fuel. New power sources are therefore of considerable long-term importance, though other potentialities should be pursued in addition to nuclear power.

Dr. H. Seligman spoke next on the immediate benefits which atomic piles are providing, in particular the industrial use of radioactive isotopes. The expansion of radioisotope production at Harwell has been so rapid that practically all the surplus neutron flux in B.E.P.O. is now used, and a limit to the supply of radioactive materials requiring high flux—such as radiographic sources—may very soon be reached, unless measures are taken to increase the available neutrons.

A number of industrial applications were described. The use of thickness gauges using a β-emitter as a source on one side of a continually produced strip and a detector on the other is extending from the paper, plastic and cardboard mills to steel mills, and for this purpose the fission product strontium-90, which emits an energetic β-ray, is required. For this purpose facilities for the separation of substantial quantities of fission products are being installed at Harwell. At present only pilot-scale facilities are operating.

'Static eliminators' containing thallium-204, for the dissipation of undesirable electric charges, are being made experimentally at Harwell and lent to firms for trial. It is thought that in six months or so static eliminators will be available commercially to satisfy all industrial demands.

Other applications make use of the extremely sensitive methods of detecting radioactive elements. For example, radioactive sodium is being used to trace a suspected leak from a lake containing fifty million gallons of water to coal pits. Radioactive bromine contained in an organic compound has been used to check the ventilation system of a factory; radioactive sodium has been used to check the efficiency of mixing of one gram of a vitamin in five tons of cattle food.

Radioactive cobalt has been used in several pipe-line operations. At the Gasification Research Station the intersection of two borings in a coal seam was facilitated by inserting a 500-millicurie cobalt source in one seam and a detector in the other. The clearing of long pipe-lines is assisted by making the scrubber radioactive, so that its position can be determined in case of blockages.

These are a few representative applications out of a hundred or so which the Atomic Energy Research Establishment has developed or helped to develop for industry. It is believed that much more use of isotopes could be made in industry, and it is hoped to start at Harwell in the early part of 1951 a training school in their applications.

Mr. W. S. Eastwood described the application of isotopes to radiography in industry. The Harwell pile is now producing γ-emitting sources having conveniently long half-lives—60 days to 5 years—and a wide range of γ-ray energies, so that the energy most suitable for the job can be chosen. The isotopes in most demand are radiocobalt (half-life 5·3 years; energy 1·1, 1·3 MeV.); radioiridium (half-life 70 days; energy 0·30, 0·47, 0·60 MeV.) and radiotantalum (half-life 120 days; energy 0·15, 0·22, 1·13, 1·22 MeV.). In the future, sources of europium (half-life 5 years; energy 0·12, 0·34, 0·41, 1·2 MeV.); cerium (half-life 275 days; energy 1·25, 0·22 MeV.) will be available.

One of the advantages of these radioactive sources is that they are comparatively easily and safely handled, and that they can be reactivated after decay by returning to the pile. They are standardized in the form of cylinders having a diameter equal to length with dimensions of 6 mm., 4 mm. and 2 mm. Specific activities can be as high as several curies per gram. The use of these isotopes is extending steadily in industry, both in Great Britain and abroad. The number which can be produced will be limited by the surplus neutrons available in B.E.P.O.

CLIMATIC LIMITS OF VEGETATION

THE climatic limits of the major types of vegetation and of plant species, especially those of economic importance, are a topic of great practical as well as theoretical interest. In Great Britain it has received comparatively little attention, doubtless because the range of climate in the British Isles is relatively insignificant and the effects of other ecological factors more striking. The subject was therefore appropriate for a joint meeting of Sections K (Botany) and K* (Forestry) of the British Association held at Birmingham on September 1.

