17. N. G. Stewart, *et al.*, "The radiological dose to persons in the United Kingdom due to debris from nuclear test explosions". A.E.R.E., Harwell Report No. HP/R. 1701, 1955.
18. R. M. Sievert and B. Hultqvist, "Variation in natural gamma radiation in Sweden". Acta Radiol, Stockholm, vol. 37 (1952), p. 388.

The Paper, which was received on 20 July, 1956, is accompanied by three photographs and two diagrams from some of which the Figures in the text have been prepared.

CORRESPONDENCE on this Paper should be forwarded to reach the Institution before 15 January, 1957. Contributions should not exceed 1,200 words.—SEC.

Discussion

The Author introduced the Paper with the aid of a series of lantern slides.

The Chairman, opening the discussion, said that although a number of experts were present, he thought that most of the audience, like himself, knew extremely little about the subject—although it was of the utmost importance from the point of view of public health engineering. At first glance, it was somewhat disturbing to read in § 2 that less than one-millionth of a curie of many radioactive materials was potentially lethal, and yet a world holding of 100,000 million curies was foreseen; if the population of the world of about 2,500 million were to receive an even share of that radioactivity, it would appear that there was a potential lethality sufficient to destroy the entire human race 40 million times over. He was comforted by the Author's statement that such a distribution was impossible. Of the very small fraction discharged to the sea, much would remain at the bottom in any case; equally it had to be remembered that there was already an enormous quantity in the sea under natural conditions.

97. It was also comforting that the very dangerous problem was in the hands of people who were carrying out their work with great thoroughness and who understood so well what they were doing. It was impossible not to be impressed by the immense amount of work which had been carried out in such a short time, starting absolutely from scratch. It was, of course, in keeping with the tempo of the development of the atomic energy programme. That programme was being constantly expanded, and where it would all end was anybody's guess. Already there was a wide gap between the production of power from coal and the total energy requirements of the country, a gap which at the moment was being filled largely by oil, the supply of which had proved rather vulnerable, so that still further pressure might be brought to bear for the development of atomic energy.

Mr R. J. Sherwood (Operations Group, Health Physics Division, U.K.A.E.A., Harwell) referred to § 68, in which the Author had stated that in the theoretical approach no allowance had been made for the discharge velocity of the effluent or its temperature, both of which increased the effective stack height. A report by Stewart[19] on effluent from the BEPO reactor at Harwell showed that, in that particular case, with a 200-ft stack, the gases usually rose to about 400 ft in a 15 m.p.h. wind. The Harwell work had been carried out after the theoretical assessment referred to by the Author had been made, and it showed that an extra factor of safety had been introduced. It had also been found that, owing to the influence of surrounding buildings at Harwell, at wind speeds higher than 30 m.p.h. the plume might be deflected towards the ground. Had the Author

[19] N. G. Stewart, H. J. Gale, and R. N. Crooks, "The atmospheric diffusion of gases discharged from the chimney of the Harwell pile (BEPO)." A.E.R.E. Report HP/R 1452.

made any recent observations at Windscale which confirmed the theoretical figures mentioned earlier in §§ 68 and 69?

99. Mr Sherwood presumed that Table 2 referred to particulate activity and not to argon. Was argon assessed? He assumed that the levels quoted were for long-lived activity; otherwise it appeared from comparison with § 40 that the activity associated with radioactive dusts had fallen by a factor of about 10 after the plant had come into operation. Mr Sherwood imagined that in practice the radon and thoron had been allowed to decay. The Author had quoted levels in the plume and in samples taken away from the plume. It was surprising to find that he had obtained the quoted level of $6{\cdot}8 \times 10^{-13}$ μc/cc. for long-lived beta-activity in areas away from the plume itself, for that was considerably more than was naturally present in the atmosphere. Might it be that bomb-debris was responsible? From Bosanquet's Paper[15] it could be deduced that the ratio between peak concentration in the plume (at ground level) and the concentration in the whole area at the same radius around the site should be about 30. Since the routine samples quoted excluded those taken in the plume, one would expect a ratio considerably greater than 30, rather than the factor of 10 suggested by the Author. Mr Sherwood wondered whether the discrepancy in the suggested factors might be accounted for by activity which did not arise from the plant operation.

100. Could the Author assess the accuracy of the theoretical predictions and the wind-tunnel work in the light of subsequent experience? From the Paper it was not immediately obvious how close the final results were to those predicted.

