RE-CONSIDERATION OF SHIELDING REQUIRED FOR HARWELL CYCLOTRON

The present form of shielding was based on figures supplied by A.G. Ward. The conclusion arrived at by Ward was that 4' of concrete or 3.0' of water with boron in solution as sodium metaborate would be adequate but that 6' of concrete and 4.5' of water were desirable. Ward advised however, that the cyclotron be housed in an excavation to permit earth shielding on three sides.

The three alternatives of concrete walls, water tanks and excavation were put up to the Ministry of Works by Dr Dalton for consideration. The first method was stated to be easier and cheaper and the third method the dearest. Consequently the concrete wall protection was proceeded with. Initially this was 6' all round but later reduced to 4' on three of the walls. The water tanks on the roof were to hold 3.5' of water with sodium metaborate in solution if necessary. The two sliding doors would also have water in them.

Two points have now arisen and led to a reconsideration of the above shielding arrangement. The first is the information on the proposed shielding at Harvard for the 92 inch. F.M. cyclotron brought over by Dr Bowden. Harvard are to use 5' of water and at least 3' and possibly as much as 8 ft of earth in addition. The second is the fact that Ministry of Works require 12' of concrete as foundation for the concrete walls this meaning that quite a large excavation will have to be undertaken even with the concrete wall shielding arrangement.

Dealing first with the Harvard figures for shielding we find that the tolerance dose of fast neutrons taken by Ward ($200/cm^2$)/Sec) is over 40 times greater than that taken by Bainbridge ($4.4/cm^2$)/sec). This seems to be partly accounted for by a factor of 10 taken by Bainbridge to represent the increased ionisation of 100 MeV particles over 10 MeV on which the tolerance dose was based. In addition Bainbridge has taken the safe figure of 10^{-5} for the reduction due to 5' of water this being based on Dancoff's calculation for 10 meV neutrons whereas Wards figure for the same thickness is $3.1\ 10^{-7}$. (Livingstones figure, however, would be even larger, namely $3.1\ 10^{-8}$). These two considerations account for the differences in designs of shielding at Harvard and Harwell. However, it was thought worth while to re-estimate the protection afforded by the present design of Harwell. This is given below.

The maximum output expected for protons is 100 - 150 MeV at 1 - 5 μAs.

For protons on Lithium it is estimated that 4 μAs at 100 MeV will give $3.6\ 10^{12}$ n/sec. Note:- For 16 MeV deuterons on Beryllium neutron yield is $6.4\ 10^{12}$ n/sec for 200 μA

Take a figure of 10^{13} n/sec as the maximum yield likely.

Tolerance dose for fast neutrons of energy round about 10 MeV is taken as 0.01 n/day.

For 100 MeV estimated dose is 0.001 n/day.

1 n unit = $3.8\ 10^8$ neutrons n/cm^2

So tolerance neutron dose is $3.8\ 10^5\ /cm^2$ which is $4.4 n/cm^2/sec$ for 24 hour day exposure.

Total reduction required is therefore between 10^{-12} and 10^{-13}

Protection of water is given at 10^{-6} for 4' by Livingstone at about 10 MeV.

Protection of earth or concrete is not known. Ward assumes $6.2\ 10^{-6}$ for 4' of water and 10^{-4} for 4 ft of concrete.

Intensity at nearest concrete wall 15' or about 500 cms. away from target is given by

$$\frac{10^{13}}{4\pi(500)^2} — 3.2\ 10^6\ n/cm^2/sec.$$

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For 6' of concrete this gives 3.2 cm^2/sec using Wards figure, or 0.2 cm^2/sec taking concrete as being half as good as Livingstones figure for water.

At the workshop 80' or 2500 cm. away the neutron intensity without shielding is

$$\frac{10^{13}}{4\ (2500)^2} = \frac{10^{r}}{.25} = 1.3\ 10^5\ /cm^2/sec.$$

With 4' of concrete this gives 13 /cm^2/sec. using Wards figure or 2 /~~sq~~. cm^2/sec. taking concrete as being half as Livingstones figure for water.

For most of laboratories protection is the same as for the workshop or rather better as the distance away is somewhat greater than 80 ft. For the nearest laboratory and for the control room most of the direct radiation will have to pass through the 4' of water in the sliding door . This will reduce the neutron intensities to 0.13 /cm^2/sec. for Livingstones figure or 0.8 for Wards figure.

At the water tank roof 10' or 300 cms. away the neutron intensity is

$$\frac{10^{13}}{4\ (300)^2} \quad - \quad 10^7\ /cm^2/sec.$$

With 3.5' of water this reduces to 55 /cm^2/sec from Livingstones figure and 280 /cm^2/sec. from Wards figure at the top of the water tanks.

In addition scattering through the watertanks which arrives at the control room or workshop 80' away will have an intensity of 0.75 /cm^2/sec for Livingstones figure or 3.6 /cm^2/sec for Wards figure.

For gamma rays the tolerance is 1.3 10^3 gamma ray quanta for continuous 24 hour working. This is at 2.2 MeV. Sodium metaborate in solution with water will be used in the tanks. The nearest laboratory or workshop is 30' from the water tank door.

5 to 10 gamma rays are produced by each neutron and the number of neutrons at water tank door is 26 10^5.

The worst condition for gamma rays is when all the neutrons incident on the water tank release gamma rays in the first few inches of water. The reduction in intensity of 2.2 MeV gamma rays produced by 4' of water is about 4 10^{-4} so at the water tank door about 10^3 gamma ray quanta escape.

Conclusions are that if Livingstones figures are correct then Target Room, Control Room and Workshop are quite safe. Side walls near Cyclotron and Roof above water tanks however are rather unprotected as far as neutrons are concerned.

For gamma rays the protection should be adequate if sodium metaborate is used in all the water tanks but will be somewhat higher than tolerance if this is not done.

There does not seem any definite justification for changing the present concrete shielding arrangement from the point of view of inadequate protection and it is always possible to introduce additional shielding inside the enclosure in the form of movable water tanks and paraffin blocks.

However, the second point has raised a doubt as to whether the excavation shielding has been given a fair consideration. This is dealt with in a separate note by Hadley who estimates that it would be £2000 cheaper than concrete and probably quicker because of labour considerations. The disadvantage of the excavation shielding is mainly in accessability and in actual assembly of the magne It should however be given more thought firstly because of the slowness of progress in the Harwell Cyclotron Hangar due to shortage of the necessary grade of labour and secondly due to the large discrepancies in figures for protection obtained from different sources.

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