SPECIAL REPORT OF RESEARCH

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College of Earth and Mineral Sciences
The Pennsylvania State University

COAL MINE REFUSE DISPOSAL
IN
GREAT BRITAIN

by

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STATEMENT OF TRANSMITTAL

Special Report SR-81 transmitted herewith has been prepared by the Coal Research Section of the College of Earth and Mineral Sciences Experiment Station. Each of the Special Reports listed below presents results obtained in connection with one of the research projects supported by the Commonwealth of Pennsylvania or a technical discussion of related research. The following is a list of Special Research Reports issued to date:

SR-1  The Crushing of Anthracite  May 31, 1957
SR-2  Petrographic Composition and Sulfur Content of a Column of Pittsburgh Seam Coal  August 1, 1958
SR-3  The Thermal Decrepitation of Anthracite  September 15, 1958
SR-4  The Crushing of Anthracite with a Jaw Crusher  November 1, 1958
SR-5  Reactions of a Bituminous Coal with Sulfuric Acid  February 1, 1959
SR-6  Laboratory Studies on the Grindability of Anthracite and Other Coals  April 1, 1959
SR-7  Coal Characteristics and Their Relationship to Combustion Techniques  April 15, 1959
SR-8  The Crushing of Anthracite with an Impactor-Type Crusher  April 25, 1959
SR-9  The Ignitibility of Bituminous Coal (A Resume of a Literature Survey)  May 4, 1959
SR-10 Effect of Gamma Radiation and Oxygen at Ambient Temperatures on the Subsequent Plasticity of Bituminous Coals  May 6, 1959
SR-11 Properties and Reactions Exhibited by Anthracite Lithotypes Under Thermal Stress
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SR-12 Removal of Mineral Matter from Anthracite by Chlorination at High Temperatures
June 22, 1959

SR-13 Removal Stability of a Coal Tar Pitch
June 25, 1959

SR-14 The Effect of Nuclear Reactor Irradiation During Low Temperature Carbonization of Bituminous Coals
July 31, 1959

SR-15 Effect of Anthracite and Gamma Radiation at Ambient Temperature on the Subsequent Plasticity of Bituminous Coals
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SR-16 The Isothermal Kinetics of Volatile Matter Release from Anthracite
August 25, 1959

SR-17 The Combustion of Dust Clouds: A Survey of the Literature
November 30, 1959

SR-18 The Ignitibility of Bituminous Coal
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SR-23 A Phenomenological Approach to the Batch Grinding of Coals
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William Spackman, Director
Coal Research Section and
Office of Coal Research Administration
SUMMATION OF RESULTS

Great Britain's mining districts, like any other coal producing area, e.g., Pennsylvania, have a heritage of derelict land, the result of former mining prosperity. Coal has been mined in Great Britain since the Roman occupation, about 2,000 years ago. Production by the end of the 19th century had reached 200 million tons per year. The 1969 production of coal in Britain totaled 150 million long tons.

Coal mine refuse has increased during the last forty years. Over 90% of the mine refuse is now discharged to banks. Refuse output was expected to peak at 60 to 80 million tons per year in 1966-68 and then gradually decline. The number and size of unsightly refuse banks have increased in the past few decades. In 1964, there were about 150,000 acres of derelict land in Britain. Half of this was caused by refuse banks, the other half by unfilled excavations. The quantity of coal mine refuse in these banks was approximately one to two billion tons mainly from bituminous operations. Some of these refuse banks are burning, which complicates the problem. In 1953, over 200 of some 400 banks examined in England, were emitting slight fumes, and some 20 were emitting severe fumes. The anthracite refuse banks, in general, did not burn. The time to act was at hand and controls were enacted to correct these conditions.

The Planning Acts of 1947 applied controls to new refuse banks started after 1949. It did not apply to banks still in use so this act had no immediate effect. The Clear Air Act of 1956 required suppression of fire in new refuse banks and those still in use. The act did not apply to banks which had been abandoned. The Rivers Acts
of 1951 and 1961 provided control over the quality of drainage from old and current refuse. Public authorities had the power to acquire abandoned heaps the owners could not or would not restore. The Mines and Quarries (Tips) Bill controls the construction of refuse banks to insure stability.

The cost of reclamation of abandoned refuse banks is normally supported by public funds. The degree of reclamation may vary from simple "cosmetic" treatment to complete establishment of recreational facilities. Costs may vary from $80 to $5,000 per acre. Some old refuse banks are reprocessed to recover available fuel. This activity in Britain has been confined mostly to anthracite refuse since, in general, banks containing this rank coal did not ignite spontaneously.

A small quantity of coal mine refuse has been used in the manufacture of bricks. Some mines produce a refuse satisfactory for refractories. "Red dog" was popular with the civil engineering industry for the last 20 years but has priced itself out of many of its former markets. Processes for developing lightweight aggregate have been continuing for the past 20 years but no commercial plant has been established. Some highway embankment fills are unburnt coal mine refuse material. Several universities in Great Britain are conducting research programs in the general field of coal mine refuse utilization and disposal.

