

ATOMIC ENERGY IN INDIA AND ABROAD.



[Reprinted from SCIENCE AND CULTURE
Vol. 20, pp. 205—227, November, 1954.]

ATOMIC ENERGY IN INDIA and ABROAD

(*With Compliments of the Editors, SCIENCE AND CULTURE*)

ERRATA

In page 3, column 1, line 35, please *read* page 16 for (p. 220).

“ ” 4, “ ” 2, “ ” 2, “ ” “ ” “ ” “ ” .

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 U.S.A. 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 U.S.A. and Britain will be faced with acute 'Energy

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 in spite 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 U.S.A. has been easily the first, due to the lead she 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 hydroelectric 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 pub-

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 with which the Chinese are tackling the problem of industrialisation. 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 industrialisation, 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.
- (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.

***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-Premiers, 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 Teh-huai, Teng Hsiao-ping, Teng Tzu-hui, Ho Lung, Chen Yi, Ulanfu, Li Fu-chun and Li Hsiennien.

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 Hsin-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-ju, 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 Hsinshua News, Sept., 29.)

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 following article by Prof. M. N. Saha (p. 220).

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 Broekhaven, 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 labora-

tory 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 U.S.A. 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 U.S.A. may get reactors before India has one but they have to depend on the central service organised by the American A.E.C., 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 U.S.A. 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) radio-activity 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. 220).

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

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 U.S.A. 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, U.S.A. has 160 millions. India produces barely one million tons of iron and steel, while U.S.A. produces over 100 million tons. The per capita consumption of iron and steel in U.S.A. is over 1200 lb., all of which is produced in the U.S.A. The per capita consumption in India is 12 lbs. of which only 7 lbs. are produced in India, the rest comes from abroad. As iron and steel are essential key materials, their poor supply embarrasses 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

* 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.

viz., basic chemicals, aluminium, coal-tar industries, machineries etc.

TABLE I

PER CAPITA NATIONAL INCOME (1949) OF SOME COUNTRIES

| Name of Country | Per capita annual income in dollars | % to U.S.A. level |
|-----------------|-------------------------------------|-------------------|
| U.S.A. | 1453 | 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

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 U.S.A. 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, because Putnam does not take into account energy produced by human and animal labour, which is negligible for U.S.A., 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

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 | 122 | 24 | 29 | 1.1 |
| 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 |

is that power-production which is the key to all industrial production

can raise their production to the level of

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 turbines 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 U.S.A. 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 4000 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 U.S.A.'s 3000 billions and China's 1500 billions, within the first 1000 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 U.S.A.'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,

produce power⁴ 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%.

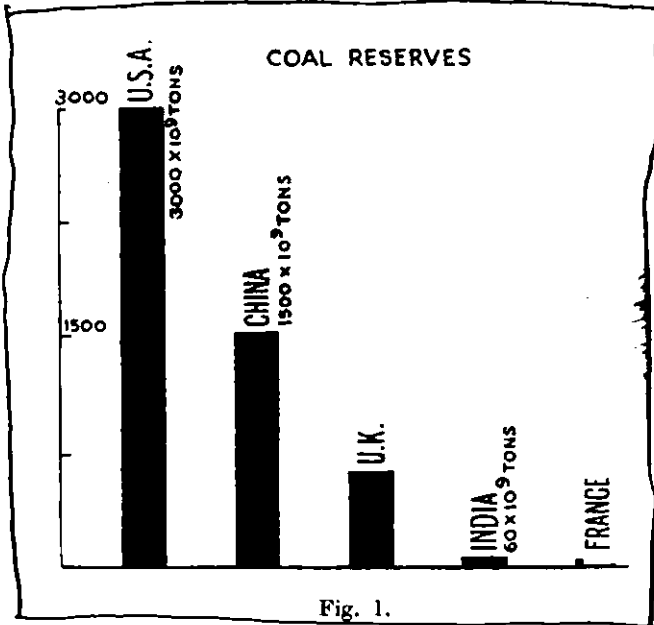


Fig. 1.

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 industrialisation.

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.

'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 :



(Here the amount of Carbon taken is 12 gms. 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

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

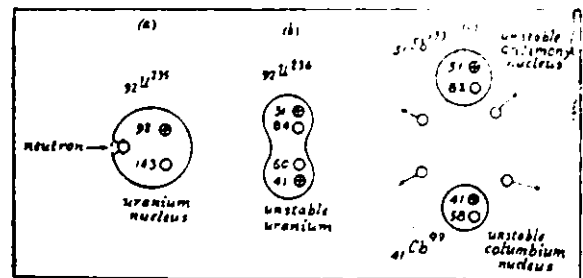
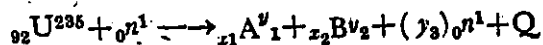


Fig. 2.

