years to produce atom bombs. So efforts at the production of more atom bombs fortunately slackened between 1946 and 1949; they were revived with far greater intesnsity when Russia exploded the first atom bomb within four years of starting, by 1951. The present position is probably that both the USA and USSR, have got materials for manufacture of a vast number of bombs, and probably the United Kingdom and one or two more countries are on the way to catch them up.

The international tension and the cold war sitll persist producing nerveousness over the whole world. Undoubtedly the banning of the atomic weapons and general disarmament would contribute the first step towards the relaxation of the present world tension. But how can that be achieved?

A dispassionate review of the historical events occurring within the last 50 years will show that the extreme form of nationalism and its natural product, imperialistic colonialism, in the hands of the technically advanced nations have been repsonsible for all the devastating wars culminating in the two great world wars. But have any of these wars achieved their objectives? We are in the midst of a great technological revolution due to the great discoveries of science and technology. They are bringing about such great and rapid changes in the methods of human living that the old world ideas of extreme nationalism and what follows from that, imperialistic colonialism are becoming quite obsolete. The time has come for a Welfare State of the world which has been rendered possible by the great discoveries in science and India has already placed before nations her own ideas in the form of *Pancha-Shila* (the five principles), formulated by Prime Minister Nehru of India.

Let the Atom work in future for *Peace and Harmony*, instead of for *Discord and War*, and usher in the golden Age!

1.3.18 THE ATOMIC ENERGY CONFERENCE AT MOSCOW*

AN Atomic Energy Conference was held at Moscow under the auspices of the USSR Academy of Science from July 1 to July 8. Besides the Soviet workers, the conference was attended by scientists of about 30 nations including the Scandinavian countries. The representatives of countries receiving the Marshal aid were conspicuous by their absence though it is understood that invitation was extended to the Governments of all countries.

The plenary session was held on July 1 at the large auditorium of the University, and Prof. A. N. Nesmjanov, President of the USSR Academy of Science, delivered the inaugural address '*On the Threshold of the Atomic Era*' and welcomed the foreign scientists. The following is a report of his speech from *Pravda* of July 2.**

On the Threshold of the Atomic Era

The Academician A. N. Nesmjanov said that in the life of the Academy, the present sessio n of the Soviet Academy of Science, is an important milestone. Academician Nesmjanov did not doubt that the present session of the Academy of Science would call forth living interest and useful work. Workers of science of many countries including those of the So viet Union, and among them members of the Academy of Science, USSR, were spending much fruitful labour for solving leading questions of nuclear physics. Less than three months ago, a conference was held in the Adcademy of Science, USSR, on theoretical physics; to a considerable degree, this Conference was deveoted to the theories of the nucleus and on questions connected with nuclear physics as a whole. Repeatedly attention was devoted at the Conference to the study of cosmic rays—on phenomena closely connected with nuclear transformations and their character, and lastly on the colossal energies of elementary particles. Although the whole field is teeming with many problems and aspects of nuclear physics, the various scientific centres of the population of our planet have not established joint efforts and focussed attention to this new realm of science, which is advancing at such a rapid tempo.

This joint effort and attention has to be established by the desire

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* Sci & Cult **21**, 76, 1955.

** The report has been translated from the original Russian by Sri Suvas C. Ray, M.Sc., of the Indian Association for the Cultivation of Science.

for further progress of humanity. Undoubtedly none of the previous developments, since the beginning of science and technology on the earth, were of such powerful influence on progress,as the release of the potential energy of the nucleus of the atom or the utilization of the colossal energy artificially realized by thermonuclear transformation. Artificially realized, because all the energy, which man and all living beings utilize on earth: energies of fuel, of water and wind, of life, and at the end of the account the brain is indebted to the source of spontaneous and natural thermonuclear process going on in the sun—the combustion process which gives rise to solar energy is itself a kind of hydrogen bomb, but prolonged in action. And now time has come to create the colossal energy of the sun on our planet, the sun itself on earth instead of the utilization of the miserable crumbs derived in this way!

The utilization of energy from atomic fuel presents before technology and economics completely new possibilities. According to the calculations of some experts, the amount of energy obtainable in the total amount of uranium and thorium, in the earth's crust, exceeds many times, by 10 to 20 times, the stock of the energy of coal and petroleum taken together. As the search of the stock of these elements is more incomplete than our knowledge of the reserves of coal and petroleum, undoubtedly further discoveries of uranium and thorium still remain to be made so that it is possible that this estimate is too small rather than too large. In this way a start already made in the utilization of energy made from nuclear fuel, can lead humanity from an otherwise inevitable futere, viz. deadlock in connection with the limited stock of carbonaceous fuel in the earth's crust.