Today, there are probably no more than 6 banks emitting even a slight odor. There are no mine refuse problems associated with any present or former strip mines. All excavations have been restored to contour, land surface and site drainage.
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H. Gordon Glover, scientist in charge of mine water investigations throughout the South Yorkshire Area of England for the National Coal Board, was appointed as Visiting Professor of Mineral Science in the Department of Mineral Preparation at The Pennsylvania State University for the Winter Term, 1969. During his appointment, Professor Glover presented several seminars on recent developments in mine drainage pollution control and washery refuse disposal control. In addition, Professor Glover acted as a consultant in his fields of specialization to various University, Commonwealth of Pennsylvania and corporate research programs.

A chemistry graduate of the University of London, England, and an Associate of the Royal Institute of Chemistry, Mr. Glover has been employed in the coal mining industry in Great Britain since 1952. His early research interests were mine fire detection and control, and since 1954 he has been concerned entirely with mine drainage and mine refuse disposal problems in which he is considered an expert. Because of Mr. Glover's deep involvement with coal mine disposal controls, he was a valuable asset in furthering the research being conducted in this area, as well as providing invaluable liaison with groups working on these problems in Great Britain.
INTRODUCTION

The coal mining districts of Great Britain (see Figure 1) and Pennsylvania share an unenviable heritage of derelict land from their former prosperity. The spoilage of the landscape by mine refuse banks occurred slowly and at first unnoticed, but in the last few decades, the rate of loss of land and the ugliness of unnatural silhouettes and burning refuse became apparent to all and the time had arrived to call a halt.

In Britain, the Planning Acts of 1947 applied controls to new refuse banks started after 1949, but did not control the banks which were still in use so that this act had no immediate effect. The Clean Air Act of 1956 required the suppression of fire in new refuse banks and those which were still in use, but did not apply to refuse banks which had been abandoned. The Rivers (Prevention of Pollution) Acts of 1951 and 1961 provided control over the quality of the drainage from both old and new refuse banks. Other statutory regulations have provided powers of compulsory acquisition by public authorities of abandoned heaps which the owners could not or would not restore. The Mines and Quarries (Tips) Bill controls the construction of refuse banks to insure stability and will give powers to public authorities to act in the case of unstable conditions being suspected in an abandoned refuse bank.

Mine refuse banks are also liable at Common Law for damage to adjacent property by atmospheric pollution, river pollution, encroachment of solid matter, etc.
Geologically, the Pennsylvania and British coalfields have much in common; not only were the two fields laid down at much the same time, but the world map for Carboniferous time, based on the theory of Continental Drift, suggests that the North American Continent was lying adjacent to the Western European coast, i.e., that there was no Atlantic Ocean. There may well have been a more or less continuous coal forming region from what is now Southern Appalachia through Britain and the present North Sea, through mid-Europe into Russia. Like Pennsylvania, Britain has a range of coal types from bituminous to anthracite.

Coal is known to have been mined in Great Britain during the Roman occupation about 2000 years ago, and has been extracted ever since. By the end of the 19th century the output was some 200 million tons per year, but until this time the coal was hand selected at the point of loading in the mine, and there was probably less than 2% of refuse in the form of stone, shale and pyrite in the run-of-mine output. There was, however, a higher percentage of small coal extracted which was discarded with the refuse; and with the exception of the anthracites, much of this coal was liable to spontaneous combustion and soon burned away, often leaving large cavities in the refuse pile which were dangerous, particularly while still hot. A little of this small coal is still discovered in old heaps; and occasionally, such concentrations of coal reveal their presence by igniting spontaneously, but the quantities remaining in the bituminous areas are negligible. The recoverable coal in the anthracite refuse banks has by now almost all been extracted.
The output of coal mine refuse has increased during the last forty years as the result of several factors:

a) mechanization of the coal mining process;

b) increased efficiency of the coal preparation processes;

and

c) exhaustion of the better quality seams which led to the extraction of inferior coals of higher ash and sulfur content; and to the concentration of mining at fewer, deeper underground mines where multiple seam extraction occurred.

The output of coal mine refuse probably reached a maximum in the years 1966-68, of about 60 to 80 million tons per year. It is expected that the fall in the output of coal in Great Britain, coupled with the cessation of mining of certain inferior coals, and changes in the pattern of the market will produce a fall in the gross output of refuse during subsequent years, although the problem may actually intensify locally at the remaining mines. In 1964 there were about 150,000 acres of derelict land in Great Britain, according to "Dereelict Land", a publication of the Civic Trust of Great Britain, and "New Life for Dead Lands", a Ministry of Housing and Local Government publication. About one half of this area of dereliction was caused by refuse banks and one half by unfilled excavations, but, unfortunately, two such areas were seldom adjacent. Of the 60,000 acres of industrial waste banks, about 20,000 acres were coal mine refuse banks. The quantity of coal mine refuse lying in banks was approximately 1 to 2 billion long tons. This refuse was mainly from bituminous mines, a small proportion was from
anthracite mines, and to complete the picture, a few hundred large banks of red-dog were left by the oil shale industry in Scotland.

As recently as 1953 according to the Alkali Inspectors Reports, the problem of atmospheric pollution in Great Britain from the burning of bituminous mine refuse banks was severe. Of some 400 banks examined in England, over 200 were emitting slight fume and some 20 were emitting severe fume. The anthracite refuse banks did not, in general, burn.

In 1969, there were probably no more than half a dozen refuse banks emitting even a slight fume in the whole of Great Britain.

