INDUSTRIAL MEDICINE

AND

HYGIENE

Edited by

E. R. A. MEREWETHER

C.B.E., O.St.J., M.D., F.R.C.P., D.I.H., F.R.S.Ed., Barrister-at-Law

H.M. Senior Medical Inspector of Factories, Ministry of Labour and National Service; Chief Medical Adviser, Ministry of Agriculture and Fisheries

With a Foreword by

THE LORD HORDER

G.C.V.O., M.D., F.R.C.P.

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E. R. A. MERCHANT

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The Section requires that every steam container is so maintained as to secure that the outlet is at all times kept open and free from obstruction. This is designed to ensure that no steam pressure can build up inside the container.

Air receivers

An " air receiver " is defined in this Section as (a) any vessel (other than a pipe or coil, or an accessory, fitting or part of a compressor) for containing compressed air and connected with an air compressing plant; (b) any fixed vessel for containing compressed air or compressed exhaust gases and used for the purpose of starting an internal combustion engine; or (c) any fixed or portable vessel (not being part of a spraying pistol) used for the purpose of spraying by means of compressed air any paint, varnish, lacquer, or similar material; or (d) any vessel in which oil is stored and from which it is forced by compressed air.

Its use is common in every trade or process where air is accumulated under pressure for industrial purposes, for example in a garage for the blowing up of tyres to the starting air bottle of a diesel engine.

The requirements of the Section are somewhat similar to those for a steam boiler and special emphasis is placed on fittings, cleaning and periodical examination by a competent person. The Section is directed, as in the case of steam boilers, etc. against the exceeding of the safe working pressure and especially against the risk of explosion as the result of spontaneous combustion through the accumulation of oil which may have passed the piston rings of the compressor.

Water-sealed gas-holders

By this is meant any water-sealed gas-holder which has a storage capacity of not less than 5,000 cubic feet (Section 33). Apart from sound construction and proper maintenance, there must be periodical examination, the results of which must be recorded. Certain samples of metal must be cut and examined, and must be reported on by a competent person at stipulated intervals.

The demolition or repair of any such gas-holder must be carried on only under the direct supervision of a competent, skilled and trained person, who is aware of the risks involved.

PROCESSES

Dust and fumes (general)

Section 47, sub-section 1, is rather more than a corollary of Section 4 (*see* p. 15). Here we have a weapon aimed especially at the control of any dust or fume, or other impurity given off by the factory processes, which is such as to be likely to be injurious or offensive. It also has regard to substantial quantities of dust of any kind—a point which is sometimes forgotten.

In the case of such dust, fume, or impurity, all practicable steps must be taken by the occupier to protect his workpeople against their inhalation, and

to prevent their accumulation in the work-room. Furthermore, wherever the nature of the process makes it practicable, exhaust appliances to draw off such dust or fume or other impurity must be provided and maintained as near as possible to its point of origin, so as to prevent it from entering the air of any work-room.

Noxious dusts

Dusts of various kinds are unfortunately unavoidable concomitants of many industrial processes and some of them are especially harmful to health. Common examples include the following.

Asbestos: when broken or crushed or during the manufacture of asbestos textiles, insulating slabs or mattresses.

Silica dust: generated in the grinding and crushing of refractory materials for pottery and refractory bricks; generated in the use of sandstones in connexion with grinding processes.

Lead dust:
in the manufacture of electric accumulators;
in the vitreous enamelling of glass;
in the manufacture of india-rubber;
and in the manufacture of pottery.

Dust which may contain anthrax spores, usually generated in the processing of wool, goat-hair, camel-hair or horse-hair, from certain localities.

Dust of radioactive compounds, used, for instance for luminizing the dials of scientific instruments.

Dust of pitch in the manufacture of briquettes and other patent fuels.

Dangerous or harmful fumes

These are to be found *inter alia* in the following: (1) the use, manufacture and storage of cellulose solutions; (2) chemical works; (3) chromium plating.

It is interesting to note that, apart from the requirements of Sections 4 and 47, all the above examples are already the subject of special regulations (*see* p. 33).

What we are concerned with in this section are the unregulated types of dust and fume—those everyday types to which we do not give a thought, such as the following (1) dust generated by wood-working machines; (2) dust generated in processing all sorts of mundane substances; (3) hair or mattress filling; (4) soap powder and similar substances; (5) dust and fumes from welding processes. If these are likely to be injurious or offensive, they must be exhausted and prevented from contaminating the air of the work-room.

Exhaust fumes

Sub-section 2 requires not only the conduction of exhaust fumes from any stationary internal combustion engine into the open air, but also the partitioning of the engine from any work-room, so as to prevent ingress of injurious fumes to the latter.

Precautions with respect to explosive or inflammable dust, gas, vapour or substance

Section 28 is directed, *inter alia*, against the accumulation of dust or other matter liable to cause an explosion. It requires enclosure of the plant and the removal or prevention of accumulations of dust (for example, on roof principals, window-sills, ledges) and by the exclusion or effective enclosure of possible sources of ignition.

Further technical requirements deal with the provision, in connexion with plant, of chokes, baffles, vents and other outlets to restrict the spread of explosions. The opening of any plant containing explosive or inflammable gas or vapour under pressure is prohibited except under certain specified conditions.

Sub-section 4 prohibits the application of heat by welding, brazing or soldering operations, or for cutting operations, to any plant, tank, or vessel which contains or has contained any explosive or inflammable substance. Such work is not permitted until all practicable steps have been taken to remove the substance or fumes, or to render them non-explosive or non-inflammable.

By Section 11, sub-section 4 of the 1948 Act a " *cutting operation* " includes any operation involving the application of heat for the purposes of taking apart or removing the plant, tank or vessel, or any part of it.

The requirements of this sub-section are not always realized by the owners of small garages, agricultural engineers, blacksmiths, and others, when repairing tanks or drums which have contained petrol, fuel oil and similar substances. A suitable factory placard, containing valuable advice as to precautions (Form 1926), is obtainable from H.M. Stationery Office.

Special requirements with regard to laundries

Under Section 55, a fan must be provided to regulate temperature in every ironing-room and to carry away the steam in every wash-house. Stoves for heating smoothing-irons should be so separated from any ironing-room or ironing-table as to protect the workers from the heat thereof, and gas-irons emitting noxious fumes must not be used.

Protection of the eyes

Section 49 requires that, in certain processes (scheduled by regulations) in which there is special risk of eye injury from particles or fragments thrown off in the course of the process, suitable goggles or other effective screens are to be provided, to protect the eyes of persons employed in the process.

The following processes are scheduled under Protection of the Eyes Regulations, S.R. & O. 1938, No. 654.

Dry grinding of metals or articles of metal applied by hand to a revolving wheel or disc driven by mechanical power.

Turning (external or internal) of non-ferrous metals, or of cast iron, or of articles of such metals or such iron, where the work is done dry, other than precision turning where the use of goggles or a screen would seriously interfere with the work, or turning by means of hand tools.

Welding or cutting of metals by means of an electrical, oxy-acetylene or similar process.

The following processes, when carried on by means of hand-tools or other portable tools, are also scheduled.

Fettling of metal castings involving the removal of metal.

Cutting out or cutting off (not including drilling or punching back) of cold rivets or bolts from boilers or other plant or from ships.

Chipping or scaling of boilers or ships' plates.

Breaking or dressing of stone, concrete or slag.

Regulations for safety, health and welfare in particular trades

At one time or another from the beginning of the twentieth century, sundry trades and processes have been certified, under the now repealed Act of 1901, as being especially dangerous. As a result their hazards have been controlled by regulations. These regulations have been continued in force by Section 159 of the Act of 1937 and, together with regulations made since that time, present a picture of perhaps surprising and certainly great diversity, as will be seen from the following examples.

Aerated Waters: S.R. & O. 1921, No. 1932.
Asbestos Industry: S.R. & O. 1931, No. 1140.
Blasting (Castings and Other Articles): S.I. 1949, No. 2225.
Brass casting: S.R. & O. 1908, No. 484.
Bronzing: S.R. & O. 1912, No. 361.
Building (Safety, Health and Welfare): S.I. 1948, No. 1145, and S.I. 1952, No. 1584.
Celluloid Manufacture: S.R. & O. 1921, No. 1825.
Cellulose Solutions: S.R. & O. 1934, No. 990.
Chemical Works: S.R. & O. 1922, No. 731.
Chromium Plating: S.R. & O. 1931, No. 455.
Cinematograph Film Manufacture: S.R. & O. 1928, No. 82.
Cinematograph Film Stripping: S.R. & O. 1939, No. 571.
Cotton Cloth Factories: S.R. & O. 1929, No. 300.
Docks: S.R. & O. 1934, No. 279 (Certain processes of loading, unloading, and so on at docks and of ships), and S.R. & O. 1925, No. 231.
Dry Cleaning Special Regulations: S.I. 1949, No. 2224.
Electric Accumulators, Manufacture of: S.R. & O. 1925, No. 28.
Electricity: S.R. & O. 1908, No. 1312.
Electricity (Factories Act): S.R. & O. 1944, No. 739.
Enamelling, Vitreous, of Metal or Glass: S.R. & O. 1908, No. 1258.
Factories (Cotton Shuttles): Special Regulations, S.I. 1952, No. 1495.
Felt Hats, Manufacture of, Using Inflammable Solvents: S.R. & O. 1902, No. 623.
File-Cutting by Hand: S.R. & O. 1903, No. 507.
Flax and Tow: S.R. & O. 1906, No. 177.
Foundries (Parting Materials): S.I. 1950, No. 1700.
Grinding of Cutlery and Edge Tools: S.R. & O. 1925, No. 1089 and S.I. 1950, No. 370.
Grinding of Metals: S.R. & O. 1925, No. 904 and S.I. 1950, No. 688.

Handling of Hides and Skins: S.R. & O. 1921, No. 2076.
Hemp, Jute, etc., Spinning and Weaving of: S.R. & O. 1907, No. 660 (but *see* Jute Regulations below).
Horizontal Milling Machines: S.R. & O. 1928, No. 548 and S.R. & O. 1934, No. 207.
Horsehair, Use of (China, Russia or Siberia): S.R. & O. 1907, No. 984.
Hydrogen Cyanide (Fumigation of Buildings): S.I. 1951, No. 1759.
Hydrogen Cyanide (Fumigation of Ships): S.I. 1951, No. 1760.
Iron and Steel Foundries: S.I. 1953, No. 1464.
Jute (Safety, Health and Welfare): S.I. 1948, No. 1696.
Kiers: S.R. & O. 1938, No. 106.
Lead Compounds, Manufacture of: S.R. & O. 1921, No. 1443.
Lead Smelting, etc.: S.R. & O. 1911, No. 752.
Locomotives and Waggons: S.R. & O. 1906, No. 679.
Luminizing: S.R. & O. 1947, No. 865.
Magnesium (Grinding of Castings and Other Articles): S.R. & O. 1946, No. 2107.
Manufacture of India-rubber: S.R. & O. 1922, No. 329.
Paints and Colours, Manufacture of: S.R. & O. 1907, No. 17.
Patent Fuel Manufacture (Health and Welfare): S.R. & O. 1946, No. 258.
Pottery (Health): S.R. & O. 1947, No. 2161.
Pottery (Health and Welfare): S.I. 1950, No. 65.
Refractory Materials, Handling, etc. of Refractory Materials, Processes in Silica Brick Making: S.R. & O. 1931, No. 359.
Shipbuilding: S.R. & O. 1931, No. 133.
Spinning by Self-Acting Mules: S.R. & O. 1905, No. 1103.
Testing of Aircraft Engines, etc.: S.I. 1952, No. 1689.
Tinning of Hollow-ware, etc.: S.R. & O. 1909, No. 720.
Use of Woodworking Machinery: S.R. & O. 1922, No. 1196, and S.R. & O. 1945, No. 1227.
Use of Wool (East Indian): S.R. & O. 1908, No. 1287.
Vehicle Painting Regulations: S.R. & O. 1926, No. 299.
Wool, Goat Hair and Camel Hair Processes: S.R. & O. 1905, No. 1293.
Woollen and Worsted Textiles (Lifting of Heavy Weights): S.R. & O. 1926, No. 1463.
Yarn: S.R. & O. 1907, No. 616.

These regulations are directed against sundry risks to health or against certain dangerous processes, machinery or plant. They require, as may be applicable to the particular trade *inter alia*, such things as the following:

exhaust ventilation to control dust and fume;
precautions in case of fire where explosive or inflammable materials and fumes are involved;
brushing down of walls and benches where there are dust hazards;
periodical medical examinations;
adequate and suitable lighting;
fencing of certain especially dangerous machines (already referred to under "Plant");
washing and clothing accommodation;

protective clothing and equipment;
accommodation for meals;
first-aid arrangements.
lighting.

Building, ship-building and docks

The Building (Safety, Health and Welfare) Regulations, the Shipbuilding Regulations, and the Docks Regulations may be described as specialist codes. They are concerned *inter alia* with the special hazards associated with falls of persons or articles and the use of lifting machinery, chains and ropes. They are voluminous and complicated. The Building Regulations, for example, contain no less than 100 separate regulations. Thus, it is not possible to do more than indicate the field in a general account of this kind.

Welfare Regulations and Orders

Many of these were made under the 1901 Act, as in the case of the Regulations for Safety and Health, and have been continued in force by Section 159 of the 1937 Act.

Here again there is much diversity, as may be seen from the following list:

Bakehouses: S.R. & O. 1927, No. 191.
Biscuit Factories: S.R. & O. 1927, No. 872.
Blast Furnaces, etc.: S.R. & O. 1917, No. 1067.
Cement Works: S.R. & O. 1930, No. 94.
Clay Works: S.I. 1948, No. 1547.
Dyeing, other than Job-dyeing: S.R. & O. 1918, No. 369.
Fruit Preserving: S.R. & O. 1919, No. 1136.
Glass Bevelling: S.R. & O. 1921, No. 288.
Gut Scraping, etc.: S.R. & O. 1920, No. 1437.
Herring Curing (Norfolk and Suffolk): S.R. & O. 1920, No. 1662.
Herring Curing (England and Wales, except Norfolk and Suffolk): S.R. & O. 1927, No. 813.
Herring Curing (Scotland): S.R. & O. 1926, No. 535/S. 24.
Hollow Ware and Galvanizing: S.R. & O. 1921, No. 2032.
Laundries: S.R. & O. 1920, No. 654.
Oil Cake Mills: S.R. & O. 1929, No. 534.
Sacks, cleaning and repairing: S.R. & O. 1927, No. 860.
Saw Mills: S.R. & O. 1918, No. 1489.
Sugar Factories: S.R. & O. 1931, No. 684.
Tanning: S.R. & O. 1930, No. 312.
Tanning (Two-bath Process): S.R. & O. 1918, No. 368.
Tin or Terne Plates, Manufacture of: S.R. & O. 1917, No. 1035.

As their titles imply, the requirements are designed to secure minimal welfare standards in respect of such things as (1) drinking water; (2) washing and clothing accommodation; (3) messrooms for taking food; (4) protective clothing; (5) first aid of a special type; (6) affixing of cautionary notices.

Many of their provisions, including drinking-water, accommodation for washing and for clothing, and first aid, have been incorporated in the general requirements of the 1937 Act, which are as follows.

Drinking-water.—This must be provided and maintained at suitable points conveniently accessible to all workpeople (Section 41). The supply must be adequate, and be drawn from a public main or some other source approved in writing by the District Council. Drinking-water is best laid on and available in the form of an upward-delivery fountain, which avoids use of drinking-vessels. When this is not possible, the supply of drinking-water must be contained in suitable vessels and renewed at least once a day. The vessels and water must be suitably protected from contamination. All supplies, laid on or otherwise, must, as directed by the Inspector, be clearly marked " Drinking-water ". If the water is not delivered by an upward jet, one or more suitable cups or drinking-vessels must be provided at each supply point, with facilities for rinsing them in drinking-water.

Washing facilities.—Adequate and suitable facilities for washing must be provided and maintained for the use of persons employed (Section 42). Such facilities must include soap and clean towels, or other suitable means of cleansing and drying. The facilities must be conveniently accessible and kept in a clean and orderly state. The Minister may by regulations prescribe standards.

Accommodation for clothing.—Under Section 43, this must be provided and maintained for the use of persons employed, in respect of clothing not worn during working hours. It must be adequate and suitable and arrangements must be made for drying the clothing if wet. The Minister may by regulation prescribe standards.

Seating.—Section 44, as amended by Section 6 of the 1948 Act has been in force since 1 October, 1950. It requires that, when any employed persons have, in the course of their employment, reasonable opportunities for sitting without detriment to their work, there should be provided and maintained for their use suitable facilities for sitting, sufficient to enable the workers to take advantage of these opportunities and, further, where a substantial proportion of any work can properly be done sitting, any employed person is to have a seat adequately and properly supported, and of a design, construction and of dimensions suitable for him and the work, together with a comfortable foot-rest if necessary.

First aid.—Section 45, and First Aid in Factories Order, S.R. & O. 1938, No. 486, require the provision and maintenance, and the ready accessibility of a first-aid box or cupboard of prescribed standards. Where more than 150 persons are employed, an additional box or cupboard must be supplied for every additional 150 or fraction of 150 persons. These figures are based on the largest number of persons employed in the factory at any one time.

The first-aid box or cupboard shall be kept exclusively to house appliances or requisites for first aid. Each such box or cupboard must be placed under the charge of a responsible person. This responsible person, in the case of a factory employing more than 50 persons, must be trained in first aid treatment and must always be readily available during working hours. (It is clearly

advisable to train a deputy, for the person in charge may be absent from the factory when most wanted.)

A notice must be affixed in every work-room, giving the name of the person in charge of the box or cupboard in respect of that room.

The Chief Inspector may exempt a factory from the requirements of this section, if there is provided therein an ambulance room, together with satisfactory arrangements to ensure the immediate treatment of injuries occurring in that factory.

PERSONNEL

Classification of personnel

The personnel of the factory may be divided as follows:

(1) The occupier or owner;
(2) The work-people:
  (*a*) men
  (*b*) women
  (*c*) young persons } protected persons

The occupier

The occupier has a direct and vicarious responsibility for the observance of the Acts and Regulations. His duties are thus both onerous and numerous. Apart from his general responsibility for the safety, health, welfare and hours of employment of the work-people, he is required to send, among others, the following notices to H.M. Inspector of Factories:

notice of intention to use any premises as a factory, Form 9, not less than 1 month before beginning occupation (Section 113, 1937 Act, as amended by Section 5 of the 1948 Act);

notice of intention to use mechanical power for the first time, not less than 1 month beforehand (Section 113);

(any person undertaking building operations subject to the Act becomes the occupier of a " factory " for certain purposes and must notify the Inspector for the District on Form 10 within 7 days if the building operation is not going to be completed in 6 weeks. Similar provisions operate in respect of works of engineering construction, which are also, as stated above, " notional " factories for certain purposes (Sections 107 and 108).)

notice of intention to use an underground workroom for the first time as a factory or part of a factory (on Form 1889) before the room is so used (Section 53, sub-section 2);

Notice of any factory accident which is fatal or which disables a person employed therein for more than 3 days from earning full wages at the work at which he was employed, on the prescribed Form 43. Particulars of such reportable accidents must also be recorded in the appropriate part of the General Register (Section 64).

Notifiable diseases

Written prescribed notice (Form 41) must be given (under Section 66) in

duration of the pneumoconiosis and on integral complications and associated diseases.

No description, however minute, can provide even a fraction of the knowledge which results from attendance at a few representative post-mortem examinations, performed and demonstrated by an experienced pathologist. Accordingly the notes which follow are intended simply to direct attention to a few matters of practical importance.

Silicosis: morbid anatomy

Characteristic appearances at necropsy

Opportunity to observe the characteristic appearances of early simple silicosis (*see* p. 167) usually only occurs in cases in which death has resulted from accident or intercurrent disease. When the thorax is opened the lungs appear quite normal. Close inspection of the visceral pleura, however, may reveal tiny seed-pearls, projecting from the surface and each defined by a ring of carbon. On palpation the nodules impart a feeling of fine granularity. This appearance is known as mammillation of the pleura, and is due to tiny discrete silicotic nodules, disposed along the course of the sub-pleural lymphatic vessels.

When the disease is more advanced, the lungs are usually more or less fixed to the chest wall by large sessile adhesions, and in the most advanced cases these may result in complete obliterative pleurisy, in which all the thoracic organs are matted together and anchored to the thoracic cage and diaphragm. This helps explain the clinical observation, confirmed radiographically, that only occasionally in pneumoconiosis does one observe either displacement or distortion of the mediastinum.

Bullae.—A common appearance is the presence of bullae (emphysema) along the free margins, particularly at the apex, along the mediastinal border and in the costo-diaphragmatic sulci. These may be present in bunches, like white grapes, or singly when they vary in size from that of a white-currant to that of a small orange. Occasionally rupture of a bulla is the cause of spontaneous pneumothorax, general or local, and in some instances this accident is fatal. In life these bullae, especially when multiple and adjacent to a massive shadow, may be identified radiographically, the walls between contiguous bullae appearing as septa traversing the translucent areas.

Procedure at necropsy

In cases with obliterative pleurisy, great difficulty often occurs in the attempt to remove the lungs for inspection and, if due care is not observed, the exploring hand may literally explode a large pus-filled tuberculous cavity, spraying the operator and attendants with grossly infected material. If this is to be avoided, the following routine procedure should be adopted in every case.

When removing the sternum make a wide exposure and avoid incising the subjacent lung. The thoracic viscera, or " pluck ", should be removed entire by detaching the tongue and stripping downwards. Even when the lungs appear irremovably bound to the chest wall, it is usually possible to find a gap in the adhesions through which an incision can be made in the parietal pleura. This done, the fingers can be insinuated into the opening and the whole pleura stripped from the ribs and intercostal muscles. Basal adhesions tend to be particularly dense, and so it is usually best to remove the lungs with the diaphragm attached.

Before detachment of the heart from the lungs, the pulmonary arteries should be carefully opened from the hilum into the lungs, for not infrequently in cases of massive fibrosis death follows pulmonary arterial thrombosis.

Next the trachea and bronchi should be systematically laid open with scissors, careful watch being kept for any evidence of bronchial carcinoma.

The lungs should then be cut in slices for inspection. This can be done very satisfactorily by laying the lung on a board, hilum downwards, and then using a long knife to make a succession of cuts parallel to the board.

Examination of silicotic nodules and masses

Discrete silicotic nodules, when present, are readily seen because, not being so contractile as the surrounding lung, they do not shrink to the same extent, but project from the cut surface. This is confirmed by palpation; the surface feels rough and shotty.

Silicotic nodules and masses are frequently described as gritty or stony on section, and this has sometimes created the idea that they represent aggregates of actual dust particles. This idea is quite erroneous; the foci, small or large, are composed of tough fibrous tissue of the consistency of firm india rubber (caoutchouc). Actual grittiness, however, may occur if calcification is present.

Masses, usually wedge-shaped or sausage-shaped rather than spherical, are most commonly located at the apex of the upper lobe or in the apex of the lower lobe, close to the hilum. It is exceptional to find a mass in the lower lobe without the existence of similar larger masses in the upper lobes. Furthermore, masses tend to occur symmetrically in both lungs, although they are usually more extensive on one side, particularly the right.

Large masses may show central cavitation and yet be without any naked-eye evidence of tubercles. First there is the circular cavity—on section a saucer-shaped depression—filled with glistening oily debris rich in cholesterol. A second type presents as a narrow ragged excavation in the long axis of the mass; it is dry, and appears as if it had been produced by a mouse gnawing in crumbly greyish cheese.

Tuberculous lesions and neoplasia

Chronic fibro-caseous tuberculosis is a common terminal condition in silicosis and, as a rule, both lesions are readily distinguished. From a small localized chronic cavity in the lung apex, a terminal miliary dissemination of tuberculosis may occur shortly before death, and (if inspection is casual)

this condition may quite easily be overlooked. In other cases the tuberculosis may be so extensive as to mask any nodules of silicosis. This is important in relation both to the selection of material for histological examination (*see* below), and to the problem of diagnosis in life (*see* p. 30).

Occasionally cancerous infiltration may be diagnosed macroscopically as tuberculous broncho-pneumonia, or *vice versa*, while a breaking-down cancer may be regarded as a simple abscess or infected bronchiectasis. Incidentally, frank purulent bronchiectasis is exceedingly rare in pneumoconiosis.

Selection of tissue for microscopical examination

These facts emphasize the importance of histological examination in every case and impose a corresponding care in the selection of suitable material.

Several blocks of tissue should be selected, and care should be taken to ensure that they represent all the pathological conditions recorded in the report. Because these cases often involve medico-legal proceedings, no matter how apparently indisputable the lesion may appear to the naked eye, any opinion thus formed should be confirmed by microscopical examination.

The hilar glands and the pleurae.—Because the hilar glands are involved early in the disease, portions of these should always be included. Blocks from the lung should, so far as is possible, include the superjacent pleura. In cases of generalized caseating tuberculosis of the lungs, it is often necessary to discover whether or not silicosis coexists; material for this is best obtained from suspicious foci in otherwise healthy-looking areas of lung remote from the tuberculosis.

Staining.—Pathologists have their own preferences for suitable staining methods but, no matter what these are, at least one appropriate section should be stained by the Ziehl-Neelsen method.

The heart.—Adhesions between the pleura and pericardium are common and sometimes the shaggy appearance of the heart suggests a recent fatal attack of acute or subacute pericarditis. This diagnosis should not be finally recorded until it is confirmed by histological examination, for it is surprising how often in silicosis the condition proves to be tuberculous, and to be associated with tubercle formation in the subjacent cardiac muscle. Hypertrophy of the right side of the heart is a well-recognized effect in long-standing cases of silicosis, especially when emphysema is a prominent feature. This, however, does not cause any substantial increase in the size or weight of the heart. Indeed the enlargement might well be described as internal—a thickening of the muscle of the right ventricle and the columnae carneae. This observation is important, for enlargement of the heart, apart from terminal dilatation, is not a clinical feature of pneumoconiosis, and when it does occur is usually attributable to concomitant disease, such as syphilis, rheumatic carditis or chronic nephritis.

Coal-workers' pneumoconiosis

Relation of post-mortem findings to aetiology

A number of coal-miners, forming a small percentage of the total employed, are engaged mainly in work which involves drilling and blasting in siliceous rock. Such men are shaft-sinkers, hardheaders engaged in the development of the mine, rippers and repairers. Some of these, after 15–20 years' work, acquire classical silicosis, or, if the exposure is associated with much black pigmentation of the lungs due to coal dust, anthraco-silicosis. These cases conform to the picture described on p. 39.

By contrast, men employed mainly " in the coal " on hand- or machine-cutting and loading at the coal-face, acquire a type of pneumoconiosis distinguishable from silicosis. The microscopical characteristics of this are described on p. 18. As in silicosis there are two main forms: (1) simple pneumoconiosis due to the action of dust alone and (2) massive or complicated pneumoconiosis, due, it is thought, to the combined action of dust and infection. Tubercle bacilli have been demonstrated in 40 per cent of these cases, and this finding supports the hypothesis of infection; but it is not yet disproved that massive fibrosis can result from intensity of dust exposure alone, especially if the coal dust contains appreciable amounts of silica. It would almost appear that doctors have too readily accepted the alleged association and influence of tuberculosis in dust fibrosis, and have gone on repeating it uncritically for over a century, so that it is now accepted as proved.

Technique and findings

The general morbid-anatomical manifestations of coal-workers' pneumoconiosis are similar to those described above for silicosis, but obliterative pleurisy is neither so frequent nor so extensive. The outstanding difference is the universal inky-black pigmentation of the lung parenchyma, which is very little altered by continuous washing under a running tap. The characteristic changes are (1) the coal nodules, (2) dendritic maculae, which are only slightly firmer than the lung tissue, and (3) the perifocal emphysema, distributed more or less throughout the lungs. Marginal bullous emphysema is unusual and if present is generally slight. All these appearances are more readily seen after the lungs have been fixed in formalin solution and especially in thin-tissue slices, prepared after the method of Gough and Wentworth.

Preparation of large tissue sections (Gough-Wentworth technique)

Gough (1952) describes the preparation of thin-tissue sections as follows:

> " Remove the lungs from the body whole and without rupturing the pleura. If there are dense adhesions take the parietal pleura out with the lung. (A few small tears do not matter except where there are large emphysematous bullae.) One or both lungs may be used. (I reserve one for bacteriological and chemical investigation.) Cut off at the hilum and fully distend by running the following

solution into the major bronchi, by means of a tube and cannula from a reservoir about 4 ft. above the lung.

Liq. formaldehyde (40 per cent)	500 cc.
Sodium acetate	200 g.
Water	5,000 cc.

" Place the lung in a container of fixative large enough for it to float freely with no distortion from pressure. Cover with a cloth wet with the fixative. The amount necessary to distend the lung varies up to about 2 litres and in the containers we use there is a further 3 litres.

" Fix for two days or longer and then cut a slice about ¾ inches thick. This may be in any direction but a sagittal one is most convenient. Good results are usually obtained after a few days' fixation, but in the absence of any urgency the slice is allowed to continue to fix for some weeks to completely destroy proteolytic enzymes.

" Wash the slice in running water for at least 72 hours to remove the formalin, and place in the following solution:

Gelatin	250 g.
*Propylene Phenoxetol	10 cc.
or *Phenoxetol	20 cc.
or ethylene glycol mono-ethyl ether (cellosolve)	20 cc.
Capryl alcohol	5 cc.
Water	850 cc.

" Remove the air from the slice to assist penetration by the gelatin. To do this place in a jar containing the gelatin solution heated to about 60 degrees C. and put under a bell-jar connected to a vacuum pump. A solution of agar is useful as a seal around the jar. With an efficient glass pump sufficient air can be removed within an hour, during which time the gelatin remains fluid at ordinary room temperature.

" Place the specimen, still in the gelatin solution, in an incubator at 35° C. for 72 hours, in a container in which it can lie flat and be completely immersed. Cast the gelatin and specimen into a block by allowing the gelatin to set in a container with a loose bottom. Remove the block by pushing out the loose bottom of the container. Fix the block to the microtome holder by warming the latter and then put weights on top of the block until the gelatin sets and sticks the block to the holder. Put in an ice box at — 15° C. for several hours, preferably overnight.

" Cut as thawing takes place. A warm cloth rubbed on to the surface is used to hasten thawing. Do not try to cut sections until the block is sufficiently thawed to cut easily. Put the sections into 10 per cent formalin for 24–48 hours to harden the gelatin. Wash in cold water for 1–2 hours to remove formalin.

" Mount on paper, using a fresh solution of:

Gelatin	75 g.
Glycerin	70 cc.
10 per cent solution of camphor in methylated spirits	10 cc.
Water	850 cc.

* Proprietary preparations of mono-phenyl ether of ethylene or propylene glycol.

" Pour some of the warm solution over a sheet of Perspex. Trim the surplus gelatin from the edges of a section and place it flat on the Perspex and cover with a sheet of Whatman's No. 1 filter paper. Run a rubber roller squeegee lightly over the paper, to remove surplus solution and air bubbles. Stand the Perspex sheet on end for 15–30 seconds and then lay flat until the gelatin sets. Thoroughly dry at room temperature and finally at 37° C. or better still in an x-ray film drying cabinet. When the preparation is completely dry, strip the paper with the section attached from the Perspex.

" Perspex is an acrylic resin. Other plastics would probably work as well. Glass cannot be used for this purpose as the sections would then adhere to the glass and not to the paper.

" The most convenient machine for cutting the large sections is the MSE ' Large Section ' Microtome (according to Gough and Wentworth) made by the Measuring and Scientific Equipment Ltd., 14–28 Spenser Street, London, S.W.1.

" The method is applicable to liver, kidney, heart, etc."

Articles sent by post for medical examination or analysis

This is sometimes necessary, and it is important for senders to know that in this matter certain post-office regulations apply. These are printed in the Post Office Guide. The main requirements are as follows:

" Deleterious liquids or substances, though otherwise prohibited from transmission by post, may be sent for medical examination or analysis to a recognized medical laboratory or institute, whether or not belonging to a public health authority, or to a qualified medical practitioner or veterinary surgeon within the United Kingdom by letter post, *but on no account by parcel post*, under the following conditions:

" Any liquid or substance must be enclosed in a receptacle, hermetically sealed or otherwise securely closed, and this receptacle must itself be placed in a strong wooden, leather or metal case in such a way that it cannot shift about, and with a sufficient quantity of some absorbent material (such as sawdust or cotton-wool) so packed about the receptacle as absolutely to prevent any possible leakage from the package in the event of damage to the receptacle. The packet so made up must be conspicuously marked *Fragile with care* and bear the words *Pathological specimen.*"

Exceptionally, pathological objects rendered innocuous by the mode of preparation and packing may be sent by sample post.

The British Post Office accepts no responsibility for the return or seizure of any packet, through the failure of the sender or addressee to comply with the necessary formalities; indeed, the specimen may be destroyed.

It is particularly important—and so often neglected—to ensure that the specimen is properly identified as to patient and sender; this is best done on or within the package and confirmed in a duplicate copy sent by separate post. The latter should also indicate details of the preservation of the specimen and the date of despatch.

Similar precautions are required when specimens are sent by rail.

DIAGNOSIS OF PNEUMOCONIOSIS

In life, the diagnosis depends on the following triad and, while any of these may lead one to suspect the presence of the disease, it must ultimately be firmly based on all three. Any anomaly should raise doubt in the mind of the physician, indicating the need for further investigation, and even for a visit to the place of work to inquire into the actual environmental circumstances of the particular case. The triad consists of the following units:

(1) clinical history and examination, with special reference to symptomatology;
(2) the history of the occupational risk, in order to define precisely the period and intensity of the silica risk;
(3) radiographic examination of the chest.

Clinical aspects

The general description of the morbid anatomy and pathology of pneumoconiosis and its complications (given on p. 8 *et seq.*) reveals the great variety of changes which may be present in the individual case. This is reflected in a similar range of clinical manifestations.

As has been proved by mass-radiography surveys, the disease is often present, and has been so for some considerable time, without the knowledge of the patient. This is due to the natural reserves of functional capacity, which compensate for diminished power; it is only when the patient exceeds these capital resources, that he becomes aware of his condition. Notwithstanding a knowledge of the dangers of his trade, when cough and slight breathlessness develop, the workman tends, in the first instance, to attribute the symptoms to smoking or to his " age ".

Dyspnoea

The earliest cardinal symptom is dyspnoea, at first occurring only on severe exertion, but as the disease and its complications advance, it may follow the slightest effort. These stories are typical. The coal-miner remarks that lately he has become aware of the " dips "—that, at the end of the shift, on the way to the " cage ", he is unable to keep pace with his mates, and that sooner or later he is compelled to rest by the roadside to " catch his breath ". Ultimately that walk becomes a succession of rests. The steel fettler tells how he has had to give up cycling to the foundry, because he could not push against the wind, and that where he used to walk, he is now quite pleased to ride on a bus. The caster of sanitary earthenware points to the reduction in his output; whereas he normally produced 12 pieces of ware each day, this diminished to 10 and later to 8 pieces. Furthermore, he can no longer do his own carrying out to the drying-sheds and must have the help of a labourer. Then again there is the young woman, who was, before marriage, for many years employed as an asbestos worker. As her

pregnancy advances, the doctor is impressed with the fact that, in the absence of complications, her breathlessness is excessive.

The story is always the same, the slowly progressive feeling of distress, yet without any sense of being ill.

Cough

Usually the breathlessness is accompanied by a short, irritating, unproductive cough, which is particularly troublesome at bed-time and first thing in the morning. On rising from bed the patient may be seized by a violent paroxysm, in which he coughs himself completely out of breath. For a time he is exhausted and, as he explains, " quite useless till the afternoon ". Whenever possible these men prefer work on the afternoon shift.

Expectorant and sedative cough mixtures ultimately prove ineffective. Doctors should warn patients against patent medicines and nips of brandy, if only to safeguard their financial resources. There is no better remedy than work; it keeps the mind occupied and avoids the introspection and depression of idleness, in which the patient becomes querulous of everybody and everything.

Sputum

When sputum occurs it is usually scant: a little tough viscid mucus. Occasionally it may be flecked with blood, but frank haemoptysis is uncommon except when tuberculosis is present. In coal-miners, even in health, the sputum may be black because of coal dust. This blackening, however, occurs as streaks in otherwise glairy mucus. Sometimes patients affected by massive fibrosis develop persistent spitting of uniformly black matter, which usually indicates disintegration of lung tissue.

Complication by tuberculosis

When tuberculosis supervenes, as is common in cases of silicosis, the patient may actually feel better, at least temporarily, for the cough becomes looser and more productive, and " clearing the tubes ", he avers, eases the breathing. However, the complete change in the nature and progress of the disease is soon apparent; he is now a sick man, tired, listless, with no appetite and steadily losing weight.

Changes in the clinical picture due to age at onset

The foregoing is a general, very simplified picture, which is really only encountered when the disease develops insidiously in the full fitness of life. Thus it is seen in coal-miners, if they contract the disease at about the age of 40 years.

Pneumoconiosis, however, in Great Britain, predominantly involves men in the later decades of life, that is from the age of 50 years onwards, by which time the disease is frequently associated with general physical decline and cardiovascular degeneration. Accordingly an inextricable complexity

of symptoms, which cannot be assigned to particular organs or systems, is the rule. Radiographic changes are readily demonstrable in the lungs and, by reason of their dramatic objectivity, attention is all too often focused on them, while concomitant conditions, which might be alleviated by treatment, are overlooked or not even investigated. In every case the doctor should ask himself whether the extent and nature of the pneumoconiosis account fully for the patient's illness.

Onset during an acute illness

Similarly, pneumoconiosis is often revealed, for the first time, in the course of an acute illness. In such circumstances the lungs represent a centre of reduced resistance, and their involvement may modify the manifestations and course of the acute disease or unduly prolong convalescence. This situation is very characteristically encountered during an attack of acute influenza, and it all too often leads to premature, ill-informed and improvident advice to the patient about the dangers of pneumoconiosis and of work in dusty occupations.

Patient's attitude toward the illness

Undue emphasis tends to be attached to the dust lesion, and the patient, convinced of the infallibility of the x-ray film, is often made disease-conscious, to his own serious detriment. Further aggravation follows the award of disablement benefit (or compensation), whereby he is assessed as " so much per cent " disabled. Because of the danger of getting worse if he continues at his job, but without due consideration of the many other important factors involved, the workman may decide to give up his skilled job. If he fails, as is so common, to obtain alternative suitable employment, he becomes the victim of a vicious circle of unfavourable influences and circumstances, largely beyond his control, and in which he can get little or no help. Ultimately, as a result, an early degree of simple pneumoconiosis may assume an importance for the individual, the family and the community, altogether out of proportion to reality.

Physical examination

This should be comprehensive of the whole patient, not restricted to the chest and finally abandoned to a radiological report on the condition of the lungs.

Examination of the chest

The physical examination of the chest follows the accepted cardinal routine of inspection, palpation, percussion, auscultation and mensuration. Nevertheless several matters merit some emphasis.

Inspection of the chest.—Inspection does not connote a few casual glances; it is a definite technique to be performed as a ritual. Among the matters

to be observed the first is the patient's reaction to the effort of undressing and dressing; this constitutes a simple exercise-tolerance test; secondly come the general build, somatic type, chest configuration and nature and range of respiratory movements. The development of the soft tissues of the chest wall and, particularly in the female, the size and conformation of the breasts, should be recorded, for these items are often important in the interpretation of the radiograph.

Percussion, auscultation and percussion.—By reason of the insidious onset and the paucity of physical signs, pneumoconiosis has been described as a silent disease. Percussion and auscultation frequently, in the presence of well-established changes, suggest no abnormality, yet on the other hand, in another group of cases, one may discover the whole range of abnormal physical signs. Even when massive shadows appear radiographically, precise areas of dullness can seldom be mapped out by percussion, while, despite the evidence of morbid-anatomical changes, clinical signs of pleurisy and bronchitis are the exception rather than the rule.

Cyanosis

Classically, cyanosis and clubbing of the fingers are regarded as regular accompaniments of chronic pulmonary disease, and so one would expect evidence of these in pneumoconiosis. Slight cyanosis is very difficult to define, even by the most careful inspection, and quite often it is present only in the imagination of the physician. It can definitely be asserted that easily recognizable cyanosis, except when associated with serious cardiac embarrassment as in cor pulmonale, is seldom observed in pneumoconiosis. Asbestosis, however, is exceptional, for in this variety of chronic pulmonary fibrosis, unmistakable cyanosis of the malar regions, lips and lobes of the ears is not uncommon, while drumstick clubbing of both fingers and toes is almost pathognomonic of the disease, in workmen employed in certain processes in the manufacture of asbestos textiles.

Diagnosis of clubbed fingers

Clubbing of the fingers, too, except as just mentioned, is a rare manifestation (Fig. 13*a*).

Any enlargement of the terminal phalanx is, by many people, mistakenly regarded as clubbing. In many artisans, who, in the course of work, are required to apply pressure with the tips of the thumb and fingers, the pulp of the terminal phalanx often becomes considerably broadened and thickened. This spatulate appearance is not clubbing.

Clubbing generally appears first in the thumb and index finger and later involves the others. When present in asbestosis it usually affects both hands symmetrically. The first changes are observed at the root of the nail, where thickening occurs and the overlying skin becomes shiny and injected. In this area the circulation is impaired and, in advanced cases the defect may actually impart a dusky blue coloration.

