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MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Application of Air Pollution Research to Power Station Design

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The application of air pollution research to power station design

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The aim of this contribution to the Meeting is to describe how the results of research work have been applied to the design of power stations in Britain. Before doing so, however, it is perhaps worth while giving an outline of the fundamental principles involved in the selection of air pollution control measures as they are seen by the engineers who must make practical decisions on plant design, and in this way define the specific objectives for the research work being undertaken.

First, it must be appreciated that unless one accepts an exceedingly narrow definition of what constitutes air pollution, then clean air must be regarded as a matter of degree and not of kind. All sorts of naturally occurring gases and particulates pollute the atmosphere, even in places remote from mankind's industrial and domestic activities. Volcanic dust and ashes, sulphur dioxide and other gases of geophysical origin, wind-blown dust, residues of sea-spray, pollen, spores, ozone, ammonia and many other substances exist quite naturally in the air we breathe. What constitutes an air pollution problem is the occurrence of pollutants in unduly high concentrations in a particular place or at a particular time. As a corollary of this, the aim of air pollution control measures is to prevent such high concentrations from occurring.

This principle is fundamental to the whole concept of air pollution control, since once it is accepted then practical control measures need not necessarily be restricted to the prevention of the emission of pollutants, but can include also the manner of emission, in so far as this can influence subsequent concentrations of pollutants in the atmosphere.

In the case of a single elevated source of continuous emission, such as a power station chimney, the basic relation defining the concentration in the atmosphere in the vicinity of the source—which can be derived from little more than the equation of continuity—is

$$C \propto Q_2/H,$$

where C is the concentration of the emitted pollutant, Q is the rate of emission and H is the height of emission. Thus it can be seen at once that there are three possible ways of limiting the concentrations from a particular source; reducing Q, the rate of emission; increasing H, the height of emission, or doing both together. In power stations all three methods are adopted in the selection of control measures for different potential pollutants, the choice being determined by the practicability and cost of the alternative techniques available.

This point has been emphasized because there is a widespread feeling that, in the field of chimney emissions, prevention is better than dispersion, although the argument presented above does not support this view. In this instance, a common objective can be reached by alternative routes and the principal consideration could, or should be, to reduce pollutant concentrations to an acceptably low level at the minimum cost to the community.

Having said that, however, it is necessary to mention that the legislative control to which power station emissions are subject does, in fact, place primary emphasis on the prevention of emission, and that it is therefore necessary for the C.E.G.B. to take this bias into account in their clean air policies, even though the logical foundations may be shaky.

The objectives of research on power station emissions can thus be defined as a search for more effective, more reliable or less costly ways of either reducing the rate or increasing the height at which potential pollutants are emitted to the atmosphere.

Taking first the most easily discernible pollutant, which is dark smoke, the aim of research has been to eliminate this at source, that is to reduce Q, the rate of emission, to the lowest possible value. The incentive for research in this case is not wholly or even mainly that of cleaner air—there is the more mundane necessity to avoid wasteful use of costly fuel, since dark smoke is an admission of inefficient combustion. The loss of as little as 1 % of the carbon in the fuel at one of the Board's larger power stations would represent an increase in the annual fuel bill of more than £150 000. Because of this commercial incentive a detailed discussion of research on burner design, combustion air control and flame stability would be rather out of place in the present Meeting, but all have contributed to the virtual elimination of dark smoke from modern power stations under all but exceptional conditions.

Turning now to grit and dust, the objective has been to reduce the rate of emission to the lowest practicable value by the use of efficient dust arrestor plant. The residual fraction of dust which escapes the arrestor plant is dispersed in the atmosphere from high chimneys. Dust emission control, therefore represents a case where dual measures are taken involving both Q and H in the relation given earlier. Another contribution to the Meeting discusses in greater detail research on improvements to arrestor plant design.

Smoke and dust emission have only been dealt with briefly since the research problems in these fields have been mainly practical ones of improving the design of available hardware, although the development of basic theory has progressed in parallel. The main interest centres on the third major form of potential pollutants. These are the gaseous pollutants, characterized by sulphur dioxide, where control is, at present, almost wholly effected by high level dispersion, that is by controlling H, the height of emission. This is, in part, because no satisfactory solution has yet been found to the problem of economically reducing the rate of emission of these pollutants, although, some progress is being made in this direction. It is also the case, however, that research has shown high level dispersion to be an eminently successful way of controlling concentrations, so that the incentive is somewhat lacking to develop novel and possibly costly techniques to do the same job another way, with all the attendant technical and financial risks. The removal of SO_2 from the flue-gases would entail the addition of a major chemical–engineering complex on a power station site and this may succeed only in creating more clean air problems than it solves.

