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Water Department

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Dear Thomas,

Following our discussion with Kenny, I have looked at the ground-water movements with which we are likely to be concerned at Mundford. The movement can be broken into two main categories - vertical movement in the unsaturated zone and horizontal movement in the saturated zone. Each of these movements includes two components - movement through the mass of the chalk and movement through fissures. The limited available evidence indicates that the hydraulic conductivity of fissured chalk may be of the order of  $10^3$  times greater than that of the unfissured chalk.

Measurements have been made of the rates of infiltration (vertical movement through the unsaturated zone) into small (6 feet square) shallow (3-6 ft deep), artificially filled lysimeters, but in my view extrapolation of these measurements to the conditions at Mundford where the rest water level is up to 80 feet from the surface would be unwise. Unfortunately alternative field data are totally lacking. We should, therefore, start from first principles.

Vertical movement through the unsaturated zone of the chalk

On your assumption that we are concerned with irradiation of water within 6 feet of the tunnel walls and on CERN's suggestion that the base of the tunnel should be at least 8 to 9 feet above the water table, we must obviously examine most closely the vertical velocity of ground water in the unsaturated zone. This water will be derived from precipitation which infiltrates to below the soil layer.

(i) Movement through the mass of the chalk: Porosity of the chalk can be assumed to be of the order of 30 per cent. The specific retention of chalk is high, however, and below the root zone the bulk of the pore spaces in the chalk will remain saturated for most of the year; any reduction below 100 per cent saturation will result from slow drainage under gravity. Laboratory measurements of the hydraulic conductivity of saturated, random samples of chalk show a range of from  $10^{-2}$  to  $2.5 \times 10^{-1}$  gallons per day per  $\text{ft}^2$  ( $4.87 \times 10^{-4}$  to  $1.22 \times 10^{-2}$  darcies: 1 darcy = 0.966 cm/sec for water at  $20^\circ\text{C}$ ). In the unsaturated zone at Mundford the chalk will drain under gravity as mentioned above, and the hydraulic conductivity will differ from the value given. In my view, problems of air entrapment will probably reduce the hydraulic conductivity of the mass of the chalk in these conditions but no factual data are available on this point. The probable velocities of water in the mass of the chalk are such that this water would be exposed to irradiation for a very long period of time. Although I am not able to quantify this statement it seems probable, however, that its volume is likely to be small in relation to that of the fissure water which is moving through the area and the hazard which it creates is correspondingly reduced.

(ii) Movement through fissures: In an area such as Mundford where the rest water level is subject to a seasonal fluctuation of some 10 to 15 feet and where Boulder Clay is lacking, we can assume that there is likely to be fissure connection between the base of the soil and the top of the saturated zone of the Chalk.

Dr. R. Thomas,  
The Rutherford Laboratory,  
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Berks.

/ A subjective

A subjective approximation to the rate of movement through fissures in the unsaturated zone can be obtained from consideration of well hydrographs and rainfall in the vicinity of the Mundford site. The water level in a well at Cranwich Heath varied from 35.40 to 31.40 feet below surface between 5th November and 31st December 1965; most of the rise in level took place after 10th December. The Meteorological Office have indicated that any soil moisture deficit in this area is likely to have been made good by about the end of November and, accordingly, infiltration will have taken place thereafter. Indeed a certain amount may have preceded the elimination of the deficit. The rise in water level shown by the hydrograph can be related arbitrarily, but not unreasonably, to rain which fell on or about the 1st to 3rd December. If this approximation is valid, and if it is also assumed that movement is vertical, this would imply a rate of infiltration of 35 feet in seven days, i.e. approximately 150 cm per day. Alternative, but still reasonable, interpretations of the same facts could imply that the velocity indicated is too low by a factor of 2, or too high by a factor of 5. I assume that the latter condition (too high by a factor of 5) would provide the worst hazard so far as irradiation is concerned because the water would then be subject to radiation for a longer period of time.

In summary, the vertical velocity past the tunnel will range from the extremely slow values indicated by the permeability measurements quoted above, to a maximum of perhaps 300 cm per day. I suggest that 150 cms/day may be a reasonable working figure for the fissure water. I do not feel able on present data to suggest a comparable value for the water moving through the mass of the chalk. I can merely indicate that the volume of water involved is extremely small, owing to the low permeability of the chalk.

#### Horizontal movement in the saturated zone of the chalk

I assume that in the saturated zone the higher velocities represent the greatest risk. This is because irradiated water which has arrived in that zone will be transmitted most rapidly to the nearest natural discharge or artificial abstraction point and there will be less time in which the radionuclides can decay. I assume that the slow movement through the mass of the chalk can be ignored as the water will be more than 6 ft from the tunnel floor..

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So far as fissure flow is concerned, however, we are faced with a range of velocity. So far as I am aware, there are no field data relevant to the particular area and we must again deal with the 'normal' chalk condition. The above statement that the hydraulic conductivity of the Chalk as a formation is some  $10^5$  times greater than that of unfissured chalk samples is relevant here. Some specific indication as to velocities can however be obtained by cases involving pollution. For example, a chemical pollutant is known to have travelled  $2\frac{1}{2}$  miles in 24/30 hours - the exact interval is not known. Assuming that it moved indirectly to the natural discharge point where it was identified, the velocity is equivalent to, say, 0.1 miles/hr (0.44 cms/sec). Allowing for the circuitous route that the pollutant may have travelled, the maximum velocity involved might be up to 1 cm/sec. Most ground water is thought to move far more slowly than this, even in fissures. Exceptionally it may move more rapidly but I suggest that 0.5 cm/sec would be a not unreasonable velocity for you to consider, provided that it is appreciated that it may be exceeded exceptionally.

I cannot emphasize too strongly that the problem we are concerned with is specific to the particular field conditions at Mundford. Of the values which I have quoted, only those relating to the Cranwich Heath well are derived from this particular area. Any computations resulting from the values quoted must be viewed in this light.

I look forward to hearing the results of the beryllium experiment.

Yours sincerely,

  
(D.A. Gray)