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)

The reaction may be written as :



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,

$$\begin{aligned} x_1 + x_2 &= 92 \\ y_1 + y_2 + \gamma_3 &= 236 \end{aligned}$$

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, the number of neutrons γ_3 are evaporated 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 $\frac{1}{8}$ 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 $\frac{1}{4}$ 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 1000 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 neutrons are produced and further fission takes place as illustrated in fig. 3. A chain-reaction is produced.

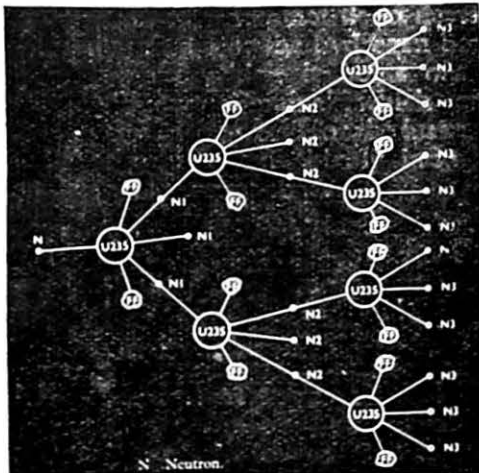


Fig. 3.

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.

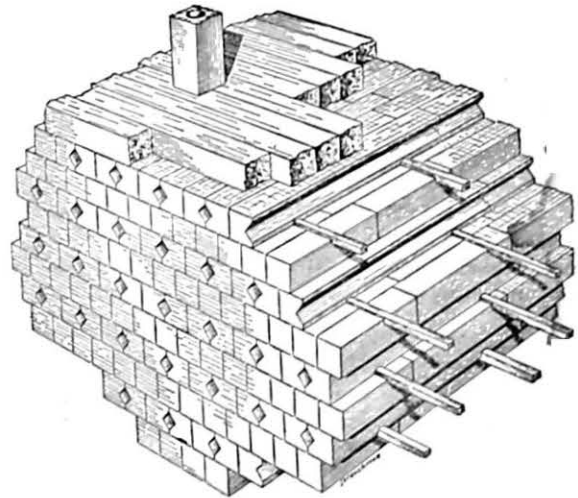


Fig. 4.

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.

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 $^1\text{H}^2$ (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 $(\text{H}^2)_2\text{O}$. Beryllium has not been used for it is difficult to work with and is poisonous.

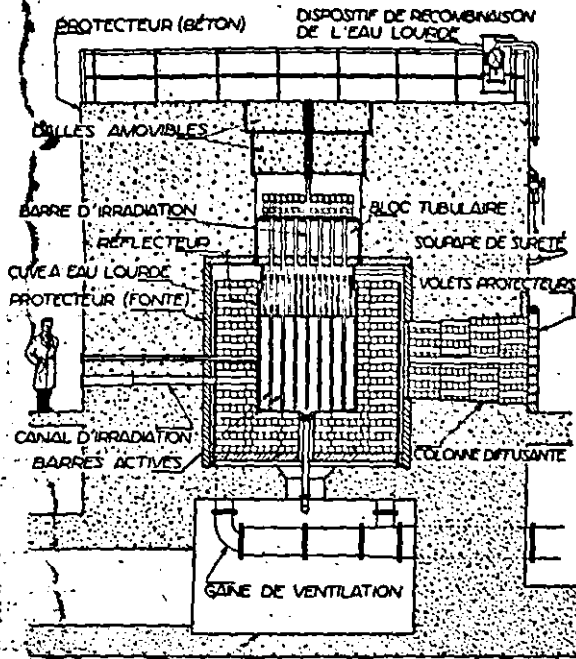


Fig. 5. Heavy Water Reactor at Saclay.

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

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 quadrillions (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 Brobkhaven reactor dissipates 40,000 kw. of power, nearly as much power as is handled by the Delhi Electric Supply. The great Hanford 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.

[FIG. 1]



Fig. 6,

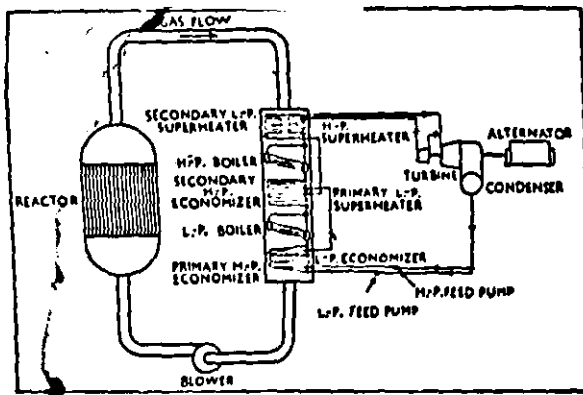
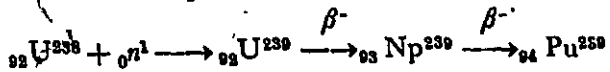


Fig. 7.