The current method of dealing with gaseous pollutants, as stated above, is by high level dispersion. When dealing with an emission which is appreciably hotter than its environment, which is the case with power station flue gases, the height of emission, H, becomes more complicated with the introduction of thermal plume rise and its dependence on many operational and environmental factors. One important research result, foretold by theory and confirmed by experiment, has been the dependence of plume rise on the heat content of the emission. For a given generating capacity, plume rise can therefore be maximized by concentrating all the flue gases into a single chimney. Despite some material engineering problems with the single chimney principle—the solution of which has led to the multiflue design and a substantial increase in cost—nearly all the new power stations planned since 1960 have been provided with a single chimney.

To illustrate this change, figure 1 shows the last of the previous generation of power stations, the 2000 MW 'C' at Ferrybridge, which in common with many stations before it, has two chimneys, in this case 198 m high. Figure 2 shows the similar capacity station at Eggborough, which was the

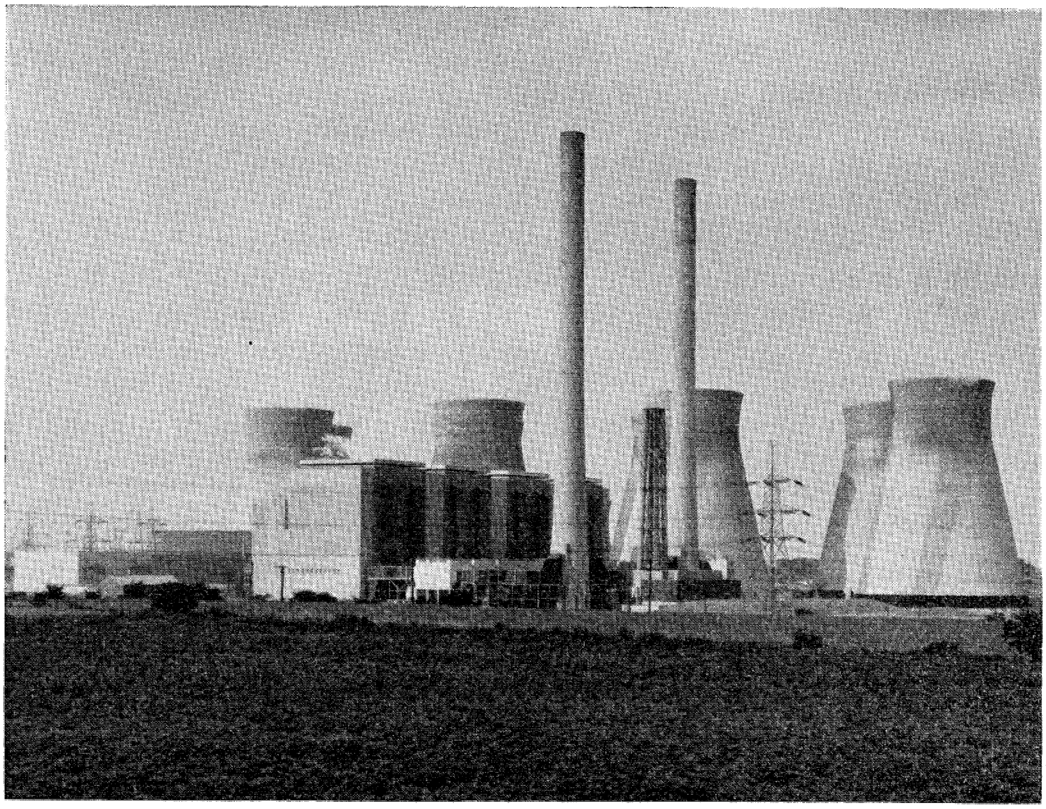

FIGURE 1.

