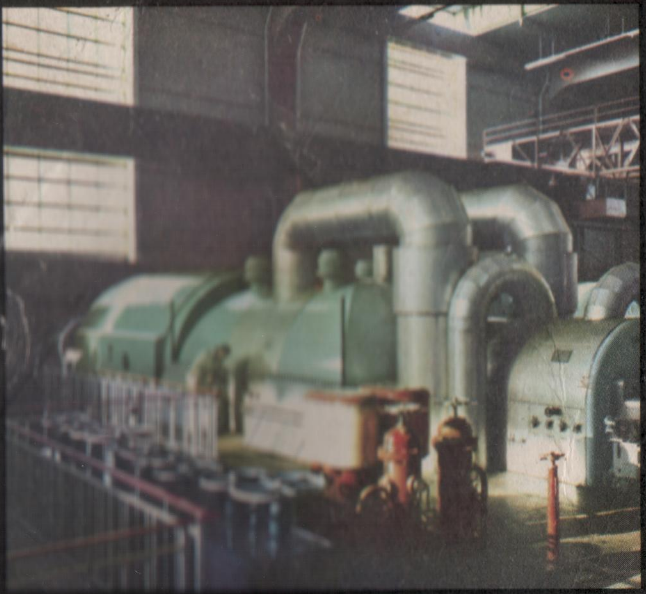
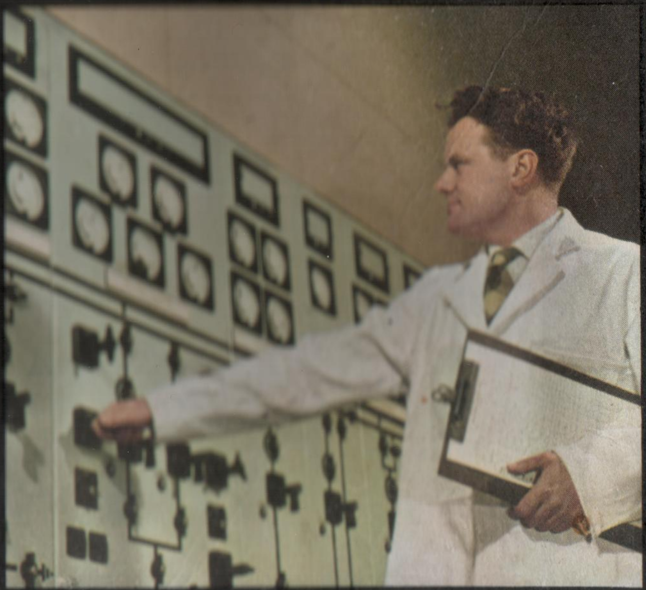
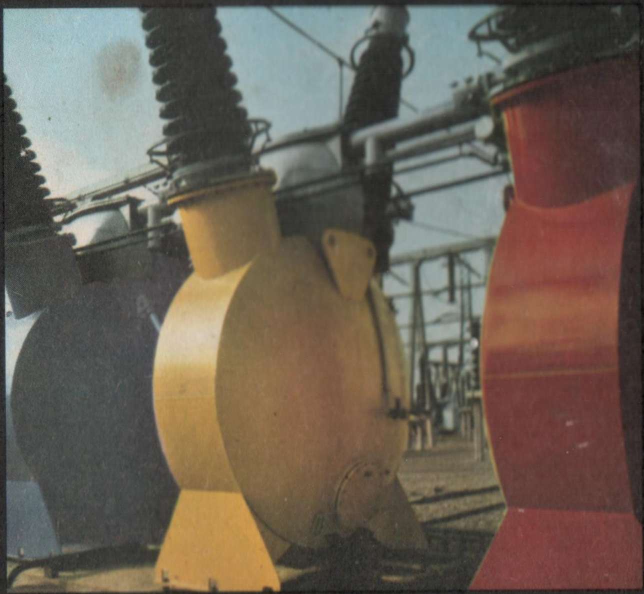
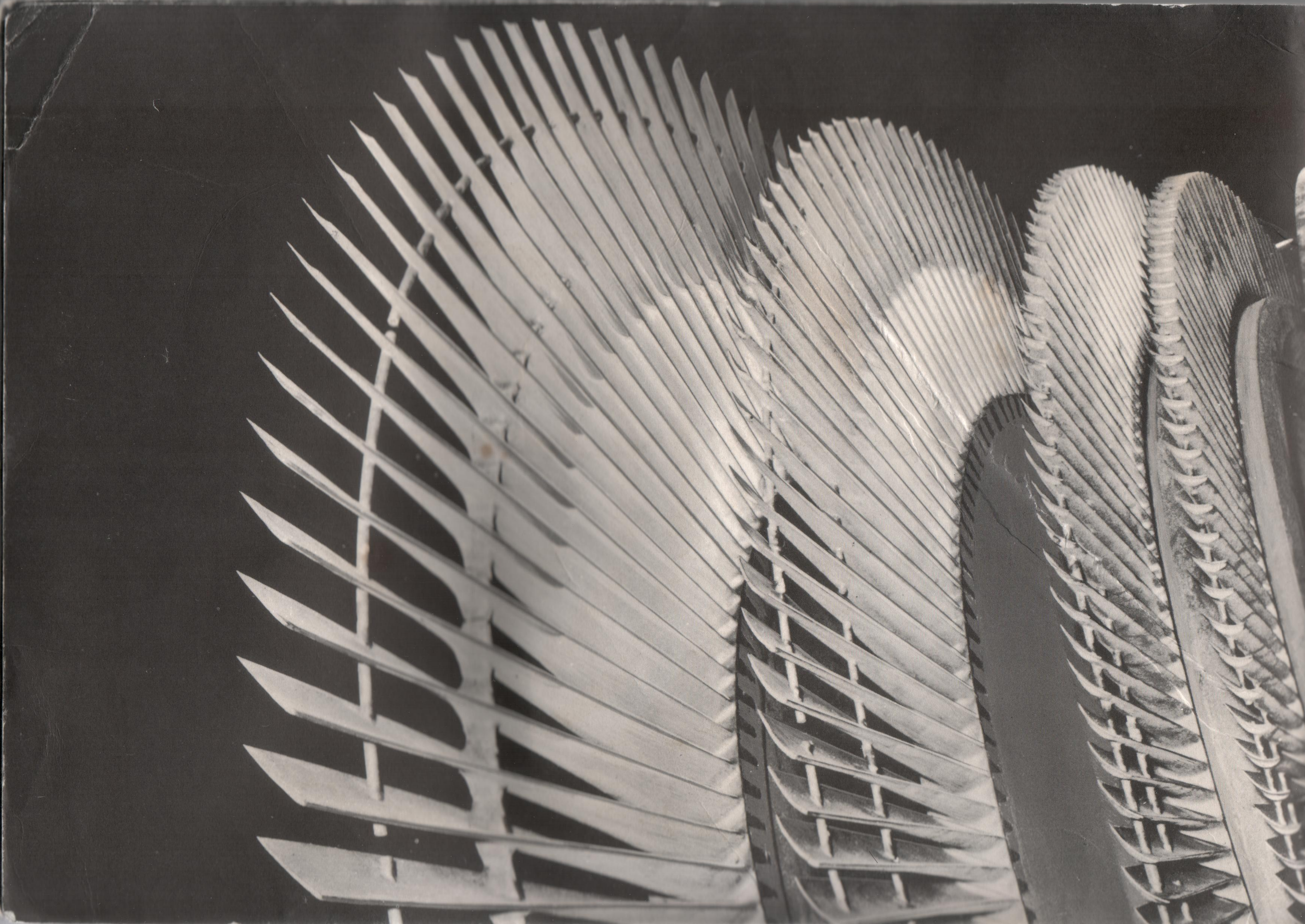
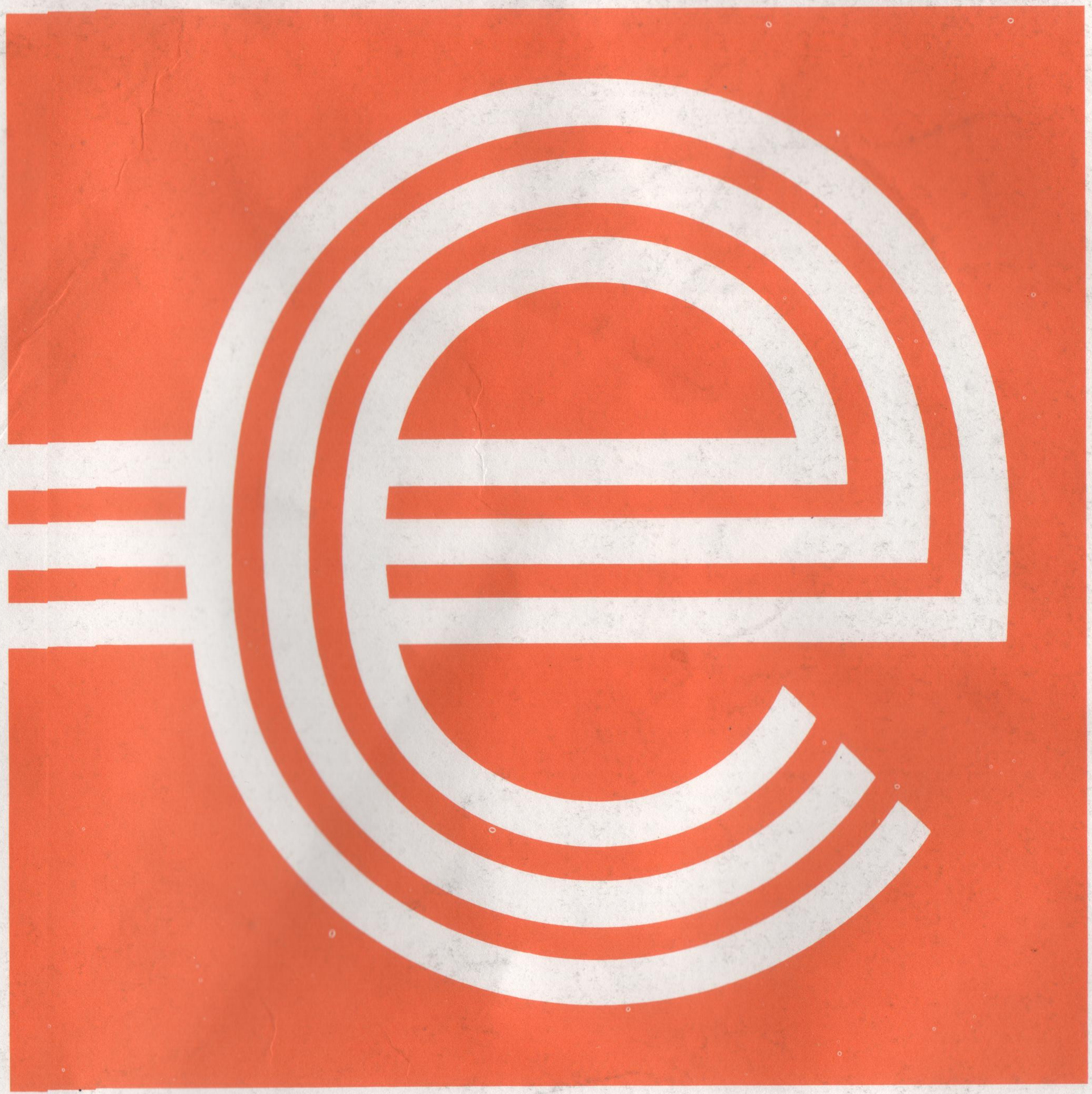
How electricity is made and transmitted