Development of nuclear power under conditions of peaceful co-existence with various social systems and friendship of peoples, would allow great technical development in all countries, help the less developed, in this way raise abruptly their power and economic condition. It is known that certain steps have already been taken in this direction by the Soviet Government. Our science and atomic industry render disinterested help, on international understanding, in making available atomic techniques to China, Poland, Czechoslovakia, Rumania, East Germany, Hungary and Bulgaria. We wish to express confidence on the peaceful utilization of atomic energy at the international conference at Geneva that is being organized by the UNO in which our Government actively participates in the form of new contributions of technical assistance to less developed countries.

Undoubtedly, one of the general ways of the utilization of nuclear fuel appears to be the production of electrical energy by atomic electrical plant. We are proud that the first industrial atomic electrical plant in the world was the creation of the Academy of Science USSR in the Soviet Union, by Soviet engineers and scientists. It is exactly a year, since it started to give industrial current. Side by side with this way of peaceful utilization of atomic energy, so many other ways are possible. What revolutions it may be possible to accomplish in transport with the colossal energy source of the nuclear fuel! What new processes may become accessible in inorganic chemistry and in the technology of high temperature transformations! What new possibilities will be discovered for the execution of mining work and for penetrating into the deep caverns of the earths' crust!

Certainly, it is the same with the great prospect of the peaceful utilization of thermonuclear transformations. Hydrogen of water is the source of fuel! Besides, it is a fuel millions and billions of times more plentiful than coal. Thermonuclear reactions for creation of wealth and for happiness of all the population of our earth will be a new high stage of power of man over Nature! It is a tempting and inspiring target which is worthy of united peoples' effort to devote amicably to its achievement! It would be our wish than this session would sound an appeal for such united effort.

We are on the eve of an imposing technical revolution. We were already entering the beginnings of the atomic epoch, we are living and working in it. It carries with it revaluation of old technical values. On every step are new events, many of which have not enough of immediate possibilities of use. Atomic industry gives in the hands of science and technology radioactive elements whose radiation could be used in medicine, in sanitation, in preserving and processing food, for defectoscopy, for automatic prospecting and in various other directions.

Labelled radioactive atoms become necessary and powerful tools of research in all those innumerable fields of science and technology which concerns the discovery of substances and investigation of processes, their transformation and movement. In chemistry, physics, metallurgy, mechanics of gaseous, liquid and solid bodies and especially biology with its rich field and manifold directions, beginning from higher physiology of neurology and ending in agronomy, the broad field of application of labelled atoms permits introduction of new methods of work and render possible new discoveries. Although fruitful applications using labelled atoms have been made, it still does not completely portray the start of science and technology of the atomic era. We can imagine almost the region of fantasy, where the labelled atoms may penetrate greatly into everyday life: for vacuum measurement of suction pumps, defectoscopy, core sampling of petroleum technology by neutrons. All this knowledge has already been made public.

Our problem is to promote in every possible manner broader and deeper utilization in science, technology, agriculture, medicine, applying at the same time all the possibilities of nuclear science and industry and we do not doubt that our session will be useful in all these directions. Great many of its participants—specialists in fields remote from the science of nuclear transformation, perhaps meeting with new principles, would find methods for the utilization of labelled radioactive atoms for their own fields. Naturally, for any progress in fields of atomic technology and power, it is not possible to be narrow. Clearly scientific refinement in the domain of nuclear physics embraces the entire fields of science. The presentations at the present session will be of interest to those whose special study is not nuclear science.

It has already been mentioned, that in August at the Geneva Conference which is being organized by the UNO on the peaceful utilization of Atomic Energy with the participation of the Soviet Union, amongst the Soviet delegation there will be members of this Academy and of the Academy of Science of the Union Republics who will present a number of papers, which will be published and become accessible. Naturally in the organization of this session there was the possibility of duplication of papers here and there. With this in view some of the papers, which would have been otherwise worthwhile to be placed at our session would not be placed here but will be read at the UNO Conference at Geneva. So works reported at the present session are being published and represent, together with the Soviet portion of the works reported at the Geneva Conference, the total contribution of Soviet science on the questions of peaceful utilization of atomic energy. It goes without saying that not much of the possibilities nor enough work that has been done on the various applications are covered.

It is our firm belief that though we are going to unprecedented heights, to unparalleled possibilities in the blossoming of science, technology and economics, we are not forgetting the atomic threat.

We are confident that the will of the people, as clearly expressed in views of the many hundreds of million signatures to the Stockholm Appeal, under the Venice Appeal of the World Peace Assembly, in the speeches and addresses at the World Peace Assembly at Helsinki, displaying everyday and everywhere the selfless struggle for peace, will triumph.

We are proud that the Soviet people and their Government are considering in advance of this great and reponsible struggle for peace, for the prohibition of atomic and hydrogen weapons as inhuman agencies of mass destruction. The Soviet scientists join their voice to the hundreds of million voices of the common people of the world, demanding immediate prohibition of atomic and hydrogen bombs and applying nuclear energy for peaceful purposes, for welfare and not for injuring people.