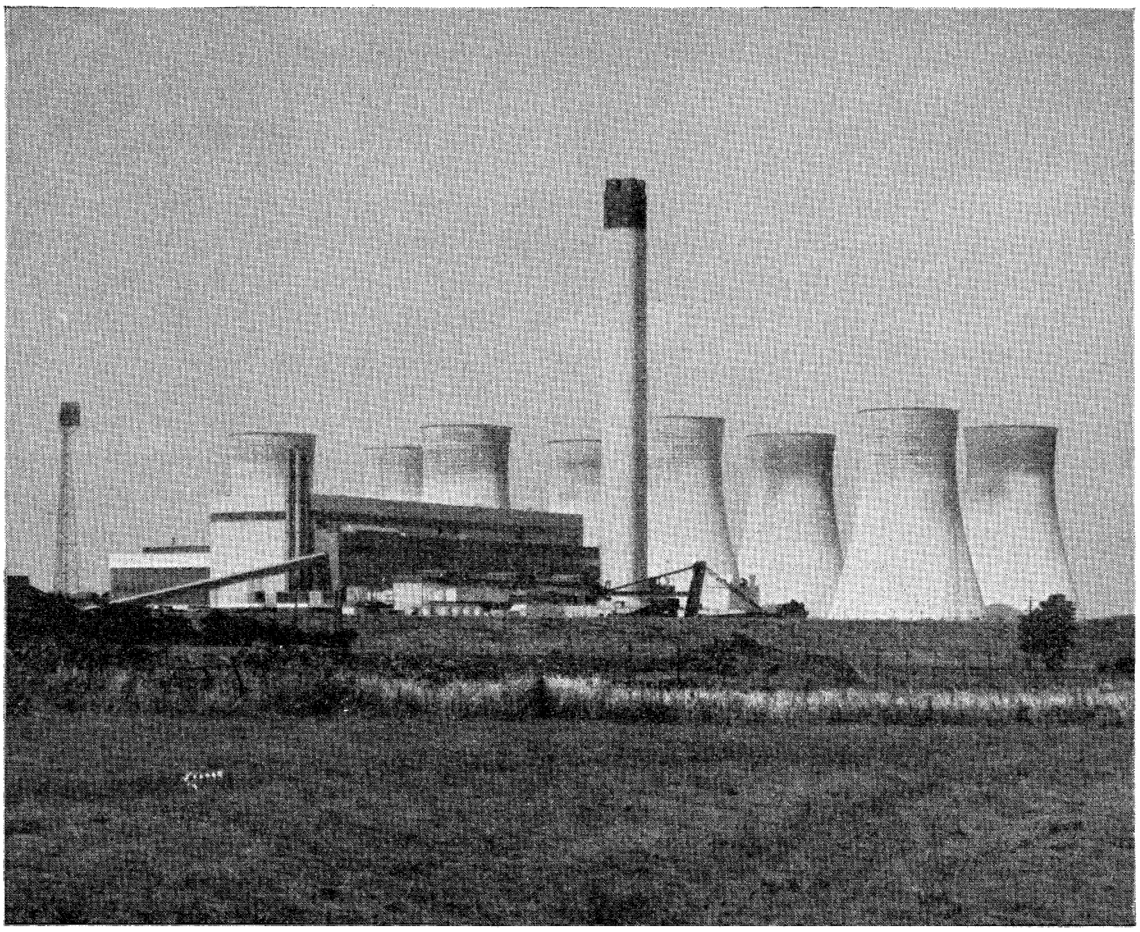

FIGURE 2.

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first to be planned with a single multiflue chimney, also 198 m in height. As a result of this change in design, it is anticipated that the plume rise at Eggborough will be nearly 20 % greater than that at Ferrybridge, and because the height of emission, H, appears as the second power in the relation given earlier, the effect in reducing concentrations in the atmosphere will be substantial.

This is but one illustration of the application of research results to the practical design of power stations. Many others could be instanced. It is, however, an unfortunate fact of economic history that the more detailed results of basic research on chimney emission behaviour are beginning to emerge just at the time when nuclear power has successfully challenged the older sources of energy. It is, in fact, doubtful whether the Generating Board will now reap the full benefit of the research it has undertaken on chimney emissions, although out results are, of course, available to other countries who have not yet reached the same turning point.

There is, however, another facet of this research which has played, and will continue for a while to play a very important role in the development of effective pollution control measures. Chimney design is one field where the engineering application of new principles has preceded—sometimes long preceded—detailed scientific investigation. Power stations have had to be built and decisions have had to be taken on the design of chimneys even when the available data on which to base decisions has been sketchy. In this situation the engineer must relay mainly on judgement and experience and the application of these skills relies on a detailed knowledge of how effective his past decisions have been. The Generating Board has therefore always maintained a very full programme for monitoring air pollution in the vicinity of operational power stations, and has thus built up a unique body of information on the actual results achieved in practice. To the research worker the mere collection of data is at the best, a humdrum task, hardly to be classified as research. To the engineer this data has been invaluable; not only has it enabled him to check the validity of his past decisions, but a suitable presentation of the data can frequently convince others that he knows what he is doing.