Mr W L. Templeton (Senior Scientific Officer, Research and Development Branch, U.K.A.E.A., Windscale Works, Cumberland) compared the sea disposal of sewage and the sea disposal of radioactive effluent. The first stages of planning followed similar lines. It was desired to give good initial dilution (whether of sewage or of radioactive effluent), using depth of water and multiple outlets and also to achieve adequate dispersion (either of the sewage or of the radioactive effluent) using the tidal currents of the coast. The difference was that, whereas in 2 or 3 days the pathogenic organisms in the sewage were killed in the sea-water, in the case of radioactivity the total amount which was discharged was not reduced in any way, but was only dispersed. That emphasized the point that the most important aspect of the work was the biological concentration. There was a continuous biological and a physical concentration, so that despite the good dilution and good dispersion in the sea it was also necessary to take account of the biological concentration taking place in fish, in seaweed, and in shellfish, which might be in the direct food chain to man.

102. That applied also to the gaseous effluent problem. Carbon dioxide or carbon monoxide could be discharged from an ordinary factory stack, and with good dilution the result was quite satisfactory. But with a radioactive effluent the position was different; the Author had quoted a survey on iodine 131 from the chemical plant, where milk had been sampled. Why had milk samples been examined? It was because of the biological concentration of the iodine 131 in the vegetation, which in time was eaten by cows and was returned to man in milk.

103. It was very important always to bear in mind the possible return to man of the liquid and gaseous effluents disposed of round about those sites. In the case of liquid effluent a large percentage was diluted in the Irish Sea and dispersed into the Atlantic Ocean but some remained on the bottom mud of the sea, and, as the Author had pointed out, that was the habitation of small animals, invertebrates, which formed the food of fish, and the fish were caught and eaten in quantity. The larger the number of sites used, the greater the amount of effluent which would have to be disposed of into the sea. A very close watch would have to be kept on the position, remembering that some of the radioactivity was being returned to man and was not destroyed, as happened when raw sewage was disposed of in the sea.

Mr H. Howells (Manager, Health Physics Division, U.K.A.E.A., Windscale Works) referred to the measurements made at Windscale. When dealing with radioactive effluent the primary concern was the chemical plant, which processed the irradiated fuel elements. The radioactive effluent arising from reactor operation was trivial by comparison; there was a difference of four or five orders of magnitude between the two. On that basis the siting of a chemical plant had to be considered very carefully, because adequate facilities had to be provided for the safe disposal of the effluent which arose; on the other hand, power reactors could be sited for near optimum utilization of their electrical outputs.

105. The problem of effluent disposal was not a new one, but in the case of radioactive effluents it was particularly difficult owing to the extremely toxic nature of the waste which arose. To illustrate that point, the maximum permissible concentration in air of sulphur dioxide was about 1 part in 10^5 parts, whereas in the case of a number of radio-isotopes only about 1 part in 10^{15} parts was permissible; the difference between the two cases amounted to ten orders of magnitude.

106. The experience obtained at Windscale was particularly important, since it was a chemical plant dealing with irradiated fuel elements and which had now been in operation for 4 or 5 years. For that reason the information which the Author had presented provided a background of knowledge which was essential for any future work in the field.

107. When considering effluent disposal in general, there were two main techniques which could be adopted. Either the toxic element could be isolated and kept in storage or alternatively the noxious component could be diluted by dispersal in the sea or in air. Those were the two classical methods of disposing of effluent; both were used at Windscale. The bulk of the radioactive effluent was stored permanently and the remainder—the relatively low-activity liquid effluent—was disposed of by pipeline to the sea. That was a dilution technique, which was applied also to the gaseous effluent, which was diluted by high stack emission.

108. So far as the highly-active effluent was concerned, it was possible and desirable to reduce the bulk to the absolute minimum for storage purposes, since obviously it was an expensive technique to adopt. The Author described how to some extent it was effected by evaporation. Alternatively; and more elegantly, an attempt was being made to remove some of the more noxious radio-isotopes, such as strontium 90 and caesium 137. If those two were removed, the remainder of the radioactive elements in the waste would decay by a factor of about 1,000 in 10 years, so that storage need not be permanent, and eventually it might be possible to dispose of them to sea by the dilution technique.

109. So far as public health was concerned, it was the effluent which was disposed of by dilution which was important. The importance of the initial radiological survey to provide a datum or reference for future measurements had been demonstrated at Windscale. It was important, after start-up of plant, that those environmental surveys should be continued, so that any ecological changes which might occur in the district would be detected. That was particularly important in the case of any metabolic chain which might lead to man.