"We are appealing", said A. N. Nesmjanov, in conclusion "to all scientists of the world to friendly joint work at the peaceful utilization of atomic energy so that the advantage which follows from this be accessible to all people, all great and small countries".

The Plenary Session

At the plenary session, the following papers were read:

(1) Soviet work on uranium-graphite reactors—by W. S. Fursov.
(2) Study of nuclear processes due to high energy particles produced in Accelerators—by M. G. Messerjakob, Director, Institute of Nuclear Problems.
(3) Radiochemical investigations of fission products produced by slow neutrons as well as by high energy particles—by A. P. Vinogradov.
(4) Application of radioactive isotopes in the field of biochemistry—by V. A. Engelhardt.

After the plenary session was over on July 1, the Conference divided itself into four sections, *viz*., mathematics and physics, chemistry, biology and technology.

The meeting of the mathematics-physics Section was held at the Physical Institute of the Academy of Science, which is also known as the Lebedev Institute after the late Prof. Lebedev who in 1902 first devised experiments demonstrating the pressure exerted by light. In 1945, the Institute was housed in a private building within the city, but now it has a very large and commodious building in the new university area. The sectional conference was attended, in addition to foreign delegates, by well known older Russian workers like Kapitza, Skobelzyn, Cerenkov, Veksler, Alikhanov and others. After each paper was read, discussions were invited.

After the termination of the discussion on July 5, excursions were arranged to various Atomic Energy Establishments of which the following may be mentioned:

(*a*) The Atomic Energy Station, 110 km south of Moscow, on the Moscow-Tula Road, at a place having no particular name; but this was christened "Atom-grad", by certain guests.

This place has a 30.000 kW reactor of which about 5.000 kW are being converted to electrical energy. The reactor fuel is 5% enriched uranium and the reactor is graphite moderated. The working of the reactor was explained in great detail by Dr. Krassin.

This place was visited on June 22, 1955 by the Prime Minister, Pt. Jawaharlal Nehru of India who has put on the visitors' book an enthusiastic record of his impressions.

There are two large buildings: one housing the reactor and the heat exchange system, the other for electrical distributing machineries. The reactor house is 20 meters under ground and 10 meters above ground.

The guests were told that this was only an experimental station where all aspects of power generation from atomic sources are being studied from the scientific, technological and economic points of view. From experience gained with this reactor, the Soviets are designing other reactors giving power loads of 50.000 and 100.000 kW. They are hopeful that these new reactors will supply electrical energy at competitive rates with thermal stations.

(*b*) The Institute of Nuclear Problems, 160 km from Moscow at the head of the Moscow-Volga canal.

Here the academy has constructed a very large synchro-cyclotron, the pole-piece having a diameter of 6 meters *i.e.*, 236 inches. This is much bigger than the biggest USA machine at Berkeley, the pole-pieces of which has a diameter of 184 inches.

The working of this machine was explained to the guests in great detail by the Director, Dr. Messerjakov who had delivered a lecture in the plenary session on "The study of nuclear process induced by high energy particles produced in accelerators."

The visitors were told that the protons of energy of 680 million electron volts were being generated and used for the study of proton-proton and neutron-proton scattering by different physical methods with a view to obtaining the laws of interaction between these elementary particles. The physical methods included the use of scintillation counters, Wilson chambers, and bubble chambers, the gas used being pentane, and sensitized photographic plates.

Here the visitors met Pontecorvo, an Italy-born British scientist who voluntarily migrated to Soviet Russia in 1950 and caused a sensation in the West, it being alleged that he carried with him a number of extremely important nuclear secrets. He is working here on fundamental problems. He assured the visitors that he had no secrets in his possession and had not communicated anything to the Soviets. He was interested only in fundamental work for which he had found ample scope in Soviet Russia.

(*c*) Electro-thermal Institute (Director—Alikhanov).

This Institute is housed in a large garden palace in the outskirts of Moscow which, we were told, once belonged to Prince Menshikov, adviser to Peter the Great.

This Institute has a heavy water-moderated reactor and a 60″ cyclotron, the reactor being used chiefly for the study of heat-exchanges. Dr. Ecklund, Director of the Swedish Atomic Energy Station remarked that this reactor was very similar in design to the one which he had planned, and was working with at Stockholm, Sweden.

(*d*) Veksler Institute (Director—Skobeltzyn: Co-directors—Veksler, Cerenkov).

The Institute is named after Veksler who in 1945 first worked out the theory of acceleration of charged particles to extremely high energies under the combined action of electrical and magnetic fields. This general theory is the basis of the modern high energy accelerators such as the synchrotron, the synchro-cyclotron or frequency modulated cyclotron, and other similar accelerators. The same work was shortly afterwards independently published by Macmillan in the USA.