Prof. P. W. Richards (University College, Bangor) opened with a discussion of the climatic limits of the Tropical Rain Forest. The optimum conditions for its development are found in areas such as the Malay Peninsula, where the climate is characterized by high and evenly distributed rainfall. Towards the periphery of the Tropical Rain Forest (using the term in the broad sense originally proposed by Schimper), the rainfall becomes more seasonal in its distribution, until a limit is reached where evergreen forest gives way to deciduous forest or savanna. This increasingly uneven distribution of rainfall is accompanied by an increase in the seasonal variation of temperature, but there is little reason for believing that temperature plays much part in determining the limits of the rain forest in lowland country. The altitudinal limit on mountains seems to be partly due to temperature, though even there other factors, such as reduced light intensity due to cloudiness, are probably important. In general, the evidence points to moisture conditions as playing the chief part in limiting the rain forest, which is thus controlled by factors affecting the ability of the vegetation to maintain its water balance rather than by factors affecting photosynthesis or the length of the growing season.

If this is so, we should not expect a very close correlation between the rain forest limits and any simple expression of climate, since factors such as soil texture, drainage, etc., affecting water uptake, are likely to be as important as factors affecting the rate and amount of water lost in transpiration.

The complexity of the factors controlling the boundary of the rain forest is well illustrated in Africa. In the Central Congo basin, Bernard[1] found a satisfactory correlation between the distribution of typical rain forest, peripheral transitional areas and savanna with Köppen's *Af*, *Am* and *Aw* climates respectively; but in West Africa conditions are not so simple. In Nigeria the boundaries between 'True Rain Forest' and 'Mixed Deciduous Forest' and between the latter and the savanna seem to be correlated not, as might be expected, with the length of the dry season, but with the total annual rainfall. As the annual total depends largely on the amount of rain falling in the wet months, which is far in excess of what can be taken up by the vegetation or stored in the soil, it is likely that the controlling factor is really the evaporating power of the air during the dry season. Recent work has shown a fairly close relation between the vegetational boundaries and the lowest mean monthly relative humidity. The limits of the rain forest in Nigeria are, however, not determined solely by climate, but are also influenced by edaphic factors such as soil depth and texture.

The next contributor, Prof. A. A. Boughey (University College of the Gold Coast), taking the place of Prof. John Walton, who was unable to be present, showed a colour film of Nigeria. The three climatic zones of the West African savanna, Guinea, Sudanian and Sahelian, were depicted.

Prof. A. Austin Miller (Reading) said that a hundred years ago the prospect of finding a simple correlation between the distribution of vegetation and climate seemed good. This optimism had proved ill-founded, and ingenious efforts to replace simple climatic values by more complicated expressions had been unsuccessful because they tried to be universal in application, they ignored factors other than climate, and were attempts to fit the vegetation to the climate rather than *vice versa*. The factors controlling types of vegetation as diverse as Tundra, Steppe and Tropical Forest are probably quite different and must be independently determined.

One control which can be demonstrated to be important, though only at fairly high latitudes or altitudes, is 'accumulated temperature'. This value, also called the 'remainder index', is a device for assessing the accumulated effective warmth, measured in day-degrees, above some more or less arbitrary threshold value. The method of calculating day-degrees recommended by the Meteorological Office cannot be applied on a continental scale; but a good approximation is obtained if the difference between the monthly mean temperature and the threshold is multiplied by the number of days in the month.

The importance of accumulated temperature was recognized by Boussingault in 1837. At first the freezing point was used as the threshold temperature, but later it was found that a figure around 42° F. is more suitable, at least when temperate crop plants are being considered. The basal temperature is different both for different plants and for different plant functions. For citrus fruits, recent work in California suggests 55° F. as the correct threshold and 1,200 day-degrees as the minimum requirement for satisfactory fruiting.

With plant formations the choice of a threshold temperature bristles with difficulties. Nevertheless, there is close agreement between the Arctic timber line and a value of 18 month-degrees above 43° F. Experience is against the view that the efficiency value of each degree above the threshold is equal; but an empirical comparison of climate at the limits of vegetation types is likely to give better results than attempts to fit the increase in rate of growth with rise of temperature to an exponential curve. To illustrate this, data have been assembled for a large number of stations near the northern timber line in Eurasia and North America. In all these stations the mean temperature of the warmest month is higher than 50° F. (thus finally discrediting the 50° isotherm for the warmest month). A growing-season of two and a half months over 43° is enough for coniferous trees in continental climates; but in maritime regions a growing season up to four months is required. Sixteen–twenty month-degrees are needed away from maritime influences. There is no evidence to suggest that temperatures of, say, 50°–60°, are more effective than those of, say, 40°–50°. This gives some encouragement for the belief that, except where superseded by killing frosts, the critical factor limiting vegetation types in high latitudes is accumulated temperature, which can best be expressed as a remainder index. This should give a measure of the heat received, during a period yet to be defined, above a critical threshold.