These remarks, have, perhaps, tended to emphasize the differences in approach between the scientist and the engineer to the subject under discussion and this is quite intentional, since many misunderstandings can arise if these differences are not appreciated. Air pollution control is and may always remain, a field where scientific accuracy is difficult to achieve. In the first place—bearing in mind that clean air is a relative term—we do not really know the goals for which we are aiming, since research on the adverse effect of air pollution has provided remarkably few guidelines on the concentrations of air pollutants that can be regarded as acceptable, and even these are frequently subject to controversy. Similarly, the prediction of the quantitative effect of a new source of emission will probably continue to require fairly wide confidence limits. In this situation a decision on, say, the height of a new chimney must contain a good deal of subjective judgement based on past experience. It is possible to compile a list of nearly 20 factors which have been found relevant to the choice of chimney height for a new power station. By no means all of these are directly related to the performance of the chimney in terms of pollutant concentration and the list also includes economic, legislative, social and even, in the broadest sense, psychological factors. It is therefore not surprising that the research worker may sometime feel aggrieved that the results of his considerable efforts do not appear to be having much influence on practical design decisions. Nevertheless, research on all aspects of chimney emissions has played a very considerable part in achieving the position today, where there is wide agreement that modern power stations can operate without making any material addition to the general levels of pollution in the areas in which they are situated.

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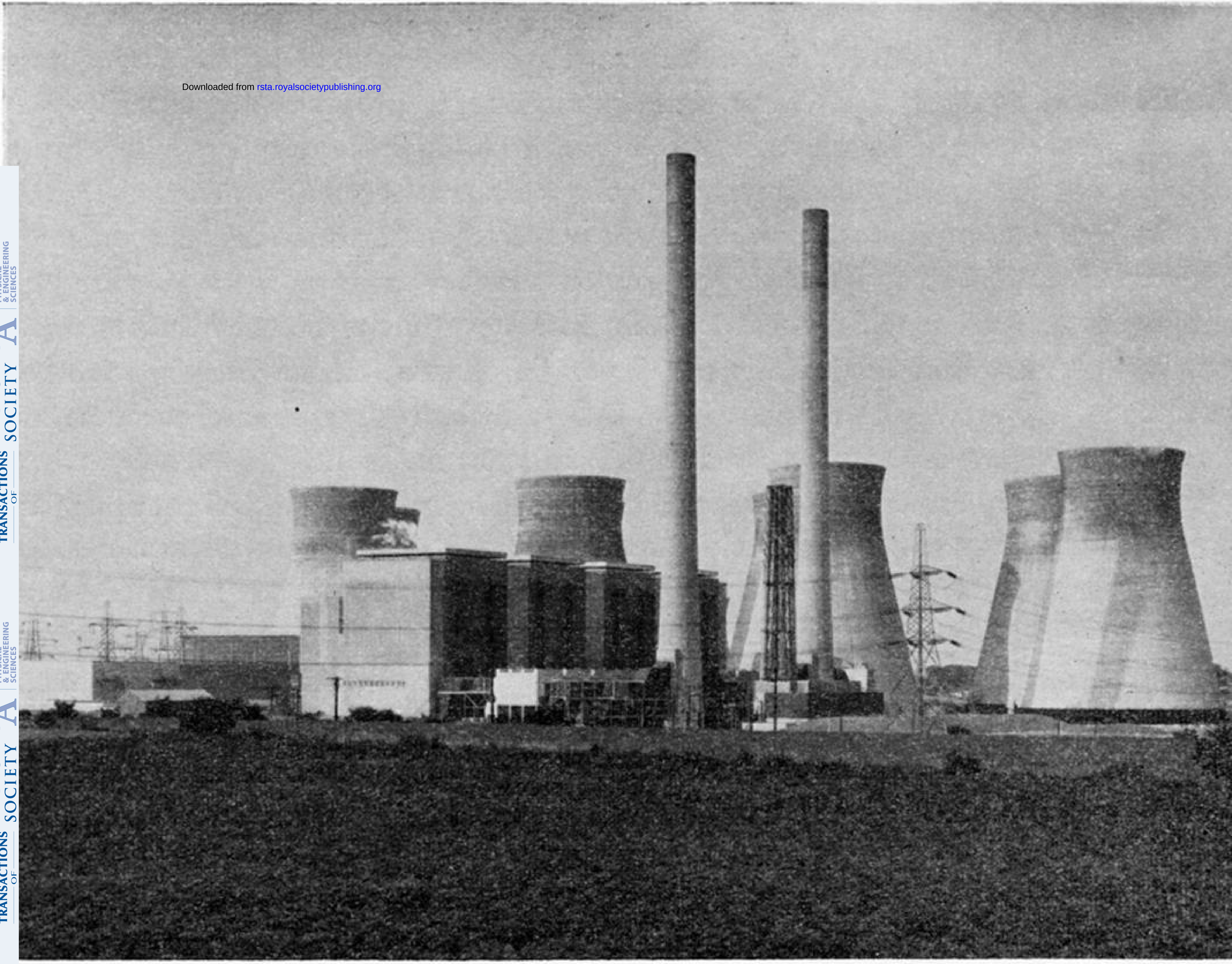

FIGURE 1.