The Veksler Institute has a synchrotron machine for accelerating electrons to 250 million electron volts, an energy at which the mass of the electron is 500 times the rest mass of the electron. These high energy electrons when they strike a target produces Röntgen rays of the same maximum energy. These Röntgen photons are many times more energetic than the most energetic γ-rays obtained from nuclear reactions These high energy photons produce various nueclear reactions when they strike nuclei including the production of mesons. Mesons are produced by photons at a thershold energy of 150 MeV and increases rapidly with increasing energy. The photon-produced mesons have been used to study the differences between electromagnetic interaction between mesons and nucleons and the specifically nuclear interaction between the same particles. For example, in the reaction

$$h\nu + P \rightarrow N + \pi^+$$

the photon em field may induce a transition of the nucleon from the proton state to the neutron state creating a meason in the process. However in the reaction

$$h\nu + P \rightarrow N + \pi^0$$

where a neutral meson is produced only a nuclear interaction of the meson field can be thought of. The difference between these two reaction cross-sections gives a valuable insight into the electromagnetic and nuclear interactions taking place in nuclei. The other possibility, that of producing pairs of π mesons by the photons has an expected threshold at about 300 MeV but this has not yet been observed at energies up to 400 MeV.

Cerenkov Radiation

The codirector of the institute, Dr. Cerenkov who explained the working of the electron synchrotron to the guests, discovered in 1934 that very fast electrons moving through a trasparent medium emitted light at a definite angle from the direction of motion of the electrons. The explanation of the effect given by Frank, Tamm and other theoretical physicists of Soviet Russia showed that the radiation was due to the electrons moving with velocities greater than that of light in the transparent medium. However, modern refinements of the theory of Cerenkov effect are being investigated and they suggest some important ideas in the general field of quantum electrodynamics. The Cerenkov effect is being used to design and construct a new type of detectors of fast particles called Cerenkov counters in analogy with the other types of counters such as the GM counter and the scintillation counter. Recently Cerenkov counters have been used to detect the very fast charged particles in cosmic radiation.

(*e*) The Physical Faculty of the University of Moscow:

The Faculty of Physics is responsible for the teaching of physics to students of the age-group 17-23 years. The work is organised in eight sections, of which the visitors had time to visit only the section of Nuclear Physics. The syllabus is almost the same as taught in the Institute of Nuclear Physics, Calcutta. The apparatus include beta-ray spectrographs of both magnetic and lens types, mass spectrographs, scientillation counters, Wilson chambers, apparatus for the measurement of nuclear magnetic moments. Cerenkov radiation counters etc. besides apparatus for a full course in electronics.

The writer of this article visited particularly the Geochemical Institute of the Academy of Science, Moscow.

A large amount of nuclear chemical work is being carried out at the Geochemical Institute of the Academy. The Director of the Institute, Dr. A. V. Vinogradov delivered a lecture on the "Radio chemical investigations of fission products produced by slow neutrons as well as by high energy particles" during the plenary session of the Conference. This lecture reviewed work done during the last five or six years by the Geochemical Institute. The writer was asked to visit his laboratory when the complaint was made that the ground covered was too much.

The laboratory is housed in a large building erected to the memory of Vernadsky who is regarded as one of the founders of Geo-chemistry. Here the writer found work proceeding on almost all branches of nuclear chemistry. They were studying fission products produced by slow as well as fast neutrons and have observed the gradual change of characteristics of fission as faster neutrons are used. A great deal of the present work in nuclear chemistry is a detailed study of the phenomena of spallation reactions. A large number of neutrons and protons are emitted by nuclei bombarded by very high energy neutrons and protons, producing many isotopes, many of which are new. These isotopes, both stable and unstable, are studied both chemically and mass-spectroscopically to find out in detail about the nature of the spallation reactions.

Another branch of study at the Geochemical Institute is the geological age of rocks and related problems. Apart from the conventional lead/helium, lead/uranium, lead/thorium, lead/lead isotope ratio determinations, the Russian group also work on the potassium 40/argon 40 and rubidium 87/strontium 87 ratio methods in minerals bearing potassium and rubidium. This group is also studying the geochemistry of the earth's crust and have shown that chemical exchanges taking place on the earth's surface produce significant changes in the isotopic constitution of the lighter elements. Such exchanges in carbon, nitrogen and oxygen have shown measurable changes in their isotopic ratios. A recent work in this field is fractional changes in isotopic ratio of sulphur 32/sulphur 34 in marine sulphates and sulphides as a result of the biological sulphur cycle during the past 1000 million years. These methods are being investigated to find out the possibility of their use in determining geological ages.

Carbon 14 which has been used to determine archeological ages in the West is also a well developed technique at the Geochemical Institute. At least three dozen mass spectrographs were found in use in this laboratory suggesting the extent of the effort to develop these methods at the Geochemical Institute.

