SOURCE OF ATOMIC ENERGY

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The following is that part of an article, entitled ' The Significance of the New Atomic Energy Programme,' which refers to the availability of power within fissile material. The article was published in March, 1955, in Fuel Efficiency, *Vol. 3, No. 21, and permission to reproduce, by the Editor and Author, is acknowledged.*

The energy sources familiar to us arise from chemical reactions, where energy in the form of heat is released by burning organic materials such as wood, coal or oil. But the source of atomic energy is quite different. The structure of the atom is a heavy central nucleus with a positive charge, and surrounding this is a field of negatively charged electrons. This nucleus, wherein resides the weight of the atom, consists of protons which carry a positive charge and neutrons which are uncharged. The neutron has, however, approximately the same size and mass as the proton. Since the atom as a whole is electrically neutral, the number of positively charged protons equals the number of negatively charged electrons. It is important to remember that the chemical properties of the atom—that is its behaviour under normal chemical conditions—are determined by the number of protons it contains. However, its mass is the composite mass of the number of protons and neutrons which it contains. Thus it will be realized that if a neutron is removed from an atom its charge, and therefore its chemical properties, are unaltered but, of course, the mass of the atom is reduced.

It is possible to have atoms which are chemically identical, such as Uranium 235 and Uranium 238, where the figures reflect the different mass of the respective atoms, which are called isotopes. Isotopes themselves can be stable or radio-active, tending to change spontaneously into other atoms or isotopes with the emission of radiation. However, if the number of protons is changed then the chemical nature of the atom alters completely, and again, any new chemical element so produced can be either stable or radio-active.

Ordinary chemical reactions, such as the burning of fuel, mean merely that the outer field of electrons of the respective atoms only are affected, the nucleus remaining unchanged. Such chemical reactions take place by releasing or absorbing energy, but the energy change is quite small. However, when the nucleus of an atom is modified, the energy and heat processes which are involved are a million times greater and, of course, the whole purpose of nuclear fission or hydrogen fusion is to achieve this tremendous energy release. The latter is not yet envisaged, but the control of nuclear fission has been established to a point where it is virtually no more of a technical process than an orthodox electrical generating station.

This nuclear fission occurs if a free neutron—which, as mentioned, is the uncharged component in the nucleus—strikes the nucleus of a fissile element, that is, one which is capable of being disrupted. The isotope, Uranium 235, is a common example of such an element. Thus the impact of a neutron on the nucleus of Uranium 235 achieves three objectives. Firstly, the nucleus splits up into two ' halves ' which fly apart and simultaneously release energy as heat. In this process new neutrons escape from the disrupted nucleus. They may collide with another fissile nucleus, so continuing the fission process and estab-