Central Electricity Generating Board

How electricity is made

On 17 October, 1831, Michael Faraday plunged a bar magnet into a coil of wire and thus generated, in his own words, 'a wave of electricity'.

Eleven days later, he rotated a copper plate between the poles of a magnet and found that power could be taken from the axis to the rim of the disc.

These two fundamental experiments provided the basis for the production of all electrical power by mechanical means.

Faraday's original experiment of holding the coil of wire stationary while varying the magnetic field is used today in all large power stations. But the bar magnet has been replaced by a rotating electro-magnet, and the coils have been arranged so that their windings are cut by the magnetic field as the magnet rotates. Thus the mechanical energy required to turn the magnets is converted into electrical energy in the windings.

In a power station the magnets in each generator are turned by engines called 'prime-movers'. Steam-driven turbines are the usual prime-movers used in this country, the steam being produced from water heated by burning coal or oil, or by nuclear fission. Hot exhaust gases from jet engines and water are sometimes used instead of steam to drive the turbines, though the amount of water available for hydro-electric use is not great. At a few smaller power stations, diesel engines provide the motive power instead of turbines.

Arcing across a wet high-voltage insulator under test *(left)*

Stacking coal in a power station stock-yard *(right)*

Coal fuel

The majority of the Central Electricity Generating Board's power stations burn coal and 75.5 million tonnes were used during 1979. Savings in the cost of transporting coal are therefore important. For this reason, many power stations have been built on the coal-fields and the electricity taken by transmission lines to where it is needed.

Coal for other power stations is taken to them either by collier or train, the colliers being used to supply power stations on rivers and the coast.

At the newest power stations, trains of special hopper wagons pass directly from the main line on to a loop of track. They unload their cargoes of coal into bunkers beneath the rails and return to the main line without stopping. This arrangement reduces coal delivery costs considerably, allowing new power stations to be built further from the coal-fields.

Oil fuel

9.7 million tonnes of oil were burnt in 1979 at oil-burning power stations, mainly constructed beside oil refineries in south-west Wales, southern and south-east England.

Nuclear fuel

In an advanced reactor, as much electricity can be made from one pound of enriched uranium fuel as from 25 tonnes of coal. Consequently, only a few lorry loads of fuel are needed at a nuclear power station compared with many train loads of coal. Sidings and collier berths are not required.

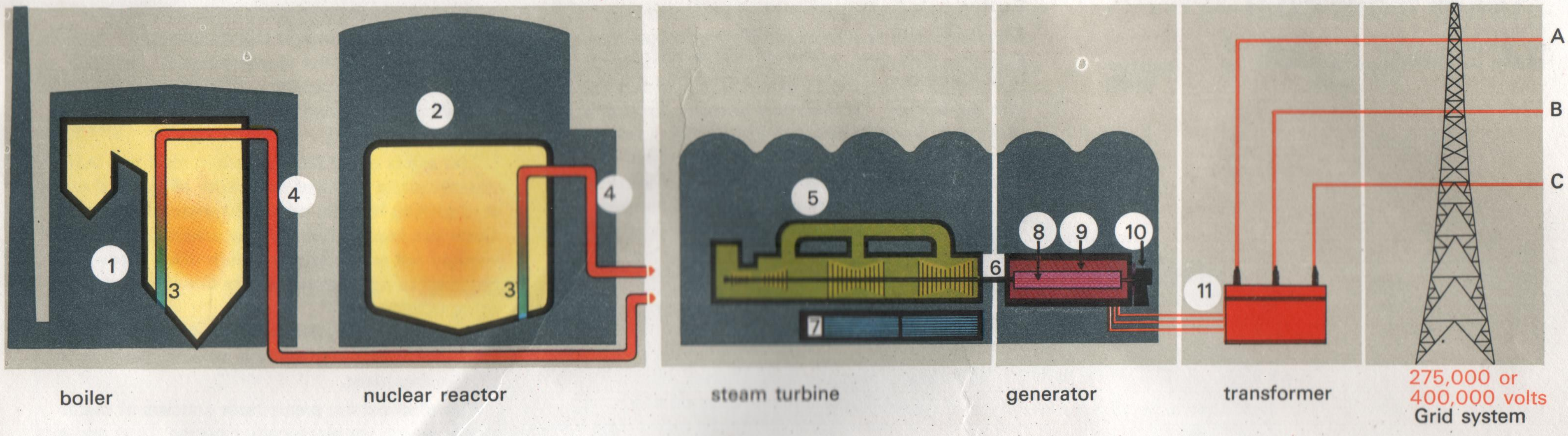
Used fuel, being radioactive, is loaded into thick steel flasks weighing 45 tonnes and taken to the nearest rail-head for despatch to British Nuclear Fuels, Ltd. for reprocessing.

How electricity is made and transmitted

Coal or oil is burned in the boiler 1 of a power station, or carbon dioxide gas is heated in the reactor 2 of a nuclear power station and the heat boils water circulating at high pressure in the boiler tubes 3 to create high-pressure steam 4. The steam is taken by pipes to the turbine 5 where it is used to drive the shaft 6 at high speed. From the turbine, the steam enters the condenser 7 and passes over tubes containing cooling water. It is thus condensed back into water and creates a vacuum which helps improve the flow of steam through the turbine. The water is returned to the boiler under pressure by a series of pumps.

The generator consists of a rotor 8 and a stator 9. The rotor (an electro-magnet made of a number of windings mounted on a shaft) is coupled to the turbine shaft so that it is turned at high speed and generates electricity in more windings that make up the stator. A small generator 10, driven from the end of the rotor shaft, produces the current required to energise the rotor.

In the largest modern generators electricity may be generated at about 25,000 volts but for efficient transmission over long distances the voltage is increased by transformers 11, to 132,000, 275,000 or 400,000 volts. The voltage is reduced again by other transformers 12 for distribution to consumers at suitable voltages—33,000 volts for heavy industries, 11,000 volts for light industries and 240 volts for homes and farms.