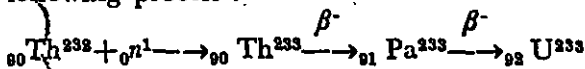
NECESSITY OF BREEDING

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



would be one which produces as much or more Pu-239 as the U-235 it consumes. Such reactors are called "Breeders". The great Hanford-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. 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 :



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 Energy Research Establishment at Harwell in a speech before the French Chamber of Deputies in August 1954, disclosed that Britain has worked out a 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 underwater 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 $\frac{2}{3}$ pence. Then only nuclear energy may be competitive with energy from thermal or hydro-electric sources. Last year, the Atomic Energy Commission of the U.S.A. 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 extre-

*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,

mely 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 ~~read~~ the revision of the U.S.A. Atomic Energy Act, which authorises its A.E.C. 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 U.S.A.—A.E.C.

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 U.S.A., U.S.S.R., 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 U.S.A. is allowed to help her private industries and friendly nations in the development of atomic power, many other nations closely allied to the U.S.A. will get the advantage of U.S.A.'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 U.S.A. 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 U.S.A. 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.

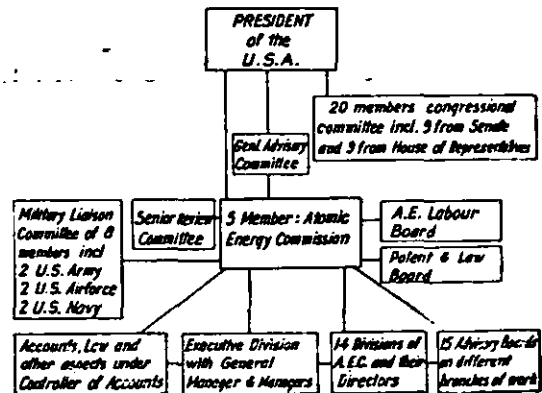


Fig. 8.

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.

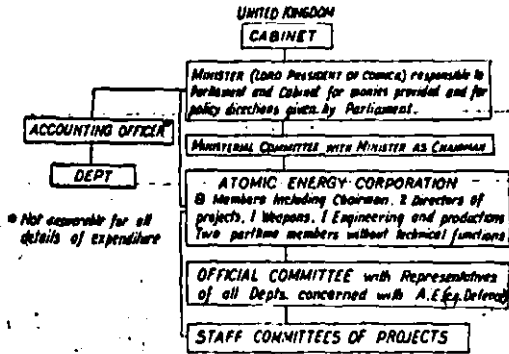


Fig.-9.

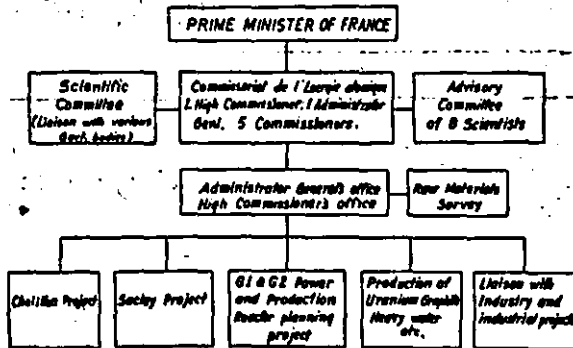


Fig. 10.

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 funda-

mental 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 U.S.A. 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 A.E.C., 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 France achieved? Only last year, the French 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 Develop-

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

ment programme dependent entirely 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 irrespective of foreign supply.

Those claims were proudly made by Dr. Dupuy, Director of C.N.R.S. (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 U.S.A., 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 entrusted to big business. The U.S.A. 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 A.E. development? The following figures are for the U.S.A.

| 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 U.S.A. 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 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 A.E. Organisation and sanction the budget. There may be a parliamentary committee to stimulate interest amongst the public and review the policy, and finally sanction 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.

one of the foremost of theoretical physicists; W. Bothe, whose work led to the discovery of the Neutron by Chadwick in 1932; G. Hertz,

