DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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Note: **DI-5**

DAΦNE SHIELDING

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1. DAΦNE OPERATING PARAMETERS

DAΦNE, the Frascati National Laboratories Φ-factory, will be installed inside existing buildings which are at present utilized for Linac and Adone operations.

The new machine will consist of three main sections: the linear accelerator (Linac), the Damping Ring accumulator and the Main Rings.

The aim is to accumulate, into the Main Rings, two electron/positron beams with a maximum intensity ~ 10^{13} particles/beam, divided in 120 bunches (average current ~ 5 A) at 510 MeV.

The Linac will operate up to 800 MeV at low intensity so as to generate a calibration beam (maximum intensity 10^3 e^-/s) for the Beam-Test Facility, which will be located in the Pion Hall.

During the normal injection of a single positrons bunch, the Linac will inject into the accumulator 45 pulses at 20 ms intervals, at 510 MeV.

The electrons injection will be performed at a frequency of 1-5 Hz. In both cases, the beam will be "cooled" into the accumulator for at least 100 ms and subsequently it will be transferred into one of the Main Rings. It will be a single bunch operation which will be repeated for 120 times up to a complete filling of the ring. Nevertheless it could be necessary to inject, for instance, half current per bunch for 240 times, etc. In any case, during the injection cycle the maximum stored charge will remain constant.

The operating parameters for a single cycle are summarized below. They are normalized to a duration of 1 s. The efficiencies (theoretical efficiencies in round brackets) in normal conditions along the injection line locations are also shown. The data, in square brackets, are referred to the operation with electrons when the values are different from the one with positrons.

a) Linac gun

Gun maximum energy	140 keV	
Pulse width	10 nsec	
No. e^-/pulse	$6.4 \cdot 10^{11}$	[$2.19 \cdot 10^{11}$]
No. pulses	45	[1]
Transp. efficiency	0.50 (0.50)	[0.50 (0.70)]
Gun-converter		[gun-510 MeV]
Total No. e^-	$1.44 \cdot 10^{13}$	[$1.09 \cdot 10^{11}$]
Final energy	250 MeV	

B) Converter (~ 2 r.l. gold or tungsten) - Linac Front End

Energy	250 MeV
No. e^- incidents	$1.44 \cdot 10^{13}$
e+ conversion efficiency	0.008 (0.008)
No. e^+ emergent	$1.15 \cdot 10^{11}$
e+ energy	10 MeV
Final energy 510 MeV	
Transport efficiency	0.95 (0.95)
	10 MeV-510 MeV
No. e^+ at 510 MeV	$1.09 \cdot 10^{11}$

C) Linac-Accumulator Transport

Energy	510 MeV
Transport efficiency	0.95 (1.0)
No. e^+	$1.04 \cdot 10^{11}$

D) Accumulator Injection

Energy	510 MeV
No. e^+	$1.04 \cdot 10^{11}$
Injection efficiency	0.95 (1.0)
No. cooled e^+	$9.88 \cdot 10^{10}$

E) Accumulator-Main Rings Transport

Energy	510 MeV
Extraction efficiency	1.0 (1.0)
Transport efficiency	0.95 (1.0)
No. e^+	$9.38 \cdot 10^{10}$

F) Main Rings injection

Energy	510 MeV
Injection efficiency	0.95 (1.0)
No. stored e^+	$8.91 \cdot 10^{10}$

The Main Rings filling time is ~120 s for the positrons and it is between 24 and 120 s for the electrons, in the case of injected current values as mentioned above.

In normal conditions, the estimated mean life time of the stored beam is ~4 h.

Whenever the current is reduced to 25% of its initial value a topping up injection is envisaged. This means 20 injections per day, every time injecting 25% of the current. This operation will be performed through reduction to 25% of the injected current. Assuming an operation of 10 months in a year and 20 injections at 25% in a typical day, equal to 5 complete injection cycles, the yearly number of these cycles will be 5x10x30=1500.

Although in normal conditions the complex operates at the energy of 510 MeV (maximum injection energy), the Main Rings can operate up to 700 MeV. In this case the maximum stored current will be reduced in order to keep the power beam constant.

2. SHIELDING OUTLINES

The new machine general layout, with respect to the existing buildings, is shown in fig. 1.

In shielding evaluation, the following procedure has been adopted. For the Linac and the Main Rings the effectiveness of the existing shields, with reference to the new situation has been tested, suggesting necessary integration. For the Damping Ring the shielding has instead been completely designed. This machine will be installed in the Leale Gamma Hall, whose walls are not suitable to house a radiation generating machine. In the evaluation of this shielding the constraints involved by the use of the pre-existing buildings have been taken into account.

Calculations have been performed by using the operating parameters mentioned in the preceding paragraph.