1
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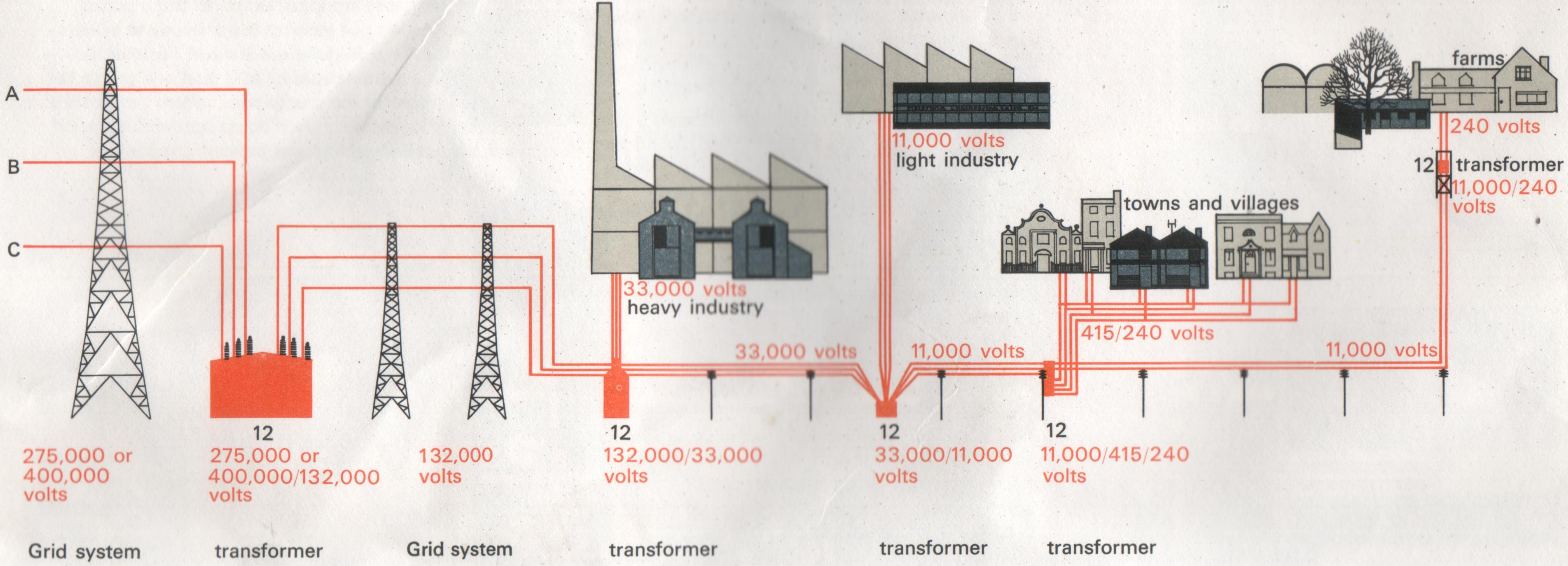
11
A
B
C
boiler
nuclear reactor
steam turbine
generator
transformer
275,000 or
400,000 volts
Grid system


A
B
C
farms
240 volts
12 transformer
11,000/240
volts
11,000 volts
light industry
towns and villages
33,000 volts
heavy industry
33,000 volts
11,000 volts
415/240 volts
11,000 volts
275,000 or
400,000
volts
Grid system
12
275,000 or
400,000/132,000
volts
transformer
132,000
volts
Grid system
12
132,000/33,000
volts
transformer
12
33,000/11,000
volts
transformer
12
11,000/415/240
volts
transformer

Steam from coal—the boiler house

The illustration shows a modern boiler burning pulverised coal at rates up to 200 tonnes an hour. From the coal store, fuel is carried on a conveyor belt 1 and discharged by means of a coal tipper 2 into the bunker 3. It then falls, perhaps through a weigher 4, into the coal pulverising mill 5, where it is ground to a powder as fine as flour. The mill usually consists of a round metal table on which large steel rollers or balls are positioned. The table revolves, forcing the coal under the rollers or balls which crush it.

Air is drawn from the top of the boiler house 6 by the forced draught fan 7 and passed through the air pre-heaters 8, to the hot air duct 9. From here some of the air passes directly to the burners 10 and the remainder is taken through the primary air fan 11 to the pulverising mill, where it is mixed with the powdered coal, blowing it along pipes to the burners 10 of the furnace 12. Here it mixes with the rest of the air and burns with great heat.

The boiler consists of a large number of tubes 13 extending the full height of the structure and the heat produced raises the temperature of the water circulating in them to create steam which passes to the steam drum 14 at very high pressure (possibly 172 bar). The steam is then heated further in the superheater 15 and fed through the outlet valve 16 to the high pressure cylinder of the steam turbine 17. It may be hot enough to make the steam pipe glow a dull red (566°C).

When the steam has been through the first cylinder (high pressure) of the turbine, it is returned to the reheater of the boiler 18 and reheated before being passed through the other cylinders (intermediate and low pressure) of the turbine.

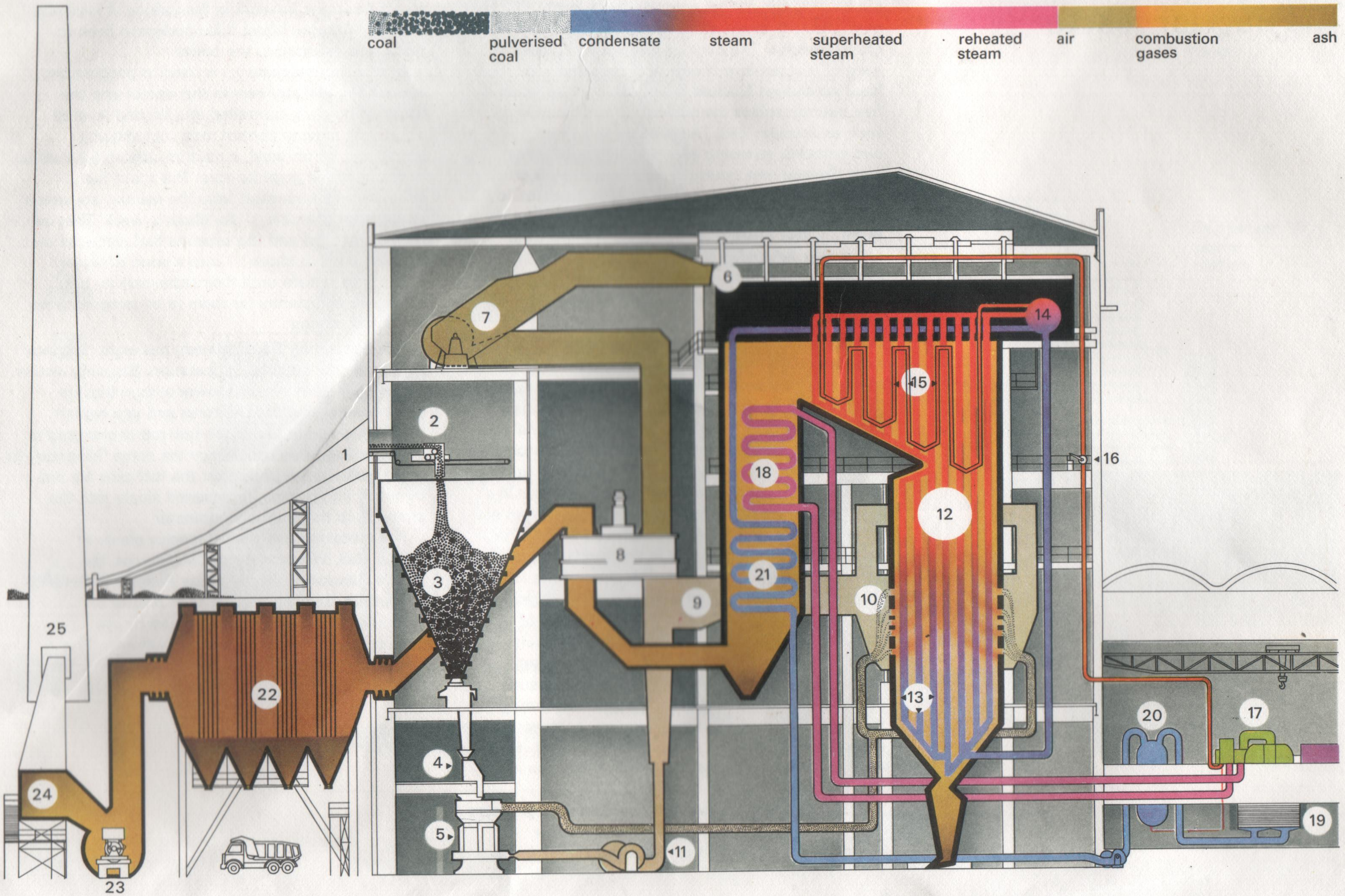
From the turbine the steam passes into a condenser 19 to be turned back into water called 'condensate'. This is pumped through feed heaters 20 (where it may be heated to about 250°C) to the economiser 21 where the temperature is raised sufficiently for the condensate to be returned to the lower half of the steam drum 14 of the boiler.

The flue gases leaving the boiler are used to reheat the condensate in the economiser 21 and then pass through the air pre-heaters 8, to the electro-static precipitator 22. Finally they are drawn by the induced draught fan 23 into the main flue 24 and to the chimney 25

The ash is either sold for use in road and building constructions or piped as a slurry of ash and water to a settling lagoon, where the water drains off. Once this lagoon (which may originally have been a worked out gravel pit) has been filled, it can be returned to agricultural use, or the ash removed for other purposes.

Oil-fired power stations have boilers that are very similar although there is no coal handling or pulverising plant.

The electrostatic precipitator consists of metal plates which are electrically charged. Dust and grit in the flue gases are attracted on to these plates, so that they do not pass up the chimney to pollute the atmosphere. Regular mechanical hammer blows cause the accumulations of ash, dust and grit to fall to the bottom of the precipitator, where they collect in a hopper for disposal. Additional accumulations of ash also collect in hoppers beneath the furnace.


coal
pulverised coal
condensate
steam
superheated steam
reheated steam
air
combustion gases
ash
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24
25

Steam raising—the nuclear reactor

The atom consists of a central nucleus having a positive electric charge around which, but relatively a great distance away, electrons having a negative charge revolve. The nucleus is made up of protons, each of unit positive charge and neutrons, which have no charge. Nuclear fission takes place when a free neutron strikes the nucleus of a fissile element, such as uranium 235. The nucleus splits into two particles, releasing energy which appears as heat. Several new neutrons are released by this splitting, some of these colliding with other fissile nuclei which also split and so produce a chain reaction. This process is controlled in a reactor.