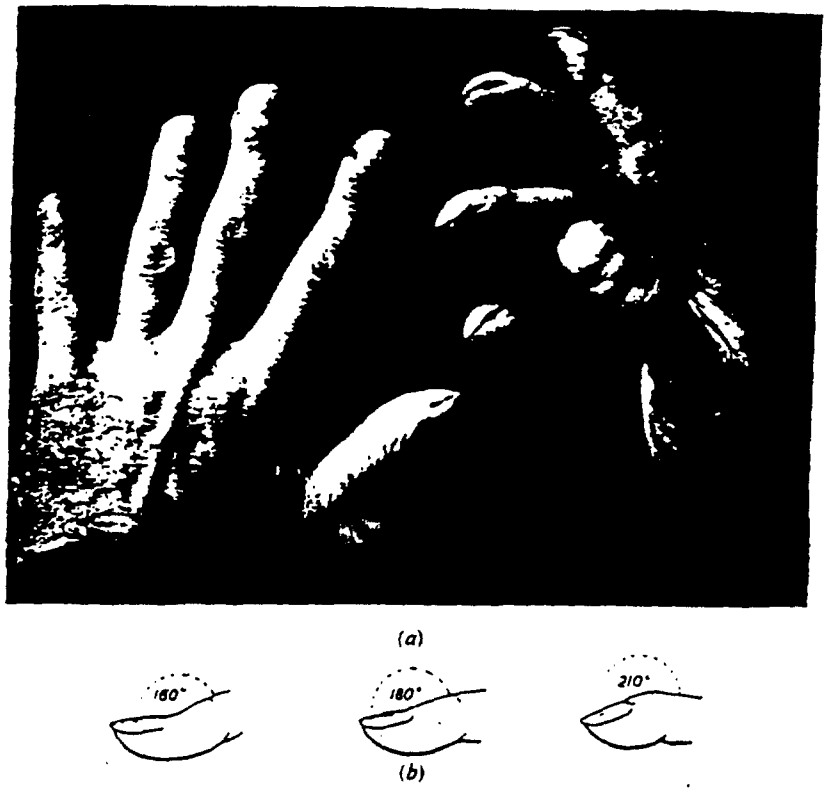

FIG. 13.—(*a*) Clubbing of fingers in asbestosis. (*By courtesy of Dr. H. Wyers.*) (*b*) Progress of finger clubbing, in the thumb, showing anormal thumb, moderate and gross clubbing.

Gross degrees are readily identified by all; difference of opinion occurs in cases generally recorded as slight, suspicious or early.

Lovibond's sign.—A very useful test is Lovibond's profile sign (Lovibond. 1938). If the finger—most characteristically the thumb—is viewed from the side, it will be noted that normally the nail forms an obtuse angle of about 160 degrees with the dorsum of the finger. When thickening occurs this angle gradually fills, until it is straight—180 degrees—and in severe cases the angle at the base of the nail becomes greater than 180 degrees with the apex upwards. In addition the curvature of the nail from front to back and side to side may be increased.

It is not intended to discuss the features and differential diagnosis of clubbing and the conditions which may simulate it. The sole purpose is to direct attention to this useful profile sign, as revealed by the essential angle, shown in Fig. 13*b*.

Emphysema

This is an important complication, particularly in relation to disability. In advanced cases the diagnosis is fairly easy, but in the early stages the usually accepted physical signs are of little help. Among these signs are (1) enlargement of the chest towards barrel formation, (2) horizontal position of the ribs, (3) widening of intercostal spaces, and (4) shallow movement.

confirmed, on measurement, by diminished expansion. In advanced cases breathing is almost entirely by the accessory muscles of respiration, and the movement has been described as *en bloc*.

Some help may be gained from radiological examination, in which exposures are made in lateral and oblique positions (*see* p. 37).

In practice, however, one is not so much concerned with the presence or absence of emphysema *per se*; the real problem is the extent of cardiopulmonary disability and, even more important, the assessment of the residual capacity for work. The scientific determination of these must largely be based on spirometry and exertion tests; but again it is emphasized that for practical purposes the test of an actual job is probably best of all. Even when the workman fails in this test, the solution is not to abandon work, but to seek, whenever possible, to modify the operations of his particular job.

Occupational history

In diagnosis the essential purpose of the occupational history is to define the period, intensity and nature of the dust hazard. Relevant to this, it is supremely important to realize that the disease, when present, may not necessarily have been contracted in the latest employment but possibly in some preceding one. Thus a bricklayer's labourer may have worked previously as a sandstone mason, or a cutlery-grinder may now be using emery-wheels, whereas during his early years in the trade he worked on sandstone grindstones. Accordingly, if one is to avoid error or omission, a definite scheme must be followed in every case.

The history should commence at the age of leaving school, and should itemize the periods and nature of employments in chronological order to date. The account of each separate employment—and in particular cases even this may have to be subdivided into periods—should be amplified by reference to the raw materials, the tools, the processes, the general environmental conditions, and any protective devices in use. Hours of work and alternation of jobs, too, are important. Inquiry should also be made into the occurrence of similar disease affecting the patient's workmates.

Some typical cases

Example 1.—According to the hospital medical records, this man's occupation was described as " stonemason for 22 years". The following are the facts.

T.J., date of birth 30 April, 1916.
Left school, aged 14 years, 1930.
1930–32, at mason's yard, errand boy and carrying tools.
*1932–37, apprentice mason—various types of stone—sandstone 1 year.
*1937–39, jobbing mason—sandstone.
1939–46, Army—infantry—Burma.
1946–48, bricklayer's labourer.
*1948–51, jobbing mason—sandstone.

Comment.—The starred items represent the periods in silica risk, as an aggregate of 6 years as a sandstone mason. After such a period silicosis is not to be expected, whereas 22 years, as indicated in hospital records, would be significant.

Example 2.—According to the hospital medical records, this man's occupation was described as " baths attendant ". The following are the facts.

A.A., date of birth 18 May, 1895.
Left school, aged 12 years, 1907.
1907–11, Lanarkshire colliery on screens.
1911–36, same colliery, underground:
trammer—3 years; loader—5 years; machine-man (coal-cutter)—17 years.
1936–38, off work—fractured pelvis.
1938–51, attendant at pit-head baths.

Comment.—In relation to pulmonary disease, the 29 years, 1907–36, are significant. The present occupation as baths attendant is misleading.

Example 3.—According to hospital medical records this man's occupation was described as foundry labourer. The following are the facts.

J.C., date of birth, 31 January, 1921.
Left school, aged 14 years, 1935.
1935–37, van-boy on baker's round.
1937–40, assistant moulder; steel foundry.
1940–51, labourer in same foundry as sand-blast operator; for the first 4 years sand was used; thereafter steel shot was substituted; castings are large and all work is done inside cabinet; wears protective helmet with air-line attached. No army service; exempt—essential occupation.

Comment.—In relation to pulmonary disease, the 14 years, 1937–51, are significant, but especially the 4 years, 1940–44, as a sand-blaster; shot-blasting also involves considerable risk from removal of moulding sand adherent to castings. These observations apply in spite of the protective devices in use.

Example 4.—According to the hospital records, this woman's occupation was described as housewife. The following are the facts.

M.T., date of birth, 12 June, 1914.
Left school, aged 14 years, 1928.
1928–38, china-biscuit brusher and scourer (silica).
1938–46, at home; domestic duties.
1946–50, china-biscuit scourer (alumina).
1950–51, at home on account of chest trouble.

Comment.—China-biscuit brushing and scouring, involving the removal of silica from the ware, involved a serious risk of silicosis. The substitution of alumina for silica considerably diminished this risk. The 10 years, 1928–38, are significant, which fact is not revealed by describing the woman's occupation as " housewife ".

Radiology in diagnosis

General considerations

The clinical investigation of every case must include radiographic examination of the chest, and it is generally accepted—as originally enunciated in 1916 by the Miners Phthisis Prevention Committee in South Africa—that the radiographic appearances in cases of pneumoconiosis afford the most reliable *single* piece of evidence in establishing the existence, extent and type

of the disease, in any particular case. It must be noted that this statement, however, is valid only subject to certain conditions, all too often forgotten or ignored in practice.

Radiographic evidence

First, the significant words are " piece of evidence "; it is a part not the whole. There is no such entity as an " x-ray diagnosis " of pneumoconiosis: the diagnosis, as is emphasized above, must be firmly based on the assessment of the aggregate evidence.

Evidence of fibrosis.—This notwithstanding, the diagnosis of pneumoconiosis cannot be sustained unless it is proved by the presence of radiographic appearances, indicative of specific anatomico-pathological changes in the lungs. Of course, this means that the disease is only recognized at an arbitrary stage of its development: namely, when the fibrosis is sufficiently mature to be radio-opaque and so distinguishable from normal lung structures. This is certainly later than is revealed by necropsy, but in life the diagnosis requires an objective sign, and this is represented by radiographic changes of characteristic type and pattern.

Evidence of emphysema.—While suggestive of the presence of emphysema, the following radiographic features, so often recorded in films taken in the lateral or oblique positions, have assumed an importance considerably beyond their reliability: (1) hypertranslucency of the lung fields, (2) the " drop-like " or ptotic heart, and (3) the dragging down of the hila on inspiration. The degree of translucency is dependent to a very large extent on the degree of penetration, so that, in an over-penetrated film, normal lungs may appear hypertranslucent, whereas in a " soft " film emphysematous lungs appear to have a normal translucency. In emphysema there is a tendency for the normal vascular markings to be obliterated, but again this may be off-set by congestion of the lung fields, caused by heart failure. On screen examination, increased translucency of the bases, accompanied by depression, flattening and restricted excursion of the diaphragm, are suggestive signs, but are not conclusive proof of emphysema. In bullous emphysema, particularly at the apices, the appearance of circular clear areas, adjacent to massive shadows and traversed by septa, is very characteristic. Moreover, this localized condition, when observed, is usually indicative of similar changes, not apparent radiologically, at other sites—namely along the free margins of the lungs.

Technical requirements

Secondly, the radiograph must be adequate for interpretation, which means that it is of high technical quality, properly exposed and processed.

Despite the great advances in x-ray machines during the past 50 years, apparatus is still imperfect, and there is need for some authoritative scientific body to certify that all components of sets comply with certain specified standards. Only thus can films of a uniformly high quality be produced.

The greatest present need among accessories is for the incorporation in every x-ray set of a reliable phototimer.

The main objective is reproducibility or repeatability; by this is meant the production at diverse times and places of radiographs which are strictly comparable. This is extremely important, if one is to avoid differences of opinion between observers, and if one is to assess accurately any alteration in the disease after an interval of time.

Recommendations of the Industrial Pulmonary Diseases Committee

This matter has been the subject of intensive study by the radiological sub-committee of the Industrial Pulmonary Diseases Committee of the Medical Research Council. In 1950 they published the following recommendations. It was not intended that these recommendations should represent finality, but rather that they should be regarded as standards to be aimed at, yet capable of attainment with existing apparatus.

"*RECOMMENDATIONS*

" 1. *Definition of a good chest radiograph*

" The basic criterion of a satisfactory chest radiograph is that the outline of the vertebral column (but not the inter-vertebral spaces) should be just visible through the heart shadow. In addition the following points should be noted:

(i) the *whole* of the bony thorax should be included to the level of the costo-phrenic angles;
(ii) the scapulae should be excluded from the lung fields;
(iii) the apices should be visible above the clavicles;
(iv) if possible the clavicles should be symmetrical at the sterno-clavicular articulations;
(v) the whole dome of the diaphragm should be included;
(vi) the outlines of the dome of the normal diaphragm should be sharp and the ribs should show good bone detail;
(vii) contrast, density, and sharpness should be such that the vascular markings are shown from hilum to periphery;
(viii) the cardiac outline and, if visible, the fissure between the upper and middle lobes on the right side, and the outlines of the left sub-clavian artery and of the inferior vena cava, should be sharply defined.

" 2. *Technical points to be observed in producing good chest radiographs*

" (i) Films must be adequate in size (*see* 1 (i)).
" (ii) The identification marker should be placed so that it appears along the upper right-hand border of the radiograph.
" (iii) The patient must be carefully positioned and the x-ray tube correctly centred.

" First place the patient so that he faces the cassette, then, standing immediately behind him, see that the neck is opposite the midline of the cassette and the shoulders below the identification marker. Now move the tube so that it is at the junction of the upper and middle thirds of the cassette (this will allow ample room for the inclusion of the diaphragm). To enable the scapulae to be

projected clear of the lung fields, and the apices clear of the clavicles, rotate the patient's arms forward and bring his shoulders downwards and forwards so that they press against the cassette. The patient's hands should then be placed so that they rest immediately below the posterior part of the iliac crests and, if the patient has long arms, well down over the buttocks, with the palms facing the tube. (Occasionally it is more comfortable for the arms to remain straight, in which case the palms will face laterally and the inner border of the arms will press against the sides of the cassette. Alternatively, a special type of apparatus may be used which allows the arms to be folded round the cassette.) Where it is possible to tilt the cassette, the top should be moved towards the patient through 5 deg. to allow closer contact with the chest.

"(iv) Exposure in relation to respiration.

"Exposure must be made on full inspiration but, in order that all movement should cease after inflating the lungs, an interval of at least one second should elapse between the instruction to stop breathing and making the exposure.

"In cases where breast shadows are likely to obscure detail in the lower zones, a recumbent or antero-posterior (A.P.) film, appropriately marked, should be taken in addition."

Two specimen radiographs (normal chest and early coal-workers' pneumoconiosis), illustrating the above technique, may be purchased on application to Miss K. C. Clark, Tavistock House North, Tavistock Square, London, W.C.1.

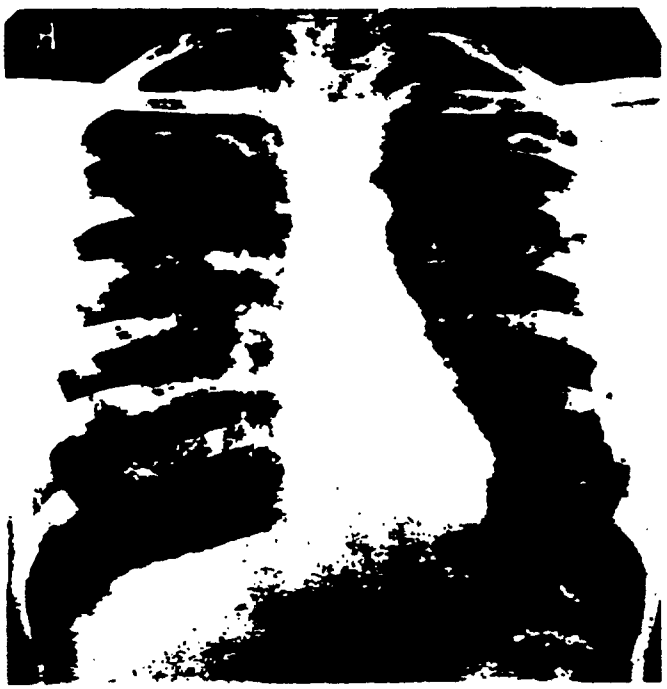

FIG. 14.—Normal chest radiograph. Male aged 40 years.

Standardization of technique

More recently a joint committee of the Joint Tuberculosis Council, The Faculty of Radiologists and the Society of Thoracic Surgeons in 1952 issued a report on *The Standardization of Radiological Terminology in Pulmonary Diseases and Standardization of Technique in Chest Radiography*, obtainable from H.M. Stationery Office.

Recommendations of the South African Silicosis Medical Bureau

The Silicosis Medical Bureau in South Africa prefer a softer film with less contrast, in which the outline of the vertebral column is completely obscured by the heart shadow. As a simple practical test to determine whether or not the lungs have been properly penetrated by the rays the Bureau points out that, in a satisfactory film, bone detail is equally clearly revealed in the anterior and posterior parts of any single rib.

Identification

In addition to any radiographic data, every film should bear the precise identification of the patient and date. These details should appear on the actual film; gummed labels or envelopes are not sufficient.

Screening and filming

Preliminary screen examination is invaluable, in fact an integral part of any radiographic examination of the chest. It provides information about function, and sometimes about structure, not revealed on a film. Unfortunately, it is not practicable as a routine procedure in hospital and clinic practice. Whenever possible, however, and certainly in all difficult cases, it should be carried out and—this is important—the observations should be included in the report.

In practice a single postero-anterior film (17 inches by 14 inches is the most useful size) is usually sufficient. Other views may be necessary in difficult cases, and the position for these is best determined by screen examination. The lordotic (or " hollow-back ") position is of particular value in the study of lesions of the middle lobe.

Experience has proved that in mass radiography surveys, to detect early pneumoconiosis among occupational groups, the 35-millimetre film is absolutely inadequate. Experiments are now in progress to test the use of 70-millimetre films.

The occurrence of small discrete focal opacities dispersed throughout the lungs would suggest that stereoscopic films might be of peculiar value. In practice this has not proved to be true, so that this technique is seldom used.

Likewise tomography is of limited value in this field, and is usually reserved for the further study of indefinite massive shadows or cavities.

Bronchography and bronchoscopy

Bronchography may provide interesting pictures of the bronchial tree in relation to the specific opacities caused by the dust, but rarely does it confer any benefit on the patient. Indeed, in some cases of advanced disease it can be a menace to the patient's health, if not to his life. Accordingly the procedure is seldom justified, and this applies likewise to bronchoscopy and to biopsy. Bronchography should certainly not be carried out in any case which is to proceed later for diagnosis and assessment of disablement by a Pneumoconiosis Medical Panel, because Lipiodol residues, especially after a long interval, can be a source of great confusion. Moreover, the patient, even when closely cross-examined, is often unaware that such an operation had been carried out.

Reading of films

Adequacy of the film

The first matter to be determined is whether or not the film is technically satisfactory; if not, the examination must be repeated. Neglect of this elementary precaution has caused bitter differences of opinion in particular cases, and has vitiated the literature of the subject.

Viewing is usually best done, in the first instance, from a distance of a few feet. This gives a general impression, which can then be amplified by close inspection at a distance of about 10 inches, while study of the characteristics of individual lesions is greatly assisted by a large magnifying glass.

The radiologist's report

As a rule the radiologist will not be aware of the clinical findings; indeed, in mass-radiography surveys no medical examination will have been made. As is pointed out on page 35, history of occupation or employment, if recorded, may be inadequately described or quite misleading. Whereas the radiologist may not be required to make a diagnosis—in fact cannot do so in such circumstances—he may, quite reasonably, be expected to say whether or not the appearances are within normal limits. This is not always a simple matter having regard to the wide variation of natural changes at different ages. To this end the medical card should at least show the age of the patient and the radiographer should briefly note the patient's build and soft tissue development of the chest, particularly the breast formation in females.

The radiographic shadows are not in themselves diagnostic, and so the descriptive, as opposed to the interpretative, report is preferable. That is to say, the report should be a catalogue of the abnormal shadows with special reference to type and distribution. Only when the radiologist is in possession of the full clinical and occupational data is he justified in suggesting a diagnosis.

Employers, insurance companies and trade unions often refer suspected cases direct to a radiologist. In such circumstances, if the radiologist is to make a report, including diagnosis, then he must either accept full responsibility for the occupational and clinical investigations or else obtain the assistance of an expert physician.

Terminology

Arbitrary zones and descriptive terminology have been recommended by the Joint Tuberculosis Council (1939) in their *Report on Skiagraphic Terminology in Pulmonary Disease*.

" The upper zone is that area above a straight line running through the lower borders of the anterior ends of the second ribs.

" The middle zone is that area bounded by the above line and one running through the lower borders of the anterior ends of the fourth ribs.

" The lower zone is the remainder of the lung below the middle zone."

Use of standard films

The researches of the Pneumoconiosis Research Unit at Cardiff have emphasized the considerable range of error of interpretation, which exists between observers (the inter-observer error) and in the same observer (the intra-observer error) in reading the same film. As a means of minimizing these errors, they advocate the use of standard films, against which any film can be matched (Fletcher and Oldham, 1949 and 1951).

It has not yet been established that, by means of a small set of films, it is possible to represent standards which will serve adequately all varieties of pneumoconiosis. In a recent experiment to test the value of standard films, Fletcher and Oldham (1951) stated the following conclusions.

" 1. The use of standard films enabled some, but not all of the observers to achieve a greater accuracy and consistency in classification.

" 2. The chief practical use of standard films appears to be to enable wholly inexperienced observers to use a radiographic classification with an accuracy approaching that of the more experienced observers."

Illustrative films

Separate varieties of pneumoconiosis, arising from particular industries and occupations, tend to have particular geographical concentrations. Accordingly, consultant radiologists and chest physicians should realize the need to maintain a collection of illustrative films for reference as occasion arises. The value of this collection can be greatly enhanced by the addition of thin-tissue sections, prepared by the Gough-Wentworth technique, illustrating the associated pathological appearances.

Reference to the characteristic radiographic appearances of the various forms of pneumoconiosis is included in this chapter in the description of each specific variety.

Transport of films

It is frequently necessary to transmit x-ray films by post. Great care should be observed to ensure that they are not damaged in transit or delivery. They should be enclosed between stiff boards and the envelope endorsed: " x-ray films—with care: do not bend or fold ".

PNEUMOCONIOSIS ACCOMPANIED BY TUBERCULOSIS

The association of tuberculosis of the lungs and silicosis has long been recorded, and Haldane (1914) was only expressing the general opinion when he said: " I believe the disease is the same all over the world and the end comes through tubercular infection ". Indeed, following Brownlee's epidemiological studies on tuberculosis (Brownlee, 1917), a high death rate from pulmonary tuberculosis at the later age-groups was regarded as an index of the probable existence of a specific dust hazard.

Clinical picture and diagnosis

Tuberculosis of the lungs, as a complication of pneumoconiosis, particularly of silicosis, may occur as a localized chronic indolent lesion, in which circumstance it may scarcely alter the clinical picture. On the other hand it may present as florid phthisis, in which the clinical features are almost entirely those of generalized caseating tuberculosis. An acute generalized miliary dissemination throughout one or both lungs is a common terminal event, and unless one is alert to such possibility, it may not be diagnosed until necropsy.

The onset of tuberculosis in pneumoconiosis completely alters the prognosis for the worse, so it is always important to decide, if possible, whether or not this complication is present. If tubercle bacilli are present in the sputum, there is no difficulty, or, again, if serial radiographs are available, progressive changes over a short interval may serve as a guide. The erythrocyte sedimentation rate is considered by some authors to be of value as an index. Experience suggests that there is no better guide than careful determination and assessment of clinical symptoms and signs. As a useful generalization, it may be said that in simple pneumoconiosis the patient is fit but distressed, in pneumoconiosis accompanied by tuberculosis he is sick and in declining health.

In compensation schemes the disease is usually defined so as to embrace silicosis or silicosis accompanied by (combined with) tuberculosis. This practice has now been extended to other forms of pneumoconiosis.

As is noted above in discussing the aetiology of the pneumoconioses, tuberculous infection is considered to play an important part; indeed, some experienced pathologists consider that silicosis and complicated pneumoconiosis of coal-workers represent tuberculosis modified by dust inhalation. All one can say is that this complex association has not yet been confirmed.

Cause and prognosis

It is indisputable, however, that tuberculosis is the predominant cause of death in pneumoconiosis. Gloyne (1951), from his extensive experience, presents the following tabulation.

TABLE II

PNEUMOCONIOSIS (ALL FORMS) ASSOCIATED WITH TUBERCULOSIS

Group	Occupation	No. of cases of pneumoconiosis	No. of cases with tuberculosis
1	Pottery workers	340	146 (42·94%)
2	Coal-miners	293	100 (34·13%)
3	Asbestos workers	121	43 (35·54%)
4	Stonemasons and quarry workers	90	48 (53·33%)
5	Iron and steel workers, metal-grinders, and sand-blasters of metal castings	78	50 (64·10%)
6	Miscellaneous occupations and occupations not stated	114	58 (50·88%)
	Total	1,036	445 (42·95%)

* After Gloyne (1951)

He further records that in 13·5 per cent of the 445 cases of active pulmonary tuberculosis in all forms of pneumoconiosis, the tuberculous lesions were detected only on microscopy. This justifies the emphasis which is placed above on histological examination and the selection of suitable material.

Similarly, in cases of extensive tuberculosis of the lungs, the silicosis may be discovered only after careful histological examination of many blocks of tissue. This means that fatal tuberculosis may complicate silicosis at any stage, though it is most frequent in the advanced stages. This is illustrated by the writer's necropsy experience shown in Table III.

TABLE III

DEGREE OF SILICOSIS ASSOCIATED WITH FATAL TUBERCULOSIS

Occupation	Degree of silicosis			
	Microscopic	Nodular	Massive	Total
Pottery—earthenware	27	65	80	172
Pottery—china	7	7	21	35
Banker-mason	3	7	11	21
Stone-dresser	1	7	10	18
Metal-grinder	2	5	4	11
Sand-blaster	4	8	6	18
Steel-fettler	—	2	3	5
Coal-miner	1	6	13	20
All occupations	45 (15%)	107 (36%)	148 (49%)	300 (100%)

Various authors, from their experience, have recorded the incidence of fatal tuberculosis complicating silicosis as between 40 and 75 per cent. It is not easy to explain this wide divergence, but Table IV, from the writer's series, reveals that as a cause of death the influence of tuberculosis is most marked when the silicosis develops at an early age.

TABLE IV

FATAL TUBERCULOSIS COMPLICATING SILICOSIS*

Age-group	Cases of silicosis	Percentage of silicosis with tuberculosis to total silicosis
Under 20 years	—	—
20-29 ..	4	100·0
30-39 ..	22	72·8
40-49 ..	103	57·3
50-59 ..	268	39·6
60-69 ..	293	34·1
70+ ..	67	22·4
All ages	757	39·7

* Based on post-mortem examination.

It is generally recognized that silicosis accompanied by tuberculosis is more rapidly fatal than the same silicosis without tuberculosis. This, however, should not be interpreted, as it has been, as implying that the tuberculosis is of an unusually fulminating type.

Incidence

Towards the end of the nineteenth century many doctors held the opinion that pulmonary tuberculosis was less common among coal-miners than among the general population. So convinced were they of this observation, that the hypothesis was advanced that coal dust had an inhibitory action on the tubercle bacillus. No scientific data exist which would enable us to form a precise assessment of the position at the present time. The most recent pronouncement, based on considerable research in South Wales, is by Mann (1951), who gives the following opinion:

> "The presence of tuberculosis, diagnosed radiologically, appears to be higher among miners with simple pneumoconiosis than in the general population. The high prevalence is related to the higher attack rate and lower progression and mortality rates from tuberculosis in miners compared with the normal population.

" It is suggested that progressive massive fibrosis, characteristic of complicated pneumoconiosis, may be a modified form of tuberculosis, in which the fibrogenic action of the tubercle bacillus is stimulated by some action of the coal dust while the caseating action is inhibited."

With the object of elucidating the relationship, if any, between massive fibrosis and tuberculous infection, the Pneumoconiosis Research Unit, in collaboration with the Welsh Regional Hospital Board, in 1951 commenced a mass-radiography survey, using full-sized films, of the whole population, numbering 30,000, of the colliery village of Rhondda Fach. By this means it is hoped to detect, isolate and treat all cases of tuberculosis able to infect others, and so in time to reduce substantially the incidence of tuberculosis in this mining community. In the course of several years—for it must be a long-term project—observations will be made to discover whether or not cases of simple pneumoconiosis, which are very numerous in this community, continue to proceed to massive fibrosis. The results of the first two stages have been published (Cochrane, Cox and Jarman, 1952 and 1955).

PNEUMOCONIOSIS AND PRIMARY BRONCHIAL CARCINOMA

In the tissues silica acts as a low-grade irritant, and chronic irritation of epithelial tissue, as in the tongue and skin, has been accepted as a possible cause of pulmonary cancer. Primary bronchial carcinoma has frequently been noted in association with silicosis, and Anderson and Dible in 1938 concluded that silica played a part in its aetiology. Extensive studies of this problem have since been made in Great Britain, South Africa and the United States, and the general opinion, so far, does not support this conclusion.

Out of a series of 6,884 cases of silicosis investigated from this aspect in Great Britain, 1·32 per cent were found to be complicated by pulmonary cancer. It is of interest that several authors have reported the simultaneous discovery at necropsy of pneumoconiosis, active tuberculosis and cancer of the lung.

James (1955) has recently examined the incidence of primary lung cancer in South Wales coal-workers with pneumoconiosis. Primary lung cancer was found at necropsy in 3·3 per cent of 1,827 South Wales coal-miners, and in 5·4 per cent of 1,531 South Wales non-miners. While admitting that the discrepancy may be partly due to factors in the selection of the material he concludes that lung cancer is found at necropsy less frequently in coal-miners than in male non-miners of the same age group. Furthermore lung cancer in South Wales miners is similar to that in non-miners in respect of the ages at death, the distribution of the histological variants of the tumour, and the distribution of metastases.

By contrast, various observers have recorded an excess mortality from cancer of the lung in cases of asbestosis.

TABLE V

CANCER OF THE LUNG AND ASBESTOSIS

Year	Author	Cases of asbestosis	Incidence of pulmonary cancer
1943	Wedler	92	16·0%
1949	Wyers	115	14·8%
1951	Gloyne	121	14·1%
1955	Merewether	344	16·0%

TABLE VI

CANCER OF THE LUNG ASSOCIATED WITH PNEUMOCONIOSIS: HISTOLOGICAL CHARACTERISTICS

Histology	Asbestosis (Wyers, 1949)	All pneumoconioses (Gloyne, 1951)
Squamous cells	9	52
Oat cells	5	2
Columnar cells	1	26
Endothelioma of pleura	1	0
Unknown	1	0

The Senior Medical Inspector of Factories reviewed (in the Annual Report of the Chief Inspector of Factories for 1954) all deaths from asbestosis officially recorded from March, 1924, to December, 1954. The total number of cases was 344 of which 205 were males and 139 females. The number of cases in which cancer of the lung was present was 55 or 16 per cent, the figure for males being 41 (20·0 per cent) and females 14 (10·1 per cent). In addition 4 male and 7 female asbestosis cases had cancer of sites other than the lung.

The mean age at death in the 55 cancer cases was higher for males than females, being 55 years and 45·6 years respectively. Similarly the mean duration of exposure to asbestos dust was 22·3 years in males (41 cases) and 9·4 years in females (14 cases). In this connexion it is explained that "many women leave the asbestos industry at a relatively early age on marriage and this may have influenced these figures to some extent. Furthermore it is possible that the presence of asbestosis may not have been recognized in some women who died subsequent to leaving the industry on marriage and the omission of these cases would tend to reduce the mean ages and duration of exposure. On the other hand it may be that asbestos dust has a more serious effect on women than on men thereby leading to a relatively earlier death after a relatively shorter period of exposure."

The mortality for lung cancer in asbestos workers has been studied by Doll (1955) among persons employed at one asbestos works. All the cases were confirmed histologically and all were associated with the presence of asbestosis. One hundred and thirteen men who had worked for at least 20 years in places where they were liable to be exposed to asbestos dust were followed up. Thirty-nine deaths occurred in the group whereas 15·4 were expected. The excess was entirely due to excess deaths from lung cancer (11 against 0·8) expected. Doll concludes that lung cancer is a specific industrial hazard of certain asbestos workers.

MEDICAL SUPERVISION AND TREATMENT OF WORKMEN IN DUSTY OCCUPATIONS

Medical supervision

For the supervision of workmen and with the object of safeguarding them from the dangerous effects of pneumoconiosis, initial examination of new workers and subsequent periodical medical examinations have been applied. In many countries statutory schemes exist, and in some industries and processes, not so covered, employers have introduced voluntary schemes. Too often, however, the examinations have been allowed to deteriorate into a sterile routine, and because of many factors, such as labour turn-over and the long latent period necessary for the development of the disease, the ineffectuality of the procedure is seldom, if ever, discovered. All such examinations should have a clearly defined purpose and they should be completed to achieve it. Records should be accurately compiled, radiographs of high technical quality taken, and the results regularly analysed and published, so that they may be linked to preventive measures. Without this critical stock-taking, the examinations lose most of their value.

The system of Miners' Tickets, which was instituted for European miners in the Rand gold mines under the Miners' Phthisis Bureau in 1916, is the best-known scheme and it has since been adopted as a pattern by many other countries. Good success has been claimed for it, but so far, on account of a variety of difficulties, it has not been possible to apply the same system to African labourers. A modified scheme, however, is now in operation and is gradually being improved in extent and quality so as to approach the arrangements for Europeans.

Initial or pre-employment medical examination

General principles

It is emphasized on page 22 that all workers employed in pneumoconiosis-producing industries and occupations are not equally prone to develop the disease; some, after a full working life-time at risk, escape altogether, while others similarly exposed contract the disease but in different degrees and after varying intervals of time. The factors which determine these circum-

stances have not yet been defined. It is agreed, however, that lungs already damaged by previous disease are less able to deal with the dust and so are more easily effectively occupied. Furthermore, because shortness of breath is one of the main symptoms of the disease, any other condition which causes breathlessness (such as cardiac disease), should contra-indicate engagement in a dusty occupation. These observations, of course, refer particularly to youths or men seeking employment in a dangerous occupation or process for the first time. When a skilled workman seeks to change from one employer to another, other considerations, such as skill, usually outweigh medical influences. Some employers, however, insist on the pre-eminence of the medical examination, mainly as a safeguard against premature claims for compensation.

Insurance companies usually insist on medical and radiographic examination as a condition of " risk cover ", and this has often operated to the detriment of workman and employer. Besides, to avoid compensation claims, some employers discharge men as they approach the critical period of exposure; again, anxious to avoid assuming the responsibility of a previous employer, a new employer may decide not to engage an otherwise excellent workman. In this way skilled men have often been victimized, put out of work for long periods, compelled to seek alternative employment and, in fact, made " too old at forty ". It might reasonably have been expected that this evil would disappear under a comprehensive State insurance scheme, but it has not done so, largely on account of the increasing fear of supplementary claims, as now permitted, under Common Law. There is a real danger that the law, in seeking to safeguard the rights of the individual, may indirectly injure the group. The challenge is to the medical and legal professions, to assist only in those cases in which they are convinced that negligence by the employer or his servants has, in fact, produced damage to the individual claimant.

Pre-employment medical examination, if it is to be justified, should be directed almost entirely towards the welfare of the workman; he is entitled to know the risks which he will endure, and whether or not the employer maintains all practicable precautions to control the danger. At the same time the employer has a right to know the condition of any workman on engagement, for purposes of record, and to have the co-operation of the workman in all measures directed to maintain his health.

It is simple for doctors to frame codes of physical requirements, which candidates must satisfy, but due regard must always be had for the practical implications under generally foreseeable circumstances. The usual approach is to demand a first-class insurance life, but such a standard may be unnecessarily high and so may hinder a free flow of recruits. Voluntary schemes have the advantage that they can be adjusted to meet labour requirements, highly selective when supply exceeds demand and relaxed in the reverse situation. Statutory codes have no such flexibility.

Requirements in Great Britain

In Great Britain, initial or pre-employment medical examination is prescribed by statute for certain new entrants to the refractories, sandstone, pottery and asbestos industries. The requirements with respect to physique are that the person is not suffering from any of the following conditions:

(1) Tuberculosis of any organ, active or inactive, except a healed primary focus; (2) pneumoconiosis or other marked pulmonary abnormality, to an extent discernible by radiological examination; (3) chronic bronchitis or asthma, if causing marked incapacity; (4) severe thoracic deformity; (5) rheumatic valvular heart disease; (6) other heart disease causing disability.

These examinations, which are conducted by pneumoconiosis medical panels, have the serious defect that x-ray examination of the chest is not made in every case, but is entirely at the discretion of the examining doctor.

Under the Coal Mining (Training and Medical Examination) Order, 1944, all persons below the age of 18 years, entering employment in coal-mining, were required to undergo a medical examination of fitness. The examinations were conducted by doctors working in panels set up by the Ministry of Labour and National Service. Whereas the scheme applied throughout the whole country, x-ray examination of the chest was included in every case only in South Wales.

This scheme, as is apparent from the provisions, had grave defects. It has now been amended by the Coal Mines (Medical Examination) General Regulations, 1952, made by the Minister of Fuel and Power, which came into operation on 10 December, 1952. The regulations place upon the owner of every coal-mine the responsibility for making arrangements for the medical examination, by a registered medical practitioner approved by the Minister, of persons under the age of 21 years first employed, or about to be employed, in or about a coal-mine. The doctor will issue certificates of fitness for mining work to the person examined and to the manager of the mine. Any person who fails without reasonable cause to submit himself for examination, or who is found to be unfit for this particular work, will not be allowed to take up employment in or about a coal-mine.

These examinations will become a normal duty of the medical officers of the National Coal Board, thereby ensuring that adequate standards are maintained. Although no provision for regular "follow-up" examinations has been included, this desirable extension may be enacted later. However, the National Coal Board's medical service can be depended upon to use these records fully in its general supervision of the workmen.

Provisions in Australia

The "21 diseases examination", prescribed for metalliferous miners at Broken Hill, New South Wales, exemplifies a very rigid code, in which the presence of any one disease constitutes cause for rejection for this employ-

ment. The examination is known locally as the " 21 diseases examination ", the enumerated conditions being as follows:

(1) All diseases of the bronchi, lungs and pleura; (2) all diseases of the heart which are demonstrable by ordinary clinical examination; (3) tuberculosis in any form; (4) venereal diseases in an infectious form, or when producing definite disability; (5) aneurysm; (6) varicose veins with ulceration; (7) anaemia, whether primary or secondary, in which the haemoglobin value is less than 75 per cent; (8) increased blood pressure—namely, a systolic pressure of over 150 mm. of mercury in a man under 30 years, over 160 mm. Hg in a man under 40 years, or over 170 mm. Hg in a man under 50 years; (9) all diseases of the kidney, including albuminuria of renal origin; (10) gout; (11) lesions of the joints: (*a*) due to rheumatism proper, gout or rheumatic gout (so-called); (*b*) due to disabling conditions arising from injury, loose cartilages, septic inflammation or chronic synovitis; (12) hernia; (13) chronic alcoholism or drug-taking; (14) paralysis or paresis of muscles not of traumatic origin; (15) neuritis; (16) epilepsy; (17) plumbism (lead poisoning); (18) defective vision or hearing; there must be reasonable uncorrected vision with each eye, and inability to hear ordinary conversation will exclude; (19) any marked disability resulting from previous injury or disease; (20) scurvy; (21) pyorrhoea alveolaris.

According to Dr. W. E. George (1947), the Medical Director:

" By this pre-employment medical examination not only are those men excluded from the industry who already have a compensatable disease, but also these men who, examinations show, have conditions predisposing to these diseases or who are otherwise unsuitable for work in the Broken Hill Mines."

Having regard to the long controversy about the influence of nose and mouth breathing on the development of the disease, it is remarkable that, in such a comprehensive schedule, no specific reference is made to the state of the upper respiratory tract and accessory sinuses.

Provisions in South Africa

In South Africa the standards for new European miners are very rigid, and this is reflected by the fact that only about 30 per cent of all applicants are passed fit at the first attempt, and finally 25–30 per cent are rejected as permanently unsuitable. The selection, however, is not only in relation to pneumoconiosis but also to general physical fitness for work as a miner.

Importance of body-type

In the assessment of fitness great reliance is placed on physical configuration or body-type (somatotype). Craw (1947) in Great Britain has testified to the value of this factor in the selection of workmen for employment in the haematite iron ore mines in West Cumberland.

Two main types are recognized, with the addition of a predominant mixed group.

(1) Pyknicosomatic, or broad, heavy, thickset type: sthenic.
(2) Leptosomatic, or lean, slender, angular type: asthenic.
(3) Intermediate or muscular type.

In Craw's experience, 5 per cent of applicants are in type 1 and 10 per cent in type 2. Fortunately, recruits are mainly selected from the intermediate type, and this constitutes 85 per cent of examinees. As a convenient means of detecting and recording physical type, two full-length photographs are taken, in full face and profile.

Radiography

Summing up, it is not possible to over-emphasize that no pre-employment examination which does not include a radiograph of the chest can be considered complete. This is a major defect of the several statutory schemes in Great Britain. The real difficulty, however, is that, on account of the rapid turn-over of labour, the procedure is very wasteful of time, labour and materials. Furthermore, all too often the films, when made, are of poor technical quality and quite useless for comparative purposes at subsequent examinations.

Periodical medical examination

This is the logical extension of initial examination, and the two are usually, though not always, combined in a single system. It is important, however, to realize that the examinations do not themselves constitute a whole, but are simply a part, of a comprehensive scheme of prevention. The care with which they are designed, completed and maintained has an important influence on the efficacy of the whole system.

Statutory schemes are at present in operation in countries all over the world and, as might be expected, these schemes are designed to meet special local influences.

Provisions in Great Britain

Periodical medical examinations in pneumoconiosis-producing industries in Great Britain are by no means new. Legge in 1900 recommended such a system for ganister miners, but the first application was not made until 1913, and then to china-biscuit workers in the pottery industry. These examinations, conducted by the certifying surgeon, completely failed, for it is recorded by a Home Office Departmental Committee, in 1928 that " after 15 years and in spite of the serious risk, not a single suspension resulted from 3,886 examinations ".

The next experiment was under the Refractories Industries (Silicosis) Scheme, 1919, which prescribed examinations to be conducted by specially appointed medical officers (tuberculosis officers). These were equally unsuccessful, largely because of variations in standards applied by the different doctors. Thus " in Sheffield 10 per cent of the examinations resulted in suspension, while in Scotland there were no suspensions, which results could not be explained by dissimilarity of risk " (Home Office Departmental Committee's Report, 1924).

A new scheme was made for the refractories industries in 1925, in which the examinations and certifications were reserved to a full-time medical board. Again the practical result was unsatisfactory, for the doctors were seconded to undertake special inquiries in cognate industries, so that the routine inspections were frequently in arrears. Furthermore, the general standard of chest radiology available to the board throughout the country was quite inadequate for early diagnosis. This method, however, is now established,

and current experience is represented by the work of the Medical Board for Silicosis and Asbestosis, now the Pneumoconiosis Medical Board, which, since 1931, has been responsible for periodical medical examinations in the refractories, sandstone, pottery and asbestos industries.

Many occupations, such as sand-blasting, steel-fettling, masons' work on sandstone and tunnelling in silica rock, involve equal if not more serious dust risks; therefore, inquiry is frequently made as to why the system has not been extended to include these workers. The answer is quite simple: namely, that for uniformity of standards the medical-board system is fundamental, and so for the examinations to be practicable and of any real value the numbers at risk must be substantial, and personnel to be examined must be reasonably concentrated, accessible, and stable over a period of years.

Value of periodical examinations

The value of periodical medical examinations in dusty industries and occupations has frequently been examined by departmental committees, and the following advantages are mentioned: (1) elimination of pulmonary tuberculosis; (2) detection of early pneumoconiosis; (3) evidence of conditions producing the disease; (4) assistance in diagnosis by providing serial records.

Theoretically, all are valid; in actual practice all are ineffective. As often as not the tuberculous workman is absent on the occasion of the medical board's visit, and so he escapes examination and suspension; no matter, for the incapacitating effects of the disease itself soon eliminate him from work.

