Paper No. 6222

An investigation into a proposal to dispose of power-station ash by discharging it into the sea at low water†

by

Frank Lester Harwood, M.I.C.E., and
Kenneth Charles Wilson, A.M.I.C.E.

Discussion

Mr Jack Duvivier (Partner, Messrs Lewis & Duvivier, Consulting Engineers, London) said that the idea of disposing of half-a-million tons a year of boiler ash from Blyth power station by placing it in the cooling water and sending it out to sea through a pipe had been novel enough to give rise to certain misgivings on the part of local authorities and other bodies concerned with the preservation of local amenities and inshore fishing. Fears had been expressed as to what would happen to the material. How far would it travel? Would it turn the sea into a viscous black bog and the neighbouring beaches into muddy morasses?

67. The Authors' firm had studied the behaviour of fine sands, silts, and clays under wave action on ocean beaches for many years and had been satisfied that there was nothing to fear from the proposal and that the material would be removed by wave action and deposited in deep water at a considerable distance from the shore and that it would not return to the beaches.

68. They had recommended, however, that scientific evidence should be available in support of their views to allay the fears which had been expressed and which were likely to be sustained when the matter came for decision before a Parliamentary Committee. It was with this object in view that the tests and other investigations described in the Paper had been carried out.

69. It seemed to him that the most interesting outcome of the model tests and investigations associated with them had been the information which they had provided about the action of density- or turbidity-currents in transporting suspensions of silt for considerable distances down the gentle slope of the sea-bed.

70. Professor Kuenen had said that turbidity-currents of low density carrying only silt and clay might form an important factor in the distribution of these finer fractions on the sea floor. They explained the mechanics of a circumstance which was well known to engineers concerned with the stabilization and protection of coasts, namely that particles of fine sand and silt did not remain in loose uncemented form on ocean beaches subject to wave action.

71. As the Authors had rightly pointed out, silt was found on the foreshores of estuaries where wave action was slight, but where estuaries opened out to sea it disappeared and only the coarser materials remained behind within the range of wave action.

72. Vast quantities of silt and clay were eroded from the coast of the British Isles every year. Wherever clays or silty clays outcropped at foreshore level between the tides, they were scoured and eroded by the waves whenever they were exposed to wave action.

73. To quote but one instance, at Fleetwood on the Lancashire coast more than

† Proc. Instn civ. Engrs, vol. 8, p. 53 (Sept. 1957).

1½ million tons of silt and silty clay had been eroded from one mile of the West Shore during the past 30 years. None of this material had remained behind or had been returned to the coast in the form of beach material, or in any other form; it had been carried away by the waves and deposited, presumably with the assistance of turbidity-currents, on the sea-bed remote from the coast.

74. In § 55 the Authors stated, "The task of engineers engaged on sea defences would be much easier if very fine sand and silt would remain on beaches." In point of fact, if fine sand and silt remained on beaches sea defence works would hardly be necessary. It was perhaps a good thing from the public point of view that fine sands and silt did not remain on beaches once they had been scoured from the virgin outcrops from which they were derived, because if they did remain people in general and bathers in particular would frequently be engulfed in a thick soft sticky morass of unconsolidated mud and silt which would give the coast a bad name. The sea was a wonderful natural sorter of materials and cleanser of beaches, for which the public had occasion to be grateful.

75. It was perhaps a curious reflection that raw untreated sewage could be lawfully turned into coastal waters through pipes in unlimited quantities whereas a fine-grained clean non-toxic granular substance like fly ash was judged to be so injurious to health and amenities that it had to be barged to sea and turned overboard in deep water.

76. The Central Electricity Authority's proposal at Blyth had been turned down, but the Authority were to be congratulated on having sponsored an interesting piece of research into a subject of which little was known. He hoped that they had not been discouraged by their failure to secure the necessary powers to proceed with the Blyth project and that they would try again when a suitable opportunity occurred, unless by that time an industrial use had been found for the fly ash which would convert it from a waste product to a national asset.

77. He also hoped that the Hydraulic Research Station at Wallingford would institute research into the habits of turbidity-currents, with special reference to the stability of eroding coastlines of silt and clay. It seemed to him that it was a subject which merited further investigation.

Mr J. A. Lewis (Partner, Messrs Lewis & Duvivier, Consulting Engineers, London) said that he wished to emphasize some points from practical experience which had a bearing on the subject.

79. On the west coast of Wales there were many sandy beaches in well-sheltered bays, but where the shelter was not adequate and there was no sand available from the erosion of the cliffs the beach might consist only of shingle and boulders. He had in mind the beach at Penbryn, where there was sand in the cliffs and a sandy beach, whereas close to it in the little bay at Cwmtydi, which was a relatively deep indentation and more sheltered than Penbryn, there was no sand in the cliffs and no sand on the foreshore.

80. Further north, at New Quay in Cardiganshire, the sand accumulated in the lee provided by the harbour works, but north of New Quay, where there was a long stretch of open coast, there was very little sand to be found on the foreshore, although it could be clearly seen by looking down from the tops of the cliffs that the sea-bed was sandy for an appreciable distance below low-water mark.

81. This was particularly noticeable at Aberayron, where, owing to the shelter provided by the harbour piers, some sand was able to lie on the flat lower foreshore south of the harbour, particularly during the calmer weather in the summer, but north of the harbour, although there was a long flat lower foreshore exposed at low tide, there was inadequate shelter to enable a sandy beach to be formed. Some groynes had been constructed to collect shingle and under favourable weather conditions small patches of sand might be found in their lee. Apart from this, the wide expanse of lower foreshore was boulders embedded in clay.

82. If an examination were made of those places where there was a good sandy beach, it would usually be noted that either there was a source of sand available from

the erosion of the foreshore or the sea-bed contours were very flat, as in an estuary, and that there were large quantities of sand on the sea-bed.

83. In places where the sand available was very fine, a sandy beach might fail to form, despite the presence of a very flat gradient. An example of this was the north coast of Kent between Reculver and Whitstable, where there was a wide flat foreshore exposed at low water, and there were beds of fine sand below and around low water level of spring tides. It might reasonably be expected that if fine sand would remain stable on a foreshore on the open coast, it would do so here, but in point of fact only very small areas of sand could be found under average weather conditions, the upper beach comprising shingle and the lower foreshore comprising clay with stones embedded in it, very often encrusted with mussels. Such sand as did lie on the beach was mainly composed of the coarser particles and was found near the bottom of the shingle beach. It seemed to become mixed with the finer shingle and managed to remain there. Apart from that, in very calm weather there were thin patches of sand to be found on the lower flat foreshore.