Because of the great number of the precautions introduced, the results should be a conservative approximation of the doses actually expected.

During the commissioning phase, the reliability of the assumptions made will be verified and, if necessary, supplementary precautions will be adopted.

3. SHIELDING DESIGN CRITERIA

As it is well-known, the Italian legislation on radiation protection is still based on the text of the 1964 Presidential Decree No. 185, and it cannot therefore provide a practical basis for the choice of the shielding design criteria for a machine whose life is presumed to last longer than the time left over to the above mentioned decree.

According to the international trends expressed by the ICRP, to which the European Directive refer, any evaluation of radiation protection has to be based on the fundamental principle of radiation protection optimization (II principle of the system of protection recommended by ICRP). According to this principle the individual doses and the number of people exposed must be kept *as low as reasonably achievable, economic and social factors being taken into account* (ALARA principle).

Dose constraints on the radiation protection optimization procedure have recently been introduced by the ICRP within the frame of this principle (ICRP90). They are source-related values of individual doses used to limit the range of options considered on the procedure of optimization.

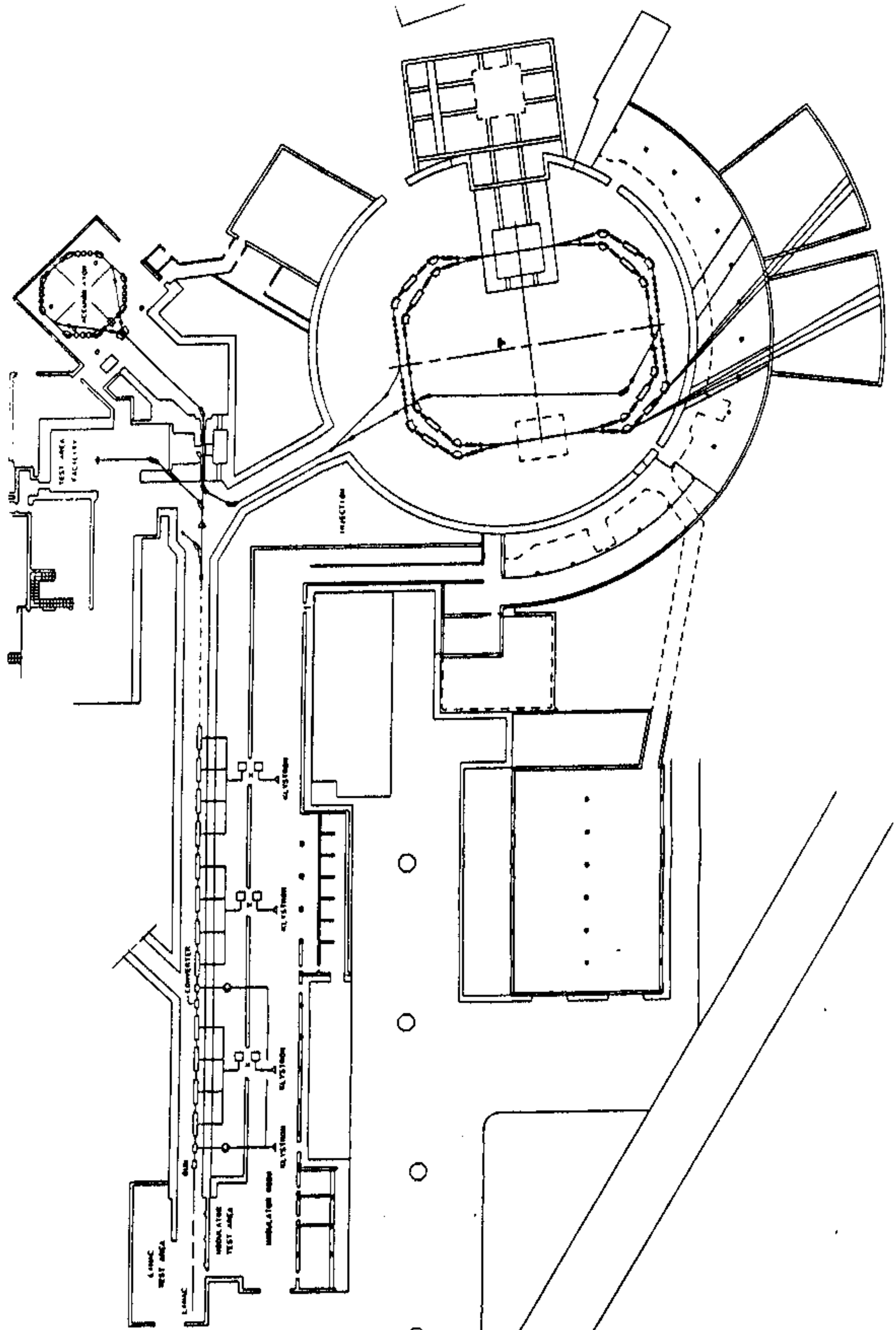

Fig. 1 - General layout of the new machine and existing buildings.