The need to prevent refuse bank combustion, and indeed to tackle the problem of land dereliction, has been greater in Britain than in Pennsylvania for the following reasons:

1. the higher population density, particularly in the coal fields;
2. the greater overall extraction from smaller coal fields (most workings are now at depths of 1,000 to 5,000 ft.);
3. the higher level of present atmospheric pollution;
4. the poor atmospheric dispersion of pollutants.

It may be concluded that the mine refuse disposal problems which are now being encountered in Pennsylvania have also occurred in Great Britain and that there is much to be gained from an exchange of observations and experiences.

TERMINOLOGY

Because of the large number of synonyms in common use, it is necessary to define certain terms as follows:
Refuse: All the solid waste from a coal mine, including tailings and slurry. The term now favored in Great Britain is "spoil" to avoid confusion with municipal refuse. Other synonyms are: dirt, gob, shale, slate, etc.

Bank: A mound of refuse. Synonyms include tip, ruck, stack, heap, and bing. The term heap is now favored in Britain and the term tip deprecated.

Red dog: Burnt refuse. Also known as red ash, red shale, etc.

Discard: Refuse larger than 28 mesh.

Tailings: Underflow from a froth flotation process. Tailings may be thickened by flocculation and sedimentation, superthickened, or pressed, i.e. (pressure filtered).

Slurry: The suspension of solids formed in a coal preparation plant circulating water, similar to tailings but containing coal particles in the finest size ranges.

Particle size distribution ranges for these materials are given in Figure 2.

TYPES OF REFUSE BANKS

Refuse from Strip Mines

There are no mine refuse problems associated with any of the present or former coal strip mines in Great Britain. British coal strip mining operations have, from the start of intensive mining in 1943, removed the top soil and the subsoil from the sites before the excavation, and have restored the contours, the land surface, and the site drainage after excavation. These requirements are incorporated in the Opencast Coal
GENERAL RANGES OF PARTICLE SIZE DISTRIBUTION FOR COLLIERY DISCARD

Figure 2
Mines Acts. Strip mines in Great Britain which have been operated for the extraction of gravel, brick clay, etc., have not been controlled by such severe statutes, and many of these sites are standing open and partially flooded.

**Abandoned Refuse Banks**

In Great Britain, most of the abandoned banks are no longer owned by the operators of the mines from which the refuse was discharged. The Rivers Acts apply to discharges from these banks, and the other regulations give powers of compulsory purchase to the local authorities. The new Mines and Quarries (Tips) Act will give the local authorities powers in control in the event of suspected instability of an abandoned bank. The Clean Air Act does not apply to abandoned banks; but most of the abandoned banks which were burning at the time of passing of the Act have now burned to completion, and few are still giving trouble, although occasionally a bank which has been quiescent may start to burn. Unless the combustion is stopped at once by drastic measures, the fire may involve the whole bank before it can be suppressed.

There is now an increased public awareness of the need to improve the aesthetic impact of many of the abandoned banks, and indeed, a pressing need for land in some areas. However, the cost of reclamation of the abandoned refuse banks is normally supported by public funds and the coal mining industry is not required to subscribe. Derelict sites bearing coal mine refuse banks usually contain abandoned buildings, canals, flooded subsidence areas, etc., so that the cost of reclamation of the refuse banks alone can seldom be isolated from the cost of the whole scheme. The degree of reclamation may vary over a wide range from
simple "cosmetic" treatment, involving little or no regrading and a minimum of tree and grass planting, to a full scheme involving a complete transformation of the contours, together with the import or transfer of soil, the establishment of recreation facilities, etc. Costs may vary from $80 to $5,000 per acre. The average cost of land restoration has ranged from $150 per acre for grass or tree cultivation on the existing surfaces to $2,000 per acre for complete reclamation. One recent scheme involving 220 acres of graded, subsided and sterile spoil heap land areas, a top soil was developed at a cost of $600 per acre for civil works plus another $125 per acre for agriculture over the succeeding three years. The total rate of reclamation of derelict land generated by all sources of industrial waste is now several thousand acres per year in the whole of Great Britain, although some counties report that despite this activity, more derelict land is being created from all sources of industrial waste than is being reclaimed. As the result of legislation and the voluntary activities of the coal mining industry, the area of new land which is being made derelict by coal mining is now insignificant.

In addition to the basic problem of the net costs, many technical problems remain to be solved before reclamation can be applied to all derelict areas. Few attempts have been made to reclaim abandoned refuse banks which produce a grossly acidic drainage, since little is known of the effects of compaction, and compaction and covering, on highly acidic refuse. Another problem which has now been recognized is delayed plant toxicity. At many sites where fertile soil was not available, grass and trees were planted directly in the refuse. Opinions differed as to whether it would be better to plant in the weathered skin which had formed on an old refuse bank, or to use regraded black or red refuse as
a top soil. No matter which material was used, however, (unless it was grossly acidic) an initial dressing of lime and fertilizer seemed to be sufficient to form a good cover of grass or a reasonable take of trees. Many of these schemes were successful, but at other sites, the cover was liable to die completely without warning, sometimes years after planting. Clear examples of plant toxicity appeared at Mitchell's Main and at Bullcroft in South Yorkshire. These problems have not been resolved and there is still a considerable amount of hit and miss in the selection of top layer materials. One feature which has emerged clearly in Great Britain is that it is seldom possible to form a cover of vegetation which will remain stable in subsequent years without some form of management. In the case of grasses, it is preferable to graze animals, but this is not always possible, and cutting, with attention to pH and nutrient control seems to be necessary. The cost of this maintenance is usually less than $30 per acre a year. Land which has been restored to active agriculture will normally be under constant maintenance.