84. On the coast of Norfolk, where the cliffs contained a large quantity of sand and there were extensive sandbanks offshore, it might be expected that a good sand beach would always be found, but this was not the case. At Sheringham and Cromer the chalk on the lower foreshore was often exposed and at Sea Palling and Waxham beds of silty clay were sometimes exposed. The formation there was very similar to that shown in Figs 18 and 19; on occasions the sand was swept away from the silt, which was exposed, and the edge of it eroded.

85. At Southwold the beach contained some sand but was predominantly stony, despite the existence of a sandbank just below low water. At Aldeburgh the beach was composed entirely of shingle, which lay at a steep angle above low-water mark, and there was a bank of sand below low water. Sand would never be found on the foreshore there—although he admitted that once he had seen it; it was unprecedented and did not last long.

86. The Authors had shown in Fig. 3 how the material to be disposed of from the power station was all much finer than the samples of a typical sand from the Cambois beach and had also instanced the disappearance of the silt from the silty clay beds on the foreshore in Lincolnshire once they were exposed and eroded. The same applied to Fleetwood, where the analysis of the silty clay forming the foreshore was very close to that of fly ash.

87. He quoted these examples to show that even sand, which was much coarser than the fly-ash material to be disposed of, would not form a beach on the open coast unless continually replenished by erosion.

88. Estuary formations, such as the Wash and Solway Firth, might be thought to contradict this argument, but the contours of the sea-bed were so much flatter there that the cases were not comparable and the finer materials were present in such vast quantities over a wide area that it was impossible for them to be removed by the sea. If silt were found anywhere on the open coast, it was not being deposited but was an old formation in the process of erosion.

89. Sandbanks tended to form on many coasts where there was much sand in transit, and full-scale experiments carried out in the United States of America had shown that these banks stopped the movement inshore of sand from the sea-bed; they represented a balance of those forces acting on the movement of sea-bed material. If the effluent from the power station were to be led sufficiently far below low water, it appeared to be certain that if any of the coarser particles were to accumulate in course of time they would do no more than form a sandbank which would not allow any appreciable quantity to reach the foreshore.

90. The model experiments recounted by the Authors showed very clearly the process by which this state of affairs arose, and he agreed that the project of disposing of fly ash by pumping on to the foreshore or sea-bed appeared to be worth considering further if there were no danger of sterilizing fish breeding grounds.

Mr A. E. Powell (Partner, Messrs Merz and McLellan, Consulting Engineers, Newcastle-upon-Tyne) agreed with the Authors' conclusions in § 64 that the proposed method of disposal of the ash was a reasonable one.

92. Under the mechanism described, 80% of the ash would be disposed of as fine material, going out to sea, and 20% would be an accretion to the beach, which was by no means the kind of beach one expected to find at a seaside resort. In fact it might well be that an accretion of the heavier material would improve the beach rather than otherwise.

93. The alternative method of disposal was by barging out to sea. The estimated cost of the dock to deal with the barges was £1 million; the barges themselves would cost £750,000; and the capitalized operating costs were another £750,000. A sum of £2½ million could therefore have been saved if the proposal had met with Parliamentary approval.

94. The cost of disposing of the material by pipeline was estimated to be 8*d*/ton, and the estimated cost by barge was nearly 8*s*/ton. Both the operating and the capital costs of the scheme which the Authority had been compelled to adopt were eight to ten times more than would have been the case with the pipeline scheme.

95. The saving by the method proposed by the Authors amounting to £2½ million was in fact the equivalent of the saving in coal which would have resulted had the heat rate of the turbines at the station been improved by about 2%. This would have meant increasing the main steam temperature by about 50°F. These figures served to show that the savings were by no means small and that to achieve similar results would have required a very material change in design.

96. In § 12 the Authors mentioned that the construction programme would have allowed a trial over a 2-year period to have taken place at a comparatively small cost, estimated at about £100,000. Had that been allowed to take place there would have been a saving in the first 2 years of operation of about £50,000.

97. This reinforced the view that the experiments and investigations would have been well worth while. He therefore reiterated the comments of other speakers that if it were possible to carry out an experiment where conditions were similar, it would be well worth while spending a considerable amount of money on the experiment itself, which would show a large saving; the full-scale saving was tremendous.

98. The Authors' slides had shown that the tidal currents were predominantly to the south or south-east; that applied to the transport of the finer material. In § 23, however, the Authors said, "... it was well established that the drift at the proposed site of the cooling-water outfall is northwards." Superficially this might appear contradictory. Indeed, there had been considerable confusion in the Parliamentary inquiry between the littoral drift and the tidal current, which was dealing with two different classes of material. Would the Authors comment on that?

99. In § 33: "The Authors consider that in nature with onshore wind-induced waves both these movements would be away from the shore and the turbidity-current would be much more rapid." Those statements were quite correct but they needed very careful reading of the preceding paragraphs in order to make it evident that this remark followed from the previous statement in the Paper.

Mr Donald Clark (Station Planning and Development Engineer, Central Electricity Authority) confined his remarks to the background to the investigation, its origins, and its ultimate fate, from the point of view of the sponsors.

101. For reasons which the Authors had outlined in the Paper, it had been proposed that ash from the power station should be deposited in the sea. The conventional method of doing this was to take it out in hopper barges and dump it beyond the 20-fathom line. Arrangements were therefore made with the Blyth Harbour Commission which would allow a dock to be built at the head of the tidal basin where the barges could be loaded, and a licence was obtained from the Ministry of Transport for deposition beyond the 20-fathom line, which at this point was about 3 miles offshore.

102. The quantity involved was quite large, ultimately 500,000 tons a year, but it was also intended to discharge into the sea a very much larger quantity of cooling water—more than 1,000 million tons a year. It was suggested that this very large volume of water might be used to sluice the ash into the sea at a very much lower cost than carrying it out by barges. On average, there would be more than 2,000 parts of water to every part of ash.