It was a pity that no Russian or English copy of the papers read were available in course of the Conference. The visitors were, therefore at some disadvantage. A glance at the contents of the papers, however, reveals the fact that the Soviet achievement on Atomic Science and Technology has been on a par with that of the United States of America and far outdistances that of other countries. Soviet Russia has apparently produced U-235, Pu-239 and U-233 in bulk, and has also produced sizeable quantities of transuranic elements up to element number 100. These have enabled the scientists to determine the chemical, nuclear, and physical properties of these elements in detail. All the apparatus and instruments used have been made in the Soviet Union.

It appears also from the papers that the Soviet atomic scientists have carried out a large number of experiments on the design of various types of reactors and are placing the results of their studies for the first time before the world.

Nuclear science and technology is being applied for the study of important problems of biology and chemistry like photosynthesis and carbohydrate exchange, study of diseases, on the fructification of plants etc. Nuclear science is also being applied to technical problems, e.g., problems of iron & steel metallurgy, boring of wells for petroleum etc.

The Canard of Atomic Spies

Sensational stories have been published in the West of "Atomic Spies" selling 'secrets' to the Soviets.

The West ought to realize that this is a gross slander on a great nation which has in the living generation top-rank scientists like Kapitza, Cerenkov, Nesmjanov, Alikhanov, Kolmogorov, Vinogradov and Skobelzyn not to mention the younger workers like Messerjakov, Fursov and others who are less known in the West. It is time that the West gives up publicizing the sensational stories of betrayal by atomic spies. For it was apparent to every sensible scientist since the publication of the Smythe Report that provided a State has sufficient industrial and scientific power, it was possible for it to duplicate USA's achievement on Atomic Energy. The Moscow Conference has revealed that for the first time Soviet Russia has achieved the seemingly impossible task in an incredibly short time relying on her own scientists and her industrial power.

1.3.19 END OF AN UNSCIENTIFIC ERA*

We hope that the Moscow Conference on Atomic Energy whose proceedings we reported last month (August, 1955), and the Geneva Conference, whose proceedings we partly report this month will mark the end of a period which has been extremely disliked by all genuine lovers of science viz., the era of suspicion and secrecy which started with the passing of the MacMahon Act by the US Senate in 1946. This was followed by similar actions on the part of other countries, USSR and England, with the result that the free flow of scientific information on one of the most exciting and pregnant discoveries in science was completely stopped. Further, a cold war was unleashed, which had surcharged the political atmosphere of the past ten years with the basest human passions, spy-scare, irksome police measures and restrictions on the liberty of individuals. It has been the heyday of third rate politicians who thrive on the fomentation of the meaner passions of mankind.

As far as "Science" is concerned, it had tended to revert to the "Magic" of ancient and medieval times, when results obtained after protracted enquiries were not allowed to be communicated but were hoarded in the minds of individuals or groups to be used against enemies, potential or existing. The era of rationalism which drew the human mind out of "Magic" to "Science", and has been responsible for the great material progress of the Western World in the last and the present century, appeared to be disappearing.

To come to more definite points; Science has flourished on the freedom which the human mind has enjoyed since the seventeenth century; freedom of enquiry, freedom of information, and freedom for intercommunication of results of enquiry. This has led to a cross-fertilization of the human mind, which has been responsible for the greatest progress in science and technology.

To take one example: let us take the discovery of Atomic Energy itself and the chain of events which led to this great discovery. Contrary to the opinion held in some countries, it can be claimed by no single person or single country, but is due to the co-operative effort of scientists of many countries. Let us take the chain of the most important events. In 1905, Einstein, a born German but then a Swiss citizen, discovered from theoretical reasoning that mass and

* Sci & Cult **21**, 117, 1955 (unsigned).

energy were equivalent i.e., a huge amount of energy is locked up in ordinary matter. We get 8 kiloWatt-hours of energy, when we burn one gram of coal, but we ought really to get $2 \cdot 2 \times 10^7$ kiloWatt-hours or nearly 3 million times more energy out of a gram of coal, if we could discover a method of converting mass into energy. In 1919, Lord Rutherford, a born New Zealander, but settled in England, who had discovered the nucleus of the atom in 1913, performed the first experiments on reaction of one nucleus with another, and verified the Einstein law of equivalence of mass and energy. In 1931, Bothe in Germany put some radium, discovered by Madame and Prof. Curie in France in 1897, on a beryllium foil and found that the combination was giving very penetrating rays. Next year the Curies in France (Joliot-Curie and Irene-Curie) performed some experiments to determine the nature of the Radium-Beryllium rays, discovered by Bothe and found that they were far more penetrating than γ-rays then known to physicists. They left the experiments at this stage, when it was taken up by Chadwick in 1932 in England who proved that the rays consisted of a stream of "Nuclear Particles" called "Neutrons" having no charge, but a mass nearly equivalent to that of the proton. Immediately afterwards Heisenberg in Germany showed that all nuclei of atoms consisted of protons and neutrons.