There have been a few disturbing reports that trees, by the action of their roots, have allowed air to enter a formerly stable refuse bank and to promote a fire.

In contrast to the general desire for the complete elimination of the abandoned refuse banks from the landscape, there have been suggestions that at least a few of the old banks should be left as monuments to the industrial society of the early 20th Century, and also suggestions that the steep contours of some of the banks should be retained for recreational purposes such as ski jumping.
Derelict land reclamation is now becoming a major industry in Great Britain. The chairman of the National Coal Board has suggested that the primary purpose of the Board's Opencast Mining Executive should be switched from strip mining to derelict land reclamation, with the recovery of strip coal as a secondary factor. The National Coal Board currently operates a mature tree transplanting service which is available to other authorities and services for reclamation schemes.

Old Refuse Bank Sites Which are Still in Use

These sites (in Great Britain) are not liable to the Planning Act controls, which were specified in the General Development Order of 1949. These controls applied to the construction of coal mine refuse banks on new sites, i.e., those which were not in use for refuse disposal in 1949, but the Order made no provision for control over sites which were in use at that time. Since some of these sites were extensive, several are still in use today, twenty years after the passing of the Act. The absence of Planning Act controls produced a considerable incentive for the continued use of these old sites, and the tendency was to place as much refuse as possible on the land available, i.e., to make the face gradients as high as possible and the depth of refuse as great as possible. This philosophy was clearly evident in the 1950's, but the following factors led to an opposite policy in the 1960's:

Fire control: High face gradients which could not be compacted were incompatible with fire control as required by the Clean Air Act of 1956.

Stability: The need for soil engineering surveys on partly used sites, and the heterogeneity of the materials in the old refuse
banks, has increased the costs of using the old sites. However, during the last twenty years, the majority of the coal mine refuse was placed on these old sites, and it is only recently that large quantities have been placed on new sites which are subject to Planning Act controls. During this twenty year period, the method of transport and placing has changed from aerial flights, tramways, Maclean tipplers, etc., to transport by road vehicle, dumper, etc., with subsequent placing and compaction by bulldozer, etc. Some mines are now using scrapers for the dual purpose of refuse transport and compaction. In addition to the need to control spontaneous combustion and to control stability, changed methods have become necessary to place the spoil into the remaining space as the sites became filled.

These old sites are now rapidly improving in appearance since, once full, the Planning Authorities normally cooperate in releasing adjacent ground for extensions. This new ground is subject to Planning control which normally requires the removal of the site soil, the finishing of the extended bank at a shallow slope, and at a selected contour which blends with the locality, and the replacement of the soil together with the establishment of vegetation. This policy is effective and many coal mine refuse banks which were formerly very obvious have now apparently disappeared from the landscape.

The old sites were liable under the Rivers (Prevention of Pollution) Acts. A very few of these sites produce a highly polluting acidic drainage, and, while a large number produce a slightly contaminated drainage, the volume of drainage is usually small and does not produce any appreciable pollution. The volume of drainage from the toe of most of the refuse banks is an insignificant fraction of the rainfall, and
there is so far no satisfactory explanation of the ultimate fate of the precipitation which falls on these refuse banks.

New Refuse Bank Sites

This heading refers to sites which were not in use for refuse disposal in 1949 and therefore are not exempted from the Planning Acts. Refuse banks constructed on these sites are liable, also, under the Clean Air Act and the Rivers Acts, and will be controlled by the Mines and Quarries (Tips) Act. Although few in number in the early 1950's, these sites have proved to be almost free from technical troubles although the operating costs have been higher. The Planning controls normally called for pre-stripping of soils and subsoils from the site, the construction of the bank by compaction, with prescribed face gradients and controlled heights. The soils were required to be replaced on the graded refuse, and returned to a prescribed state of agriculture or other usage. Refuse banks constructed to these specifications have not developed fires, and have not so far given any acidic drainage problems. The fertility of the soil covers has been good. No conditions were usually included in the Planning consent regarding the mechanical stability of the embankment, but it is expected that this aspect will be controlled by the Mines and Quarries (Tips) Act.

CURRENT REFUSE DISPOSAL TO BANKS

Well over 90% of the current make of coal mine refuse in Great Britain is discharged to banks, and there is no prospect that it will be possible to reduce this proportion appreciably for many years to come. The control of refuse bank construction is therefore important
and will be considered in some detail. A refuse bank should be considered to be a civil engineering structure and, as such, it should be designed to precise factors of safety in respect of mechanical stability and risk of atmospheric and river pollution, and the finished bank should form an acceptable part of the environment. Unfortunately, much of the necessary design information is not available, and it is currently necessary to include large safety factors, particularly in respect to mechanical stability.

Fundamentally, there does not seem to be any severe conflict of interests between the different requirements of mechanical stability, fire control, river pollution, land value, and appearance, but several new problems arise when all these features are found in the same bank. In Britain, the present emphasis is on mechanical stability, and it has been found to be convenient to use the voidage of the placed refuse as a common factor with which to judge the control of all the required parameters. These different requirements will now be considered in turn.