103. The size and therefore the cost of the cooling-water outlet ducts was very large, and it was out of the question to extend these ducts far below the low-water mark. It was observed, however, that in this area erosion was taking place; as the Authors had pointed out, the colliery waste a little to the north was steadily disappearing into the sea to the south of the site. It was also known that the ash would be made up of material very much smaller in particle size and would presumably be more easily washed away.

104. A study was made of the available literature, particularly of Bascom's Paper[3] to the American Geophysical Union, in which it had been concluded that wave action on an open sea beach would remove most particles of a size smaller than 0·17 mm. The fly ash would all be substantially smaller than this and much of the boiler ash could be reduced below this size by suitable grinding. Size analyses were made of the fly ash and also of sand from the Cambois beach, as well as from other beaches miles away to the south which were used extensively for recreational purposes. The prospects seemed fairly bright.

105. At that stage the Authors' firm had been asked to go into the whole matter in detail. At the same time the Authority set about obtaining advice on the fishing and on the marine biology of the area, which turned out to be comparatively sterile. He did not want to exaggerate this; there was fishing and crabs and lobsters were caught in the area, but by comparison with many stretches of coast it was not an important fishing ground.

106. Mr Powell had referred to the question of costs. Table 1 summarized these costs. It compared the two schemes, one discharging by pipeline with the cooling water and the other carrying the material by barge out to sea. The pipeline scheme had the feature of being very much cheaper both in capital outlay and in running cost.

TABLE 1.—SUMMARY OF COSTS

	Pipeline	Barge
Capital cost	£146,000	£1,927,000
Annual capital charges . .	£10,600	£126,500
Annual operating costs . .	£6,100	£69,900
Total annual cost	£16,700	£196,400
Cost per ton	8*d*	7*s* 10*d*

107. The results of all these investigations suggested that there was a reasonable prospect, to put it no higher, of discharging the ash into the sea with the cooling water in a way which would not be detrimental to anyone. The Authority felt that the scheme should be given a trial. It might be thought that they would have been well advised to try it out on a small scale, if only by taking some ash to the beach, dumping it, and watching what happened. In fact, they very nearly did so; only the excellence of their legal advice prevented it, for the lawyers warned them that they would be breaking the law in that it would be contrary to one of the clauses of the Blyth Harbour Act, 1858.

108. For the same reason, the only way to obtain authority for the scheme was to promote a Parliamentary Bill and to run the gauntlet of Parliamentary Committees. When the Bill was published it was opposed by local fishing interests and also by local authorities further down the coast who feared for the cleanliness of their beaches. The only major discharges in the immediate vicinity of those beaches were the River Tyne, which was hardly a crystal clear stream at its mouth, and a number of sewage discharges, most of them made by the local authorities themselves. Nevertheless, they opposed the Bill. This meant that it had to be considered by two Parliamentary Committees.

109. Perhaps he could not say very much about what happened in those Parliamentary Committees without running foul of Parliamentary privilege. The Bill went first before a Committee of the House of Lords, and the Promoters felt that their Lordships' Committee considered it very carefully. The questions which they put seemed to indicate a considerable grasp of the technical issues at stake. At the end of the day, they approved the scheme. But it had to run the gauntlet of the Commons Committee, who disapproved it. That was the end of the scheme.

110. Mr Duvivier and Mr Powell had both expressed the hope that the C.E.A. would not be discouraged by this experience. He did not think they were discouraged, but they might go a very long time before they found a project with the same conjunction of favourable circumstances as had been found at Blyth.

Mr R. C. H. Russell (Principal Scientific Officer at the Hydraulics Research Station, D.S.I.R.) said that there was one mechanism by which fine materials were carried out to sea that was not mentioned in the Paper. He was referring to turbulent dispersion. It was not possible to separate the effect of this mechanism from the effects of the other mechanisms, namely density-currents and mass-transport, because whenever waves arrived at a muddy beach all three mechanisms operated together. However, he would rate its importance as equal to that of the other mechanisms in the offshore regions of the beach, and as paramount in the region of the breakers.

112. The mechanism worked in the following way: two zones of water adjacent to each other had different degrees of turbulence and accordingly different quantities of fine material in suspension. Owing to the existence of turbulence the fluids mixed and the result was a net flow of suspended solids from the more turbulent to the less turbulent zone. The mechanism applied to shelving beaches because the velocities associated with the waves were greater in shallow than in deep water. Accordingly in shallow water the turbulence was greater, and the quantity of solids in suspension was greater than in deep water. The mixing of inshore water with offshore water led to a net flow of suspended material out to sea.

113. It happened that the mechanism worked best just when the density-currents worked best; that was to say when there was fine material lying on a steep beach. On flat beaches density-currents had only a low velocity and turbulent dispersion could not operate either, because the turbulence was uniform over the whole area and mixing would not result in a net flow of solids in any direction.

114. The two mechanisms differed, however, when the quantity of fine material on the beach had become small. There would then be insufficient material to generate a density-current; but the turbulent-dispersion mechanism would continue to operate even when there were only a few fine particles left. If a lot of mud was placed on a beach it would be initially removed by both mechanisms operating together, but the final cleansing would be performed by turbulent dispersion.

115. He thought that Tests III and IV in the wide basin were performed under unnecessarily unfavourable conditions. Initially the density-current flowed down the sloping beach and reproduced, at any rate qualitatively, what would happen in the sea. When, however, the current reached the limit of the model it would have been reflected and flowed back again, whereas in the sea the density-current would have flowed down the slope and away out to sea. The Authors said that after 10 hours' running the

whole basin had been covered with silt—which was to be expected under the circumstances.

116. In § 41 the Authors quoted the SOGREAN Laboratory: "On the other hand the waves transported material towards the shore. Several minutes after the waves were applied the water to the shoreward side of the outlet was clouded with fly ash in suspension right up to the beach." One of the Authors had been present during the test and noted the fact that the beach itself had remained clean. He had then been unreasonably guarded, Mr Russell thought, in concluding that "in view of the scale of the model this was probably of no significance." In Mr Russell's view the fact was significant; if the discharge of fly ash had been not into a model but into the sea, they would have found that simultaneously the water was cloudy and the beach was clean.

117. This state of affairs could be witnessed at Southend at the higher stages of tide. The upper part of the beach at Southend was steep and clean, while the lower part was very flat and muddy. At the higher stages of tide waves passing over the lower muddy foreshore put up a lot of fine material into suspension and the water acquired a muddy appearance: yet the beach remained clean.