Early diagnosis of pneumoconiosis is almost entirely dependent on radiographic changes and, with a technically satisfactory film, considerable accuracy can be achieved by panels of experts, but unfortunately the standard of chest radiology is still inadequate. This same criticism is even more valid for serial films, which are necessary for detecting or confirming alterations in the disease and its complications. But even if the diagnosis is established in the early stages of the disease, the workman usually feels quite fit and, apart from the radiographic evidence, the doctor is unable to demonstrate any deviation from health or incapacity for work. Accordingly, if diagnosis does not automatically involve certification and compulsory suspension, advice to the workman to find a safe job out of the dust is summarily dismissed. In our highly industrialized modern State, economic employment and family considerations supersede slight deviations from full health.

Provisions in South Africa

In South Africa, periodical examination of European miners, about 2,,000 in number, consists in a clinical and radiographic examination; short-service miners—men with less than 7 years' underground service—are examined at intervals of 3 years during the period; those between 7 and 13 years are examined every 2 years, and after 13 years, annually.

Altogether about 300,000 native African labourers are employed at the mines. By reason of their large numbers, associated with an annual turn-over

of 90 per cent, it has not, so far, been found possible to apply the same system to them. The use of mass-miniature radiography, however, has now made radiographic examination possible for all at the beginning and at the end of each contract period, as well as intermediately whenever indicated by clinical manifestations of disease.

As is well known, the native African labourer is peculiarly prone to suffer from acute tuberculosis. As an index of possible infection, the following system has been in operation, with considerable success, for many years. Each native labourer, whether working on the surface or underground, is weighed each pay-day at intervals of 6 weeks. Any native who has lost 5 pounds in weight between 2 successive examinations, or 6 pounds between 3 successive examinations, is sent for medical and radiographic examination.

Periodical x-ray examinations

In recent years various experts have advocated the introduction of a system of periodical x-ray examinations for all miners throughout Great Britain. The National Coal Board, together with the Ministry of Fuel and Power, is at present considering an appropriate scheme.

Desiderata for a general scheme of supervision

While it is not possible to make general recommendations, the following matters appear to merit consideration in the preparation of any scheme of pre-employment and periodical medical examination.

(1) The examination should be directed primarily to the safety, health and welfare of the workman, individually and as a group.

(2) The examination should be adequate without being wasteful of medical man-power, time or materials, and should fulfil its purpose.

(3) The examination must include, on each occasion, a technically satisfactory radiograph of the chest, not only for present diagnosis, but as a permanent record and for comparison with later films of the same case.

(4) The medical examination should be part of a much wider preventive scheme, concerned with efficient control of production and collection of dust.

Treatment of established pneumoconiosis

Pneumoconiosis is not curable naturally or by device. Nevertheless much can be done to assist individual patients, if only by reassurance and encouragement. Burdened, physically and mentally, as the patient is by his malady, there is no justification for the all too frequent assertion: "I am sorry nothing can be done for your condition."

Treatment in early cases

In early cases of pneumoconiosis it is remarkable how much benefit accrues from a few weeks' rest, either at home or in a convalescent home. Indeed, the change is often so remarkable that employers not infrequently suggest that the doctor has been mistaken in the diagnosis. Thereafter a course of general rehabilitation, with instruction in proper methods of

breathing, is often of considerable value. Some patients suffer from bronchial spasm, and this can be eased by anti-spasmodics, adrenaline or Neo-epinine, prescribed as aerosols for inhalation. When infection of the lungs coexists, benefit may follow treatment by sulphonamides and penicillin.

Treatment with cortisone and ACTH

The Medical Research Council is investigating the action of cortisone and ACTH on the development and course of silicosis in laboratory animals. Harrison and his co-workers (1952) observed that, in rats "dusted" with quartz, cortisone interfered with the accumulation of quartz particles into focal aggregates, and so retarded the development of discrete silicotic nodules. Montgomery (1952), using cortisone and ACTH with mice, reported similar findings, but also that, once the fibrogenic response to quartz is fully formed, the drugs are without effect. (*See also* Magarey and Gough, 1952.)

Trials on pneumoconiotic patients have been deferred for the time being, because it has been reported that cortisone may cause a flare-up of quiescent tuberculosis.

Treatment with aluminium

Aluminium therapy is discussed in the section dealing with this disease. (*See* p. 73.)

Continuance of employment

The most important purpose of treatment must always be to keep the partially disabled workman employed up to his capacity. This is, in fact, the only effective measure for both the workman and his dependants. In spite of the risk there may be no alternative but to keep the workman at his own occupation. It is the job which he knows and can accomplish with the minimum of effort. If the hours of work can be adjusted for him, so much the better. The workman should be instructed how to safeguard himself and others, just as the tuberculous patient in a sanatorium learns the discipline of his new life. Furthermore, he too should have the advantage of regular medical supervision and expert guidance.

If alternative employment is available, there is no need for doctors to be too meticulous about its lightness or suitability, for the pneumoconiotic patient is capable of considerable adaptability, and he often reveals unsuspected reserves of physical strength.

Prevention and control

This is the only satisfactory approach to the problem and the principles are reasonably well defined. Whenever possible, non-injurious materials should be substituted for silica; thus, in cutlery-grinding, carborundum and alundum have replaced sandstone grind-stones, in china manufacture alumina has replaced flint, and in sand-blasting, non-siliceous abrasives have been substituted for quartzose sand. It should be noted that, on account of the chronic nature of the disease, the beneficial results of these measures are

not immediately reflected in statistics of morbidity and mortality; one must wait the passing of the old generation. Mechanization of processes is another valuable method by which the number of men at risk is substantially reduced. The intensity of the noxious dust cloud can be reduced by effective exhaust ventilation, and by the use of wet methods in place of dry. Respirators are of limited value, either because they fail to arrest the most dangerous minute particles or because they are uncomfortable for continuous wear during heavy work. Other aids are comprised in good house-keeping in the factory.

More specific reference to preventive measures in relation to special varieties of pneumoconiosis is made under the appropriate subjects. (*See* pp. 79, 81, 86, 101.)

Assessment of disablement

The radiographic changes in pneumoconiosis can be classified according to type and extent. These changes are of value in diagnosis, but even more important is their significance in relation to prognosis and working capacity. Accordingly, many investigations have been designed to discover *if* any correlation exists between radiographic appearances and the functional capacity of the lungs. These researches have merely served to confirm the common clinical experience, that slight changes may be accompanied by severe disablement, while extensive massive fibrosis may not diminish either working capacity or output. This means that x-ray changes should never be used or relied upon as an absolute measure of respiratory function or capacity for work. This notwithstanding the conclusions drawn by Hart and Aslett (1942), based on the study of coal-miners, are valid: namely, that " in the wide age-group 15-79, the proportion of men with respiratory disability, as indicated by breathlessness or by impaired exercise tolerance, increased progressively in the succeeding x-ray categories—normal reticulation, nodulation and major consolidation ".

Formerly, under the Workmen's Compensation Acts, the amount of compensation was based on loss of earning capacity. This mode of assessment has now been abandoned, so that under the National Insurance (Industrial Injuries) Act, 1946, benefits are based on the degree of disablement assessed on a percentage basis, in which 100 per cent is equated with 67*s.* 6*d.*

Tests of residual capacity

As a means of estimating the impairment of physical capacity by reason of the degree of pneumoconiosis, a variety of exercise-tolerance tests have been devised. These include stepping and climbing tests, the bicycle test and toe-touching. All these have been criticized as unscientific and of little practical value. " James's Box ", as now used by the Pneumoconiosis Medical Panels, is an attempt to standardize the stepping test and to provide a numerical index.

Measurements of pulmonary function by spirometric tests, based on respiratory gas exchange, have also been tried. These measurements have included: (1) maximal breathing capacity (the maximal quantity of air which can be moved in and out of the lungs in a unit of time); (2) residual air, determined by an open-circuit oxygen method; (3) vital capacity; (4) oxygen and carbon dioxide content of the expired air; (5) oxygen saturation and oxygen and carbon-dioxide tension of arterial blood; (6) degree of dyspnoea.

A substantial contribution has recently been made by Hugh-Jones (1952), who has devised a simple standard exercise test for measuring dyspnoea on exertion. The following is the author's summary:

" The method is a simple step-test which enables a patient to be given a known and standard amount of exercise, comparable to exercise on a bicycle ergometer, without the use of complex apparatus. The standard exercise is achieved by adjusting both the height and the rate of stepping to compensate for variations in weight between one patient and another, the appropriate values being got from a nomogram without calculation.

" The exercise period is five minutes. A suitable work load is usually 350 kg.m./minute.

" The patient's ventilatory response is recorded with a domestic gas-meter. This is expressed as a ' standardized ventilation ' (S.V.), which is got from the ventilation in excess of the resting level during both exercise and recovery and gives a valid measure even if the patient cannot or will not complete the five minutes' exercise. In all subjects who complete the test the S.V. is numerically equal to the exercise ventilation (E.G.) at a steady rate.

" For measuring the symptom of breathlessness the ventilation caused by the exercise should be related to the patient's maximum voluntary ventilation (M.V.V.) measured independently. A dyspnoeic index $\frac{(S.V. \times 100)}{(M.V.V.)}$ is suggested as an alternative to the index previously used by other workers--namely, $\frac{E.V. \times 100.}{M.V.V.}$ The former index avoids the necessity for repeat testing at a lower exercise level in those who fail to complete the exercise, when the usual index becomes invalid."

Comparison of tests with actual work

The practical problem is to estimate the residual working capacity of the patient and, commendable as these recent tests are, they are still of little real help. There is still no better measure than the test of an actual job. The workman will often surprise all by his undiscovered reserves of physical power, and doctors tend to over-estimate the demands of jobs. It is unfortunate that the emphasis in awards of " percentage disablement " is on the loss of power rather than on residual capacity. Moreover, the need is to measure the whole man, mental and physical, and one might almost add, spiritual. Unscientific as it is, there is no better means to this end than the shrewd clinical judgment of a good doctor, who will, of course, not neglect the proper use and interpretation of mechanical aids.

Legislation concerning dust and its suppression and medical care

In relation to dust diseases of the lungs, legislation is threefold, providing for (1) control of dust, (2) Disablement Benefit and Allowances, also Death Benefits, (3) medical supervision of workmen.

Control of dust

Section 4 of the Factories Act, 1937, provides that effective and suitable provision shall be made for securing and maintaining the adequate ventilation of any factory, and for rendering harmless, so far as is practicable, all fumes, dust and other impurities, which may be injurious to health, generated in the course of any process or work carried on in the factory.

Section 47 of the Factories Act, 1937, provides that in every factory in which there is given off any dust and fumes, of such a character and to such extent as to be likely to be injurious to persons employed, all practical measures shall be taken to protect the persons employed against the inhalation of dust.

These are general provisions for all factories, and they are supplemented by regulations to meet the special circumstances of particular industries. The full text of these is contained in the Factory Orders (Ministry of Labour, 1951). As an example of such provisions, the following is the text of Section 5 of the Pottery (Health) Special Regulations, 1947.

> "After the expiry of three months from the making of these Regulations, ground or powdered flint or quartz with or without the addition of other materials shall not be used in any factory to which these Regulations apply for any of the following purposes:
>
> (*a*) the placing of ware for the biscuit fire;
>
> (*b*) the polishing of ware;
>
> (*c*) as an ingredient in a wash for saggars, trucks, bats, cranks or other articles used in supporting ware during firing;
>
> (*d*) as dusting or supporting powder in potters' shops."

Benefits and allowances on disablement

Workmen's compensation for disablement and death, by reason of dust disease of the lungs, was first enacted in the Refractories Industries (Silicosis) Scheme, 1919. The provisions of this scheme were very restricted, but subsequent legislation has considerably extended their scope and application, as now presented in the National Insurance (Industrial Injuries) Act, 1946. The Act, which came into force on 5 July, 1948, replaces the Workmen's Compensation Acts and at the same time introduces a new attitude to injury by accident or disease arising out of and in the course of employment. The State, as part of a comprehensive scheme of social insurance, accepts the liability to make certain payments to the injured workman and his dependants.

Previously the amount of compensation was determined by loss of earnings, but subject to an over-riding maximum. This system has been abandoned.

and the criterion of assessment of disablement is now loss of physical or mental faculty, which means " loss of health, strength and power to enjoy life ", as measured by comparison with another person of the same age and sex, whose physical and mental condition is normal.

The benefits are in the form of a pension, in which 100 per cent is equated to 67*s.* 6*d.* plus dependants' allowances, and which is increased, in certain circumstances, by special additional allowances. Assessments are made in units of 10 per cent, and awards are provisional, subject to review, until made final by an award of 100 per cent. Weekly payments can no longer be commuted for a lump-sum settlement. In addition, receipt of such benefits does not exclude, as heretofore, the right to institute proceedings under Common Law.

In March, 1952, under the Pneumoconiosis and Byssinosis Benefit Scheme, provision was made for payments out of the Industrial Injuries Fund for total disablement or death from pneumoconiosis or byssinosis, in certain cases not covered by either the Workmen's Compensation Acts or the Industrial Injuries Act. This scheme was extended to include similar cases in which the disablement is partial.

It should be noted that workmen in receipt of disablement benefit, if the relevant qualifying conditions are fulfilled, are also entitled to receive unemployment or sickness benefit or retirement pension.

A much more fundamental change—and one considered retrograde by some experts—has been introduced: namely, that receipt of disablement benefit for pneumoconiosis without tuberculosis does not necessarily, save in exceptional circumstances, involve suspension from further work in the dangerous occupation or processes. Whenever tuberculosis is present, however, suspension is compulsory.

Statutory definition of pneumoconiosis.—Pneumoconiosis is defined in the National Insurance (Industrial Injuries) Act, 1946, Section 57 (3) as follows: " . . . fibrosis of the lungs due to silica dust, asbestos dust or other dust, and includes the condition of the lungs known as dust reticulation."

The definition covers pneumoconiosis or pneumoconiosis accompanied by tuberculosis. Byssinosis is not comprehended in this definition. It is treated as a separate entity, for which specific legislation exists.

Scheduled processes and occupations.—It should be noted that the provisions apply only to the processes and occupations listed in Part 2 of the First Schedule of the National Insurance (Industrial Injuries) (Prescribed Diseases) Regulations, 1948, and as extended.

This restriction—especially under compulsory insurance—has been considered unfair and the cause of hardship in certain cases. The Minister of National Insurance on 17 November, 1950, referred the matter to the Industrial Injuries Advisory Council for consideration and advice.

The Report (Pneumoconiosis, H.M.S.O. Cmd. 8866) was published in July, 1953. The Committee recommended that:

(1) There should be no change in the definition of pneumoconiosis for the purposes of the Act.

(2) A new provision should be introduced to enable benefit to be paid to claimants from unscheduled occupations involving exposure to dust who are suffering from pneumoconiosis due to the nature of their insurable employment in those occupations since 5 July, 1948.

(3) Claimants under the above new provisions should be required, before being given access to the Pneumoconiosis Medical Panels, to satisfy the Insurance Officer that there is reasonable cause to suspect that they are suffering from pneumoconiosis.

Procedure to obtain benefit.—Any workman who seeks to receive benefit in respect of disablement by reason of pneumoconiosis or byssinosis should apply at the local National Insurance Office. If, after preliminary inquiries, it is proved that he is entitled to proceed under the Act, his case will be passed to the Pneumoconiosis Medical Panel for the area. An x-ray examination of the chest is arranged, and if on scrutiny of the radiograph the doctors are satisfied that there is no evidence either of pneumoconiosis or of tuberculosis, the claim is rejected without further investigation. If the claimant appeals against this decision or if there is radiographic evidence of disease, the workman is examined clinically by a medical board, consisting of 2 or more members of the panel. The board's decision, a joint consultative opinion, on the diagnosis is final; that is to say, it is not subject to appeal. In diagnosed cases the board fixes the percentage of disablement, and if the assessment is provisional (not final) it appoints the date of review. This award is subject to appeal, but not until the end of 2 years from the original date of assessment. If, however, a workman can show evidence of aggravation of his condition, it is open to him to seek immediate re-examination and re-assessment of the degree of his disability.

The medical board also gives the workman expert advice as to his future employment, and only in very exceptional circumstances (but always in tuberculosis) does it have power to suspend him from the occupation or processes. In relation to death claims, it should be remembered that the statute requires a post-mortem examination. Failure to observe this may involve an exhumation or the setting aside of the claim.

Alteration of the medical organization.—At present the Ministry of National Insurance, following the Report of the Committee on the Pay and Organization of the Civil Service Medical Staffs (1951) is in process of disbanding the Pneumoconiosis Medical Board and transferring its duties to the chest consultants under the Regional Hospital Boards. The existing members of the Pneumoconiosis Medical Panels will operate together with this service.

Information.—The Ministry of National Insurance have prepared an excellent series of leaflets explaining the different benefits and allowances and how to obtain these. Copies may be obtained free at large post offices and at the local National Insurance Office.

Requirements concerning medical supervision

The provisions for initial and periodical medical examinations are contained in the National Insurance (Industrial Injuries) (Prescribed Diseases) Regulations. 1948. The law requires that workmen in certain scheduled processes in the refractories, sandstone, pottery and asbestos industries shall undergo initial examination; also, if found suitable, regularly thereafter, so long as they continue at work in the occupation or process, periodical medical examinations at the prescribed interval of 2 years. The examinations are made at the place of work by members of the Pneumoconiosis Medical Panel for the area. It should be noted that these statutory examinations are restricted to the industries named, and that these by no means cover all workmen engaged in a serious dust hazard. Some employers whose workmen are not covered by this provision have made private arrangements for the examination of their employees. Examples of such voluntary schemes are those of the Cumberland Haematite Mining Companies and of the British Steel Founders Association.

Specific Pneumoconioses

SILICOSIS

Silicosis is the specific variety of pneumoconiosis which is due to the inhalation of silica dust. Its occurrence is world-wide, affecting all races, males and females alike. In relation to the pathological lesion, Haldane's assertion in 1914, that " the disease is the same all over the world, and the end comes through tubercular infection " is still substantially true. By reason of different industrial practices, associated dusts, and differing racial constitution and habits and climatic conditions, the incidence and severity of the disease and its accompanying clinical manifestations, in particular communities, vary considerably from one country to another. This is equally true within a single geographical area, as is exemplified by the diverse manifestations of the disease and its varying influence in Staffordshire potters, Cornish tinminers and Aberdeen granite-masons. Likewise there are differences within an industry, as observed in foundry workers, or even among workers in the same occupation.

Silica and its uses

Silica is widely distributed in Nature, forming 70 per cent of the earth's crust. It is the chief constituent of many rocks and also occurs as flint and natural quartzose sands. In addition to being abundant, readily available and comparatively cheap, it has certain qualities peculiarly valuable in industry. Thus it is insoluble in all acids except hydrofluoric (important for pottery and glass manufacture), highly abrasive (important for metal-grinding and sand-blasting) and refractory to very high temperatures (essential for brick-making for furnace linings and moulding in foundries).

All processes which involve the manipulation of silica, especially in the dry state, in such a way that it is broken up into minute particles and inhaled, are able to produce silicosis. Consequently, in Great Britain the disease is associated with coal and metalliferous mining in siliceous strata, cutting and dressing of sandstone, grinding of metals on sandstone, certain branches of pottery manufacture (earthenware in particular), the manufacture of silica bricks (the refractories industries) and, in foundries, the cleaning and freeing of castings from adherent sand. In these industries large numbers of men and women are at risk; but there are many other operations, such as flint-crushing, the packing of scouring-powders, tunnelling in rock, and the mechanical cleaning of the stonework of sandstone buildings, in which the exposure may be very intense and the danger very serious, although involving only a small number of workmen. For this reason the risk run may not be realized by the doctor and the disease consequently overlooked.

As is stated on page 35, the purpose of the occupational history of a patient suspected to be suffering from dust disease of the lungs is to define the period, intensity and character of the dust hazard. Neglect to explore this in detail is a common cause of diagnostic error.

Aetiological factors in silicosis

In the production of the disease it is generally accepted that the following conditions apply:

(1) The silica must exist in the crystalline form as free silicon dioxide.

(2) To gain entrance to the lungs and establish effective occupation, the particles must be under 10 microns in diameter.

(3) The dust particles are most active when under 1 micron in diameter, and are freshly fractured, mechanically or by heat at very high temperatures; this ensures the maximum superficial area relative to size.

(4) The intensity and period of exposure are inversely proportional, so that if the dust cloud is very intense the period necessary for development of the disease is correspondingly short and *vice versa*.

(5) The action and reaction are intensified by infection, notably tuberculosis, and the growth of the tubercle bacillus is favoured.

In legislation, the term, "Refractories Industries", means processes carried on at mines, quarries, factories and workshops at which refractory material containing not *less than 80 per cent total silica* (SiO_2) is got or manipulated with a view to manufacture or sale. This, unfortunately, has been interpreted by many as meaning that no danger exists if the total silica content is under 80 per cent, a conclusion which is quite wrong. The correct explanation is that this limit was fixed entirely for administrative purposes: namely, to separate the silica-brick industries from the manufacture of fire-clay and common brick.

Again to permit the continued employment in coal-mines of men who are diagnosed cases of pneumoconiosis, the permissible concentration of

air-borne dust, in stone drifts and hard headings (that is to say, in siliceous rock), in all collieries is fixed at " not more than 450 particles per cc. between 0·5 and 5 microns in size ". These are known as " approved conditions ", but they should not be interpreted as signifying safe conditions.

Under present conditions in Great Britain, silicosis in a diagnosable stage seldom occurs, save in exceptional circumstances, after less than 15–20 years' exposure to the risk, and so it is uncommon under the age of 40 years. This is well illustrated by recent statistics for the pottery industry (Jones, 1952), set forth in Table VII.

TABLE VII

ANALYSIS OF 108 NEW CASES OF SILICOSIS, BY LENGTH OF EXPOSURE BEFORE DIAGNOSIS

Employment in the pottery industry	Period in years						
	Under 10	10–19	20–29	30–39	40–49	50 and over	Totals
General earthenware -	—	2	4	18	23	3	50
Sanitary earthenware	—	—	10	7	8	—	25
Electrical earthenware	—	—	—	1	—	—	1
Earthenware dust tiles	—	3	3	2	3	—	11
China - - -	—	—	2	9	—	2	13
Mill-men - - -	—	1	4	—	—	—	5
Polishers - - -	—	—	1	1	1	—	3
Totals - -	—	6	24	38	35	5	108

* After Jones (1952): period from 4 July, 1948 to 31 December, 1950.

Although generally the threshold of disease is reached after 15–20 years' exposure, under certain conditions the onset of the disease may occur after a very short period. The writer once observed a group of cases in flint-crushers, after less than 12 months' work in the process. Again, although in very intensive risks it is almost certain that every workman will be affected, sooner or later and in varying degrees, in the ordinary run of industry it is not inevitable that every workman should contract the disease in the course of a working life-time. There is a personal constitutional factor involved in the development and progression of the disease. This factor has not been determined, although infection, especially tuberculosis, is suspect.

Pathology and course of silicosis

With every breath the workman inhales the dust; sometimes the concentration is high, sometimes low. The coarse particles are arrested and rejected by the natural defences of the respiratory tract, while the finest particles

gain access to the alveoli, from which scavenger cells return them to the outside or transfer them to the lymphatic glands within the lung parenchyma, under the pleura and at the hilum. Over a period of years the attack goes on, and the occupation of the lungs by the dust advances. All the while a reaction is occurring in the lymphatic glands, which is finally revealed by the appearance of tiny spherical nodules of fibrosis. Slowly these nodules increase in diameter, and others appear elsewhere. Individual nodules achieve a size up to 5 millimetres; contiguous nodules become confluent, and in the most advanced stages large " cricket-ball " masses result. These fibrous areas diminish the amount of functional lung, so the healthy areas try to compensate. The lung between the fibrous areas becomes emphysematous, and bullae appear along the free margins.

FIG. 15.—Silicosis with active tuberculosis. Lung of a Cornish tin miner. There is a tuberculous cavity in the middle zone with adjacent silicotic nodules. (*By courtesy of Prof. J. Gough.*)

The bed of the pulmonary circulation becomes greatly extended and narrowed, the walls of the arterioles become thickened and rigid, anastomoses develop between the pulmonary and bronchial vessels, and bronchial spasm increases the intrapulmonary vascular pressure; all these conditions combine to cause hypertrophy of the right cardiac ventricle, and in advanced cases to produce cor pulmonale, with terminal congestive heart failure. An indolent pleurisy anchors the lungs to the chest-wall, diaphragm, pericardium and mediastinum. At first the changes are localized in the root zone or the

upper lobe of one lung, usually the right; but slowly and inevitably the disease appears in the contralateral lung and so it advances in both. It is not necessarily, however, an orderly advance; indeed it rarely is so; from the stage of localized nodulation, massing may result, even before the nodulation has extended elsewhere. This is usually suggestive of an infective process. At any stage overt tuberculosis may appear and lead to a fatal outcome.

In the absence of tuberculosis the advance is slow, but death may be precipitated by acute intercurrent disease, such as influenza or pneumonia, while in older patients death may occur from cardiac failure.

The foregoing description indicates a slowly developing continuous process, and some readers may wonder why so long a period elapses before the disease can be diagnosed. The explanation would appear to be that a substantial period is necessary to complete the silica reaction within the lung tissues.

In relation to the foregoing, the following practical point is worthy of notice. Among men exposed to very intensive risks under adverse environmental conditions—for example, tunnellers in silica rock—a workman may be examined radiographically before leaving the job and be pronounced clear of any sign of pulmonary disease. Some time later, usually about 2 years, on further radiographic examination he may be found to have massive shadows indicative of advanced fibrosis. This signifies that the disease may develop after a workman has ceased employment in the dangerous process. In Great Britain, however, such cases are exceedingly rare.

In the beginning the individual nodules are very minute and the fibrous tissue immature. The actual identification of the disease during life depends on the appearance of abnormal radiographic opacities in the lung fields, and presumably these must be of a certain minimal size and radio-opacity (maturity of fibrous tissue) before they can be distinguished from the normal structure of the lungs. These are personal opinions, but are supported by the fact that occasionally at necropsy the extent of the disease is considerably greater than is revealed by a recent radiograph; indeed, histological examination may establish the presence of the disease when the radiograph is considered normal. This is particularly true in acute risks, such as those run by sand-blasters. The fact that pathological examination is more precise than radiographic examination does not invalidate the fact that during life the diagnosis of the disease must include demonstrable radiographic changes in the lungs.

Diagnosis

In life the diagnosis depends on the triad described below, and, although any of its constituents may lead one to suspect the presence of the disease, it must ultimately be firmly based on all three. Any anomaly should raise doubt in the mind of the physician, indicating the need for further investigation, and even for a visit to the place of work to investigate the

actual environmental circumstances of the particular case. The triad is as under:

(1) clinical history and examination, with special reference to symptomatology;

(2) the history of the occupational risk, to define precisely the period and intensity of the silica risk;

(3) radiographic examination of the chest.

Clinical and related aspects

For a period of years, save in very serious dust hazards, the workman, although inhaling silica particles regularly at his job, is unaware of any injury to health; the pathological process is latent, the onset of the disease insidious. During this phase, radiographic examination of the chest may disclose definite silicotic changes, but the patient denies any inconvenience. This, however, is not strictly true, for close questioning will usually reveal that he is troubled by a cough and slight breathlessness on exertion. He is fully aware of these symptoms, but has dismissed them as due to smoking or his " age ". The cough is dry and harsh, occurring in bouts first thing in the morning or last thing at night. The shortness of breath is reflected by the fact that he now prefers to ride where he had previously walked, or if he does walk his pace is slower and he is aware of the hills.

Then suddenly and indirectly the disease in the lungs is discovered. The workman suffers from a " cold " or an attack of influenza; recovery is delayed and the cough and breathlessness are aggravated. Even so his general condition is good; he is not sick, only distressed. At this juncture he becomes the victim of a host of extraneous aggravating circumstances. Convallescence is prolonged and sick benefits are inadequate; the family begins to run into debt. The doctor advises an x-ray examination of the chest and the diagnosis of early silicosis is confirmed. Anxious as the workman may be to return to work, this must be postponed, for the doctors and his trade union have advised a claim for compensation. This involves more delay, during which his domestic problems increase and his mind is focused on his chest. All the while the work habit is slowly being lost. He is sick with fear and worry; he knows that the doctors are not mistaken because " it is on the x-ray ".

The change to an easy cough, with muco-purulent sputum (occasionally blood-stained), loss of appetite, weakness and wasting indicates associated tuberculosis. The patient is now obviously a sick man and thenceforth deterioration is rapid.

In simple silicosis, even when the changes in the lungs and pleura are gross, clinical examination of the chest yields remarkably little information; it is a silent disease. The mode of clinical examination and the recording and significance of the occupational history are described on pages 35–36 and these apply to silicosis.

Radiographic examination of the chest

The radiographic appearances are represented by changes which reflect the characteristic pathological lesion, the silicotic nodule, and its progression to confluent silicosis and to silicosis accompanied by tuberculosis.

Nodulation

The specific characteristic by which silicosis can be identified in individual cases is the appearance radiographically of nodulation. This term, nodulation, has been opposed because it involves the idea of volume rather than area, and anticipates the pathological lesion represented by focal opacity. The word, however, is firmly established in radiological literature and its use must be accepted for the present.

Stages of silicosis

Many classifications of the disease into stages have been devised; the following was recommended for international use by the International Labour Office in 1930. On the basis of the Pneumoconiosis Research Unit's classification of pneumoconiosis in coal-workers, it may, in time, be possible to elaborate a general classification covering all pneumoconioses, but this is not yet possible.

"INTERNATIONAL CLASSIFICATION OF THE STAGES OF SILICOSIS

"In the 'first stage' symptoms referable to the respiratory system may be either slight or even absent. Capacity for work may be slightly impaired. There may be a departure from the normal in percussion and in auscultatory signs, and the radiograph *must show* an increased density of the linear shadows, *and* the presence of *discrete shadows, indicative of nodulation.*

"In the 'second stage' there is an increase of the physical signs observable in the 'first stage' and the radiograph shows an increase in the number and size of the discrete shadows indicative of nodulation with a tendency to their confluence. There must be some degree of definite impairment of working capacity.

"In the 'third stage' all the above conditions are grossly accentuated and indications of massive fibrosis are usual. There is serious or total incapacitation."

The first of these stages may be further divided into 3 sub-stages, (*a*), (*b*) and (*c*), on the basis of the extent of nodulation present:

(*a*) indicating the earliest, partial distribution;

(*b*) more widespread nodulation;

(*c*) generalized nodulation, but still discrete.

This classification, despite the emphasis upon the increased density of the linear shadows in the first stage, is excellent for general use; but in individual cases, and relatively to the peculiar manifestations of silicosis in certain processes, one must on occasion give a liberal interpretation to the defined

stages. This applies particularly to cases which, radiographically, show only a single small apical mass, also to the diffuse hazy shadows in cases of rapidly forming silicosis, as occasionally seen in flint-crushers and sand-blasters.

The silicotic nodule on the radiograph

Alternative terms in use for nodulation are mottling or stippling, which, according to size, is described as pin-point, fine and coarse. No precise definition of what constitutes a nodule radiographically has been made. The term denotes the image of the essential pathological lesion, the encapsulated spherical nodule of collagenous tissue, which, in the early macroscopical stage, has a diameter of 1–3 millimetres. Radiographically the nodules appear as white dots, with an average diameter of 2 millimetres, clean-cut, spherical, and well-defined against the black background of translucent lung. As a rule they are discrete and not linked by intervening strands, and when they are viewed from a distance the eye is focused on the white dot with its black halo. The old mature silicotic nodule occasionally simulates calcification, even in the absence of calcium deposit, and in Great Britain it is characteristically seen in sandstone-masons, sandstone-quarrymen and Sheffield cutlery-grinders. In South Africa this type of appearance is much more common among gold-miners (Simson and Strachan, 1935; Simson, Strachan and Irwin, 1930).

Distribution of nodules according to the stages of silicosis

Silicosis is an inhalation disease and, as one would expect, the distribution of the nodules is bilateral and relatively symmetrical. In the earliest stage (1 *a*) the lesions are predominantly in the upper zone of the lung fields. As the disease advances, individual nodules may increase in size and new nodules appear in other zones. Progression in uncomplicated cases is slow. In the presence of infection, especially tuberculous infection, massing occurs, with the sudden appearance in radiographs of round " cricket-ball " or elongated " sausage " opacities. The masses tend to localize, particularly in the middle zones close to the hilum, thus presenting a dumb-bell appearance; in other cases they may be situated at the periphery under the scapulae, or close to the apices when they appear as " angel wings ". Only rarely are these masses located in the lower zone, and when a single globular opacity is noted there, without evidence of nodulation or similar opacities elsewhere in the lung fields, the clinician should be very guarded in making a definite diagnosis of silicosis, even if the workman's employment has involved a silica risk.

When discrete nodulation occupies more or less the whole of the lung fields, a " snowstorm " effect is created, suggesting very extensive disease. In this connexion it should be remembered that, by projection of the solid organ upon a flat film, superimposition of nodules in depth occurs and is

apt to convey an exaggerated impression of the actual amount of lung involved.

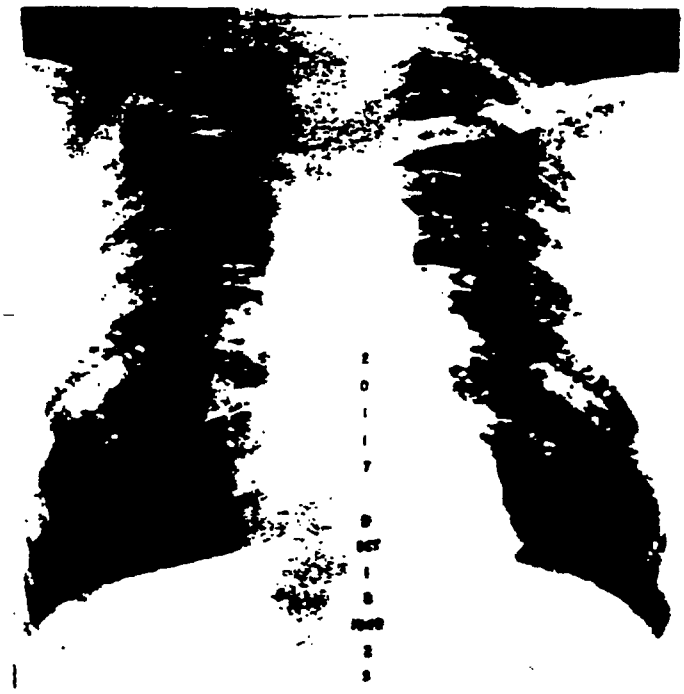

FIG. 16.—Gold-miner (S. Africa), aged 46 years. Classical discrete nodular silicosis. Note unusual density of nodules and enlargement and calcification of hilar glands. (*By courtesy of South African Silicosis Medical Bureau.*)

Some unusual radiographic appearances.—Among the slate quarrymen in the Blaenau Ffestiniog area of Merionethshire, Davies (1939) has described the occurrence of silicosis in which the radiographic picture shows certain peculiarities. The outstanding feature is the appearance of round nodular opacities, arranged like clusters of grapes in the mediastinum and perihilar regions. They appear to be calcified, but the calcification is confined to the periphery, the centre of the shadow being comparatively clear. They have a dappled appearance; hence the terms "egg-shell" and "mulberry" have been applied. Davies suggests that the condition is the result of very concentrated exposures to silica, which produce silicotic infiltration followed by a degenerative process, leading to the deposition of lime salts. There are, nevertheless, many processes in other industries in which exposure to almost pure, free, crystalline silica is much more intense, yet these appearances have only occasionally been noted. McVittie (1946) in South Wales states that he has occasionally seen incomplete circumferential calcification in

confluent silicotic masses in the lungs. In his opinion the condition is evidence of old tuberculous infection of the lung, and this seems the more probable explanation.

Differential diagnosis

In the differential diagnosis of silicosis from other diseases, the following conditions, which may present similar radiographic appearances, are frequently cited: (1) acute and chronic miliary or disseminated tuberculosis of the lungs, (2) miliary carcinomatosis, (3) tropical eosinophilia, (4) leukaemia, (5) sarcoidosis, (6) bronchomycoses and (7) haemosiderosis associated with mitral stenosis.

Difficulty occurs only when the diagnosis, as all too frequently happens, is based upon the radiographic findings alone. Although the radiograph still provides the best single piece of evidence upon which to base an opinion, the diagnosis can only be made in conjunction with the clinical findings, and on the precise occupational history of the workman during the whole of his working life, with special emphasis on the nature and extent of any dust hazard. With reference to the clinical aspect, this broad generalization is useful: in uncomplicated silicosis the patient is distressed rather than sick, whereas, when tuberculosis supervenes, toxic manifestations appear and the workman is soon sick and in declining health.

Silicosis accompanied by tuberculosis

Active tuberculosis is the most common complication of silicosis (40–70 per cent of all fatal cases), and frequently when the patient is first seen the whole clinical and radiographic picture is that of extensive tuberculosis of the lungs, but, chiefly for reasons related to workmen's compensation or assessment for disablement benefit, the clinician must decide whether or not silicosis is also present. It is useless to believe that in such cases one can distinguish between silicotic nodules and tuberculous foci. In such circumstances a presumptive diagnosis only is possible, based almost entirely upon a critical assessment of the occupational risk. Because questions of workmen's compensation invariably attach to these cases, it should be noted that legally one is not concerned with the degree of silicosis, with the relative predominance of the silicosis or the tuberculosis, or with which lesion came first. The law, for purposes of compensation, defines the disease simply as (1) silicosis or (2) silicosis accompanied by tuberculosis.

Prognosis, management and treatment of silicosis

Prognosis

When the diagnosis of silicosis is established for the first time in the case of a workman, he is naturally disturbed and turns to his doctor for information and advice. The following is a reproduction of a leaflet prepared by the writer for the guidance of a group of foundry-workers. It will serve as

a prototype, which other doctors can improve or adapt to their own special problems in other silica industries.

" SOME PRACTICAL INFORMATION ABOUT PNEUMOCONIOSIS

" When a workman suffers from a disease he is not greatly interested in its technical name, but he is very concerned to know how it will affect his health and ability to earn his living. The report which by your consent has been sent to your doctor may suggest that, as a result of your recent x-ray examination, there is reason to suspect that you have contracted a degree of pneumoconiosis. By giving you some simple but expert information on the disease in general it is hoped to avoid undue worry to you and your family. In due course you will be able to consult your own doctor, who in turn may refer you to a specialist.

" In a wide variety of occupations it is recognized that the workmen in the course of their employment inhale fine particles of silica dust into the lungs. At first there is no apparent ill-effect, but after a number of years the irritation of this dust within the lungs causes minute scars (fibrosis) to form in these organs. This is dust disease of the lungs, which in medical language is known as pneumoconiosis. There are several varieties of pneumoconiosis, the best known being silicosis. Certain workmen employed in steel-foundries, particularly those engaged in removing adherent sand from castings by means of hand- or machine-tools, are exposed to this risk. This fact is probably known to you; at any rate it is well known to your Trade Union officials. It is known to the Government, and in certain occupations and processes pneumoconiosis is recognized as an industrial disease for which, under the National Insurance (Industrial Injuries) Act, 1946, provision is made for payment of disablement benefits (compensation) which are substantially higher than those paid for ordinary sickness. Details of these benefits and information relating to them are set out in the official pamphlet supplied to you.

" *How does the disease affect a workman?*

" For a number of years there are no noticeable ill-effects. Usually the earliest sign is breathlessness on exertion, and this shortness of breath and tightness of the chest may get gradually worse if the disease progresses. Whenever such symptoms occur it does not necessarily mean you have contracted pneumoconiosis. Breathlessness may result from many causes, excessive cigarette smoking, as many of you know, being a very common cause; another cause is ' getting old '.

" *How is the disease diagnosed?*

" The diagnosis can be made only after full medical investigation, which must include x-ray examination of the lungs. This is the only certain means of recognizing the disease, especially in the early stages, and, indeed, the disease cannot be considered to be present unless proved by the appearance of abnormal shadows on the x-ray plate.

Can the disease be cured by treatment?

" No, the scars such as occur after a deep cut on your hand are permanent, but in future years, due to more prolonged action of the dust or inflammation, they may become bigger and tougher. Progression, however, is usually slow.

" *Are there any serious complications?*
" Yes, in *some* cases tuberculosis of the lungs may result.

" *What should a workman do about his job when he discovers that he has contracted the disease?*
" The disease is due to the dust, so that if he continues in his job he is likely to inhale more of the dangerous fine particles, which in time may aggravate his condition. If he gives up work in a dusty occupation he minimizes this possibility, but tuberculosis may still occur as a complication. Whether a workman should give up his skilled occupation or continue in it is a matter for expert medical advice in each individual case. In the first place, a workman rightly feels that the best person to give him advice is his own private doctor, whom he has selected for himself. If the doctor deems it necessary he can refer the workman to a specialist in chest diseases, or through the local Insurance Officer to the Ministry of National Insurance experts of the Pneumoconiosis Medical Panel.

" A craftsman does not readily give up his skilled job. First, he may feel too old to learn another trade and, secondly, whatever employment he might get outside his own job is likely to mean a sacrifice of wages greater than he can afford. What, then, is he to do? He knows his own circumstances best and he alone can decide which is the lesser risk for him, either to risk getting more dust or to suffer the risk of a lowered standard of living.

" As already mentioned, the progress of the disease, unless complicated by tuberculosis, is slow, so there is no need to rush into a hasty decision to give up the job, and, moreover, there is no need to stand off from work to obtain an examination by the Pneumoconiosis Medical Panel. If a claim is made for such an examination it will be arranged by appointment.

" In these circumstances men over the age of 40 years will probably find that it is best for them to carry on. Younger men will also be well advised to carry on until they can find suitable alternative employment. At the same time it should be borne in mind that any man who feels his condition is getting worse can always consult his own doctor, who, if necessary, can arrange for further examination by a local chest specialist.

" In the case of men who obtain a percentage disablement award under the National Insurance (Industrial Injuries) Act, 1946, the Pneumoconiosis Medical Panel keep them under regular review at intervals."