**Mechanical Stability**

The National Coal Board has made an intensive study of this problem. The first factor in any consideration of refuse bank stability is the foundation. The most spectacular refuse bank collapses have occurred not because the refuse itself was unstable, but because the bank was lying on an unstable foundation such as a supercharged aquifer and/or a clay bed, the whole possibly fractured by mining subsidence. These collapses did not necessarily occur while the bank was being constructed, and some appeared in unexpected places and parts of the banks. The
technology of foundation strengths is well established, the main problem being the high cost of a thorough investigation. Naturally, the costs are much less when a new site has to be investigated than when an old site on which some refuse has already been placed is to be used. The importance of foundation stability is shown by the recent reexamination of the geological, hydrological, and soil engineering aspects of the foundation of almost every coal mine refuse bank in Great Britain.

The design of the refuse bank itself is currently based on classical embankment theory. The refuse is considered as an engineering soil, the strength parameters of which can be assessed by conventional tests, to provide data for design factors such as height and face gradient in terms of degree of compaction and moisture content of the refuse.

Engineering soils may be broadly classified as cohesive and non-cohesive. Embankments containing cohesive soils fail by rotational collapse, as diagramed in Figure 3. Since the shearing resistance of the refuse in the potential failure surface determines the effective stability, incipient failure planes (which, for example, may have been formed by tipping tailings over a long face during the construction of the bank) are obviously very important. An embankment containing noncohesive soil fails by the sliding of loose material down the face on flat layers. Cohesive soils may be considered to contain a continuous matrix of fine particles, and any larger pieces are not in effective contact; whereas, noncohesive soils contain larger pieces which are in contact while the finer material is insufficient to fill the voids.

In Great Britain, there appears to be a general correlation between the rank of the coal and the cohesivity of the associated refuse. The
SOME TYPICAL CAUSES OF INCREASE IN SHEAR STRESS

Figure 3
anthracite mines tend to produce noncohesive refuse and low rank bituminous coal tends to produce highly cohesive refuse. The shape of the particle size distribution curve gives an idea of the cohesivity of refuse which can be verified by shear tests. Obviously, the particle size distribution is not the only strength parameter; the degree of compaction and the water content are also of prime importance. The interrelationship of these factors is shown in the typical compaction diagram (Fig. 4), for which a material with a certain size distribution and of specific gravity 2.0 has been assumed. In the absence of water, and assuming that complete compaction could be achieved, the dry density would be 124.8 lb. per cu. ft. At this compaction there would be no voids, i.e., the material would have almost the bulk density which it possessed in the ground before extraction. In the presence of water (of specific gravity 1.0), the dry density of the fully compacted material would fall as shown by the full line. Material having a 10% moisture content (dry basis) would have a voidage of 17%, this being the volume occupied by the water. These voids would form pores, which if interconnected, could make an embankment appreciably permeable. High permeability is undesirable since it could allow water to pass through the material carrying polluting salts, and could also wash away fine particles, thus increasing the permeability. Furthermore, should some of the water drain from the pores, air would have access to the interior, with, in the case of mine refuse, the risk of fire and acidic salt formation.

It is seldom possible to compact materials such as coal mine refuse to the degree of compaction indicated by the full line of Fig. 4, and it is normal to obtain a relationship between dry density and moisture
EXAMPLE OF RELATION BETWEEN MOISTURE CONTENT AND DRY DENSITY FOR MATERIAL OF SPECIFIC GRAVITY - 2.00 (Broken Line)

Figure 4
content of the form shown by the broken line. The relationship at low moisture contents is irregular and varies between types of refuse, but all types of refuse exhibit a rising curve with a maximum as shown at the higher moisture contents. Compaction of refuse at moisture contents of more than about 4% above the maximum of the curve is not possible, since the refuse has no bearing strength. It is normally assumed that a moisture content slightly greater than that corresponding to the maximum is the optimum at which to place refuse into a bank. The dry density which can be achieved by compaction is influenced not only by moisture, which on the one hand is a necessary lubricant and on the other hand is responsible for creating voidage, but also by the particle size distribution of the refuse. It is obvious that for perfect compaction, there must be a range of particles, each of the appropriate size just to fill the gaps between the other particles. The shape of a particle size distribution curve which will just meet this requirement is known as a Fuller curve\(^1\), which, although an approximation because of the uncertain shape of the particles, is a useful concept.

Discards from wet coal preparation processes in Great Britain are typically delivered to the refuse banks with moisture contents of from 5% to 20% moisture. Excessive moisture in discard is not a serious problem unless the fines content is high, since drainage of the tipped discard for a few hours will usually reduce the moisture content to the optimum for compaction. At sites where very wet discards are delivered regularly, it may be necessary to make special provision to prevent the

\[\text{Percentage passing any sieve} = 100 \sqrt[\text{The aperture size of that sieve}]{\frac{\text{The size of the longest particle}}{}}\]
water draining from the fresh deliveries from running into the placed refuse.

Unfortunately, the British coal mines produce not only discard, but large quantities of fine refuse (slurry or tailings). Slurry is not too difficult to handle since it can usually be dewatered reasonably cheaply either by vacuum filter or in lagoons, and may then either be sold as a low grade fuel or mixed with the discard in one way or another. Tailings, however, are a serious problem at many mines. The solids content of the tailings may represent 25% of the weight of total refuse from the mine, and the tailings solids may contain over 40% of particles smaller than 2 mm. Such tailings have the properties of a plastic clay. Typical quantities of materials discharged from a bituminous mine are:

- 900 t dry discard associated with 150 t water.
- 100 t dry tailings associated with 200 t water.
- Total 1000 t dry refuse associated with 350 t water.