Their values should be equal to the doses really obtained in the well-managed plants (BAT or *best available technology* in the USA terminology). These values have not yet been formally specified, but it is not difficult to make forecasts on the basis of the results currently available in the literature for radiological practices.

Real operational limits, therefore, arise from the application of this principle. If the procedure of optimization has been effectively carried on, there will be few cases where limits on individual doses have to be applied. These individual limits are recommended exclusively to prevent exposures likely considered unacceptable in normal circumstances (III Principle of the system of protection recommended by ICRP). The average values of the individual limits, recently fixed by ICRP, are of 20 mSv/y (2 rem/y) for the radiation workers, and 1 mSv/y (100 mrem/y) for the members of the public (ICRP90).

Moreover, the definition of the controlled and supervised areas can be useful as radiological protection guideline.

According to the European Directive, which will be soon incorporated in the Italian legislation, a "controlled area" is every area where 3/10 of the limits recommended for the radiation workers may be exceeded, and a "supervised area" is one where the overcoming of 1/10 of the limits may occur.

After all, taking into account the dose levels normally found around the accelerators, it was deemed advisable to build the new machine maintaining the doses, within the areas outside the shields frequented by the staff, at a 1-2 mSv/y maximum, in normal working conditions.

A shifting from these values (for example in the case of beam losses greater than expected, or operating for a number of hours/y greater than expected, etc.) could at most cause the classification of some areas among the "controlled areas".

Considering the particular operation mode of DAΦNE, the sensibility of workers, public and Authorities towards the ionizing radiation, and the proximity to the contiguous ENEA Center, it is regarded advisable to introduce limits also on the injection dose rate outside the shield in the areas normally frequented by workers.

In normal working conditions, the dose rate should not exceed some μSv/h (some tenth of mrem/h), whereas in unusual conditions a rate of some tens of μSv/h (some mrem/h), for short time, could be allowed. Greater dose rates should immediately be eliminated by the machine safety systems (beam or radiation monitors with interlocks on Linac).

4. SOURCE TERMS

For shielding evaluation purposes, three components of radiation field which are produced when an electron beam, with an energy of hundreds MeV, hits a thick target or the thin walls of the vacuum chamber under a small angle have to be considered.

First of all, an electromagnetic cascade is produced. The resulting electron-photon stray radiation is strongly oriented in the forward direction. During the cascade development, low-energy neutrons (giant resonance neutrons) are produced through photons interaction with the e.m. field of the nucleus and high-energy neutrons (> 15-25 MeV) through photons interaction with neutron-proton pair (quasi-deuteron model) or nucleon interaction via pions productions.

For each one of these components, whose characteristics are known enough, a source-term has been considered as following explained.

a) Bremsstrahlung

The dose equivalent rates at 1 meter from an optimum high-Z target per unit incident electron beam power are given in the IAEA Report No. 188 by (IAEA79):

$$\dot{D}\ [(Gy \cdot h^{-1})\ (kW \cdot m^{-2})^{-1}] \cong 300\ E_0 \qquad \theta = 0° \qquad (1)$$

$$\dot{D}\ [(Gy \cdot h^{-1})\ (kW \cdot m^{-2})^{-1}] \cong 50 \qquad \theta = 90° \qquad (2)$$

where E_0 is the energy of the electron beam in MeV and θ is the angle between the beam direction and the location of interest.

Dose rate as function of the angle in the range 10°-90° is assumed to change as $\theta^{-3/2}$ (Fa84).

b) Giant resonance neutrons

According to the above mentioned IAEA Report, the neutron yield for thick lead targets, disregarding the target self-absorption, is:

$$Y = 2 \cdot 10^{12} \quad n \cdot s^{-1} \cdot kW^{-1} \qquad (3)$$

The giant resonance neutrons are emitted isotropically with an average energy of a few MeV.

Whenever the neutron source is located in lighter materials (for instance in the magnets iron of the Damping Ring) the use of eq. (3) represents a conservative approximation.

c) High-energy neutrons (E > 25 MeV)

The photoproduction of high energy neutrons due to the collision of an electron beam on a thick target has been extensively reviewed on the occasion of the LEP shielding calculation (Fa84). The situation most closed to the case under examination is represented by a calculation for a 400 MeV electron beam incident on a copper target (Ga69).

The neutron yields resulting from this calculation, in the angular ranges 0°-30° and 60°-120°, seem to be a reasonable approximation for the source terms to be used here.

