LEP Note 274
6.10.1980

E-6

CONCENTRATION OF O_3 AND NO_x IN THE AIR INSIDE THE LEP TUNNEL

W. Richter

I) Introduction

The calculation of the content of toxic gases in the tunnel air is based on the predicted synchrotron radiation as calculated by O. Gröbner [1] and on the production rate of O_3 and NO_x as calculated by A. Perrot [2]. The disintegration of O_3 has been assumed with a half-life time of 35 min as observed in electron accelerators without ventilation, as indicated by J. Tuyn [3].

II) Assumptions

In order to get values which take the geometry of the machine components inside the tunnel into account, the following assumptions - based on the Pink Book [4] - have been made :

- constant dissipation of synchrotron radiation through-out the total length of regular and dispersion suppressor cells (3164 m per octant).
- no dissipation of synchrotron radiation in the remainder of the ring tunnel (636 m per octant), see appendix 1.
- radiation into the magnetic core being attenuated according to the geometry of the dipoles (quadropoles and sextupoles being considered as dipoles) for the total length of the magnetic cores (3022 m per octant).
- no attenuation of the radiation by magnetic cores for the total length of the drift spaces (142 m per octant).
- no lead shielding of the vacuum chamber for the total length of the bellows (47 m per octant); results are also indicated for bellows with equivalent shielding.

Five zones of the tunnel cross-section have been used for the calculation of the production of O_3 and NO_x. They are shown for a magnet section in fig. 1 and for a drift space in fig. 2. The production rate over the whole area of each of these zones is constant, and there is no production in the remaining area. This is equivalent to the real situation where all the air of the tunnel cross-section contributes to the gas-production at a different rate, see appendix 2.

III) Results

Table 1 shows the contribution of the individual zones to the total production of toxic gases for a vacuum tube with and without lead shielding.

Table 2 and 3 show the concentration of O_3 and NO_x in the escaping air during machine operation for an air velocity inside the tunnel of 1 m/s, corresponding to about one air exchange per hour.

Fig. 3 shows the distribution of the concentration along the tunnel during machine operation.

Access to the tunnel cannot be allowed as long as the concentration of O_3 is above 0.1 ppm. No access-limitations are required for the calculated concentrations of NO_x. The required waiting times for access to the air exit region of the tunnel are shown in Table 4.

Formulae for these calculations see appendix 3.

IV) Conclusions

For the proposed vacuum chamber with a lead shield of 3 mm on top and bottom and 8 mm on the sides an air velocity of 1 m/s inside the tunnel is sufficient. For phase 1 no access restrictions to the tunnel are required.

For stage 1 (86 GeV) the required waiting time for access is about 32 min (or 14 min if bellows have a lead shield). This can be diminished to 14 min (7 min) if the air velocity between machine stop and access permission is raised to 3 m/s.

For stage 2 (130 GeV) the corresponding waiting times are 53 min (48 min) or 19 min (18 min) if the air speed is raised to 3m/s just after the machine stop.

For the dilution of the O_3 concentration at the discharge point of the tunnel air only in stage 1 and 2 is a chimney required.

V) Comments

The content of this note was discussed in a meeting on 2.10.198o with O. Gröbner, B. Milman, R. Perin, A. Perrot and J. Tuyn. The most important statements were :

A. Perrot : The range of G-values for the production of O_3 and NO_x varies in the literature between G = 0,2 and 20. It depends on the volume and other factors. The adopted values of G = 6 for O_3 and G = 1,5 for NO_x are mean values. In the worst case the concentrations may be twice as big.

O. Gröbner : The results for a vacuum chamber without lead shielding are optimistic, because the effect of the low energy radiation is neglected. A 10% bigger production rate is to be expected.

R. Perin : The exhaust air with the relatively high concentration of NO_x should not be blown through areas with sensitive equipment (klystron-tunnels).

J. Tuyn : The standard formula for the dilution of the concentration due to ventilation cannot be used for the calculation of the waiting time, because it does not consider the "half-life time" of ozone.

The meeting concluded that the values for concentration and waiting times of the note have the right magnitude and can be used for further studies. Concerning the shielding of the vacuum chamber, it was recommended that separated shielding be avoided because of the additional handling effort (R. Perin) and because of the requirement for an additional cooling circuit (O. Gröbner).

VI) References

[1] O. Gröbner : Energy deposition by synchrotron radiation in various parts of the vacuum chamber of LEP. Note 227.

