RADIATION MEASUREMENT WORK AT THE PRINCETON-PENNSYLVANIA ACCELERATOR

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Summary. Since the P.P.A. has a proton current of 10^{12}, per second at 3 Bev., a careful study was made of its shielding requirements before construction began. The resulting design has been proven to possess excellent attenuation characteristics and flexibility of adaptation for varying demands by experiments.

The personnel dosimetry is based on Bonner spheres and T.E. ion chambers as well as the more conventional ones. A comparison and discussion of measurements made with the two types of detectors mentioned is made. Results of dose, particle flux and radioactivation measurements inside and outside the main shield, are presented.

Introduction. The Princeton-Pennsylvania Accelerator is a 3 Gev proton-synchrotron which worked (until the present maintenance shut-down) with an intensity of nearly 10^{12} protons/sec., twenty-four hours per day, Monday through Saturday, with an efficiency of about 80%. This large current led to different kinds of problems: 1) the detection and dosimetry of particle fluxes outside the collimated beams and their attenuation by appropriate amounts of shielding; 2) the dosimetry and scheduling of personnel working around the self-radioactivated synchrotron and the control of the flow of possibly radioactive tools and machine components from the shielded room of the accelerator complex; and 3) damage to materials.

Some of these problems have long ramifications, but for the sake of brevity, we will not mention them here.

These problems were investigated from three different points of view: 1) the protection of the individual from exposures greater than those set in present Federal and State laws; 2) the accumulation of a body of data in the form of carefully made exposure surveys and medical examinations in order to provide Princeton University with the data which could be used in its own defense in the case of a law suit; 3) the development of new dosimetry techniques or the refinement of old ones.

Dosimetry in the Experimental Areas. In the experimental areas there exists a wide spectrum of conditions extending from the collimated beams in which the uncharged components hardly add to the total dose, to the regions behind very thick shielding, where one may almost talk of an equilibrium between the surviving high energy neutrons and the lower energy particles.

There are several possible approaches to personnel dosimetry in such areas. The best would be to determine the radiation field in each location of interest, e.g., the flux vectors of each type of particle at many points in the interesting parts of their energy spectra. Then with a knowledge of particle interaction in a piece of given material, one could calculate (by a Monte Carlo method) the energy transferred to it by the field. The calculation could be suitably modified to introduce Q.F.'s and the rem dose could be calculated later for legal purposes.

The above method is indeed the ideal one from a purely academic, esthetic and theoretical point of view, but it does not give an answer in a few minutes to the questions, *'May I go in? 'How long can I stay there?'* Therefore, we have found it necessary, initially, to put our effort on the development of simple instruments which could be trusted in the hands of technicians and which would give acceptable readings of the radiation fields interpretable as rem-doses. Thus, our practical dosimetry work is based on the use of a) Bonner spheres, and b) muscle tissue equivalent ionization chambers.

The Bonner spheres are used only in areas where the dose can be assumed to originate predominantly from neutrons. Then the following assumptions can be made: a) the spectrum is continuous; b) the contribution from all other sources is not greater than the neutron dose; c) the total rem-dose is calculated assuming a dose of 7×10^{-7} rem per count for the Bonner sphere dosimeter. The justification for parts a) and c) follows from the results of a Monte Carlo calculation for our thick shield made by Ching Tsao et al[1], and numerical calculations we have made on the value of the rem-dose/count for a 12" Bonner sphere for a large number of combinations of neutron energy spectra and ranges, as shown on Table I. The assumption b) follows from the work of B. Moyer[2] at the Lawrence Radiation Laboratory.

The muscle tissue equivalent chamber[6] is used in regions where a significant flux of charged particles may be present, i.e., in regions of collimated beams or places where the shielding is relatively thin (~ 0.6 Kg/cm^2). When the M.T.E. chambers are used in open beams, a Q.F. of 3 is adopted, to have a single Q.F. for all momenta. Otherwise a conservative value of 10 is used.