At 400 MeV, between 0° and 30°:

$$Y = 2.5 \cdot 10^{-4}\ n \cdot sr^{-1} / e^{-} \tag{4}$$

and between 60° and 120° :

$$Y = 1.2 \cdot 10^{-4}\ n \cdot sr^{-1} / e^{-} \tag{5}$$

For different angles the corresponding values are deduced from the results of the calculations above mentioned.

5. ATTENUATION COEFFICIENTS

a) Bremsstrahlung

In order to evaluate the attenuation of the bremsstrahlung emission at 0°, the IAEA Report No. 188 data have been used, as taken by the author in the Aladdin shielding calculations (Sw85):

	TVL (cm)	λ (cm)	1/λ (cm^{-1})
Ordinary concrete	47	20.4	0.049
Lead 5	2.2	0.46	
Iron 10.82	4.76	0.21	

At 90° a TVL=43 cm (λ=18.7 cm; 1/λ=0.053 cm^{-1}) has been assumed for the ordinary concrete (Ho81).

The use of these attenuation coefficients for ordinary concrete represents a conservative approximation considering that in a recent paper a λ value, lower than 40 $g \cdot cm^2$ equivalent to 17 cm, at 0° and for energy lower than 1 GeV, has been assumed (Di89).

b) Giant resonance neutrons

For the giant resonance neutron component, a TVL=39 cm (λ=40 g cm^{-2} =17 cm; 1/λ=0.059 cm^{-1}) has been assumed for ordinary concrete (Ho81).

Since the attenuation of this component in lead is negligible, it was not taken into account.

c) High-energy neutrons

The attenuation coefficients of ordinary concrete for the high energy neutron component quoted in specialized literature are mostly comprised between 100 and 120 $g \cdot cm^{-2}$ (IAEA79, Je79, Te88, Ho81).

In the present calculation a value of 115 g·cm^{-2} (λ=48.9 cm, 1/λ=0.02 cm^{-1}) has been assumed as in the LEP shielding calculation (Ho81).

For the attenuation of this radiation component in lead, the results of a Montecarlo calculation, purposely executed by the Fluka code, has been used. The neutron spectrum has been assumed similar to the one produced by a 400 MeV electron beam incident on a copper target (Ga69). It was found that for neutrons whose energy is higher than 15 MeV, a 10 cm lead transmission factor (later on indicated by w) equal to 0.7 may be considered, in terms of neutrons fluence. For neutrons of energy higher than 25 MeV such factor is 0.68.

6. ABOUT NEUTRONS FLUENCE-DOSE EQUIVALENT CONVERSION COEFFICIENTS

ICRP, in its Publication 60, introduced remarkable changes concerning the definition of quantities used in radiation protection and factors necessary to weigh absorbed doses. In particular, the *quality factor* is substituted by the *radiation weighting factor* and consequently the *dose equivalent* is substituted by the *equivalent dose*. The new conversion coefficients between physical quantities (as particles fluence) and radiation protection quantities have not yet been published.

The above mentioned innovations are not merely formal for the neutrons. They cause the doubling of the doses which are calculated according to Publication 21 (ICRP71) in the intermediate energy range. In our calculations, the neutron fluence-dose equivalent conversion coefficients recommended in Publication 21 have been revalued considering the ratio of the weighting factors in Publication 60 relatively to the quality factors adopted before.

So the conversion coefficient used for the giant resonance neutrons is f_{NRG} = 2.87 μSv h^{-1}/n cm^{-2} s^{-1} and for the high-energy neutrons f_{NHE} = 1.8 μSv h^{-1}/n cm^{-2} s^{-1}.

7. TRANSVERSE SHIELDING EVALUATION

Evaluations concerning transverse shielding have been performed supposing that a percentage fraction of the particles primary beam, later on indicated by p, is lost in a point of the machine assimilable to a "thick target".

For an heterogeneous shield with an effective thickness of b cm of lead, followed by t cm of ordinary concrete, the dose equivalent rate (expressed in μSv/h) in a point at 0° is given by:

$$HG = 4.8\cdot10^{-4}\,\frac{QE^2p}{d^2}\;e^{-0.46b}\;e^{-0.049t} \qquad (6)$$

$$HNRG = 2.5\cdot10^{-5}\,\frac{QEp}{d^2}\,f_{NRG}\,e^{-0.059t} \qquad (7)$$

$$HNHE = 6.25\cdot10^{-7}\,\frac{QEp}{d^2}\,f_{NHE}\,w\,e^{-0.02t} \qquad (8)$$

where d is the target point distance, HG, HNRG and HNHE the radiation components taken into account, i.e. photons, giant resonance neutrons and high energy neutrons, respectively.

For the locations in which the attenuation due to the magnets iron is also to be considered, the relating attenuation factor ($e^{-0.21f}$, where f is the iron thickness) will have to be introduced into eq. (6).