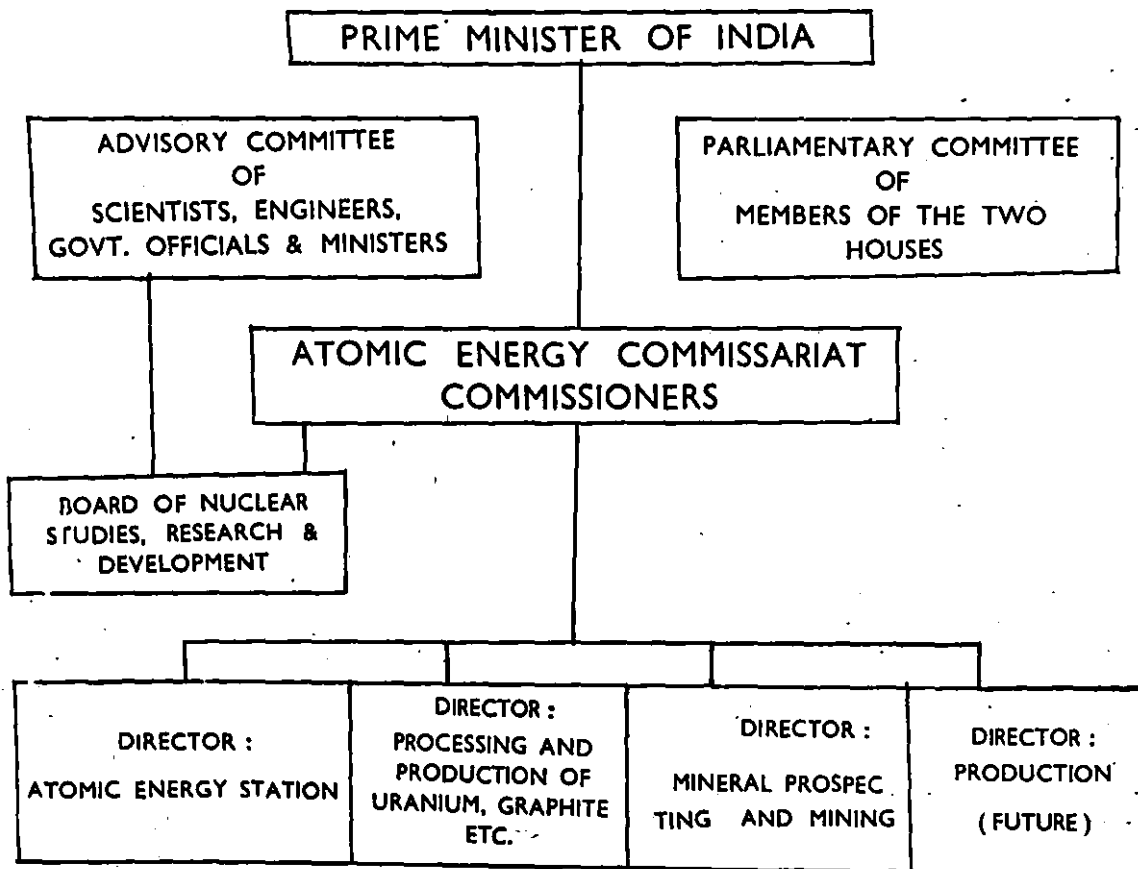


Fig. 11.

There should be in addition a Board of Nuclear Studies and Research to interest universities and laboratories in the work connected with nuclear energy development and fundamental research in nuclear sciences, and engineering and personnel training.

Before I conclude I should like to 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,

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 U.S.A. and U.K.; 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 Czechoslovakia; lower grade ores in Eastern Germany, and plentiful Graphite in Bavaria. Germans had access to the Norwegian heavy water plants.

In fact, there were all conditions prerequisite for the success of such an undertaking; in fact, U.S.A. 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 Dutchman by birth, had migrated to U.S.A. 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 Party politics. The really 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 had never 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-Marshall 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 scientists 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 government 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.

"In spite 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 thought 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 realized 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 dispatch Otto Hahn is quoted as stating : "We knew that (plutonium) must exist, but we did not succeed 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 uranium isotopes or by building a uranium pile." This is a typically careful statement, 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."

THE PROGRAMME FOR THE DEVELOPMENT OF NUCLEAR ENERGY IN GREAT BRITAIN*

JOHN COCKCROFT

THE Department of Nuclear Energy of Great Britain has been engaged for several years in developing nuclear energy for the purpose of creating a new source of energy in addition to the motive power already produced by means of coal. We are doing it because we feel that our energy requirements are likely to increase much during the next twenty years and that consequently there will be a shortage of at least 20 million tons of coal per year. We do not propose to replace coal as a source of energy, but rather to increase it by means of energy obtained through the fission of uranium.

This purpose is served by using an atomic pile as a new source of heat which can be used for raising steam and for operating the steam turbines and the electric generators. The atomic pile is already well known to you. There are two principal types of piles which can be used to produce motive power in the near future. The first type, proposed in France by Joliot and his associates in 1940, consists of bars of uranium metal suspended in a reservoir of heavy water. In the second type, uranium metal bars are enclosed within pure graphite. Both the piles produce heat as well as radioactive products in the uranium metal as a result of uranium fission; this heat can serve to produce steam.

