Rutherford Laboratory

Technical Leaflet

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ELECTROSTATIC GENERATORS

As an introduction to the development which leads up to the Oxford project, of which a cutaway is illustrated in the centre panel, we describe (A) the principle of the electrostatic generator: (B) how the single ended machine is of particular value for experiments in nuclear physics: (C) how the range of energy available has been greatly extended by the use of the tandem principle: and (D) how the tandem principle in turn leads to the compound system of the Oxford project.

(A). PRINCIPLE OF THE ELECTROSTATIC GENERATOR

The modern electrostatic generator was invented in 1931 by Robert J. van de Graaff, and the machine is often known by his name: another familiar variant is the Wimshurst machine of the school laboratory. In figure 1 a schematic is shown of such a machine, and a model is shown with the exhibits. An endless belt is driven between two pulleys. A series of sharp points (e.g. gauze) at the earthed end of the machine are driven at a low electrical voltage (5-10 kilovolts), and the air in the neighbourhood of the sharp points breaks down and transfers charge to the belt. The charge is carried up within a dome, where it creates another region of high field when in the vicinity of a second set of sharp points. Again the air breaks down; since charge cannot remain inside a hollow conductor, the charge originally sprayed on to the belt at earth potential appears on the outside of the terminal. The voltage builds up until breakdown occurs, as the model demonstrates (or should demonstrate). For steady static operation, a resistor chain carries the terminal charge back to earth.

(B). VALUE OF THE ELECTROSTATIC GENERATOR IN NUCLEAR PHYSICS

Anything like Fig. 1 or the model can be persuaded to operate above 1 million volts only with difficulty. A major step forward in technology was made by R.G. Herb in 1935, who housed a generator inside a pressure vessel. This does two things. In the first place, the high pressure inhibits breakdown, and the electric strength of the system is greatly increased. In the second place, the gas can be made very dry: dryness is a vital factor in good performance. The weight of gas in the Oxford pressure vessel is 4 tons. This and many other design features make 6 million volts on the terminal a normal performance. Fig. 2 shows a cutaway of the Harwell 5 MeV machine. Ions (positive particles) generated in the terminal in an ion source, are repelled ('like charges repel') from the terminal, down an evacuated tube, to the base of the machine. The beam of ions (which behaves like a current in a wire) is deflected through 90° by a bending magnet and is focussed between a pair of jaws. The difference of the currents to the jaws is amplified and fed back to a control (corona needles) facing the terminal. If the voltage of the machine rises above the desired value, the beam is insufficiently deflected, the lower jaw receives excess current, and the corona control injects more current to the terminal, reducing its value to the correct figure. If the voltage falls, the reverse takes place. By this means, stabilities of ± 1 KeV in 5 million electron volts are readily obtained.

The electrostatic generator is not the only way of producing a beam of ions at 6 million volts: and, as compared with a cyclotron, it is certainly not the cheapest. However, for experiments in nuclear physics, it has two major advantages: precision and flexibility. Of precision we have spoken above. It is also a flexible machine, because any material capable of being ionized can be used, while the voltage can be readily varied by spraying more or less charge on the belt. Whilst this may seem obvious, this advantage is absent from other means of acceleration (cyclotron, linear accelerator) where, because they are resonant systems, voltage and mass variation are achieved only with difficulty. It is primarily for these advantages (precision and flexibility) that the electrostatic generator is widely used in nuclear physics.

(C). THE TANDEM PRINCIPLE

The chief limitation to the electrostatic generator has been the voltage which can be readily achieved: voltages up to 10 million have so far been realized, but only with difficulty. High energies are now available by a principle of charge exchange. Originally patented by W.E. Bennett in 1937, the principle is this. It so happens that the atoms of many elements, including hydrogen (whose nucleus is a proton) can not only lose a (negative) electron and so become positive, but can attach an electron and so become negative. The ion source is, then, not a positive ion source at (terminal) positive potential, but a negative ion source at earth potential. These ions are then injected towards the positive terminal (100 kilovolts, in Bennett's patent). Having gained energies of 100 kiloelectron volts, they then pass through a small quantity of material - a very thin foil, or a tube containing gas - which strips the fast-moving negative ions of their electrons and turns them into positive ions. These are finally repelled from the positive terminal, and the final energy of the protons is 200 kiloelectron volts. If the positive terminal voltage is 6 million volts, the final proton energy is 12 million electron volts. Such a machine has been called in the Western world a tandem (or charge-changing machine in Russia), and a diagram of the Harwell 12 MeV tandem is shown in Fig. 3. In this way, particle energies of 12 million electron volts are realized while accepting the electrostatic generator limit of 6 million volts.