[2] A. Perrot : Evaluation des doses de radiation délivrées aux aimants fer-beton et production d'ozone et d'acide nitrique dans le volume le plus confiné des aimants. LEP note 225.

[3] J. Tuyn : private communication.

[4] Design study of a 22 to 130 GeV e^+e^- colliding beam machine (LEP). CERN/ISR-LEP/79-33.

Tab. 1 Percentage of gas production in the different zones at stage 1 (86 GeV)

area	zone	with lead shielding 1)	without lead shielding
magnet section	1	6,4%	15,0%
	2	1,0	2,5
	3	0,5	0,7
	4	0,1	0,1
	5	31,6	64,2
drift space without lead	2	20,5	6,6
	3	19,1 2)	6,2
	4	5,2	1,7
	5	9,3	3,0
drift space with lead	2	1,9	-
	3	2,7	-
	4	0,7	-
	5	1,0	-
		100 %	100 %

---

1) lead shield 3 mm at top and bottom
8 mm on sides of vacuum chamber

2) this influence of the bellows will diminish from 54,1% to 3,1% if the bellows have a similar shield as the vacuum chamber.

Tab. 2 Concentration of O_3 at air exit

	with lead shield	without lead
phase 1 (50 GeV)	0,02 ppm 1)	0,24 ppm
stage 1 (86 GeV)	0,29 ppm 1)	2,73 ppm
stage 2 (130 GeV)	1,82 ppm 1)	

Tab. 3 Concentration of NO_x at air exit

	with lead shield	without lead
phase 1 (50 GeV)	0,01 ppm 1)	0,10 ppm
stage 1 (86 GeV)	0,12 ppm 1)	1,10 ppm
stage 2 (130 GeV)	0,73 ppm 1)	

Tab. 4 Waiting time for access to tunnel

	with lead shield	without lead
phase 1 (50 GeV)	none 2)	27 min
stage 1 (86 GeV)	32 min (14 min)	55 min
stage 2 (130 GeV)	53 min (48 min)	