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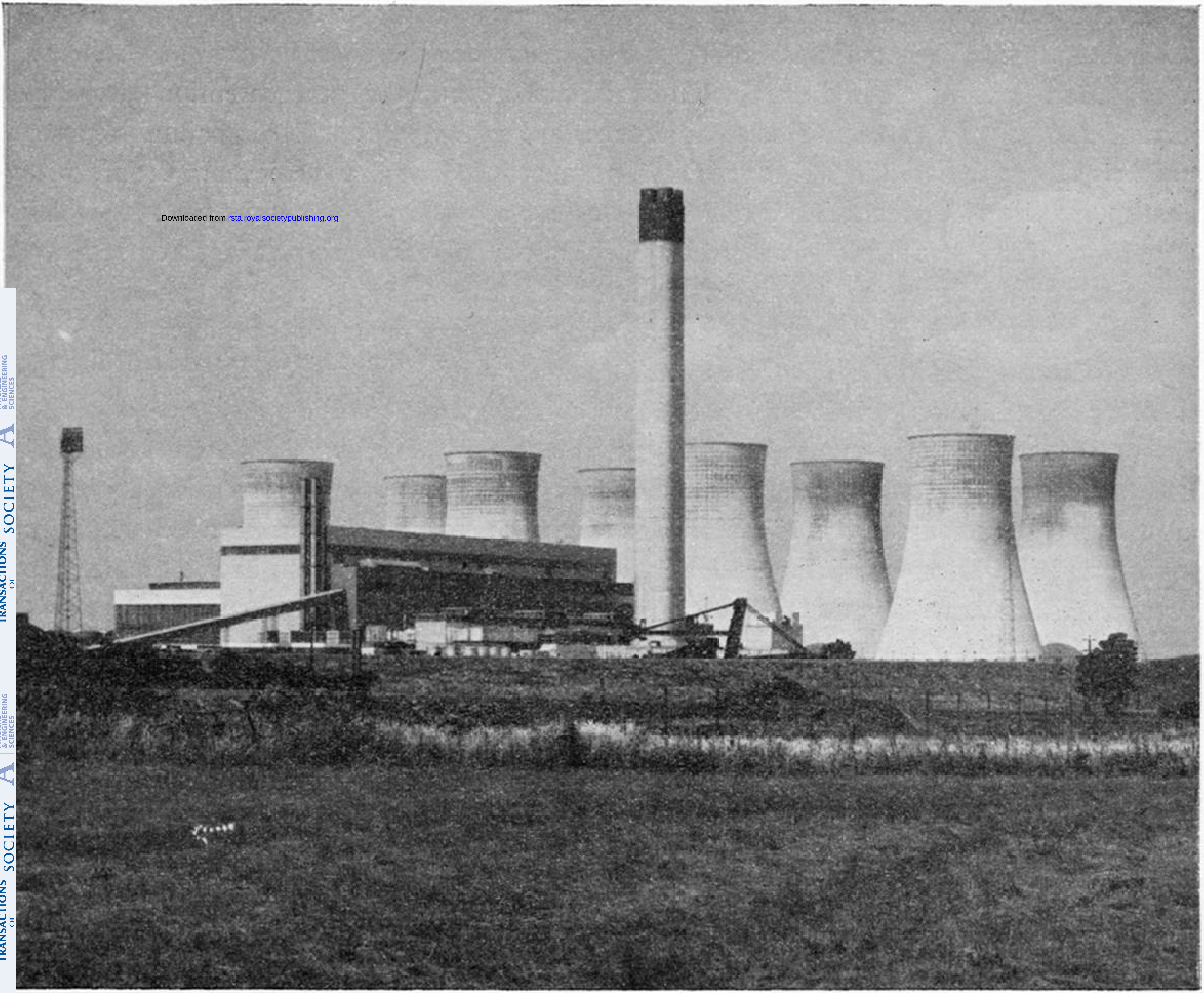

FIGURE 2.

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