DISPOSAL OF A 400 MeV SYNCHROCYCLOTRON AND A SUMMARY OF MONITORING DURING NORMAL OPERATION

I. Birchall,

Radiation Protection Officer,
University of Liverpool, England.

1. INTRODUCTION

The Liverpool Synchrocyclotron started to operate in May, 1954, gave an internal beam in July and an external beam in January 1955, and this report summaries the dose to personnel from 1954 to 1968 when the machine was finally closed down and the subsequent dismantling and disposal in the period 1968 - 1971.

The Synchrocyclotron was designed to produce an extracted proton beam of energy 383 MeV at a current of 3 x 10^{-2} microamperes. Neutrons having energies in the range 200 to 400 MeV and pion beams having energies of 96 MeV and 150 MeV were produced.

The siting of the accelerator was, by the standards of the 1970's, somewhat unfortunate. The machine room wall abutted directly on to private land owned by the church and to which the public had access and the experimental room opened directly on to a public street with houses in the immediate vicinity. But the worry about external radiation levels sometimes paled into insignificance at the activities of the local children. The neighbourhood of the accelerator buildings presented a fairly hostile environment for children and one of their favourite diversions was to break through the wire fence and to make a den in some suitable corner. A favoured spot on top of the shield wall and below an access corridor had a neutron beam intensity of some 3 rem/week. It may also be argued that the rigid site boundary necessitated by its location in the City lead to a premature closure of this accelerator, since there was no possibility of expanding the experimental facilities.

Bulk shielding was provided on one side by the solid rock face into which the building was sited, on two sides 6 feet of concrete plus 15 feet of pulverised sandstone was provided. On the fourth side the experimental room was sited and the shielding between this area and the machine room consisted of a fixed shield of 12 feet of concrete plus removable steel loaded concrete blocks (ρ = 5.0, 300 lbs/ft^3) equivalent to 24 feet of ordinary concrete. The roof was of concrete 5½ feet thick.

Access was limited to a cylindrical steel door of 7 feet diameter filled with sand and weighing 30 tons at the ground floor level, or a doorway in the roof. Both doors were provided with double interlocks, one magnetic and a simple microswitch.

The bulk shielding was generally adequate, the weaknesses lay in the door and the roof. An internal screen wall was provided between the door and the machine, without this a fairly sharp beam was produced in areas outside the perimeter fence. Roof penetration produced a neutron exposure rate of some 3 rem/week in rooms adjacent to the upper section of the accelerator building. This was effectively reduced by the simple expedient of moving the interlocked door down the corridor so as to include the high level area within the accelerator control area.

In 1965 the site adjacent to the accelerator was levelled during the construction of a Cathedral, this meant that some of the natural rock which had formed one of the shield walls was appreciably reduced in thickness. The building of the Cathedral fortunately coincided with the gradual run-down of the synchrocyclotron as further complications arose, as the Cathedral building began to tower above the cyclotron building it became possible for people to jump on to the roof of the experimental room and hence gain access to the roof of the machine room. Children did in fact do just this and the roof had to be fenced off.

2. PERSONNEL MONITORING

Personnel dose was routinely monitored by film badges and track plates used on a two-weekly change system. During special operations, for instance emergency repairs, use was also made of Q.F.E's and finger doses were occasionally checked during maintenance work. In looking at the doses recorded it must be borne in mind that as most of the radiation fields had very steep gradients the dose measured was critically dependent upon the position in which the film was worn. For instance during cleaning operations a comparison was made between film badges clipped on the trouser belt and Q.F.E's in the top pocket. The following were obtained during the cleaning, inspection, dismantling and removal of the chopper.

	Operator 1	Operator 2	Operator 3
Film dose (mr)	29	31	67
Q.F.E. dose (mr)	110	175	50

These doses are typical of the general level received on maintenance work, when the radiation levels varied from approximately 70 mr/h near the mouth of the 'c' to some 6 r/h at the target.

Recorded finger doses were never very high, usually in the range 50 to 150 mr, this in spite of having to handle materials having surface exposure levels of between 250 and 1500 mr/h. (Typical surface exposure rates were 270 mr/h(Al), 495 mr/h(Fe) and 1200 mr/h(Cu).)

