PROBLEMS OF INDUCED RADIOACTIVITY AROUND THE 200-BeV ALTERNATING-GRADIENT SYNCHROTRON*

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The 200-BeV alternating-gradient synchrotron (AGS) under study at the Lawrence Radiation Laboratory has a design beam intensity of 3×10^{13} protons per pulse, or 1.5×10^{13} protons/sec at maximum repetition frequency. This is an average beam power of 500 kW, compared with approximately 1 kW for the existing Brookhaven National Laboratory's AGS and CERN proton synchrotron. Present shut-down radiation fields at the BNL-AGS range from several mrem/h for most of the tunnel to a few rem/h in the target areas, as shown in Fig. 1. Scaling these levels by either the beam power or the beam current leads to the conclusion that all of the main ring tunnel would be unfit for human habitation, and hence machine maintenance couldn't be carried out by unshielded workers.

Figure 1 illustrates the enormous variation in beam loss and associated induced radioactivity with distance from target position, the high values occurring close to targets and confined to within a quarter of a betatron wavelength downstream from them. Because beam loss is almost completely associated with targeting and not with acceleration, we have placed primary reliance on extracted external proton beams. We have assumed that at least 85% of the circulating beam will be extracted, so the maximum beam interaction within the main ring will be 15%. If an internal target is used, the beam will be limited to 15% of full beam. On Fig 1 we have indicated what γ levels would be expected a few hours after shutdown for the present BNL-AGS, the BNL-AGS with increased beam current, and the 200-BeV AGS with a slow extracted proton beam. The data refer to both the open side of the C magnets and to the similar region between magnet ends. In the 200-BeV case, we also indicate the reduced levels to be expected on the yoke side of the magnets, of which we will have more to say. The important conclusion is that, for most of the ring enclosure, radiation levels are sufficiently low to allow personnel entry for machine maintenance.

A transverse γ-field plot was synthesized for the K-8 magnet location at the BNL-AGS and is shown in Fig. 2. Not surprisingly, the highest radiation levels are due to the high levels of radioactivity in the magnet pole faces and are found opposite the open side of the C magnet. A general background level is associated with the radioactivity of the concrete tunnel walls. Figure 3 shows the γ field due to the magnet structure itself after the wall contribution has been subtracted. The table on Fig. 3 shows how the radiation levels at other locations and at different operating conditions for the BNL-AGS and our 200-BeV AGS may be estimated. A high-energy nuclear-cascade function has been used to construct an induced activity model. At CERN, beams of 10 GeV/c and 20 GeV/c protons were incident on a large steel block and the resultant cascades were mapped with nuclear emulsions. Most of the cascade was confined to small distances transverse to the beam line. In the accelerator case, beam is lost all around the machine and the problem becomes one in which there effectively is an infinite line source. One is able to construct activity functions which depend both on the distance from the line source to the surface of the iron (air gap) and on the distance from the surface of the iron into the iron.

Figure 4 shows a cross section of a BNL magnet in which the density of the coils was assumed to be the same as that of iron. Isoactivity lines and isotransmission lines are shown for 1-MeV gamma rays as seen by an observer 1 foot from the coil face, at beam height. A numerical integration over the cross section of the magnet yields the γ dose to be expected. The same procedure was carried out for an observer 1 foot from the yoke side of the magnet. The calculated dose was a factor of 73 lower on the yoke side than on the open side, in excellent agreement with the measurement with wall contribution subtracted as in Fig. 3.

Figure 5 demonstrates how to calculate the dose reduction when a dense gap block is inserted into the open gap. For the block shown, at iron density, the dose reduction was approximately 20. One thus has a model with which to calculate any simple shield, and the dose reduction that can be achieved becomes almost arbitrary.

Thermal neutron activation of impurities in the concrete tunnel walls can be a serious, if

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unexpected, problem but can be easily dealt with in any new machine. Evaporation neutrons of a few MeV energy are produced in copious quantities by the high-energy nuclear cascade in the magnet yoke. These neutrons are not absorbed in the relatively thin iron magnet and are thermalized in the concrete walls. Sodium is the most serious impurity since usually its concentration in concrete is about 1% by weight, the thermal neutron absorption cross section is 0.53 barn, the Na^{24} made has a 15-hour half life (which is exceedingly unfortunate from a tunnel reentry standpoint), and the γ emitted is unusually hard at 2.75 MeV. Manganese-56 with a 2.6-hour half life is also to be expected. These radioisotopes can be greatly reduced in number by adding a neutron absorber such as boron to the tunnel-wall concrete.