Active tuberculosis may become manifest at any stage, so it is important that the silicotic workman should be under regular periodical medical supervision. As a means of detecting the transition from simple to complicated silicosis, tests of the erythrocyte sedimentation rate have been advocated, but, in this matter, there is nothing superior to the shrewd clinical observation and judgment of the experienced physician.

In silicosis accompanied by tuberculosis the workman must give up his employment, to safeguard not only himself but his fellows. As a general rule this is no undue hardship, because he is, or soon will be totally unfit for work, and the present rates of compensation and additional benefits approximate to his previous earnings.

Sidero-silicosis

The brick-red lungs of haematite iron-ore miners are very characteristic. In this instance the universal pigmentation is due to iron-oxide and the condition is called siderosis. Stewart (1933) has stated that sections, when appropriately stained, do not give a Prussian-blue reaction; this contrasts with the reaction in the lungs in haemosiderosis. When silicosis occurs in a haematite miner, the disease is named sidero-silicosis. In such a case the radiographic appearances are rather unusual for, on account of the minute radio-opaque particles of iron oxide, the opacities present as a very fine dense mottling and a connecting reticulostriation.

Aluminium in the prevention and treatment of silicosis

In 1937 a Canadian research team, Denny, Robson and Irwin, working at the McIntyre Porcupine Mine, Ontario, published details of experiments in which they had made the following observations:

(1) The addition of small quantities of metallic aluminium dust almost completely inhibited the solubility of siliceous material in the beaker.

(2) Seven rabbits dusted with quartz, to which less than 1 per cent of metallic aluminium dust had been added, showed hardly any fibrosis, whereas 6 control rabbits, dusted with quartz only, showed well-developed silicosis.

These authors submitted that the aluminium, having been converted into hydrated alumina, reduces the toxicity of quartz in tissues in three ways: (1) by flocculation; (2) by absorbing silica from solution and (3) chiefly by coating the quartz particle with an insoluble and impermeable coating, which has been identified as a gelatinous hydrated alumina.

Later researches (Denny, Robson and Irwin (1939)) confirmed these findings and established that the same properties were possessed by hydrated alumina, particularly the form designated as XH 1010.

This work was not altogether novel, for such inhibiting qualities had long been attributed to coal dust and iron oxide.

Based on these observations, however, aluminium powder was first used at the Porcupine Mine in 1943: (1) as a prophylactic; (2) to arrest early silicosis; (3) as treatment of disability arising from silicosis.

Metallic aluminium has been applied in two forms: either (1) as freshly milled powder, produced by grinding small pellets or (2) as "canned" powder made in bulk in a mill and distributed in sealed containers. Powdered amorphous hydrate of alumina has also been used. This is a more elegant preparation, in so far as it is white as contrasted with the metallic powder which resembles soot.

The following methods of application have been employed: (1) inhalation of freshly produced metallic powder; (2) change-house dispersal of canned metallic powder; (3) inhalation in chambers, into which either canned metallic powder, or the amorphous hydrate of alumina, has been dispensed.

The use of these measures has been sponsored, under patent rights, by the Canadian organization, McIntyre Research Limited. In granting a permit to use the method, the Corporation emphasizes that the invention is not a substitute for dust-preventive measures, and they insist on these and on general good-housekeeping in the factory, mine or quarry (Conference, 1950).

Subsequent experimental work by other observers, including King, Ray and Harrison (1950a) as well as reports of serious pulmonary disease among workers employed during World War II in handling aluminium powders in Germany, suggested that the treatment might have adverse effects, particularly in tuberculous patients. There is no evidence, however, that, in the form and concentration used and by the methods employed, the use of aluminium powder produces any harmful effects in human beings.

Outside Canada it can be said that there has been no haste to adopt the method on a practical scale, though several countries have instituted pilot trials. In Great Britain, the Medical Research Council has arranged tests at a tin-mine in Cornwall and in connexion with the pottery industry at Stoke-on-Trent. So far, no report on the results has been published but, from notice of termination of these schemes, it would appear that the method has not proved itself. From all centres improvement has been claimed in some cases, but the benefits appear to be psychological. The real merit of the scheme is probably represented by the insistence on dust control.

Treatment

Treatment in general is as outlined in the general account of pneumoconiosis on p. 54.

In the Report of the Third International Conference of Experts on Pneumoconiosis held at Sydney in 1950 (I.L.O. Geneva, 1953, 2 vols.) it is stated that:—

> " There was no conclusive evidence before the Conference that the inhalation of aluminium in any form prevents the development of silicosis in man. There was no evidence before the Conference that aluminium powder is of value as a therapeutic agent in human silicosis or that it is harmful when used for this purpose. There was some evidence that under certain conditions the inhalation of aluminium in industrial processes may be harmful and, further, there was experimental evidence that in animals the inhalation of aluminium dust aggravates pulmonary tuberculosis."

Aluminosis

The final sentence of this statement refers to the observations of Goralewski (1940 and 1941) on an outbreak of respiratory disease, which occurred among a group of German workers engaged in handling finely divided aluminium metal. The chief symptoms included repeated attacks of bronchitis associated with dyspnoea and loss of weight. Clinical signs were few but about 20 per cent of the patients showed diminished vital capacity. Goralewski found

a high incidence of x-ray changes in 125 workers, 31·2 per cent being regarded as having "significant" changes and 19·2 per cent having "conclusive" changes. In most instances the radiographic changes consisted of increased striation with a few localized deposits; however, 4 cases showed bilateral and symmetrical reticulation with larger and more numerous deposits, and in three men who had been exposed for periods from 11 to 20 years, the appearances varied from diffuse stippling to large conglomerations. In 3 cases, spontaneous pneumothorax occurred. This sudden appearance of pulmonary disease, in an industry in which no previous trouble had been observed, was attributed to new and more intensive methods of manufacture, involving the production of a greater quantity of dust, the particles of which were more minute and not, as formerly, coated with a film of aluminium stearate.

Shaver's disease

A similar outbreak of pulmonary disease attributed to alumina dust was later observed in Canada by Shaver and Riddell in 1947 among workers engaged in the manufacture of the aluminium abrasive, corundum. The essential part of the process is the fusion of bauxite with iron and coke in an electric furnace at a temperature of 4,000°C. During fusion dense white fumes are evolved and these consist principally of alumina and silica. The onset of symptoms was gradual but in some cases the period of exposure was very short. In Shaver and Riddell's original cases, 23 were classed as well-established and their exposure varied from 23 months to 19 years with an average of 5·9 years. The most frequent symptom was dyspnoea, usually accompanied by cough and sputum, some degree of substernal discomfort, and some loss of weight. A special feature, particularly of advanced cases, was the occurrence of spontaneous pneumothorax, often bilateral. This was present in all known fatal cases. The radiographic appearances in established cases consisted of lace-like reticulation most pronounced in the upper lobes.

Naked-eye examination of the lungs revealed irregular areas of fibrosis, pigmentation of the hilar glands, thickened pleura and emphysema with bulla formation. Histological examination showed thickening of the alveolar walls, emphysema and fibrous infiltration. The fibrous areas in the lung parenchyma were not nodular but rather a diffuse replacement of the normal lung tissues. The lung ash of three fatal cases contained 28 per cent to 40 per cent alumina and 21 per cent to 30 per cent silica.

The aetiology of Shaver's disease remains obscure but the influence of silica cannot be ignored and indeed many experts believe that it plays a major part.

The disease has also been reported in corundum workers of other countries (Riddell and his colleagues, 1950), notably Germany, where several fatal cases have occurred. In Great Britain investigations have been made among workers exposed to alumina in the smelting of aluminium but so far no case of aluminosis has been identified.

Prevention of silicosis

This follows the scheme described for the pneumoconioses in general; but specific measures, as they apply to particular industries and occupations, are noted in the illustrations which follow.

Industries and processes specially at risk

Silicosis is a risk in many industries and processes throughout Great Britain, but because many of these, by their nature, have a narrow geographical location, special experience of the disease in the incidental occupations is largely restricted to the practitioners in the area. Thus the pottery industry has its main concentration in North Staffordshire, cutlery grinding in Sheffield and slate-mining in North Wales. Others, though still localized, are more widespread in their distribution. These include metalliferous mining in silica rock, tin-mining in Cornwall and lead-mining in Durham, sandstone quarrying, ganister mining, and work in iron and steel foundries. It is not possible here to describe and discuss individually the wide variety of industries and processes. The following examples have been chosen as being representative and because each serves to illustrate some important aspect of the disease.

Pottery industry

The term, pottery, denotes all articles made or formed of baked clay, and so includes such diverse products as domestic table-ware and electrical insulators, fine china figures, and common building bricks. Commonly, however, the term is used so as to exclude building materials, bricks, roofing and flooring tiles and drainage pipes.

The manufacture of pottery is largely concentrated in and around Stoke-on-Trent, in North Staffordshire, which district is known and renowned throughout the world as the " Potteries ". In Great Britain the total number employed in the pottery industry is about 81,000, and of these 56,000 are in North Staffordshire; women constitute rather more than 50 per cent of the total.

Pottery manufacture

In the manufacture of a piece of pottery there are generally two component parts:

(1) the substance known as " the body ", which is porous in character and may be made either of simple native clay unmixed with other ingredients, or composed of several ingredients, such as Cornish (china) stone, china clay, combined in the case of English china with calcined bone, or in that of earthenware with ball-clay and calcined flint;

(2) the glaze, which is a preparation of various silicates and silico-borates, to which is usually added a lead compound; this is applied at a later stage for the double purpose of rendering the porous body impervious and imparting to the surface a smooth gloss-like finish.

The clay ware, whether pressed by hand or cast in plaster-of-Paris moulds, is dried in hot-air cupboards, then fired to biscuit hardness in an oven. Next follows the glazing or dipping of the ware and the " glost-firing ". Decoration may be applied either under glaze or on glaze.

The manufactures in the production of which the pottery industry is mainly engaged may be enumerated as follows: (1) china, (2) earthenware, (3) tiles, (4) majolica, (5) Jet and Rockingham ware, (6) electrical fittings, and (7) sanitary ware.

China.—All translucent ware, generally speaking, is embraced in the term, china. In Great Britain the body contains a large proportion of calcined bone, whereas in continental porcelain the translucent effect is obtained by means of felspar, in place of bone.

Earthenware.—This category includes the great bulk of opaque ware, plain or decorated, made principally for domestic and general use; the body is made up of ball-clay, china-clay, flint and Cornish stone.

Generally speaking, tiles, electrical fittings and sanitary ware are made from the earthenware body, whereas Jet and Rockingham ware, some tiles and sanitary fireclay goods are formed from native clays without the addition of calcined flint.

Historical note on the pottery industry

From existing records (*see* page 2) it seems indisputable that silicosis—" potters' rot " or " potters' asthma "—has been identified in the pottery industry for over 200 years. In the beginning the rapid onset, heavy incidence and advanced stages of the disease were particularly noted among millmen and in flint-crusher-men, engaged in handling and preparing the raw materials to form the " body " of the ware. Almost equally alarming was the problem in china manufacture among bedders and placers; oven " odd-men " and women engaged in brushing and scouring the ware in the china-biscuit warehouse were affected.

The quality of the earthenware body was improved by the addition of calcined flint (up to 40 per cent of its weight) to the other ingredients; ball-clay, china-clay, china-stone and felspar. Whether in pressing or casting, scraps and spillage constantly occur, and this material dries on benches, floors and the aprons of workmen. As a result the potter is " white as a miller ", and the atmosphere is constantly vitiated by a dust containing a considerable number of fine particles of free silica, which are constantly inhaled by the workmen. Silicosis has always been common in this section of the trade, and in 1875 Dr. W. Farr, in the Fifth Report of the Registrar-General, made the following statement:

> " Earthenware manufacture is one of the unhealthiest trades in the country, and the age of joining it is low, but mortality after the age of 35 approaches double the average; it is excessively high; it exceeds the mortality of publicans."

In 1889 Arlidge, consulting physician to the North Staffordshire Infirmary, stated that: " The mean age at death of male potters, aged 20 and upwards, was 46½ years, while that of non-potters stood at 54 years.

Present incidence

In 1951, W. W. Jones, a member of the Pneumoconiosis Medical Panel at Stoke-on-Trent, presented the figures given in Table VIII, based on his recent experience.

TABLE VIII

ANALYSIS OF 241 NEW CASES OF PNEUMOCONIOSIS BY OCCUPATION: FROM 4 JULY, 1948 TO 31 DECEMBER, 1950 *

Section of the industry	No. of cases of pneumoconiosis in 2½ years	Approximate No. of workers in section
General earthenware†	122 (*63*)‡	15,000
Sanitary earthenware†	58 (*27*)	2,250
Electrical earthenware (porcelain)†	1 (*1*)	1,500
Earthenware dust tiles†	24 (*14*)	2,000
China	18 (*17*)	3,000
Millmen and mill labourers	7 (*5*)	1,000
Polisher	8 (*5*)	250
Glost placers, etc.	3 (*1*)	1,000
Totals	241 (*133*)	26,000

* After Jones (1951).
† All processes up to and including the preparation for glazing.
‡ The italicized figures in brackets represent the number affected by silicosis.

It should be noted that a distinction is made in Table VIII between silicosis and pneumoconiosis; the latter term apparently denotes those cases in which the radiographic appearances conform to those arising from a mixed dust, predominantly containing silicates, originating from the clays which compose the body of the ware. A further point requires emphasis; namely, that readers should not be misled into calculating comparative rates of incidence of the disease in the separate sections, for the populations at risk vary considerably in age distribution and likewise in the period of exposure.

Reference is made on p. 77 to the mortality statistics of Farr and Arlidge. Since then some improvement has been recorded, but to a large extent this must be attributed rather to sanitory influences affecting the population generally than to particular improvements in the industry. This is no cause

for complacency for, in a consecutive series of 750 necropsies among pottery workers, between 1931 and 1946, silicosis or silicosis accompanied by tuberculosis accounted for the deaths of 43 men under the age of 45 years (Meiklejohn, 1949*a*).

Prevention in general

In the china section a considerable preventive advance was made about 1931 by the introduction of the use of alumina. This section of the industry, however, involves only 3,000 out of 26,000 workmen employed in dangerous processes. Earthenware manufacture, the largest branch of the industry, remains highly dangerous, and unfortunately no similar specific preventive has so far been discovered. For the present it is necessary to rely on good house-keeping and increased mechanization.

Alumina in prevention

China-ware in the clay state undergoes considerable contraction in firing, and so, to prevent deformity and distortion, it is necessary to support each piece throughout this process. This was achieved by bedding flat ware and placing hollow-ware in "saggars"; these were fire-clay boxes, which were filled with finely powdered flint. The flint was unaffected at the firing temperatures and acted almost as a fluid medium, thereby providing the necessary support. The bedders and hollow-ware placers were exposed constantly to the inhalation of considerable quantities of fine flint dust; so also were the odd-men—labourers who filled and emptied the ovens. When the biscuit-firing was completed, the ware was carried to the china-biscuit warehouse, where it was freed from adherent flint in preparation for glazing. This work of brushing and scouring was very dusty, and was carried out by women and girls, namely the china-biscuit warehouse workers.

All these occupations had long been recognized as among the most serious silicosis risks of the industry. Cases of the disease were not uncommon after 10–15 years' employment. The cause of the disease was apparent, and potters, by patient research, practical experiment and practical trials, sought to discover a substitute for the flint. By 1931 it was proved that alumina (Al_2O_3, or corundum) was a satisfactory practical medium, but before establishing the new method it was necessary to discover whether or not alumina was free from danger to the health of the workmen.

On behalf of the Industrial Pulmonary Diseases Committee of the Medical Research Council, an inquiry among a suitable group of workers engaged in the production of alumina was made in 1936 by a team of experts. They concluded: "There is no evidence of pneumoconiosis or any other pulmonary disease arising from the considerable dust to which these workers have been exposed" (Sutherland, Meiklejohn and Price, 1937). This was further confirmed by review of the same workmen 10 years later (Meiklejohn and Jones, 1948).

Convinced of the value of the methods, manufacturers, in increasing numbers, voluntarily made the change, and finally, under the Pottery (Health) Special Regulations, 1947, it became illegal to use ground or powdered flint in placing and other cognate processes. In addition, alumina became an almost universal substitute for flint and other siliceous materials in many other industries, with consequent benefit to the health of the workers.

Metal-grinding

As an example of the successful prevention of silicosis, the history of the disease among workmen engaged in the grinding of metals is significant.

Occupational hazards

Thackrah of Leeds, in his book, *The Effects of Arts, Trades and Professions on Health and Longevity*, published in 1831, specifically mentions the occurrence of dust diseases of the lungs among Sheffield metal-grinders, and he quotes the opinion of Knight that fork-grinding ought to be confined to criminals. Thereafter there are many accounts of "knife-grinders' rot or phthisis". Calvert Holland in 1843 gave this striking description of the morbid anatomical appearances of the disease:

> "In some instances the lungs have presented an appearance as if black currants had been distributed throughout the whole of them."

Hall in 1857 added this interesting conclusion from his experience:

> "There is no necessary connexion between the Sheffield grinders' disease and thoracic consumption, although both affections may be present in the same individual."

Metal-grinding includes the production of a wide variety of cutting implements, table cutlery, razors, edge-tools, scythes, saws, axes and scissors. Sheffield is the main centre of manufacture, but a few factories are located in and around Birmingham. The work is performed in workshops, called "hulls" or "wheels", and originally the grinding was done on gritstone or sandstone wheels of varying size, revolving in troughs, some containing water, others dry. When no water was used the process was called dry-grinding, and was used, for example, in fork and razor grinding; when water was used, it was called wet-grinding, and was used in table-blade and pen-knife grinding. Because the wheel revolved rapidly, the friction of the blade against it resulted in a fine spray of metal dust from the blade, of silica from the stone and, in wet-grinding, of water from the surface of the stone and from the trough. This water was often highly infected with tubercle bacilli, because the men were apt to spit into the trough. For the proper performance of the work it was necessary regularly "to true up" the face of the grindstone by "hacking", "rodding" and "racing"—all very dusty operations, especially the last, which was usually performed dry. Some idea of the rapid attrition of a grindstone, and hence of the dust cloud, is conveyed by the fact that a saw-grinder would wear a stone, 6 feet

in diameter by 10 inches across the face, down to 2 feet by .0 inches in about 8 weeks.

Incidence of silicosis

The occurrence of silicosis among grinders is reflected by the excessive mortality from tuberculosis as shown in Tables IX and X.

TABLE IX

MORTALITY AMONG GRINDERS FROM TUBERCULOSIS

Years	Rates per thousand		Ratio
	For grinders	For all persons over 15 years of age	
1923	6·9	1·2	5·75:1
1924	7·2	1·1	6·55:1
1925	6·3	1·1	5·73:1
1926	5·7	1·0	5·70:1
1927	7·8	1·0	7·80:1

TABLE X

MORTALITY AMONG GRINDERS

Causes of death	Quinquennia							
	1886–90	1891–95	1896–1900	1901–05	1906–10	1911–15	1916–20	1921–25
All causes: total deaths	536	548	529	622	573	607	581	515
Pulmonary tuberculosis: total deaths – –	191	207	199	291	295	322	224	201
Percentage of total deaths due to pulmonary tuberculosis – – –	35·6	37·8	37·6	46·8	51·5	53·5	38·6	39·0

Although cases of the disease occurred after 10 years' exposure, more often the period was 15–20 years, dry grinding being more vicious than wet. This means that ironmongers, joiners and cabinet-makers, who sharpen tools, are not likely to contract the disease from such casual exposure.

Prevention and control in metal grinding

To control the dust and so safeguard the health of the workman, " fannies " (or exhaust hoods) were fitted to the grindstones, and so far as possible the work was carried on under a continuous spray of water.

Some workers, especially when racing the stone, bound a damp handkerchief over the nose and mouth, preferring this to a respirator. These devices, however, made no substantial reduction in the number of cases, although they may have assisted to delay the onset of the disease.

In the early nineteen-twenties, manufacturers began to experiment with grindstones composed of non-siliceous abrasives: (1) natural, such as emery, and (2) artificial, including carborundum, alundum and aloxite. Substitution of natural sandstone grindstones by the non-siliceous wheels really began on a large scale in 1928, and in the next few years the former were reduced in numbers from 2,000 to 200. The change-over is now almost universal and the salutary effect is reflected in recent mortality statistics, presented in Tables XI and XII by courtesy of Dr. H. Midgley Turner, consultant chest physician, of Sheffield.

TABLE XI

MORTALITY AMONG GRINDERS FROM RESPIRATORY TUBERCULOSIS

		Rate per 1,000		
	Year	Grinders	All persons over 15 years of age	Ratio
	1923	6·9	1·2	5·75:1
	1924	7·2	1·1	6·55:1
1921 Census figure of grinders in Sheffield used	1925	6·3	1·1	5·73:1
	1926	5·7	1·0	5·70:1
	1927	7·8	1·0	7·80:1
	1928	6·1	1·0	6·10:1
	1929	6·8	1·1	6·17:1
	1930	5·7	1·0	5·70:1
1931 Census figure of grinders in Sheffield used	1931	7·8	0·9	8·66:1
	1932	4·3	0·9	4·77:1
	1933	4·1	0·9	4·55:1
	1934	4·1	0·8	5·13:1
	1935	4·8	0·9	5·33:1
	1936	3·0	0·8	3·75:1
	1937	3·7	0·9	4·11:1
	1938	2·8	0·6	4·67:1

TABLE XII

MORTALITY AMONG GRINDERS

Quinquennia	All causes: total deaths	Pulmonary tuberculosis: total deaths	Percentage of total deaths due to pulmonary tuberculosis
1886–90	536	191	35·6
1891–95	548	207	37·8
1896–00	529	199	37·6
1901–05	605	291	48·1
1906–10	573	295	51·5
1911–15	607	322	53·5
1916–20	581	224	38·6
1921–25	515	201	39·0
1926–30	414	158	38·2
1931–35	423	116	27·4
1936–40	412	83	20·1
1951 (males only)	64	8	12·5

It is important to note that the introduction of effective preventive measures is not immediately reflected in mortality statistics, for a generation of workmen have already been affected by the disease and so their deaths influence the mortality statistics for many later years. Dr. Turner also enters this caution:

> " Since 1930 quite a number of grinders have been advised to give up grinding and transfer into other trades when they have developed either tuberculosis or silico-tuberculosis. Some of these might recover, but others might die some years later and then be recorded as an entirely different trade. I think to some extent this accounts for part of the reduction in the percentage of total deaths due to pulmonary tuberculosis."

This notwithstanding the writer is satisfied that the trend is favourable and substantial and is such as one would expect in the circumstances.

Concurrently the incidence of the disease declined among the grindstone makers employed in the millstone-grit quarries in Derbyshire, on the outskirts of Sheffield. This craft, which once constituted a flourishing industry, now scarcely exists.

Radiographic feature of grinders' silicosis

In relation to the disease in metal-grinders and grindstone-makers there is a clinical feature of note: namely, that the radiographic mottling is often

extremely dense, suggesting calcification, and it has been in these cases that one encountered the typical "snow-storm" appearance. At necropsy the nodules were large, firm and encapsulated, but without evidence of calcium salts.

Foundries

Ferrous-metal castings

While sporadic cases of pneumoconiosis have been reported (Harding and McLaughlin, 1955) in non-ferrous foundry workers, this section is restricted to iron and steel foundry workers.

These castings include an infinite variety of articles, which differ considerably in shape, size and weight, as exemplified by the numerous small items of a domestic stove made of iron or a ship's propeller of fine steel alloy. In relation to pneumoconiosis, it is not the final product which matters but the processes of production and finishing. The industry is widely distributed throughout Great Britain, but the main centres are, as might be expected, in or adjacent to colliery areas.

McLaughlin (1950) very concisely describes the principal stages of manufacture as follows:

> "In the making of a casting there are certain fundamental processes. First a pattern of the casting is made, usually in wood; but metal, plaster, special compounds or combinations of these may be used. A mould is then made by ramming sand around the pattern, so that when the pattern is removed an impression of it remains in the sand. Then molten metal is poured into this impression and when the metal cools a solid casting is formed. If a hollow casting is required a sand 'core' is prepared with its external surface conforming to the internal shape desired in the casting. This core is then placed in the impression left in the mould by the pattern so that the molten metal fills the space between the core and the mould. After the metal has solidified the sand is removed from the casting. The initial rough removal of the sand is done by processes known as 'knocking out' or 'stripping' and the final cleaning by various processes is called 'dressing' or 'fettling'."

It is the removal of the sand which constitutes the danger to the workmen. First there is the stripping of the incrustation of mouldings and and the knocking out of the cores; this is done on the foundry floor or in a nearby area, and the work contaminates the general atmosphere of the shop and adjacent bays with fine dust. The next stage is the cleaning of the castings, that is to say the freeing of the surfaces from adherent "burnt-on" sand. This comprises a variety of methods, according to the nature, size and purpose of the casting.

(1) Brushing, either by hand or power-driven wire brushes.

(2) Rumbling and barrelling, in which small castings are tumbled against each other in a revolving cylinder. The operation may be improved by the addition of powdered abrasives, steel shot or alundum.

(3) Grinding on abrasive wheels.

(4) Blasting, by means of abrasives forcibly projected against the casting by compressed air or a rapidly revolving wheel (wheel-abrading).

(5) Dressing or fettling with pneumatic or hand tools.

(6) Hydroblast: this is a recent development and consists of a large machine, which cascades the castings with a mixture of water and sand at high pressure.

Blasting in foundries

Originally this was carried out by projecting a stream of crushed quartzose sand against the surface of the casting, by means of compressed air. The labourers were known as sand-blasters, and disabling and fatal silicosis often appeared in these workmen after 2–5 years in this occupation (Merewether, 1936). In the treatment of large castings the work had to be done in the open on the foundry floor, and all workmen in the vicinity were involved in the risk. With smaller castings it was possible to clean them in cabinets: sometimes the sand-blaster worked inside the cabinet or in other cases he was able to operate from the outside. In the former method he was protected by a leather suit, gauntlets and a helmet attached to a positive air-pressure line.

A great advance in control of the disease was achieved by the substitution for the sand of non-siliceous abrasives, steel shot, and various forms of alumina (corundum). This protection is not absolute, for the shot, even when regularly cleaned, becomes contaminated by the sand from the casting. The latest development is the hydroblast, but this is a large and expensive plant, requiring for its operation large cheap supplies of water. Accordingly this method is restricted to a few very large foundries.

The number of sand-blasters is small and, whereas up till a few years ago, this was probably the most serious risk in Great Britain, considerable advances, by the methods recorded above, have been made to protect these workmen.

Dressing or fettling

The object of dressing or fettling is to free the surface of the castings from adherent sand, and to smooth them by removing rough edges and small metal projections. Sometimes the process is done without previous blasting, but more usually the castings have been cleaned. Originally the chipping was done with hand tools—hammer and chisel—but nowadays pneumatic chisels are in general use. Hand-tools must still be used in hollow castings, as in tank turrets. This involves serious risk to the workman, because he is confined in a narrow unventilated space, where he is exposed at breathing level to a very intense cloud of very fine, freshly fractured particles of sand.

When hand-tools were in use, for a variety of reasons the intensity of the risk was considerably less than it is now, and cases of the disease, although admittedly serious, tended to be restricted to workmen employed in confined areas. The pneumatic chisel has intensified and extended the risk to a wider group, and cases are regularly discovered after 10–15 years in the occupation. The problem is so serious that the workers' trade union has called either for abolition of pneumatic tools or for the fitting to them of some device to control the dust.

It is worthy of note that, in some instances, dressers are almost wholly employed on castings from which the sand has been almost entirely removed. Even so they inhale numerous fine particles of iron and steel. In these cases the radiographic appearances resemble simple pneumoconiosis, in which the fine nodules and striation are sharp, like filigree. These radiographic appearances probably represent fine radio-opaque inclusions—in fact they are indicative of siderosis, not silicosis.

Moulding in foundries

Hitherto there has been a tendency to regard moulding and the incidental processes on the foundry floor as comparatively safe, and to consider any cases which did arise as due to some unusual circumstances, such as the use of siliceous parting powder. Recent experience indicates that the risks of the actual moulding operations have probably been under-estimated.

Again it has generally been accepted that the incidence and severity of pneumoconiosis is substantially less in iron than in steel foundries; indeed until 1948 the disease was compensatable only in respect of certain processes in the freeing of steel castings from adherent sand. McLaughlin (1950) accounts for the difference thus:

> " It should be noted that the pneumatic tool is not often used to clean iron castings, but that cleaning or fettling is done by such methods as rumbling or barrelling, brushing with wire brushes and by grinding. The moulding sand used in iron foundries has not usually such a high silica content as that used in steel foundries and because the melting and pouring temperatures of iron are not as high as those for steel, there is less ' burning on ' of the moulding sand. Iron castings therefore are not so difficult to clean as steel castings are. The methods used are less vigorous and there is probably not so much breaking up of the sand grains as there is in the fettling of steel castings. Again because the free silica content of the moulding sand is lower in iron than in steel foundries, the dust inhaled by the iron fettlers contains less free silica. This last fact appears to be reflected in the pathology of iron dressers' lungs in that the characteristic appearance is the peribronchial and perivascular fibrosis usually associated with a ' mixed dust ' pneumoconiosis, caused by dusts containing lower percentages of free silica than those usually found in trades in which classical silicosis develops. It will be noted, however, that even in iron dressers typical silicosis is sometimes found."

Prevention of silicosis in foundries

As described above, various methods have been adopted to control the dangerous dust, and hence the incidence of the disease in the group and its seriousness in the individual. At present fettling processes give rise to the most serious complaint, and it has been urged that the use of pneumatic chisels should be prohibited. This is an unrealistic attitude. The need is for some device or attachment to these tools, which will suppress the dust and collect any excess that escapes at the point of production. The greatest advance would accrue if moulding sand could be dispensed with, but the

use of permanent metal moulds has proved possible only for a few simple castings. A similar salutary advance would follow if a harmless moulding medium could be found to replace sand. Several have been tried. Olivine (a magnesium silicate) which occurs naturally in Norway, fulfils both the practical and the health requirements, but available supplies are inadequate and the cost is uneconomic for use in Great Britain. Another possibility is, while retaining sand, to find some means of obtaining a clean cast—that is to say, a cast with the minimum of burnt-on sand. Thereby the need for fettling would be correspondingly reduced. Some success has been achieved by facing the moulds with paints and compositions prepared from zirconium metal.

Granite industry

Granite is an igneous rock, wholly crystalline and composed of mica, felspar and quartz. The rock is worked in widely separated areas, in Leicestershire, Cumberland, North Wales, Cornwall and Aberdeenshire. It is used mainly for monumental works, public buildings, sea-walls and quays, headstones, kerbs, setts and chippings, and the construction and repair of roads. An important fact to note is that many other minerals, chiefly by reason of their physical properties, are sold in the trade as granite, whereas, petrologically, they are not granites but quartzites. Crushing of these for road-metal and chippings may cause silicosis after a comparatively short period of exposure, between 2 and 5 years. King, Ray and Harrison (1950b) have studied the effects in rats.

The risk to workmen employed in the granite monumental trades is well illustrated by the industry in Aberdeen, where 40 firms employ 1,500 men, of whom 500 are engaged in processes involving a dust hazard (Mair, 1951). At this point it may not be out of place to underline that any estimates of the incidence of silicosis among these workmen should not be related to the total number employed, but only to those actually engaged in dusty processes.

Dusty occupations and processes

The native rock is obtained in large blocks from open quarries where, before delivery to the yards, it is roughly shaped by hand, by the use of hammers and wedges. The next job is to cut the mass into pieces of approximate size; this is done with carborundum saws, working under a continuous flow of water, so that the dust is controlled at source. Then the mason (or squarer), using hammer and chisel, shapes the stone to the required size and form. This work is dusty, and the degree of dustiness varies according to whether the men work in open or closed sheds. The surfaces are levelled (or "dunted") by means of a pneumatic multi-toothed tool, or hammer, called a surfacing machine, which is operated by a "dunterman". This is the dustiest job and the most serious risk.

The workman and his habits of work are of much interest. Up to 20–30

years ago, stonemasons were wont to grow a walrus moustache, which acted as a form of respirator, and the bowler hat, so regularly worn at work, acted as an excellent safety helmet. To ensure that the dust was carried away from him, the operative placed the stone on the bench (or banker) and took up his working position so that the wind came from the rear and blew the dust out of the shed into the open air.

Recent experience of silicosis among granite workers

Mair (1951) has surveyed the Aberdeen masons. He records the following facts:

> " Of the 510 members (practically 100 per cent) of the stone-cutter population who submitted themselves for x-ray examination 56 (10·9 per cent) showed radiological evidence of silicosis. This percentage incidence, at first impression, looks ra er formidable but it must be emphasized that many of these cases are really in the very earliest stages of radiological silicosis and without any demonstrable signs or symptoms. In the main the cases are grouped towards the later years of life, in particular after 55 years of age."

Table XIII, from the same source, relates the occurrence of silicosis to age, and from these data it can be calculated that, of the 201 men over the age of 45 years, 53 (26·4 per cent) are affected, which is not such a favourable situation as the author suggests in the quotation above. It appears, however, that severe incapacitating disease mainly affects men in the advanced age-groups; thus the 11 cases showing massive shadows showed a mean age of 65·4 years.

TABLE XIII

INCIDENCE OF SILICOSIS BY AGE IN THE ABERDEEN GRANITE INDUSTRY*

Age in years	No. of cases of silicosis	No. of masons	Percentage affected
16–20	—	47	—
21–25	—	16	
26–30	1	53	1·7
31–35	1	66	
36–40	—	78	0·8
41–45	1	49	
46–50	2	24	12·7
51–55	5	31	
56–60	17	67	25·7
61–65	14	50	
66–70	11	18	52·0
71–75	—	11	
over 76	4		
All ages	56	510	10·9

* After Mair (1951).

Clinical features

In general, the features of silicosis in granite masons conform closely to the disease in other silicosis-producing industries. The radiographic appearances, however, seldom present as discrete mottling; coarse reticulation and diffuse, fluffy, translucent opacities are the rule.

Miscellaneous industries

For the general reader, metalliferous mining, in highly siliceous rocks, raises no peculiar matters for discussion. Gold-mining, in the quartzite ore-bodies on the Rand (Simson and Strachan, 1935; Simson, Strachan and Irvine, 1930), and tin-mining, in the granite lodes of Cornwall, are the classical examples and these have been amply recorded. The great improvements, which have resulted from the abandonment of dry-drilling in favour of wet-drilling with axial water-feed drills, are noteworthy. Silica particles are not easily wetted or deposited by plain water, but the value of water-sprays can be materially enhanced by the addition of wetting agents, such as castor oil and petroleum products.

Some cases of silicosis escape detection or are misdiagnosed, because the name of the occupation does not immediately suggest the risk. This again underlines the need to discover the nature of the processes and the raw materials. Thus several cases of silicosis have been recorded in grave-diggers. The explanation is that these particular workmen were excavating the cells in solid sandstone and they were, in fact, rock-drillers. In like manner soap-packers may be handling abrasive soap-powders, which largely consist of silica flour. As a rule, however, these instances are rare.

Bricklayers form a larger group, and when employed at foundries they may be engaged in the building, repairing and dismantling of furnaces, or at gas-works in similar processes in the retorts. The linings of some of these structures are made of refractory bricks, often of very high silica content, over 80 per cent. In addition, the actual work must often be completed in very confined spaces where no protection is practicable. This work constitutes a definitely serious silicosis hazard, but this is usually mitigated by the intermittent nature of the work. The possibility of cases of pneumoconiosis among these workmen should not be overlooked, particularly as early diagnosis is valuable in this group, enabling affected workmen to be employed elsewhere in their own occupation and without further risk.

ANTHRACO-SILICOSIS AND SIDERO-SILICOSIS

Anthraco-silicosis

In collieries a small number of men are employed mainly in development work, which involves extensive drilling and blasting in silica rock. According to the individual coal-field, these men are variously designated as rock-men, hard-headers, hard-ground workers and cutters. Others similarly exposed, but not to the same degree, are pit-sinkers, rippers and repairers, and

brushers. As might be expected, some of these men contract silicosis, usually after about 15–20 years in the occupation. At the same time they inhale heavy concentrations of coal dust, and the occurrence of silicosis in a black lung has been named anthraco-silicosis. The same condition, but one in which the blackness even more closely resembles Chinese ink, occurs in some foundry-workers, if they are handling moulding sands containing lamp-black, and in workmen engaged in crushing and handling natural graphite (*see* p. 103).

PNEUMOCONIOSIS IN COAL-MINERS

In recent years in Great Britain, the study of the pneumoconioses has been dominated by the researches into the pulmonary diseases of coal-miners. Hart and Aslett (1942) observed that the same diseases affected other groups of workmen handling and moving coal, such as coal-trimmers at the docks, and so they suggested the wider title: pneumoconiosis of coal-workers.

Historical survey

Early in the nineteenth century the pathological anatomists of Paris, including Laennec, directed attention to " a peculiar form of animal production ", which they named melanosis. The nature of the condition caused considerable controversy, but ultimately two separate varieties were identified: (1) true melanosis, due to disseminated cancerous deposits, and (2) spurious melanosis, due to the inhalation and retention in the lungs of invisibly small particles of carbon, produced by the burning of coal, wood and other inflammable materials. All persons, particularly town-dwellers, were considered to be susceptible.

It was not until 1831 that Gregory of Edinburgh definitely asserted that black infiltration of the lungs was a disease " to which that numerous class [coal-miners] of the community would appear to be peculiarly exposed ". Stratton, in 1837, proposed the term, anthracosis, to describe the pathological appearances observed in the lungs. At this period and continuing until 1875, the main focus on the disease was in Scotland, where the local physicians made important contributions to the aetiology, pathology and clinical aspects (Black, 1953). A clear distinction was made between the serious fibroid or melanotic phthisis, which occurred particularly among the miners working in the stone, and the benign pigmentation of the lungs—anthracosis—which affected workers at the coal-face. As ventilation of the mines improved, the disease became less prominent and for many years it was thought to have disappeared. About 1920, however, doctors began increasingly to report the advance of pulmonary diseases among coal-miners, particularly in South Wales, and since then pneumoconiosis of coal-miners has attained almost to epidemic proportions in this area. Whereas the peak there now seems to have been passed, the incidence of certified cases of the disease is steadily rising in the other coal-fields (Meiklejohn, 1951 and 1952).

Aetiology and pathology

The winning of coal, whether by hand or machine, necessarily involves the production of dust, which is a complex mixture of the constituents of the coal and of the diverse strata in which it occurs. Thus, according to the geological area, the air-borne dust includes fine particles of carbon from the coal, silica and limestone from the intervening strata and silicates from the clays and shales. In pits where coal-dust explosions constitute a risk, additional dust arises from the materials, such as gypsum, which are spread, as a preventive, on the roadways and ledges. The air is further contaminated by gases derived from the decomposition of the coal and by irritant fumes from explosives used in blasting. Other factors which may influence the occurrence and progression of pulmonary disease among miners are high working temperature, increased humidity and strenuous physical exertion.

All underground workers are not similarly or equally exposed to the inhalation of dust. Reference is made on page 189 to anthraco-silicosis in development workers, who are mainly employed in drilling and blasting in silica rock. Those most seriously exposed to high concentrations of coal dust are the machine-men and loaders at the coal face (Black, 1953).

The several kinds of coal, anthracite (hard), bituminous (soft), and semi-bituminous (intermediate) belong to the inert dusts and this pathological reaction and its course are described on page 19 and more fully elsewhere. In their inquiry into chronic pulmonary disease in South Wales coal-miners, Hart and Aslett (1942) concluded that the incidence of pneumoconiosis was somehow related to the hardness or rank of coal. Thus the disease was more prevalent in the anthracite than in the bituminous or steam-coal pits. The " rank " of a coal is roughly inversely proportional to the amount of volatile matter which it contains. In South Wales, anthracite coals with less than 5 per cent of volatile matter have the highest rank, and bituminous coals with over 30 per cent of volatile matter have the lowest rank.

Subsequent experience has shown that the occurrence of the disease in soft-coal areas approximates closely to that in the hard-coal areas. It is generally agreed, however, that the disease is due to the dust, which must be inhaled in large quantities, although it has not been discovered which constituent is causative and what determines the reaction of the individual. It can be asserted, however, that throughout the coal-fields of Great Britain the disease is the same and that wherever it occurs the manifestations are identical.

Geographical distribution of the disease

No precise knowledge exists of the incidence of the disease either in the separate coal-mining divisions or in particular occupations. At present the focus of the problem is in South Wales but the disease is by no means restricted to this area. Since 1944 the annual number of certified cases in South Wales has been about 3,000 partially disabled and 350 totally disabled, whereas the figures for all the other British coal-fields combined are

450 and 150 respectively. Relating certification to populations at risk, Dr. C. M. Fletcher has summarized the position by stating that throughout the period 1930–48, the prevalence of pneumoconiosis was 40 times as great in South Wales as in the rest of Great Britain (Fletcher, 1948). It is important to realize that prevalence, in this context, merely relates to certification and not to the actual incidence of the disease in the separate areas. The statistics in Table XIV, prepared by the Ministry of National Insurance from official records for the period from April to December, 1950, provide a more detailed statement of the incidence of certifications in the various coal-fields.

TABLE XIV

INCIDENCE OF CERTIFIED CASES OF PNEUMOCONIOSIS IN THE SEPARATE COAL DIVISIONS IN GREAT BRITAIN

Coal-mining area	Working population 1,000's	Certified cases: annual rate per 1,000
Wales, Monmouth, Forest of Dean, Bristol and Somerset	105·900	18·91
Kent	6·000	14·20
North Staffordshire, South Staffordshire, Caunoch, Shropshire and Warwick	54·500	5·33
Scotland	80·800	5·21
Lancashire and North Wales	56·300	3·60
Durham	106·800	2·19
Yorkshire	134·000	1·79
Northumberland and Cumberland	48·700	0·54
Nottinghamshire, Derbyshire and Leicester	94·700	0·31

Again it is important that these figures and estimates should not be misinterpreted. They are not a true measure of the occurrence of the disease in separate coal-fields; they simply denote the numbers of cases diagnosed and assessed by the pneumoconiosis medical panels under the National Insurance (Industrial Injuries) Act, 1946.