---

1) these values are only half as big if the bellows have also a lead shield

2) values in brackets are for bellows with lead shield

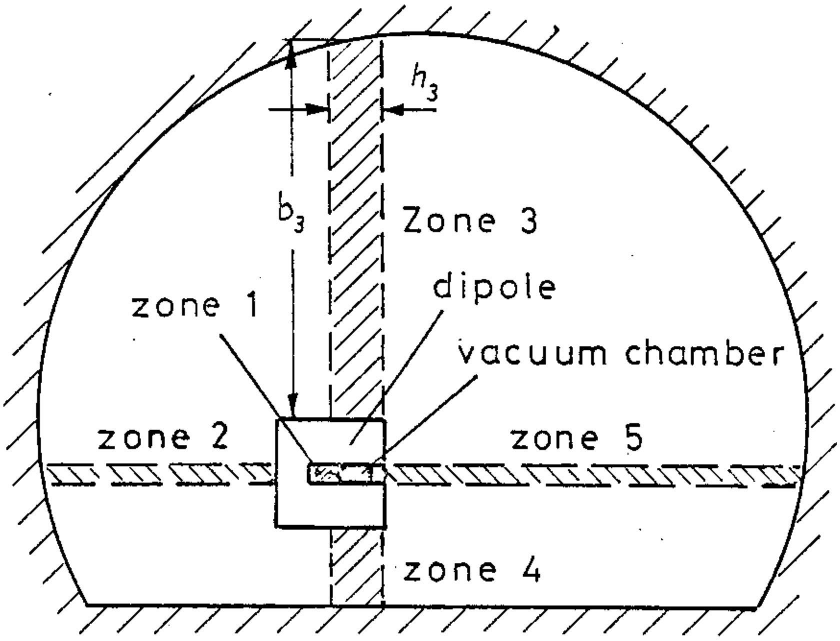


Fig. 1

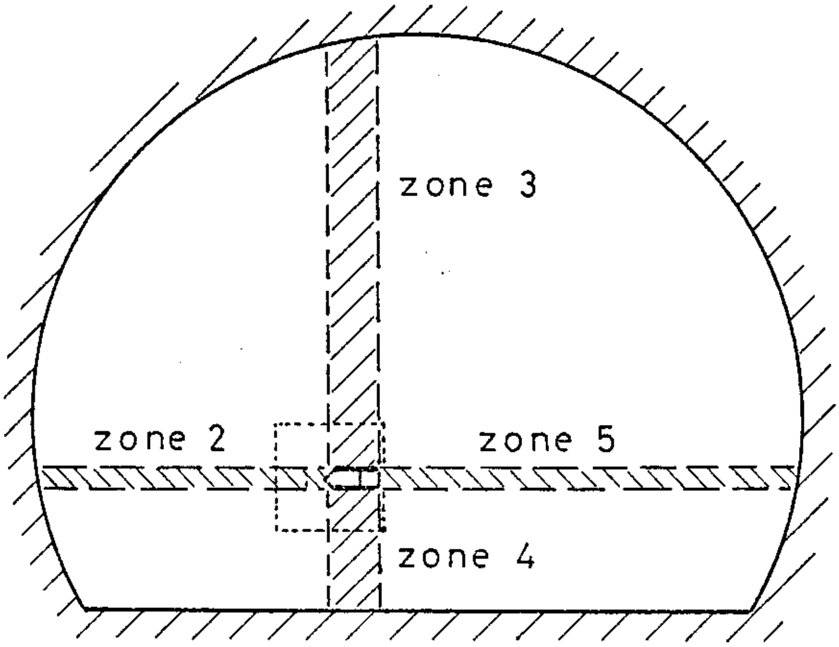


Fig. 2

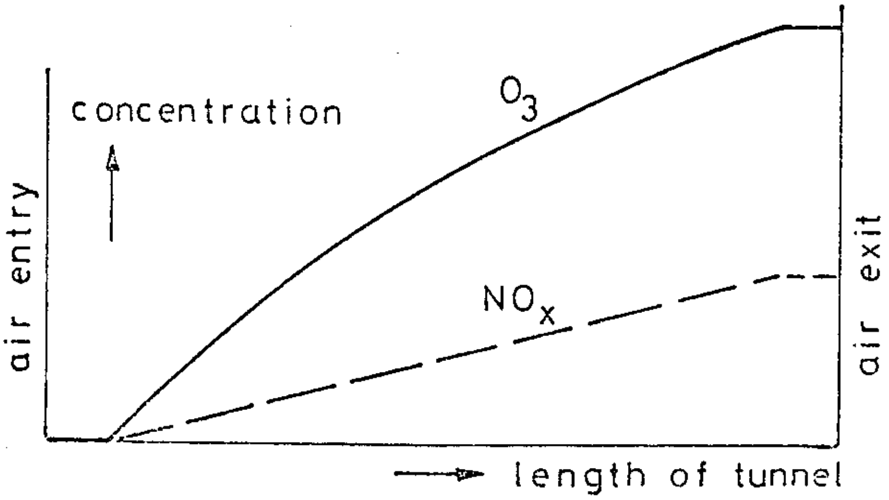


Fig. 3

Appendix 1

Synchrotron radiation in RF sections

The synchrotron radiation in those parts of the tunnel where there are no bending magnets drops down according to fig. 9.4 in [4]. The starting point of this curve corresponds to 50% of the radiation in the magnets, because only the beam which comes from the magnet side produces the decaying radiation pattern. The beam which comes from the straight section produces no radiation until it reaches the bending magnets.

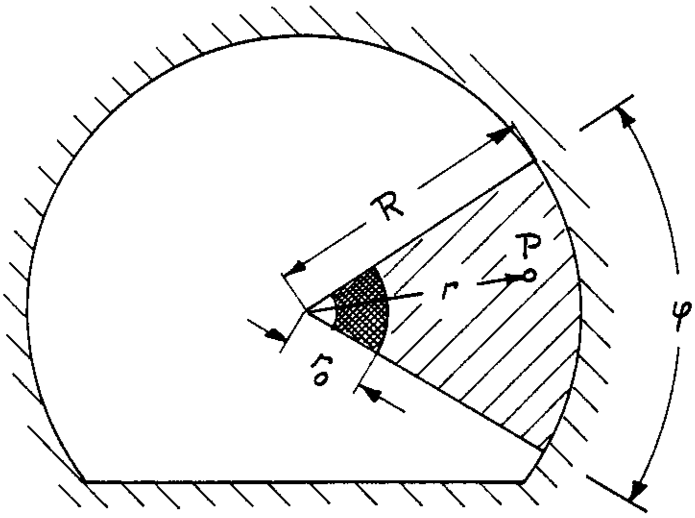
The integration of the curve b of fig. 9.4 can be done in two parts: one for the length of the 10% magnet, the other for the remainder. Dividing these results by 100% radiation gives the equivalent length of magnetic core and drift-length which have to be added to the calculation, if this effect has to be taken into account. The obtained values are :

6,4 m magnetic core
2,6 m drift length

The first value adds 0,4% to the calculation which can be neglected. The second value adds 3,7% to the drift-length, but a substantial part of this second part is shielded by correction lenses or cavities. Therefore also this second part was not included in the calculation.