In the county of Cumberland in the U.K. two large units of nuclear energy are under construction, which we hope to see in operation at the end of about two years. These piles consist of a graphite core, interspersed with bars of uranium metal and enclosed within a cylindrical boiler, six metres in diameter. The heat from the hot uranium bars is to be transmitted to four generators by carrying carbon dioxide gas under pressure from the core to the generators. The steam then passes to an ordinary turbo-generator. The efficiency of conversion of heat into electricity will be limited by the temperature of uranium fuel, which in these early piles, will be 400°C. This will give a conversion efficiency of about 25 per

cent. This is almost equal to the average efficiency of all the power stations of the Department of Electricity in the U.K., but it is low compared to the efficiency of 30 per cent which has been achieved in the most modern power stations.

At present, the efficiency of this type of nuclear energy reactor is limited by the temperature at which fuel materials can be used. Development in metallurgy, it is believed, will bring about an improvement in the situation.

You might ask how the price of this electric energy (from nuclear reactor) compares with that produced in factories using coal. I shall immediately say that these first units of electricity from nuclear energy will be economic for the single reason that plutonium is produced as a secondary product. This secondary product is of considerable value not only for its military use, but also for its use as a primary fuel in the power units of the future. Through these two uses, we shall obtain precious information about its operation which, we hope, will directly lead to the construction of a better unit designed entirely for the production of motive power.

The cost of electric power from nuclear reactors will depend on three principal factors:

- 1) the primary cost of the reactor,
- 2) the price of uranium metal-bars,
- 3) the efficiency of use of the uranium fuel.

Our preliminary studies with the new and improved type of graphite reactor suggest that the primary capital cost will be perhaps twice as great as the cost of an ordinary power station of the Department of Electricity. This results in the primary constituent within the cost, being equal to 70% of the present average cost of generation.

The price of uranium metal bars, suitably encased as fuel, is well known. It depends on the price of uranium minerals, the cost of purification and extraction of the metal and finally on its fabrication cost. Our experiences have shown that large scale operation helps us much to reduce the cost of conversion of the mineral into the combustible metal bars.

The greatest uncertainty in cost now arises from the considerable uncertainty of efficiency in the utilization of uranium fuel. These

*Lecture delivered before the Scientific Committee of the French Chamber of Deputies on July 1, 1954. Translated from French into English by Sri S. N. Sen.

nuclear reactors burn as primary fuel the lighter uranium— U^{235} , which constitutes only about 0.7 per cent of the total. But thanks to the alchemical properties of the pile, a new fuel, the plutonium, is produced from the heavy uranium, almost as rapidly as the primary fuel burns itself. Thus as the primary fuel

burns, it is replaced by more plutonium produced from the heavy and inert uranium. Small variations in the rate of conversion have a great influence on the total utilization of uranium. In the absence of more experience, we can only know, with an uncertainty factor varying from three to ten, how much uranium