The question now arises, how well do these two methods agree?

By comparing the readings from an M.T.E. ionization chamber with the number of counts in a 12" Bonner sphere behind the shielding in areas that we believed to be rather clean neutron fields (and where we normally use the Bonner sphere as a dosimeter), we found that 1 count in the Bonner sphere as an average would correspond to 8.6×10^{-8} rad in the M.T.E. ionization chamber. We find from Moyer's data that approximately 75% of the biological dose behind a concrete shielding is due to

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neutrons, and with the help of Table I, that one count in the 12" Bonner sphere for an unknown neutron spectrum will correspond to 3×10^{-7} rem. We can therefore, in the mixture of neutrons and γ-rays behind the shielding, estimate that 1 count in the Bonner sphere corresponds to 4×10^{-7} rem. From Moyer's data we find furthermore that this mixture will have an average quality factor of the order of 2.8, and this, together with our result that one count equals 8.6×10^{-8} rads, leads to a biological dose of 2.4×10^{-7} rem/count. We therefore feel confident that our choice of 7×10^{-7} rem/count gives us a safety factor of at least 50%.

A program of rechecking the detection efficiency of the Bonner spheres as a function of neutron energy and sphere diameter is underway with the design and construction of an absolute neutron flux detector of the proton recoil type.

Dosimetry in the Synchrotron Room. Under normal operating conditions, the radiation levels four hours after beam turn-off at a distance of one foot from the vacuum chamber range from 1 rad/hour down. Occupancy times in such areas and handling of radioactivated components is not only a function of the amount of initial activity, but also of the half lives of the many radioisotopes created in the bulk of the machine itself.

We have measured the activity versus time after shut-down (Fig. 1) at characteristic points near the machine, far away from any target. The early part of the decay curve shows a half-life of about 20 min. and we have made it a rule to delay all non-urgent work from one half to a full hour to reduce the personnel exposures.

The first significant long half-life is of the order of fifteen hours and we believe that it originates from the decay of Na^{24}, since we know (from irradiation of copper and Al plates and epoxy-resin) that a great part of the initial radioactivity is due to Na^{24}.

At about 200 hours after the shut-down we may see another characteristic half-life greater than 35 hours. This correlates with the expected activities[7,8], and with a γ-ray analysis made of a copper plate irradiated close to the target. The analysis showed mainly the following activities: 27 day Cr^{51}; 71 day Co^{58} and 45 day Fe^{59}.

For dosimetry around the synchrotron we use conventional "cutie-pies" and small volume gamma dosimeters of the type developed by Hurst et al[9] at Oak Ridge, since the work often involves the insertion of hands in volumes too small to be surveyed by the large cutie-pie chamber. Also, we have under development a small volume beta-dosimeter for this same purpose.

Since this accelerator is still young, the problem of storage of radioactive components is not yet serious. Great efforts are made to check all materials, tools and test equipment as they leave the synchrotron room to avoid sending radioactive sources to "clean" laboratories. The machine shops are provided with vacuum cleaners equipped with absolute filters and all machining of radioactive materials is carefully planned and closely supervised. Typical concentrations of Na^{22} in the epoxy cement of our vacuum chambers is 2×10^{-11} C/gm.

Radiation Damage Studies. We have, as part of the radiation damage studies, made a comparison of the total absorbed dose measured by thick-walled, air-filled ionization chambers made of aluminum and brass, and changes in properties of polyethylene and teflon in the mixture of protons, neutrons gammas, pions, etc., six feet down-stream from a dumping target (at doses of the order of 10^5 rads). We found, that the changes in the infrared spectrum (carbonyl, transvinylene and vinylidine lines) of polyethylene and the tensile strength of teflon, were similar for equal doses (rads) of this mixture and of 3 Mev. electrons.