Mr J. R. D. Francis (Civil Engineering Department, Imperial College, London) remarked that the Authors had eventually made out an excellent case for their conclusion that fly ash would not be deposited on the beach; but in his opinion the model tests were not reliable, nor did they give much information on the general problem of silt disposal, because the scaling laws had been incorrectly applied. In the wave-basin experiments the vertical scale had been 1/100, so that the scale of velocities had been 1/10. For true dynamical similarity in this model, which had a scale exaggeration of 2, the ash used should have had a vertical speed of settling one-fifth of that of the ash used in the prototype. The ash used, however, was similar to the ash which would have been used in the full-size prototype (§ 28), so that its vertical speed of settling was five times too great.

119. The increased relative settling speed had probably caused the ash to fall out of suspension too soon after it was ejected from the outfall, so that in this respect the model as tested had given a pessimistic view of the ash-deposition problem. There was a possibility that this error of scaling might have resulted in errors, not only of the magnitude of the ash banks but also of the whole type of deposition, which may have given ash banks different in both profile and location from those actually observed.

120. It would have been easy to have obtained a lower settling velocity without using very finely ground ash, by using a material of lower density. This technique was now fully established and "sands" of perspex or other synthetic materials were readily available to give any settling velocity that may be required (see, for example, reference 2 on p. 69 of the Paper).

121. Another factor leading to unreliability of the model experiments was that the effluent had apparently been at the same temperature as the model sea. In the prototype the effluent water would be many degrees warmer, and so would be less dense than the surrounding sea for a considerable distance seaward. A light jet such as this would rise to the sea surface and might be quite persistent. Even the addition of about 1·3 part per thousand by weight of ash (§ 44) was unlikely to make the effluent heavier, for water decreased its density at 20°C. by about 3 parts per thousand per 10°C. The effect of the light effluent on the form of the ash banks was difficult to assess without experiment, but it would seem that there was a distinct possibility of ash being carried quickly to sea in the thin hot upper layer, but that when particles had settled into the colder substratum, quite different fluid motions might be found. This might well give a different arrangement of ash banks from that discovered by the tests at uniform temperature.

The following contributions were received in writing.

Mr G. E. Vincent (Engineer at the Laboratoire Dauphinois d'Hydraulique, Grenoble) agreed with the Authors' statement that, in a zone largely subjected to wave action, the great majority of the finest elements originating from continental erosion were carried out to sea, the finest of them going out farthest. The same would also apply to solid particles with similar characteristics deposited on a shore of this kind. A certain number of factors, such as the winds out at sea, the mass-transport current in the waves, the turbulence above the sea-bed, and density-currents, contributed either simultaneously or successively to the seaward movement of the finest particles.

123. It was well known by now that density-currents likely to transport appreciable quantities of mud could occur in natural reservoirs such as lakes, as well as in artificial reservoirs receiving flood-water.

124. At sea, density-currents of this nature could occur so long as they were sufficiently supplied with fine particles (50μ approximately); the waves had a determining effect on their formation, particularly from the breaking zone onwards, as well as on their development in a seaward direction. The most favourable conditions for their formation seemed to occur immediately after gales.

125. Mr Vincent had recently taken part in a study of solid movements caused by the waves on a horizontal bed.[4] The main conclusions reached from this experimental study were:—

(*a*) The investigation of conditions for the onset of grain movement of the bed material showed that the action of waves could be appreciable, even at depths of several tens of metres. A wave of 6-m amplitude with a total length of 120 m would be capable of putting a 0·3 mm grain into motion at a depth of 60 m.

(*b*) The experimental investigations, as well as the viscous-fluid theory, showed the existence, close to the bed, of an entrainment current of liquid particles which always worked in the direction of wave propagation.

(*c*) In test flumes, this entrainment current formed part of a mass-transport within the liquid, the vertical distribution of which varied with the characteristics of the fluid motion. On a horizontal bed, it generally gave rise to an effective sediment transport in the direction of wave propagation, because the preponderant part of the liquid-velocity component, near the bed, was in that direction.

(*d*) Owing to the existence of the mass-transport current and the onset of suspension of material above the bed, some sediment transport could exist out to sea. The results of the investigation gave an explanation of why, under the action of long and regular swell, material tended to be carried in the direction of the waves and built up on the beach whereas, under storm conditions, a strong resultant turbulence produced suspension and favoured erosion of the beach.

(*e*) On a sloping bed, transport towards the shore was counterbalanced by the effect of gravity, currents caused by winds from seaward, and density currents set up in the wave-breaking area. So that, finally, material eroded from land surfaces was, in part, gradually carried away towards the open sea.

126. Mr Vincent then mentioned another investigation with which he had been concerned. It was a study of a particular problem in connexion with mining-waste disposal at sea, which had recently been studied at the Grenoble laboratory. The problem occurred on the western shore of Cap Corse, where the working of an asbestos mine would produce some 500,000 tons of steriles annually, which would have to be conveyed into the sea. This problem was to a certain extent similar to the one discussed

[4] G. E. Vincent, Sixth Conference on Coastal Engineering, Florida, Dec. 2–7, 1957. G. E. Vincent and F. Ruellan, Soc. Hydrotech. France, June 1957, Session No. 58.

in the Paper, particularly as far as the quantities involved were concerned, although the grain sizes of the material were far from being the same in both cases. The grain size at Cap Corse varied from a few microns up to about 1 cm.

127. Neglecting conventional solutions such as dumping waste out at sea from barges or overhead cable-ways, the laboratory investigation had been specially concerned with a scheme whereby the waste would be conveyed out to sea through a submerged pipeline on the sea-bed, and with an alternative method of dumping on the shore.

128. It should be pointed out that the sea-bed at the point concerned was much steeper than at Blyth; the −50-m level was about 1,200 m from the shore, and once outside the −100-m level (about 2 km from the shore), the bed fell away fairly suddenly, with a slope of about 50%.

129. The results of the investigation had shown that it would be difficult to use a pipeline transportation layout in this case, chiefly because most of the materials that were too coarse to form reasonable density-currents would decant as soon as they left the pipe. This would cause heaps in the shape of truncated cones to form, developing in a similar way to volcanoes, and which, if at a depth of about 40 m, would make it possible to stock only part of the quantities disposed of annually.