(D). THE OXFORD PROJECT

Even with 12 million volts, the field available to nuclear physics is limited: interaction of protons with heavy atomic particles (e.g. uranium) require energies of 17 million volts before the reaction can take place, because of the Coulomb repulsion of the central nucleus. Therefore the Oxford project aims at providing particles of energies of 20 million electron volts. In this project, half of the machine is a horizontal tandem, purchased from H.V.E.C., of U.S.A. It is installed in the basement of the building; the ion source and magnet have been provided by the N.I.R.N.S. and Oxford teams, and operates in what is now a standard way. In addition, however, the N.I.R.N.S. team are designing, installing and commissioning a large injector: a standard vertical single-ended machine of which the centre terminal normally runs negative, to voltages up to 8-10 million volts. These ions are accelerated in the same way as (B), deflected into the horizontal, and injected into the tandem. Here they will be attracted to the centre terminal, stripped to become positive, and accelerated to emerge with energies of 20-22 million volts.

The injector is a standard machine, except that its general dimensions are about 50% above conventional machines. Thus, the height of the pressure vessel is

42 ft., and its diameter is 13 ft. The design of the stack has required careful consideration of the requirements of strength and stability. A highly polished intermediate electrode, 20 ft. high and 8 ft. in diameter, should give 25% increase in electrical strength. Access to the stack is achieved by the use of a platform, normally at the base of the vessel, which is elevated by hydraulic rams. Stabilization of voltage is achieved by a liner, the voltage of which is varied so as to counteract the variation of terminal voltage. This principle of stabilization has been established at Harwell in a test machine, which has accelerated electrons to 4 million volts, and in which stabilities of 80 volts in 1 million have been achieved.

The remaining pictures in the display show the build-up of the Oxford project. Fig. 4 shows a schematic cutaway of the whole installation. Finally, a demonstration is given of some of the components used in electrostatic generators.