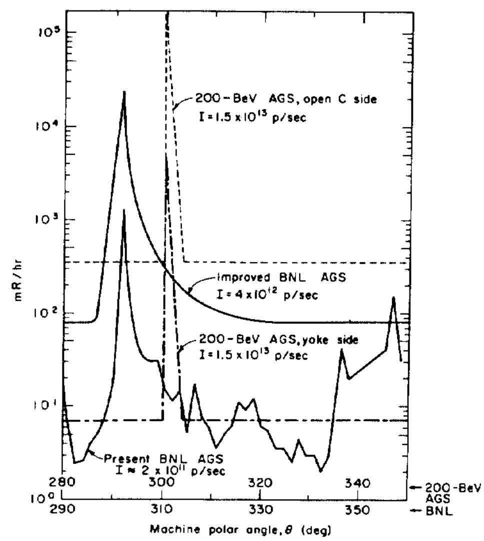

Fig. 1. Residual γ-fields at BNL and 200-BeV AGS vs machine polar angle. Measurements are taken between magnet ends, a few inches from vacuum chamber.

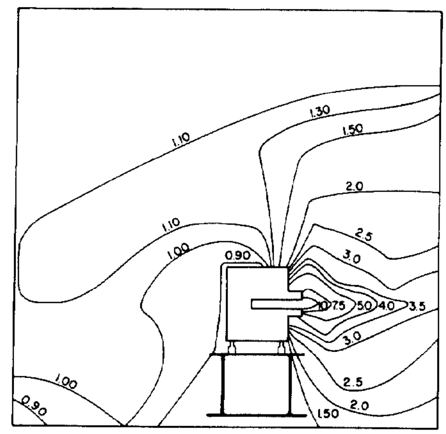

Fig. 2. Transverse γ-field at BNL-AGS magnet K8, 6 hr after machine turn-off.

TO PROJECT THESE NUMBERS TO OTHER OPERATING CONDITIONS OR MACHINES		
CONDITIONS		MULTIPLY BY
1. Present BNL AGS	Quiet Section	0.27
2. Present BNL AGS	Hottest Target Section	550
3. Improved BNL AGS $I=4\times10^{12}$ p/sec	Quiet Section	6.3
4. 200-BeV AGS $I=1.5\times10^{13}$ p/sec	Quiet Section 85% Extraction Eff.	4.7
5. 200-BeV AGS $I=1.5\times10^{13}$ p/sec	Hottest Target Section 85% Extraction Eff.	13 500
6. 200-BeV AGS $I=1.5\times10^{13}$ p/sec	Average of Magnets Near 3 Extracted Beams (24 Magnets)	700

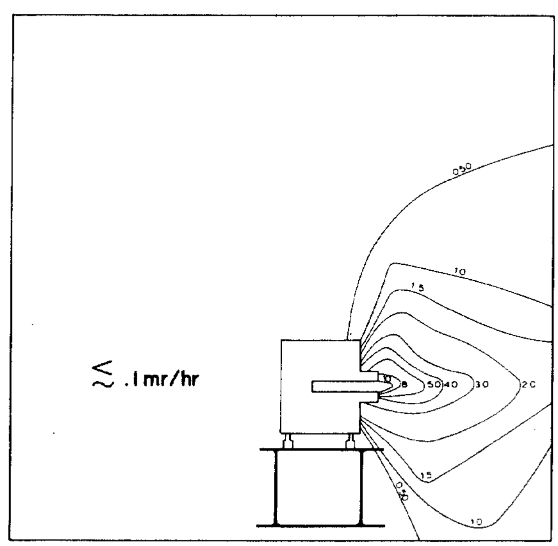

Fig. 3. Same as Fig. 2 with wall contribution (≈ 1 mR/hr) subtracted. Table extrapolates data to other operating conditions and 200-BeV machine.