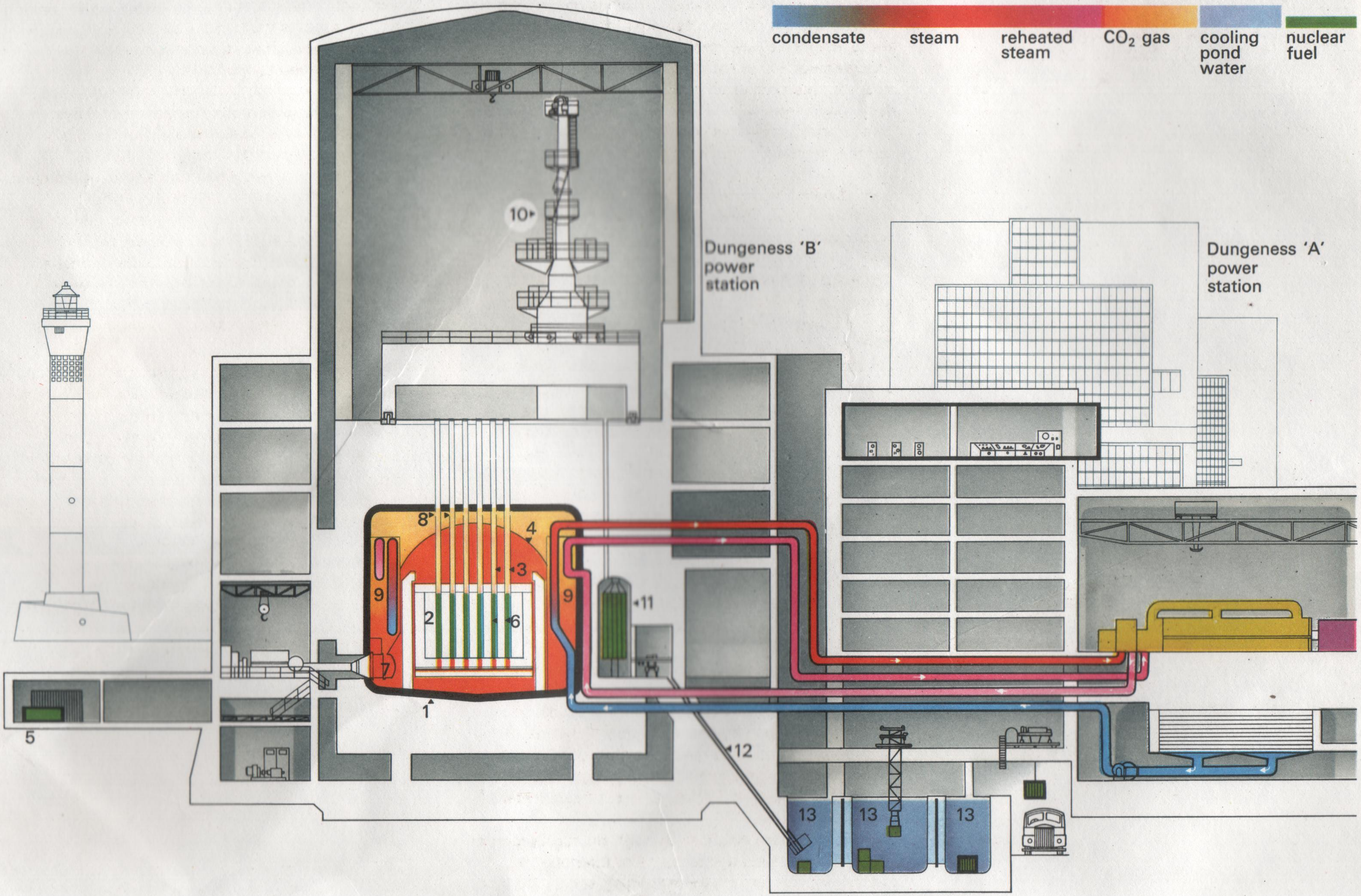
The first Advanced Gas-cooled Reactor (AGR) came into operation in 1976 at Hinkley Point 'B' power station, Somerset. The illustration shows an AGR of this type which is being completed at Dungeness, Kent. The reinforced-concrete, steel-lined pressure vessel 1 contains the reactor, boilers and ancillary equipment. The reactor consists of the moderator 2—a core of pure graphite constructed from thousands of separate graphite blocks and containing numerous vertical channels 3—surrounded by an inner pressure cylinder 4. The enriched uranium dioxide fuel which is used in the reactor is kept in a new fuel store 5 until required. It is in pellet form and is sealed in stainless steel cans forming a Fuel 'Pin'. A cluster of 36 of these pins is arranged in a graphite sleeve to form a 'Fuel Element'. Eight of these fuel elements are tied together to form a fuel stringer, one of which 6 is placed in each vertical channel of the core. Nuclear fission takes place in the fuel elements and the heat liberated is carried away by streams of carbon dioxide gas (CO$_2$) under high pressure. The gas is pumped by gas circulators 7 up through the vertical channels in the moderator, passing round the fuel stringers and leaving by ports 8 to enter the boilers 9 at the top, where it heats water to produce steam.

Once the steam has been through the high pressure stage of the turbine it is reheated in the boiler before passing through the remaining stages (as in a conventional power station). And again, after the steam has done its work in the turbine, it is passed into a condenser where it is condensed back to water and returned to the boiler.

A refuelling machine 10 is used to position and remove the fuel stringers in the reactor and the fission process is controlled at a desired level of activity by moving control rods (not shown) containing boron-steel, a neutron-absorbing material, in or out of the graphite core. The spent fuel stringers when removed from the reactor, are stored in a special chamber 11 for about a week. They are then dismantled and the separate fuel elements are lowered down a chute 12 into a pond of water 13 where they remain until their radio-activity has decreased sufficiently for them to be removed from the power station.

The Generating Board already has eight 'Magnox' nuclear power stations in operation. Basically similar to the AGR, they work at lower carbon dioxide gas pressures and temperatures and use natural uranium metal for fuel. Each fuel rod is enclosed in a magnesium alloy can, hence the name 'Magnox'. In these earlier types of reactor, the fuel pins are not bunched into groups but inserted singly into the channels in the graphite moderator.

The prototype gas-cooled reactor plants at Calder Hall, Windscale and Chapelcross, the Steam Generating Heavy Water Reactor (SGHWR) at Winfrith, and the 'fast breeder' reactor at Dounreay, are owned and operated by the United Kingdom Atomic Energy Authority. The electricity they generate is supplied to the national Grid.


condensate
steam
reheated steam
CO_2 gas
cooling pond water
nuclear fuel
Dungeness 'B' power station
Dungeness 'A' power station
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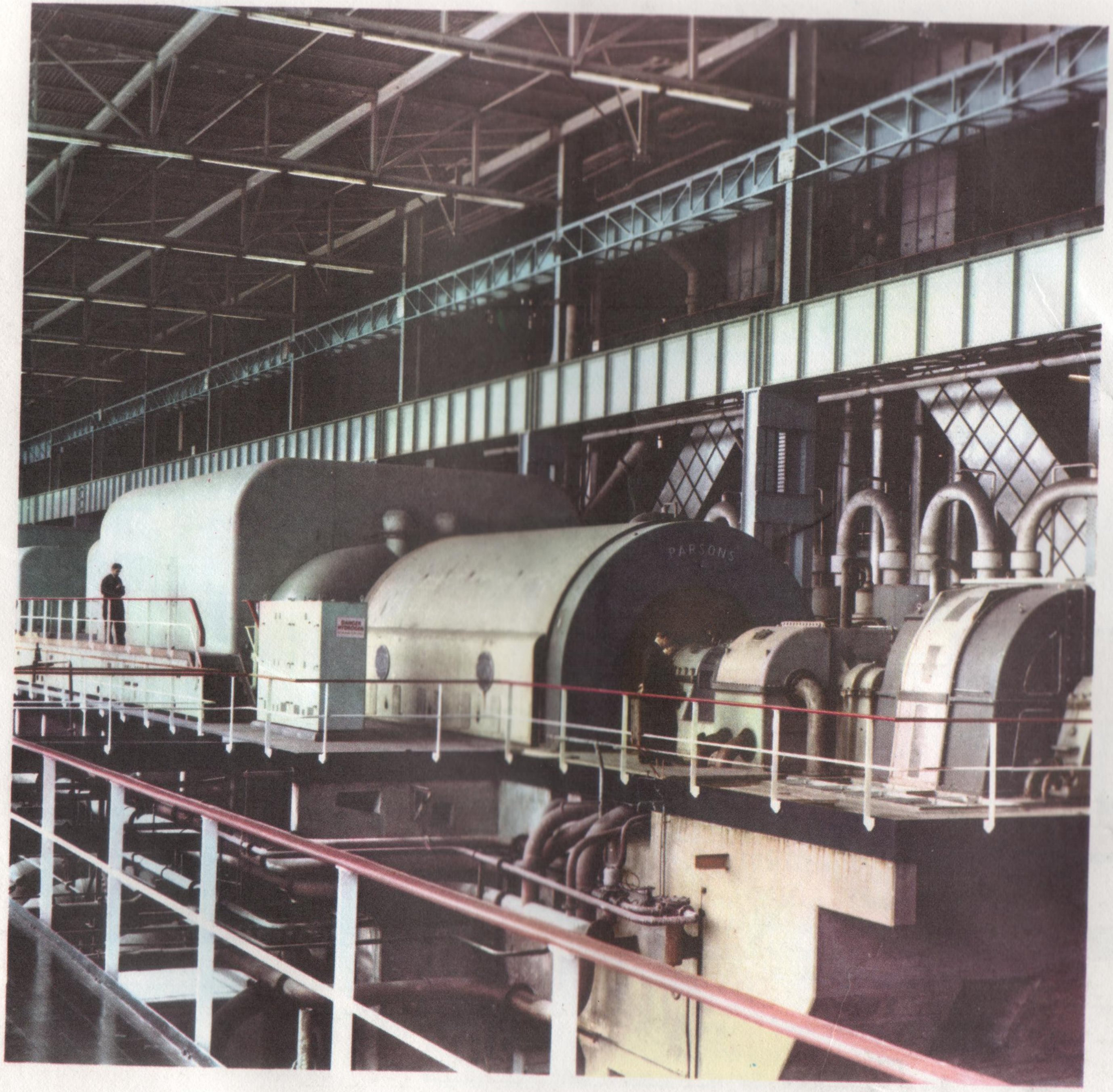
13
13
13