It was common practice to take air and smear samples during maintenance operations but these never registered high levels. Common figures for air and smear samples were $10^{-10}\mu c/cm^3$ (1/10th m.p.c) and $10^{-6}\mu c/cm^2$ respectively.

The body doses recorded for members of the crew were relatively high as can be seen from the annual totals listed in Table 1.

Table 1

Initial	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
E.W.	0.85	6.05	6.7	4.7	3.85	3.45	3.05	3.3	3.5	3.59	1.81	1.14
L.H.	1.06	5.60	8.3	5.3	4.05	3.17	2.43	4.69	3.2	2.39	2.0	1.52
B.H.	1.20	4.35	6.0	3.5	2.48	0.85	1.39	0.81	1.38	.76	-	-
A.C.	1.00	4.90	6.6	3.95	4.48	0.71	3.14	3.12	2.38	1.59	1.18	.89
H.M.	-	4.25	5.9	4.3	3.65	0.95	2.91	2.74	2.48	2.35	2.01	1.14
J.H.S.	-	-	-	-	2.5	0.7	1.88	3.35	2.18	2.67	1.49	1.18
W.O'T.	-	-	-	-	-	0.34	1.93	0.68	4.20	2.92	2.57	1.34
T.G.W.	-	-	-	-	.25	1.5	0.98	0.90	4.0	1.89	1.73	1.16
J.R.W.	-	-	-	-	.30	.63	.3	.49	.56	1.41	3.4	1.17
K.J.	-	-	-	-	-	-	-	-	-	0.45	1.44	.47
M.C.P.	-	-	-	-	-	-	2.30	2.10	0.80	0.46	1.13	1.04
T.O'B.	-	-	-	-	-	-	-	-	-	-	-	.13

It can be seen that there were two peak years 1956 and 1960/61 and a marked dip in 1959.

The 1956 peak arose it is thought from the necessity to keep changing the filament and the shroud, there was a marked decline in doses when a cold cathode arc source was used. The 1959 minimum is attributed to a long shut-down when the field coil on the main magnet burned out. The subsequent rise is explained by the need to operate on a 24 hour basis in order to make up for lost time. The apparent reduction in individual dose levels from 1962 onwards is somewhat deceptive as the work was simply being spread over more people. In fact there was a fairly constant total annual dose required to run this accelerator of some 20 man rads/year.

3. AREA RADIATION SURVEYS

The protection problems posed in operating such a powerful machine in a built-up area are clearly shown by the following examples of beam leakage.

(1) Roof penetration - mean neutron exposure rate on the roof top was 10 mrem/h with a maximum of 33 mrem/h.

(2) 30 ton door - exposure levels of up to 5 mrem/h were found in areas outside the physics boundary. This was almost entirely due to neutrons, the gamma contribution being in the range 0.02 - 0.10 mr/h. The area covered by the 0.25mrem/h contour included part of a school playground and also a public street. An internal shield wall had to be erected in the machine room to cover the door, this effectively reduced the external beam to a maximum of 0.25 mrem/h.

(3) Natural Rock Shield

The original plan and construction of the building relied very heavily upon the natural sandstone rock on the East Side. The land on this side was owned by the Roman Catholic Church and when they started to flatten the top of the sandstone hill in early 1965 in order to construct a Cathedral we had to re-assess the adequacy of the shield wall.

Measurements were made with the machine running at full power and an internal beam accelerated in both clockwise and anticlockwise direction. An escape beam was evident along the whole side of the building although there was a very appreciable depression opposite the centre of the cyclotron, presumably due to the shielding effect of the yoke of the magnet. Measurements at ground level close to the wall indicated dose rates generally in the range 20 - 40 mrem/h with an odd peak value of 175 mrem/h. At 4 ft high the levels were lower, from 10 - 20 mrem/h, at 12 ft from the wall the spread was greater, 5 - 35 mrem/h. (The n/γ ratio $\sim$ 33 : 1).

Extra shielding was erected along the entire wall, consisting of 6 ft high x 6 ft thick iron loaded concrete blocks, estimated to give a factor 200 reduction for 100 MeV neutrons. Some adjustment and increase in the internal shield walls was also made.

The levels close to the wall were reduced to a maximum of 0.25 mrem/hr but levels further from the wall reached 1.5 - 3.0 mrem/h in places, due either to undercutting of the shield or scatter from the top floor.