130. In this particular case, it would seem more appropriate to dump relatively "high-grade" materials on the shore. This would be more economical and would have the added attraction of causing a gently sloping stretch of coarse sand to develop along the coast, providing an effective form of protection for the bottom of the cliffs along the top of which the Cap Corse road ran.

131. It could be feared that asbestos debris in this waste material, which would be finer and lighter than the rock fragments, might be carried out to sea, where they would cover a large area and thus interfere with biological activity on the sea-bed.

132. An investigation carried out opposite a dump containing several million tons of a very similar material a few miles further north along the same coast had shown that the majority of these particles had not got beyond the 20-m line out to sea.

Mr F. V. Lindsey (formerly Civil Engineer, National Coal Board, Opencast Executive) said that he had recently been a householder on the coast affected by the proposals in the Paper.

134. The disposal of colliery waste along this coast, as seen 3 years ago, had already given rise to nuisance, apart from the devastating effects of such eyesores as spoil heaps on the coast scenery. The dump at Lynemouth (§ 59) had been subject to spontaneous combustion, with the attendant smells and danger. The beach north of Blyth had been strewn with lumps of shale and smears of coal-dust (§ 61), which the Authors had admitted to be "perhaps not ideal beach material". At Holywell Dene, which entered the sea at Seaton Sluice 3 miles south of Blyth, a beautiful little ravine had been transformed into a noisome drain by the use of the stream to carry away coal-dust. Under certain conditions of wind and tide this coal-dust was carried in suspension in the sea along the coast so that off the whole of the beach between Seaton Sluice and Blyth the water had been like black ink.

135. In view of the damage and unsightliness already caused, proposals for works which might further disfigure the beaches (§§ 49 and 60) and which would certainly deposit foreign matter in the sea, could be regarded only with apprehension. It might be said that there was a lot of water to take care of this disposal; no doubt the first man to turn waste matter into the Tyne had said just the same thing! Evidence of the wide concern about the increasing pollution of inland and coastal waters was to be found in a Paper[5] by Marriott to the Conference of the Association of Public Health Inspectors at Eastbourne on 19 September, 1957.

[5] John Marriott, "River and sea pollution—a public health challenge". J. Ass. Publ. Health Inspectors, vol. 66, p. 137 (Nov. 1957).

136. With regard to § 64, what advice had been received as to the effect of the ash on marine life? It could hardly have been favourable to the project.

137. Another point to be considered in this connexion was the wide-spread damage to the surface which had been caused by underground mining. Surely when a part of the extracted material had been recovered it should be used to rectify as far as possible the damage caused in its extraction? The proposition that there was no suitable place on land for disposal (§ 3) should not be too readily accepted. In the hinterland of Northumberland there were large tracts of sunken land available for rehabilitation. Admittedly this was a formidable economic problem, but one which, in these days when people were becoming more than ever conscious of the necessity of conserving natural resources, would have to be tackled. After all, inland power stations without the sea at their back door had to devise other means of disposal, and perhaps make a virtue of necessity. Bradford, for instance, made use of power-station waste in the controlled tipping of the city's refuse. Had the wider issues involved in the proposal in the Paper been sufficiently considered, or had the immediate financial advantage to be derived been allowed undue weight in formulating the scheme?

138. It was interesting to learn (§ 23) that the dumping of waste on the beach near the Rockers (and also at Lynemouth?) had been originally embarked on as a preventive of erosion. Mr Lindsey had assumed that it was because it was the readiest means to hand. What evidence was there that the dumping of loose material on a beach had been successful in preventing erosion?

Mr D. I. H. Barr (Assistant Engineer, Messrs James Williamson and Partners, Consulting Engineers, Glasgow) observed that the deductions which had been given by the Laboratoire Dauphinous d'Hydraulique (§ 48) assumed the existence of a plunge; that was, an inverted stationary wedge with a curved front, the salt water of the sea forming the wedge and ash-carrying heated salt water from the outfall forming the underflow. While the effect on density of the heat imparted by the condensers to sea-water would be small compared with the effect of the addition of 20 g of ash per litre of sea-water, it was not made clear why the water abstracted from the Tidal Basin should always be sea-water. The average flow of the River Blyth appeared to be of the order of 170 cusecs, and flows approaching 1,350 cusecs might be comparatively common. Unless it could be assumed that a salt wedge extending up the river to the intake would always be present, it would appear that relatively fresh water might at times be taken in from the Tidal Basin and discharged, after heating and dosing with ash, from the outfall. Such an occurrence would be most likely at low water, and combined with river temperature in excess of sea temperature, as occurred during summer months, might result in the outfall water being less dense than the sea-water, even when carrying a fair amount of ash. Around low water springs such ash-carrying water might move along the shore to the south of the outfall, and since a swirl would probably be formed when water level was below culvert level, might be brought close in shore.

Mr H. D. Rimmer (Senior Resident Engineer, Sir William Halcrow and Partners, Peterborough) asked the Authors if they could give the gist of the advice on the effect of fly ash on marine life. Some fish liked mud, but perhaps not inert and sterile mud!

141. He had once spent 6 months close to a large bank of precipitators from which the ash had been loaded into lorries before being put into barges and dumped at sea; that experience had convinced him that the ash should be slurried as early as possible. Human life, at least, did not seem to thrive on inert and sterile dust! At that time the ash was supposed to be very difficult to wet, but ejectors had now been developed by which a rich slurry could be formed readily, and he took it that such ejectors would have been used in the present case. They also made possible ash disposal by land reclamation, as was now commonly done, and he hoped that wet disposal would be universal in the near future, even if the cost was slightly greater in some cases than it would be with dry handling.

142. Although the fly-ash problem would be present for many years, it might disappear in time if the cyclone furnace which was now being developed was successful. In this furnace he believed that almost the whole of the fly ash was tapped as slag from the bottom of a kind of reverberatory furnace.

143. Regarding the likelihood of the ash collecting on the beaches, perhaps it could be said roughly that on most beaches, at a given spot, in given conditions of weather, and so on, one particular size of particle tended to predominate ("size" here being, not absolute size, but a function of dimensions, density, and shape). Thus most beaches at the heads of estuaries tended to accumulate silt, while more exposed points collected sand or shingle. Anything smaller than the natural size at the given point tended to go back into circulation. In Cornwall, where good concrete sands were scarce, one of the best available was derived from china-clay washings. These were allowed to travel down river and accumulate on the beach, where wave action gradually loosened and removed adherent clay, which was drawn out to sea. Additional washing was, of course, given before the material was fit for making concrete.