Turbine hall, Thorpe Marsh power station *(left)*
Sizewell nuclear power station, Suffolk *(right)*


L.T.4

Steam into mechanical power— the turbo-generator

From the boiler, a steam pipe 1 conveys steam to the turbine through a stop valve (which can be used to shut off steam in an emergency) and through control valves 2 that automatically regulate the supply of steam to the turbine. Stop valve and control valves are located in a steam chest and a governor 3, driven from the main turbine shaft 4, operates the control valves to regulate the amount of steam used. (This depends upon the speed of the turbine and the amount of electricity required from the generator.)

Steam from the control valves enters the high pressure cylinder of the turbine, where it passes through a ring of stationary blades 5 fixed to the cylinder wall 6. These act as nozzles and direct the steam on to a second ring of moving blades 7 mounted on a disc secured to the turbine shaft. This second ring turns the shaft as a result of the force of the steam. The stationary and moving blades together constitute a 'stage' of the turbine and in practice many stages are necessary, so that the cylinder contains a number of rings of stationary blades with rings of moving blades arranged between them. The steam passes through each stage in turn until it reaches the end of the high pressure cylinder and in its passage some of its heat energy is changed into mechanical energy.

The steam leaving the high pressure cylinder goes back to the boiler for reheating 8 and returns by a further pipe 9 to the intermediate pressure cylinder. Here it passes through another series of stationary and moving blades.

Finally, the steam is taken to the low pressure cylinders, each of which it enters at the centre 10 flowing outwards in opposite directions through the rows of turbine blades—an arrangement known as double flow—to the extremities of the cylinder.

As the steam gives up its heat energy to drive the turbine, its temperature and pressure fall and it expands. Because of this expansion the blades are much larger and longer towards the low pressure ends of the turbine.

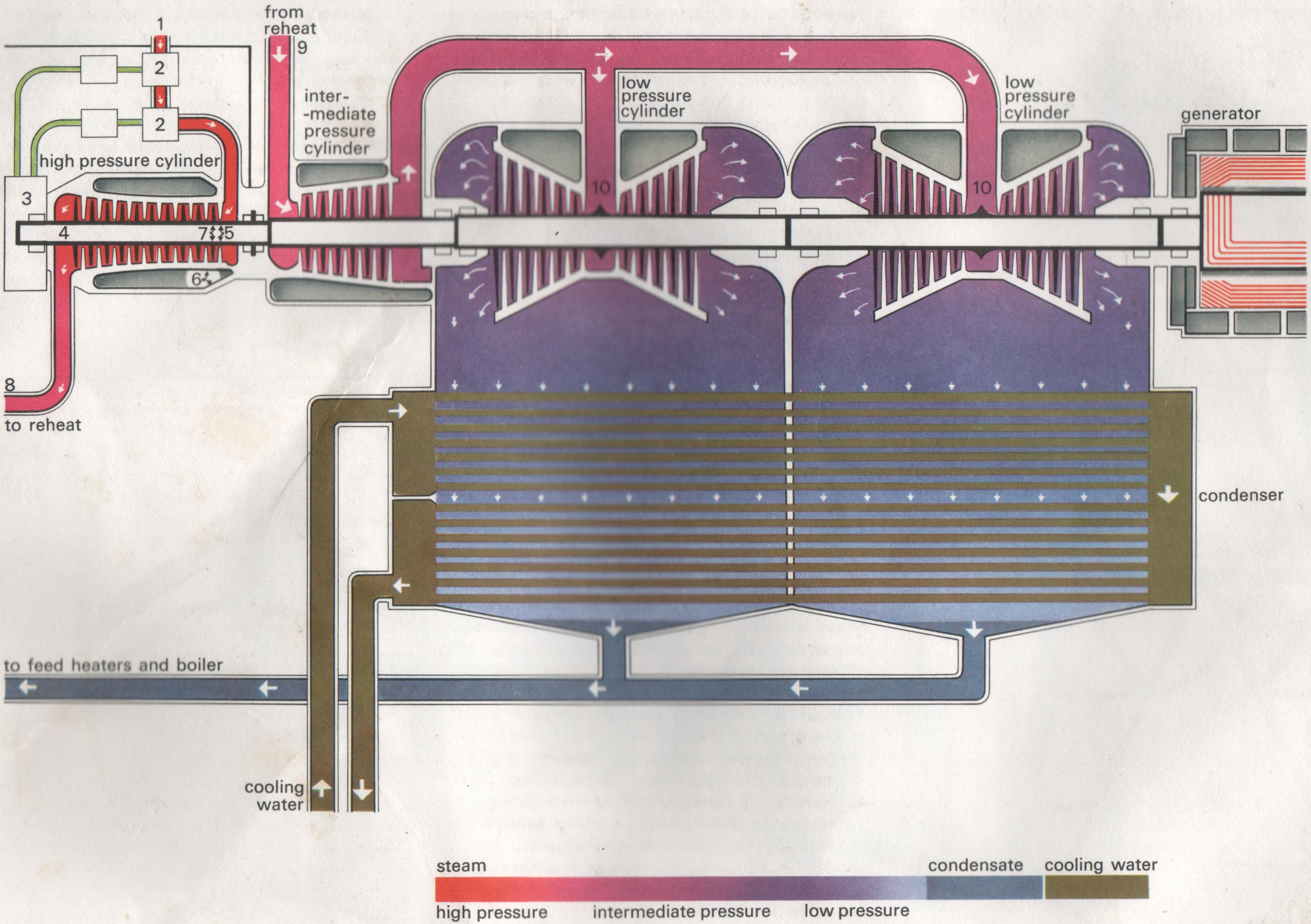
The turbine shaft usually rotates at 3,000 revolutions per minute. This speed is determined by the frequency of the electrical system used in this country and is the speed at which a 2-pole generator must be driven to generate alternating current at a frequency of 50 cycles per second.

When as much energy as possible has been extracted from the steam it is exhausted directly to the condenser. This runs the length of the low pressure part of the turbine and may be beneath or on either side of it. The condenser consists of a large vessel containing some 20,000 tubes, each about 25mm in diameter. Cold water from the river, estuary, sea or cooling tower is circulated through these tubes and as the steam from the turbine passes round them it is rapidly condensed into water—condensate. Because water has a much smaller comparative volume than steam, a vacuum is created in the condenser. This allows the steam to be used down to pressures below that of the normal atmosphere and more energy can be utilized.

From the condenser, the condensate is pumped through low pressure feed heaters by the extraction pump, after which its pressure is raised to boiler pressure by the boiler feed pump. It is passed through further feed heaters to the economiser and the boiler for reconversion into steam.

Where the cooling water for power stations is drawn from large rivers, estuaries or the coast, it can be returned directly to the source after use. Power stations situated on smaller rivers and inland do not have such vast water resources available, so the cooling water is passed through cooling towers (where its heat is removed by evaporation) and re-used.

A power station generating 2,000,000 kilowatts (kW) of electricity requires about 227,500 cubic metres of water an hour for cooling purposes. Where cooling towers are used, about one hundredth part of the cooling water evaporates and a certain amount is returned to its source to carry away any impurities that collect. Most of it, however, is recirculated.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6
8
from reheat
9
high pressure cylinder
inter-
-mediate
pressure
cylinder
low
pressure
cylinder
10
low
pressure
cylinder
10
generator
to reheat
condenser
to feed heaters and boiler
cooling
water
steam
condensate
cooling water
high pressure
intermediate pressure
low pressure

Switching and transmission—power to the Grid

Electricity is usually produced in the stator windings of large modern generators at about 25,000 volts and is fed through terminal connections to one side of a generator transformer 1 that steps up the voltage to 132,000, 275,000 or 400,000 volts. From here conductors carry it to a series of three switches comprising an isolator 2, a circuit-breaker 3 and another isolator 4.

