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PROPOSAL FOR A SHIELDING PHILOSOPHY AND RADIATION MONITORING SYSTEM FOR THE LEP EXPERIMENTAL AREAS

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1. INTRODUCTION

In order that the radiation dose rates in the LEP experimental caves should never reach levels where some interaction with machine operation must occur, very thick shielding (several metres) would have to be placed all around the experimental detectors at the interaction regions. However, such bulky shielding is a great inconvenience to the experiments and the use of an unnecessarily thick shield is costly. Not only should the cost of the shield itself be taken into account, but also the additional expense of the cables which have to pass through the shield and the increased complexity of the experiment.

A very flexible approach has been adopted at PETRA whereby maximum use is made of the self-shielding properties of the experimental detectors. This leads to a number of advantages for the experimental physicist, such as short cables and easy access to electronics mounted directly onto the outside of the detectors.

Finally the shielding requirements must be defined to take correct account of the CERN annual reference level of 1.5 rem.

This flexible approach requires that in the approval stage of the experiment a formal assessment must be made of the shielding provided by the experiment and shielding designed around all parts which are not well shielded. Since the shield will not be "total", a radiation monitor system must be provided which will cut machine operation whenever predefined levels occur. This balance between minimum shield design and radiation alarm levels must be determined according to the ALARA[*)] principle in addition to ensuring that the personnel are not exposed to more than the CERN annual reference level of 1.5 rem.

[*)] The principle that exposure to ionizing radiation should be as low as reasonably achievable.

2. GLOBAL ESTIMATIONS AND EXPERIENCE AT PETRA

Estimates of possible doses and dose rates in the LEP Experimental Halls have already been made using pessimistic assumptions of beam losses (Appendix I). The same methods and pessimistic assumptions were also applied to the case of PETRA to allow a comparison to be made*). Table 1 shows the doses due to an accidental beam loss and a maximum possible dose rate during injection for PETRA and LEP under the same assumptions. The shielding configuration in these calculations was 1 m of concrete and a distance of 4 m from the beam. This corresponds to what is specified as being the minimum shielding requirement at PETRA.

It should be noted that a radiation situation corresponding to the catastrophic loss of a beam giving an estimated dose as indicated in Table 1 of Appendix I, has never been observed at PETRA, since the design figures have not yet been reached. The values of the table, however, show clearly that injection losses determine the potential radiation hazards in the experimental areas of electron storage rings and that the expected situation at LEP is very similar to that assumed in the PETRA design under the assumption of similar shielding arrangements.

Although the calculations are pessimistic it is clear that the maximum dose rates under injection loss conditions are very high and must be reduced or avoided. Increasing the concrete shield by 80 cm will only reduce them by a factor of 5 (fig. 1). A less clumsy way is to limit high dose rates by the use of radiation monitors to inhibit injection in case of abnormal losses in an experimental area. This has the added advantage of helping to avoid radiation damage to the sensitive detectors of the experiment and can be a useful diagnostic of machine problems for the operators.

Such a philosophy of combining a reasonable thickness of shielding as protection against the sudden loss of beams with a reliable radiation monitoring system was adopted for the experimental areas of PETRA and has so far led to very satisfactory operation.

Annual doses in the PETRA experimental halls of approximately 200 mrem are recorded using the minimum shield requirement specified above. However,

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*) The PETRA beam parameters were taken from the report DESY D3/19, 1975. The maximum beam current so far achieved is one order of magnitude less.

even this minimum shielding is not required on the top of the experimental layout where there is no access.

There has been no evidence of radiation levels from a catastrophic beam loss, hence the radiation doses measured at PETRA can be assumed to be due to injection losses. The installed radiation monitors have a threshold level of 7.5 mrem/h and typically inhibit injection, about twice a month. The reason is always readily apparent.

3. PROPOSAL AND DISCUSSION

In order to stay below the annual reference dose of 1.5 rem it has been proposed that for new installations producing radiation the maximum dose to be expected should be 1 rem per year, i.e. during normal operation and service periods no person should receive more than 1/5 of the annual dose limit. To achieve a radiation situation in the experimental areas which can be called "ALARA", the installations should be planned and shielding and geometrical factors defined such that an annual area dose of 1 rem will never be exceeded. The occupancy time will then provide a sufficient additional safety factor.

It is proposed that the same radiation shielding philosophy as used at PETRA should be adopted for LEP. The minimum shielding requirements of 1 m of concrete (or the equivalent of iron) combined with a closest approach of 4 m can also be used but if a close parallel with PETRA is used the resulting area dose is likely to be higher around LEP (Appendix II).