By reason of a definite policy pursued by the miners and their union in South Wales, the medical arrangements, statutorily established for certification and assessment of disablement, have been used to provide an irregular system of periodical medical and radiographic examinations for men at work, irrespective of whether or not these men suffered any symptoms. As a result, certifications probably constitute a fairly comprehensive index of the incidence of the disease in South Wales. The recent trend of these assessed cases suggests that the peak has been passed; but there is, as yet, no evidence of a slump.

In some other coal-fields the approach has been entirely different; men have presented for examination only when sick and unfit for work. Accordingly, assessed cases in these areas are not a measure of the incidence of the disease. Recently, however, disturbed by publicity about the disease and its

consequences, more and more men in these areas have been seeking examination by the medical boards, and the number of assessed cases is mounting year by year. This is well exemplified in Scotland, where certifications have steadily increased from 109 cases in 1944 to 798 in 1953.

These submissions are admirably illustrated by a comparative analysis of all cases of claims coming before a medical board in South Wales and another in Scotland from April to December, 1950. Scrutiny means inspection of a preliminary radiograph, which is used, as a screen, to eliminate from clinical investigation all cases which do not present any radiological changes.

TABLE XV

DISPOSAL OF APPLICATIONS, APRIL TO DECEMBER, 1950

Area	Negative on scrutiny	Disease not diagnosed	Disablement: proportion of assessments			Number of applicants
			under 20%	20%	over 20%	
South Wales	54%	19%	17%	6%	4%	6,441
Scotland	31%	18%	1%	6%	44%	630

Further proof of this different approach in separate areas emerges from mass-radiography surveys outside South Wales. In one such survey as many cases—previously undiagnosed—were discovered among men at work in one large pit, as had been diagnosed and assessed throughout the whole coal-field, employing 70 times the number of men, during the whole of the previous year.

Indeed, it seems reasonable to conclude that the incidence of diagnosed cases of pneumoconiosis in any coal-field or district varies directly with the number of radiographic examinations carried out among experienced underground workers.

Radiology in diagnosis

Present concepts of the radiographic manifestations of the disease are based on the studies conducted by the Pneumoconiosis Research Unit at Cardiff since 1945.

The earliest abnormalities consist of minute opacities, up to 1 millimetre in diameter, and occupying a very small localized area of the lung fields. These opacities increase in number, becoming more widely distributed and more closely aggregated. Increase in size may proceed up to 5 millimetres in diameter, and concurrently, in some instances, this may be accompanied by greater radiological density. Ultimately the whole of both lungs may appear finely stippled while the normal vascular pattern is obscured. This condition, characterized by disseminated fine opacities, is termed " simple pneumoconiosis " and represents the pathological state in which coal

			Yrs. in industry
Case 3			
1910–12	Maintenance man	Probable both ends	39
1912–26	Hand furnace foreman	Dry end	
1927–	Kiln worker	Dry end	
Case 4			
1922–33	Labourer	Probably both ends	25
1933–36	Unemployed		
1936–	Labourer	Probably both ends	
Case 5			
1935–47	Mill and roast foreman	Dry end	14
1947–	Training supervisor for workers	Wet end	
Case 6			
1928–51	Cooper: contact with dichromates mainly		22
Case 7			
1923–49	Furnace man	Dry end	27
1950–	Gateman		
Case 8			
1929–38	Labourer	Probably both ends	21
1938–41	Watchman		
1941–	Foreman		
Case 9			
1942–	Barrow man in kiln room	Dry end	8
Case 10			
1918–49	Fireman in ore furnace room	Dry end	33
1949–51	Labourer in yard		
1951–	Labourer loading and unloading ash		

Carcinogenic factors of water washings

The case for some carcinogenic factor in the chromate process as practised in the United States of America seems unassailable. The clue to the carcinogen is still hidden, but some evidence as to its location can be evoked from the brief occupational histories given, if we make certain assumptions. In view of the consistent failure to demonstrate any carcinogenic action by chromates, bichromates, chromite ore, or chromic salts in animals, it seems necessary to seek other chromium sources if it is held that it is indeed among derivatives of chromium that we should find it. It is the suggestion of the American investigators that the carcinogen may lie in the water insoluble residue which remains after leaching out the chromate with water. If the process is one not using lime in the roast, then the leaching will take not only soluble alkalies and chromates, but also aluminates and vanadates: if lime is used the latter are rendered insoluble and will remain in the *residues*.

The residue (or " mud " as it is called) is sufficiently rich in chromium to make it worth while to return it to the process. Hence it is dried in a rotary drier, crushed, ground to a fairly fine mesh, mixed with soda ash, roasted and leached in substantially the same way as the original ore for the main process. Some is returned to the primary mixing.

nodules occur in greater or smaller numbers throughout the parenchyma of the lungs. As in simple silicosis, the radiograph may suggest a more serious degree of pneumoconiosis than is revealed by lung sections; this is due to the projection of a solid organ on a flat surface, whereby super-imposition in depth of individual opacities occurs.

The various degrees of severity of simple pneumoconiosis are classified radiologically into 4 categories of increasing abnormality, based mainly on the number and area of distribution of the opacities (*see* p. 95).

In some cases of simple pneumoconiosis additional opacities appear. These shadows are of larger size, more homogeneous and somewhat denser in appearance. They may be single or multiple, and normally they first present in the upper zones of the lung fields but ultimately may be distributed throughout the whole of both lungs. They are irregular in shape, vary in size and tend to increase in density. In long-standing cases of the disease, contraction may occur in the fibrotic masses which these shadows represent, thereby causing displacement and distortion of adjacent structures. At the same time the outline of the shadows may be sharpened by contrast with enveloping areas of increased translucency due to emphysematous lung. These massive shadows give this condition the name, " Progressive Massive Fibrosis " (P.M.F.), and it corresponds to the infective nodules and collagenous fibrosis described by Gough (Gough, 1940, 1947). The combination of " simple " pneumoconiosis and progressive massive fibrosis is termed " complicated " pneumoconiosis. The qualification, progressive, is open to criticism, for it does not signify clearly the character of the progress and, moreover, simple pneumoconiosis too may advance in the range of categories 1–4. Complicated pneumoconiosis also is classified radiologically into four categories of increasing abnormality. (*See* p. 96.)

Radiological classification

The Pneumoconiosis Research Unit has classified the radiological changes as set out below. Not only in Great Britain but throughout the world the system has already met with considerable acceptance, and further experience in use should result in modifications, so that finally it may provide an international classification. While its authors hope that ultimately it may be found applicable to all pneumoconioses, in its present form it is not considered sufficiently exhaustive for this purpose.

Simple pneumoconiosis of coal-workers

Coal-workers' pneumoconiosis is divided, on both pathological and radiological grounds, into two main subdivisions.

Simple pneumoconiosis is characterized pathologically by generalized small foci (less than 5 millimetres in diameter) of dust deposition throughout-the lungs, associated with reticulin (or occasionally collagenous) fibrosis. It gives rise to a radiological appearance of disseminated opacities of a characteristic type in both lung fields.

The characteristic opacities are minute (0·5–1·5 millimetres in diameter), more or less circular and fairly well-defined in outline. They are usually arranged in clumps. The appearance is thus of a granular type, but fine linear opacities often connect adjacent minute opacities, enclosing small translucent areas, resulting in a fine lace-like appearance. Larger, more or less circular opacities also occur, with a diameter up to 5 millimetres.

Complicated pneumoconiosis is a combination of simple pneumoconiosis and progressive massive fibrosis (P.M.F.). The latter is characterized pathologically by collagenous fibrosis in nodules ranging in size from 1 centimetre to large masses several centimetres in diameter, and is characterized radiologically by more localized opacities (in the early stages often resembling those caused by tuberculosis), with a tendency to progress in the course of time to the formation of large massive shadows.

Classification of simple pneumoconiosis

In simple pneumoconiosis of coal-workers, four categories of increasing abnormality are now verbally defined, as follows:

Category 1: *minimal pneumoconiosis.*—A few characteristic opacities, 0·5–3 millimetres in diameter, are seen, usually in the second, third or fourth anterior rib spaces midway between the mediastinum and the periphery, more commonly on the right than on the left. The vascular markings are clearly visible. To make a diagnosis of category 1, the characteristic abnormality must be found in at least 2 rib spaces. Each area of abnormality must extend over 1 square centimetre or more.

Category 2: *moderate simple pneumoconiosis.*—Opacities 0·5–3 millimetres in diameter are more numerous and are distributed throughout the lung fields, with the exception of the peripheral third, where they are sparse or absent. The vascular markings are still visible, although not so clearly as in the previous category.

Category 3: *marked simple pneumoconiosis.*—With the exception of an occasional large vessel in the upper and lower zones, the vascular markings are now obscured by opacities 0·5–5 millimetres in diameter, profusely distributed throughout both lung fields, including the outer third of the lung. The apices are usually clear.

Category 4: *maximal simple pneumoconiosis.*—In these films, opacities 0·5–5 millimetres in diameter are more profusely distributed throughout the whole of both lung fields, extending even to the apices.

Grounds for categorization.—It should be noted that the distinction of the categories is made chiefly on the following grounds:

(*a*) the diffusion and profusion of the opacities;
(*b*) the presence or absence of the opacities at the periphery of the lung fields;
(*c*) the degree of obscuration of vascular markings.

In cases in which the distribution of opacities is uneven, the category is determined by whichever half lung field shows the greatest change.

Criticisms of category 1.—Category 1 has evoked considerable criticism, and indeed many experienced chest physicians and radiologists do not regard this degree of change as signifying any abnormality whatsoever. They submit that it is indistinguishable from the normal or natural, particularly in the advanced age-groups of workmen. The difficulty emerges from a conflict of attitude between the physician, who is concerned with clinically significant disease, and the scientific investigator, who is seeking to discover the earliest sign of a pathological process. Each, regarded from his particular standpoint, is correct.

FIG. 17.—Coal-miner (Scotland), aged 59 years; underground work—45 years. Simple pneumoconiosis. (*By courtesy of Pneumoconiosis Medical Board.*)

Complicated pneumoconiosis of coal-workers

The various categories of complicated pneumoconiosis are designated by a title and coded by a capital letter.

Categories of complicated pneumoconiosis

A. *Localized ambiguous opacities.*—Considerable ambiguity exists in the interpretation of these shadows. Superficially they resemble tuberculous

infiltrations: on closer study, however, they are found to be different. At the periphery, the typical granular opacities of simple pneumoconiosis can still be seen: but towards the centre of the localized opacities the former become larger, hazier in outline, and more homogeneous, losing their granular appearance. Some of these larger opacities fuse to form still larger coalescent shadows, which are occasionally multiple and fluffy in character. They are usually seen in one or other upper zone, but occasionally in the mid-zone. About 50 per cent are unilateral, when bilateral they are nearly always asymmetrical.

B. *Massive shadows.*—Here, one or more massive shadows may be clearly distinguished. They are more extensive and more homogeneous than the ambiguous shadows but are still of uneven density. Their outlines may be well-defined in parts but, in general, they are hazy and are often obscured by surrounding ambiguous shadows.

C. *Advanced massive shadows.*—Massive shadows are now the chief feature of the film. They have an outline that is more easily defined than in category B, sometimes by reason of an increase in the surrounding translucency. The density is more uniform and usually increased, but there is a type of faint massive shadow of even density included in this category.

FIG. 18.—Coal-miner (Scotland), aged 64 years; underground work—50 years. Massive shadows; complicated pneumoconiosis. *(By courtesy of Pneumoconiosis Medical Board.)*

D. *Advanced massive shadows with distortion of the thoracic structures and gross emphysema.*—The massive shadows have the same characteristics as those described under C, but distortion of the surrounding structures has taken place. This distortion may affect:

(1) the mediastinal structures (trachea, hila and heart);
(2) the lung parenchyma (giving rise to large translucent areas);
(3) the diaphragm (giving rise to peaking, flattening or haziness of the outline).

The film is placed in this category when at least two of these types of distortion are present.

Cavitation

Cavitation of massive shadows may occur at any stage, giving rise to areas of increased translucency within the shadows. Cavitation does not affect the categorization.

Difficulties in categorization

The category of progressive massive fibrosis in any film under consideration is determined by the most advanced disease present. Thus a case with a category-C shadow on one side and a category-A shadow on the other will fall into category-C.

In the interpretation of radiographs it has been proved that there is a considerable error between observers (inter-observer error) and in the same observer (intra-observer error) when required to categorize the same film on separate occasions (Cochrane, Davies and Fletcher, 1951). As might be expected, these errors are most common in relation to the early stages of simple pneumoconiosis. As a means of achieving consistency of radiological diagnosis, the Pneumoconiosis Research Unit advocates the use of standard films, representative of the separate categories, against which any unknown film can be matched. So far it has not been found possible to provide sets of these standard films for general distribution, but the idea is good and, although not universally practicable as yet, the method should be rigidly applied in all research projects which involve the interpretation of chest radiographs.

Radiographic progression

The division of pneumoconiosis into " simple " and " complicated ", and the further classification of each of these forms into four categories of increasing radiological abnormality, must not be interpreted as signifying that the disease progresses step by step from one stage to the next and finally from one form to the other.

If a workman continues to work underground in dangerous concentrations of dust, then simple pneumoconiosis may appear, and gradually over years advance steadily through the categories 1 to 4. However, in the absence of further exposure to dust, simple pneumoconiosis does not progress, as such,

beyond the category already attained. Progressive massive fibrosis has not been observed to occur except on a background of simple pneumoconiosis. The Pneumoconiosis Research Unit has endeavoured to discover at what stage of simple pneumoconiosis progressive massive fibrosis is likely to develop—in other words to find whether there is a "critical stage" of simple pneumoconiosis. So far its observers have not noted the development of progressive massive fibrosis on a background of category 1, but commencing at category 2 there is an increasing proneness to this development. There is, as yet, little evidence as to the extent—attack rate—of the transformation, but Mann in 1948 recorded: "that 97·5 per cent of the cases reached category 3 before developing progressive massive fibrosis and that 25·0 per cent of these category 3 cases developed progressive massive fibrosis in six years". Furthermore, it would appear that once category 3—or, though more rarely, category 2—of simple pneumoconiosis has been established, the development of progressive massive fibrosis may occur, whether or not the workman continues at work in his dusty occupation (Stewart and her colleagues, 1948). Massive fibrosis, likewise, is nearly always progressive in extent of lung involved.

These observations are interpreted as indicating that progressive massive fibrosis is not due merely to dust but to some other factor, possibly tuberculous infection, superimposed upon a lung sufficiently damaged by coal dust. This suggests, as many believe, that simple and complicated pneumoconiosis represents two separate pathological conditions, in the causation of which coal dust is a common agent.

Rheumatoid arthritis and pneumconiosis of coal-workers

In some cases of rheumatoid arthritis among coal-miners in South Wales (Caplan, 1953) has recorded a high incidence of massive fibrosis of the lungs. The radiographic shadows, however, are of a peculiar and uncommon form. Instead of the usual gradual enlargement of irregular fluffy opacities to form large massive shadows, in these cases multiple, well-defined round opacities 0·5–5 centimetres in diameter appear relatively quickly, usually in the periphery of the lung fields on both sides. The background of simple pneumoconiosis also is less well-marked than is usual in progressive massive fibrosis (P.M.F.). These round shadows usually remain stationary, but sometimes enlarge slightly, may cavitate, and in long-standing cases show some signs of shrinkage. In three fatal cases tubercle bacilli were recovered from areas of massive fibrosis, and Caplan suggests that the joint lesions may be a form of "tuberculous rheumatism".

This syndrome has since been the subject of an epidemiological investigation by Miall and his colleagues (1953) in the mining community of Rhondda Fach. They have confirmed Caplan's original clinical and radiographic observations. In their experience the widespread nodular fibrosis is radiologically distinguishable from typical progressive massive fibrosis, but

the available evidence suggests that the aetiology of both types of lesion is similar. They conclude that:

> "As these rheumatoid lung lesions in miners can develop several years before, concurrently with, or several years after the onset of arthritis, the suggestion is that there may be a particular type of tissue reaction to dust and tuberculosis in the lungs of miners who are predisposed to the development of rheumatoid arthritis. Recent work on adrenal cortical hormones and their relationship to rheumatoid arthritis and to tissue reaction suggests that this may be part of the explanation."

Disablement

As a rule simple pneumoconiosis is not associated with serious impairment of the general physical capacity for work, and so many physicians regard the condition as benign. Some patients, however, suffer severely from breathlessness, due to impaired lung ventilation and insufficient oxygenation of the blood arising from emphysema. By contrast, progressive massive fibrosis is almost invariably serious and characterized by severe disablement, due not only to dyspnoea but to toxaemia.

The estimation of the degree of disablement is similar to that described for the pneumoconioses in general. Many attempts have been made to correlate the extent of disablement with the radiographic categories. After full discussion, the Third International Conference of Experts on Pneumoconiosis at Sydney in 1950 recorded that "classification of radiographic appearances cannot be used for the assessment of clinical conditions or disability".

While the radiograph does not reveal either the fixation of the chest or the degree of pleural adhesion, it does give some idea of the type, distribution and anatomical extent of the disease. Furthermore, although the x-ray film may have a very limited value in the individual case, it still possesses a group or average value, for in general the functional capacity of the lungs is in proportion to the extent and character of the abnormal x-ray shadows.

At present an increasing number of doctors in mining areas are becoming convinced that severe disablement, apparently of pulmonary origin, may occur in miners, especially machine-men, without presenting any abnormal radiographic appearances in the lungs. The general opinion is that this state is due to emphysema, which they assert to be of occupational origin. Accordingly representations have recently been made that, in certain industries, bronchitis and emphysema should be recognized as occupational diseases.* Advocates for this policy may now find support for their arguments in the Silicosis Amendment Act, 1952, of the Union of South Africa, which makes provision for compensation benefits in respect of "Pulmonary Disability", which is defined thus:

> "Pulmonary disability" means an impairment of the cardio-respiratory functions of a person which, in the opinion of the Bureau:

* For up-to-date discussion of the subject see Report of the Departmental Committee appointed to Review the Diseases Provisions of the National Insurance (Industrial Injuries) Act. H.M.S.O. Cmd. 9548, London. 1955.

(8) to wet the tops of loaded trams or tubs during transit, by means of automatic sprays installed at strategic points;

(9) finally, to consolidate dust on selected roadways by spraying the floor with water and applying specified quantities of a deliquescent salt at suitable intervals.

All this means, of course, that there must be available an adequate supply of water, often under pressure, at many parts of the mine.

Medical supervision

While these methods are being applied and made more effective, it is realized that there is a need to supervise the health of working miners. The National Coal Board, as an employer, has set up a full-time medical service covering every coal-mine throughout Great Britain. Since 1944, a statutory system of pre-employment medical examination has been applied to all juvenile new entrants to the pits. Fletcher (1948) has claimed that there is an equally urgent need for a system of periodical examinations, which he asserts is possible by means of mass radiography (Cochrane and his colleagues, 1951). Relying on the researches of the Pneumoconiosis Research Unit, Fletcher argues that if, as the result of such examinations, young men, who show simple pneumoconiosis below the upper limit of category 2, were advised to cease working under conditions of exposure to dust, their pneumoconiosis should not progress any further, and thus they should avoid progression to complicated pneumoconiosis and serious disability.

The National Coal Board, in consultation with the Ministry of Fuel and Power, is, at present, considering the introduction of an appropriate scheme. The theoretical concepts of such a scheme are not in dispute, but, having regard to the present narrow state of our knowledge and experience of the disease, there is some controversy as to the practicability or desirability of such an undertaking. The social and economic consequences of the disease, as revealed by experience in South Wales since 1943, emphasize that the most important part of any scheme which is devised must be effective arrangements for the rehabilitation and resettlement of disabled workmen (Hugh Jones and Fletcher, 1951).

Approved dust conditions for sufferers from pneumoconiosis

Under Regulations issued in 1948 (Statutory Instrument 1371/48: Regulation 40(*a*)), the Pneumoconiosis Board is precluded from issuing a certificate of suspension in respect of a person who is found to be suffering from pneumoconiosis unaccompanied by tuberculosis, and who is employed in an occupation involving work underground in any coal-mine or the working or handling of coal above ground at any coal-mine.

The Regulations provide that a man examined by the Pneumoconiosis Board will be sent a letter advising him whether or not he can reasonably continue to work in the coal-mining industry and under what conditions.

Two forms of letter are used by the Pneumoconiosis Board:

(*a*) (i) *A form used in cases in which the disease is seriously incapacitating.*—In this letter the Pneumoconiosis Board advises the man either to work in a dust-free surface job or alternatively to leave the industry. It is pointed out that if the man chooses to return to work in the industry he should give the Pneumoconiosis Board permission to tell his employer of its findings so that a request may be made to the employer to see whether the man can be found work " in approved dust conditions ", which in this context means reasonably dust-free work on the surface.

(ii) *A form for use in cases in which the disease is in an early stage.*—In this letter the Pneumoconiosis Board advises the man that he can continue to work in the coal-mining industry without danger to his health, provided that the work is " in approved dust conditions " (*see* sub-paragraph (*d*) below), and the letter requests the workman to give permission for the Pneumoconiosis Board to tell his employer of its findings, so that a request may be made to the employer that the man shall, if possible, be placed in work " in approved dust conditions ", and subject to periodical medical examination.

(*b*) It will be for the individual man to choose whether or not he wishes to return to, or continue, work in coal-mining, and also whether or not he agrees to the Pneumoconiosis Board's findings being communicated to his employer.

(*c*) If the man chooses to return to, or continue, work and agrees to the Pneumoconiosis Board's findings being communicated to his employer, the Pneumoconiosis Board will communicate their findings to the manager of the colliery.

(*d*) The approved conditions in the class of case referred to in sub-paragraph (*a*) (ii), above, are expressed in terms of permissible concentration of air-borne dust, the standards at present operating being as follows:

(i) For coal dust clouds in anthracite collieries: not more than 650 particles per cc. between 1·0 and 5·0 microns in size.

(ii) For coal dust clouds in other collieries: not more than 850 particles per cc. between 1·0 and 5·0 microns in size.

(iii) For stone drifts and hard headings in all collieries: not more than 450 particles per cc. between 0·5 and 5·0 microns in size.

It should be emphasized that these standards have no legal backing, and that there is no question of the law being broken if a man returning to work is given a job in which the standards may occasionally be exceeded. In fact, even under the best systems of dust prevention, they may occasionally be exceeded. The standards are not meant to be peak measurements. They are meant to show the conditions as determined by several measurements made at representative times and points. The measurements from which the averages are calculated are, therefore, not to be made in abnormal conditions.

PNEUMOCONIOSIS DUE TO GRAPHITE AND SOOT

Graphite, otherwise known as plumbago or blacklead, is a mineral found mainly in the U.S.S.R., Korea, Ceylon and Madagascar. It is very soft, greasy, black and opaque, and normally occurs geologically in granitic and

(*a*) has substantially and permanently diminished the capacity for manual work of the person in question; and

(*b*) resulted from the performance, by the person in question, of work in a dusty occupation.

Prevention

During the twentieth century, manual methods of winning and manipulating coal have increasingly been replaced by mechanical means: machine-cutters, power-drills, mechanical picks and mechanical loaders and conveyors. At the same time there has been an increase in the use of explosives for blasting, and meanwhile pits have become deeper and more extensive, so that the working coal-face may be 3 miles from the shaft. Thus underground ventilation, despite more efficient systems, has become more difficult to maintain. All these factors have contributed to increase the amount of air-borne dust and hence the risk of pneumoconiosis.

Control of dust

Prevention of the disease can derive only from control of the dust—of dust production rather than of dust collection—but it will never be possible to mine coal without the production of some dust. Accordingly the purpose must be to try to reduce the concentration of air-borne dust to such levels as will not cause disabling pneumoconiosis in a normal working lifetime. This is essentially an engineering task, calling for new methods of mining and machines of better design. Shot-firing too must be reduced to a minimum. Moreover, there can be no substantial success without the willing, active and intelligent co-operation of workmen and management. Ultimately improved mechanization should contribute to the reduction of the number of cases of pneumoconiosis, by reducing considerably the number of men employed in dangerous dusty operations.

Application of water.—According to H.M. Chief Inspector of Mines, experience has shown that, in general, the most effective means of suppressing mine dust is through the application of water by methods which vary according to circumstances. For example, water may be used underground:

(1) to infuse the solid coal at the working face before actual coal-getting begins;

(2) to allay the dust during coal-cutting, by projecting jets of water under pressure on to the cutting chain of the machine;

(3) to suppress the dust raised by shot-firing, especially in tunnels, by sprays of atomized water;

(4) to spray loose coal (or rock debris) before loading;

(5) to allay the dust made by pneumatic picks by projecting on to the coal-face a cone-shaped water-spray, which surrounds the cutting pick;

(6) to wet the dust made by percussive drills in hard rock by means of a jet of water under pressure, passing through the hollow drill steel;

(7) to suppress dust by spraying the coal with water under pressure at transfer and loading points of conveyors;

quartz strata. Thus in the course of mining operations it becomes contaminated with mineral impurities, and according to its source the free silica content varies between 3 and 10 per cent. Parmegianni (1950) gives the following approximate values of Italian graphite:

C	56·20%	
SiO_2	24·86%	(free SiO_2 approx. 11%)
Al_2O_3	8·56%	
Fe_2O_3	2·97%	
CaO	0·55%	
MgO	1·48%	
Calcination losses	3·73%	
Alkali (by differences)	1·65%	
	100·00%	

So it emerges that graphite is not pure carbon but has a substantial silica content.

Mining of graphite

The mineral is obtained by mining, in which the drilling operations are generally done " dry ". For industrial purposes the raw material is submitted to various milling processes: crushing, grinding and calcination. Large quantities are used as pigments, and as stove-polish (blacklead) graphite serves to protect metal surfaces from the corroding effect of smoke, sulphurous gases, acids and alkalis. Compounded with an equal amount of fine china clay, it is moulded into " leads " for the manufacture of pencils. In the electrical industry it is used in the production of carbon rods, electrodes, and brushes for dynamos. Its most extensive use, however, is in the foundry industry, as graphite crucibles and as a facing material for sand-moulds.

Incidence of pneumoconiosis

Pneumoconiosis has been observed to occur among miners and process workers; and in Great Britain, particularly among workmen engaged in the milling processes (Dunner, 1945). The clinical picture is that of a slowly developing pneumoconiosis, in which the radiological and pathological changes resemble those of coal-workers' pneumoconiosis, simple or complicated. In 2 fatal cases, Gloyne, Marshall and Hoyle (1949) found the lungs full of black liquid, in which they identified " graphite bodies ", which in their general form resembled the curious bodies found in asbestosis (*see* p. 110). The outstanding feature of these cases, which I have observed among foundry workers, is the intense universal blackness of the lungs, which remains quite unaltered even when the lungs are washed under running water—this despite the fact that the water is converted to inky blackness.

Manufacture of artificial graphite

Artificial graphite is prepared by crushing, grinding and calcining of gas and oil cokes, and is used in the manufacture of shaped carbon blocks and electrodes for use in electric furnaces in the production of aluminium metal. This material is a very pure form of carbon, and the silica content seldom exceeds 1 per cent of the total weight. It has been proved, and accepted for purposes of industrial disablement benefit, that labourers employed in the milling operations suffer from pneumoconiosis similar to that found among workers in natural graphite.

In Great Britain, soot, lamp-black or "nearly pure carbon" is manufactured commercially by the incomplete combustion of gas and tar oils and petroleum distillates. Mineral impurity constitutes only a trace. The chief use of this product is as a reinforcing filler in rubber-compounding. In addition to producing rigidity in the vulcanized rubber, the carbon increases the tensile strength and the resistance to abrasion.

No definite evidence of pneumoconiosis, in either the lamp-black or the rubber industry, has so far been recorded in Great Britain, but Brauss and Gärtner (1951) have recorded the occurrence of cases in Germany.

A similar product—gas-black—is manufactured in America by burning natural gas, which is 95 per cent methane. This work, it is reported, does not cause any pulmonary disease.

Recently the writer has observed a few cases of simple pneumoconiosis among a group of workmen in the north of England who were engaged for many years (30 to 50) in the manufacture of soot (no silica impurity).

Cause of coal and graphite pneumoconiosis

These observations are important in relation to the aetiology of pneumoconiosis of coal-workers. The problem is whether these cases of pneumoconiosis are due to the small amount of silica within the coal or graphite or are due to the carbon itself. That there is no simple answer to this question will be realized, if one recalls that the pathological changes in the lungs may be determined, not only by the quality of the dust, chemical and physical, but also by mere quantity of fine particles, while both factors may be further influenced by associated infection.

ASBESTOSIS

Asbestos, meaning unconsumable, is a collective term applied to a group of silicate materials, which, while differing widely in chemical composition, resemble each other in certain valuable physical properties. They are finely fibrous in structure, and so can be split readily to microscopic size without loss of identity. Single fibres have been noted up to 43 inches and down to 0·000003 inch in length. The fibrous structure, which, in varying degree, is associated with flexibility, enables it to be spun into yarn and then woven

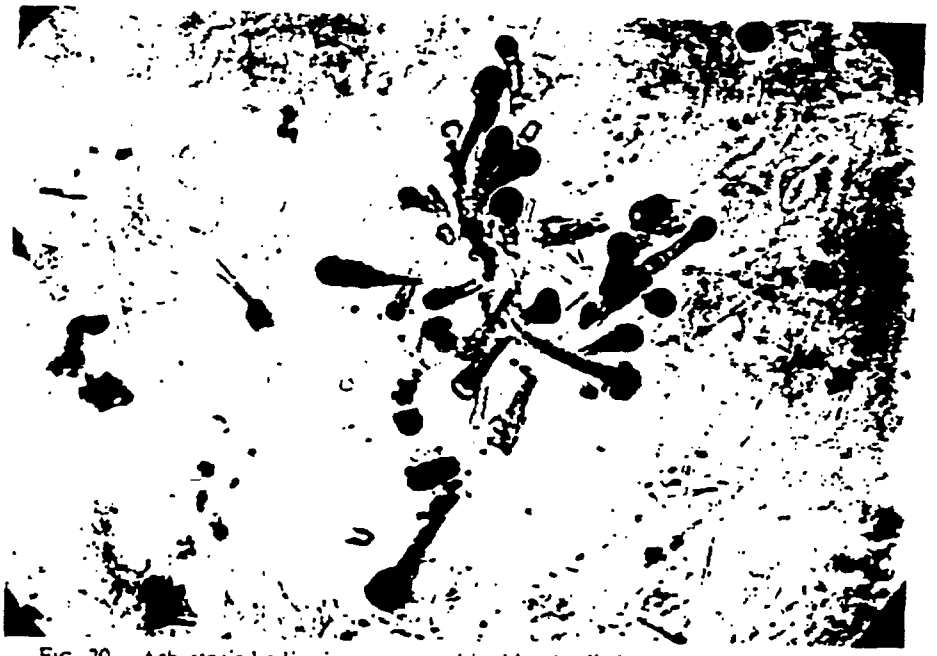

FIG. 20.—Asbestosis bodies in sputum: white blood cells indicate comparative size.

FIG. 21.—Asbestosis bodies in sputum: white blood cells indicate comparative size.

(7) Very early forms unsegmented (" sausage-shaped ").

(8) Later forms crenated, segmented, or resembling a series of oval discs, or beads strung together in a necklace form. Sometimes, later, a short length of fibre is seen between the segments.

(9) Bulbous or pointed extremities (or one bulbous and one pointed suggesting " heads and tails "). Simson and Strachan (1931) have noted sharply angled forms suggesting incipient fracture, and believe that the tapering tail forms may be the broken ends of this fracture.

(10) Generally quite straight, occasionally curved, very rarely S-shaped. During examination in a wet preparation, slight pressure on the cover slip will sometimes cause them to bend owing to the elasticity of the central fibre. This proneness to bend under stress and strain may explain the curved forms often seen in sections of tissue, as suggested by Gardner and Cummings.

(11) Forms seen " end-on " look like knobs or door-handles. Small secondary knobs and bosses sometimes seen thereon.

Histological technique.—Gloyne (1933) describes the following technique for the identification of these bodies:

After digestion of the sputum with equal quantities of concentrated antiformin and centrifugation, the antiformin is pipetted off, and the deposit covered with a small quantity of a 5 per cent solution of ammonium sulphide. The asbestosis bodies are then coloured black. This colour can be removed with hydrochloric acid.

Sections.—In the case of sections the following technique has been found useful:

After removal of the paraffin wax with xylol and alcohol in the usual way, the section is washed with water and then flooded with ammonium sulphide, which is allowed to remain for several minutes. The section is next washed and counter-stained with an aqueous solution of neutral red, dehydrated, and mounted in balsam. This method of staining also shows the presence of a large amount of iron in the sections. Unfortunately the black colour is slowly removed by the mounting fluid, and the sections will only keep for a few weeks.

Staining with haematoxylin.—Haematoxylin, which also has an affinity for iron, can be made to colour asbestosis bodies, but it is rather a deposition of stain than a true staining reaction. The technique is as follows:

After digestion of the sputum with equal quantities of concentrated antiformin and after centrifugation, the antiformin is pipetted off and replaced by a 5 per cent solution of Ehrlich's haematoxylin. Blueing of the haematoxylin immediately takes place owing to the remains of the alkaline antiformin. The mixture is well shaken and allowed to stand for ½–1 hour, and then centrifuged again and the deposit mounted as a wet preparation. By this means the asbestosis bodies become a dark-brown or black colour, according to the length of time they have been exposed to the haematoxylin.

Although these haematoxylin-coloured bodies give the impression of having the haematoxylin deposited on them rather than having actually taken up the stain, after washing over-night they still retain sufficient stain to give a dark-brown effect under transmitted light.

envisaged before. In this connexion the dictum of the Committee that " For practical purposes the conditions arising from flyer spinning carried on without exhaust under good conditions may . . . be taken as the 'dust datum' "* was agreed, and this level of dust production was accepted as the basis on which to assess the dustiness (and hence the necessary protective measures) of other processes. Nothing has emerged to suggest departure from this practical standard. It should be remembered that ring spinning is more dusty than flyer spinning, and therefore local exhaust ventilation should be applied to ring spinning. Doubling, plaiting and braiding may be linked with flyer spinning in this connexion. At one time prohibition of the industry was advocated—a completely futile and absurd attitude, as is proved by the present importance and development of the manufactures. A substantial measure of control has been achieved by mechanization and by enclosure of machines with Perspex panels.

As a means of safeguarding the health of workmen in dangerous processes, the statutory system of initial and periodical medical examinations by the Pneumoconiosis Medical Panels is in operation. This medical supervision is supplemented at most large factories by the work of the firm's own factory medical officer.

OTHER SILICATES CAUSING PNEUMOCONIOSIS

Apart from asbestos, silicates do not constitute a serious cause of pneumoconiosis among workmen. One important reason, of course, is that the population at risk (excluding the clay industries, bricks and tiles) is small. Sporadic cases, however, have been reported, and certain relevant facts are worthy of note.

Silicate minerals exist in two forms: (1) fibrous, which includes (*a*) asbestos, (*b*) talc, (*c*) sillimanite, and (*d*) sericite; (2) non-fibrous, including (*a*) mica, (*b*) china and ball clays, and (*c*) Fuller's earth.

Talc and French chalk

Talc is hydrated magnesium silicate, and in its compact form is known as steatite or soapstone, which is familiar as the chalk used by tailors for marking cloth. The purest talc deposits occur in association with dolomite and marble, and the chief sources of supply are the United States of America and Manchuria. Talc exists in fibrous and plate forms, and the special qualities which make it valuable in industry are low conductivity to heat and electricity and resistance to fire: hence its use in insulation. About 90 per cent of the talc production is marketed in ground form, as a white powder, which is used as a filler for paints, distemper, paper and soaps. Popularly it is best known as toilet powder and as a dusting agent (French chalk) in the manufacture and handling of rubber.

* Report on Conferences between Employers and Inspectors concerning Methods for Suppressing Dust in Asbestos Textile Factories. H.M. Stationery Office, 1931.

The occurrence of small nodules of fibrosis (talc granuloma) in the peritoneum after laparotomy has been attributed to the French chalk used in dusting surgeons' rubber gloves. From time to time various observers have reported isolated cases of talc pneumoconiosis, particularly among workmen in the rubber industry, and in the manufacture of electrical insulators from steatite porcelain. In 1949 McLaughlin, Rogers and Dunham recorded the first case in Great Britain of talc pneumoconiosis to be proved by pathological examination. The clinical, radiographic and pathological changes are similar to those in asbestosis, though talc appears to be much less fibrogenic than asbestos and the symptoms are comparatively slight. The similarity is further emphasized by the occurrence in lung sections of curious bodies, resembling asbestosis bodies.

Sillimanite

This particular material has been used to any substantial extent only during the past 20 years. Nowadays it finds increasing use in the manufacture of high-grade refractories and electrical porcelain. This development may ultimately diminish the number of cases of silicosis, by displacing silica in the manufacture of some refractory products.

Henry and Middleton (Middleton, 1936) examined a group of 13 workmen employed in handling sillimanite in dusty conditions, but though they noted slight radiological changes in the lungs, which might have been due to dust, they found no disability and no sign or symptom of disease.

Sericite

Sericite, sometimes called " secondary white mica ", is a hydrous silicate of aluminium and potassium in which the chief constituents are silicon dioxide (46 per cent) and alumina (37 per cent). It does not occur separately, but as a constituent of many sandstones, sandy shales and quartz conglomerates, in the form of minute scales and fibrous aggregates. These fibres are of a size which enables them easily to enter and be retained within the lungs.

The importance of sericite in relation to pneumoconiosis is entirely due to the fact that, in 1933, Professor W. R. Jones, a geologist at the Imperial College of Science and Technology, London, after the analyses of the ash of silicotic lungs, disputed the role of free silica in the aetiology of silicosis, while advancing the hypothesis that, though free silica might be the causal agent in isolated cases of the disease, its action was insignificant compared with that of sericite, myriads of fibres of which he was able to demonstrate in affected lungs. This hypothesis has not withstood the critical judgment of experts, nor has it been proved experimentally that sericite can cause progressive fibrosis of the lungs in laboratory animals.

Mica

Mica is the outstanding example of a silicate occurring in plate form.

Several varieties exist, but the most important are muscovite, phlogopite and biotite.

Muscovite, a hydrated silicate of aluminium and potassium, may be taken as typical of the group. It occurs in large single crystals, usually from a few inches to a foot in diameter and weighing several pounds. The characteristic feature of these crystals is that they can be split, almost infinitely, into sheets of microscopic thinness. The sheets are transparent, flexible, almost non-infusible and dielectric.

Industrially mica is used either in sheet or in powder form, and workmen engaged in its preparation and handling are often exposed to considerable clouds of fine plate dust. Dreessen and his colleagues (1940) in America found pneumoconiosis in 8 men who had been exposed to heavy concentrations of mica dust for periods lasting from 18 to 46 years.

China clay

In Great Britain, workable deposits of kaolin or china clay, a decomposition product of felspars in granite or in granitic rocks, occur extensively, but almost exclusively in Cornwall and Devonshire. Since its commencement nearly 200 years ago the industry has given employment to hundreds of workmen.

When ground, pulverized and freed from impurities, china clay is extensively used in the manufacture of pottery, and as a filler in paper, textiles, rubber, paints and many other manufactured goods.

Thomas (1952) has described a case of silicosis in a china-clay miner, and in the pottery industry fatal cases of silicosis and of silicosis accompanied by tuberculosis have been observed in china-clay workers. These cases, however, are uncommon, and as a rule have only become manifest after very long periods of employment in the processes, namely, 30–40 years.

Other clays

Brick clays

Brick clays are impure hydrated silicates of alumina, and they occur chiefly as superficial deposits, which have been derived by chemical weathering of rock formations. In their natural state they are not suitable for the manufacture of good-quality building-bricks, but require considerable additions of coarse sharp sand and " coal-breeze " or ashes. The following is an analysis of a good brick clay:

Silica sand	53·95%
Alumina	25·55%
Oxide of iron	8·06%
Lime	0·68%
Alkalis	1·54%
Water and various impurities	10·22%
Total	100·00%

CHAPTER 3

INDUSTRIAL CARCINOGENESIS AND TOXICOLOGY

M. W. GOLDBLATT and JUDITH GOLDBLATT

PART I: *Occupational Carcinogenesis*
PART II: *Some Aspects of Industrial Toxicology*

PART I

Occupational Carcinogenesis

SOME GENERAL CONSIDERATIONS

THE LACK of knowledge of causes of spontaneous cancer in man is often held to be the most serious handicap in real advance towards cure. But in the case of occupational cancer the causes are in several instances known, but cure in the sense of chemotherapy is far off. On the other hand, prevention is a more attainable target, when a cause is known.

It may be helpful to quote from one or two statements recently made by Haddow (1951): " . . . the cancer cell is but a modification of the normal cell "; " . . . conversion to malignancy may be due to a subtle and elusive re-orientation of enzyme construction quite unaccompanied by any gross changes affecting protein structure or immunological specificity and that there is on this account little or no protective reaction on the part of the host such as occurs in infections "; " . . . the malignant cell appears highly stable, if not indeed irreversible, as is shown by the manner in which its newly acquired genetic properties are transmitted and maintained, quite indefinitely and with no sign of reversion ".

In occupational carcinogenesis no less than in spontaneous carcinogenesis these statements are equally justifiable, and indeed cast a certain light on certain facts, whilst making it more difficult to understand others.

In occupational carcinogenesis the outstanding characters are: that the tumours are not distinguishable from non-occupational tumours: the causes are either known or can be reasonably assumed to be known; the time of

are not easy of attainment and place on the physician responsibility for precise knowledge of the significance of the radiological and pathological changes and of the social factors involved. While based on the general established facts of the disease, advice must be directed specifically to the individual patient.

Prevention of the disease, however, must remain the single unremitting purpose of all those engaged in industry.

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induction of the tumours from the first exposure is usually very long; the tumours may first show themselves many years after exposure to the "carcinogen" has completely ceased.

Since there is no particular reason to regard a worker who enters a particular industry with a cancer hazard as specially susceptible to the particular form of cancer frequently found in it, we must consider that the tumour arises from the action of the occupational hazard (or a derivative of it) on the special tissue cells and that these cells are so modified as to take on the character of tumour cells.

Now, whereas in the case of spontaneous tumours no one can say how long the hidden process of change has been going on, in the case of occupational tumours a pretty good estimate can be made on how long the attack by the carcinogen may have been going on.