110. The problem of radioactive effluent disposal on a large scale had first arisen at Windscale. The present methods represented the first solution of the problem and might, by future standards, be regarded as crude. The safety of the present techniques had been demonstrated. Future methods would need to be equally safe, but more economic, in order to deal with the considerably greater quantities of effluent which would arise from future programmes.

Professor A. N. Nissan (Professor of Textile Engineering, The University of Leeds) asked what sort of quantities were involved. How much storage of very high activity was being effected? Were there vast underground tanks which might be subject to earth movements and cracking followed by the possible pollution of water supplies; or was the material stored in containers of insignificant volume? Turning to concentration by evaporation, Professor Nissan said that, for the engineer, it was usually an expensive job. What order of quantities was involved in the present case? What was meant when it was said that larger quantities would be involved as the programme developed?

112. Referring to flocculation technique, what influence had the activity itself on the size and efficiency of the flocs? The Author had already said that some materials did not adsorb so efficiently as others; was that because of the nature of the material or the activity? Would stable isotopes be equally inefficient?

Mr R. A. Peddie asked the Author to amplify what he had said about concentration by incineration. What was incinerated and how were the effluent gases cleaned? Mr Peddie's background was that of coal-fired power stations, so that he had had experience of gas washing and of electrostatic precipitation, neither of which was as effective as some people claimed. That being so, he was interested in what was done at Windscale. Among the items on the Author's high activity list which were put into storage there was one which Mr Peddie would have thought it possible to incinerate, namely the graphite boats. To anyone associated with coal-fired plant that would seem to be the ideal solution, and it would reduce the bulk storage problem. The question of incineration was also of interest because of the references in the Papers at the Geneva Conference in 1955 to the difficulties in American practice of designing incinerators and to their high running costs.

Mr E. A. Howes (Section Head, Reactor Materials and Chemical Engineering, Nuclear Power Branch, Central Electricity Authority) said that he, too, had been concerned with emission from coal-fired stations and referred to the fact that the Author had mentioned in his bibliography a Paper by Bosanquet and Pearson,[13] another by Sutton,[14] and another by Bosanquet, Carey, and Halton,[15] and remarked that since the Author had done the work described in his Paper there had been other Papers: one by Nonhebel and Hawkins,[20] and another by Katz.[21] Had there been any published correlation between the Author's findings at Windscale on gaseous effluent dispersal and the theoretical considerations in the Papers mentioned in the bibliography and in the others which Mr Howes had mentioned as subsequent publications? If they had not been correlated, and if the material was unclassified and could be correlated, the Author and his colleagues, by undertaking the work, would be doing a very valuable service to those interested in the downwind concentrations of effluents such as sulphur and other chemical effluents from large stacks.

Mr C. D. C. Braine (Partner in the firm of Messrs G. B. Kershaw and Kaufman, Consulting Engineers, London) hoped that the Author would be able later to give a rather different type of survey on the broader aspects of the problem from the point of view of public health. The United Kingdom was entirely surrounded by the sea. Mr Braine did not know how many equivalents to Windscale it was proposed to construct in Britain, but he could imagine that in a hundred years' time the sea-water around the coasts might be as polluted by radioactivity as it was at present by sewage effluent. He thought that most people recognized today how much pollution there was in English coastal waters but pollution by sewage effluents did not give rise to risks comparable with those that would occur with radioactive wastes.

116. In a hundred years' time, if the use of atomic energy grew on the fantastic scale suggested by the Chairman, what was going to happen? Such developments would not be confined to the United Kingdom. If France, at Cherbourg or anywhere on the Channel, started doing the same thing on a big scale, with all the radioactive effluent sweeping up the coast towards Dover, what would be the position? Such a situation in the tideless Mediterranean might give rise to grave difficulties. How soon would atomic power wastes become an international problem, instead of merely a local one worrying at present only a few people in Cumberland?

117. An American delegate at the Geneva Conference had told him that the Americans were very worried indeed about future developments in North America. There again it

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[20] J. E. Hawkins and G. Nonhebel, "Chimneys and the dispersal of smoke". J. Inst. Fuel, vol. 28 (1955), p. 530.