In order to achieve an annual area dose of well below 1 rem around the experimental areas of LEP the following measures are proposed:

1. Provide a shield over the full azimuth since part of the actual area dose measured in PETRA is due to skyshine. A solution with no roof shield like in PETRA would anyway not be acceptable for LEP because of an expected increased skyshine from the concrete roof of the LEP halls*). A complete shielding will also avoid any problem with overhead access via cranes or walkways which would be more difficult to control than at PETRA.

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*) At PEP a 1.50 m gap between the top of the main shielding wall and the roof of the hall is closed with a 30 cm concrete curtain. According to measurements quoted in the PEP design handbook this reduces the dose in the halls by more than one order of magnitude.

2. Provide for a thicker shield in areas where this is possible: any sections of clear beam pipe should be shielded with 1.20 m of concrete giving an additional factor of two. (Fig. 1 shows that beyond 1.20 m only high-energy hadrons remain and additional shielding is less effective.) Civil engineering of the experimental areas must provide an infrastructure, especially with respect to floor load, so that in case of need, e.g. transparent or no detector, a complete shielding wall (1.60 m) could be installed between the detector and the experimental cave.

3. Equip areas of minimum shielding with an effective fail-safe radiation monitoring system which will inhibit injection in case dose rates exceed a preset value. A level of 25 mrem/h would appear to be reasonable as the 1 rem limit would allow 40 hours at this level. An operator alarm at a lower level, say 5 mrem/h, would also help to ensure that the length of time during which abnormal conditions exist would be kept as short as possible. Such a two-level system would then be consistent with PETRA experience that electrons are only lost in an experimental zone when there is something wrong, and also protect the experimental equipment. The comparison with PETRA suggests that such an interlock level would be unlikely to be reached particularly during interleaved injection into LEP.

With these measures carefully implemented the area dose in the LEP experimental areas will stay well below 1 rem per year even when the machine reaches its full performance at 85 or 125 GeV as specified in LEP Note 239.

It should be emphasized that a once and for all choice of the interlock level is not necessary and an important rôle of the monitoring system will be to provide up-to-date information on the area doses, when they occur and under what conditions. This will then allow a realistic application of the ALARA principle by reducing the alarm or inhibit level or even increasing the thickness of the shielding if necessary, particularly where this can be done without inconvenience to the experimental installation.

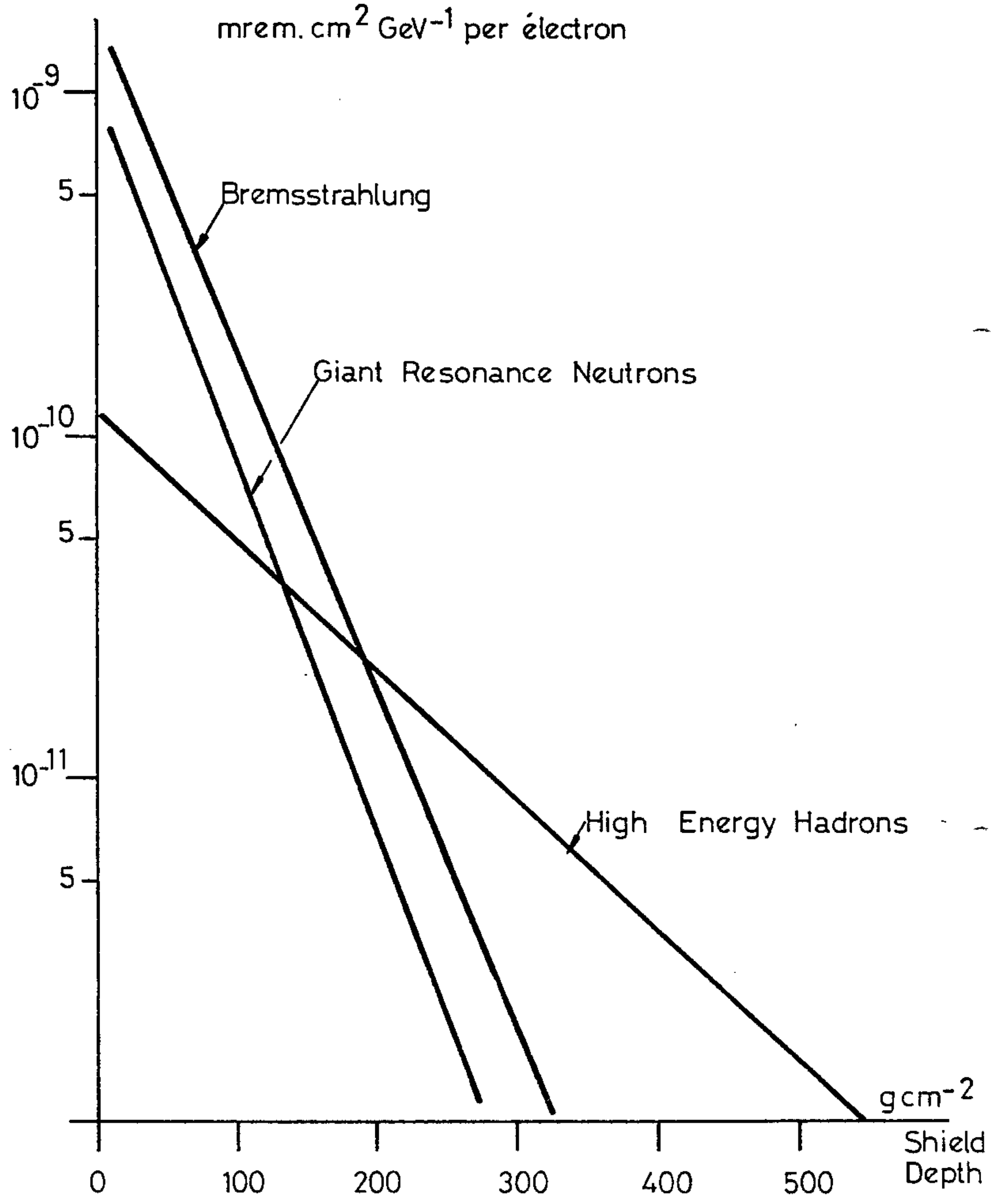
Three inconveniences of this shielding philosophy should be mentioned:

1. The experimental areas of LEP have to be considered as controlled radiation areas and will not have the free accessibility which exists at PETRA. Since physicists are expected to continue to work around

the existing proton machines at CERN they will continue to be under personnel monitoring control, and therefore the requirement to carry a dosimeter will not be an additional problem.

2. The price for increased flexibility will be the need for a regular radiation inspection and some restrictions on the experiments themselves. For example the removal of a calorimeter for repair will be more complicated if it forms part of the radiation shield. Similarly, experiments which can be opened for access will not be able to remain open during machine operation, when interaction zones have to be kept fully shielded.

3. The radiation monitoring system will have to fulfill important criteria with respect to safeguards against failures. A proposed system is described in Appendix 3.



Source terms and attenuation in concrete

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APPENDIX I

Technical Memorandum

M. Höfert
25 May 1981

SHIELDING REQUIREMENTS AND RADIATION SITUATION IN THE EXPERIMENTAL AREAS OF LEP

INTRODUCTION

Following a discussion in the framework of the Radiation Working Group for LEP, the approach with respect to shielding and access to experimental areas at PETRA was considered in principle applicable to the underground experimental areas of LEP$^{1)}$. It is however necessary to define clearly the conditions under which the solution adopted at PETRA would work for LEP and point out differences which exist between the two installations.

SHIELDING ESTIMATIONS

The basic formulae and source terms for the various radiation components to be considered in the case of electron accelerators have been discussed previously$^{2)}$. Although the pessimistic assumptions used in the report are likely to lead to overestimations in terms of doses and dose rates in the actual case outside the shielding enclosure, it will be possible to compare the situation at PETRA and at LEP on equal terms.

Since the interaction regions have to be conceived for minimum background with respect to synchrotron radiation and off-momentum particles, from the main ring, there are only three types of beam losses that have to be considered: injection losses, continuous beam decay, and catastrophic loss of a stored beam$^{3)}$. It has been shown previously that only injection losses could lead to appreciable dose rates outside the beam enclosure, while catastrophic losses would cause bursts of single doses.

At PETRA a minimum shielding of 1 m of concrete or 40 cm of iron has to be placed around intersection points with the further constraint that the nearest approach to the beam line is fixed at 4 m. Under these circumstances, if the same philosophy for LEP is adopted, the dose rates and doses can be estimated for both installations and are given in Table 1. The calculation has been performed with respect to a point-like loss in the interaction region. The results are based on the high-energy particle component for a source term of $1.2 \cdot 10^{-10}$ rem cm^2 GeV^{-1} and a λ for concrete of 115 g cm^{-2}. Taking values of $5 \cdot 10^{-11}$ rem cm^2 GeV^{-1} and a λ of 92 g cm^{-2} will lead to figures which are a factor of 4 lower[4)].