Table I shows the order of times involved :

TABLE I

SHOWING THE AVERAGE PERIOD FROM START OF WORK TO APPEARANCE OF TUMOUR

Disease	Occupation	Carcinogen	Appearance of tumour (years)
Cancer of lung	Chemical worker	Chromate	14·5
Cancer of bladder	Dyestuffs worker	Aromatic amines	17–19
Cancer of lung	Asbestos worker	Asbestos	7–21
Cancer of skin	Tar distiller	Tar	23
Cancer of skin	Pitch worker	Pitch	23
Cancer of skin		Arsenic Medication	up to 30
Cancer of nose and lung	Copper and nickel workers	? Arsenic	11–12 (1–30)
Cancer of scrotum	Mule spinner	Mineral oil	46

What are the factors necessary to induce the tumours, for it is almost impossible to imagine that the known occupational hazard can take so long to reach the effective point of action or to initiate the essential biochemical or pathological process?

We hold the view that the occupational hazard is a local potentiator (Goldblatt, 1947) of particular tissues and that the essential excitor of the carcinogenic process is endogenous in origin.

It is quite certain that occupational carcinogens are not equally potent against all tissues, for example aromatic amines do not produce lung or skin tumours, mineral oils do not produce lung tumours, chromates never produce skin tumours although irritation of skin is common, arsenic never produces bladder tumours in spite of great and maintained absorption and excretion of arsenicals.

Although a single kind of occupational "carcinogen" may induce tumours in more than one location or organ, there does seem to be some predilection for particular kinds of cell.

No advance will, in our view, be made until some picture of the char-

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acteristic biochemical activities of individual cell-types is obtained, and how known carcinogens can affect it.

As we have said, knowledge of causes is vital for prevention of occupational cancer. Chemotherapy of cancer, however, does not call for knowledge of causes, for the good reason that the cause of the growth is not necessary for the continued life and development of the tumour.

This is particularly clearly shown by the fact that the tumour may appear many years after all contact with the occupational hazard has ceased. In other words, once the cancerizing process has established a focus, however small, of autonomous growth, however slow, the initiating process is no longer essential, but the cancerized cell will multiply true to type.

Chemotherapy must, therefore, be directed to the cell. Either it must be killed, or its growth inhibited. Reversion to normality does not seem a possible goal.

DIFFICULTIES IN ESTABLISHING THE EXISTENCE OF AN INDUSTRIAL DISEASE

It is hardly necessary to stress the immense difficulties which derive from the character of the disease which is indistinguishable from the non-occupational counterpart of it.

In the case of occupational tumours this is especially the case. There is nothing to distinguish the scrotal cancer of a mule-spinner, the pitch wart of a lens-maker or the bladder tumour of a dye-maker as clinical entities from the non-industrial disease. Except in statistical factors as, for example, the frequency of a particular location in the mule-spinner's tumour (left side of scrotum), the frequency at different ages in the dye worker, and the association with a known carcinogen, the occupational and non-occupational are indistinguishable. The difficulty is reflected in the frequent differences of opinion expressed by different authorities when trying to attribute a case to the proper cause.

ANIMAL EXPERIMENT

No amount of animal experiment can resolve this aspect of the matter. Animal experiments can, if the experiments have been positive, answer the question: could the particular job give rise to the disease with a high degree of probability? But if the experimental work has been negative, it can give no answer at all.

Even to attain this degree of probability a great deal of luck must be had in the experiments.

The following postulates would seem reasonable in defining occupational disease:

(1) Statistically the incidence of the disease in the occupation must be highly significant and it must arise from that occupation but not necessarily in the course of it.

(2) Experimentally it should be possible to simulate the disease in animals by procedures comparable to those arising in the course of the occupation, or other appropriate means.

(3) Failure of experimental efforts need not preclude prescription of the disease. In certain cases it may be necessary to demonstrate the material concerned in the tissues, organs or secretions of the subject.

This, or something like it, might be sufficient if the world were peopled only with honest men and if the response of appropriate animals were similar to that of human beings.

The fact is, however, that we have to make judgments on the evidence before us in a given case. The dilemma is often very great.

The truth may be obvious to the clinical observer, but the experimentalist may be unable to help him. A great deal of work remains for investigators to do in this field.

CHROMIUM

Incidence

There is good reasonable suspicion that chromium compounds can lead to cancer of the respiratory tract, and various investigators had come to a conclusion of this kind. Gross and Alwens (1938) had found 39 cases of bronchogenic carcinoma among 2,000 workers in the German chromate industry.

By 1943 Gross and Koelsch had found 8 additional cases in the chrome colour industry.

It is instructive to tabulate the age incidence at death among these 47 cases:

Age Group	*Frequency*
21–30	1
31–40	6
41–50	10
51–60	19
61–70	11
	47

Although most of the cases were over 45 years of age at death, the numbers less than 40 years of age at death are, in our view, strongly in favour of an occupational factor being engaged. In this 1943 series the substances involved were lead and zinc chromates, and these authors were particularly impressed by the much greater solubility in water of zinc chromate compared with that of lead chromate. They suggest that zinc chromate dust may be a specially dangerous hazard to the lung.

Two cases of bronchogenic carcinoma in workers exposed to lead and zinc chromates were described by Letter Neidhardt and Klett (1944).

In their B.I.O.S. (British Intelligence Objective Subcommittee) report Weldon and his colleagues (1947) dealing with information obtained at the German chromate factories at Leverkusen and associated centres

(Bitterfeld, Griesheim and Uerdingen) stated that some 30–40 cases of lung cancer had occurred at these factories. It was the view of the senior industrial doctor at Leverkusen that the condition was very insidious and the induction period might be as long as 30 years.

In our own experience of lead chromate manufacture, we have never found a case of lung tumour among men who for many years prior to the institution of medical control had inhaled much chromate dust from which lead poisoning was not infrequent.

Suspicion of chrome cancer had been published in Britain as long ago as 1890 (Newman, 1890), but the tumour there described was a carcinoma of the anterior part of the nares and was attached to the inferior turbinate. Although in the vicinity of the perforated septum, which was present in this case and many others in the factory, there is no reason to suppose that the well-known chrome ulceration of the nasal septum is a possible precursor of epitheliomatous changes. Legge (1922) found no such changes in his observation of 175 cases of chrome ulceration.

More recently Machle and Gregorius (1949) have analysed the cases of death from cancer among about 1,445 employees in chromate-producing plants in the U.S.A. Among 193 deaths from all causes, 21·8 per cent were cancers of the respiratory tract, whereas among a control group of 733 deaths, only 1·4 per cent were cancers in this location. This and other suggestive evidence gives a strong presumption that in the chromate-producing industry there is a hazard of lung cancer. Baetjer (1950) confirmed these findings from a study of the records of two hospitals in a chrome-producing area in Baltimore.

In addition, this phenomenon cannot be found in plant handling only bichromates, and chromic acid (hexavalent Cr). The suggestion therefore is that the monochromates are the cause. The incidence of nasal perforation and chrome ulceration is sufficiently high to have expected adequate evidence of lung tumours in electroplating, dye-manufacture, manufacture of anthraquinone, the preparation of chromium catalysts and many other processes, as well as the manufacture of bichromates. But in Britain no such cases have been found. Such evidence outside Britain as there is tends towards the attribution of the condition to chromates. Hueper (1942) thinks that the chromium compound acts upon some naturally occurring compounds in the body with the production of the true carcinogen.

Bidstrup (1950, 1951) in 1949 carried out a radiographic survey of 724 workmen in the chromate-producing industry and found only 1 case of pulmonary carcinoma. By comparison of the data thus obtained with that of the incidence of lung growths at different ages among men in the general population in Great Britain, it appeared that the crude death rate among chromate workers was unlikely to be as high as 25 times the normal as appeared from the calculations of Machle and Gregorius. Calculating from the incidence of and death rate from pulmonary growths according to age

from the results of a mass radiography survey of the Ministry of Health, only 0·4 would be the expected incidence and death rate among the 724 workers studied by Bidstrup. It is thus evident that no clear conclusions could be drawn from the available size of sample.

Atmospheric concentration

The atmospheric contaminants in the factories studied were chromite ore ($FeO.Cr_2O_3$) sodium and calcium carbonates, monochromates and dichromates. Having regard to the conditions of manufacture Buckell and Harvey (1951) concluded that the moist air-borne contaminations would tend towards a prepondcrance of monochromates. These authors estimated the insoluble (Cr^{+3}) and soluble (Cr^{+6}) chromium in atmospheric samples at different points of the processes and found values over 2 milligrams per cm. *total* Cr ($Cr^{+3} : Cr^{+6} = 430 : 1$) at the initial stage of crushing the chromite ore with only a small proportion of soluble chromium compounds to about 0·9 mg./cm. ($Cr^{+3} : Cr^{+6} = 1 : 166$) and 0.5 mg./cm. ($Cr^{+3} : Cr^{+6} = 1 : 519$) at the end stages of the process when the conversion to soluble chromate was complete and drying and packing were carried out. Comparing their findings with those of Bourne and Yee (1950) for departmental chromium air concentrations in an American factory, manufacturing sodium dichromate, Buckell and Harvey make an error in giving the ratio of $Cr^{+3} : Cr^{+6}$ in the ore preparation as 6 : 1; it was in fact in the American factories about 50 : 1 at that point in the process and at the nearby lime and ash mixing with ore 12 : 1.

The conditions in the British factories appear on the whole to have been rather worse than in the American factory at the earlier stages as far as atmospheric concentrations of chromium were concerned.

It is not possible to draw any conclusions from the British work, but longer term observation, envisaged by Bidstrup, may lead to more clarity.

Carcinogenicity

In the meantime more evidence continues to appear of the carcinogenicity of chromate. Brinton, Frasier and Koren (1952) studied the morbidity and mortality data of sick benefit associations in the United States of America and found that the cancer rate for chromate workers was 7·1, whereas that for workers in other industries were 0·7 per cent. Indeed, the mortality from cancer of all sites among chromate workers was found to be 4½ times the expected incidence from the general population in the United States. With regard to respiratory cancer the actual incidence was 29 times that expected. The mortality from cancer in all other locations among chromate workers was no greater than that expected. Thus the high incidence of death from cancer of all sites was therefore due to the very high incidence of respiratory cancer.

A very comprehensive study of the health of workers in the chromate-

producing industry in the United States by a large team of workers, including the last-mentioned authors, has recently been issued as a Public Health Service Publication, No. 192, and contains an interesting suggestion as to the possible aetiology of the pulmonary cancer among chromate workers.

It is clear in this report that data previously published by Brinton, Frasier and Koren, 1952, are included. One table in the more recent publication includes the significant data from our present point of view: we present here this data in abstract form.

TABLE II

NUMBER OF DEATHS FROM CANCER OF THE RESPIRATORY SYSTEM (EXCLUDING THE LARYNX AMONG MALE MEMBERS OF SICK BENEFIT ORGANISATIONS IN 6 CHROMATE PRODUCING FACTORIES COMPARED WITH THE EXPECTED NUMBER BASED ON THE AVERAGE DEATH RATE FOR THE UNITED STATES, 1940–1948 INCLUSIVE (ABSTRACTED)

Age and colour group	Ratio of actual to expected number	No. of deaths		Annual number of deaths per 100,000 males	
		Actual	Expected*		
Total					
15–74 years –	28·9	26	0·9	470·8	16·7
15–44 years –	40·0	4	0·1	125·4	2·5
45–54 years –	30·0	12	0·4	850·5	25·8
55–74 years –	20·0	10	0·5	1,085·8	57·2
White males –	14·3	10	0·7		
Coloured males –	80·0	16	0·2		

* This is obtained by muluplying the appropriate person-years in the chromate plant by the average death rate for the U.S. for the 9 years 1940–1948 inclusive.

Turning now from the vital statistics of past years to the present condition of workers in the chromate industry, the authors turn to the data obtained from almost all possible clinical and laboratory examinations. Radiographic and clinical examination of 897 chromate workers revealed 10 cases considered to have bronchogenic carcinoma. This was confirmed by open operation in 5 cases, biopsy in 1 case, post-mortem in 1 case and bronchial washings in 1 case. One of the remaining two cases has died, and the other had manifest evidence of extension of the neoplasm and an accompanying anaemia (R.B.C. $1{\cdot}7 \times 10^6$).

The nature of the sectioned tumours was squamous cell carcinoma. Of the 10 cases 7 were white and 3 coloured. Ages varied from between 40 and 50 years in the coloured cases and from 53 to 62 years in the white cases. The induction period of the tumours varied from 8 to 39 years, 7 out of the 10 cases having perforated septa.

Processes and occupations

Since the interesting suggestion on aetiology made by these American investigators relates to a special feature of the chemical reactions involved in the manufacture of chromates and since the relation of this feature to

Diagnosis of asbestosis

While the methods of diagnosis follow those for the pneumoconioses in general—namely, occupational history and clinical and radiographic investigation—the relative value of these items is unusual and so merits comment.

Occupational history

Reference is made on page 107 to the authoritative contributions made to our knowledge of asbestosis by Merewether and others 20 years ago. At that time the industry was comparatively new, factory conditions were not good, and neither employers nor workers realized the dangers of the material and the processes. The type of workman was poor and the labour turn-over was heavy. The great majority of cases, when diagnosed, were in the advanced stages of the disease, and the symptoms, clinical signs and radiographic changes were correspondingly severe. Furthermore, by present standards the technical quality of x-ray films was unsatisfactory, with the result that radiographic interpretation was not always reliable. Meantime, conditions have substantially altered for the better, and patients present themselves for diagnosis at a much earlier stage—indeed, sometimes before the disease has had time to develop. Despite increased knowledge and experience of the disease and the higher standard of radiology, a firm diagnosis in the earliest stages is still often extremely difficult.

Another matter worthy of note is that, in the spinning, weaving and asbestos-mattress sections of the industry, the workers are predominantly females, but doctors outside the immediate locality of the factory seldom associate dust disease of the lungs with women, particularly young girls. This is further complicated by the fact that the disease may not become manifest until the woman has married and left work, and her occupation is then designated as "housewife". Pregnancy—especially in the later months—is sometimes the circumstance which aggravates any dyspnoea and leads to investigation of the cause. Furthermore, early radiographic changes in asbestosis are usually most marked in the lower halves of the lung fields, and the female breasts, when engorged in pregnancy and occasionally during menstruation, may obscure these changes when present, or simulate them when they do not exist.

However, by reason of the great publicity which the disease has attracted in the main centres of the industry, the workman usually announces the diagnosis to the doctor, who himself is equally aware of the local scourge. Nevertheless, even without this guidance, any doctor should be aware of the possibility, provided that he has investigated the occupational history in the manner described.

Clinical aspects of asbestosis

Dyspnoea is the single universal complaint, and it is all the more conspicuous because frequently it is quite out of proportion to the clinical signs

into textiles. The following are the special qualities of the material which make it of use in industry: (1) resistance to fire and heat, (2) low heat-conductivity, (3) high electrical resistance and (4) inertness to chemical action.

Varieties of asbestos

The several varieties of asbestos fall into two main groups: (1) chrysotile, or serpentine asbestos, and (2) amphibole asbestos, which includes (*a*) amosite, (*b*) crocidolite and (*c*) tremolite.

Chrysotile

Chrysotile asbestos, which constitutes 90 per cent of world production, is a hydrated magnesium silicate. The fibres are short (usually a fraction of an inch), very fine and of a silky sheen. Thetford (Quebec) is the chief source of supply; lesser quantities are obtained in Southern Rhodesia, the U.S.S.R., and elsewhere.

Amphibole

Amosite contains iron from which it derives a dirty brown colour. Deposits of this variety of asbestos occur almost entirely in South Africa. Normally the fibres are several inches long and of poor spinning quality. Accordingly, its main use is for the manufacture of heat-insulating blocks, and as a binding material in the composition used in the production of asbestos cement sheets, which are nowadays so extensively used in the fabrication of modern houses and other buildings.

Crocidolite, or blue asbestos, occurs mainly in the Cape Province of South Africa, and in the industry it is usually designated "Cape Blue". It is extensively used when resistance to chemical action is required.

Tremolite asbestos is obtained from Italy. It is white and the fibres may exceed a yard in length. Because of undue brittleness, it is not suitable for the manufacture of cloth, and so is chiefly employed for insulation purposes, such as the lagging of boilers and steam pipes.

Mining and manufacture of asbestos

Mining

The mineral is obtained either in open quarries or in shallow mines, and the normal operations are drilling, blasting, breaking and sorting. When freed from waste rock, the asbestos is dried and successively crushed to a fine powder. Foreign matter is removed by screening, and particles of iron are extracted by passing the material over powerful electric magnets. The crude fibre is then graded according to length of fibre, and is packed for despatch to the manufactories.

Manufacture

Asbestos textile manufacture is similar to that of other fibres, such as

Pathology and morbid anatomy of asbestosis

In crushing operations, fiberizing and disintegrating, in opening, spinning, weaving and the filling of asbestos mattresses, production of fine thistledown dust occurs. This consists of fine needles or spicules of asbestos, which are inhaled by the workmen. Most of the dust inhaled never reaches the lungs, but is arrested in the upper respiratory tract and trachea, from which it is rejected in the nasal mucus and sputum. Whereas only the minute particles of silica gain entrance and are retained within the lungs, much larger particles of asbestos, when inhaled, because of their physical form, are mechanically trapped. Fibres up to 200 microns have been detected in the air passages, but dangerous fibres measure up to 20 microns. In the lung no local necrosis results, nor is there any leucocytic reaction. As a result of mechanical irritation the pulmonary epithelial cells are desquamated, and fibroblasts appear round bronchioles and alveoli, in interlobular septa and in the subpleural tissue. Finally, collagenous fibres appear around the distal ramifications of the bronchial tree.

Gardner and Cummings (1931) have shown, by animal-inoculation experiments, that the chief site of asbestos-dust localization is the respiratory bronchiole.

They describe the early lesion, in the guinea-pig exposed to inhalation of asbestos dust, as follows:

> "The asbestos dust . . . is carried by the inspired air only to the distal respiratory bronchioles. . . . The mononuclear phagocytes from the adjacent connective tissues enter the lumen of the air passages and engulf the particles. The phagocytes with their contained fragments of dust are frequently pushed aside into the alveoli which pouch out of the sides of the bronchioles, where many of them remain indefinitely. More dust entering the lung is held up by the partial obstruction created, and further reaction is largely proximal to the point of original localization."

At 60 days the authors describe the dust-cells of the terminal bronchioles as being increased, and the lumina of some of the lateral alveoli completely blocked with mononuclear phagocytes and giant cells. At the end of 2 months small asbestosis bodies appear. After 90 days' exposure it was found that the amount of cellular reaction had not kept pace with the number and size of the asbestosis bodies. Hyperplasia of the lymphoid tissues was now visible. At the end of a year the walls of the bronchioles proximal to the alveolar ducts were thickened from excessive local accumulation of phagocytes, but definite proliferation of fibroblasts was not noted until after 550 days. This was confined to the walls of the air spaces adjacent to the deposits of dust phagocytes. At the end of a further 100 days a true fibrosis developed, contracting the air spaces, which now appeared to be filled with compact masses of dust cells and phagocytes, fibres and bodies. After 2 years the mischief had reached the periphery of the lung, and sub-pleural greyish-white nodules were uniformly distributed over the surface.

King, Clegg and Rae (1946) have recorded the results of experiments in rabbits exposed to the intratracheal injection of asbestos fibres of varying length. In

as blue-black polygonal areas ⅛–¼ inch in diameter. These are distributed over the whole of the cut surface, but are most evident in the lower lobes. This may be due to confluence or simply to the greater bulk of the base of the lung. Anatomically it will be observed that these polygonal fibrosed areas conform to the size and shape of the pulmonary lobules, which they have, in fact, replaced.

All these changes may be considerably modified according to the terminal illness: broncho-pneumonia, tuberculosis, bronchial carcinoma or congestive heart failure.

Other organs do not show any characteristic changes: they are not involved in the disease save indirectly and in relation to complications and sequelae

Microscopical appearances

Asbestos fibres (natural and altered), plugs of mucus and desquamated epithelium may be observed in the main air-passages. In the terminal bronchioles and alveolar ducts, these changes are more advanced and associated with the presence of large mononuclear phagocytes. The alveoli and lymphatic vessels are blocked with dust and phagocytes. Connective tissue surrounds the bronchioles, alveolar ducts, air-sacs and blood vessels, and penetrates into the interlobular septa and beneath the pleura. In the most advanced stage, all appearances of lung structure are obliterated by fibrous tissue.

The asbestosis body

Curious bodies in the lungs were first described by Stuart McDonald in 1927. They are now recognized as a feature of exposure to the inhalation of asbestos fibres, and they have been identified in the lungs, pleura, sputum and faeces. It is now accepted that they are formed from the original fibre by the following process:

(1) deposition of some material around the fibre so as to thicken it; (2) fissure or cracking of this material giving rise to the appearance of segments; (3) fragmentation, or the separating off from the asbestosis body of fractured portions of the deposited material. Gloyne (1932) summarizes the variety of appearances as follows.

(1) Marked variation in length (24–60 microns) and breadth (12–24 μ). Gardner and Cummings (1931) record their being as long as 250 μ in experimental animals. The short forms are sometimes seen within phagocytes.

(2) Golden yellow colour: Gardner and Cummings have pointed out the resemblance of this colour to the haemosiderin deposits found in areas of tissue in which haemorrhage has occurred.

(3) Homogeneous structure when viewed by ordinary transmitted light.

(4) By cutting down the light, a suggestion of a central fibre can often be seen. This fibre may also sometimes be seen projecting beyond the body.

(5) No differentiation with polarized light.

(6) Tendency to be arranged in irregular clumps and clusters.

cotton, wool and flax. First the fibres are opened in a Crighton machine, then follow in succession carding, spinning and weaving. All these operations, unless carefully controlled, produce considerable amounts of fine thistledown dust, which is wafted far and wide throughout the factory premises and even into neighbouring buildings, including adjacent offices. Water, or even wetting agents, so useful in the control of dust, are of no value because asbestos is practically unwettable.

The cloth is used for the manufacture of fire-protective clothing: suits, helmets and gloves, and safety curtains. It is sewn into covers which, when filled with crude fibre, form mattresses or pads for the insulation of heating boilers, tanks and pipes. In the form of tape, it is very easy of application for the protection of domestic pipes against either frost or heat loss. Bonded with bitumen it is moulded into slabs for use as panelling, or cut and shaped into brake-linings, gaskets and other forms of packing for machines. In the manufacture of cement roofing-tiles, flat or corrugated sheeting, rain-pipes and other building materials, asbestos is introduced into the "mix" as a binder. During World War II, small quantities were incorporated into the cotton-wool filters of gas-masks.

Waste asbestos boarding is often crushed and used as a filler in paint manufacture. The importance of this reference is that very frequently the workmen in these processes do not know the danger, which is aggravated by an almost entire lack of safety precautions.

The main centres of asbestos textile manufacture in Great Britain are at Rochdale, Leeds, Cleckheaton, Barking and Glasgow.

History of asbestosis

In 1906, Montague Murray reported the case of an asbestos-worker, who had died in the Charing Cross Hospital in 1900 of "typical fibroid phthisis". The man, a card-room worker aged 34 years, had stated that 10 of his work-mates had died at about the age of 30 years. Sporadic cases continued to be recorded, and finally in 1928 Seiler reported on a case, which seemed definitely to establish the relationship between the inhalation of asbestos dust and disabling and fatal pulmonary fibrosis.

Therefore the Home Office instituted an official inquiry into the asbestos manufacturing industries throughout Great Britain, and the report by Merewether and Price remains the authoritative account of the disease. (*See* Merewether, 1930.) The occupational origin was proved, and accordingly asbestosis was recognized as a compensatable disease under the Workmen's Compensation (Silicosis and Asbestosis) Act of 1930. In addition all workmen employed in certain scheduled occupations were required to pass an initial examination, and thereafter, at yearly intervals—since extended to 2 years—to submit to periodical medical examination. Any workman found at such examination to be suffering from asbestosis was immediately suspended permanently from all further work in the processes.

in the lungs. Considerable emphasis has often been laid on the showers of persistent fine crepitations, which are particularly audible over the bases of the lungs. These adventitious sounds are intrapulmonary, but they do not necessarily indicate disease, for they can be detected within a few weeks of commencing work and without any accompanying departure from health. The most probable explanation of their occurrence is that they are due to obstruction of the bronchioles by asbestos fibres, and this is supported by the simultaneous appearance of altered fibres in the sputum. The presence of true asbestosis bodies in the sputum is not diagnostic of the disease; these bodies merely indicate that asbestos fibres have been inhaled and retained sufficiently long in the lung to acquire the characteristic changes. Stewart (1933), however, has expressed the opinion that clumps of fibres may denote disease associated with breaking-down of lung tissue. This observation is analogous to the occurrence of elastic tissue in the sputum in tuberculosis, and of persistent "black spit" in the late stages of massive fibrosis in silicosis and pneumoconiosis of coal-workers.

In advanced cases all the clinical signs of lung fibrosis may be detected, and they are usually associated with evidence of cardiac distress. Apart from dyspnoea, two features are impressive: (1) an earthy cyanosis and (2) the sudden appearance of an extraordinary degree of drum-stick clubbing

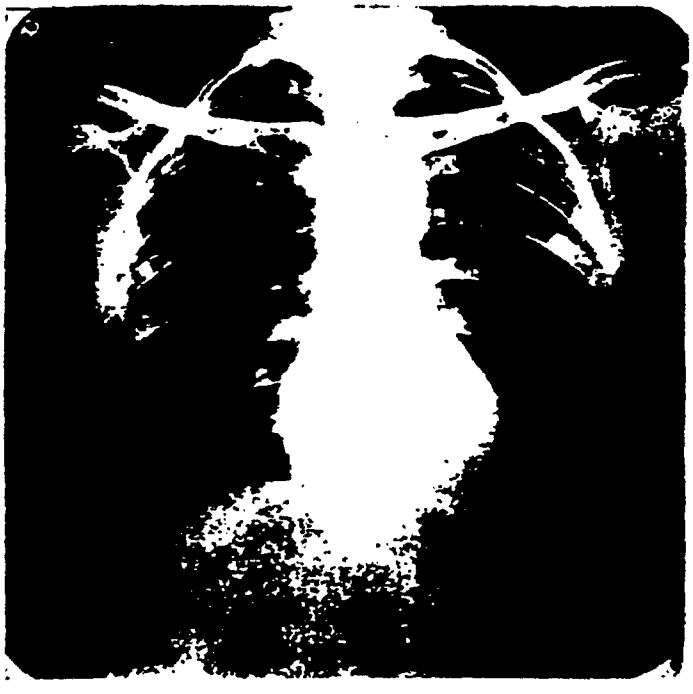


FIG. 22.—Normal chest radiograph. Female, aged 24 years: married. Note obscuration of basal lung fields by heavy breast shadows.

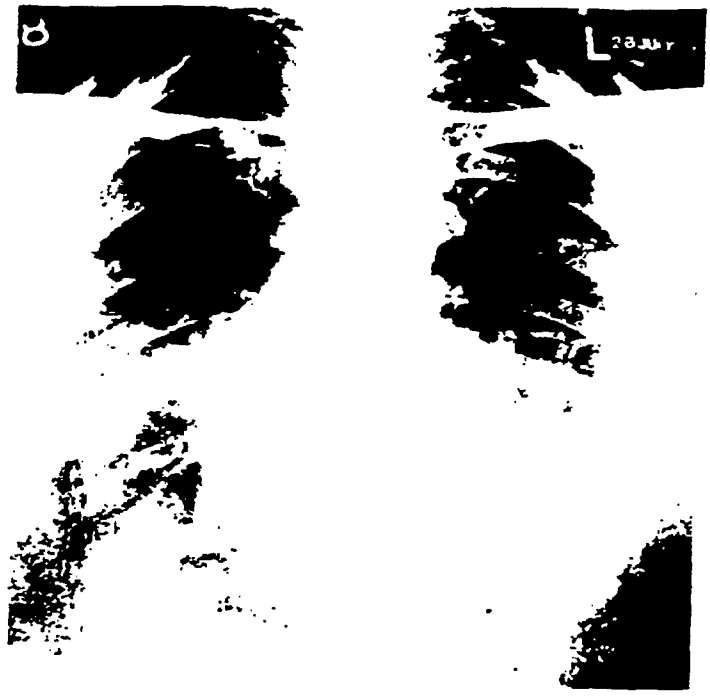


FIG. 23.—Male aged 49 years (1953). 1926–38, asbestos millboard cutter; 1938–43, timekeeper and gatekeeper; 1943 *et seq.*, despatch clerk. Typical radiographic appearances of advanced asbestosis; clubbing of fingers (*see* Fig. 13). At present working regularly. (*By courtesy of Dr. H. Wyers.*)

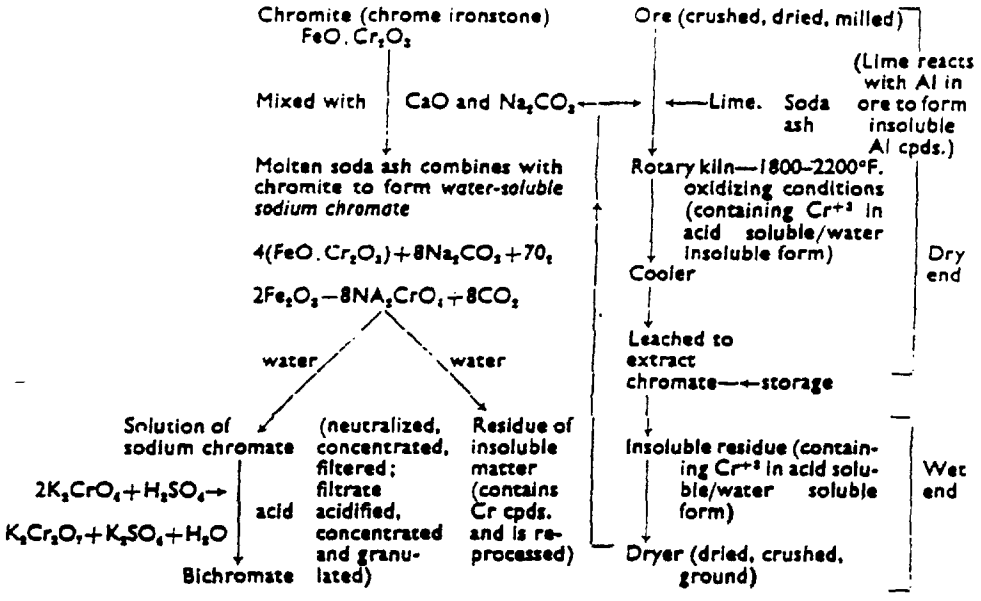
of the fingers and sometimes of the toes. Out of Wyers' series of 53 consecutive cases, clubbing of the fingers was present in 29 cases (Wyers, 1949).

Complications of asbestosis.—Pulmonary tuberculosis occurs as a complication, but there does not seem to be the same close relationship to asbestosis as exists in silicosis. An excess mortality from cancer of the lung and other organs has been recorded by several observers. Wyers, the medical officer to a large asbestos manufacturing company, stated in 1949 (*see* Table V) that he had collected details of 115 deaths from asbestosis, and that of these cases 11 males and 6 females showed pulmonary cancer, whilst cancer of other organs was present in 3 males and 4 females (in the pancreas, colon, stomach and ovary). Despite the frequency of clubbing of the fingers, frank infective bronchiectasis is unusual. Congestive heart failure and bronchopneumonia are common terminal conditions.

Radiological appearances in asbestosis

Often the first fact which impresses the reader is the smallness of the chest, as if the lungs were shrunken from apex to base. The next feature is a general haziness of the lung fields: this has been described as veiling or a

particular jobs in the process can be recognized, the following schematic representation of the American (and German) basic chemical processes is given:



Operatives with lung tumours; their function and location

Although it is unlikely, as with all unskilled chemical labourers, that functions are sharply divided, it is useful to see if the principal operation carried out by the workers in whom lung tumours had been diagnosed had any common feature. The following data indicate broadly the nature of the work carried out for years by these workers.

			Yrs. in industry
Case 1			
1929–31	Lime-mill operator	Dry end	21
1931–33	Handling drums of dichromate and chromate	Wet end	
1933–	Granulator-soda operator	Dry end	
Case 2			
1932–34	Washer: crystalline sodium dichromate	Wet end	18
1934–39	Packer: crystalline sodium dichromate	Wet end	
1939–45	Boiler operator: crystalline sodium dichromate	Wet end	
1945–	Cooker and helper: chromic acid department		

animals treated with long fibres (15 microns) a nodular reticulinosis developed, comparable with the experimental silicotic nodule, whereas in animals treated with short fibres (2–5 microns) a diffuse reticulinosis appeared. The addition of powdered aluminium did not afford any benefit in either group.

Post-mortem appearances

Macroscopical findings

The morbid appearances to the naked eye are very similar to those described above for silicosis (*see* p. 23). No specific change occurs in the air passages. The pleural changes, however, are more marked than in any other variety of pneumoconiosis. Generally the pleura is everywhere thickened, and in advanced long-standing cases the lungs appear encased in a glistening yellow sheath like a plastic material. All over the pleura is puckered and raised in folds, and it insinuates itself universally into fissures and sulci. Not infrequently the whole space between the visceral and parietal pleura is completely obliterated by massive tough sessile adhesions. These changes, as is shown on page 115, dominate the radiographic appearances.

The asbestosis lung is firm and airless, and when it is cut with a knife the fibrotic character is immediately apparent. The characteristic lesion presents

FIG. 19.—Female aged 35 years. Asbestos spinner 5 years. Post-mortem section of lung showing blue-black polygonal areas of asbestosis and thickened pleura. At the lower pole a squamous carcinoma surrounds an abscess cavity. (*By courtesy of Dr. H. Wyers.*)

ground-glass appearance. While there is no orderly progression of changes, the next stage is characterized by fine mottling or stippling, localized or general, and particularly conspicuous in the lower halves of the lung fields. This mottling may later become coarser, thus producing a granular pattern. Thereafter the whole picture is dominated by the sclerotic pleurisy described on page 109. The costo-phrenic and cardio-phrenic angles are obscured, and the outlines of the cupolae of the diaphragm and of the cardiac shadow appear shaggy, because of opacities, which, as so aptly described by Wyers, resemble teased-out cotton-wool. In some cases a very characteristic appearance is presented by the horizontal fissure, which is thickened and presents a lenticular rather than a fine linear shadow. It is also often considerably depressed in level, especially laterally, so that instead of appearing horizontal it is oblique, with the convexity directed upwards and outwards.

Differential diagnosis

It cannot be said that the condition requires to be differentiated from any other condition. If the investigation follows the routine which is outlined, almost complete accuracy should be achieved. It may be said, however, that, in the early diagnosis of asbestosis, as a supplement to the occupational history, the clinical features are a more reliable guide than radiographic changes and, indeed, often precede them.

Incidence of asbestosis

In Great Britain the risk of contracting the disease occurs in the asbestos manufacturing industries, and to a small extent in heat-insulation work, pipe and boiler covering (lagging) and the other incidental processes, such as stripping the old composition. The risk varies, of course, with the dustiness of the process and, in the absence of efficient dust suppressing and collecting devices, the most dusty operations are (1) preparatory processes of crushing, opening, sieving, mixing and blending, (2) sack filling and emptying and all handling of loose asbestos, (3) carding and card cleaning and grinding, (4) cloth weaving, (5) mattress making, and (6) cleaning dust settling or filtering chambers. In recent years considerable advances have been made in controlling the dust at the source of production. Thus, whereas in 1929 cases were identified after 7 years' exposure—some even after a much shorter period—the corresponding figure now is 10 years.

Prevention

There is no specific method of prevention, except the suppression and control of dust. In this connexion as long ago as 1930, the Asbestos Industry collaborated wholeheartedly with the Factory Department (then of the Home Office and now of the Ministry of Labour and National Service) in devising methods of localized exhaust ventilation for application to operations and machines (for example, cloth looms), the necessity for which had never been

Over 80,000 persons (including about 8,000 females) are employed in clay getting and brick manufacture, but the occupations are not regarded as a source of disabling pneumoconiosis.

Fire-clays

Fire-clays occur abundantly in Great Britain, chiefly in the coal-measures underlying the coal-seams. Again they are hydrated silicates of alumina, but have a higher silica content (65 per cent) than have ordinary brick clays, and often contain pockets of free silica. Flint may be added in the manufacture of refractory bricks. Their chief quality is refractoriness to high temperatures, and this makes them especially valuable in the manufacture of melting-pots for glass-making, for crucibles used in melting metals and refining steel, and for fire-bricks used in the lining of furnaces.

Silicosis occurs among workmen engaged in the demolition and repair of furnaces, gas-retorts, melting-pots and crucibles (Deaner, 1941). These operations are very dusty, and this feature is aggravated by the fact that the work must be carried out in a very enclosed space in which the workman cannot protect himself. Such workmen at steel-works and gas-works are usually classified as brick-layers or labourers, which again emphasizes the importance for the doctor of discovering accurately the precise details of the occupation in which the workman is employed.

Shales

Allied to clays are shales, which are impure silicates of alumina, and are characterized by their greater hardness, due to heat and pressure, and their laminated fissile structure. They occur abundantly in certain coal-measures. In central Scotland extensive deposits of oil-bearing shales occur and are mined for the extraction of mineral oils. A few cases of simple pneumoconiosis have been observed among these miners, but only of very slight degree, occasioning little or no disability, and seen usually in men over the age of 60 years. Pneumoconiosis cannot be regarded as a serious risk of this occupational group. The significant fact, however, is that hitherto the mining has been almost entirely by manual methods, but that recently mechanized methods have been introduced, with the result that the amount of air-borne dust has been considerably increased. If mechanization is to be extended then due regard must be paid to control of the production of dust.

CONCLUSIONS

Many more sources of sporadic cases of pneumoconiosis exist and are recorded in the literature. Indeed, among occupational diseases the dust diseases of the lungs constitute the problem of the age. Towards mitigation of the disease in individual patients, (1) early diagnosis and (2) resettlement, when necessary, in suitable alternative employment are paramount. These

In this residue there are compounds which derive from the replacement of the iron in chromite by sodium or magnesium or by calcium when lime is used. Such compounds are acid soluble but water insoluble. Almost the whole of these compounds hold their Cr in the trivalent state and are present in the roast and in the residue after leaching up to nearly 3 per cent but are, of course, absent from the chromite ore.

These compounds are stated to be " far less inert than the original ore ", but it must be confessed that the precise meaning to be attached to the words " less inert " is not clear. On the grounds, however, that such compounds are not mainly at the dry end of the chromate process and in the re-processed residues, and that most of the positive cases had prolonged exposure to those parts of the process (waste and residue) where the acid soluble/water soluble compounds would be expected, it is proposed that they are more likely to be related to the carcinogenic effect. In respect of the other main source of trivalent chromium, chromite, it is pointed out that there were no cases among men exposed only to chromite ore in high concentration.

The universal exposure of all workers in these processes to hexavalent chromium is held to exonerate this form (that is chromates, dichromates) as the effective carcinogen, but the possibility of metabolic reduction to trivalent forms still remains. However, the failure to induce tumours with hexavalent chromium in any species militates against the force of this argument.

The situation as seen by the American investigators is that there can be no doubt about the carcinogenic hazard in the chromate-producing industry, that there is some indication that the carcinogen is trivalent chromium in the form of acid soluble/water insoluble compounds (alkali metal substituents of chrome ironstone or calcium chromate—chromite complexes) which are quite distinct from monochromates and dichromates (water soluble) and chromite ($FeO.Cr_2O_3$) which is water and acid insoluble.

Moreover, the suspected form of chromium being less inert than chromite and less soluble than monochromate and dichromate, the presumption is that its physical and chemical properties lend something to its potency.

Analysis for the atmospheric concentrations of the various forms of chromium indicates that the highest mean exposures to the acid soluble/water insoluble form occur at the dry end of the process and especially where residues and roast are handled (mill room labourers, mix operators (residue), residue mill operators).

Non-employment of residues

Some weight may, according to the American investigators, be attached to the fact that in the British factories, the residues from the leaching tanks (rich in acid soluble/water insoluble chromium complexes) are not reprocessed but removed whilst moist and dumped outside the factory. Workers in the British factories are thus much less exposed to the

suspected form of chromium and chrome cancer of the lung has not been reported in spite of similar or even higher concentrations of Cr^{+3} or Cr^{+6} in the working environment.

The development of a lung tumour in circumstances less complex is of value in the possible elucidation of aetiology. In the relatively much less complicated conditions of chromium plating in which the chromium trioxide (CrO_3) is dissolved in dilute sulphuric acid, the hazard lies in hexavalent chromium compounds, and it is noteworthy that lung cancer is not a feature of the industry. Such chromium compounds as reach the lung tissue from spray dissemination in the working environment are quickly dissolved and absorbed, although there is considerable temporary histiocytic lung response.

Elektron polishing

A recent case described by Asang (1952) is more than a little suggestive of trivalent chromium as the carcinogen in the development of a lung tumour after chronic damage to the lung. Here a worker (non-smoker) had been engaged for 10 years as a polisher of Elektron metal (magnesium alloy with small quantities of aluminium, zinc, silicon and manganese) objects. Casters with this alloy are known to complain of irritation of the upper respiratory mucous membranes, but in the case of this man it was held that SO_2 (liberated in the special casting process) was responsible for his chronic bronchitis. Perforation of the nasal septum developed and was due to the fact that the metal objects were dipped in an alkaline dichromate bath, thus providing the articles with a coating of aluminium and magnesium chromate ($Na_2Cr_2O_7 + 2NaOH \longrightarrow 2Na_2CrO_4 + H_2O$). The polishing operations led to the liberation of a chromate-containing Elektron dust which was constantly inhaled by the workmen. Seven years after leaving this work he again developed a severe productive cough with fever, and x-ray examination showed an extensive, dense, homogeneous shadow in the right hilus region. The presence of a tumour of the lung was confirmed by tomography, bronchography, bronchoscopy and biopsy; the last mentioned showed the early stages of carcinomatous changes without significant infiltration, but with extensive chronic inflammatory reaction. Extirpation of the right lung followed and histology showed a small, well vascularized, papillomatous tumour of the bronchial mucous membrane—probably early carcinoma. The bronchial wall adjacent to the tumour showed massive inflammatory infiltration with ulcerated mucous membrane, and the bronchial twigs distal to the stenosed area showed epithelial proliferation and squamous epithelial metaplasia. In the regions surrounding the hilus were many foreign body granulomata rich in macrophages. The intense foreign body reaction so long after having left the polishing work and the easy demonstration spectrographically of chromium and magnesium (8–10 milligrams of chromium) in the ashed lung point clearly to long retention of insoluble chromates (very slow microchemical transformation to and elimination of soluble forms) and probably

also reduction to trivalent chromium compounds. Lung injuries or tumours associated with Elektron dust have not so far been reported.