[21] M. Katz, Report No. 110. Defence Res. Chem. Labs, Canada, Sept. 1952.

would be interesting to have a broader view of the position, because America was a vast continent with many miles between the Pacific and the Atlantic. If the Americans, as was bound to happen, did a great deal of such work in the interior of the country, how were they going to dispose of their effluent and what would be their problems as compared to Britain's? They would, Mr Braine imagined, be entirely different. The Russians, with their vast land areas, might be able to operate in deserts, but if they had to rely to a considerable extent on disposal by water they would have a problem which was not likely to affect anyone in the United Kingdom, but which might seriously affect Japan.

118. Could the Author comment on how he and his colleagues foresaw the developments a generation hence? No one a hundred years ago would have imagined that today it would be impossible to find unpolluted sea-water anywhere round the coasts of Britain; and the time was surely not far off when radioactivity would begin to deter bathers along many stretches of coastline.

Mr J. A. Maughan (Senior Design Engineer, Nuclear Industrial Structures Ltd, London) asked if there was an automatic system for the regular checking of the effluent from Windscale or was there simply an occasional spot check taken?

120. In the vicinity of Windscale there was a considerable amount of edible seaweed, and a Geiger counter showed that it was radioactive. It was to be expected that the oyster beds at Bradwell would become similarly affected when the proposed nuclear power station was started there. Could the Author say what was the level of activity likely in such cases? On the other hand, the knowledge that the luminous dial of a wrist-watch would excite a Geiger counter suggested that the radioactivity evident in seaweed was not necessarily dangerous as yet.

121. Would the Author say more about the storage of radioactive material? Normally, it would be desirable to store it for its half-life period. In some cases that would be a very long time, and in certain instances thousands of years; very costly tanks and containers would then be required, and the question arose of reducing the quantity by evaporation. Eventually, after many years, what was to be done with all the material? It had been suggested that some of the radioactive material should be put in special canisters and dumped in the sea. That was probably satisfactory for the present decades, but when the canisters disintegrated what would happen to the people living at that time, especially if all the canisters failed at the same time?

Mr P. E. Betts (Assistant Engineer, Research and Development Department, Messrs Merz & McLellan, Consulting Engineers) said the Author had mentioned that the water in the cartridge-cooling pond would be mildly radioactive and that it would be used to dilute other effluents. Presumably nuclear power stations would have cartridge-cooling ponds. How would the effluent from them be dealt with?

Mr A. T. Sneller (Assistant Engineer, Messrs J. D. and D. M. Watson, Consulting Engineers) asked whether a chemical plant such as that at Windscale would be necessary for each nuclear power station, or whether Windscale was rather a special case and more in the nature of a research organization. He had in mind the fact that the cost of the work which had been done there must be very considerable, and if such a plant had to be provided for each nuclear power station one would expect a high price for the electricity generated at those stations. Was it possible to concentrate the irradiated rods and deal with them centrally?

124. In § 26 the Author had mentioned that work had been commenced on methods of reducing the activity by adsorption and flocculation, and he had summarized that in § 55. Could he give fuller experimental figures, for requests were already being received for radioactive wastes to be allowed into sewers? A stage had not yet been reached where there was any serious level, but figures for those methods of flocculation might well be useful to consultants and local authorities in the future.

125. In § 93 the Author had mentioned long-term storage and burial in sealed containers; what quantities were involved; was it a question of hundreds of thousands of

gallons a year, or of just twenty to thirty containers being dumped in the depths of the sea, where presumably they would stay for all time?

The Chairman asked if the Author could give some idea of cost—he had probably no very exact idea at the moment of what all the work of effluent disposal meant as a proportion of the total cost of producing atomic energy. Would it be 1%, 5%, 10%, or . . . ?

127. What was being done on the subject in America? The Americans must have had their problems, as Mr Braine had already mentioned. Had the Author any information to give on the American experience up to now, and had there been any collaboration between the two countries on the subject?

128. Mr Braine had also referred to the contamination of the sea-water round the coasts of the United Kingdom. The conditions at Windscale seemed to be quite favourable so far as currents were concerned, but the Chairman wondered whether that would be so everywhere, particularly on the East Coast, and to what extent it was possible to rely on float tests even where long staves were used. He had read recently of some experiments done on float tests for sewage discharge where all the generally accepted precautions had been taken, but in which it had been found by the alternative use of radioactive isotopes that the float results were very misleading. The radioactive material had shown that the currents were in fact quite different from those previously indicated by the float tests. The Author had similarly started with float tests but had ended with the measurement of radioactivity. The Chairman thought that that was the ultimate test and the sound test, but he too wondered what would be the final condition of Britain's overloaded coastal waters.

The Author, in reply, said that he did not know of any published work on the relation between theory and practice on gas discharge, but he supported the suggestion which had been made.