The last speaker, Mr. J. MacDonald (Forestry Commission), considered a practical aspect of the problem, namely, the importance of climatic limitations in British forestry. In Britain, exotic trees are of prime importance because the native tree flora is so small. Climate restricts the number of species which can be grown and limits the range within which particular species are successful. It affects both the establishment and regeneration of trees and their over-all performance.

In Great Britain occasional severe winters and frosts during the growing season are more important than mean temperatures and variations in the seasonal distribution of rainfall. Eucalypts reach large dimensions in favoured localities in Scotland and could be used in forestry, but for exceptional winters; and Asiatic larches are excluded from practical use because of their susceptibility to late spring frosts.

Japanese larch and Corsican pine illustrate the effect of climate on the range of a species for forestry purposes. The former can grow almost anywhere in Britain, but it is much more successful in the north and west than in south-eastern England, probably because it requires fairly abundant rainfall during the growing season. The Corsican pine also grows in all districts, but is not reliable above 700 ft. This seems to be owing to frosts in autumn; Day has shown that the cambium is still active in October.

Frosts in the growing season are indeed the most hampering feature of the climate of Britain for the forester. This is especially true of Breckland, where frosts may occur even in June and July. A possible solution to this problem is to mix frost-resistant with less hardy species, so that the latter obtain some protection during the stage of growth when they are most susceptible. A more permanent solution may be to select late-flushing strains or to breed in frost-resistance by crossing. One example of the effect of climate on regeneration is the enormous loss of tree seedlings due to frost-lift, especially on impervious soils.

The most important way in which climate affects British forestry is by fixing an upper limit for successful planting. The chief factor involved is undoubtedly exposure to wind, though mechanical injury by snow is also important. Little is known about this subject, because in the past foresters rarely tried to plant trees at high elevations and the natural forests of Britain give little clue to the safe upper limits for planting. Trial plots at various altitudes near Beddgelert in North Wales suggest 1,250–1,750 ft. as the practical limit for forestry, but different species are strikingly different in their behaviour at high altitudes, and much more information is required.

In the open discussion which followed the papers, Dr. Syrach-Larsen (Denmark) pointed out that *Pinus radiata* is an example of a tree with a very small range as a native species, but capable of growing as a crop under a very wide range of conditions. Other speakers stressed the importance of extreme, as well as mean, conditions, and also directed attention to the importance of microclimates.

P. W. RICHARDS

[1] Bernard, E., "Le climat écologique de la Cuvette Centrale Congolaise", *Pub. Inst. Nat. Agric. Congo Belge*, 1945.

'FRESHLY FRACTURED SURFACE' THEORY OF SILICOSIS

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FROM time to time, references have appeared in the literature of silicosis to the importance of fresh grinding of silica in the production of disease. Although this question appears never to have been experimentally investigated*, certain recent publications have suggested that the belief in the importance of freshness is widespread, and has influenced the conduct of experiments, as well as leading to the evolution of theories based on the assumption that it has been completely proved. It therefore seems worth while considering the history of this theory, and the evidence for and against it.

The idea appears to have been first mooted in 1935 when, following the publication of the work of Bragg[1] on the crystal structure of silica, it was suggested by Heffernan[2] that this substance's peculiar biological activity could be explained by the presence of unsatisfied valencies at the surface of its particles.