Fig. 2 shows the dose equivalent rate of the three components of the radiation field (eq. 6, 7, 8) as a function of the concrete thickness, in the case of an heterogeneous shield made of 20 cm of lead followed by ordinary concrete. The dose rates refer to a location at 10 m distance from the area in which a catastrophic loss of a beam like the one used for the injection into DAΦNE ($Q=9.38\cdot10^{10}$ e^-/s, E=510 MeV) occurred.

It is worth mentioning here that in a very recent paper (Sa91) a methodology for the calculation of doses caused by forward electromagnetic radiation generated by high energy electron beams is illustrated. This method, if applied to our case, would lead to smaller dose values than those obtained as described above. This is due to the choice of a more favourable lead attenuation coefficient when followed by concrete.

If the location of interest is at 90°:

$$HG = 0.8\cdot10^{-4}\,\frac{QEp}{d^2}\,e^{-0.46b}\,e^{-0.053t} \qquad (9)$$

$$HNHE = 3\cdot10^{-7}\,\frac{QEp}{d^2}\,f_{NHE}\,w\,e^{-0.02t} \qquad (10)$$

while for the giant resonance neutrons eq. (7) is still valid.

Fig. 3 shows the dose equivalent rate of the three components of the radiation field described by eq. 9, 7, 10 as a function of the concrete thickness, in the case of a lateral shield composed of ordinary concrete only. The rate values refer to a location at 10 m distance from the area in which a catastrophic loss of a beam like the one used for the injection into DAΦNE ($Q=9.38\cdot10^{10}$ e^-/s, E=510 MeV) occurred.

In the following we have considered the beam loss expected in normal working conditions. The possibility to have greater beam loss, even though for limited working periods, has also been examined.

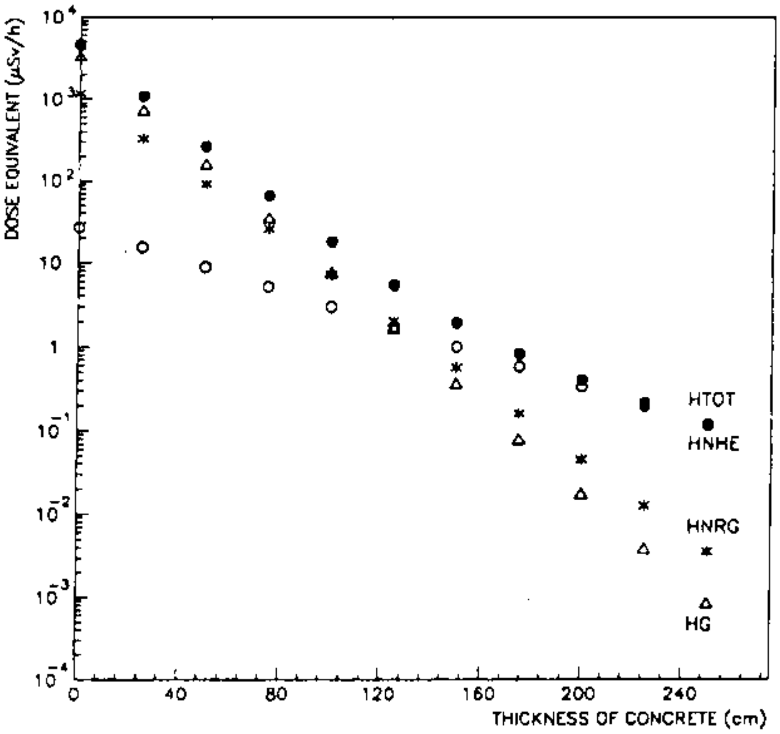

Fig. 2 - Dose equivalent rate for the three components of the radiation field, in the forward direction, as function of the concrete thickness, in the case of an heterogeneous shield made of 20 cm of lead followed by ordinary concrete. The dose rates refer to a location at 10 m distance from the area in which a catastrophic loss of a beam like the one used for the injection into DAΦNE ($Q=9.38\cdot10^{10}$ e^-/s, E=510 MeV) occurred.