The circuit-breaker, which is a heavy-duty switch capable of operating in a fraction of a second, is used to switch off the current flowing to the transmission lines. Once the current has been interrupted the isolators can be opened. These isolate the circuit-breaker from all outside electrical sources, so that there is no chance of any high voltages being applied to its terminals. Maintenance or repair work can then be carried out in safety.

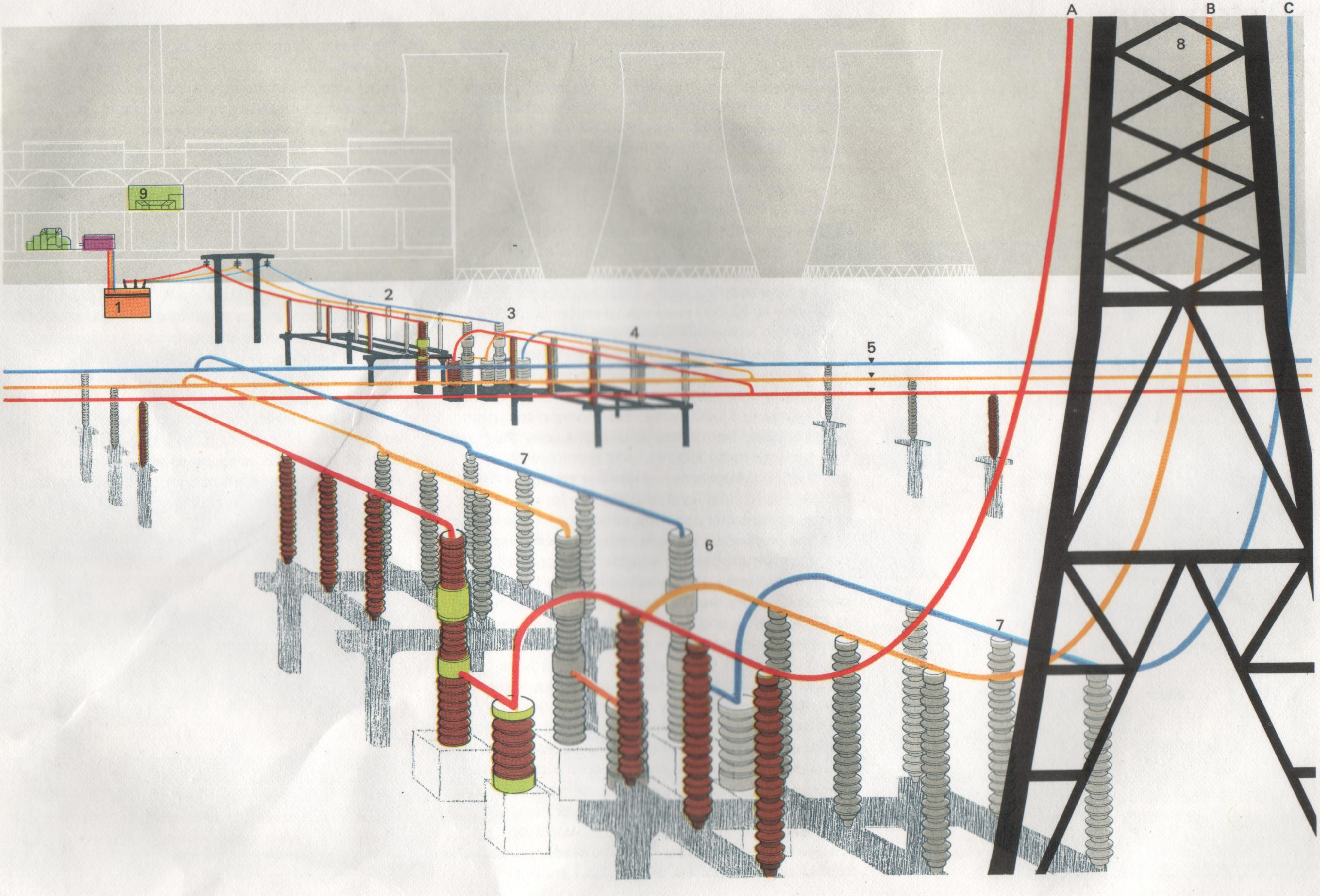
From the circuit-breaker the current is taken to the busbars 5 —conductors which run the length of the switching compound—and then to another circuit-breaker 6 with its associated isolators 7, before being fed to the Grid 8. Each generator in a power station has its own transformer, circuit-breaker and associated isolators but the electricity generated is fed onto a common set of busbars.

Circuit-breakers work like combined switches and fuses but they have certain special features and are very different from the domestic switch and fuse. When electrical current is switched off by separating two contacts, an arc is created between them. At the voltage used in the home, this arc is very small and only lasts for a fraction of a second but at the very high voltages used for transmission, the size and power of the arc is considerable and it must be quickly quenched to prevent damage.

One type of circuit-breaker has its contacts immersed in insulating oil so that when the switch is opened, either by powerful electrical coils or mechanically by springs, the arc is quickly extinguished by the oil. Another type works by compressed air which operates the switch and at the same time 'blows out' the arc.

Three wires are used in a 'three-phase' system for large power transmission as it is cheaper than the two wire 'single-phase' system that supplies the home.

The centre of the power station is the control room 9. Here engineers monitor the output of electricity, supervising and controlling the operation of generating plant and high voltage switch gear and directing power to the Grid system as required. Instruments on the control panels show the output and conditions which exist on all the main plant and a miniature diagram indicates the precise state of the electrical system.


A
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Distribution

The electricity generated at modern power stations is fed to the national Grid system from substations operating at 275,000 and 400,000 volts 1 and at 132,000 volts 2. It is carried to Grid supply points by means of transmission lines usually consisting of overhead conductors suspended from transmission towers. Three conductors make a 'circuit' and usually transmission towers carry two circuits. In the illustration however, all high-voltage circuits are shown as a single line for clarity. In many built-up areas underground cables are used instead of overhead lines. These are shown as dotted lines in the illustration.

At a Grid supply point 3, bulk supplies of electricity at 33,000 volts are taken for primary distribution in the towns and to industrial areas, groups of villages and similar concentrations of consumers. The lines are fed into intermediate substations 4 a, b and c, where transformers reduce the voltage to 11,000 volts. Secondary distribution lines radiating from these substations carry the power into the area to be supplied and terminate at distribution substations 5. Here the voltage is reduced to its final level of 240 volts for use in shops, commercial premises, schools and homes etc.

Some consumers use electricity in such quantities that they are supplied at a higher voltage than that used in the home. Heavy industries may have their own link 6 from the Grid supply point taking power at 33,000 volts, and light industries 7 and hospitals are often supplied directly from intermediate substations at 11,000 volts. The railways have special substations 8 alongside the tracks, drawing electricity from the Grid supply points—the latest rail electrification schemes working at 25,000 volts.

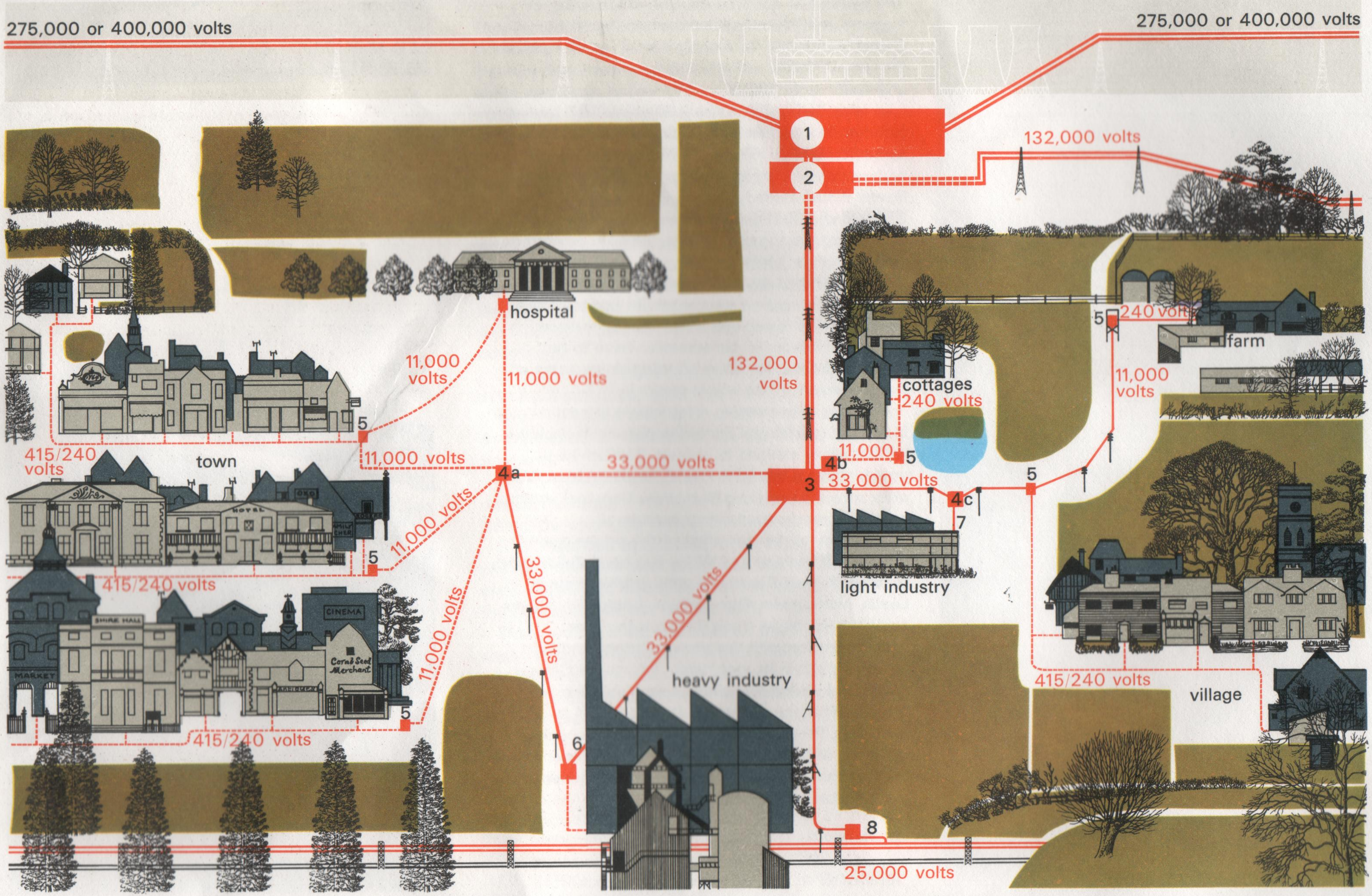
Where existing power stations are already close to consumers, as in London, the power is often fed into the local primary distribution network at 66,000 or 33,000 volts, connections to the Grid system also being made in case of breakdown.