Preliminary experiments were made to study the radiation effects in semiconductor components by our high energy particles and we found that at nearly all locations near the vacuum chamber, but six or more feet from the meson or dump targets, one could expect diode lifetimes to be six months or longer. This has been confirmed in that many transistors are used in the beam sensing system and no failures have been reported. No radiation effects were noticed in thermistors. Also, we are planning to study the radiation damage of transistors under different working conditions.

Other Neutron Flux Monitoring. In addition to the doses recorded using Bonner spheres, M.T.E. ion chambers, "cutie-pies", etc., we have installed in fifty different locations cadmium-clad polyethylene moderators with cobalt disk integrators of the type described by A. Smith[10]. These are used in areas surrounding the accelerator complex, as well as on top of the synchrotron magnets. A graph of the integrated neutron fluxes through the upper part of the synchrotron magnets with different positions is shown in Figure 2.

Conclusion. With the present equipment we feel there can be some confidence about satisfying the government safety standards while working in the large experimental areas which are associated with high energy experiments.

This information is easily obtainable by use of neutron integrators, Bonner spheres, and M.T.E. ionization chambers, as well as the more conventional devices.

Whereas the neutron integrator gives information only after long exposure, the Bonner sphere gives reliable results at once which may be shown by a ratemeter. Although the 12" Bonner sphere produces results that can be correlated with tissue dose it may perhaps be possible to construct one with another diameter and/or with discrete neutron absorbers that will have an even closer correlation, to either the NBS dose curve or the data from O.R.N.L.

References

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Table I - Dose (rem) per neutron count in a 12 inch Bonner Sphere with a 4 mm diameter, 4 mm long $Li^6I(Eu)$ crystal. The columns labeled N.B.S. and ORNL refer to doses per unit neutron flux flattening at 10 Mev or monotonically increasing with energy, respectively. See references 3 and 4.

ENERGY RANGE	N(E)	NBS (3) rem/count	ORNL (4) rem/count	$(Q.F.)_{av.}$
0 - 12 Mev	1	2.67×10^{-7}	3.38×10^{-7}	7.4
0 - 24 Mev	1	3.20	4.85	6.1
0 - 24 Mev	1/E	2.68	2.92	4.3
0 - 5 Mev	Ee^{-2E}	4.14	4.16	10.2
0 - 8 Mev	Ee^{-E}	2.75	2.85	8.9
0 - 18 Mev	$Ee^{-E/2}$	2.58	2.95	9.4
0 - 24 Mev	$Ee^{-E/5}$	2.77	3.88	6.6
0 - 11 Mev	Pu-Be[5]	2.53	2.98	7.9
0 - 12 Mev	U^{235} Fission[3]	2.55	2.96	9.1

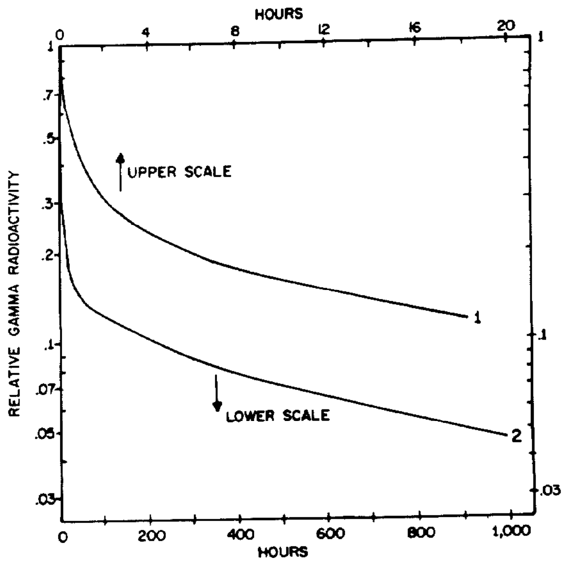

Fig. 1. Relative gamma radioactivity from typical points of the self radioactivated synchrotron as a function of time from shutdown (t = 0). This curve is the composite of many measurements.