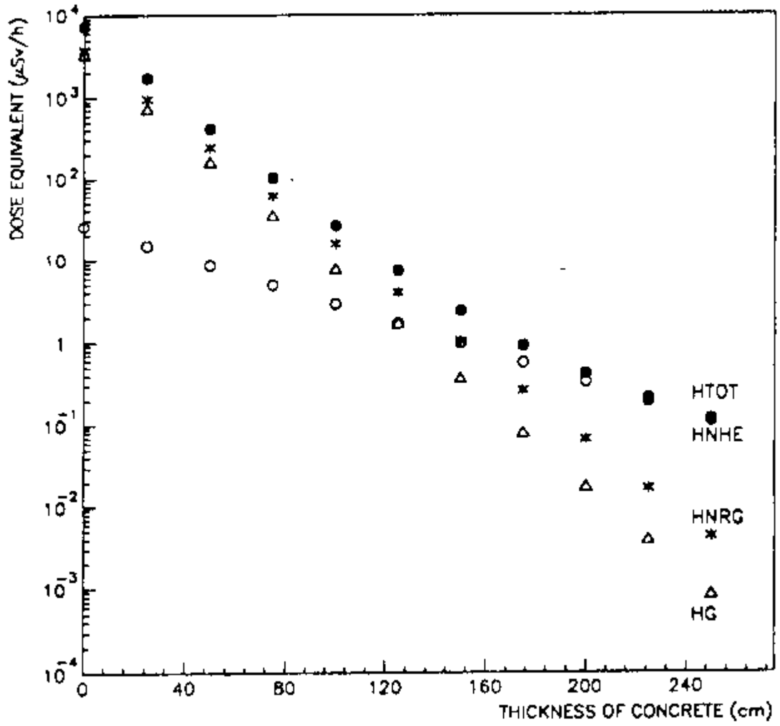

Fig. 3 - Dose equivalent rate for the three components of the radiation field, in the 90^o direction, as function of the concrete thickness. The rate values refer to a location at 10 m distance from the area in which a catastrophic loss of a beam like the one used for the injection into DAΦNE ($Q=9.38\cdot10^{10}$ e^-/s, E=510 MeV) occurred.

8. LINAC

Transverse shields along the tunnel of the Linac presently in operation, is made of ordinary concrete 1 m thick, followed by 3.5 m of earth, on the Modulators Room side, and by 6 m of earth on the opposite side.

Since the doses found outside the tunnel have never been different from the background, not even when the machine working power reached several kW, one must conclude that the above shields are fully adequate for the new machine too.

However, we have checked the adequacy of the shields by using the methodology illustrated in the preceding paragraphs.

The converter area is the most important one when the electron beam ($1.44 \cdot 10^{13}$ e^-/s at 250 MeV) hits the converter for the positron production.

In these conditions, the dose equivalent rate on the side with 6 m of earth, results absolutely negligible and it is equal to $5.27 \cdot 10^{-2}$ μSv/h corresponding to a annual dose of 2.64 μSv in the hypothesis of 1500 complete cycles of injection per year (equivalent to 50 hours of continuous operation).

On the Modulator Hall side, instead, there are 5.65 μSv/h (i.e. 283 μSv/y) in practically inaccessible locations immediately outside the shields; such dose rates become 1.64 μSv/h (82 μSv/y) at a 4 m distance. These evaluations do not take into account that a lead thickness will be placed around the converter to reduce doses due to induced activity.

At the end of the Linac, there will be a beam absorber composed of 20 cm of lead followed by 200 cm of concrete. The dose equivalent rate, one metre behind the absorber, is therefore equal to a few tens of μSv/h at the most, in case of maximum beam power. It is a fully acceptable value if we consider that the area will be inaccessible during the machine operation.

The Linac tunnel is provided with an effective roof shielding (about 3.5 m of earth), so it is not necessary to examine the skyshine effect.

9. DAMPING RING

9.1 Transverse shielding

Transverse shielding of the Damping Ring has been evaluated by considering the beam losses in normal working conditions and the most probable causes of catastrophic beam losses.

In normal working conditions, with a theoretical injection efficiency of 100%, a loss of a beam fraction equal to 5% has been assumed. These beam losses are concentrated in the septa which are placed at 2 cm from the trajectory and, consequently, represent the limiting apertures.

The beam losses essentially occur in the radial plane of the orbit placed at 180 cm from the floor. For such beam losses, the evaluation of the shielding thickness must be performed along the *a* direction shown in fig. 4, taking into account the effective thickness (about 19 cm) of the H magnets iron. In addition, for conservativeness, it was assumed that a further beam fraction, equal to 10%, will be uniformly lost along the entire machine.

