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A Preliminary Report on Health Physics Problems at the Brookhaven Alternating Gradient Synchrotron (AGS)*

MASTER

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The alternating gradient synchrotron at Brookhaven National Laboratory is a proton synchrotron currently operating at 30 GEV with 25 pulses per minute and 10^{11} protons per pulse. During the period of machine tune-up and initial operation, a general understanding of the Health Physics problems involved has been obtained. Although definitive results are not yet available, a preliminary summary of experience to date and of experiments in progress may be of general interest.

As has been our previous practice at the cosmotron[1], survey measurements have been made in mrad/hr with well saturated ti[illegible] chambers, and dosage rates in mrem/hr have been estima[illegible] by a conservative choice of r.b.e. based on rather sca[illegible] detailed composition of the radiation. Personnel moni[illegible] means of Eastman NTA nuclear track films calibrated ag[illegible] ionization chamber using radiation from the AGS or Cos[illegible] is used routinely, this being considered as high enoug[illegible] exposure situations encountered in practice.

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One distinctive feature of the AGS is the ex[illegible] fluxes of μ-mesons. For instance, for one target location, such a flux emerging from the 16-foot heavy concrete shield results in dose rates up to 100 mrad/hr. Since high-energy μ-mesons will produce minimum ionizing tracks not recorded by the NTA films, there was some concern lest the personnel monitoring system might not provide the necessary guidance in properly controlling exposures. However, a preliminary test indicates that enough tracks are registered on the NTA film, presumably due to other components, so that interpretation using an r.b.e. of 10 will yield about four times the actual exposure in rads. Thus the result is fail-safe for an effective r.b.e. of 4 or less. Since the r.b.e. appropriate for minimum ionizing particles per se is less than 1, the effective value for the flux in question is almost certainly well below 4.

It is probably worth noting that the NTA system of personnel monitoring is to some extent self-correcting when the track counts are interpreted with a fixed value of r.b.e., 10 in our case. Those components of a mixed radiation field, such as μ-mesons, and high energy protons, to which the film is insensitive are the same components that have a low r.b.e. and contribute relatively little to the rem dose. Thus for most situations, dose is not underestimated and the system continues to function as required. However, it is clear that this problem requires a great deal more study, particularly in the case of beams that have been carefully purified for experimental purposes.

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1) "Health Physics Program for the Brookhaven Cosmotron", F.P. Cowan and J.S. Handloser, BNL 264(T-43), November 1953.

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Before leaving the μ-meson flux situation discussed above, it may be of interest to mention that an additional 4 1/2 feet of 250 lb/cu.ft. concrete reduced the reading of the tissue-equivalent ionization chamber only from 6.6 to 4.6 mrad/hr, corresponding to an exponential half thickness of 8.7 feet. With drastically increased beam intensities promised for the future, the acuteness of the shielding problems for radiation of this nature is clearly evident.

A knowledge of the depth-dose pattern in the human body is necessary if dose rates measured with an ionization chamber are to be interpreted properly in controlling personnel exposures. Such measurements, made at the Cosmotron, indicated that except in high energy beam areas there was no significant build-up in the body but that under special circumstances such a build-up might occur. Naturally we have been anxious to obtain more data on this problem at both machines. As many of you know, such data must be obtained when infrequent opportunities for experiments occur but some data has already been collected at the AGS. To begin with, there was no measurable difference between entrance and exit doses in the μ-meson flux area. This is to be expected in view of the extremely penetrating nature of this radiation. At another location with relatively poor shielding there was also no appreciable build-up. In a pure beam of 3.8 GEV protons and 7.6 GEV π^+ mesons there was a 40% build-up at a depth of 6" in paraffin. In another beam consisting of pions, protons and some high-energy alpha and triton contamination, a 30% build-up at 4" of paraffin was followed by a precipitous drop, presumably due to the stopping of the heavy particles. Much more data is needed, but some general conclusions may perhaps be made on the basis of these and similar experiments. In many areas where the radiation consists of a mixture of high and low energy components, there will be no build-up with depth since the build-up due to high-energy components will be counterbalanced or over-ridden by the drop-off due to absorption of lower energy components. In fact, there may be a substantial net decrease at the depth of the bloodforming organs in some cases. For some high-energy beams, build-up will be negligible since the thickness of the body is small compared with the interaction length of the particles. For some situations on the other hand there will be a dose build-up in the body, but our experience thus far indicates that the exit dose is unlikely to be more than 1.5 to 2 times the entrance dose. Fortunately, these latter situations are not those in which most personnel exposure is likely to occur. Perhaps we should be thankful that, as with the NTA personnel monitoring system, natural phenomena are working with the Health Physicist to some extent and the depth dose problem, while worthy of careful study, doesn't appear to be as serious as we had feared.