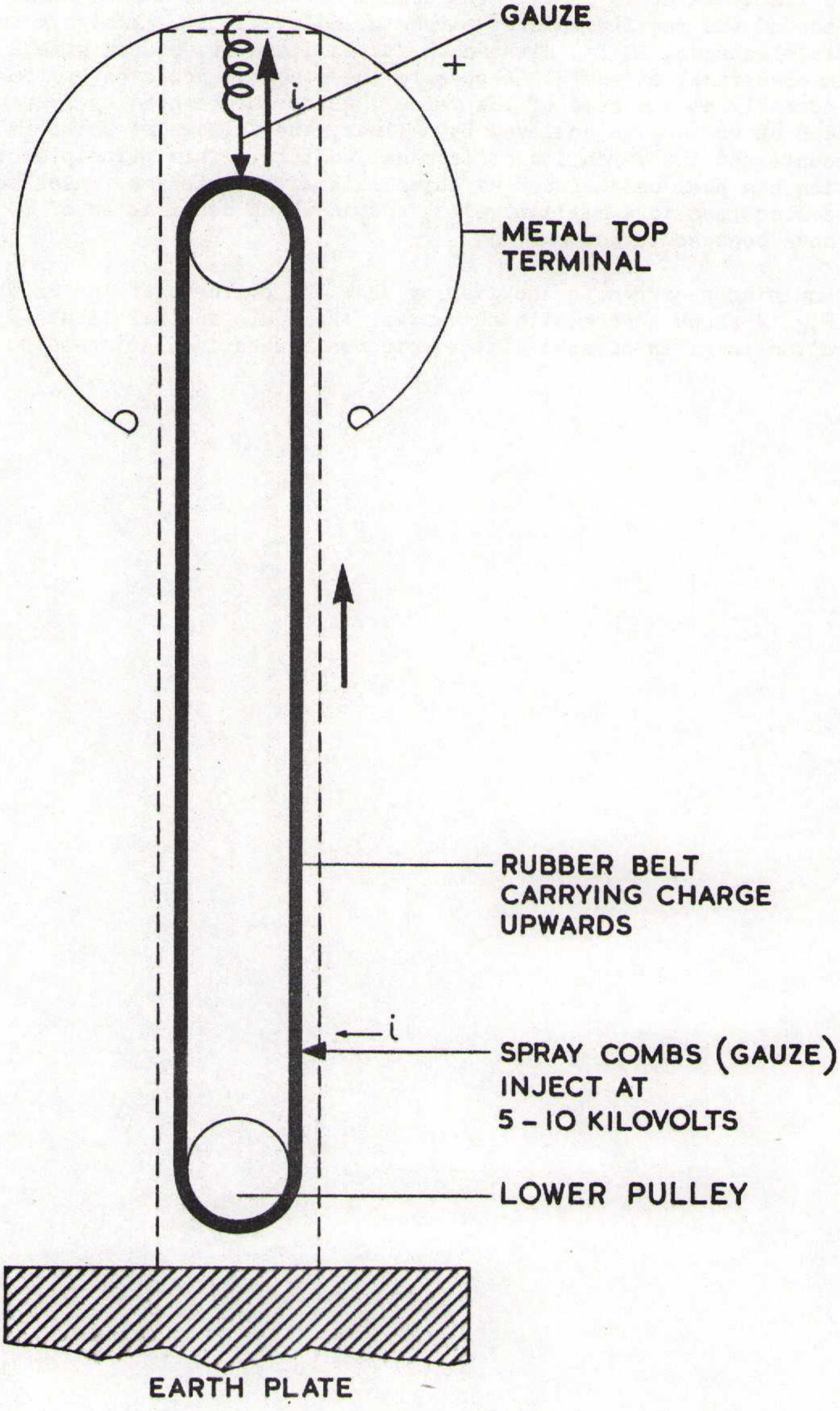
GAUZE
+
i
METAL TOP TERMINAL
RUBBER BELT CARRYING CHARGE UPWARDS
i
SPRAY COMBS (GAUZE) INJECT AT 5 – 10 KILOVOLTS
LOWER PULLEY
EARTH PLATE

FIGURE 1.