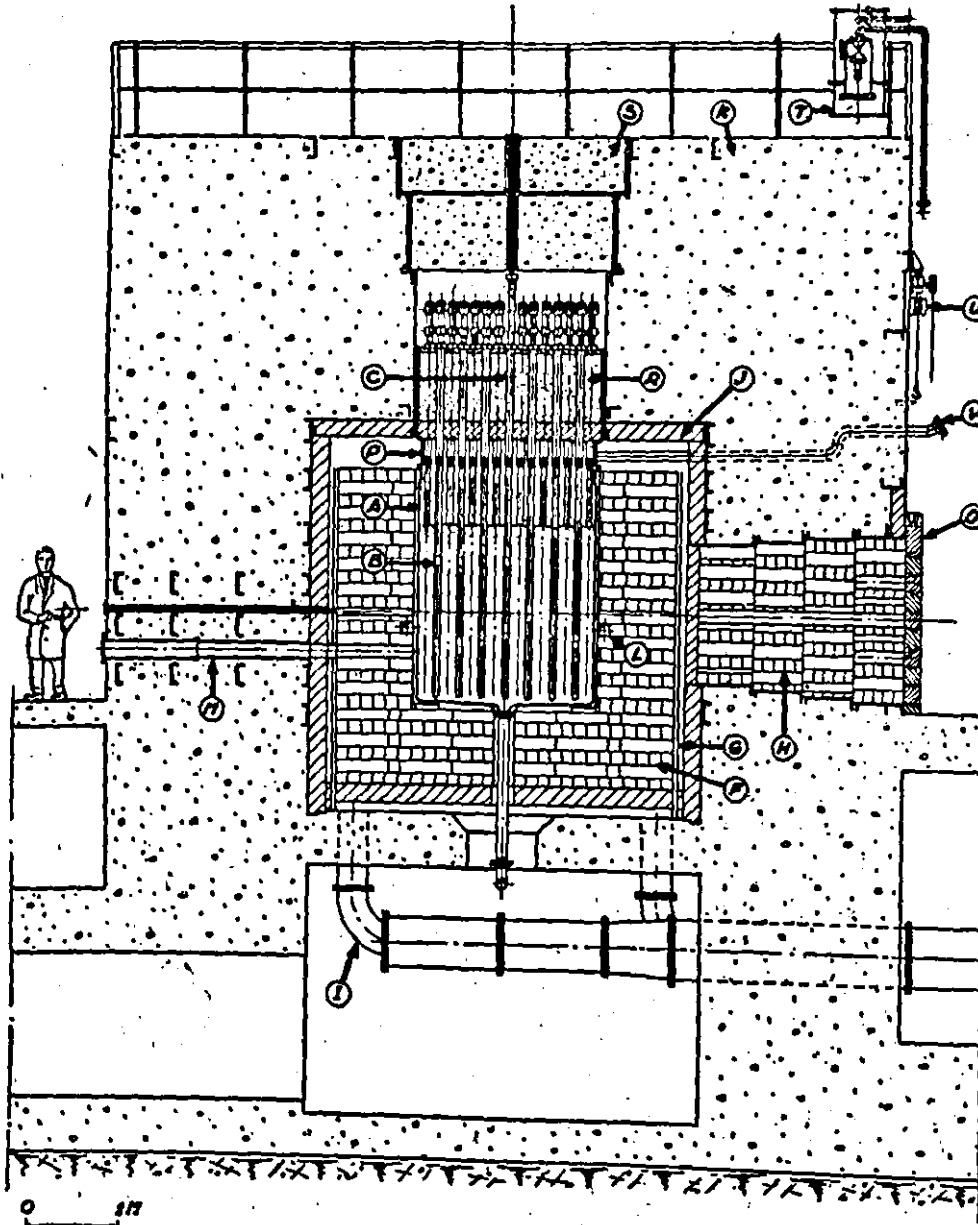


Fig. 1. Vertical Section of the Reactor at Saclay in France.

A. Heavy Water container; B. Assembly of uranium bars and the cooling tubes; C. Central tube; F. Reflector; G. Intermediate aluminium covering; H. Diffusion column in graphite (source of very slow neutrons); I. Ventilation covering in cast iron; K. Concrete shielding; L. & M. Tangential and radial canals for irradiation (as seen from the front); O. Protecting shutters of the diffusing column; P. Band; R. Tabular block for suspending uranium bars; S. Removable slabs; T. Apparatus for recombination of heavy water; U. Hoisting gear; V. Safety valve.

is required for producing a given quantity of energy. At present our pessimistic calculations indicate that the cost of nuclear energy will be about 30% higher than that of energy produced by coal. We could produce energy at a price of about four francs per unit of electricity* and if our efficiency of utilization improves, we might approach more closely the price of electricity produced by coal.

PRESSURIZED WATER REACTOR

We shall consider also other types of nuclear reactors which promise reduction of the primary cost of the investment of uranium and expenditure on fuel. Let us, for example, study the design of a reactor which employs ordinary water in place of graphite for con-