The distribution of electricity must be arranged so that as far as practicable, supplies are not interrupted if there is a fault in one section of the system. How this is done is shown in the diagram: 33,000 volt lines run from the Grid supply point 3 to the intermediate substation 4 a and to the substation serving heavy industry 6. A further 33,000 volt line connects these two points together. If the direct connection to either substation breaks down, supplies can still be maintained by means of this connecting link.

This arrangement for securing supplies has widespread use throughout the transmission and distribution networks.

There is no fixed pattern for local distribution, the arrangement of substations and transmission lines being developed as a result of the requirements of the area. Sometimes an intermediate substation may be built beside a Grid supply point as in the diagram; occasionally, even the Grid supply point may be in the town centre.

In 149 years, electricity has developed from a laboratory experiment to an indispensable form of energy. Its uses are so widespread and important, and they are becoming so sophisticated, that without it modern civilisation would collapse.


275,000 or 400,000 volts
275,000 or 400,000 volts
1
2
132,000 volts
hospital
11,000 volts
11,000 volts
132,000 volts
cottages
240 volts
5
240 volts
farm
11,000 volts
5
415/240 volts
town
11,000 volts
4a
33,000 volts
4b
11,000
5
3
33,000 volts
4c
5
7
light industry
11,000 volts
5
415/240 volts
CINEMA
SHIRE HALL
HOTEL
MARKET
Corn & Seed Merchant
11,000 volts
33,000 volts
33,000 volts
heavy industry
415/240 volts
village
5
415/240 volts
6
8
25,000 volts

Generating and transmitting electricity

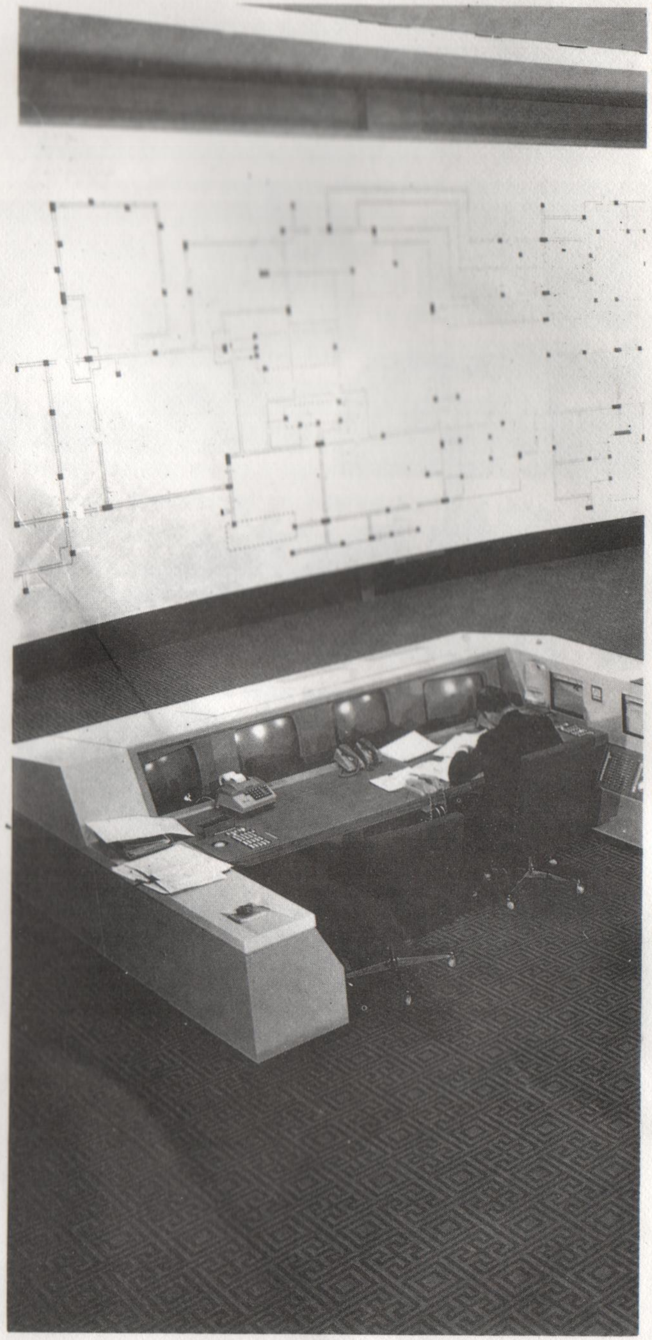
The generation and transmission of electricity in England and Wales is the responsibility of the Central Electricity Generating Board, which operates the largest power system under single control anywhere in the world.

In early 1979, this system comprised 131 power stations, able to meet a simultaneous demand of some 56,000,000 kW, and 7,800 route kilometres of high voltage transmission lines—the Grid system. Power is transmitted over the Grid at 132,000, 275,000 or 400,000 volts. More than 5,109 kilometres of transmission lines are now operating at the latter very high voltage.

Power stations generate electricity most economically when they operate 24 hours a day. However, as the demand for electricity is never constant, changes in consumption have to be balanced by starting up or shutting down some of the generators in the power stations.

The cost of generating electricity is the main factor that guides the control engineers in deciding which power stations to operate. Modern large power stations have the lowest running costs, the older and smaller generators away from fuel sources being the most expensive to operate.

To supervise the operation of the power stations, the area of England and Wales has been divided into seven with Grid Control Centres at Manchester, Leeds, Nottingham, Birmingham, Bristol, St. Albans and East Grinstead. Each Centre is in direct communication with the power stations and Grid Supply Points in its area, while a National Control Centre in London is in direct communication with all the Grid Control Centres. During the 24 hours of every day, this organisation is constantly checking the costs of generation, planning new generating programmes and issuing instructions for generators to be started up or shut down.



Organisation and employment

The Central Electricity Generating Board employs about 62,000 people with a wide variety of jobs. Electrical and mechanical engineers, chemists, boiler operators, turbine drivers, fitters, crane drivers, instrument mechanics, clerks, typists, cooks, receptionists, telephone operators and other workers are employed at power stations.

More specialist engineers plan and design new stations and transmission lines and develop the complicated telecommunications network necessary to control the whole system. Architects work on the outward appearance of new power stations whilst landscape architects develop the sites and routes for transmission lines so that the finished structures blend into the surrounding countryside.