4. DISPOSAL OF MACHINE

Working on the basis that everything which came out of the machine-room was radioactive, the accumulation of waste was quite steady. Low activity waste which conformed to the requirements of the Radioactive Substances Act, 1960, namely not more than 100μc (H.L.$<$ 1 year) or 1 mc (H.L. $>$ 1 year) per bin, with a surface exposure rate limit of 20 mr/hr, made up the bulk of the waste. This was disposed of, sometimes in 5 ton batches, by burial at the Local Authority tip with the approval and co-operation of the public health department. High activity waste had to be removed by the Atomic Energy Authority who usually buried it at Drigg. In all these operations the organisations concerned co-operated readily and the actual monetary expense to the University was very small.

The disposal of the accelerator itself and all the ancillary equipment was greatly helped by virtue of the fact that the land on which the building stood was leased to us until about 1975. So that we have been able to proceed at a leisurely pace taking some advantage of decay to reduce our problem. However at the beginning it promised to be a costly and involved operation. The materials had to be categorised as follows:

(a) Active material which was still useful and could be retained in a radiation area - portable shield blocks, magnet section. Much of this material went to the Rutherford Laboratories.

(b) Material of high activity for disposal via the A.E.A. magnet pole pieces, the tank, target assemblies, the D's.

(c) Active material of low activity for local tip disposal.

(d) Inactive material for sale or re-use - instrument panels, pumps and those pole piece sections of low S.A. for controlled melt down with other none-active steel etc.

The specific activity was determined in one of two ways, either by taking drill samples and measuring the activity in a gamma well counter or by simply measuring the count-rate and applying a formula

$$\frac{c}{gm} = \frac{\text{Count Rate x Constant}}{(1-e^{-\mu r})}$$

This is based upon the expression for exposure rate at the surface of a semi-infinite solid and contains a correction for the finite thickness(r). These proposals were accepted by the Ministry of Housing and Local Government although this was characteristically a verbal acceptance and not in writing.

The dismantling and disposal of the main tank, the D's and ancillary equipment was carried out essentially by a team of five who received a mean body dose of 1.24 r and a mean hand dose of 1.66 r in three weeks. These are by no means excessive when one considers that the dose rate in the tank varied from 100 mr/h to 3 r/h. It took a further three weeks to remove the main magnet sections to the Rutherford laboratory where they were to be used as shield material. This was carried out by a team of four who averaged only 4 mr/day. The surface dose rate on the magnetic sections varied from 0.05 mr/h to

180 mr/h. During all these operations regular checks were made on urine and dust activity, the only significant activity recorded was that of the face mask of the cutter who had to burn various sections of the tank.

The disposal is not yet complete as we are at the present time negotiating for the removal of the pole pieces, that is approximately 250 tons of high grade steel having specific activities in the range 0.0002 to 0.009 μc/g.

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VIALETTES: Vous avez dit au cours de votre exposé que certains matériaux de structure de l'accélérateur, encore partiellement actifs, avaient été reversés dans l'industrie privée. Pouvez-vous nous indiquer la limite de contamination massique maximale admissible retenue pour autoriser ces opérations.

BIRCHALL: There is no stated upper limit, provided that adequate supervision of dilution with non-active material is available. For practical purposes we have been given 10^{-5} µCi/g as the limit which requires no supervision.

BAARLI: What is your figure of 10^{-5} µCi/g of "inactive" materials deduced from? It appears to me that this figure is considerably lower than for the NaCl.

BIRCHALL: The Department of the Environment gave us two limits on specific activity for our magnet steel.

The 10^{-5} µCi/g is the level at which we can dispose of material without restriction. The value of 5×10^{-5} Ci/g and above, would require controlled dilution.

OLIVER: What was the sensitivity of your system for detection of contamination? How much above background was the 10^{-5} µCi/g level?

This activity level must be compared with activity found in specimens of steel due to ^{60}Co contamination during manufacture where these sources have been used to detect general wear.

BIRCHALL: The Geiger counter gave a count of approximately twice × background for a level of 2×10^{-5} µCi/g.

BARBIER:

i) What was the internal accelerated beam current of your machine?

ii) What was the dose-rate between magnet pole pieces one hour after stopping the machine?

BIRCHALL:

i) The extracted proton beam current was 3×10^{-2} μA, I do not remember the actual value for the internal beam current.

ii) The dose-rate was approximately 6 R/h.