In 1934, the "neutrons" have been established as a powerful tool of research, and Fermi and a group of young Italian physicists who were lucky to procure a sizeable source of neutrons in the Radium-Beryllium combination, tried another daring set of experiments viz., whether by smuggling neutrons into nuclei of the heaviest element uranium which can be done without effort, they could produce transuranic elements i.e., elements heavier than uranium and coming after it in the periodic classification (a law telling us about properties of known and unknown elements which was given by Mendeleev in Russia and Lother Meyer in Germany half a century earlier). They got very puzzling results which they were unable to explain. The issue at this point was taken up by Joliot-Curie and Savitch (a Yugoslavian) who showed that the uranium mass irradiated by neutrons contained an element having properties similar to actinium, element No. 89, but they were unable to explain how it could be formed out of neutron-irradiation of uranium atoms. At this stage, the threads were taken up by Hahn and Strassman in Germany who showed in 1939 that on irradiation with neutrons, the uranium nucleus is split up into two nuclei of lower mass and atomic number, say Barium (56) and Xenon (36), and the two splinters separate with great energy, which can be calculated from the Einstein law. They discovered the phenomenon of fission and showed that, mass for mass, the energy released in the fission process was 2·5 million times larger than the energy obtained in the process of combustion. And lastly, Bohr in Denmark pointed out that it is the rare isotope U^{235} contained in the proportion of 1: 140 in ordinary uranium which undergoes fission, the more plentiful isotope remaining unaffected.

This is the "story" of the great discovery of "Fission of Nuclei" which has opened to mankind a great source of energy, which promises to solve the problem of "Energy-famine" in the rapidly industrializing world for the next thousand years. This opens the first practical way of conversion of mass to energy. Even the great Lord Rutherford, the prince amongst experimenters who died in 1937, could not foresee a reasonable period within which the energy locked up in the mass of the nucleus could be converted to useful energy for mankind. But the discovery came just two years later, and six years after in 1945, the atom bomb was dropped.

Our short review of the chain of events leading to this great discovery shows that it would have been impossible but for the freedom of publication, and freedom of inter-communication which existed amongst the scientists of the world before World War II. Let us see what would have happened if the British Government, after the discovery of the neutron in 1934, had put a ban on the publication of the information and restricted the movements of the discoverer, Dr. Chadwick and others who were in the know. Or suppose Mussolini's Government put a similar ban on the publication of results obtained by Fermi in 1935. The discovery of "Fission" would probably have taken another hundred years, and it might not have come at all !

In the chain of events which led to the discovery of fission neither the USA nor the USSR had taken very outstanding parts. However, the guidance given by the periodic classification, the work of a Russian, contributed a great deal to the discovery of fission and may well have been impossible without the knowledge of the periodic table. The USA also contributed by the invention of machines like the cyclotron, the betatron and the Van de Graff generator, producing high energy particles, which are extremely useful in provoking nuclear reaction.

The pattern of international intellectual co-operation without which the discovery of the fission process would not have been possible for a long time, completely changed after 1945. During the war, owing to the Nazi menace, the USA had utilized the discovery to forge the atom bomb. The launching of this great attempt was mainly due to the initiative of the foreign refugee scientists, Fermi, Szilard and Wigner who persuaded the late Prof. Einstein to write to the American President to mobilize the resources of the State towards this great effort. But for the USA's great industrial power and pooling together of her great scientific and technical man-power in a great effort, the atom bomb might have come a century later, just as the mass use of electricity for domestic and industrial purposes came half a century later (in 1881) than the discovery of electromagnetic induction by Faraday (1831).

The spirit of cooperation which existed amongst the Allies during the World-War II, entirely stopped after the war, and the MacMahon Act was passed in 1946 to prevent the flow of scientific information about atomic energy work done under government patronage in the USA and Canada, even to countries which had been late comrades in arms. The Act also forbade the export of essential materials like uranium, and scientific apparatus. But undaunted the United Kingdom and Soviet Russia made great efforts and were able to set up reactors. Soviet Russia was able to produce their first atomic explosion within 3½ years of the passing of the MacMahon Act, and the hydrogen bomb actually eight months before the USA. This must have been extremely disconcerting to the war-mongers in the USA, for experts like General Grove and Dr. Vannevar Bush had predicted that if the Soviets were not aided, they would take 15 to 20 years to produce the first atomic explosion. The undeniable fact that the Soviet could do it in course of 3½ years from start established the following three points:

(1) That the Soviets have got a number of scientists and technicians who could plan and execute an atomic energy programme comparable to that of the USA.

(2) That the Soviets have developed an Industrial Power comparable to that of USA.

By industrial power is meant the capacity to design and put into production diverse chemical and heavy machineries plant; the capacity to produce electrical and other forms of power. The hugeness of the effort needed will be apparent from the following figures.

The USA produced altogether 400 billion units of electricity in

1950. Of this fully $\frac{1}{10}$ i.e., 40 billion units were diverted for atomic energy work—for chemical plants for extraction of uranium and other elements; for running gaseous diffusion plants, for extraction of $U,^{235}$ the key material in the release of atomic energy etc. etc..... The energy is almost equal to the whole amount of electrical energy consumed by the UK.