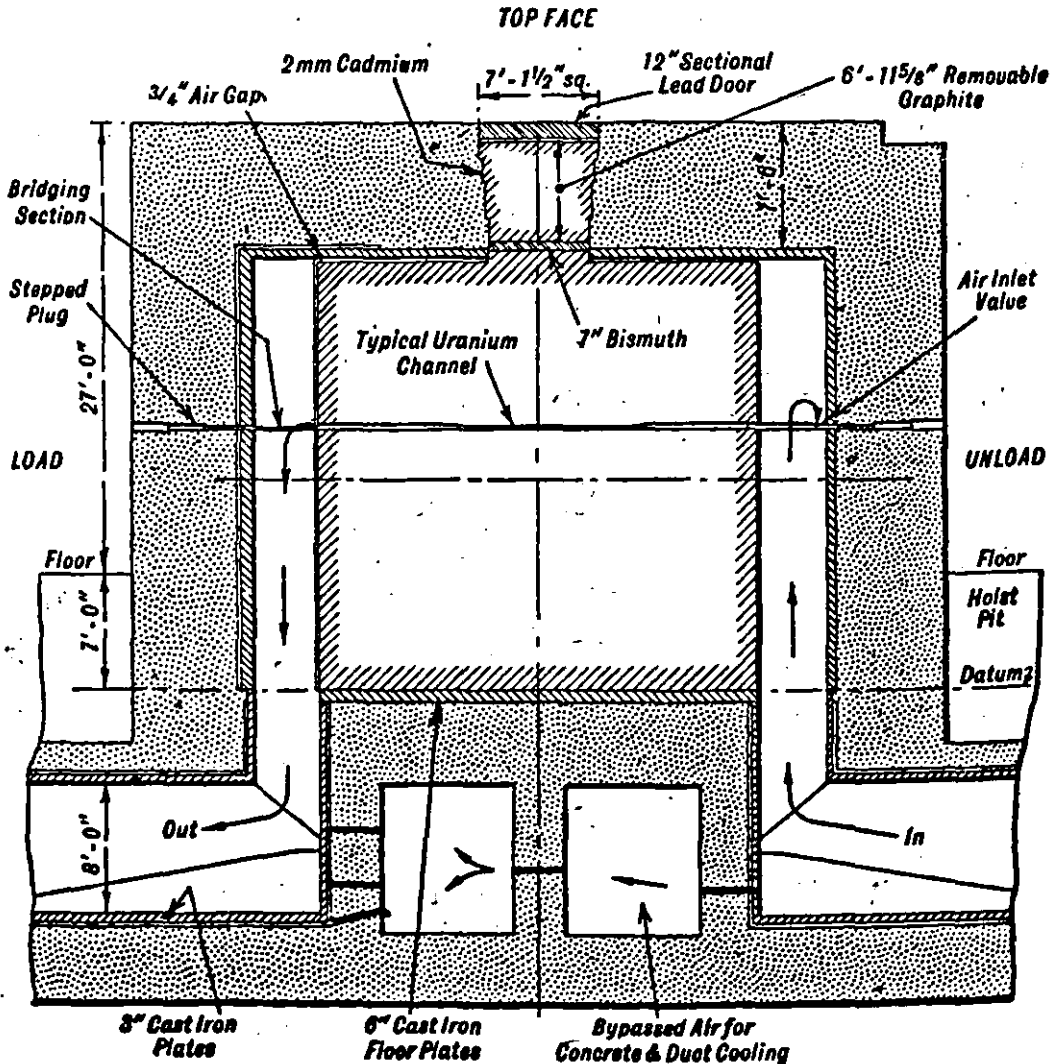


Fig. 2. Diagram of Bepo—the graphite-moderated, natural uranium British experimental Pile at Harwell, U.K.

*In American money, this is about 12 mil, which is about double the cost of production of electrical energy from coal.

closing the uranium metal bars. Such a pile consists of a pressure cylinder containing the uranium bars with water. In this case water

will circulate, flowing by the side of the bars and then enter the steam generators.*

BOILING WATER REACTOR

Alternatively it could also boil in the pressure cylinder and produce steam. Considering the protection of the workers, the latter principle attracts us most.**

The greatest advantage of this type of power unit is that more heat could be produced for each ton of uranium so that the large initial expenditure on uranium could be reduced considerably. One can use ordinary water for surrounding the uranium metal bars and for transferring the heat. In this case, although initial expenses on the pile are reduced, it is necessary to use more expensive uranium fuel containing more U-235 in order to compensate for the unfavourable nuclear properties of ordinary water.

It is also possible to use heavy water, but the current commercial price of this will greatly increase the initial expenditures of the power plant. In France, you are working on the methods of producing heavy water; we are also studying it and it is quite possible that it will succeed.†

In one modification of this pile which has been developed in the United States, uranium is dispersed in heavy water to give rise to a kind of soup (Slurry) which gets heated and can be made to circulate to produce steam in a separate generator. This pile promises a high efficiency of utilization of uranium and will possibly also permit the use of thorium as a source of secondary fuel, U²³³. But it presents to metallurgists very difficult problems of corrosion.

*In the American pattern of the proposed pressurized reactor, the reactor vessel is a cylinder—9ft. in diameter, 28 ft. high and is meant to stand a pressure of 2000 lbs (133 atmospheres). The temperature of the fuel which is uranium enriched in its U-235 content by 1.5 to 2%, is 315°C. Total quantity of uranium is 15 to 20 tons. The water will have a temperature between 260° to 315°C. This water will go to the heat exchanger, and the heat will be conveyed to a boiler generating steam at a pressure of 40 atmospheres. The fuel will last for about 3 years.

**In the first experimental boiling water reactor in America, it has been found that the generation of steam within the reactor core does not cause continual changes in reactivity or any unstable operation as had been feared earlier. It is now believed that it is possible to design B.W.R. which will operate in a stable, self-regulating manner and, in the event of trouble, will shut themselves down without any serious damage. These developments constitute a major contribution towards safe power reactor.

†A plant for production of heavy water has been set up jointly by the British Atomic Energy Authority and the Govt. of New Zealand in New Zealand.