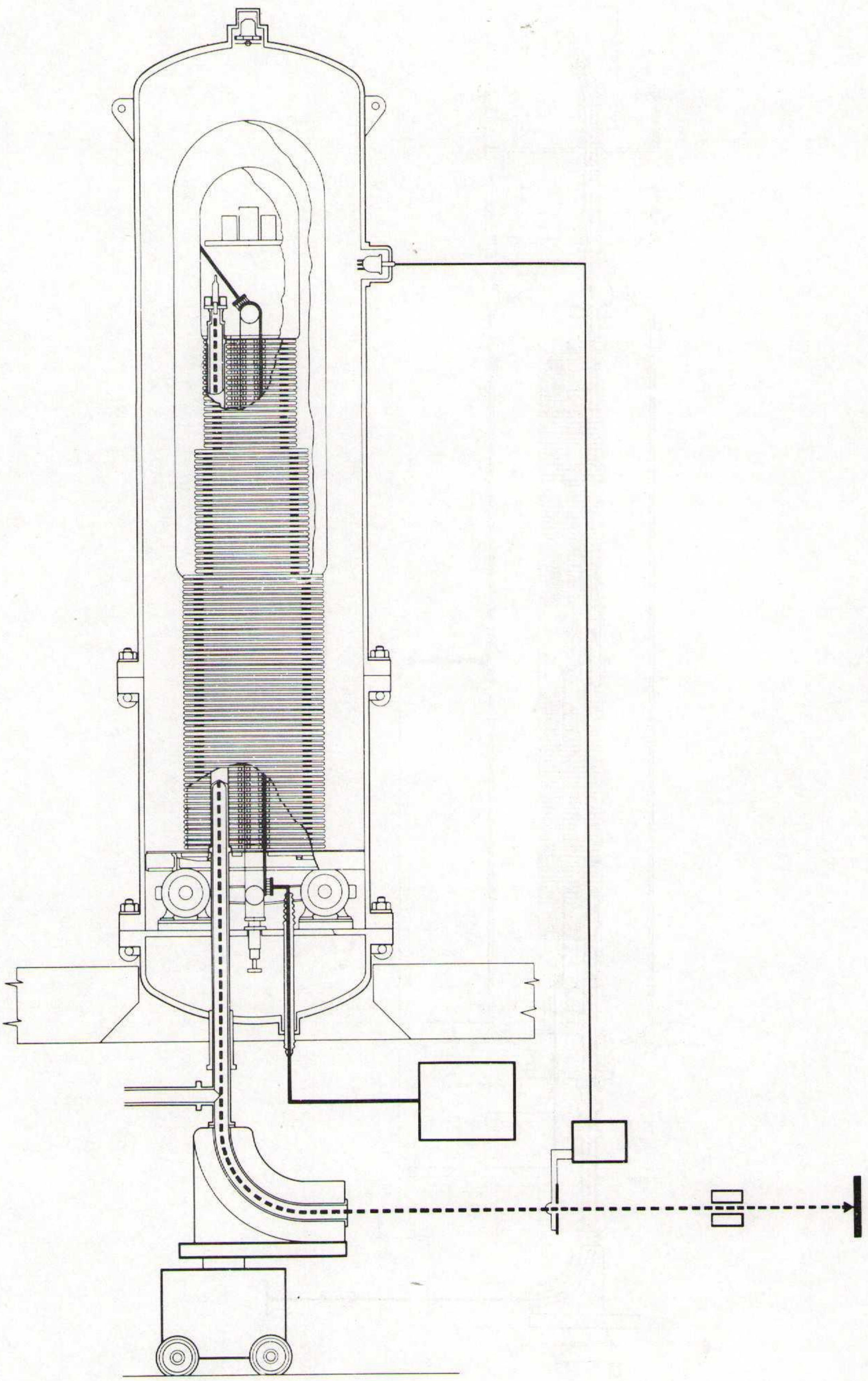

FIGURE 2 CUTAWAY OF HARWELL 5 MeV MACHINE

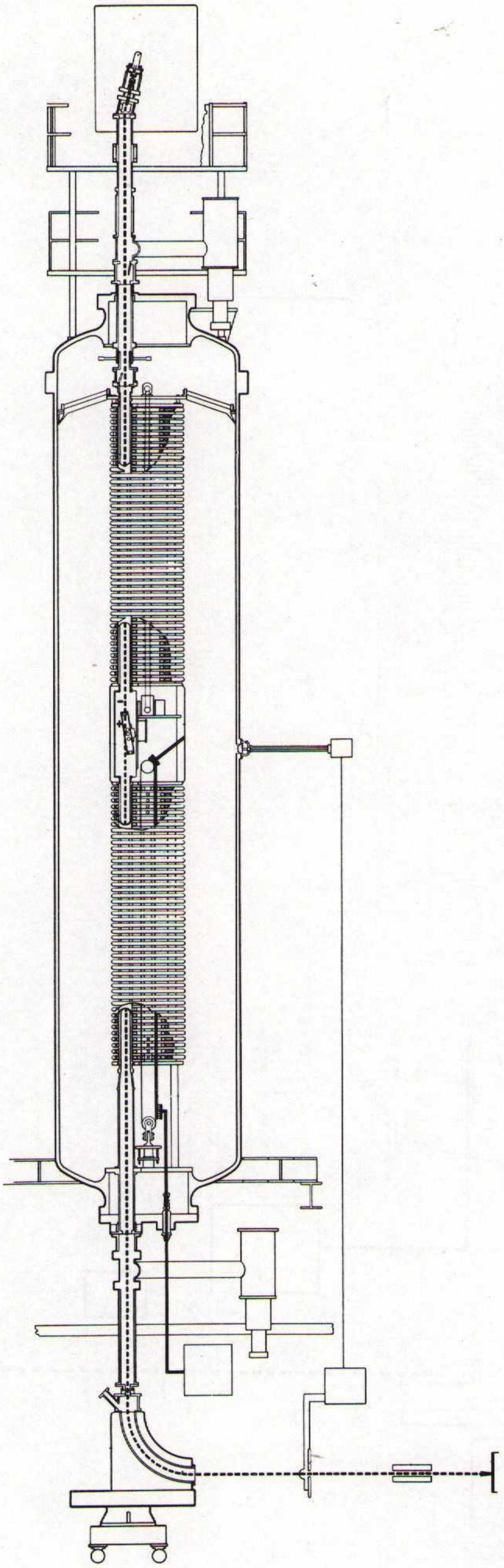