One of the major hazards encountered at high-energy accelerators is posed by beams brought out through the shielding, either scattered from a target or by ejection of a portion of the internal beam. The scale of this problem may be appreciated by an extrapolation of data obtained on an external proton beam at the Cosmotron by J. Handloser in 1956 using a small saturated ionization chamber. For an external beam of 10^{11} protons per pulse the dose rate at a 1" diameter focus will approximate 580 rad per pulse. Medical experience with X-rays[8] indicates that the threshold dose for production of cataracts is as follows:

for single exposure	200 r
for exposures spread over 3 weeks to 3 months	400 r
for exposures spread over more than 3 months	550 r

2) "A Clinical Study of Radiation Cataracts and the Relationship to Dose", G.R. Merriam and E.F. Focht, Am. J. Roentg., 77, 759, May 1957.

These numbers should be roughly applicable to minimum ionizing particles such as high-energy protons. The rate of incidence is quite low at the exposure levels cited but one must recognize the possibility of a cataract developing for any acute exposure over 100 rad. Thus a single pulse can easily cause a cataract under the circumstances described above.

It is interesting to compute the dose rate using 1.8 MEV per gm/cm^2 as the rate of energy loss for minimum ionizing particles. For the case discussed above we have

$$\text{protons per sq. cm. per pulse} = \frac{1.0 \times 10^{11}}{3.14 \times 0.5^2 \times 2.54^2} = 1.97 \times 10^{10}$$

$$\text{dose rate} = (1.97 \times 10^{10})(1.8)(1.6 \times 10^{-6})(\frac{1}{100}) = 569 \text{ rad per pulse}$$

The close agreement is certainly fortuitous but tends to strengthen one's confidence in the measurement.

For operation of the AGS at 10^{11} protons per pulse, activation of the machine itself and of the interior of the tunnel, while considerable immediately after shutdown, isn't high enough to cause serious operating difficulties. Typical dose-rates at the surface of the vacuum chamber and at some other locations are in the range of 50 to 500 mrad/hr. Targets are a different story, however. The degree of activation depends strongly on the target material. One recent example was a 1" x 1/2" x 1/16" uranium target irradiated for 10 minutes at 10^{11} protons per pulse. The surface dose rate was estimated, on the basis of survey meter readings, to be of the order of 1000 rad per hour shortly after shutdown. Most of the exposure is due to beta radiation but the beta-gamma ratio varies widely (from 5 to 100 in most cases) depending on the nature and geometry of the target.

The activity of AGS targets is tremendously higher than that of cosmotron targets for the same values of protons per pulse. Not only is more energy available per pulse but the strong focusing utilized keeps the beam intact for a large number of traversals of the target. At the higher beam intensities expected soon, we are going to have to handle targets with surface dose rates at shutdown of 10 rad/sec or more, an operation that will require carefully planned technique and close health physics surveillance.

In conclusion, I should like to express my feeling that there are many challenging dosimetry problems for the Health Physicist at the billion volt machines. The μ-meson situation discussed above is one example. Presumably, in association with the primary meson flux, there is a spectrum of electrons resulting from muon decay, extending to very high energy, a bremsstrahlung spectrum due to the electrons and possibly some photoneutrons. Threshold detectors can be of assistance in studying such mixed radiations but must be used wisely as there will usually be more than one reaction yielding a chosen product, when a variety of high energy particles are involved. Certainly one of the most urgent needs is a practical method for determing the LET spectra for a variety of exposure situations.

As Health Physicists, we play a dual role. First and foremost, we make conservative and safe evaluations of hazards on the basis of incomplete knowledge so that scientific work may proceed as expeditiously as possible. In addition, we attempt to extend and refine our dosimetry to the point where, on the basis of fuller knowledge, restrictions may be relaxed and the productivity of machines and experimenters may be correspondingly increased.

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