This mixture containing 35% water (dry basis) is too wet for compaction and will not drain freely to a compactable condition. It may dry if spread in thin layers in evaporating weather but such conditions are unusual in the British winter. The costs of transport, draining and placing of discard may be from 5 to 20 cents per ton of dry solids, whereas the cost of dewatering the tailings may be $2 to $4 per ton of dry solids equivalent. Current methods of dewatering tailings are by filter presses, which are expensive and particularly unpopular as far as operators are concerned, and lagoons, which have the fundamental disadvantage that they will not dewater the tailings sufficiently. When the clay content of tailings is high, dewatering in a lagoon ceases when the solids content has risen to about 65% since the permeability is then too low to permit any appreciable rate of dewatering even in a
mildly evaporating environment. Tailings which have been dewatered to 65% solids content can be reworked into dry old mine refuse, but can only be added to fresh discard with considerable difficulty.

Attempts are being made to use very high molecular weight flocculents (superflocculents) for the rapid dewatering of tailings in conical thickeners. Solids contents of about 60% to 70% can be achieved with retention times of a few hours or less, but it has not yet been shown that this product can be incorporated satisfactorily in fresh discard in the appropriate proportions.

Having designed an embankment that will be stable at the time of construction, it is also necessary to consider the continuing stability and infinitum. The main sources of danger are movement of water and gases inside the bank which will be determined by the permeability, which will in turn have been determined by the type of refuse and the degree of compaction achieved. Waters may enter the bank either from above (meteoric water), or from the side as drainage from adjacent ground, or from beneath as rising ground water, and it may be necessary to control these water flows if the refuse has any appreciable permeability. Meteoric water may be controlled by the gradients of the surface of the embankment, and by natural earth covers consolidated by vegetation. It may also be necessary to provide drains on the surface of the bank. In the case of banks with large areas of more or less flat top, the top should be sloped inwards and not domed, so that the water may be collected by a herringbone of drains and taken off through a properly formed conduit. The domed form of construction can force large volumes of water over the edges of the bank into any incipient failure cracks which may have appeared round the top of the sloping sides.
Superficial water from adjacent ground should be taken clear of the bank by a suitable culvert. Open channel toe drains are not normally favored because of the need for maintenance, and the increased risk of inducing a rotational slip. Rising ground water is a problem which, on a new site, should have been taken care of by exposing the aquifer at bedrock, and covering with a blanket drain which will carry away the water even when subjected to the loading of the refuse bank.

The design of drains which can take water out of bedrock while remaining permeable under a bank, and out of adjacent ground and out of mine refuse is an important problem. Current practice is to use the accepted "rules" of rubble drain design which have been developed for engineering soils. These are based on the particle size distribution of the rubble in the drain and the material which is to be drained, and also on the assumption that the finer particles of soils will remain cohesive in the presence of moving water. These "rules" may not necessarily apply in all respects to coal mine refuse. There is also an urgent need to reexamine the finer points of these rules since the high class aggregates, which can be used for drainage in normal civil works, can seldom be afforded for mine refuse bank protection, and it may be necessary to develop new rules applicable to lower quality filter media.

In practice, several of the very large new refuse banks are being designed in the form of strong, well drained, outer embankments holding back heterogeneous mixtures of discard, tailings, etc.

It is necessary to appreciate that the design of a refuse bank as conventional embankment must for the time being, be based on the strength properties of fresh refuse, since it is seldom possible to find weathered
refuse of known age and history. It is obvious by inspection that most types of fresh refuse change their mechanical properties on weathering and that, therefore, the strength of completed embankments almost certainly changes. The principle minerals present in coal mine refuse are coal, silica, clays, and pyrite, together with ankerites, limestones, calcite, siderite, etc. These minerals are found in various grain sizes, bonded by various physical and chemical cements. The materials which are mainly coal bonded do not change their physical strength much on weathering, nor do the materials of high silica content such as the sandstones. The silt and mudstones, however, particularly those which have a high clay content, may disintegrate sooner or later after the moment of exposure in the mine. The peat-earth mudstones of the Warwickshire and Cannock Chase coalfields in Great Britain disintegrate to clay-sized grains during the brief period of immersion in the coal preparation plant. In other coal fields of Great Britain, the mudstones may remain intact for years inside a refuse bank, but collapse into fragments within a few days of subsequent exposure to alternate drying and wetting or to freezing. These mudstones may disperse to clay-sized grains or just fracture into only a few hundred pieces. It is obvious that refuse banks which contain any appreciable proportion of these disintegrating mudstones may suffer appreciable changes of strength characteristics after construction. A more subtle, but equally serious change of strength may appear if the rate of oxidation of the pyrite becomes sufficiently high to influence the chemical environment of the surrounding refuse. The reduction of the pH may dissolve calcitic and sideritic cements which have been holding aggregates together, and may alter the mechanical properties of clays by changing the exchangeable
cation and possibly by affecting the lattice. It is apparent that much more information on the rate of weathering and its effect on the mechanical strength of mine refuse is urgently required, and this forms one of the most pressing of the National Coal Board's research programs.