Heffernan recognized that these valencies could be satisfied by hydration, which would occur very rapidly in any normal atmosphere, and therefore it was necessary to postulate, in support of the theory, that only freshly fractured dust was active. There was no evidence in favour of this postulate, and even at that time there was considerable experimental evidence against it. The work of Gardner[3] had shown that it was possible to produce silicosis in animals by exposing them to the inhalation of clouds produced by stirring up commercial ground silica. Although Gardner was in the habit of buying this by the ton ready ground, and keeping it for many years before use, he never observed any deterioration in its power to produce silicosis. Moreover, one of his most strikingly successful experiments[4], which was extensively quoted by Heffernan (*loc. cit.*), was the parenteral injection of graded sizes of quartz, the grading being produced by a tedious process of water sedimentation and decantation, involving the suspension of the silica in water for periods of days before its injection, so that there would be ample time for hydration and leaching of the surface to take place.

The possibility that freshly fractured silica surfaces were especially active was again suggested in 1938 by Briscoe and others[5], as a result of experimental studies of the physico-chemical properties of finely ground materials. They suggested it as a possible ". . . explanation of the failure of attempts in the past to induce silicosis in animals by exposing them to artificially induced dust clouds". They did not state what experiments they referred to; but since there are a number of other possible explanations for the failure of attempts of this kind, a hypothesis which purports to explain the failure of any experiment must also explain the success of those of Gardner.

Although these defects in the 'freshly fractured' silica theory were well known to many workers in the field of experimental silicosis, no arguments were publicly adduced against the theory and, as a result, it became tacitly accepted as true by many people, and was adduced as an explanation of certain other phenomena. For example, Denny, Robson and Irwin[6], in their classical experiment on the prevention of silicosis with metallic aluminium, used a tumble-mill method for the production of the quartz cloud, and attributed the fact that they produced silicosis in rabbits in such a short period as six months to the use of a 'freshly fractured' cloud. In the absence, however, of any precise data about the concentration and size analysis of the cloud (they sampled only with a konimeter), it is unjustifiable to interpret their results in this way.

In 1947 Policard[7] reasserted the theory and gave the following examples:

(1) In spite of the fact that the sheep in the North African desert are continually exposed to the inhalation of sand, they do not develop silicosis. This he attributed to the fact that desert sand was weathered and therefore had no unsatisfied surface valencies.

(2) Sand-blasters are liable to silicosis because, although only exposed to the inhalation of sand which, as stated under (1) above, is weathered, and therefore harmless, the sand is broken up by heat and impaction and therefore presents 'freshly fractured' surfaces.

(3) Silicosis used to be common among millstone workers, in spite of the fact that the concentration of the dust cloud to which they were exposed was apparently very low, because the dust was freshly generated and therefore 'active'.

Policard's statements were not much disputed at the time, although King[8] suggested that the period required for hydration was so short that it would take place usually before the inhaled particles reached the alveoli, and also pointed out that, as mentioned above, Gardner had frequently produced silicosis in animals with dust nearly twenty years old.

The fallacy in the 'desert sand' theory was pointed out later by Heywood[9], who quoted the evidence of Bagnold[10] to show that desert sand contains very few particles less than about 200 μ in diameter and that the airborne dust in the desert comes from adjacent arable land and is almost entirely non-siliceous. The failure of desert sheep to develop silicosis can therefore be readily understood, and the liability of sand-blasters to the condition can be explained simply by their exposure to the finer particles produced by the shattering of the sand grains, without any need to postulate special activity of the surfaces of the particles.

The third example adduced by Policard is entirely speculative, since there is little or no evidence about the concentration and composition of the dust to which the workers were exposed.

These objections, however, appear not to have been generally recognized, and the 'freshly fractured' theory continues to enjoy a popularity for which it is difficult to see any justification. For example, Briscoe[11], Heffernan[12,13] and Policard[14] have all

* Recently, Rüttner (*Z. Unfallmed. Berufskr.*, 1, 66; 1950) has published results of experiments in which silica dust extracted from the lungs of deceased silicotics was injected intraperitoneally into mice and shown to be as active as freshly ground dust. These results cannot, however, be accepted without reserve, as the process of extraction of the dust from the lungs involved vigorous treatment with strong acid, which might be said to have created fresh surfaces on the particles.