The Authors, in reply, said that they were a little surprised but very pleased that there had been such universal agreement with their conclusions.

145. Mr Duvivier had commented on the discharge of sewage. The Authors pointed out that under any new scheme sewage was permitted to be discharged into the sea only after float and other tests had satisfied the authorities that it would not return to the beach. They cordially supported Mr Duvivier's hope that the Hydraulics Research Station would undertake research into turbidity currents.

146. Mr Lewis had made some comments on a number of beaches; to this list they would add St Margaret's Bay, where the beach consisted almost entirely of shingle, although during long spells of calm weather some fine sand did accumulate on the outer foreshore; there did not seem to be any source of coarse sand within the range of the inshore movements of beach material. At Sheringham, after a heavy gale the sand on the middle and lower foreshore might be considerably reduced and considerable areas of chalk might be exposed particularly on the east beach, but during calmer weather the sand returned and on the west beach particularly there was nearly always a very fine sandy beach below the shingle belt. The east beach was less well-favoured but it was rarely the case that it had not an ample sandy beach for the holiday-makers in the summer. At Cromer the sand predominated and the shingle was usually not separated from the sand. The chalk which was much lower than at Sheringham was rarely seen except below low water mark and in general there was a very fine expanse of sand along the whole frontage.

147. One of the reasons there was warping along the edges of the Wash was that there was very little wave action. The Wash was one of the places where silt was deposited and could be seen. The point had been raised in the Parliamentary Committee of the House of Commons, and reference had been made to the warping along the edge of the Wash, which permitted the reclamation of some agricultural land every year. It had been said in various publications that that material came from the eroding coast to the north—the Lincolnshire coast. The Authors did not know if that was so; they had tried to find some relative figures for the quantity of silt brought down by the various rivers discharging into the Wash and the quantity deposited in this warping but had been unable to obtain any very useful results.

148. In reply to Mr Powell, the Authors emphasized what they had tried to make clear in the Paper—that when issuing from the cooling water outfall the material was in different sizes. It had been expected that it would behave, therefore, in different ways. It had been thought that the coarser material (16% of the whole) would remain in the vicinity of the outlet and would be carried on to the neighbouring beach; in other words, it would constitute more or less permanent beach material. So far as they knew, there was no exact analogy between this material and natural beach material which they had encountered; the density was considerably less and it was possible that fly ash of larger sizes than corresponding sizes of sand would be borne away because of the lighter

density. But if a direct analogy from sand were taken, a certain proportion of the total material would have remained on the beach and would have been affected by the littoral drift. That was movement of beach material by wave action.

149. It was true that a complication was introduced by the fact that occasionally beach material was also affected by the inshore currents; it was lifted by the sea and while it was water-borne it would obviously move in the direction in which the water was moving. In general, however, beach material was moved about by the action of the waves, which more often than not were oblique in their approach to the coast. The material went either one way or the other according to that obliquity. In the case of Blyth, an analysis of the wind records and various other indicators to which he had referred brought them to the conclusion that the coarse material would be borne northwards from the outfall. The Authors had also reached the conclusion that it would not travel further than the Wansbeck.

150. The importance of the tidal currents was that if very fine material had issued from the mouth of the cooling-water outfall at 5 ft/sec, it would have been carried a considerable distance before being settled on the bottom of the sea. The very fine particles would have taken longer to settle than the coarser particles and while in suspension would have been affected by the tidal currents, in general moving towards the south-east.

151. The paragraph to which Mr Powell had referred—§ 33—had been very much condensed and should be read in conjunction with § 32, which referred to the two-way movement of fly ash near the bed—first, a movement of ash in suspension towards the shore in the direction of the waves, and secondly, a turbidity- or density-current moving along the bed away from the shore in the opposite direction to the waves. The Authors had then stated that they "... consider that in nature with onshore wind-induced waves both these movements would be away from the shore and the turbidity-current would be much more rapid".

152. Waves generated in a two-dimensional channel were generated by a paddle, whereas waves on the coast were usually generated by an onshore wind. He said "usually" because although ultimately all waves were produced by wind except tidal waves, sometimes they might be brought about by a storm very far away, in which case there might be a heavy swell with no wind at that point. In the majority of cases, however, waves were caused by an onshore wind and the effect was to induce a current of water in the direction of the shore on the surface. This had to be compensated in some way by a current in the opposite direction, and the Authors considered that this was the current near the bed which had the effect of moving material in suspension or near the bed away from the coast.

153. There was an example of this. In 1955 Mr Harvard had arranged for a diver to inspect the lifeboat slipway at Cromer, situated at the end of the Corporation Pier. The toe of the slipway had about 9 ft of water at M.L.W.S. The investigation, at which he had been present, had been carried out during the summer, which, it would be remembered was a very fine summer. At that time the sea-bed along the slipway had been completely exposed; there had been hardly any sand or shingle at all and the chalk could be seen very clearly. The diver had reported that all along the slipway the sea-bed was clear chalk. Indeed, it could often be seen through the clear calm water.

154. A few months later, in the autumn, some work had been started on the toe of the slipway; in the intervening months there had been onshore gales. The diver had then reported that there was 15–18 in. of sand all along the slipway, completely covering the chalk. That showed the effect of onshore gales. The lower part of the beach had been very low indeed and the timber piles of the old jetty at Cromer—pulled down some time in the 19th century—had been visible, which was rarely the case. At Cromer the plunge line was about 200 yd seaward of the end of the slipway. This phenomenon was well within the range of the inshore movements of beach material.

155. Mr Clark had drawn attention to the large scale of the problem—500,000 tons of material a year and the very large quantity of cooling water. This might have led people to wonder if, while a small quantity of material would be dealt with

satisfactorily by the mechanisms mentioned, this very large quantity would be more than the sea could deal with; but although the quantity sounded large, it was comparatively small in relation to the activity. Mr Duvivier had referred to some of the large quantities of material which were removed from Britain's coasts every year.