FAST BREEDER REACTOR

In yet another type of pile called the fast fission breeder reactor, one hopes to utilize uranium fuel with an efficiency at least ten times greater than that I have already spoken of*. We have constructed one reactor of this type, having a low energy, and it is our intention to build an experimental reactor having great power. This type presents very difficult technological problems and probably it will remain without commercial importance for ten years. Of immediate greater interest are the piles using thermal reactions.

SUPPLY OF URANIUM

If we want to have from nuclear energy a significant contribution to the power resources of the world, there must be sufficient supplies of uranium. I have referred to our aim of obtaining from uranium useful energy equivalent to *twenty million tons* of coal per annum. To achieve this object, it will be necessary to build nuclear energy stations which will develop *five thousand megawatts of electric energy*. That would need about three years of construction if the amount of generating material in Great Britain continues to increase at the same rate as at present.

For working these stations it would be necessary to have about *two thousand tons of uranium per annum* if we accept the *pessimistic figures* of efficiency in the utilization of uranium and about ten times less this quantity if we accept the more optimistic calculations. If the breeder reactors are crowned with success, the required quantities will be further reduced by ten times.

In the long run we may also have the possibility of using thorium as a source of nuclear energy, but to do this, it is necessary to expose thorium long enough in the reactors for producing the secondary fuel, uranium-233.

In the long run there will thus possibly be enough of uranium and thorium for meeting the needs of the world. In fact, one commission

*Because of the low capture to fission ratio with high energy neutrons, the number of excess neutrons available is great enough so that breeding or complete conversion of U-238 to plutonium is theoretically possible. However, the higher concentration of uranium necessary for criticality in fast reactors increases the costs due to fuel investments.

Potentially however, the value of the additional plutonium produced from the excess neutrons in fast reactors might be enough to make this type of reactor the most economical power producer.

in the United States estimated that the resources of energy contained in uranium are *fifty times greater than those in coal and oil*, provided breeding can be achieved in reactors. In my opinion this is probably a conservative estimate.

In short, the efficiency of utilization of uranium will be perhaps low to start with, and the metallurgists, chemists and engineers will have to make intensive efforts for achieving the highest figures I have cited.

I figure out a development period of eight years in which we shall build and put into action the first two power stations in England. We shall then build and operate the better types. After all these efforts, and provided we are successful in them, we should be ready to undertake the construction of nuclear energy stations which will produce five thousand megawatts of power, I have mentioned. This will be possible by 1965-70.

In the United Kingdom, we are working on these new developments with the help of the Industry, and the Department of Electricity. The future nuclear energy stations will be built by the Industry and operated by the Department of Electricity. The role of the Department of Nuclear Energy will be to render research service, to be engaged in central development, to carry out research work and to introduce new designs. Harwell is the principal centre of research and development and there we have a *school of reactor technology* for the engineers of the Industry. Our Industrial Group at Risley has worked out pioneering designs which resulted from the study of designs carried out at Harwell. The Industry and the Department of Electricity are taking part in this programme at Risley. Our first two nuclear energy stations will be operated by the workers of the Department of Electricity as well as by those of the Nuclear Energy Department.

Nuclear energy is not considered only as a source of power; there are possibilities of important applications of the radiation in industry and in chemical engineering. In the industry, ethylene is polymerized into polyethylene under high pressure and at a high temperature. The yield of polyethylene may sometimes be doubled in the presence of radiations from radioactive materials or from

other sources. Alternatively, the use of high temperature can be avoided in the presence of radiation. This subject is being actively studied at Harwell and in the United States.

The radiation can also influence the properties of plastics like polyethylene. Particularly, it greatly increases the resistance of polyethylene to high temperature. It could be of importance, for example, in the case of valve-holders which may be used at high temperatures. A sister organization has recently requested us to irradiate twenty thousand valve-holders. Polyethylene bottles will resist temperatures necessary for sterilization by steam. Irradiated polyethylene can also be used for insulation of cables and in electrical machines working at high temperatures.

There are three possible sources of this radiation :

- 1) One can place the plastic materials inside the protective covering of the reactor,
- 2) One can use radiation given off by the waste materials produced in the fission process,
- 3) Linear accelerators at high intensity, which have been developed at Harwell, can also be used.

We do not know yet which of these will be more economic.

Precautions are taken in employing the highly radioactive fuels, supplied by the pile, as sources of radiation for these operations.

Before I finish, I should like to express thanks for the friendly co-operation we have received from the French scientists. During the war, our initial trials with heavy water were made possible by the co-operation of French scientists, Messrs. Gueron, Goldschmidt and Halban, who brought to England 180 litres of heavy water,—all that had been there at that time, and who worked with us here and later in Canada under the Canadian nuclear energy development project.

Since the war we have received much valuable co-operation in the application of radioisotopes and also in other research projects. We fervently hope that this co-operation will grow in future to our mutual advantage.