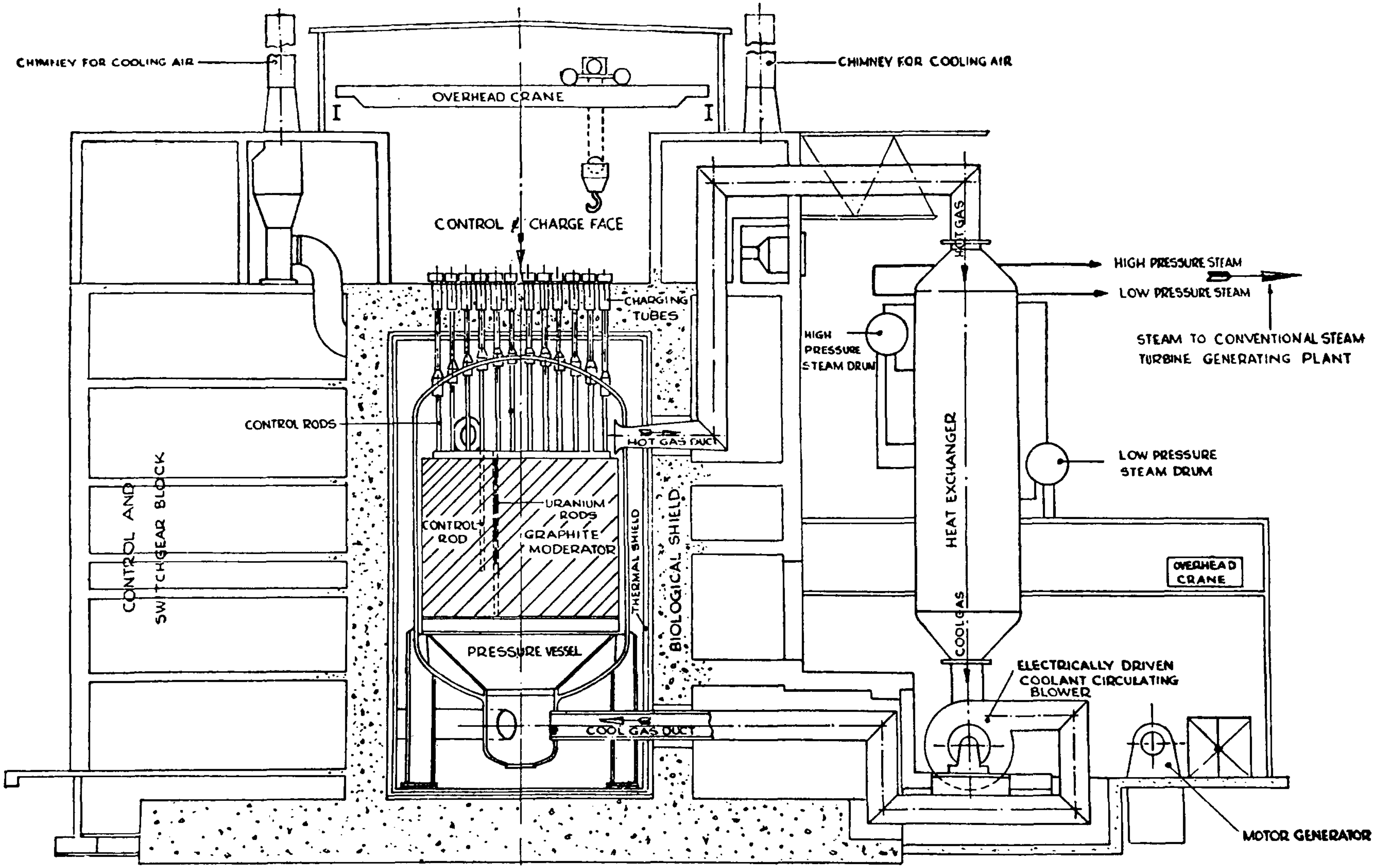

FIG. 1—A GAS-COOLED POWER REACTOR

lishing a chain reaction which is capable of control and which provides a continuous release of energy.

On the other hand, some of these neutrons may be captured by the nucleus of a non-fissile atom such as Uranium 238. This atom increases its mass and becomes Uranium 239, and is itself highly radio-active, suffering a rapid change to Plutonium 239. The importance of the change is that this Plutonium 239 differs from the parent Uranium 238 in that it is itself fissile, so that it can undergo fission by impact with another neutron. Of course, in the whole process some neutrons may be absorbed or lost in ways which make no contribution either to the chain reaction or to the production of new fissile material.

The two ' halves ' of the original nucleus are called fission products, and because they are highly radio-active and potentially harmful to life they must be controlled for a long time, although their bulk can be made quite small. It is the heat from the fission of the nucleus which is the source of usable energy.

In simple terms, then, the reactor or the part of the plant in which fission is taking place replaces the orthodox coal or oil-burning furnaces of existing power stations. The reactor which is bring built at Calder Hall is shown diagrammatically in FIG. 1. It consists of a mass or core of many thousands of accurately machined graphite bricks, which is called a moderator. Its purpose is to slow down the fast-moving neutrons without capturing them. In this graphite core there are a large number of vertical channels. The whole is enclosed in a steel pressure shell surrounded by concrete.