156. Mr Russell's exposition of turbulence-dispersion was new to the Authors, who were pleased to learn that there was another mechanism which would have the effect of taking the material out to sea. Mr Russell's remarks about the basin test, which he thought too rigorous, would be noted, but the difficulty was that ash mixture was very dilute and unless the model was run for a considerable time it was impossible to accumulate a reasonable quantity of fly ash to see what happened to it. If it had been run for only a short time there would not have been much to see. It would, of course, have been pleasant to have had a very much larger basin, but it was in any case quite large and was the largest available at Grenoble.

157. Mr Francis had referred to the scale of the material used in the model experiment; one of the difficulties was that no-one could predict exactly what would be the grading characteristics of the ash for the new station. In Fig. 3, p. 55, the estimated granulometric analysis of the ash in the prototype was given; in § 7 of the paper it was stated that the ash would consist of 80%of fly ash and 20%of boiler ash ground to a maximum size of $\frac{1}{8}$ in. The median size (estimated) of the mixture could be seen from Fig. 3 to be about 0·035 mm. The fly ash used in the experiments was from a French power station and did not exactly correspond to any of the fly ashes shown in Fig. 3. (Incidentally there were considerable differences between fly ashes from British power stations.) The median size of the French fly ash used averaged about 0·02 mm. Material with a lower settling velocity than that of the prototype had therefore been used although the Authors regretted that the exact figure was not available.

158. The Authors had discussed this point with the Laboratoire Dauphinois d'Hydraulique, who made the following remarks:—

"*Speed of settling*:

"Mr Francis points out that a correct application of scaling laws should have called for the use of ash with a speed of settling scaled down by a ratio of 1 to 5.

"For fine particles, the speed of settling is roughly proportional to the square of their diameter (specific gravity being the same), therefore such a reduction of speed could have been achieved by the use of model ash having grain sizes 2·24 times smaller than prototype ash. Fig. 3 of your Paper shows that the scatter of grain size is greater than that—for instance at the 50% level it varies by a factor of 6 (hence a factor of 36 for the speeds of settling).

"At the time of the tests we were sent sieve analyses of ash from Littlebrook and Dunston power stations, which seemed to indicate that the scatter of several samples could well be of the order of a factor of 2 these two samples being a little closer together than this. Fig. 3 shows that our estimate was conservative.

"If we assume that the full line on Fig. 3 represents the most accurate average properties of Blyth Power Station fly-ash, we may even say that we, unwittingly, chose the best possible ash characteristics, because, as can be seen from our report, the French ash used was very similar to Dunston power station ash and thus very nearly twice as fine as the Blyth power station fly-ash as shown on Fig. 3.

"Another way of looking at this problem, of how accurate should the speed of settling be reproduced, is to remark that the central part of the granulometric curves extend over a very wide range of diameters and hence of settling speeds.

"It can be seen on Fig. 3 that the particle diameters will range, e.g., from 0·003 to 0·3 and this implies a range of settling speeds of about 1 to 10,000.

"We think that the above comments are sufficient to prove that it would not have been reasonable to spend a lot of time and money to improve the similarity of the settling speed or rather speeds. There is no doubt, in view of the bulk of material involved in the tests, that it would have been very lengthy and costly either to prepare a finer ash by sieving or grinding (?) down the prototype ash, or to use ground plastics. The use of the latter is 'fully established' but it is very costly for large models. However, we wish to stress the fact that we did take (less costly) precautions against errors of this kind in two different ways.

(*a*) Settling speed, although undoubtedly playing its role in the behaviour of the ash, is in fact a rather less important factor than turbulence and other water motions induced by wave action. In order to vary this factor we made practically all tests with a series of different wave heights. We somewhat exaggerated these wave heights so as to introduce an approximate correction for the scale effect on turbulence. The range of results thus obtained was much greater than that due to the differences of grain size mentioned above.

(*b*) Grain size analyses were made at various locations for the most important tests thus it was possible to check on the influence of settling speed. Without wave action the finest grains were carried farther out, but with wave action the effect was reversed. This shows again that the speed of settling is far from being the major factor.

"Mr Francis also raises the question of the effect of heat on the density of the effluent water. There again it would have been costly and lengthy to make a model with the proper differences of temperatures. It is obvious that this criticism does not apply to the tests made with relatively high concentrations. On the other hand when the concentration is low we agree with Mr Francis that the overall density of the effluent may become less than that of the surrounding sea, we also agree to the possibility of the ash being carried out quickly in the upper layers. When it falls into the colder substratum it may well find 'different fluid motions' but unless the latter are very peculiar it seems that the overall temperature effect would be to increase the spreading of the ash.

"The results of the tests made with a mixture of low concentration (specific gravity 1·0013) shows that (cf. paragraphs 44 and 45 of the Paper):—

"*Without waves*:

'The material was spread in a thin layer over the whole basin with a small heap a little distance from the outlet and small walls of material'. . . .

"*And with waves*:

'The result was to spread the material fairly evenly over the whole basin.'

"It is extremely likely that the same result would have been obtained had we used a slightly heated effluent to reproduce the actual density relationship. Thus in such a case there are practically no 'ash banks'. Mr Francis' concern about their 'different arrangement' does not seem justified.

"Generally speaking, we think that Mr Francis' remarks come from a misapprehension of the actual scope and purpose of the model tests in question. It is very important to distinguish between purely scientific investigation of basic laws of nature and industrial research. In the first case phenomena are studied in their 'pure' state and they are, as far as possible, isolated from all non-relevant effects. It may then be rewarding to spare neither care nor cost to improve the accuracy of the experiments.

"Industrial research deals with phenomena in the raw, not with tame specimens and, as a rule, no single line of attack involving either models, computations, comparison with past experience, etc., will give a complete answer. The most that can be done is to weigh all sources of circumstantial evidence against each other and try to make the best decision according to one's lights.

"The way in which your paper is written is a very good illustration of the above argument and we trust that the model has been a 'reliable' tool for you because you knew its limitation and did not ask it to reply to questions which it was not built to answer.

"It is true, nevertheless, that the model would have been 'unreliable' and, we should say, in many other ways than those pointed out by Mr Francis *if* it had been expected to give all the answers by itself. But this is not a blemish on the reputation of model techniques as, to our knowledge, the same could be said of any other single line of investigation that can be used in such complicated practical problems."

159. To these comments the Authors would like to add that they personally did not see how a three-dimensional model, even of the fairly large size used, could have been adapted to preserve the water in the basin at the correct relative temperature to the water entering, bearing in mind that the test had lasted for some hours.