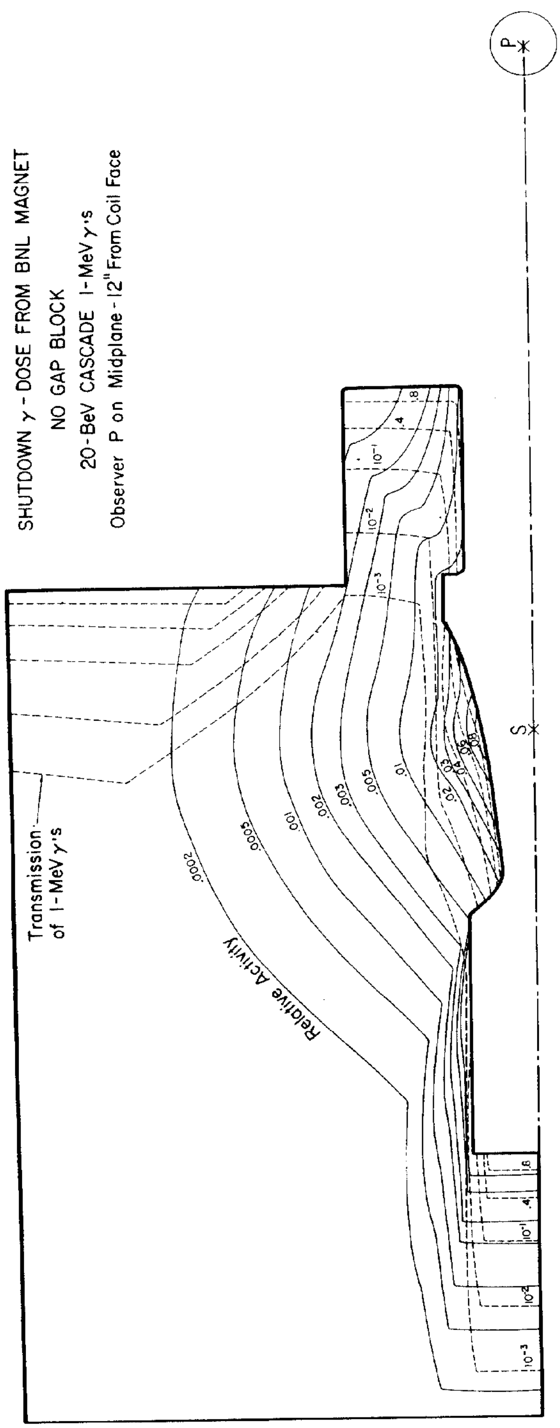

Fig. 4. Cross section of BNL-AGS magnet with isoactivity and isotransmission lines superposed.

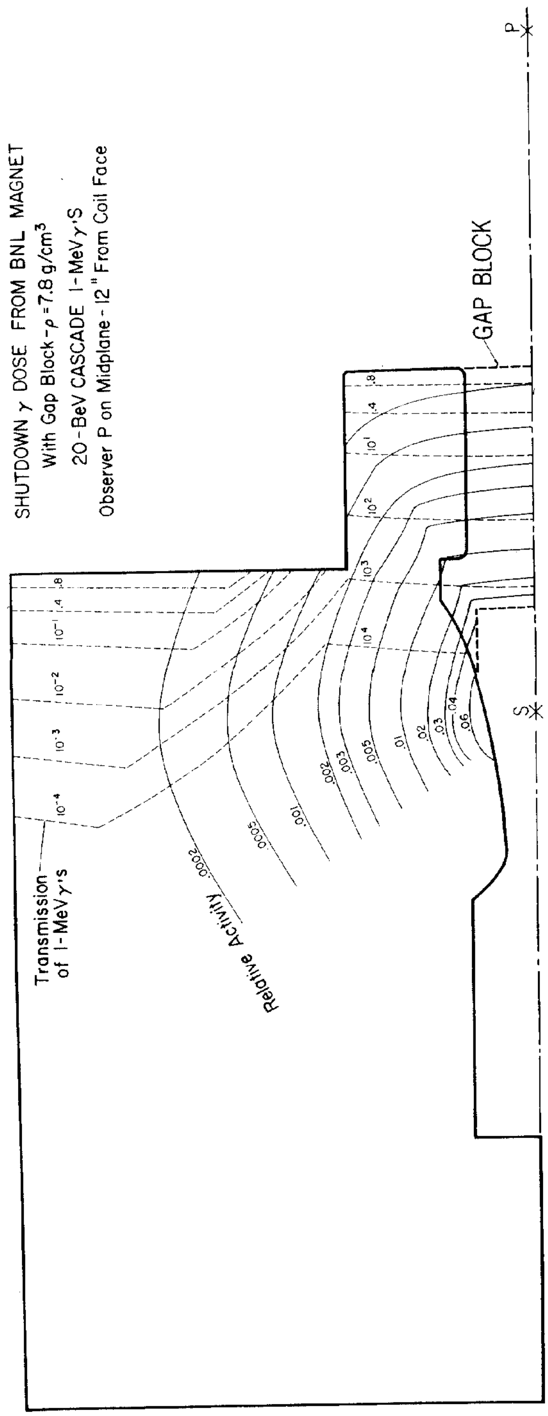

Fig. 5. Same as Fig. 4 with gap block inserted into magnet gap.