If, as seems likely (although not explicitly stated) sulphur or sulphur compounds were used in the casting of the Elektron, the conditions were well set to reduce the alkaline dichromate later used on the alloy to trivalent chromium in the heat of mecnanical polishing.

The mere presence in the lung of inert material is not, in general, likely to be followed by the development of neoplasms, although the case of asbestos is apparently anomalous in this respect.

The nature of the activity required in order to produce a tumour is, of course, unknown, but the inference from the data in the chromate industry, in the electroplating industry and now in the alkaline dichromate treatment of Elektron alloy all seem to point to a derivative of trivalent chromium.

It must rest with more investigation to prepare the carcinogenic compound and to demonstrate its potency as dust in exposed animals.

ARSENIC

As in the case of chromium, a satisfactory experimental basis is lacking also in the case of arsenic. There is no doubt that, clinically, arsenic in one form or another can be followed by the development of tumours, for example after long medication with arsenical preparations (psoriasis); after long occupation with arsenical sheep dips (arsenite); in the extraction of arsenious oxide from ores; in the use of arsenic as preservatives; in glass manufacture for decolorizing the glass; in smelting operations; in the horticultural use of lead and calcium arsenate; and in the preparation of certain pigments.

Cancers of the skin, lungs and ethmoids, have all been attributed to arsenic in appropriate circumstances (Nieberle, 1939; Amor, 1939; Goldblatt, 1950). The commonest recorded cases attributable to arsenic are skin cancers.

Hueper (1942) in reference to arsenical lung tumours says: " It appears fair to state under the existing circumstances that the possibility of a causal relation between the inhalation of arsenic dust and the development of pulmonary malignancy may be conceded, but the probability of such a relationship is small ". This statement is an expression of the fact that in spite of the exposure of very great numbers of persons to the hazard, surprisingly few cases have in proportion to them been described.

Currie (1947) is very dubious in spite of his experience of cases arising in men exposed to arsenical dust and to arsenical insecticides. Thus, he describes a case of a columnar cell adenocarcinoma in the right lung with areas of lesser differentiation, some metaplasia and necrosis in a man aged 55 years who had been exposed to arsenical dust for 43 years. The neoplasm had extended round the subclavian vessels and involved the pleura. He suggests that arsenic may induce cellular changes which give rise to endogenous carcinogens: derivatives of melanin, suggested by the marked

In the case of the phosphoamidase described by Gomori, the substrate is entirely synthetic, N(*p*-chlorphenyl)-amino phosphoric acid, the enzyme is a hydrolase with a *p*H optimum well on the acid side at 4·6 and a temperature optimum of about 40°C. (Holter and Si-Oh-Li 1949) yielding phosphoric acid and *p*-chloraniline. By treating histological sections with buffered substrate and a lead salt, the location of the active enzyme can be demonstrated by the subsequent transformation of the precipitated lead phosphate into black sulphide with dilute ammonium sulphide. This, the basis of Gomori's method, and the more conventional methods of Holter and Si-Oh-Li leave no doubt that this peculiar enzyme is widely distributed in the tissues in small amounts, but the interesting claim is made by Gomori that large amounts are demonstrable in the grey matter of the central nervous system and in malignant epithelial tissues. Study of seventy different malignant tumours indicated the presence of this enzyme activity which appeared to vary in parallel with the malignancy of the cells (Gomori, 1949).

Having confirmed Gomori's work, Ebner and Streker (1951) proceeded to attempt its application to cytological material and, in particular, to vaginal smears, with the object of recognizing malignant cells without further staining methods. These workers found that the time of incubation of the cell smears (and indeed histological preparation) was a determinant in distinguishing the nuclei of normal from those of malignant cells. Six hours' incubation with the substrate is sufficient for the malignant nuclei to give a strong reaction, whereas after this time normal nuclei are not sufficiently potent to be recognizable. The significance of these results is that an enzyme with no apparent physiological substrate should be more manifest in cancer cells than in normal cells. To put these observations on a rational basis it will be necessary to pursue the recognition and isolation of —N—P≡ compounds in normal and malignant tissues. No doubt the relation between these elements and arsenic will not be overlooked.

NICKEL

Since some measure of controversy attaches to the probable cause of the tumours of the nose, nasal sinuses and lung which have been described in the nickel refining industry, and since the earliest theory rests upon a characteristic of a particular process, we may give a brief account of the two principal processes in use.

The ore from which nickel is most commonly extracted is the sulphide ore from Sudbury, Ontario, Canada, which consists mainly of three minerals: pentlandite (NiFe)S, chalcopyrite ($CuFeS_2$), and pyrrhotite (Fe_6S_8), but gold, silver and platinum are also extracted from the concentrated residues. This ore contains about 2·5 per cent nickel pentlandite, and the first process for nickel production is to concentrate the nickel-rich mineral by separating it from the nickel-poor minerals.

Stage 1

The ore is crushed and ground very finely. This breaks up aggregates and the different minerals are now free and separated from one another. The minerals can be in part sorted by magnetic separators, and further concentrated by differential flotation.

Stage 2

Differential flotation. The ground material is passed into prepared water, agitated and vigorously aerated, the water having in it calculated small amounts of flotation reagents.

The principle of flotation is to produce a film on the particles of the mineral to be separated so that they will stick to and be carried up by air bubbles which are produced by means of frothing agents, agitation and aeration. Flotation is a method of preferential wetting. Flotation agents include:

Frothing agents: pine oil, cresylic acid, amyl alcohol, eucalyptus oil, tar oil, petroleum oil.

Filming agents: oleic acid, potassium ethyl xanthate, sodium diethyl dithiophosphate, amines, phenols.

Controlling agents: soda ash, lime, copper sulphate, sodium cyanide, by the judicious use of which the degree of filming of a particular mineral can be gauged to a nicety.

The desired mineral particles are carried up into the froth layer and can be skimmed off, the undesired particles remaining suspended in the body of the water.

Stage 3

The fraction rich in nickel, but still containing a good deal of copper and iron sulphide, is smelted in a reverberatory furnace. (This is a furnace in which the product to be smelted is spread on a hearth and heated by heat reflected from an arch roof over the hearth.) The effect of this is to convert the iron into iron oxide, a process which is completed by blowing in a bessemer converter (oxidizing conditions) when the elimination of the iron as a slag is almost completed, leaving as a separated mass a coarse *matte* consisting of 75 per cent (copper plus nickel). (*Matte* is a French word signifying a metal which has undergone only a single smelting—used in the sense of " coarse metal " in the smelting industry.)

The order of composition of the *matte* may be 50–55 per cent nickel, 25–30 per cent copper, 0·1–5 per cent iron and 14–17 per cent sulphur.

The further processing of the *matte* of copper and nickel sulphides may be carried out by one of two methods—the Orford (sodium sulphide process) or the Mond (nickel carbonyl process)—the latter being commonly applied to a later stage product of the former process.

Orford process

(1) Cu—Ni sulphide *matte* is fused in a small blast furnace with sodium sulphate, sodium hydrogen sulphate and with coke (reducing agent) as fuel.

Na_2SO_4, $NaHSO_4$ $\longrightarrow$ Na_2S and CO burnt away to CO_2.

The fused sodium sulphide " dissolves " the fused Cu and Ni sulphides.

(2) On cooling the melt of mixed sulphides, two layers are formed:

(*a*) top layer contains most of the Cu and a little Ni.
(*b*) bottom layer contains most of the Ni and some Cu.

(*a*) returned to blast operation to remove more copper

(*b*) Ni-rich second bottom layer to refining by Orford or Mond process

At this point we must note that 30 or more years ago the method used in Great Britain for the removal of copper from the copper-nickel sulphide *matte* was by leaching the roasted *matte* (oxidation) with sulphuric acid containing some copper sulphate, and there is every reason to believe that the sulphuric acid of that time in Great Britain contained a great deal of arsenious oxide and arsenic acid. Ordinary commercial sulphuric acid of specific gravity 1·7 might contain 3·18 g As_2O_3 and 2·56 g As_2O_5 per litre (Chemical Trade Journal, 1906). Since removal of the copper by this method would still leave the residual nickel and other metals contaminated with copper-arsenic compounds, there was no doubt that in subsequent processes of drying, grinding and calcining, which is essential for the carbonyl process, an enormous amount of arsenical dust must have been evolved.

It was this arsenical dust which in one way or another was regarded as the effective agent in producing the neoplasms of nose, ethmoid sinuses and lungs, and there seemed much to justify such a view (Amor, 1938).

If, however, the Orford process is used the copper is removed as described above, and the Mond carbonyl refining process can be applied to the copper-free *matte* without using sulphuric acid. But in the modern manufacture of sulphuric acid by the contact process in which the catalyst is sensitive to arsenic (among other elements), the sulphur dioxide must be thoroughly scrubbed free from arsenical compounds, and it is probable that a risk from arsenical tumours can no longer be valid, provided contact acid is used.*

* Sulphuric acid, except that made by the Pt-contact method, is seldom, if ever, free from arsenic.

We will assume, therefore, in the next stage, that the hazard of arsenic need not be considered in modern times.

In the *Orford process* the next procedures are straightforward and include crushing and grinding the nickel-rich bottoms; removal of Na_2S by water; leaching the residue with dilute sulphuric acid to remove iron; washing and drying the residue; sintering, crushing and fusing in a reverberatory furnace with low-ash coal to reduce to nickel and cast into anodes; finally electrolysing to purify and recover the nickel as a cathode slime.

In the *Mond process*, the impure nickel oxide is reduced to metal in a cast-iron furnace with hollow hearths heated to 300–350°C. by passing water gas ($H_2 + CO$) through it in a direction opposite to that of the entering nickel oxide. The finely divided nickel is passed into a furnace at 75–90°C. and there meets the carbon monoxide-rich water gas remains, forming volatile $Ni(CO)_4$. This gas, nickel carbonyl, is passed over nickel shot at about 150–180°C. : at this temperature the carbon monoxide is liberated from the carbonyl and the nickel is deposited. The carbon monoxide released is recirculated to be used again in the process. The nickel thus obtained is very pure but can be further refined by electro-deposition from nickel ammonium sulphate using a cast-nickel block as anode and plating a polished sheet cathode of pure nickel.

The official inclusion of nickel as an industrial carcinogen in Britain is clearly expressed in the list of Prescribed Diseases. The disease is described as (1) carcinoma of the mucous membrane of the nose or associated air-sinuses, and (2) primary carcinoma of a bronchus or of a lung, and the nature of the carcinogen as *nickel produced by decomposition of a gaseous nickel compound.* The basis of this prescription rests upon data reported in the Annual Reports of the Chief Inspector of Factories which is tabled below:

TABLE III

NOTIFIED CASES OF NICKEL CANCER

Period	No. of cases of cancer of nose	Average induction time, years	No. of cases of cancer of lung	Average induction time, years	
1923–48 –	47 (46)	23	82 (72)	25	All reported from one nickel works. Deaths in brackets.
1948–50 –	5 (3)		11 (18)		All reported from same nickel works.
	52 (49)		93 (90)		
1929–30 –	—		(3)		Discovery from death registers in the region.

In his Annual Report for 1950 the Chief Inspector refers to the unremitting but unrewarding efforts for many years to identify the carcinogenic agent and tentatively suggests that it is present in the factory dust and that its

effects probably lie dormant for long periods. Thinking of the long induction period he suggests that the biochemical changes associated with advancing years may evoke further changes in the already tainted cells. He emphasizes that the very great rarity of cancer of the nose in the general population renders this condition a very sensitive index of a specific carcinogen in this industry.

It is clear from the formula of prescription that the official view is that these tumours are produced by nickel when respired in some specially active or finely divided form characteristic of its liberation from $Ni(CO)_4$. This is not an indictment of nickel in general as a carcinogen, for there is no evidence that it is active in this way in its usual uses and applications. Finely divided nickel has chemical activities not possessed by the compact metal, for example it can absorb gases, it can catalyse hydrogenation reactions, and is readily and spontaneously oxidized in air. But there was still the dilemma that there had been no cases of malignant disease reported from other nickel refineries in other parts of the world (Canada, Germany, America) and attributed to occupational factors. This fact probably led to the official limitation to a "gaseous compound of nickel" because the Mond process is predominantly used only in Great Britain.

However, evidence which confuses the issue further has appeared from Norway where Løken (1950) has reported three cases of cancer of the left lung among workers refining nickel, but apparently not by the carbonyl process.* All of these successfully pneumonectomized cases were squamous cell bronchogenic carcinoma, but one of them was complicated by other changes: some typical of Boeck's sarcoid, others of local fibrosis and here and there asbestosis bodies were seen. In this interesting, if confusing, case of a man of 46 years who for 10 years had worked at the roasting furnaces in a nickel refinery there was a remarkable amount of nickel found in the lung (1 mg/g dry weight determined spectrographically; 2·8 mg/g dry weight as determined chemically), and this nickel has been retained in the lung for at least 8 years, for the worker had left the exposure 8 years before extirpation of the lung. The form in which this nickel was present in the plant dust was not stated by the author, but we may guess it to have been nickel or nickel oxide. The other two cases, aged 58 and 59 years respectively, had each worked at the furnaces for 22 years: nickel analyses in the lung were not carried out, but there can be no doubt about the severity of their exposure. No mention is made as to environmental hygienic arrangements in the plant, nor to the numbers of men employed in the factory. The three cases were all recognized between spring 1947 and autumn 1948, a significant fact in itself. Although the author does not appear to comment on any presumed cause of these conditions, the likelihood of nickel as the sole factor cannot be overlooked in two cases certainly,

* In a personal communication Løken states that the process was electrolytic and that since his 1950 report 2 new cases have been discovered in the same factory.

and three probably. The possibility of some synergistic mechanism in the first case mentioned above suggests itself particularly in view of the presence of asbestosis bodies.

If we assume that these tumours were very likely to have been induced by nickel or a compound of nickel, and that the process was of the Orford type with no use of carbon monoxide in refining, then we must doubt whether there is any need for the decomposition of the carbonyl in the induction of the lung tumours, but may still suppose that the nickel was inhaled as metal fume at the reverberator.

The absence of any mention of the occurrence of nasal or ethmoid tumours in the Norwegian factory even after many years may be significant and may constitute a difference between the sequelae of nickel decomposed from the carbonyl and those of nickel produced by reducing the oxide with carbon.

We may now briefly summarize some of the pros and cons of the theories offered to explain nickel tumours.

Arsenic theory

This view is fallen into disfavour partly because it has, in the past, been too often invoked; partly because of the absence of collateral evidence of arsenical affections (dermatitis, skin cancer) as pointed out by Hueper (1951); partly because of lack of evidence that sulphuric acid containing oxides of arsenic used for many years in many industries where dust and fume were prevalent had ever given rise to nasal or lung tumours; and partly because heavy exposure to arsenical dusts which led to perforation of the nasal septum does not give rise to cancers of the nose or ethmoids.

Metal theory

The idea that a metal whether implanted in the tissues, inhaled as a fume or fume dust, or deposited in the lung from the decomposition of an inhaled gas can subsequently slowly produce a cellular response which takes on the characters of dedifferentiation, anaplasia and malignancy, is relatively recent.

This conception was perhaps rendered easier by the fact that contact with certain metals seemed to evoke allergic responses in some individuals, although certain assumptions are necessary if the commonly accepted views on allergy are to be retained, that is that in certain persons there exist in the tissues or body fluids substances (antibodies) which can combine with compounds formed from the combination of body proteins with certain externally applied chemical agents, the resulting compound being able then to evoke in the skin or other physiological system a non-specific response. Some such form of wording is necessary to express the undoubted fact of idiosyncrasy, but it rests upon a great deal of both simple clinical and subtle experimental data derived from immunological methods. Moreover, it must be realized that a state of idiosyncrasy can be " spontaneously " induced and that a workman, for example, who has been able to work with many chemical

substances for many years without any abnormal skin responses can, for subtle and cryptic reasons most often undiscernible, suddenly develop an intolerance which precludes the continuance of his work with one or more of them.

In the case of metals reports have appeared from time to time of idiosyncrasies. Prosser-White (1934) refers to Toomey's collection of cases of dermatitis from wearing "chromium plated" articles, for example wrist watches, metal bracelets, garters and shoe buckles, necklaces, spectacle frames; to DuBois' two cases of sisters with dermatitis of the wrist from "nickel-plated" watches; to the metal garters and spectacle frames described by Alvarez Sainz de Aja and Fox.

DuBois was able, in his sensitive cases, to evoke a skin reaction to coins which were made of almost pure nickel. Preininger (1934) also described a significant case of a cashier with hypersensitivity to nickel coins, but this man also had a dysidrotic eruption of the hands. Jadassohn and Schaaf (1929) as a result of five years' very careful study of 700 workers in nickel plating found 35 cases of dermatitis of whom one was specifically sensitive to nickel metal.

Taylor and his colleagues (1945) described 6 cases of skin sensitivity to nickel metal in soldiers wearing army spectacles made from a copper-nickel-zinc alloy; it was stated that when perspiration was present there occurred an electrolytic formation of nickel salt.

A considerable number of such peculiar cases have been reported, but there is difference of opinion as to what precisely is happening at the surface of contact of the metal and the idiosyncratic skin.

In the case of many organic chemical compounds it is more or less readily demonstrable that, as a result of lipoid solubility, they can penetrate the skin barrier, the subsequent cellular or vascular response depending on the factor or factors supplied by the dermal or systemic constitution.

A process analogous to or identical with this can be postulated for certain "lipoid-soluble" metallic elements, for example mercury, lead. But in the case of the metals the term "lipoid-soluble" means that they can be reduced to extremely fine states of division in the presence of fats, and by the application of appropriate forces. Such forces are produced by workers handling lead, for instance, and no doubt a small amount of lead is absorbed.

Mercury, lodged as extremely fine droplets in the folds of the skin, may be subjected to similar forces in the course of work and be absorbed into the skin from a fine dispersion in the lipoids of the skin. The old-fashioned medicinal inunction of mercury depended on the passage of minute globules dispersed in a fatty medium under the forces of massage and probably warmth. Nickel, however, could not, we suggest, find itself in any similar condition and hence, in order to penetrate into the skin, must be converted into compounds as liable to induce reaction dermatitis as nickel salts, which are well known indirect dermatitic agents (nickel itch).

For the evocation of the antigen-antibody reaction which is held to be the basis of idiosyncratic allergic responses, the penetrating compound must combine with a skin or other protein to form the antigen. Since nickel salts can, on the allergy theory, do this, it is necessary to know whether nickel itself can form nickel salts on the surface of the skin.

One could enlist the mere fact of its dermatitic action to support the formation of a salt on the sensitive skin.

Nickel must be kept for a very long time in contact with water to form an oxide (Schönbein, 1928); and there is some evidence that it very gradually forms a colloidal solution in contact with water (Traube-Mengarini and Scala, 1912). In contact with dilute acids nickel gradually dissolves within 8 hours to the following approximate extents:

TABLE IV

DISSOLUTION OF NICKEL IN VARIOUS SOLUTIONS

Solution	Decrease in weight mg.Ni/cm²
1 per cent hydrochloric acid	30
1 per cent sulphuric acid	39
1 per cent nitric acid	61·5
0·5 per cent tartaric acid	23–24
0·5 per cent lactic acid	16
Saturated sodium chloride	3–4
20 per cent sodium hydroxide	1–1·5

(Approx. readings from curves given by B. Krulle (1930), *Chem. Ztg.*, 54, 429.)

Human perspiration contains rather less than 0·1 per cent lactic acid more or less buffered in different individuals to *p*H values varying from 4 to 7·5. It is not difficult, therefore, to believe that a relatively poorly buffered sweat is well able to erode a nickel surface, and more easily in warm conditions, to form a nickel salt.

Very little of the exciting agent is sufficient for the idiosyncratic skin to react and it therefore seems reasonable to regard sensitizing to nickel metal as another aspect of sensitizing to nickel salts.

It is suggested that lines of thought of this kind should be applied also to the carcinogenic effect which may follow the deposition and maintenance of nickel or other metal in a tissue or organ.

The mere deposition of an inert body in a tissue or organ is in our view not ever sufficient to induce a neoplastic change.* Nickel deposited by whatever means in the lung or nose or other part is gradually transferred into inorganic or possibly organo-metallic compounds which exercise the mysterious effect called carcinogenesis or potentiate them to it. However difficult it may be to demonstrate such chemical changes, it is impossible to envisage a carcinogen or potentiator of carcinogenesis which is chemically and physically inert.

* Recent experiments in which subcutaneous tumours were induced in rats by single or multiple implantations of apparently inert polymers or metals require further confirmation and study (Oppenheimer, *et al.*, 1953, 1955).

The ease with which such changes can take place in the body will depend upon the location of deposition, the state of division, the ease of removal by normal tissue mechanisms, and the physico-chemical potentialities of the organs and tissues.

Experimental induction

One of the earliest papers on the experimental induction of tumours by a single implantation of metals into the femur (bone) of rabbits was that of Schinz and Uelinger (1941), who claimed to have produced metastasizing sarcomas and adenocarcinomas thereby, not only at the site or near the site of injection, but also in distant organs (lungs, liver). In this remarkable contribution, to which we shall refer again, the authors describe the elements they used, arsenic, chromium and cobalt, as insoluble in themselves but gradually dissolved in the organism and effective as trace elements. They offer certain suggestions as to possibilities for the dissemination of the elements they used, for example, formation of complex compounds with protein because of the availability of coordinative unsaturated groups; possibility of the activation of certain enzyme systems by minute absorptions of these elements or incorporation in the enzymes themselves.

These experiments were conducted with great assiduity for the periods of observation of the 8 animals in which tumours were induced (or noted) varied from 4 to 7 years. Of the 12 animals used, 1 died without having developed a tumour, 7 died from cancer and 1 was alive at the time of writing, with a round-cell sarcoma of the lung; 3 were still alive at the time of writing. No data were given as to the normal incidence of tumours in the strain of rabbits used, but it is reasonable to regard 8 out of 12 animals as convincing. Nickel was not used in these experiments, but Hueper (1951, 1952) using a different method of introducing the metal into the body was able to induce a good many tumours in rats of a species not having a genetic tendency to tumour formation.

Pure metallic nickel powder was suspended in lanoline (61 per cent nickel by weight) and 0·05 millilitres, representing 50 milligrams of nickel, was injected under ether anaesthesia into the marrow cavity at the distal end of a femur until some was seen to exude from a hole drilled at the proximal end of the bone. This was done in 25 rats. In 6 months 2 had died without any tumour formation; in 7–16 months a further 17 had died, 12 without tumour formation, and in the remaining 5 there were found 3 osteogenic spindle cell sarcomas, 1 squamous cell carcinoma of a fistulous duct, and a dubious round-cell sarcoma in the abdominal cavity. The tumours were large and varying in size from a golf ball to a tennis ball.

In a second group of 25 rats, 5 monthly injections of 0·05 millilitre of a similar lanoline-nickel suspension into the right pleural cavity through the supraclavicular fossa were made. Eight animals died within 6 months, and 10 between 7 and 16 months; 4 sarcomas were found at the site of injection

in the latter. These tumours were very malignant and grew rapidly, extending downwards into the sternum, abdominal wall and upward and backward involving the spine. They varied from a large walnut to more than a golf ball in size, fixed to the thoracic wall and all, as stated, were induced at the site of injection.

In a further 20 rats 0·1 millilitre of a similar nickel suspension was injected three times at 2-monthly intervals into the right nasal sinus with great care so as not to puncture the palate. Six of the animals died within 6 months, and of those dying between 7–16 months after the first injection (3 animals) one developed a round-cell sarcoma in the thoracic and abdominal lymph glands.

Thus, all told, 10 malignant tumours were found in the 30 animals dying between 7 and 16 months after the first injection by each of the routes: of these 10 tumours 8 were at the site of injection and 2 remote from it. Hueper lays some stress on the fact that histological examination showed close promixity between the nickel deposits and the neoplasms, and estimates that the minimum latent period of induction was 6 months.

These observations were controlled by similar injections of lanoline and of asbestos powder suspension in lanoline in two groups of 70 rats without any production of tumours. Hueper also failed to induce tumours in 150 rats injected intramuscularly with suspensions of mineral oils and other compounds.

Further, in a preliminary communication Hueper (1951) referred to his failure to induce tumours with chromium, chromite ore, beryllium, arsenic, uranium*, asbestos, and to the fact that dogs, rabbits and guinea-pigs had not developed tumours even with nickel powder.

Although the kind of experiment described by Hueper is far from simulating anything found in industrial conditions, the fact of tumour induction even in artificial conditions must be accepted as corroboration of the clinical evidence of the dangerous character of nickel dust, whether inhaled in active form from carbonyl or in the grosser forms of dust. To evoke the response, manifestly a long period is required and in the case of metal tumours probably also a long contact with the responding tissue. It is, in this connexion, interesting to note that Barnes and Denz (1951), found that after 30 minutes' exposure to $Ni(CO)_4$ rats had in their lungs only 5–10 per cent of the nickel inhaled, and conclude that nickel is rapidly translocated (notably to the liver and brain) in the body, and is not firmly retained by the tissues. However, the level of nickel in the lungs after a day from exposure to nickel carbonyl is maintained for many days and it was suggested that the effect of the high concentration which is found on the first day is instrumental in creating the necessary conditions for the entry of nickel (element) into the vascular endothelial cells. We have seen that in the case described by Løken

* In a later communication Hueper *et al.* (1952) state that the deposition of 50 milligrams of uranium (pure α-emitter) into the marrow cavity of the femur of rats led to the development of 11 sarcomas at the site of injection in 33 rats, surrounding or in the immediate vicinity of the uranium deposits.

there was 1 milligram per gramme of nickel in the lung even 8 years after cessation of exposure. If Løken's results were correct, there must have been some 1·2 grammes of nickel in the lungs—a wellnigh incredible figure—completely out of harmony with Barnes and Denz's conception of non-retention unless there was very great difference, as seems likely, in the physical form and states of the nickel.

ASBESTOS

The association of what appears to be purely mechanical trauma with a later development of neoplastic change has a long history both in the experience of myriads of medical observers and in that of theorists who invoked it in the exposition of a theory of cancer. If such an association is looked at askance it is not because it is denied that it can occur, but rather that it is too facile and even sterile an explanation. Of the tens of millions of mechanical traumas occurring daily, the number which can be later recognized as having possibly initiated a neoplastic process *in situ* is minute. Most pathologists would sum the matter up by saying that if trauma is followed by the development of a tumour at the site of the original trauma, then that site was not normal at the outset.

Co-carcinogenesis

The classical experimental basis for the effect of the super-imposition of trauma on an abnormal site is the *Deelman phenomenon*. Deelman showed in 1923 that if a tarred area of animal skin is injured by wounding or other physical effect, tumour formation might be hastened and its location thereby determined. This observation was later confirmed by other workers who used pure carcinogens and laid the foundation of what is now called co-carcinogenesis. Co-carcinogenesis may be defined as the augmentation of the action of a carcinogen by some suitable additional treatment which shows itself in increased numbers of induced tumours and/or shortening of the induction time. In general the term co-carcinogenesis is applied to an effect produced by local application of an agent to a tissue (Berenblum, 1947). A co-carcinogen is not itself a carcinogen although Anderson (1948) appears to think otherwise, regarding co-carcinogenesis as a synergy between subliminal doses of two or more carcinogens. Such mechanical irritation as strongly brushing the skin, and foreign body fibrosis, have been shown to be effective as co-carcinogens. Heat, cold, radioactive radiations, croton oil and resin, all possess co-carcinogenic power.

The precise nature of co-carcinogenesis is difficult to understand except as an expression of certain experimental facts. The significant matter from our present viewpoint is that for a co-carcinogen to produce its effects it must be applied after a preparation of the tissue has taken place by a carcinogen, or even after an overt carcinogenic response has regressed.

Although the whole conception of co-carcinogenesis has arisen from

experimental work on mouse and rabbit skin, some such idea must be evoked by a problem such as that of asbestosis and cancer, until some more experimental evidence of direct carcinogenesis by asbestos or a decomposition product of it can be obtained. If such an idea is feasible, then we must also assume a pre-neoplastic preparedness in the organ in which the co-carcinogen (asbestos or the fibrous tissue in the peribronchiolar reaction) later induces a further development into true neoplastic growth. The preparedness of the tissue if it is to be regarded as more than a form of words is brought about by something independent of the asbestosis, and this must be regarded as an endogenous factor. But some special property must also attach to the asbestosis for the alleged cancer induction in this condition is not apparently found in the long-standing cases of silicosis.

We will first consider the evidence that asbestosis leads in a proportion of cases to cancer of the lung. As long ago as 1938 the suspicion arose that asbestos workers might be more than normally prone to lung cancer.

Nordmann (1938) analysed six cases of lung cancer and showed that the range of exposure periods was 7–21 years, and the range of intervals between entering the industry and death was 15 to 21 years. The malignant disease in some cases occurred years after leaving the industry. Half of these cases were comparatively young, 35–41 years of age at death. In one remarkable case a 71-year old woman had worked in asbestos for only 19 months. Later in the same year he referred to a further seven cases of associated asbestosis and lung cancer, including Gloyne's (1936) finding of six cases of carcinoma of the lung in 50 necropsy cases of asbestosis.

In the 1947 Annual Report of the Chief Inspector of Factories, Merewether tabulated the age incidence among 235 deaths caused by asbestosis: in 13·2 per cent of these cancer of the lung was present, and it is especially important to note that 4·8 per cent of the age-group 25–34 years and 5·6 per cent of the age-group 35–44 years had this condition. It will be seen that the over-all figure is closely in agreement with Gloyne's findings.

In a further report* carrying this analysis up to the end of 1954, he found that amongst 344 deaths, in 55, or 16·0 per cent, cancer of the lung was present.

In their series of papers on asbestosis Lynch and Cannon (1948) give an analysis of the post-mortem examination of 40 cases of asbestosis among which 3 cases of carcinoma of the lung were found associated with medium or advanced grades of asbestosis, which, according to these authors, is seven times the general incidence in the United States.

In a more recent study of the clinical picture and pathology of asbestosis, Behrens (1952) estimated that of 309 cases of asbestosis reported in the literature there were 44 cases of carcinoma of the lung (14·2 per cent) whereas in a series of 2,204 cases of silicosis only 32 such tumours were found (1·4 per cent).

* Annual Report Chief Inspector of Factories for 1954, pp. 190–193.

The discrepancy between the two incidences in Switzerland is of the same order as that found in the smaller series by Lynch and Cannon in the United States.

Suggestive as these and other data are, Stoll, Bass and Angrist (1951) were dissatisfied with the statistical weight one could put upon available figures at that time which included, in addition to those of Lynch and Cannon, a series of 235 cases of asbestosis with 31 carcinomas of the lung (13·2 per cent) which is again almost identical with the finding of Behrens. They refer also to another series of 115 cases with 14·8 per cent lung tumours.

Describing the case of a worker who had been engaged for only 6 years covering pipes with asbestos and who had refused to take precautions by wearing a respirator, they point out that except for weakness and persistent cough nothing noteworthy was found until malignant cells were found in the bone marrow. Radiographs of the chest showed numerous large discrete oval shadows which were interpreted rather as metastatic deposits than primary tumours. Post-mortem examination showed asbestosis with scattered large nodules and metastases in kidneys, brain and liver. Histological examination confirmed the presence of asbestosis bodies and anaplastic carcinoma of the lung, with numerous metastases. There appeared to be some doubt about the primary focus of malignancy in this case, and the authors inclined toward a multiple origin. Whether this case is relevant to the problem of asbestosis cancer is open to question, but the authors were led to suggest that asbestos must itself be regarded as a direct carcinogen in respect of its composition as a silicate.

A less compromising attitude is taken by Werber (1952) who states categorically that in 7–17 per cent of cases of asbestosis after a latent period of about 1½–20 years, as a result of epithelial metaplasia, carcinoma becomes established in the lung. Werber then reports what appears to be a clear-cut case successfully operated on. The patient was a man of 58 years who, after years of work in asbestos with complaint of irritant cough, showed, in a mass radiographic investigation, a well-marked dense round shadow in the right lower lung field associated with bilateral finely granular shadows in the middle and lower fields, more marked on the right side.

Lobectomy of the right lower lobe confirmed the presence of a non-keratinizing squamous cell carcinoma. Nearly the whole of the lower lobe was occupied by an almost certainly bronchogenic (postero-lateral segment) tumour. Asbestosis bodies were found in the lung and in an excised hilus lymph node. Recovery was uneventful and x-ray examination showed later expansion of the upper and middle lobes.

A suggestive case is also described by Cureton (1948) of a young woman of 37 years who 15 years before had left asbestos work after 7 years in the industry. Necropsy showed a predominantly squamous-celled bronchial carcinoma accompanied by asbestos bodies and fibrosis in both lungs. This author is cautious about the relation between the neoplasm and the asbestosis

but points out that the woman was very young for a squamous growth.

As in the case of most other occupational tumours, it is commoner to find workers without the neoplastic reaction than with it, even after all the apparently necessary and sufficient conditions for its development have been found to exist. Many such cases have been amply described. We give one or two from the Continental literature.

Having worked for 22 years consecutively applying insulating (asbestos) material to articles, a man aged 40 years was killed in a street accident, never having complained of respiratory troubles. Franchini and Canepa (1949) performed the post-mortem and found a fracture of the base of the skull as the immediate cause of death. The lungs were massively and extensively fibrosed mainly in the middle and lower lobes, with lymphocytic infiltrations and thickened elastic tissue; many asbestosis bodies were found occupying the lungs and lymph nodes. No mention of neoplastic change is made. It is specially interesting that, as in so many other cases, the massive pulmonary changes should have been unaccompanied by complaint.

This is of importance because if after a period of exposure to asbestos dust a certain measure of fibrosis is developed and thereafter the industry is left, we may picture a static non-symptomatic, non-progressive fibrosis, but a continuing process of cancerization in a certain number of cases. Whether the preceding fibrosis is necessary for the subsequent neoplastic process or whether the latter is conceivable without the former, it is not as yet possible to say.

The entry of any particles or fibres into the lung, even when they are soluble in water, produces a phagocytic response from the septal cells in the alveolar walls and giant cells with many nuclei soon develop. In the case of a soluble compound the ultimate degeneration of the dust cell permits the second stage of the absorption of the compound. This is readily shown experimentally with any of the common laboratory animals. The lung presents a temporary barrier to soluble particles; in the case of insoluble particles the barrier is more permanent, depending on the size of the particles. The smaller particles may be taken up by phagocytic cells arising from various sources and disposed of in lymph glands, in the interstitial tissue of the lung and even to some extent in organs from which they can be excreted. Everything depends upon the size.

Phagocytic cells may, however, be completely frustrated both by the nature and size of particles. In such cases they surround the foreign material and a process of local fibrosis sets in, the foreign unattackable material remaining more or less *in situ*.

A small particle (2–3 micrograms) will ultimately enter the alveoli and the fibrous reaction will start from the alveolar walls and lymphatics, if it cannot otherwise be disposed of. If the particle is big (10–15 micrograms) and cannot therefore proceed into the ultimate air passages, it is held up and the reaction occurs more proximally in the bronchiolar tree.

In respect of the basic features of the body's reaction to asbestos fibres there is nothing to choose between them and particles of silica. The particular differences, which are undoubtedly observed, arise from different physical form; difference in solubility; difference in size, and the possible difference in carcinogenic properties.

The term asbestos is vague and industrially may refer to any of a series of complex silicates. It belongs to a group of crystalline magnesium silicates, which include talc (steatite) $Mg_3H_2(SiO_3)_4$, Meerschaum $Mg_2H_2(SiO_3)_3.H_2O$, possessing varying degrees of resistance to heat and to chemical agents. It is best as recommended by Spencer (1937) to preface the word asbestos with the particular mineral from which it is derived, for example serpentine asbestos and amphibole asbestos (hornblende). Unfortunately, more words than one are used in this industry for the same natural product.

The common forms, with country of main origin, used in the various industries with which our present theme is concerned are:

(1) *Serpentine asbestos* (*Canadian*) (chrysotile*; amiant). Chrysotile is the most used of the fibrous silicates. Empirical formula : $H_4Mg_3Si_2O_9$ $(= 3MgO.H_4(SiO_3)_2)$.

As mined the following is the analytical composition of an average sample of the naturally found mineral (serpentine: hydrous magnesium silicate):

	per cent
SiO_2	43
Al_2O_3	0·52
$FeO.Fe_2O_3$	1·0
MgO	41·36
H_2O	13·79

(2) *Amphiboles.* Empirical formulae:

$H_2Ca_2Mg_5(SiO_3)_8$	Tremolite (Italian)
$H_2Ca_2(MgFe)_5(SiO_3)_8$	Asbestos (amphibole asbestos)
$CaMg_3(SiO_3)_4$	Actinolite
$H_2Na_2Fe''Fe_2'''(SiO_3)_8$	Crocidolite (Blue asbestos—South Africa, Australia)

(3) *Amosite asbestos* (*South Africa*) (ferro-anthophyllite). Empirical formula: $H_2(MgFe)_7(SiO_3)_8$.

Their commercial value is due to the long fine, infusible, non-conducting fibres in which these silicates exist and can be worked and it is this character which motivates the characteristic changes in the lungs when inhaled over considerable periods. In the mining of serpentine and of the asbestos from it as a mass of fine, silky crystals in Canada, Cartier (1949) found that he could divide the 3,242 workers of whom 40 per cent had been in the mines for 10–40 years into two groups, one exposed to the dust of serpentine, which remained free from asbestosis and the other, exposed in grinding,

* Not to be confused with chrysolite which is an isomorphous mixture of Mg_2SiO_4 (forsterite) and Fe_2SiO_4 (fayalite).

screening, suction and bagging to the dust of the dried separated fibrous silicate, in which all the cases of asbestosis developed. Among the 22 cases of asbestosis found by radiography and confirmed post-mortem, there was no mention of any cases of cancer of the lungs. More clinical and occupational data on these cases would have been desirable. On the basis of the findings elsewhere, 1 or 2 cases of lung cancer would have been expected. On the experimental side Cartier implies that his clinical data are confirmed by exposure of animals to the two kinds of dust.

Cartier makes two statements of considerable interest as to the severity of asbestosis among his miners.

(1) During his 3 years of clinical observation (more than 10,000 complete medical examinations) no worker has died of uncomplicated asbestosis under the age of 60 years, even after 20–30 years' severe exposure to asbestos dust; nor has he seen among asbestosis cases as severe cyanosis or dyspnoea as that seen in asthmatics, lung cancer or advanced tuberculous cases. From this he concludes that pure asbestosis is not as severe a disease as it is considered in Great Britain and elsewhere where manufacturing processes are carried out with the separated asbestos.

(2) Pure asbestosis, often even radiologically very advanced, is found among workers who show no clinical signs, no diminution of respiratory function and can without discomfort carry out their habitual tasks.

The claim by Cartier amounts to this, that asbestosis as usually described is really a mixed disease, complicated by cardiopathies and even tuberculosis, and that " pure " asbestosis as seen by him is by no means a severe condition. Having been in close association with such notable authorities as Gardner and Vorwald, these statements cannot be ignored because of relatively short experience of the industry. It may be that Cartier considers a life of 60 years amply sufficient for the relatively few cases who develop the disease severely enough to die from it. He does not, however, in this paper give the populations at risk so that we cannot calculate essential data. It may be relevant to his thesis that the population around the Thetford mines is almost entirely pependent upon them for their " gagne-pain ".

Cartier's second statement is, however, borne out by the case of Franchini and Canepa. It will be recalled that whereas the general view in Great Britain is that the symptomatic picture is more severe in asbestosis than in silicosis, the reverse view is held in America. The long period of absence of symptoms has been known for many years, but the diminution in vital capacity is demonstrable even when the worker is perhaps unwilling to admit any respiratory abnormality. As was pointed out over 20 years ago by Merewether and Price (1930) and Merewether (1930), the worker is inclined to attribute his discomforts to causes other than his work.

A more normal case history is that given by Luton, Champeix and Faure (1951) who describe what is stated to be the first case of asbestosis reported in France. This was a man aged 62 years who, having worked for 11 years

in an asbestos cloth factory ($2{\cdot}25–4{\cdot}0 \times 10^6$ particles (1–2 μ) per litre of air) complained of dyspnoea on exertion and was somewhat cyanosed. Radiographically the fibrotic condition progressed in the middle and lower lobes until he died 7 years later. Necropsy findings were of the classical kind: diffuse fibrosis, thickened plurae, no nodulation, many asbestosis bodies with giant cells and many mineral particles in the lungs.

Dust particles were found also in the vessels of the liver, kidney and spleen. No mention is made of metaplasia or neoplastic changes. These authors discount the possibility of a chemical influence of asbestos particles on the pulmonary tissues.

We have been at some pains, but without success, to elicit any statement or evidence in the literature of asbestosis which could be interpreted as more than a verbal attribution of the effects of asbestos particles to irritation. For the fibrotic effects there does not seem any reason to seek causes other than sharp " insoluble " foreign bodies larger than a critical size. The work of King, Clegg and Rae (1946) in which they pursued the mechanical action theory of Gardner, presented a reasonably full picture of the response of the lungs of rabbits to insufflation of small (2·5 μ) and large (15 μ) asbestos fibres. Gardner and his school had emphasized that, as we have already mentioned, with asbestos particles size is everything, small particles being innocuous, big particles hazardous, and that this distinguishes their effects from those of silica and quartz which are entirely the result of small particles. Nevertheless, King, Clegg and Rae did find some effect from the inhalation of small (2·5 μ) particles of asbestos, which might be described as a diffuse fibrous tissue reaction affecting mainly the interstitial tissue and alveolar walls with hyperplasia of the bronchial nodes and some nodular areas of giant-cell reaction. Phagocytosis of these small particles was probably easy enough to restrict the reaction to the locations mentioned. With larger fibres (15 μ), the foreign body giant-cell processes were apparently overlapped by a more permanent reaction, nodular in distribution, which fixed the asbestos particles *in situ*.