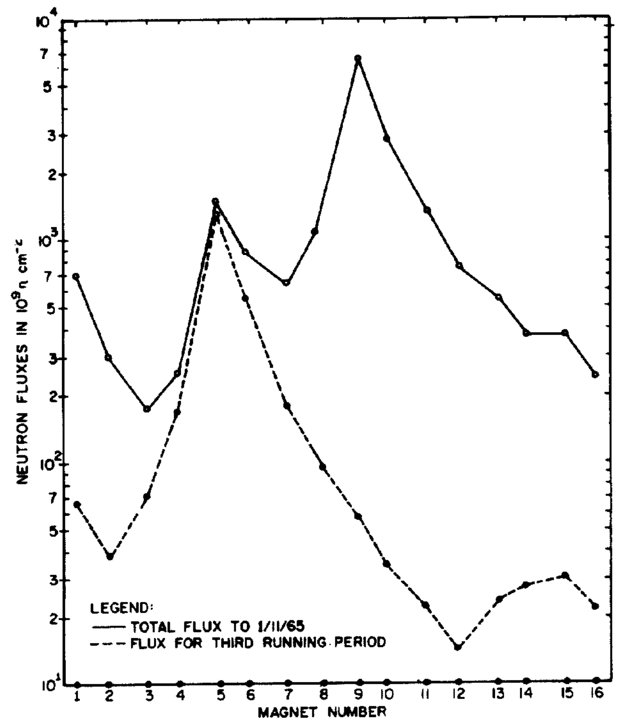

Fig. 2. Neutron fluxes measured on top center of the synchrotron magnets in units of 10^9 n cm^{-2}. Curve A: integrate flux from 4/15/63 until 1/11/65. The 1 inch Pt pion target was located from 4/15/63 until 11/12/64, downstream in magnet #8. Curve B: flux during the third running period, 11/12/64 to 1/11/65. A liquid-H_2 target was located downstream in magnet #8; a dump target was placed upstream from magnet #5.

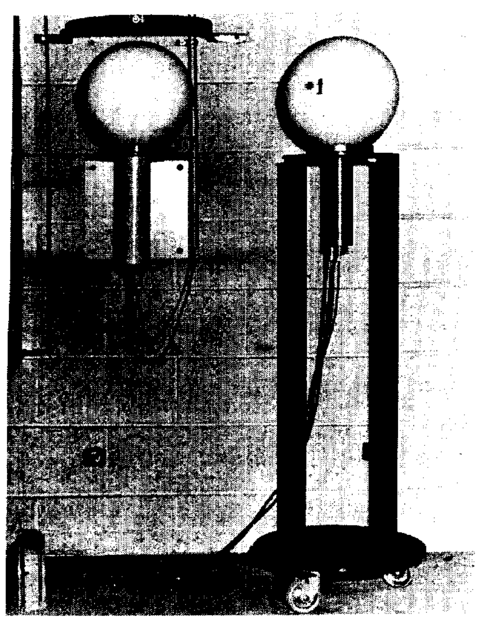

Fig. 3. Photograph of a fixed and a mobile Bonner sphere monitoring stations. The signals from a total of twenty-six such units are collected in two control points.

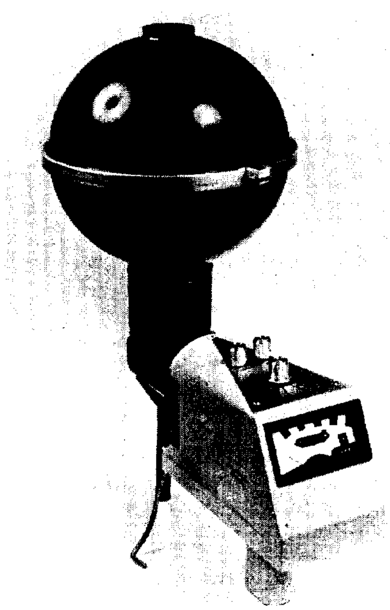

Fig. 4. Photograph of a muscle tissue equivalent ionization chamber survey meter.