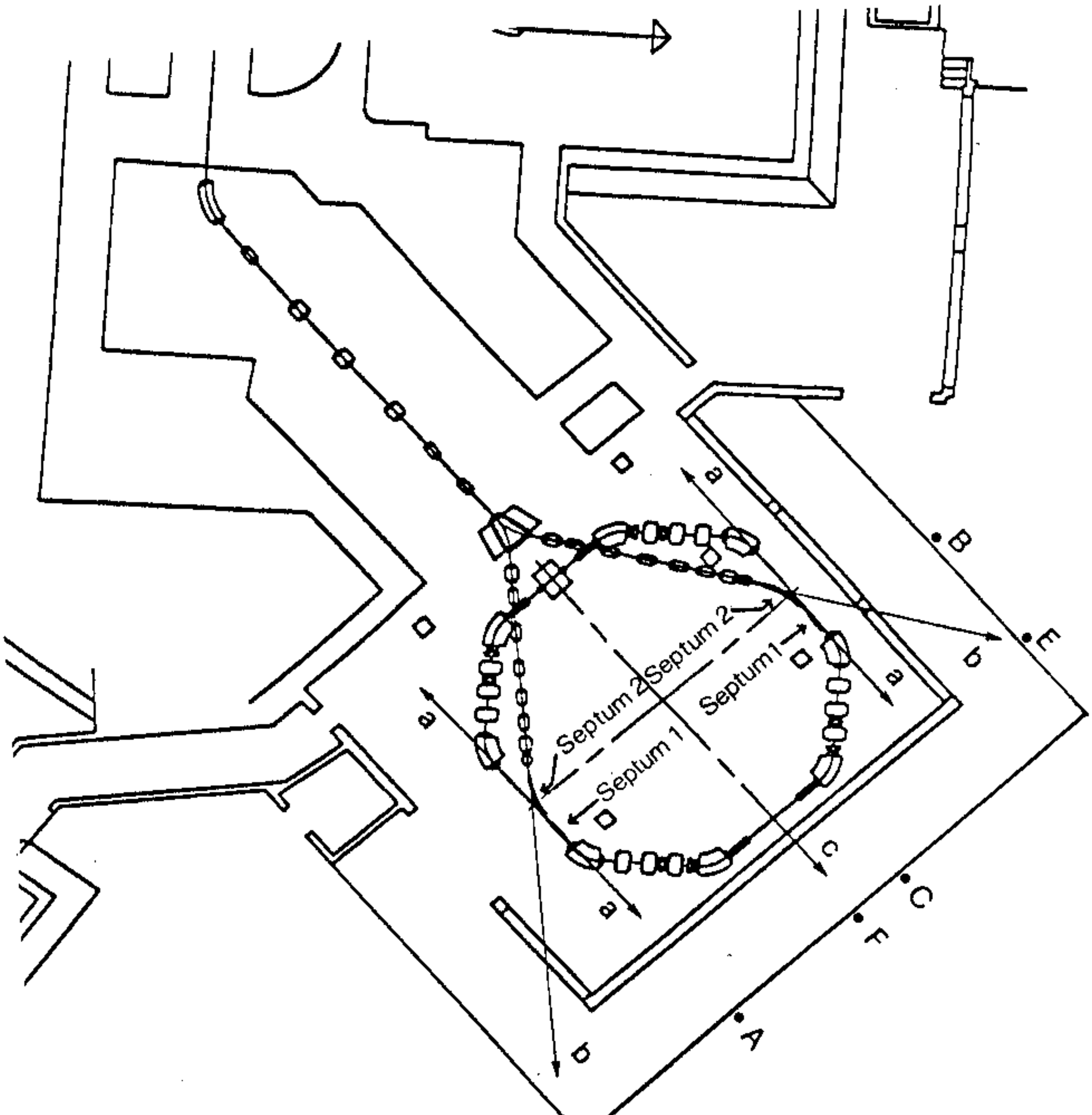

Fig. 4 - Damping Ring layout relating to beam losses distribution.

During the commissioning we can not exclude beam losses greater than the ones we have considered above. Therefore the possibility that under special circumstances beam losses may reach up to 50% was taken into consideration. Let us point out that, whenever such situation becomes probable, the machine will be set to operate at low power. All initial commissioning operations have to be performed by reducing the Linac current to 10% and the frequency to 1 Hz or less.

Localized catastrophic beam losses may accidentally occur in the following cases:

a) injection with magnets off (radiation in *a* direction)
b) septum 1 off (radiation in *a* direction)
c) septum 2 off (radiation in *b* direction)
d) kicker magnets out of order (radiation in the *a* directions)
e) Y magnet off (radiation in *c* direction)

In consideration of the advanced hypothesis, "typical" points have been identified as shown in fig. 4, namely:

A for normal beam losses in septum 1 in the 0° direction, and for the a), b), and d) cases of catastrophic beam losses;
B for normal beam losses in septum 1 in the 90° direction;
C for uniformly distributed beam losses;
E for the c) case of catastrophic beam losses;
F for case d) of catastrophic beam losses.

As the uniformly distributed beam losses is concerning, the machine has been assimilated to an octagon, on each side of which a beam fraction proportional to its length is lost. In each point, the dose is essentially due to the beam losses along the two nearest adjacent sections. To simplify the calculations, the radiation observed in the 0° direction has been supposed to be produced in the central point of the originating section, while the source in the following section has been localized in the point of this section nearest to the point of interest.

The gas bremsstrahlung contribution is not relevant in this case because of the machine operation modes and because this radiation always crosses the magnets iron on a effective length of about 19 cm.