The fuel is natural uranium which contains only one part in 140 of the fissile Uranium 235, the remainder being the non-fissile Uranium 238. This natural uranium is made in the form of rods sealed in metal cans and placed in the vertical channels inside the graphite core. Nuclear fission takes place in these rods and the surplus neutrons travel in the graphite and uranium until they bring about further fission or are absorbed to form plutonium, or are lost.

Heat is liberated continuously and is removed by circulating carbon dioxide gas under pressure through the core. The graphite, by moderating or reducing the average speed of the neutrons, brings the fission reaction to a low value, known as the thermal level. That is why a reactor with a moderator is called a thermal reactor. Without this moderator a large proportion of the neutrons would be absorbed by the relatively abundant Uranium 238, which captures fast neutrons more readily than does Uranium 235, so that the chain reaction would come to an end. The control over the whole process is achieved at a fixed level by moving rods of neutron-absorbing material in or out of the graphite.

As the reaction proceeds some Uranium 235 is used up ; some of the Uranium 238 is converted to Plutonium 239 ; the fuel rods change, giving rise to fission products, and eventually the fuel must be removed and a fresh supply added.

The next step, of course, is chemically processing the fuel which is removed to separate both the Plutonium 239 and the depleted Uranium which has now a lowered proportion of Uranium 235 than is present in the natural uranium. FIG. 2 shows diagrammatically the way in which this is achieved. It is, of course, necessary to define the rate at which any fissile fuel burns, and it is expressed in its heat output, such as megawatts per metric ton of fuel. If 1 ton of fuel burning at a rate of 3 megawatts remains in a reactor for 1,000 days, the level of irradiation achieved is 3,000 megawatt days per ton. As yet the only naturally occurring fissile element is Uranium 235, and this is diluted to a large extent by the non-fissile Uranium 238.