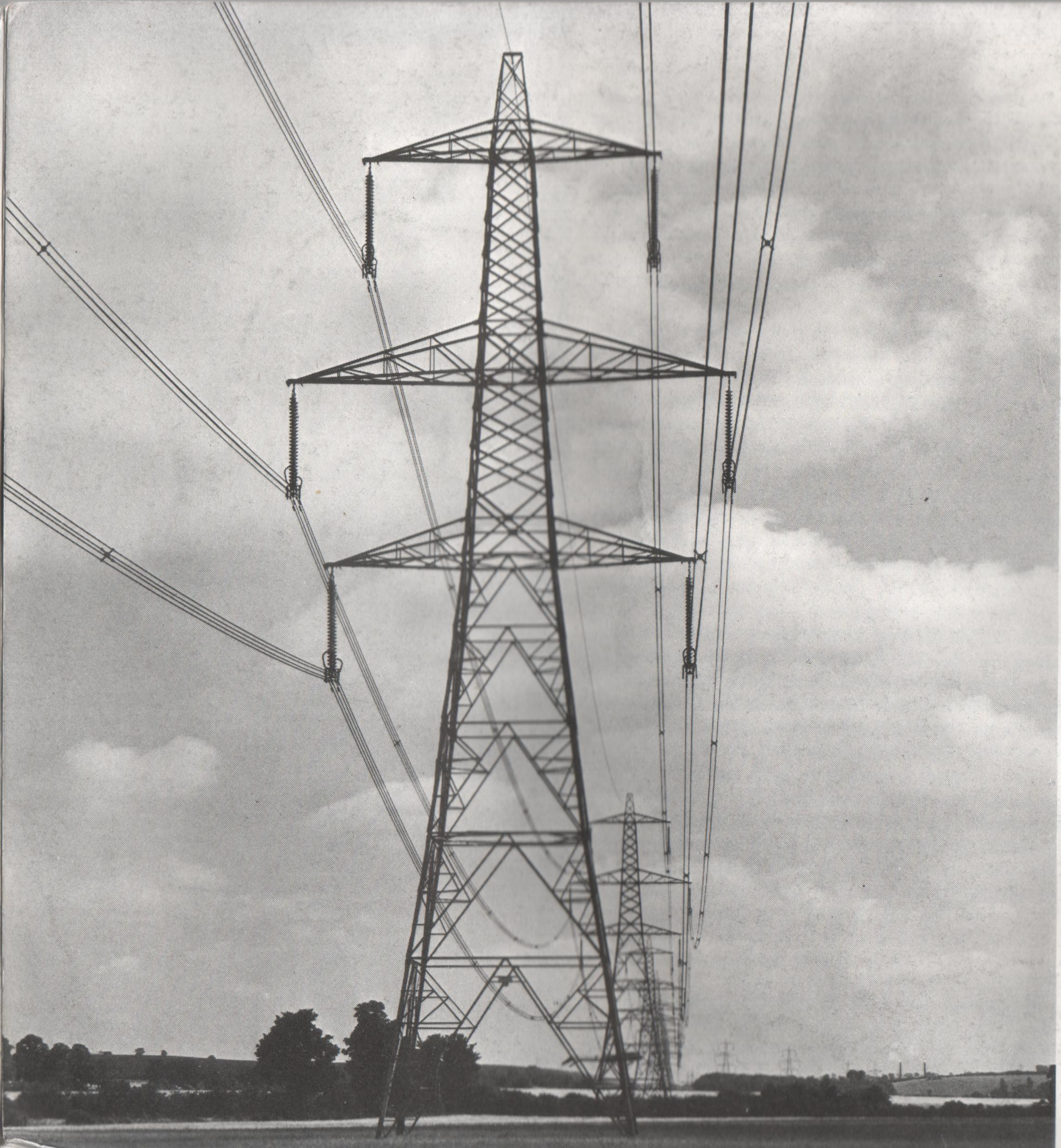
Wayleave officers are responsible for discussions with local authorities about the routes for new transmission lines, and for negotiating with all owners and occupiers for the right to run the lines over their land.

Highly skilled linesmen and other construction workers build the transmission towers and then 'string' the electricity conductors between them.

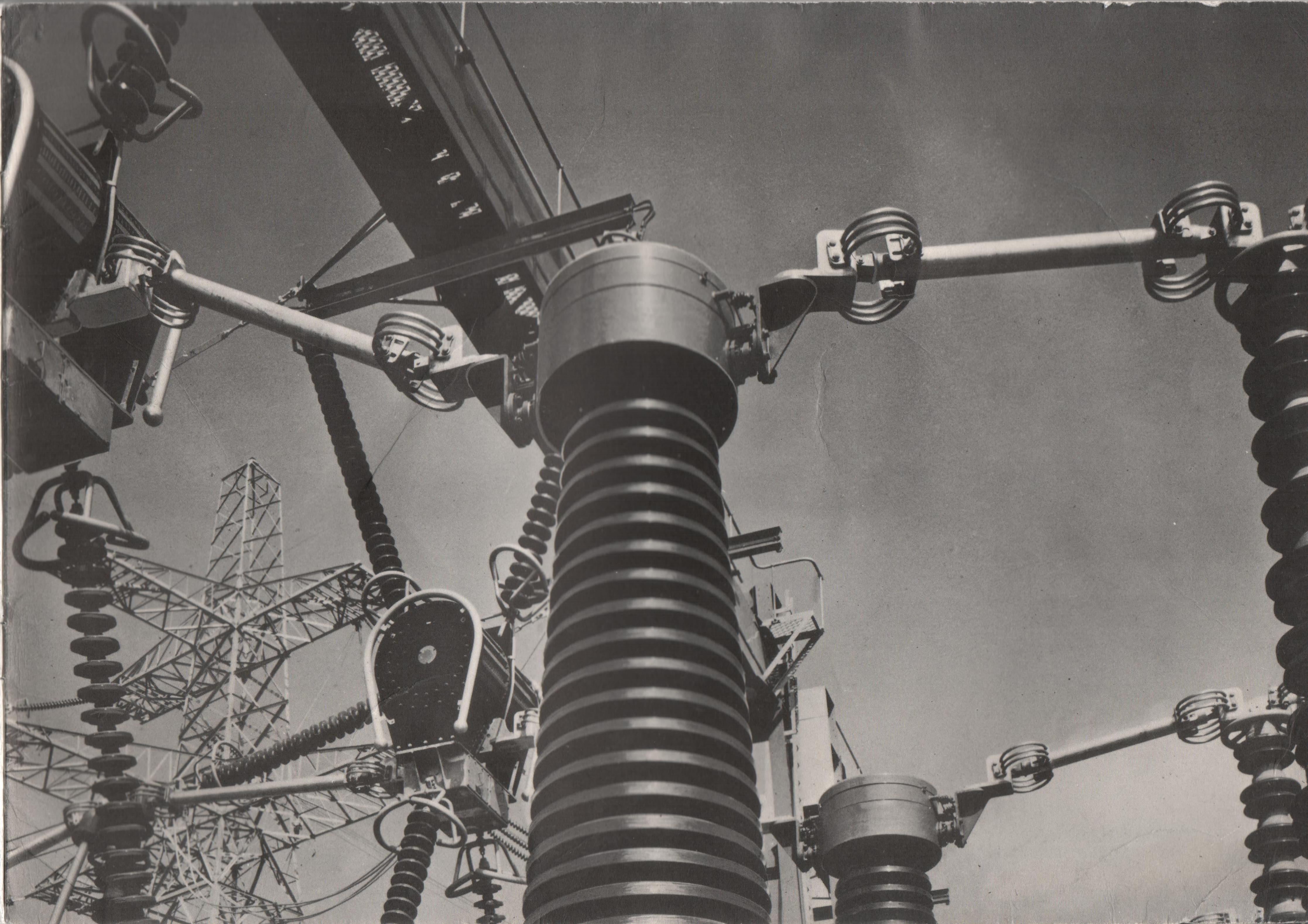
In the research laboratories, more engineers and chemists, together with physicists, mathematicians, metallurgists and biologists, work in company with the administrative and welfare staff.

There are many opportunities for people without engineering backgrounds. Accountants, medical and catering staff, solicitors, librarians, photographers and other specialists work for the industry and there are always openings for secretaries, typists and clerical staff.

National Control Centre, London (*left*)
Fuel being stored in buffer storage tubes during the fuelling of No. 4 reactor at the 1,320 MW AGR, Hinkley Point B power station in Somerset *(right)*.



Suspension towers on the CEGB's
Sizewell-Sundon 400,000 volt transmission line.



Enquiries to: ■for further copies; □for details on careers and training:

■Director of Information
□Education and Training Officer
Central Electricity Generating Board
Sudbury House 15 Newgate Street
London EC1A 7AU

■Regional Public Relations Officer
□Regional Personnel Manager
Bankside House Sumner Street
London SE1 9JU

■Regional Public Relations Officer
□Regional Personnel Manager
Bedminster Down Bridgwater Road
Bristol BS13 8AN

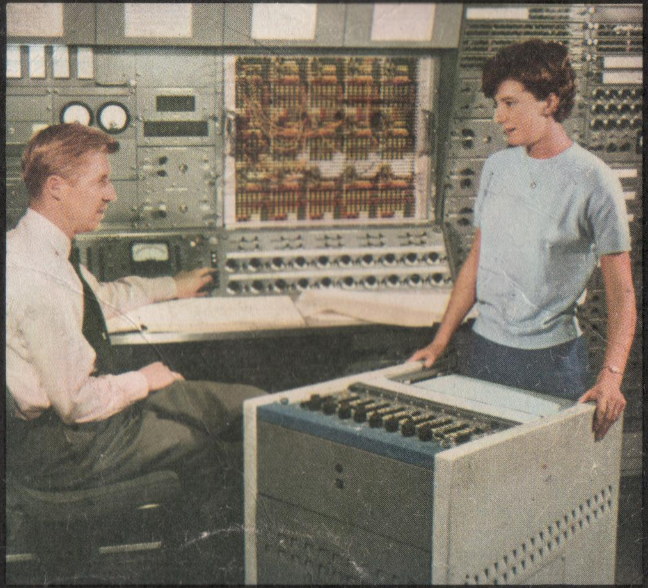
■Regional Public Relations Officer
□Regional Personnel Manager
Haslucks Green Road Shirley
Solihull West Midlands B90 4PD

■Regional Public Relations Officer
□Regional Personnel Manager
Europa House Bird Hall Lane
Cheadle Heath Stockport SK3 0XA

■Regional Public Relations Officer
□Regional Personnel Manager
Beckwith Knowle Otley Road
Harrogate HG3 1PR

■Divisional Public Relations Officer
□Divisional Personnel Officer
Generation Development and Construction Division
Barnwood Gloucester GL4 7RS

■Divisional Public Relations Services Officer
□Divisional Personnel Officer
Transmission and Technical Services Division
Burymead House Portsmouth Road
Guildford Surrey GU2 5BN



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