160. The maximum difference in temperature between the ash-laden water issuing from the circulating-water outfall culvert and the sea was estimated to be 12°F, and taking temperatures of 62°F and 50°F respectively, the respective densities had been calculated to be very nearly the same. At Poole where the circulating water discharged into Poole Harbour, which was usually very calm, and where the tidal range was small, the warm water was discharged at a rate of about 100,000 gal/min and tests made in the middle of summer had shown that at high water in a distance of ½ mile the water had fallen to the same temperature as the harbour water. The temperatures had been: harbour water 61·5°F, cooling water at outlet 69·0°F. It seemed fairly evident that at Blyth a fall in temperature sufficient to bring the densities of the ash-loaded cooling water to a higher value than that of the sea would have occurred very shortly after the water issued from the culvert, and before any appreciable quantities of ash had been deposited. The usually turbulent sea at Blyth would promote mixing of the warm water with the cold and also help to keep the ash in suspension.

161. Mr Vincent seemed to be in general agreement with the Authors' conclusions. It did not appear that on open sea beaches material from outside the plunge line was carried on to the beach, and since material in the silt category was constantly being eroded from cliffs in many parts of the world and from the sea-bed itself within the range of wave action, and yet was not found on open sea beaches, it could be assumed that there was no natural process capable of moving material of this nature from the sea-bed to the beach, but that there was a contrary process, however it might be explained. The Authors were very interested in the investigation described dealing with mining-waste disposal.

162. The Authors had much sympathy with Mr Lindsey's point of view and agreed that the dump at Lynemouth was especially disagreeable. They had not described the lumps of shale and smears of coal dust as "perhaps not ideal beach material" but had used that expression to describe that coarse part of the ash which it was considered would remain on the beach. If Mr Lindsey could see this coarse ash he would agree that, in appearance, it was not unlike beach sand; the Authors had pointed out in § 5 that the material closely resembled a naturally occurring mineral. They did, however, consider the bank of yellow and grey stone from the colliery waste dumping south of the Rockers to be performing a useful service on the Blyth beach and there was no doubt that it was counteracting the erosion which had undoubtedly been taking place formerly; where the waste was tipped it formed a very unsightly heap, but the material that had been spread along the top of the upper beach between there and the Cambois cable-way was not unsightly and looked much like the coarse natural beach material found high up on some beaches around the coast.

163. In the Paper the Authors had drawn attention (§ 59) to the very large quantities of material already being dumped in the sea in this area, some on the beaches and some beyond the 2-fathom line; the ash would be dumped in the sea and the only point at issue was whether it should be dumped from barges beyond the 20-fathom contour or sluiced out to sea in the circulating-water outfall; the Authors considered that apart from the coarse ash the ultimate destination would be much the same in either case.

164. The Authors were not themselves concerned with the effect the ash might have on marine life; the Authority had advice from marine biologists and other suitably qualified persons on that aspect; indeed the Authors' firm had been asked only to say what they considered would happen to the ash under the proposed method of disposal.

165. The question of whether or not the ash could be disposed of inland had been

gone into by the Authority and it was understood that it was not feasible, but the Authors were not concerned with that aspect of the matter.

166. A study of the position of high and low water marks as recorded by successive Ordnance Surveys showed that this coast had formerly been eroding but appeared to be doing so no longer.

167. In reply to Mr Barr, the fresh river-water would flow over the top of the incoming tidal water and a proportion of the fresh water reaching the Tidal Basin could undoubtedly be drawn in at the circulating-water intake at certain states of the tide, particularly near high water and low water when the tidal flow was slack. The Tidal Basin formed a Y junction with the river; at L.W.S.T. the river above the turning basin, at the entrance to the Tidal Basin, was only about 250 ft wide and the river velocities would therefore be at a maximum at that time. The effect of the outward flow of fresh water on the surface of the incoming tide was studied and could be clearly detected for some distance below the Tidal Basin, and it was thought that only a very small proportion of this fresh water would enter the cooling-water intake.

168. The river was tidal to a point just below Bedlington and to just above Sleekburn on the tributary; a considerable proportion of the fresh water would be held back by the flood tide. The tidal water passing the mouth of the Tidal Basin in a spring flood tide would be of the order of 200×10^6 cu. ft, of which 40×10^6 cu. ft would be extracted for cooling; the total river flow over the period on the figures given by Mr Barr would amount to between $3{\cdot}7 \times 10^6$ and 30×10^6 cu. ft, of which only a small proportion would be likely to reach the intake.

169. The Authors do not think that substantial quantities of fly ash would have travelled alongshore near the low water line since the crown of the outfall was only about a foot above M.L.W.S. and the circulating water would emerge at a velocity between 5 and 10 times that of the maximum tidal currents inshore. Under certain abnormal conditions, perhaps it was possible that some fine ash might have been deposited, but it would have been moved seaward in the course of a tide or so and could not have remained on the beach.

170. Mr Rimmer had asked for the gist of the advice on the effect of fly ash on marine life; there was considerable controversy between the experts engaged on either side and the Authors felt that they should not give their views as to which side had the better of it in this respect; the only fair thing would be to give a precis of each expert's evidence, and this they felt would not be very suitable matter for inclusion in the Proceedings, nor could it be given without obtaining the permission of the many experts engaged. The Authors agreed with Mr Rimmer about the unpleasantness of the fly ash in a dry state when blown about by the wind; this could be a nuisance when the material was disposed of on low-lying inland areas. They would repeat that they considered none of the fine ash would have accumulated on the beach.

171. It would be a very good thing if the ash could be converted into slag, in which form it would be much less objectionable when disposed of on land. There were many possible avenues of useful disposal of the material; it could be used, in conjunction with clay, to make excellent bricks and it was being converted into concrete aggregate on a considerable scale; it was also a useful diluent of cement in marine and other works; it was to be hoped that these uses would grow and gradually overtake the supply.

172. Reference 3 (Bascom's Paper on the relationship between sand size and beach-face slope) was relevant to Mr Rimmer's concluding remarks.

173. In conclusion the Authors again draw attention to the very large volume of water that would be discharged from the culvert and, by comparison, the very small quantity of ash that would have been borne in it; they would also draw attention to the velocity of the stream where it would emerge from the mouth of the culvert.