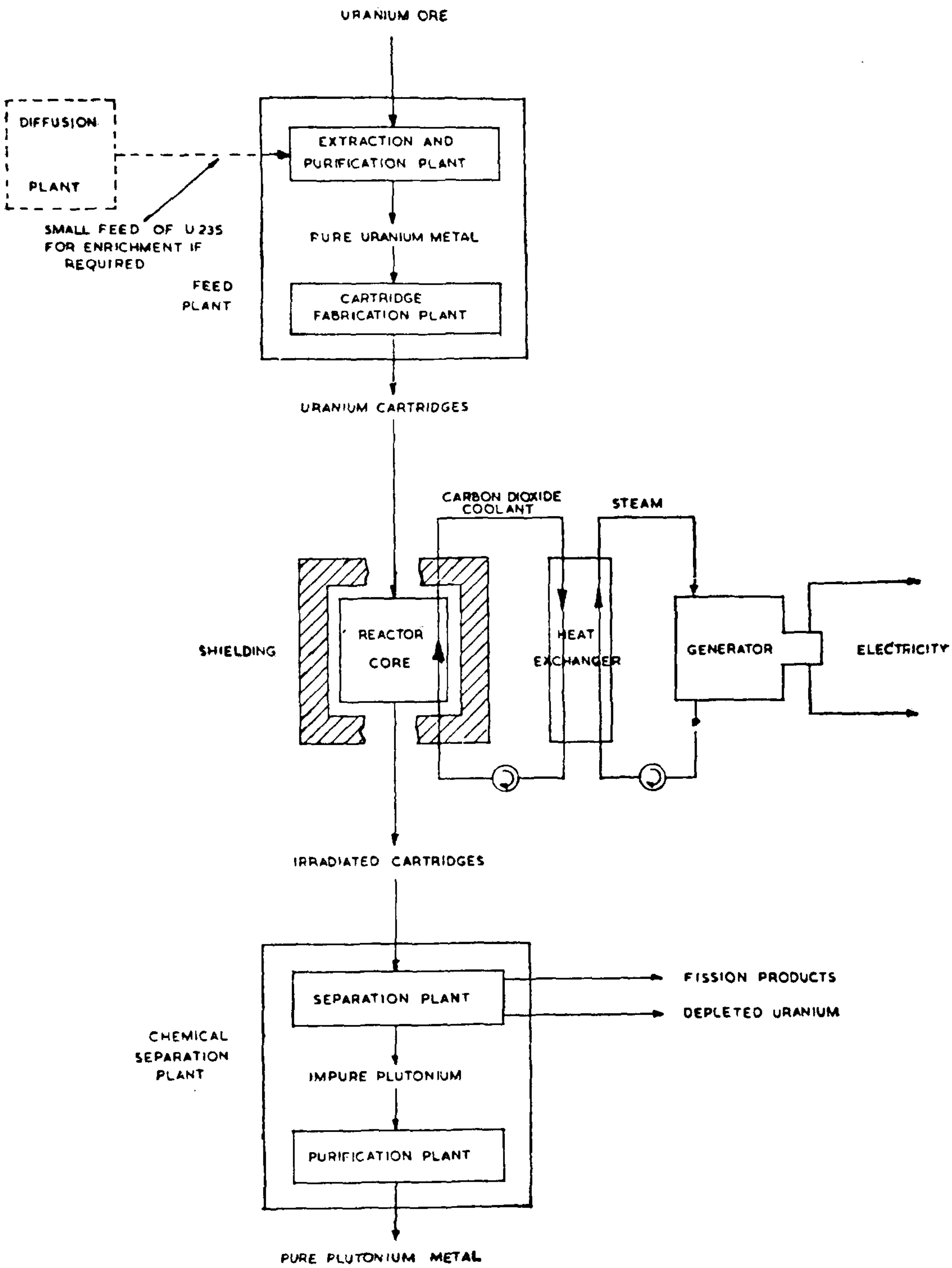

FIG. 2—NUCLEAR POWER UNIT AND ANCILLARY PLANT

Quite obviously then, if only the Uranium 235 were used it would mean that the natural uranium was being consumed quite inefficiently. The advantage of a nuclear reactor is, however, not only to produce heat but to make fissile material itself, for there are elements known as fertile materials—for example, Uranium 238 and Thorium 232, and these fertile materials can be converted into fissile ones.

At Calder Hall, natural uranium containing fissile Uranium 235 and fertile Uranium 238 is used. The fissile material is disrupted to produce heat and a small part of the fertile material is changed into fissile material. The amount of new fissile material produced varies from one reactor to another, and it is possible in certain cases to produce more fissile material than that consumed in the process, resulting in an overall gain in the amount of fissile material.

This leads to the description of such a reactor as a breeder reactor and in the United Kingdom, where there are no supplies of naturally occurring uranium, such a system is of obvious importance. In a reactor based upon natural uranium, less fissile Plutonium 239 is produced than the amount of Uranium 235 consumed, so that there is no overall gain in fissile material. However, it is possible to extract the plutonium and use it in the same type of reactor instead of natural uranium, or in a different type of reactor. If this plutonium is used with Uranium 238 more Plutonium 239 is produced, but there is still an overall decline in fissile material, although by using this plutonium from early reactors there is a great increase in efficiency as opposed to using natural uranium as a whole.

Quite obviously then, one of the early steps was to obtain a supply of plutonium because it can be used by two different methods: firstly, it could be used with a fertile element, Thorium 232, in a thermal system, and this would produce Uranium 233. This Uranium 233 could be extracted and used in place of the original plutonium charge. There would be no overall gain, for about as much Uranium 233 would be produced as Thorium 232 was used, but the overall use of raw material would be very efficient.

The alternative use of plutonium is with Uranium 238 in a fast reactor with no moderator. There would be a decisive gain here in fissile material, and it would be a great advance in the economic use of these expensive raw materials.

There are four types of atom which can be used in a thermal reactor as a moderator—carbon, light hydrogen, heavy hydrogen and beryllium, but the most practical one, in the light of present knowledge, is carbon used in the form of graphite. When it comes to cooling, one can use a gas such as carbon dioxide or helium, or liquids like heavy water, light water and molten sodium metal, although it is thought that carbon dioxide for gaseous cooling and light water for liquid cooling are the probable choices.