130. A number of interesting comments had been made on the use of an incinerator. He thought that U.K.A.E.A. experience would be the same as that described by Mr Peddie. They did not like incinerators nor the types of scrubber of which they had had some experience. They had used a variety of scrubbers, including electrostatic and wetted-ring types, and found them to be of only limited efficiency, 80–90% being the general figure, though rather better results had been obtained in some cases. The remaining air-borne activity was taken up the stack and discharged at a height. They incinerated laboratory wastes such as filter paper and tissues. They had once made the mistake of incinerating P.V.C. gloves, but that had led to the evolution of hydrochloric acid which was destructive to the ducting. The incineration of graphite boats had been suggested, but it was difficult to set them alight. They were exceedingly difficult to ignite, and on one occasion when that had been done they had glowed at a very high temperature and burnt out the firegrate.

131. There was a regular and continuous check on a 24-hour basis on all the activity discharged from the site, no matter from what source it came.

132. Coming to the main issues, the international one was, he thought, of the greatest importance, and there he would draw attention to reference 4 at the end of the Paper. The National Academy of Sciences in Washington had recently issued a Paper dealing with the hazards to man of nuclear and allied radiations, which had one section on the discharge or disposal of active wastes, referred to the build-up of activity with time, and introduced the problem of the disposal of sewage. It made the suggestion that there should be international collaboration. The Author was confident that some basis for international agreement would be found, and discussions were about to take place to explore the problem between the United Kingdom and the United States of America. The United States had admittedly a different problem, their sites being inland; they had chosen sites such as Idaho and Oak Ridge, with desert round them, and for a period of time they could dispose of activity in the desert. They had acquired experience in that field, as Britain had in disposal at sea.

133. The two countries were now exchanging ideas and finding how to progress in the next stage, possibly the next 10 years. He did not think either would claim to be able to see 50 or 100 years ahead. Both were clear that the techniques which they used would have to be improved. They would expect their future chemical plants to be very much better in separation of the activities. If the present figure was, say, 1 part in 1,000, he would expect in 10 years to reduce that to 1 part in 10,000 or even in 100,000. He would also expect to find the use of improved forms of treatment. They were learning how to separate out individual isotopes such as caesium and strontium. Their knowledge of the processing of difficult isotopes such as ruthenium was increasing, and they should be able to find a more tractable material.

134. The fundamental problem was to deal with the large quantities of activity which at present was stored on the sites. He had been asked about the extent of that problem at the moment. It was certainly manageable today and would be for the next 10 years. They used tanks of conventional cylindrical shape with dished ends, inside concrete sumps which were lined so that if activity escaped from the tanks it was still retained in the lining. They knew that they could not go on increasing a hundredfold or a thousandfold the development of atomic energy in the United Kingdom and still use the techniques employed today, and so, at Harwell in particular, new processes and new techniques were being developed. For instance, one suggestion was to adsorb the activity on clay which would be fired and provide a relatively insoluble solid and stable material in the form of a brick.

135. The question of the relation between power stations and chemical plants had been raised. It was unlikely that there would be a chemical plant on each power station; in fact, it was expected that, initially, ten or twenty power stations would be served by one chemical plant. It would be wrong to associate the two together. The power station had a very low effluent, and the effluent from the power-station cooling-pond would contain only one-ten-thousandth of the activity which was at present discharged from the Windscale site. That gave far greater latitude in siting a power station, but he would qualify Mr Howells's remark by saying that some slight caution was still used in siting such power stations, and they were not yet sited with a view to maximum economy in electrical distribution. It was felt that the development of atomic energy was so new that they would prefer not to site such stations in the middle of a large town, and the public would probably prefer them not to do so. Although the activity was small, it was better to have them near the sea and not inland. Until the power station sites had been in operation for some time, it was not possible to be much more specific.

136. The radioactive materials treated in the effluent behaved in precisely the same way as their non-active counterparts. The isotopes of strontium, for example, behaved in exactly the same way as normal strontium, but in radioactive work one was dealing with very small quantities, possibly 1 part in 10^{10} or 10^{12}, whereas in normal chemistry it would be 1 in 10^4 or 10^6, so that the behaviour with regard to adsorption was different. Broadly speaking, however, the difference in behaviour lay in the pH value of the solution, and by taking the pH value up to 10 p.p.m. it was possible to increase the adsorption of some of the isotopes, such as caesium. Ruthenium did not adsorb particularly well even at the high pH value.