DISCUSSION

As can be seen, the radiation situation around both machines is rather similar. Experience with PETRA has not allowed a verification of the estimates made in Table 1 because apparently beam losses during injection are either limited or not localized near intersection points so that radiation monitors (tripping level at 7.5 mrem/h) were found to stop injection only about twice a month.

Although stored beams were lost in PETRA, no evidence of instantaneous doses in experimental halls was observed.

Since the total integrated dose in a year's operation of PETRA stayed far below 1.5 rem, the experimental area outside the shielding enclosure does not, according to the German law, have to be considered as a controlled radiation area. Consequently personnel monitoring is not required.

For the underground experimental areas at LEP the situation is somewhat different.

As CERN follows the stricter Swiss law where personnel dosimeters are required for annual dose values of 500 mrem, everybody working in the underground experimental areas during scheduled beam operation has to wear personal dosimeters. Additional reasons for individual dosimeter control are the use of radioactive and other radiation sources (X-ray sets, betatron) and the mobility inside the experimental teams where physicists tend to work also around the still existing proton machines at CERN.

CONCLUSION

It seems possible to copy the shielding philosophy adopted at PETRA for the LEP experimental areas. The solution of a minimum flexible shielding arrangement however requires a reliable radiation monitor system which would interrupt the operation of the machine in case dose rates in experimental areas exceed predetermined limits during injection periods.

REFERENCES

1. Draft Minutes of the Fifth RAWOG meeting, 27/4/81.
2. Höfert, M., Stevenson, G., HS-RP/IR/81-05.
3. Potter, K.M., LEP Note 259 (1980).
4. Tesch, K., Particle Accelerators 9, 201 (1979).
5. Dinter H. and Tesch, K., Interner Bericht DESY D3/19, 1975.

Table 1

Operation conditions	PETRA[5]	LEP
Injection energy in GeV	7	22
Electrons/sec injected	$2.7 \cdot 10^{11}$	$1.1 \cdot 10^{11}$
Dose rate in mrem/h	660	850
Stored beam energy in GeV	15	85
Electrons stored (1 beam) and lost	$1.2 \cdot 10^{13}$	$5.1 \cdot 10^{12}$
Dose in mrem	18	43

COMPARISON BETWEEN PETRA AND LEP

An analysis of the experimental data in 1980 on area monitoring around the experimental halls of PETRA gives the following picture. The average value of the annual dose in the four experimental halls is about 100 mrem at beam height and 200 mrem above beam height, which clearly shows the influence of skyshine due to the open roof philosophy.

These doses were achieved with an estimated total of $2 \cdot 10^{16}$ electrons and positrons injected into PETRA in 1980 during an injection time of 770 hours and for an operation time of 3800 hours. The injection efficiency typically amounts to 50%.

According to the calculation in Appendix I, a dose of 100 mrem (behind a complete shield) corresponds to a loss of $1.5 \cdot 10^{14}$ electrons (or positrons), i.e. 1.5% of the injected and accepted beam per experimental area. A lower source term and a smaller attenuation length as proposed by Tesch would increase this figure to 6% *).

On the other hand, it is interesting to see that on the basis of the table in Appendix I the trigger level of the radiation monitors around PETRA of 7.5 mrem/h corresponds to $3 \cdot 10^{9}$ electrons lost per second (although not necessarily placed behind 1 m of concrete and at a distance of 4 m from the beam). This figure is close to 50% of the "typical" injection rate of $8 \cdot 10^{9}$ s^{-1}, which seems to be a high value. Area measurements at PETRA concentrated on and revealed stray photons and neutrons which will, according to the attenuation lengths given in Fig. 1, dominate the radiation spectrum in cases of imperfect shielding. The beam loss pattern particularly around holes will influence the radiation situation considerably so that the absolute percent figures quoted above are subject to considerable systematic uncertainties. A comparison between PETRA and LEP can however be attempted under the assumption of similar operational conditions.

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*) Tesch, K., Particle Accelerators 9, 201 (1979).

In the case of LEP the total number of electrons and positrons injected annually has been estimated to be $4.2 \cdot 10^{16}$ for an operational period of 4000 hours*). Assuming like in PETRA a loss of 50% at injection and a 1.5% loss of the rest in an experimental area, an annual area dose of 700 mrem will result provided that a roof shielding is installed in the experimental caves of LEP.

Realistic injection rates into LEP could be $3 \cdot 10^{10}\ s^{-1}$ in a dedicated and $5 \cdot 10^{9}\ s^{-1}$ in an interleaved mode. Comparing once more with the experience of PETRA, this would mean that dose rates ranging from 90 to 15 mrem/h for the two operating conditions could be expected at a rate of about twice a month. In order not to hamper the operation of the machine and at the same time avoid excessive dose rates, a tripping level for the radiation monitors around LEP of 25 mrem/h is proposed.