**Fire**

It is considered that the measures which are being taken to control stability will almost certainly eliminate the fire risk in all but the most noncohesive refuse. It has been observed that almost any method of constructing a refuse bank is less liable to lead to fires than the old loose "tippled" heap, and that provided the refuse is placed in layers (even tens of feet thick at some sites) and the faces are compacted, not only do fires not develop, but the refuse remains cold (50°F).

The reduced tendency to spontaneous combustion in refuse banks in recent years is probably also due to some extent to the smaller particle sizes of the refuse, the high water content, and in some but not all cases, the lower coal content. Fire is no longer a factor of immediate concern in current refuse disposal in Great Britain. The fires which were burning on the old sites have either burned out or been extinguished by compaction and over-tipping of highly compacted refuse. Recent boreholes have shown that elevated temperatures are retained in these over-tipped banks for many years, even though continued oxidation was clearly impossible.

**Amenity**

The Planning Act requirements which are intended to preserve the amenities of a locality have achieved their purpose. Planning conditions
normally require that a new site should be stripped of soil, which will 
eventually be replaced on the finished bank, that face gradients should 
be low (usually a slope of 1 in 3.5 or 4 minimum) and limits are usually 
placed on the maximum height of the bank and the form of the silhouette. 
Refuse banks formed to these specifications have shown no signs of fire, 
and revegetation has been successful. It is unlikely that any serious 
river pollution problems will occur. Despite the low face gradients, 
it is necessary to design the embankments on the basis of the strengths 
of the refuse and the foundations. These technical advantages have only 
been obtained at a cost both in material handling and difficulties 
attending the purchase of the necessary large areas of land. The dry ton 
disposal cost of refuse has doubled, tripled and even quadrupled as a 
result of increased legislation.

**River Pollution**

The effects of all the changes of method of refuse construction 
which have occurred in recent years have not yet been evaluated. Coal 
mine refuse frequently takes several years to become acidic, and the 
long term effects of exposure of the refuse before concealment in the 
heap, such as now occurs at some sites, have not yet become apparent. 
Another possible source of polluting effluents may be the drainage from 
large areas of fairly flat surface of a refuse bank of low permeability, 
which may accumulate sufficiently to scour and to wash down large 
quantities of solid materials. Apart from the undesirable deposition 
of materials on adjacent properties, and the pollution of water courses, 
erosion is to be deprecated since it washes away leached refuse and/or 
fertile soil faster than it can form.
A few of the old refuse disposal sites (which are still in use) yield a very acidic drainage. These problems are being resolved by methods such as chemical treatment of the drainage or discharge to old mine workings to control the immediate problem, coupled with major civil works including regrading of the old refuse, an absolute prohibition on the use of water to control fires, and the placing of fresh refuse by controlled compaction, with low face gradients, soil covers etc.

UTILIZATION OF REFUSE

Although various methods of coal mine refuse utilization are being reevaluated with renewed urgency, there seems to be little chance of using more than a small fraction of the refuse from the current production or of using much of the refuse lying in abandoned banks.

Recovery of Coal

Where possible, old refuse banks are reprocessed to recover available fuel; but this activity in Great Britain has largely been confined to anthracite refuse, since that did not, in general, burn whereas most of the rich bituminous refuse has long since burned away. A few of the bituminous refuse banks made in recent years contain 10% to 20% of recoverable coal, but the reworking of these banks would in any case have little effect on the overall problem of refuse disposal. The refuse from these operations would seldom be of any more value than refuse already available in nearby banks, which has not yet found a market.
Bricks

A small quantity of coal mine refuse has been used directly for the manufacture of bricks for many years and a continued steady demand is forecast. However, most of the coal mine refuse in Great Britain contains carbonaceous minerals of too high a rank to make a good burnt brick. A few of the abandoned refuse banks have been reworked as sources of brick clays. The National Coal Board produces over 400 million bricks a year, but not all these bricks are manufactured from coal mine refuse.

Refractories

A very few mines produce refuse suitable for the manufacture of refractory bricks, and a few small mines are operated primarily for the extraction of the refractory mineral with the production of coal as an ancillary process. The quantities of fire clay produced by the National Coal Board in 1966-67 was 15,300 long tons, and there is an additional production from privately owned coal and fire clay mines.

Red Dog

This material has become sufficiently popular in the civil engineering industry in the last twenty years to have priced itself out of many of its former markets. A good quality red dog now costs about $1 a ton in some areas of Great Britain. Unfortunately, most of the red dog is of inconsistent quality because of clinkers, variability of firing, uncertain particle size, low crushing resistance, high sulphate content, excessive frost heave, etc. No attempt has been made in Great Britain to produce red dog by deliberate combustion of mine refuse in industrial plants.
Lightweight Aggregate

The development of processes to produce lightweight aggregate has been continuing for at least twenty years in Great Britain, but no commercial plant has yet been ordered. Experimental quantities of the material are being produced with promising results.

