# RADIATION LEVELS IN THE BOOSTER ENCLOSURE

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## I. INTRODUCTION

After the booster is turned off, the two most significant sources of radiation caused by proton losses will be:

(1) The booster magnet steel, and

(2) The walls of the enclosure

The level of activation of both these components will of course depend on the as yet unknown machine losses. It is only a slight oversimplication to say that the activity induced in the machine is all long-lived (halflives of several hundred hours) while the activity induced in the walls comes only from 15 hr $^{24}$Na (2.75 and 1.37 MeV gammas). The amount of $^{24}$Na created in the walls by thermal neutron capture by $^{23}$Na and spallation depends strongly on the composition of the concrete. It is important to estimate the dose rate from these two sources in advance, since an excessively high dose rate will restrict and/or delay access to the machine for maintenance and repair.

## II. CALCULATION

A proper Monte Carlo Calculation would follow the development of the extra nuclear cascade out of the magnet iron, through the space in the tunnel and then into the tunnel walls. Gamma rays coming from radioactive nuclei created in various locations would then be propagated back to the passageway area of the tunnel. Such a calculation would take at least several months to complete, by which time the booster enclosure would have already gone out for bids.

We have therefore made an estimate of the dose rate in the enclosure using information from the following sources:

(1) A calculation by R. G. Alsmiller, Jr. (ORNL) of the neutron leakage spectra and gamma dose rate from a steel cylinder in which 3 GeV protons are lost.

(2) A Monte Carlo Calculation of the nucleon-meson cascade in iron by J. Ranft (CERN), and

(3) Measurements of induced $^{24}$Na activity in concrete made at CERN by D. Nachtigall and S. Charalambus. The incident flux is unknown.

The above information allowed us to make the following calculation:

(1) Source term: The spectrum of fast neutrons leaking out of the magnet was taken from the work of Alsmiller. The Ranft data was used to get proton/neutron and pion/neutron ratios.

(2) These spectra were propagated to the walls of a booster enclosure of simplified geometry in which the dose from the walls is independent of position in the tunnel.

(3) The reaction cross sections given by Nachtigall and the proposed NAL concrete composition (limestone aggregate) were used to calculate the $^{24}$Na activation of the surface layer of the wall by fast particles via the reactions

$^{24}$Mg (n,p) $^{24}$Na

$^{27}$Al (n,$\alpha$) $^{24}$Na

$^{27}$Al (p,3pn) $^{24}$Na

Si (spallation) $^{24}$Na

Ca (spallation) $^{24}$Na

listed in order of decreasing cross-sections. Dealing only with the surface layer eliminates the problem of the development of the hadron cascade inside the wall. This value is used to normalize the calculated flux to Nachtigall's results for the depth distribution of $^{24}$Na produced by fast particles.

(4) The gamma dose rate in the tunnel is then calculated from the normalized $^{24}$Na distribution in the wall.

$^{24}$Na can also be produced by the capture of thermal neutrons by $^{23}$Na in the concrete. We assume that the ratio of thermal/fast neutrons in the booster will be the same as that measured by Nachtigall. We then use the Nachtigall results of $^{24}$Na activity in concrete as a function of $^{23}$Na content to estimate the contribution of thermal neutrons to the dose rate.

## III. RESULTS

The dose rate in the enclosure can be written as the sum of 3 components:

$$D.R. = L\left[\frac{M}{R} + F + T \cdot N\right]$$

where L is the number of protons lost uniformity around the booster each second, in units of $10^{11}$p/sec (the current design estimate has L = 1). R is the distance in meters from the line source magnet. M, F and T are coefficients describing the relative contributions of the machine activity, the activity produced in the walls by fast particles, and thermal neutron capture by $^{23}$Na. N is the weight fraction of Na in the concrete. Inserting the calculated values of

the coefficients gives:

$$\text{Dose Rate} = L\left[\frac{7.1}{R} + 1.3 + 1000 \cdot N.\right] \text{ mrem/hr}$$

The contribution of the fast particles to the dose rate is surprisingly sensitive to the composition of the concrete: use of CERN concrete, with ~28 times as much Si as the proposed mixture, would triple the value of F.

At a distance of 1 meter from the magnet the presence of 1% Na in the concrete would more than double the dose rate, and cut the maximum occupancy time per person from 12 to 5.4 hours per week.

Measurements made at CERN indicate that proton losses (apart from beam scrapers, etc. which will have additional shielding) and machine activation are not uniform around a synchrotron, but vary up and down from the mean by about an order of magnitude. This sort of local variation in induced activity should be considered from the point of view of machine maintenance and repair when making a decision on the type of concrete to be used in the booster enclosure.

## IV. CONCLUSION

A concentration of 0.1% by weight of sodium in the concrete would increase the average exposure dose to personnel by about 10%. Hence, an upper limit of 0.1% Na in the concrete for the booster enclosure is recommended. In addition, since over one third of the activity produced by fast particles comes from the spallation of the 0.39% Mg present in the proposed NAL concrete, it is suggested that the Mg content of the concrete be limited to 1% by weight.