FIGURE 3 12 MeV TANDEM

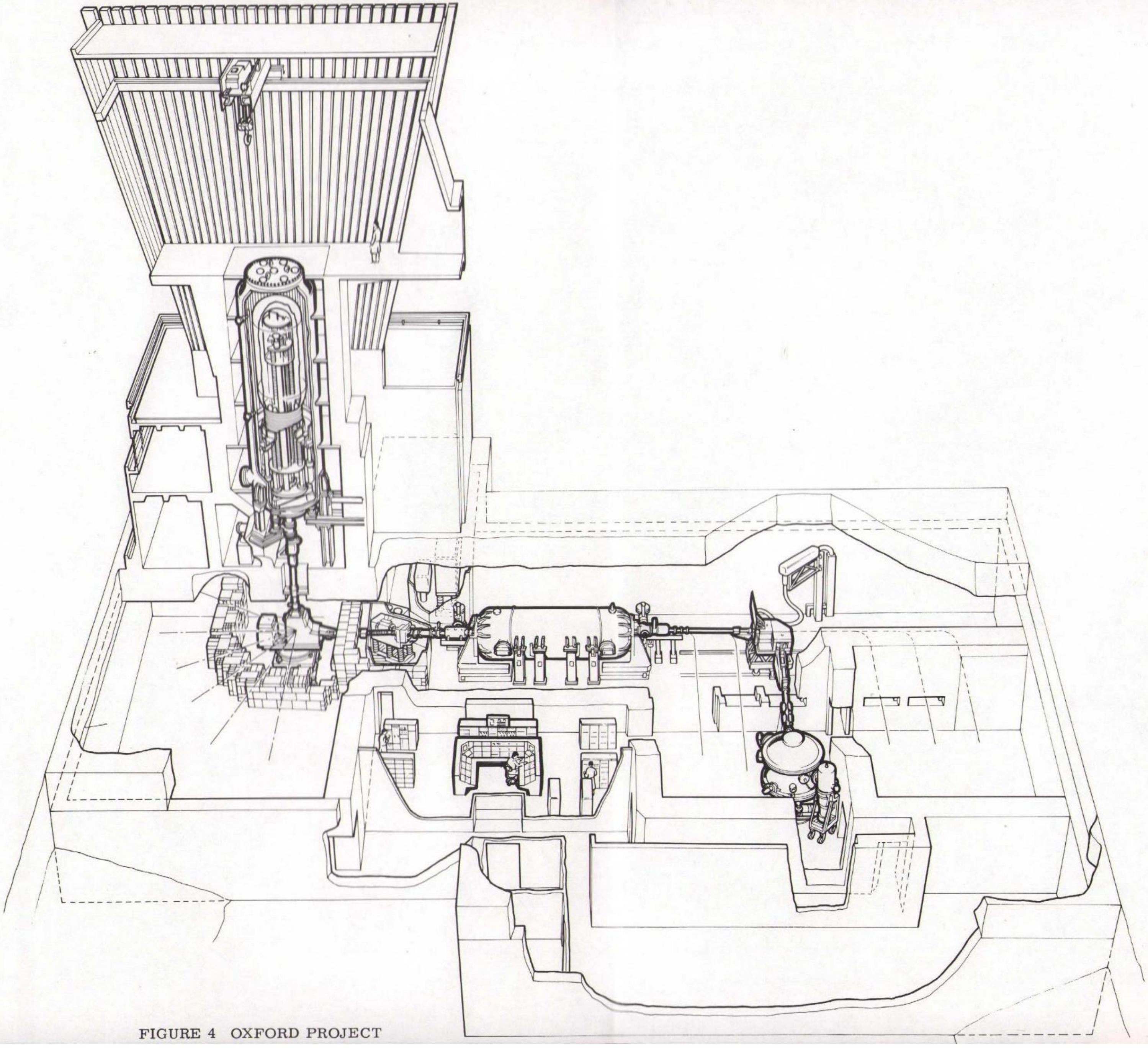

FIGURE 4 OXFORD PROJECT