Land Fill and Highway Embankments (Black Refuse)

During the last two years, the attitude towards the use of unburnt coal mine refuse as base fill for civil works has changed in Great Britain. Such material was traditionally suspected of being liable to spontaneous combustion and was specifically excluded from most contracts and approved specifications. The success of the coal mining industry in controlling fires in refuse banks, and the construction of major civil works such as the Boulderhead Dam in Northumberland (England) from coal measure shales, have led to a new approach and the Ministry of Transport (advised by the Road Research Laboratory) has recently permitted the use of unburnt refuse in highway embankment fills, etc., subject to consultation by the local authority with the National Coal Board and the Road Research Laboratory as to the best method of placing and the best types of refuse to use. The sole advantage of unburnt refuse lies in its low initial cost, which obviously becomes less significant as the haul distance increases, so that the market is limited to areas near to the coal fields. Several embankment and fill schemes using black refuse are now under construction in England, and the National Coal Board is building experimental embankments, which will be fitted with instruments to determine the extent of thermal and chemical changes. Both fresh refuse and refuse which has been exposed banks for several years will be used in these schemes.
Agricultural Soil

It has been shown that bituminous mine refuse can be mixed with pulverized fuel ash to produce a soil which is more fertile than either component, and there was a chance that mixtures of P.F. ash and tailings might be used as soil conditioners in particular localities.

This potential outlet now seems unlikely to be realized since the producers are confident that all the P.F. ash produced in Great Britain will be utilized in the manufacture of concrete within the next few years. Small quantities of tailings are used directly for land irrigation, but the quantities are low.

ALTERNATIVE DISPOSAL OF REFUSE

Underground Stowage

After a promising start in the early 1950's, this method of refuse disposal has not been widely used in Great Britain, at least as far as the disposal of refuse separated in the coal preparation plant is concerned. Very few mines return refuse from the surface, and reports in the literature indicate that the costs are unfavorable, even when the mines have a surface subsidence problem. The quantity of refuse reported as having been power-stowed by the National Coal Board in 1958 was about 2 million tons and was somewhat less in 1965, after which time records have not been maintained.

Hydraulic Transport

The feasibility of hydraulic transport of coal mine refuse is again under consideration in view of all the extra costs which now have to be faced in the construction of a refuse bank. There are plenty of spaces
within a few tens of miles of most of the British coal fields which could usefully be filled with mine refuse without causing any stability, fire or drainage problems. These sites include marshy ground, estuaries, etc. No definite plans for hydraulic transport schemes for refuse in Great Britain are known.

CURRENT RESEARCH

The following list summarizes current research and investigation projects in the general field of coal mine refuse disposal in Great Britain.

**Soil Engineering**

- **Durham University**
  - Mineralogical changes in weathered refuse, and strength of fresh and weathered refuse. (NCB grant)

- **Sheffield University**
  - Chemistry, mineralogy, and biology of weathered coal mine refuse with particular reference to the Mansfield marine band horizon. (NCB grant)

- **London, Cardiff, Swansea, Herriott Watt (Edinburgh)**
  - These universities are conducting some work in this field.

- **National Coal Board**
  - (Doncaster)--development of gamma ray density probes, and other instruments.
### Fertility of Weathered Refuse

**York University**

Toxicity and fertility, chemical, biological and microbiological aspects. (West Riding County Council and Nuffield Foundation grants.)

**Strathclyde University**

Development of fertility in acid refuse.

**County Councils of Durham, West Riding, Nottingham, Staffordshire, Lancashire, and others.**

Many grass and afforestation projects are being undertaken, some on an experimental basis.

### Mineral Weathering

**National Coal Board Scientific Control (Durham, Cardiff and Doncaster.)**

A study of the change in chemical, physical and mineralogical properties of different types of refuse on weathering.

### Permeability of Refuse

**National Coal Board, Scientific Control (Cardiff and Doncaster.)**

Determination of the hydropermeability of old and fresh mine refuse before and after placing, and the validity of current filter drain design theory, with particular reference to piping, and the dewatering of tailings.
### Mineral Preparation

**National Coal Board, (Bretby), and various reagent manufacturers, etc.**
- The dewatering of tailings and slurries.
- Various contractors and NCB.
- The recovery of coal from abandoned refuse banks.

### Utilization of Refuse

**Ministry of Transport, (Road Research Laboratory)**
- Use of red and black refuse.

**Building Research Station and National Coal Board, (Research and Development Department)**
- Development of lightweight aggregate.

### Quality of Drainage

**National Coal Board, (Doncaster)**
- A study of the relationship between the source and the quality of drainage from refuse banks.

### FUTURE PROGRAMS OF RESEARCH

There will be considerable developments in the civil engineering controls over the placing of refuse on banks and considerable research will be needed on the effects of weathering. The factors which must be known to calculate the economic water content, at which the refuse should be discharged from the coal preparation plants, will be evaluated. A better appreciation of the factors which determine the fire and polluting drainage risk will be made so that these problems can be controlled with more certainty. Further work is needed on the toxicity and fertility of refuse to plants both when fresh and after weathering. Further research into methods of refuse utilization will be conducted.
LONG TERM FUTURE

The present acceptance of compaction and water control as the fundamental parameters of construction of refuse banks may eventually have to be reexamined. It is possible that a more fundamental parameter will be the face gradient which is a factor not only in stability, but in the cost of new sites, the value of recovered land, aesthetics, fire control, pollution, vegetation, etc. It may be that many of the problems of stability will be solved by the realization that a low face gradient would be the most satisfactory solution at many sites.

Once the present situation has stabilized, it will be desirable to reexamine the whole subject of coal mine refuse from the moment of winning of the refuse in the mine, through the mine transport system, and the coal preparation system to the final method of disposal. This study should reveal the most economical solution to the overall problem.