It is not known how many billions of units of electrical and other forms of energy were used by Soviet Russia. Their total production of electrical energy in 1953 was nearly 160 billion units. Of this, probably quite a good part was diverted to atomic energy work. The severe cuts in the consumption of electrical energy by the civilian population in the period 1950-54, in the main industrial districts of Moscow, the Urals, and Uzbekisthan, point out to the diversion of very large amounts of electrical energy to atomic work.

We can compare these figures with those in an under-developed country;—the total production of electrical energy by India was 5 billion units in 1949; it had risen to 7 billions in 1954.

(3) The efficiency of the administrative machinery of the Soviet enabled them to divert their industrial power towards the attainment of the objective, and realize it within the incredibly short period of 5 years; and bring the Soviet Russia's atomic might on a parity with the United States.

This story can be written only when more data about the Soviets' effort are available.

The upshot of all this work has been the realization by the top politicians of all countries that the atomic war will not be an one sided affair. It will mean the destruction of both parties—as in the fight between a tiger and a bear. This has killed the 'Cold War' by war-mongers.

Events leading to the Geneva Conference

Let us briefly recall the various events that led finally to the Conference on Peaceful Utilization of Atomic Energy under UN auspices at Geneva. The most important factor, although purely psychological, that affected the thinking of statesmen and scientists all over the world was the success of Soviet Russia and the United States in developing the thermonuclear or hydrogen bomb in 1952 and 1953. Both Soviet Russia and the USA were able to explode hydrogen bombs built on the principle of fusion of light nuclei out of some of the fairly abundant elements on the earth and fission of normally unfissionable but abundant uranium (238), in 1952 and 1953. These bombs, each equivalent to several million tons of TNT in explosive power, would become in the years to come comparatively inexpensive to build and one such bomb would be enough to destroy New York or Moscow. These facts led to the sober realization that not only the USA and USSR but any major nation of the world would soon have the power and strength to destroy civilization entirely. The saturation of military destructiveness had so exceeded all expectations that war as a means of achieving political objectives became meaningless. Successful breeding of fissile material from thorium (232) and uranium (238) and fusion of the light elements could in principle provide such large amounts of energy that the depletion of mineral fuels such as coal or oil or their abundance in certain regions of the earth and their comparative dearth in others would cease to have any important economic significance as atomic energy of fission and fusion become gradually cheaper.

It was in this context that Eisenhower gave an address to General Assembly of United Nations in December, 1953. He said, in effect, that we were already living in an atomic age. The benefits and the wealth that could be available from this new source are so extensive that all can share the advantages of atomic energy without appreciable diminution in any country's share. A future atomic war would be so devastating to both sides that it is unthinkable, and he called on the UN to create an international agency to extend the benefits of the atomic technology to everybody. Eisenhower further pledged the support of his country to any action that the UN may take to extend the peaceful advantages of atomic energy throughout the world in the hope that increasing prosperity for all nations would remove the causes of war.

The United Nations responded to President Eisenhower's "Atoms for Peace Plan" and appointed a Seven-Nations Committee in 1954, consisting of USA, Canada, UK, France, Brazil, USSR and India to draw up a plan for a conference on peaceful utilization of atomic energy of all nations of the world and arrange simultaneous release of information so long withheld on advances of nuclear science and technology not directly related to war. The announcement of the UN sponsored conference initiated a lot of activity in the USA, UK and USSR to gather support and extend their own programmes of peacetime uses of atomic energy. The USA concluded a series of bilateral agreements with seven countries for sale of atomic materials and exchange of information. India is one of the countries and was able to purchase 10 tons of heavy water from USA under this agreement to set up her first nuclear reactor in Trombay.

In January 1955, the delegates from the seven countries met in New York to prepare a programme for the UN convened conference on peacetime utilization of atomic energy. At about this time Bertrand Russell made a suggestion that India, the only one of the seven sponsoring nations, was truly friendly with both sides and pointed out India's suitability for the Chairmanship of the forthcoming conference. The meeting of seven delegates accepted the suggestion and it was decided that the Indian representative should be the Chairman of the forthcoming conference. The venue was decided to be Geneva in neutral Switzerland and the date was fixed as August 8, 1955.

The USSR called for an Atomic Energy Conference at Moscow in the beginning of June of this year in which she for the first time made public some of her achievements in the peacetime utilization of atomic energy. The record was an impressive one. Soviet Russia declared at this conference that she too was willing to help the governments which would approach her for help in developing atomic energy in their respective countries. Thus was born the high purpose and the goodwill of all the nations of the world that initiated the Geneva Conference.