Appendix 2

Simplified calculation of gas production



If one considers the radiation source to be a line along the axis of the tunnel, one can treat the problem as a two dimensional one.

The radiation at point P of the shaded surface is

$$\varrho = \varrho_0 \cdot \frac{r_0}{r}$$

where ϱ_0 is the radiation emitted from the surface r_0.

The gas production is proportional to ϱ and time t and the total amount of gas produced in the shaded area can be expressed by

$$G_p = \int_{r_0}^{R} \varrho \cdot r \cdot \varphi \cdot \ell \cdot t \cdot dr$$

where $r \cdot \varphi \cdot \ell \cdot dr$ is a volume element for which the radiation is constant; ℓ = length of tunnel. We find

$$G_p = \int_{r_0}^{R} \varrho_0 \cdot r_0 \cdot \varphi \cdot \ell \cdot t \cdot dr = \varrho_0 \cdot r_0 \cdot \varphi \cdot \ell \cdot (R - r_0) \cdot t = E_0 \cdot (R - r_0) \cdot t$$

with $E_0 = \varrho_0 \cdot r_0 \cdot \varphi \cdot \ell$ the total amount of radiation emitted from the surface $r_0 \cdot \varphi \cdot \ell$. This means that the result is identical to the case where gas is produced by the radiation ϱ_0 in the volume $r_0 \cdot \varphi \cdot \ell \cdot (R - r_0)$. This leads to the zones of fig. 1 and 2.

If one treats the case as a three-dimensional one, the production rate inside the tunnel would be bigger by the factor $\pi/2$. However, the shielding conditions inside the tunnel due to the magnetic cores change the situation considerably so that the two dimensional calculation method corresponds better to reality.

Appendix 3

Formulae for the calculations

Gas concentration according to A. Perrot [2] in a zone

$$C = 8 \cdot 10^{-6} \cdot \frac{E}{\ell} \cdot \frac{G \cdot t}{h} \quad [ppm]$$

with

$E/\ell \left[\frac{W}{m}\right]$ = energy emission due to synchrotron radiation per zone and length of tunnel

$h\,[m]$ = width of zone

$G \left[\frac{moleculs}{100\,eV}\right]$ = gas production per absorbed energy
= 6 for O_3; = 1,5 for NO_x

$t\,[s]$ = time

Mean concentration in tunnel air at exit

$$C_m = 8 \cdot 10^{-6} \cdot \frac{G}{F} \sum_i \left(\frac{E}{\ell}\right)_i \cdot b_i \cdot t_i \quad [ppm]$$

$F\,[m^2]$ = tunnel cross section without the surface which is used for equipment = $9m^2$

$b_i\,[m]$ = length of radiation path in zone i

$t_i\,[s]$ = time to pass through zone i
= L_i/v = length of zone / mean air speed

Reduced ozon mean concentration due to half-life of 35 min

$$C_r = C_m \cdot \frac{1 - e^{-0{,}02\,T}}{0{,}02\,T} \quad [ppm]$$

$T\,[min]$ = total time of gas production
= total radiation length of octant /mean air speed

Waiting time for access to tunnel

$$T_w = \frac{v_m}{v_s} \cdot \left[\frac{L_o + L_m}{v_m} + 50 \cdot \ln\left(1 - \frac{1 - e^{-0{,}02\, L_m / v_m}}{10 \cdot C_r} \cdot e^{0{,}02\, T_w}\right)\right] [min]$$

L_o [m] = length without radiation (at the end) = 318 m

L_m [m] = length of radiation (magnet cells) = 3164 m

v_m [m/min] = mean air speed during machine operation

v_s [m/min] = mean air speed at beginning of machine stop

C_r [ppm] = concentration of O_3 at machine stop