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*) K. Goebel (ed.), The radiological impact of the LEP project on the environment, CERN 81-08 (1981).

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APPENDIX III

TECHNICAL MEMORANDUM

G. Rau
16 September 1981

PROPOSAL FOR A RADIATION MONITOR AND ALARM SYSTEM FOR LEP EXPERIMENTAL AREAS

1. GENERAL ASPECTS

The radiation alarm monitors for LEP experimental areas should be instruments of highest reliability designed specifically for monitoring radiation which could arise in areas in which personnel are permitted to stay or to have access during machine operation. The radiation to be detected will consist of neutrons from leakage through ducts (energy range: thermal up to ∿10 MeV), X-rays (klystron galleries) and gamma rays (energy range: 50 keV to ∿1 MeV) due to synchrotron radiation or beam losses. Radiation levels from ∿0.5 mrem/h up to 10 rem/h should be measured by these instruments.

The monitors should provide a signal indicating "good working conditions" (BF) of the instrument, an "A" (area) alarm signal set at approximately 2 to 10 mrem/h to inform machine operators and/or radiation survey personnel about high radiation levels in an area or for eventually driving radiation warning displays. A "B" (beam) alarm signal set at about 25 mrem/h should, in case of catastrophic local beam losses or high injection losses, switch off the beam via the interlock system after an allowed delay time.

2. DETECTOR

The most realistic choice of a detector to cope with the abovementioned type of radiation and the requirement of high reliability is a gas-filled ionization chamber. As the detector has to be sensitive to neutrons and photons a plastic (polyethylene) walled ion chamber with an appropriate gas filling (e.g. air, argon or any other simple gas mixture not requiring frequent refilling) is proposed. The chamber should have a sensitive volume of approximately 10 ℓ at atmospheric pressure to provide enough charge for the measuring circuitry.

A 10 ℓ polyethylene chamber filled with air of 1 atm produces a current of ∿1 pA/mrad/h (^{137}Cs gamma rays) and ∿0.8 pA/mrad/h (Pu-Be neutrons).

3. MONITOR ELECTRONICS

The electronics which is now in common use for low-level current measurements should be of the charge digitizing type. Experience at CERN with similar monitoring instruments provided for radiation measurements around the various PS and SPS experimental areas shows that a digitizer calibration of 1 pico Coulomb per charge reset is realizable without difficulties. Such a charge digitizer directly attached to the proposed ion chamber would measure a dose increment of 1 μrad per pulse released.

A 24 V DC power supply should be used both for the monitor electronics and for generating the polarizing voltage (∿500 V DC) for the ionization chamber).

4. INSTALLATION, INTERCONNECTION AND OPERATION OF THE MONITOR AND ALARM SYSTEM

A simplified block diagram of the proposed radiation monitor and alarm system is shown in Fig. 1. Three radiation monitors should be provided for each experimental area with the possibility of extending the system to five monitors per zone, if necessary. The monitors should be installed near to the weakest point of the shielding and if enough monitors are available at places with the highest occupancy by personnel.

The monitors are linked to a power supply/control unit via one multicore cable. This cable is used to transmit the 24 V supply to the monitor and to bring back to the control unit all important signals indicating "good working conditions" of the monitor electronics, as well as the measuring signal corresponding to a certain dose received by the monitor.

A small radioactive priming/test source should be incorporated into the ionization chamber to produce a constant current corresponding to a radiation level of ∿0.2 to 0.3 mrad. Therefore pulses are released continuously from the monitor indicating that the instrument is working correctly.

The control units could be either of a ratemeter type or a pulse-counting device. They must provide essentially the "BF" (good working condition), the "A" and the "B" radiation alarm signals. "BF" and "B" alarm signals of three monitors per area should be logically combined and the information that at least two out of the three monitors in each experimental zone are operational must be available at the LEP control room (via the interlock system) before injection can be allowed. On the other hand any "B" alarm signal must switch off the beam in case one of the monitors covering a particular zone measures radiation levels exceeding the preset "B" (∿25 mrem/h) alarm level.

The question of how to use the "A" alarm levels or which of the radiation monitors should be linked to the LEP data acquisition and control system and eventually to the existing RP data acquisition, and the possibility to integrate doses over longer periods or to display present mean dose rates at various places where monitors are provided should be discussed when the LEP data transmission and data acquisition system has been defined.

SCHEMATIC LAYOUT OF
A RADIATION MONITOR AND ALARM SYSTEM
FOR LEP EXPERIMENTAL AREAS