King, Clegg and Rae make the significant comment that these nodular, somewhat acellular, areas of intra-alveolar connective tissue were strictly comparable to, if less intense than, those produced by quartz, which means that the lung does not distinguish them.

In respect of small particles they suggested that if fibres $< 2{\cdot}5$ μ in size were insufflated, they would be completely removed from the alveolar wall and fail to produce interstitial fibrosis. It seems possible that in the case of Luton and his colleagues the smaller particles were phagocytosed and discharged into the circulation in the way probably envisaged by King and his co-workers, since they report having found dust particles in the vessels of the liver, kidney and spleen.

Summing up the many years of research of Gardner and his co-workers on the effects on animals' lungs of asbestos particles administered by

inhalation, intratracheal insufflation, intravenously or intraperitoneally, Vorwald, Durkan and Pratt (1951) recall that ordinary industrial (asbestos) dust and, especially, long fibre asbestos dust from which the small fibres had been separated, produced characteristic peribronchiolar fibrosis which remained static on discontinuance of exposure, whereas to particles of 3 μ and less there was no tissue reaction (King, Clegg and Rae, 1946). On substituting Brucite (native magnesium hydroxide containing only 0·9 per cent silica as silicate—Brucite is a crystalline compound easily split into thin sheets and has a flexibility comparable to that of asbestos fibre), for the asbestos peribronchiolar fibrosis is similarly established, but dust of glass fibre which is not flexible and, of course, cannot be split does not, on long inhalation, lead to fibrosis.

The dependence of the fibrosis on physical form was, however, settled by the failure to induce fibrosis by long inhalation of asbestos which, having been fused and ground, no longer retained its original structure.

The Gardner school held that the combination of size, physical form and immobilization in a rhythmically moving organ is the determinant of the pathogenic effect. Effects somewhat similar to this pulmonary fibrosis can be obtained by injection of asbestos fibres into the peritoneum.

But at no stage in all these impressive researches was any clue obtained which might have offered any support to the possibility that asbestos could act as a carcinogen. There is no reliable criterion by which one can anticipate carcinogenicity and, as is well known, relatively minute changes in the structure of a chemical carcinogen are sufficient to diminish or eliminate carcinogenic action.

If asbestos is indeed to be regarded as a carcinogen, the need is felt to demonstrate some property which can be regarded as something more than inertness. The simplest such property is solubility. Solubility confers some activity on a compound as, for example, in the case of silica, the solubility of which in aqueous conditions is sufficient to found a chemical theory of silicosis.

Asbestos has, however, not given much evidence of a solubility which might be significant.

In analysing the working environment for asbestos dust Sundius and Bygden (1938) made the curious remark that only amphibole asbestos could be recognized in their analyses, in spite of the fact that the asbestos commonly used in industry contains mainly chrysotile and to a considerably lesser extent amphibole asbestos. This statement, if confirmed, might mean that chrysotile is dissolved in the analytical process. In fact, chrysotile is the least resistant of asbestos types to chemical and physical agents: it is decomposed by hydrochloric and sulphuric acids, it loses water at red heat and its fibres can be fused in the bunsen flame. (Crocidolite—blue asbestos—is also fusible to a black magnetic glass but is resistant to chemical agents).

Assuming that chrysotile might be capable of exerting some chemical

effect by virtue of these and perhaps other related properties, the mind turns to the asbestos body which, lying in the lung tissues for long periods, might have some significance other than that usually attributed to them of being a structure in which the enclosed asbestos fibre can lie innocuous. In the experiments of Gardner and his school the injection of isolated asbestos bodies did not produce fibrotic reactions. But this need not deter us.

Cooke (1930), who, with MacDonald, discovered the asbestosis body, made the following comment: " they consist of central nuclei of asbestos spicules upon which colloidal aggregates of blood proteins, plus, possibly, soluble fractions of asbestos, and, in the case of chrysotile workers, iron salt, have been absorbed and moulded by currents in the bronchi and alveoli ".

In recent work Champeix and Bouteville (1950) examined asbestosis bodies in the electron microscope at magnifications of 25,000. It may be recalled that Champeix was associated with the view opposing a chemical factor in the aetiology of asbestosis (Luton and his colleagues).

Electron microscopy

The procedure to examine an object as delicate as an asbestosis body in the electron microscope presents much difficulty, and the interpretation of the photographs obtained should be correspondingly cautious.

Champeix and Bouteville treated expectorated material as follows:

Alkaline digestion of the diluted sputum with NaOH (equal volumes). After 10 minutes' warming in a porcelain dish, allowed to cool.

Homogenized fluid divided among several centrifuge tubes and centrifuged cautiously to avoid disintegration of the asbestos bodies.

Decanted and residues spread on several slides.

To examine in the optical microscope, mount in Canada balsam.

To examine in the electron microscope the smear allowed to dry and with a micro-manipulator a single asbestosis body is lifted on to the collodion membrane of the object carrier. This operation is difficult and delicate and the hazard of fracture of the asbestos body is great.

As regards the general morphology of the asbestosis body, the electron microscope confirms in greater detail and without deformation the findings with the optical method—the central, needled fibre ($\frac{1}{2}$–1 μ thick, length always > 10 μ) surrounded by an amorphous, somewhat opaque rounded envelope (2–3 μ thick) in parts appearing as if burst and giving a general impression of a colloidal, proteinous gel: the extremities ovoid, ellipsoid, fusiform or sometimes angular.

Two observations suggested solution of the asbestos fibre: (1) there were no fibres less than 10 μ in length in any asbestosis body; (2) removal of the colloidal envelope of the asbestosis body by means of the micro-manipulator shows the central fibre with one edge semi-transparent as if it were being dissolved away.

These facts lead the authors to some dubiety on whether the fibrosis is

due to a maintained mechanical irritation produced by the insoluble amphibole, or to a chemical effect brought about by the dissolving silicate. It may be recalled that Alden and Howell (1944) stated that amosite needles are capable, where embedded in epithelial tissue in the skin, of eliciting a non-inflammatory epithelial proliferation. This statement was made from observations on amosite workers who developed hyperkeratotic epithelial thickening after penetration by a small splinter-like fibre. X-ray examination and biopsy show no evidence of a foreign body in these " corns ".

Solubility of asbestosis bodies

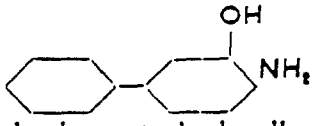
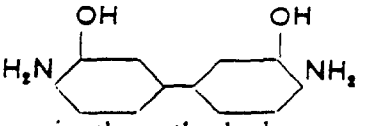
More work is required on this problem especially quantitative studies of the solubility of asbestos types in a variety of conditions, together with an identification of the products after solution. The question is not one of explaining fibrosis of the lung by a chemical process, for this is almost decisively negatived by the undoubted fact that the smallest particles of asbestos have not in fact produced a fibrosis in the experience of most investigators. The question is rather one of finding a product of solution which, by entering the modified squamous epithelium of the lung, or by changing its environment, can lead to de-differentiation or to tumour formation. The majority of pulmonary tumours in men are anaplastic or undifferentiated or (epidermoid) squamous epitheliomata and they constitute a type of new growth in the lung which has hitherto eluded the experimentalist. Probably the only claim to have induced a true cancer in the lungs of mice was that made by Nordmann and Sorge (1941) who exposed 100 mice to undefined asbestos dust and stated that 20 per cent of the animals developed cancer. There is considerable doubt, however, whether the evidence presented is really acceptable.

In fact, cancer of the lung (truly so called—not adenomas as found and induced in mice) has not hitherto been produced by inhalation of any material. W. E. Smith (1952) in a very forceful consideration of the experimental aspects of cancer of the lung concludes " that we are singularly ill-equipped for the experimental study of one of the chief problems of human cancer ".

Until this charge is successfully answered we may for practical purposes regard asbestos or a derivative of asbestos as a probable co-carcinogen in that proportion of cases of diffuse fibrosis of the lung in which the necessary preparedness of the lung has been brought about, probably endogenously. Such a view has, at least, the merit of less sterility than the common panacea for carcinogenic dilemmas, irritation.

AROMATIC AMINES

Of the few identifiable chemical agents which may without doubt be accepted as standing in the line of causality of particular types of human neoplastic disease, certain aromatic amino intermediates in the dyestuffs industry occupy the most interesting and, from the point of view of the experimentalist, the most fruitful position. Not only have they been repeatedly reported in

If  and  can be similarly shown to be locally carcinogenic, the ortho-hydroxy amine hypothesis will be greatly strengthened.

The implications of this hypothesis, if substantiated, will be far-reaching in foreseeing possible carcinogens in the organic chemical industry.

BERYLLIUM

In the considerable literature which has grown up on the effects of beryllium and compounds of beryllium on the skin and the lungs, and, in the experimental field, on many other tissues, certain terms and phrases recur frequently which it may be well to clarify briefly first of all, since some arise from technology and others from pathology.

Extraction of the metal from the ore

Beryllium is called glucinium (symbol Gl) by the French because some of its salts have a sweetish taste and, since it was a Frenchman, Vauquelin, who discovered the metal in 1797, the right to call it by this name may be accorded. However, the more usual name beryllium (symbol Be) was given by Wöhler to it in 1828 from the name of the mineral beryl ($Be_3Al_2Si_6O_{18} = 3BeO.Al_2O_3.6SiO_2$). A form of beryl which is transparent and green (from its content of chromium oxide) is called emerald, and a bluish green form is called aquamarine.

Beryllium is the fourth element in the periodic table, with atomic weight 9·013, atomic number 4 possessing a nuclear charge of 4: thus the atomic symbol for the only stable isotope of beryllium is ${}^{9}_{4}\mathrm{Be}$. There are altogether 4 isotopes of beryllium corresponding to atomic or mass numbers, 7, 8, 9, 10, containing respectively 3, 4, 5, 6 neutrons in the nuclei.

Practically all the atoms of beryllium are the stable ${}^{9}_{4}\mathrm{Be}$ variety. This stable isotope bombarded with α-particles (that is helium atoms ${}^{4}_{2}\mathrm{He}$) yields many neutrons (a million α-particles will release about 30 neutrons ${}^{1}_{0}\mathrm{n}$)

$$ {}^{9}_{4}\mathrm{Be} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n} $$

the neutron having a mass number 1 and no nuclear charge: the product ${}^{12}_{6}\mathrm{C}$ being that isotope of the five isotopes of carbon which constitutes almost 99 per cent of the ordinary form of carbon with atomic weight 12·01.

The nuclear mass of beryllium being so light, a fast moving neutron striking it can be much retarded without much loss in energy. This constitutes a very valuable property in the use of beryllium in nuclear physics.

Another consequence of its low atomic number is that beryllium is *very permeable to x-rays* and so, having regard to its toughness and its high M.P. (1,284°C.), it is very suitable for windows in x-ray tubes.

Another property of beryllium often referred to is that it is of great importance for making *non-sparking tools*. Tools spark because the great energy released at the points of friction or impact is sufficient to render incandescent the minute particles of metal which become detached. In order to obviate this tools are required which combine non-sparking with sufficient hardness. Copper is a non-sparking metal but is too soft, and it is, therefore, alloyed with beryllium to bestow enough hardness to make it cut.

The effect of beryllium on the hardness of copper may be partly seen from the following data:

Composition (%)			*Relative Hardness*
Cu	Be	Ni	
97	2·5	0·5	340–360
98	0·25	1·4	210–220

Common beryllium-copper alloys contain about 2 per cent beryllium and 0·35 per cent nickel or cobalt. The alloys are hardened by heating to 250–300°C. This heat treatment precipitates the beryllium into very small, hard particles in the copper and these greatly increase the hardness and strength, but diminish its ductility. Inasmuch as the thermal conductivity of the beryllium-copper alloy is about ten times that of steel, the advantage gained by the lower temperature at the tooled surface is obvious.

The casting of aluminium alloys is much facilitated by incorporating 0·1–0·5 per cent beryllium in them: this promotes greater fluidity during casting and refines the grain of the final alloy casting.

Fluorescent lamps

Pathological phenomena have been extensively described in connexion with the manufacture and handling of fluorescent lamps. Some elementary points about fluorescence and fluorescent lamps may now be added.

The ordinary electric incandescent lamp depends simply upon the loading of a resisting wire of high melting point and high tensile strength and in an inert atmosphere with current until the wire (filament) becomes incandescent and emits visible light. To produce radiation within the narrow range of the visible spectrum (3,800–7,600Å) very high temperatures must be reached with consequent high loss by heat radiation: the efficiency of an incandescent lamp is less than 5 per cent, that is less than 5 per cent of the energy put into a tungsten filament lamp appears as radiation in the visible spectrum.

The fluorescent lamp, on the other hand, depends upon an arc discharge which generates ultra-violet radiation which, by the introduction of suitable synthetic compounds, called *phosphors*, is turned into visible radiation The phosphors carry *activators* which may be present in solid solution.

The fluorescent lamp is a mercury-vapour lamp and consists of a cylindrical glass tube containing mercury vapour and coated on its inner surface with

compounds of different composition according to the light-effect desired. The arc is struck across two electrodes which resemble the filaments of incandescent lamps, but are coated with oxides of alkaline earths (calcium–magnesium–barium). As the arc is struck with alternating current, the electrodes are heated and emit electrons from the coating.

The light emitted by impingement on the *phosphor* is usually of longer wave length than that of the impinging or exciting radiation which must correspond with an absorption band possessed by the phosphor generally in the ultra-violet region.

Both ultra-violet radiation and electrons are capable of exciting electrons (that is transference from a lower to a higher energy state) in the metallic activator in the phosphor compound. When the excited electrons return to their original orbits, they yield up the energy they had received and this energy is transformed into the energy of luminescence.

Any particular colour effect is produced by suitable choice of mixtures of phosphors and its application to the lamp tube in an appropriate carrier and in effective particle size.

In fluorescent lamps, commonly used phosphors are zinc silicate (activator manganese); calcium halophosphate (calcium phosphate + calcium fluoride or with calcium chloride) with small amounts of manganese or antimony as activators. Zinc beryllium silicate ($8ZnO + BeO + 5SiO_2$) with 0·25 MnO as an activator gives a maximum intensity in the green, whereas with 0·45 MnO as activator the maximum shifts into the red. Zinc beryllium silicate has since about 1948 been substantially eliminated from use as a phosphor initially because of the toxic effects of beryllium, and also because other compounds gave a better luminescence.

Preparation of the metal

Hazards arise in the extraction of the metal from the ore. This is not easy to do and involves fusion of the ore at high temperatures.

Since, as we shall see it has been suggested on experimental grounds that beryllium may lead to malignant neoplasm after a very long latent period, we will briefly describe some of the methods used for preparation of the metal.

Method 1.—Beryl ore is melted at about 1,600°C. and its crystal structure disrupted by suddenly cooling in cold water. Thereby the reactivity of the ore with sulphuric acid is very much increased. The wet glassy mass is dried, finely ground, treated with strong sulphuric acid and heated, when each part of the original molecule reacts separately. On treatment with water the silicic acid remains as insoluble silica whilst the beryllium sulphate and aluminium sulphate go into solution from which ammonia alum can be separated by addition of ammonium sulphate.

Crude $BeSO_4$ is obtained on evaporating the filtrate and can be freed from the remaining aluminium (and iron) by further careful treatment with ammonium sulphate. The $BeSO_4$ is crystallized and heated to 1,300°C. when a very pure BeO is obtained, sulphur dioxide and oxygen being released.

Method 2.—The ore is fused with soda ash (Na_2CO_3) and the *ground* mass treated with sulphuric acid. This permits separation of the silica and most of the aluminium as alum by addition of ammonium sulphate. The filtrate of $BeSO_4$ still contains some aluminium sulphate (and iron). By oxidation of the iron and careful precipitation with soda ash, most of the impurities are removed (with some loss of beryllium). Repetition of the process on the filtrate and final treatment with ammonia gives a high grade $Be(OH)_2$ which can be filtered off, washed, dried and ignited to a pure BeO.

Method 3.—The use of fluorides in extracting beryllium goes back many years and has undergone many modifications. One of the most recent is to treat the finely ground beryl ore with sodium fluoferrate (Na_3FeF_6) at 750°C.

$$(Fe_2(SO_4)_3 + 12NaF \rightarrow 2Na_3FeF_6 + 3Na_2SO_4)$$

$$2Na_3FeF_6 + 3BeO.Al_2O_3.6SiO_2 \xrightarrow{750^\circ C} 3Na_2BeF_4 + Fe_2O_3 + Al_2O_3 + SiO_2$$

Extracted with water in oxidizing conditions, the sodium beryllium fluoride dissolves and on treatment with caustic soda, the hydroxide is precipitated, separated, washed, dried, and ignited at about 800°C. The BeO thus obtained is not free from fluoride, but is suitable for making beryllium alloys.

The need to choose a method which will not expose the workers to constant hazard is well illustrated in the report by Vigliani (1949) on the effects of a process for making a copper or aluminium alloy used in Italy in 1940–1943.

The beryl ore was finely ground and mixed with " acid sodium fluoride " and baked at 700°C. (probably in briquette form). Sodium beryllium fluoride is formed, is milled, extracted with water and " soda " and " wet-handled " until beryllium hydrate is thrown down. The hydrate was " dried " to the oxide, ground, milled with ammonium fluoride, and heated in a vacuum oven at 350°C. This yields BeF_2 which was ground by hand and alloyed with copper or aluminium in electric ovens in the presence of magnesium which removes fluorine. The alloys contained 20 per cent beryllium.

Dust of sodium beryllium fluoride, beryllium fluoride, magnesium and sodium fluorides and fumes from molten beryllium were rife, so much so that Vigliani states even flies could not live in the sheds, glass was etched by the contaminated air, and the surrounding country was rendered arid.

Little wonder, therefore, that among 230 workers in these conditions Vigliani found 31 per cent with conjunctivitis and 11 per cent with blepharitis; 24 per cent with dermatitis and 21 per cent with HF (hydrofluoric acid) ulceration of the skin (Vigliani refers to those as torpid skin ulcers: it seems to us likely that these were due to hydrofluoric acid); 30 per cent with bronchitis and 15 per cent with subjective symptoms of thoracic involvement; 30 men with ulcerated or perforated nasal septa and 18 per cent with x-ray evidence of thickening of bronchial walls.

Vigliani held that the dust from the crushed beryl, the oxide and the hydroxide were harmless and that the signs and symptoms were due entirely to beryllium fluoride and hydrofluoric acid.

From the BeO, the stage at which we left the outlines of the processes above, $BeCl_2$ is prepared by passing chlorine over the oxide at 1,000°C. in presence of carbon.

$$2\ BeO + C + 2Cl_2 \longrightarrow 2\ BeCl_2 + CO_2$$

the chloride being separated from the carbon dioxide by maintaining subliming conditions (that is below M.P. of the chloride, 400°C.) and freedom from water vapour and air ($BeCl_2$ produces fumes in moist air). The $BeCl_2$ (a poor electrical conductor) is electrolysed in a high-grade resistant stainless steel pot containing molten salt to which the $BeCl_2$ is added at about 730°C. The anode is of graphite, the steel pot acts as cathode and the electroylsis must be carried out in the absence of air (that is an inert gas is passed in and sweeps out liberated chlorine).

The beryllium is deposited on the inner surface of the pot as a flake which is removed after the process is stopped (that is when the M.P. of the residue has reached a little over the M.P. of the salt, 802°C.). The flakes are freed from salt with water and kept cold and dry to inhibit oxidation.

The nature of the process used in the Italian factory mentioned is similar to that of Kjellgren (1945) for the extraction of beryllium metal, which was devised to overcome many difficulties in the apparently simple removal of fluorine from BeF_2 by means of magnesium. It seems not improbable that the Italian process (details of which are not known to the writer) was far from overcoming these difficulties with a consequent enormous increase in hazards.

With this slight technical background we proceed now to the association of pathological effects with *compounds to which workers can be exposed* in particular processes in which beryllium is extracted or used.

TABLE XIV

PATHOLOGICAL EFFECTS OF BERYLLIUM COMPOUNDS

Beryl ore		There have been no reports of cases of occupational disease in the mining of beryl ore in the handling of the ore before its entry into extraction processes.
Compounds not containing beryllium which occur in the processing of beryllium ore	Acids—	Hydrofluoric and sulphuric;
	Alkalis—	Sodium carbonate; sodium hydroxide;
	Salts—	Ammonium sulphate; ammonium and sodium fluorides; aluminium sulphate
Compounds containing beryllium not associated with pathological effects		Probably none, but there is no reason to regard the finished articles made from a beryllium alloy as harmful on that account
Beryllium compounds	BeF_2 $BeSO_4$	Subcutem lead to local necrosis and fibrous thickening
	Na_2BeF_4	Conjunctivitis Allergic dermatitis Acute irritation of upper respiratory tract Ulceration and perforation of nasal septum Acute pneumonitis (possible connexion with allergic response)
	BeO $Be(OH)_2$	Acute pneumonitis. Chronic berylliosis (connected in some way with positive patch tests to soluble beryllium salts).
	Zn Be silicate.	Subcutaneous granulomas
	Metallic Be in finely divided condition	Acute pneumonitis; subcutaneous granulomas; chronic berylliosis: dermatitis

Excretion and retention of beryllium compounds in the body

Very considerable amounts of beryllium can be excreted in the urine without apparent pathological disturbances. De Nardi and his colleagues (1953) in their observations of 5 workers who had had attacks of acute berylliosis and were still working in the industry found the concentration of beryllium in the urine to vary between 0·3 microgram per litre and 7 microgram per litre. Workers who had left exposure to beryllium still showed values as high as 0·2, 0·5 and 0·6 microgram per litre even 4 and 5 years later. Klemperer and his colleagues (1951) found beryllium in the urine of workpeople 10 years after cessation of exposure.

The retention of beryllium in the tissues has been shown by several investigators and the ultimate significance of this cannot yet be foreseen. Machle and his colleagues (1949) give the following data for beryllium in tissues of fatal cases of acute and chronic berylliosis.

TABLE XV

AMOUNT OF BERYLLIUM FOUND IN TISSUES IN FATAL CASES
(micrograms per 100 grammes)

Type of case	Lung	Liver	Kidney	Bone	Spleen
Chronic – –	20	*	*	3·0	*
Chronic – –	16·8	2·0	0·2	0·4	0·4
Chronic – –	12·0	8·4	27·2	13·5	4·3
Acute – –	20·0	4·0	—	—	—
Acute – –	13·0	0·5	6·0	0·3	0·4
Acute – –	200·0	—	—	—	—
Boeck's sarcoid –	*	*	—	—	—
Boeck's sarcoid –	*	*	—	—	—

* Less than 0·3 microgram beryllium per 100 grammes of tissue.

The tissue analysis of 4 women and 1 female child who died from chronic berylliosis contracted in 4 cases through living almost next door to or within a half-mile from the plant, and in 1 case through contact with the husband's clothing, are given by De Nardi et al. (loc. cit) as follows:

	micrograms	100 *grammes*
Lungs – – – – –	0·1	0·9
Liver – – – – –	0	1·5
Bronchial lymph nodes – –	0·6	10
Spleen – – – – –	0	0·7
Rib – – – – –	0	7·7

The findings in different laboratories analysing the tissues from these cases at various times after death are confusing, but there was no doubt that beryllium was present in many tissues in all the cases.

In the chronic form of beryllium poisoning, whether in the skin, the lungs

or other organ, the emphasis is constantly laid upon the delay in the development of overt manifestations of disease and upon the resemblance between the granulomatous lesions and those of Boeck's sarcoidosis.

The American literature has amply described and illustrated the nature of the chronic lesion. The first case of granuloma of the skin fully described in Great Britain was that of Lederer and Savage (1954), who excised the lesions from a girl aged 20 years who, having received penetrating wounds in the hands and feet from splinters of a fluorescent lamp tube (phosphor contained an average of 8 per cent beryllium as zinc beryllium silicate), developed four painless and non-tender lumps (two were slightly ulcerated) at the sites of injury 4 years later. The histology of the lumps was indistinguishable from that of sarcoid. Some of the nodules showed multiple granulomas (mono-nuclear epithelioid cells surrounded by scanty lymphocytes with a few multi-nucleate giant cells) with much caseation. Beryllium was not detectable in the nodules either histochemically or spectrographically, but the long interval since the initial injuries occurred may account for this. Other observers of these lesions have shown beryllium to be present (*see* van Ordstrand and his colleagues (1950)), but the case of Lederer and Savage appears to have come to notice after a much longer interval than those of other authors.

These tumour-like growths are regarded differently by various observers. Some would claim that in order to develop a granulomatous reaction, it is necessary to have present an adjuvant material which can evoke a histiocytic response. Lloyd Davies and Harding (1950) seem to regard granuloma formation as a response to continuing irritation which occurs " when particulate dust persists in aggregations ". These authors were writing about the lung lesion, but it is not easy to accept the implication that the reaction to beryllium is more or less non-specific and that all that is involved is size of particle, solubility and maintenance *in situ*, although they did say that some of the granulomas they produced by intratracheal injection in rats were related specifically to beryllium oxide.

The identity of the granulomas produced in the skin, in the lungs, in the liver and at other sites would seem to point to a generalized chronic effect of beryllium and to the effect of being specific.

That something more is involved than a straightforward local response is suggested by (a) the long latent period (b) the relative rarity of the lung lesions (in factories which had 3,027 exposed workers during 13 years, only 8 cases of chronic berylliosis were found by De Nardi and his colleagues) (c) the evidence of positive patch-tests to soluble beryllium salts in all cases of chronic berylliosis which had been differentially diagnosed from sarcoidosis by history of exposure to beryllium, the clinical course, x-ray evidence, and determination of lung biopsy material for beryllium. The similarity between chronic berylliosis and sarcoidosis (Besnier-Boeck-Schaumann disease) is great, but the differences are more significant.

Sarcoidosis	*Chronic berylliosis*
No acute form	May follow acute form when latter not fatal
Fatal issue very rare	Mortality high
Lesions do not caseate	Skin lesions do caseate
Frequent eye lesions	No eye lesions
Lesions sometimes found in the myocardium	No myocardial involvement
Probably a form of tuberculosis in subject of high resistance (occasionally tubercle bacilli have been found in cases called sarcoidosis)	Possibility of an allergic response to a Be-protein complex
No loss of weight in patient	Great loss in weight
Often no symptoms	Always symptoms

Osteogenic sarcoma induced by beryllium compounds

From what has been said it is apparent that beryllium as such (that is the beryllium ion) is responsible for a variety of clinical effects which will one day probably all be unified in a single process motivated by it.

In 1946, Gardner and Heslington (1946) showed that the intravenous injection of suspensions of beryllium silicate and zinc beryllium silicate in rabbits induces osteosarcoma after some 8 months. Their results were confirmed by Barnes (1949), using the same compounds, in 3 out of 6 rabbits, and he noted that the particles (? nodules) of these insoluble compounds were visible months after injection in the liver, spleen, lung and other tissues, but did not evoke more than minimal tissue response.

In a later more detailed communication, Barnes, Denz and Sissons (1950) reported that of 17 rabbits which had survived intravenous injection twice weekly of an aqueous suspension of zinc beryllium silicate (non-radioactive; particles $<5\mu$), 6 developed tumours and similarly of 11 survivors of beryllium silicate 1 developed a tumour.

The induction times of these tumours in relation to dose were:

Total dose		*Induction time—weeks after injections*
$Zn.Be.SiO_4$	1·0	32, 53, 61, 83
$Zn.Be.SiO_4$	2·1	45, 49
Be silicate	1·2	39
Be silicate	1·2	30 months

All these animals showed striking medullary bone formation with tumour tissue, sometimes anaplastic undifferentiated round-cell and spindle-cell sarcomas, located in the humerus, tibia, scapula, with metastases in the lungs, lymph nodes, liver and peritoneal and pleural surfaces; tumour emboli found in some of the lungs. The metastases in the lymph nodes seemed to indicate some difference from the usual blood borne metastases in the osteogenic sarcoma found in human subjects, otherwise the beryllium tumours were indistinguishable from human tumours.

The first changes (of a continuous process of malignant transformation) were small beryllium-containing nodules in the bone marrow, and these authors thought that it was beryllium acting upon these nodules which initiated the malignant process. That the metal ion could be liberated in the tissue from the phosphor (highly insoluble even in strong acids) was demonstrated by intradermal injection of 0·1 millilitre of a 10 per cent suspension which was followed by analytical detection of beryllium ion in the surrounding tissue.

As to fibrotic responses, the similar nodules found in the lungs and liver seemed not very active, but in the spleen, where they were also seen, extreme fibrosis and atrophy was encountered without malignancy.

Cloudman, Vining, Barkulis and Nickson (1949) injected rabbits and mice twice weekly intravenously with suspensions of zinc beryllium silicate, zinc silicate and beryllium oxide, until all had received 20–22 injections. These investigators were able to induce metastasizing tumours of bone in both species with the phosphor, but not with beryllium oxide.

Dutra (1949), commenting on the possible significance of their findings for men absorbing beryllium in industry, stated that no such tumours had hitherto occurred and that the doses required to produce tumours far exceeded any possible occupational absorption by man.

Dutra and Largent (1950) in their experiments used male and female young adult albino rabbits from stocks which during 20 years had not had any incidence of osteo-sarcoma. The compounds used were very pure BeO and a phosphor containing BeO, ZnO, SiO_2 in molar proportions. Neither compound possessed any radioactivity and the mean particle size of the powders used was less than 1 μ; each compound was administered intravenously as a 1 per cent suspension in normal saline solution. Each animal was injected 3 times weekly until the doses of beryllium were from 13 to 116 milligrams per kilogram of bodyweight.

Of 9 animals thus treated, 6 that survived for 1 year or more from the first injection developed osteosarcomas, the first appearing in 11½ months. There did not seem to be any relation between the dose and the time of finding the tumour. Tumours were located in the most diverse places—scapula, head of humerus, body of a lumbar vertebra, distal end of femur—in some of the animals they were multiple. Metastases were found in the parietal pericardium, parietal pleura, and the liver of a single animal, as well as in the lungs of all six. Some of the primary tumours broke through the bones and invaded muscles. One tumour was roughly 4½ × 3½ × 2½ in. in size.

The tumours, primary and metastatic, conformed in all respects with those seen in human subjects, and were transplantable into the anterior chamber of the guinea-pig. The white compounds injected were seen in the marrow, in phagocytes and there was a fibrotic reaction in the spleen and the liver. But the tumours themselves were surprisingly free from the injected

materials, whilst liver, lung, spleen were very rich in beryllium, which appears to have been taken up by reticulo-endothelium.

In later experiments Dutra, Largent and Roth (1951) exposed rabbits to the dust of beryllium oxide and found that an animal which had respired air containing 6 microgram BeO per litre on 235 occasions had developed a widely metastasized osteogenic sarcoma on the medial surface of the inferior ramus of the left os pubis. The metastases were in the lungs, pericardium, diaphragm, spleen and liver.

The induction of sarcomas by beryllium metal was demonstrated by Barnes (1950) by the intravenous injection of a washed suspension of the finely divided metal in water. Of 5 rabbits given 40 milligrams of beryllium intravenously, 2 developed characteristic bone sarcomas.

There is no evidence as yet of an occupational carcinogenic hazard, and when the phenomenon of beryllium sarcoma rested solely on the earlier experiments with intravenous injection, it could be suggested that the phenomenon was perhaps somehow attached to this mode of administration (Dutra, 1949). But this phase is now passed, for it is clear that sarcomas can be induced by inhalation of beryllium oxide dust and also that it is the beryllium ion itself which is the initiator of the process. Nash (1950) advises caution against suggestions that these tumours may arise in industrial workers and in support states that although it is reasonable to suppose that workers have during the last 10 years (1940–50) absorbed and deposited beryllium in their bones, no ill-effects have been reported.

We have already seen that people dying from chronic berylliosis (occupational and non-occupational) have varying but sometimes considerable amounts of beryllium in the bones but, as would be expected, much less than is found in intravenously injected rabbits.

Klemperer and his colleagues found 0·06 micrograms per day beryllium in the urine of a worker who had been making beryllium phosphors for 2 years, but who had left that work 10 years before. In some ways more striking was the average daily urinary excretion of 0.11 microgram of beryllium by a worker 15 months after a single day's exposure to the oxide. These authors point out that at this rate of excretion it would take three years to excrete 0·1 milligram of beryllium, which could easily be taken in by a single breath. But they go on to say: " the failure to find beryllium in the urine of a number of patients with pulmonary granulomatosis suggests the possibility that in some individuals disease may result from the inhalation of amounts of beryllium too small to cause detectable excretion. Therefore it is doubtful whether the absence of urinary beryllium can be relied on as an indication of safe working conditions ". Too small to be detectable in the urine may, then, not be too small to induce granulomatosis. One may hope that it is too small to induce sarcomas.

Not every subject who inhales even considerable amounts of beryllium compounds develops chronic berylliosis; not every rabbit injected intra-

venously with beryllium compounds develops a tumour. But if we recall that those which do, must possess significant if unknown characteristics, we may hold that it is too soon to be sure that no long term hazard exists after the absorption of beryllium compounds.

One has seen too many cases of malignant disease long after all vestige of exciting substance has disappeared from the body to be certain that a carcinogen, however administered, will not ultimately show its effects.

So startling an effect of a non-radioactive element and its insoluble compounds invites both experiment and speculation as to the kind of mechanism involved, although it must be conceded that knowledge of undoubted initiators of the carcinogenic process has not hitherto led to any coherent view of the changes in the normal cell which deflect it into the path of malignancy.

The soluble salts of beryllium do not induce neoplastic change, but on intravenous injection are highly toxic to the liver. This latter property is attributed by Aldridge and his colleagues (1950) to the accumulation of a large part of the injected beryllium within the sinusoids. The effect on the liver can go on to necrosis with all the well-known consequences of destruction of hepatic function.

On the other hand, intravenous injections of suspensions of the insoluble beryllium compounds do not specifically pick out the liver, but the particles are picked up by the reticulo-endothelial cells. But we must in addition visualize that even from the insoluble beryllium compounds, there is a gradual liberation of beryllium ions, and that it is these which exert both the granulomatous proliferation action and the sarcomagenic action. The phenomena of acute berylliosis does not, we suggest, appear to differ, at least pathologically, from a powerful chemical pneumonitis which may be as much attributed to the anion as the cation of the beryllium salts.

How to correlate so relatively common a phenomenon as proliferation of granulomatous tissue with so malignant a process as osteogenic sarcoma is unknown.

There are a few observations on the effects of beryllium on phosphatase, which in view of the undoubted relation of phosphatase to bone formation may be worth recalling here.

Aldridge and his colleagues found that in acute poisoning by soluble beryllium salts there is a rise in serum alkaline phosphatase as the jaundice is aggravated by greater destruction of the liver and that liver phosphatase also increases. Hoagland, Greer and Hood (1950) induced sarcomas in rabbits with zinc beryllium silicate and beryllium oxide, but failed to do so with beryllium phosphate. They also found that there was a very great and rapid rise in serum alkaline phosphatase and in phosphatase in the vicinity of and in the substance of the induced tumours as well as at metastatic sites.

Serum alkaline phosphatase is increased in a number of clinical conditions, for example rickets (infantile, adolescent and renal), osteomalacia (adult

counterpart of rickets) osteitis fibrosa and deformans, jaundice, and osteogenic sarcoma.

It was long ago shown by Kay (1930) that malignant disease of bone is associated with a high plasma phosphatase and he was, on the whole, inclined to the view that in such cases it is a secondary phenomenon, that is, presumably, that there is a liberation of this enzyme from the areas of active calcification in the tumour tissue. The findings of Hoagland and his colleagues that the alkaline phosphatase in and around the tumour tissue and in the lung, liver and kidney sites of metastases, was enormously increased compared to normal tissue content confirm those of Kay.

As Kay himself pointed out, it is by no means easy to understand the biochemical function of intracellular phosphatases and in the special case of beryllium it must be added that this ion is an undoubted *in vitro* inhibitor of alkaline phosphatase.

In two studies which arose from the sarcomagenic activity of beryllium, Klemperer, Miller and Hill (1949) showed that kidney alkaline phosphatase is inhibited about 40 per cent by a concentration of beryllium of 10^{-6} Molar and this occurs with any of the ordinarily used substrates, β-glycerophosphate, hexose diphosphate and phenyl phosphate. Further, this inhibition does not occur against acid phosphatase.

Alkaline phosphatase belongs to a series of enzymes which are activated by magnesium ions but Grier, Hood and Hoagland (1949) found that beryllium is a more powerful inhibitor than magnesium is an activator. The same result was obtained using alkaline phosphatase from various sources and notably from the tumours induced by beryllium. No other enzyme system catalysed by magnesium is inhibited by beryllium.

Aldridge (1950) obtained more convincing evidence of the inhibitory action of beryllium on alkaline phosphatase by removing inorganic phosphorus from the enzyme (rabbit kidney) preparation by dialysis, so that the final phosphorus concentration was $5{\cdot}3 \times 10^{-7}$ M. Using beryllium sulphate at a concentration of $5{\cdot}2 \times 10^{-6}$ M, Aldridge obtained 100 per cent inhibition and at $1{\cdot}3 \times 10^{-6}$ M 79 per cent inhibition of the unactivated enzyme, that is about twice the inhibition obtained by Klemperer and his colleagues (1949). The enzyme activated with 10^{-2} M magnesium was 95 per cent inhibited by $1{\cdot}7 \times 10^{-6}$ M beryllium and 70 per cent inhibited by $1{\cdot}7 \times 10^{-6}$ M beryllium. A concentration of beryllium which produced 66 per cent inhibition of the unactivated enzyme only produced 30 per cent inhibition of the activated enzyme.

By time studies of the inhibition and activation of the enzyme, Aldridge produced evidence that magnesium can reverse the beryllium inhibition immediately on contact and suggested that in this competition for the enzyme the source of the toxic effects of beryllium may be discovered.

The specificity of the action of beryllium is emphasized in later work by Klemperer (1950) who showed that it has no effect on the tissue respiration

of liver slices or on muscle glycolysis: adenosine-triphosphatase, carboxylase, arginase, carbonic anhydrase, uricase, are not inhibited. This author definitely attributed the toxicity of beryllium to its inhibition of alkaline phosphatase.

The difficulties of finding a rational explanation of these facts in relation to the induction of granulomas or of sarcomas lie in the contradictory effects which, in our present knowledge, may be attributed to this enzyme, not to mention the multiple possible substrates on which, in theory, it could act *in vivo*.

There can be little doubt that the last word in the story of beryllium has not been said. Cases of chronic berylliosis still appear in spite of the application of many careful precautions. The recent cases reported by Slavin (1952) of 9 women engaged in cathode coating in wireless valve factories who developed chronic berylliosis with 5 deaths, showed on necropsy (4 cases) the characteristic lesions, but only minute amounts of beryllium were found in the lungs. The variable susceptibilities of different subjects notwithstanding, it is clear that the levels of so-called permissible concentrations in the working environment must be scaled down to almost vanishing point.

De Nardi and his colleagues summarize the recommendations in respect of permissible concentrations from those of Eisenbud and his colleagues (1949) and of the U.S. Atomic Energy Commission thus:

Daily average permissible concentration in the working environment – – – – –	2 μg/cm.
Transient concentration never to exceed – –	25 μg/cm.
Monthly average concentration of beryllium in the atmosphere in the vicinity of a beryllium plant not to exceed – – – – – – –	0·01 μg/cm.

This last rather startling figure is based on a very careful study by Eisenbud and his colleagues of the atmospheric pollution with beryllium at various distances from a particular plant, in the vicinity of which chronic berylliosis had occurred from *non-occupational exposure* in 11 persons of whom 3 died.

We abstract data from this paper which are of considerable interest relating the occurrence of cases, distances from the beryllium plant and the estimated concentration in the air at these distances:

TABLE XVI

Distance from plant (mile)	Number of cases	Ground-level estimated concentration at noted distances, μg Be per cm. (read from curve)
0–¼	5	0·1–0·2 at ¼ mile downwind
¼–½	3	0·08 at ½ mile downwind
½–¾	2	0·045 at ¾ mile downwind

The authors estimated that the average concentration at ½ mile from the plant during the preceding 7 years in which no cases had occurred lay between 0·01 and 0·1 microgram per cubic metre.

But it was in the period prior to 1946 in which these cases developed that the concentration at ½ mile was estimated at about 0·1 microgram per cubic metre.

This then was the rationale of the recommendations as to the areas in the vicinity of the plant.

Moreover, it appeared that the incidence of cases in the plant, in spite of high atmospheric contamination (production of BeO, Be—Cu and Be), was relatively low, a fact attributed by Eisenbud and his colleagues to possible smaller particle size of the dust carried away from the plant through the stacks.

Present position in Great Britain

Berylliosis is a prescribed disease in Great Britain but experience of it is small. The Chief Inspector of Factories reported in 1950 that a close watch was being kept on the conditions of extraction of the metal and of the manufacture of fluorescent lamps. Dust control is under supervision, but no information is given as to what standards are applied. Periodical medical examinations of workers is carried out with particular attention to records of weight.

There has been 1 fatal case of chronic berylliosis and 1 case of acute berylliosis with recovery.

In the factory where the fatal case occurred, x-ray examination of 60 men and 78 women gave no evidence of pulmonary granulomatosis, although 16 showed changes not associated with symptoms.

The further development of knowledge of the extraordinary effects of beryllium ion rests with future research.

SOOT

In recalling the often quoted publication by Pott (1775) on "Chirurgical Observations relative to the Cataract, Polypus of the Nose, the Cancer of the Scrotum, the different kinds of Rupture and the Mortification of the Toes and Feet", it may be wondered whether a modern study by a statistician of the data upon which Pott made his statement of relation between occupation and disease would have substantiated his claim. Pott's original description of the disease is contained in a small section of a small treatise.

The first to attribute the scrotal condition to soot were the victims themselves who called it the Soot Wart and we may surmise that just as Ramazzini took note of the views of the sufferers from industrial disease so also did Pott. This is well shown by the following paragraph : " The fate of these people seems singularly hard; *in their early infancy*, they are most frequently