We are proud that India is recognized for her idea of peaceful co-existence and her position as a neutral and friendly country to all nations, the recognition of which has given India the role of honour of being the Chairman of the Geneva Conference. However, out of the 470 papers discussed at the Conference, only seven are from India. Even Sweden, Holland and Norway have contributed more, scientifically speaking, to the conference. This should lead us to soberly reflect on the fact that the recognition and honour at Geneva are not matched by our achievements at home or our contribution to the Geneva Conference. The conference has been like bursting of a dam. The scientific world is being flooded by a flow of papers kept secret for the last ten years or more.

The Era of Atomic Imperialasm

The political accent is already shifting with the free flow of information about technical progress. Now that the threat of war is receding the countries that have achieved great progress wish to obtain direct and indirect political and commercial benefits using atomic developments as a lever as well as for utilization of their large stock of fissile materials.

We are on the threshold of a new era of atomic imperialism somewhat similar to the commercial imperialism of the West in the nineteenth century. A situation has now come about where the great nations of the world, the USA, USSR and UK, have now the monopoly of atomic fuels, atomic machinery and technical knowledge, which they have so far kept as jealously guarded secrets. Now the secrets no longer exist. Moreover these countries have spent a large amount of money and developed an atomic technology which has a great economic future. It is only natural that atomic fuels, atomic machineries and technical knowledge are now for sale to the under-developed or have-not countries something like the commercial imperialism of the European countries during the last hundred years. Today we have the beginnings of a new kind of commercial imperialism which we may call atomic imperialism. This theratened even France and to overcome this dependence the French decided to achieve what they called 'atomic autonomy'. The Frernch decided to make a mighty effort, scientific, technical and industrial, to obtain all the key materials within French territory and develop their manufacture for atomic energy work within France. Recently the French have claimed to have achieved complete atomic autonomy. Our objective in India should be like the French atomic autonomy. Without atomic autonomy many of the benefits of atomic energy will only be illusory and can be quite dangerous because of the complete dependence for technology and materials on one or the other of the great powers which can thus have an economic stranglehold on the country.

If achievement of an atomic autonomy for India is a much desired goal, then the method by which we may achieve it deserves close examination. The basic nuclear science and technology must be fostered to a far greater extent than heretofore, so that there is in the country widespread knowledge of fundamental interest and study in this field. The necessary industrial and technological power has to be developed in the country so that sufficient industrial resource, both technical and economic, required for the growth of nuclear technology and engineering can be set apart for this purpose. We have quoted earlier that the USA uses 40 billion units of electrical energy for atomic energy work out of the 400 billion units generated in contrast to India's 7 billion units of electricity generated in 1954. We have not in fact the margin of industrial power which we can devote to atomic energy development in our country. An indication of our weakness in this direction is the inability to develop our raw materials of atomic energy such as beryllium, uranium, graphite and heavy water as yet because we do not have the extra power or industrial capacity to devote to it. In this industrial and technological sense we do not yet seem to be ready for atomic energy. We can only be dependant on whatever is obtainable from the USA, USSR and UK in the new climate of competitive atomic imprerialism. The task now before us is to strengthen our country economically, industrially and scientifically. This is fundamental as it gives us the foundation of atomic autonomy later on. It also gives us a breathing spell as with receding threat of war the prices for selling of atomic materials and equipments by the great powers become cheaper. The price of nuclear reactors has already in the last five years progressively diminished in the USA so that universities and colleges are planning to instal research reactors and some have already done so. The US Government is encouraging the building of research reactors in universities and colleges as a sort of premium on the future. This tendency is further accelerated by technical advances in reactor construction and in the production of raw materials. The generation of energy from reactors is a field where technical advances are being made almost every day and it is certain that the prices will soon become reasonable. However, if we are not scientifically or technically ready for it the promised age of atomic benefits will be very hollow to us. The energy of fission has been used in reactors for generation of electric power or propulsion but the still more powerful and therefore cheaper energy of fusion which is released in a hydrogen bomb has not yet been controlled or used. Many scientists in the USA and Russia have predicted the eventual control of fusion energy. However, we still do not possess the key that would make control of fusion energy easy and practicable like the delayed neutrons in fission. When the key is still to be discovered it is hazardous to guess. Earlier this year Mr. Strauss, the Chairman of USAEC, made the conservative guess of fifty years as the time required for achievement of controlled release of fusion energy. Dr. Bhabha in his presidential address at the Geneva Conference has ventured to predict the useful release of fusion energy in 25 years. It is a bright and optimistic picture.

However, in the hurry to introduce atomic developments in the country we may be spending say, 10 to 20 crores of rupees on a reactor to produce electric power which may result in prolonged atomic dependence on the country of purchase, but we may be wasting our money as well, as the same reactor may cost a-fifth as much five years from now. It seems more useful to initially strengthen and develop the foundation from which the atomic energy industry can grow.

What concerns us deeply is: when can we hope to have our own atomic energy industry in India like the more fortunate nations and obtain the benefits that this new technology promises for us all ?

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