On the basis of the above, the following solution is adopted: a general shield made of ordinary concrete 100 cm thick, reinforced by 10 cm of lead around septa no. 1 and 2, 15 cm of lead in the *a* directions and a 20 cm thick lead beam absorber just behind the Y magnet. Furthermore, around the shields an approximately 5 m deep area will be delimited and interdicted.

With such shields configuration, the doses expected in points A, B and C, immediately outside the enclosed area, in normal working conditions (5% beam losses in the septa, and 10% uniformly distributed) during the operation with positrons, are summarized in tab. I. The dose rates in the case of 50% beam losses in the septa, or uniformly distributed, and the number N of yearly hours needed to achieve in such situation the project aim of 1 mSv are also shown in tab. I.

Tab. I Doses expected in points A, B and C for different working conditions.

Point	$\dot{H}$ (μSv/h)	H (μSv/y)	$\dot{H}$ (μSv/h)	N (h/y)
	p=0.05%		p=0.5%	
A	0.87	43.8	8.7	115
B	1.34	67.2	13.4	75
C	2.71	135.4	13.5	75

The dose rates in the "critical" points, in the case of catastrophic beam losses, are summarized in table II.

Tab. II Doses expected in points A, E and F in case of catastrophic beam losses.

Point	$\dot{H}$ (μSv/h)
A	17.5
E	1.4
F	6.9

In order to limit the duration of such beam losses, the currents of the magnets (septa, kicker and Y magnet) will be interlocked to the Linac gun.

9.2 ROOF

Skyshine effect has been studied simulating both the geometry of the Damping Ring building and the transport of radiation in air by the Morse code (Fa92).

In the calculations, for the sake of simplicity, the catastrophic loss of the injected beam is supposed to occur in a thick lead target placed at the center of the machine.

The average ambient dose equivalent rate, due to the neutrons in the zone between 10 and 22 metres from the target, at a 2 metres quota, is found to be ~ 150 μSv/h. By increasing the distance the dose rates decrease.

Using the empirical formula suggested by Nakamura et al. (Na81), an approximately 2.5 times higher values would be found. The discrepancy, not particularly relevant for this kind of evaluations, can probably be explained by the inability of a general formula to reproduce the phenomenon precisely.

The photon component was assumed negligible, not only because it is less important in this specific problem, but also because through the addition of few cm of lead on the source it may be easily suppressed.

With a concrete roof 40 cm thick, using the Morse code, it was found that the dose rate decreases to 0.85 μSv/h in the areas distant between 10 and 22 metres from the target, while with a 50 cm thickness, in the same locations, the dose rate is 0.25 μSv/h. In height the dose rates may be about a factor 10 higher.

It has been decided to install a 40 cm thick roof. In the case of the beam losses estimated in the project, the dose rates due to the skyshine effect will be negligible everywhere.

10. MAIN RINGS

The Main Rings will be installed in the Adone Hall, whose walls consists of 1 metre ordinary concrete thick. The effectiveness of this shield in the new conditions has been tested and the zones requiring reinforcements identified.

The shield, at present above the Adone ring, whose geometry was specifically designed for this machine operation, is not utilizable for the new one.

Some general improvements are expected to be made in the Main Rings building: the roll up door will be replaced by a shielding sliding door; one of the two sliding doors in the Counting Room could be eliminated, while the other two could be rationally restructured; the large windows overlooking the area in the Detector Building Control Room will be closed.

The following calculations have been performed considering the new machine customary working conditions, that is at 510 MeV. The results obtained may however be considered valid at 700 MeV, taking into account that current in this case would be reduced so as to leave the beam power unchanged. By keeping equal the current, the doses would increase no more than about a 2 factor.

10.1 GAS BREMSSTRAHLUNG SHIELDING

One of the main sources of the stored beams losses is the interaction of the electron beam with the residual gas in the vacuum chamber. This may constitute a considerable radiation risk under many circumstances. Although the phenomenon occurs in all locations of an accelerator, nevertheless in correspondence with the straight sections it is of great importance for radiation protection purposes.

Gas bremsstrahlung dosimetry evaluations have been made here starting with results of measurements carried out at the Adone ring. With a 500 MeV electron beam, at a distance of 9 metres from the machine, a dose rate of 23 μGy/h per mA of stored current, at a pressure of $1.33 \cdot 10^{-7}$ Pa (10^{-9} Torr), has been measured (Es86). This figure may be representative of the order of magnitude of the doses expected for DAΦNE, if we disregard in first approximation the discrepancies due to the different length of the straight sections in the two machines. Considering however that the current in the new machine will be much higher, about 5.3 A, the expected dose rates, distance and pressure being equal, will be of the order 0.1 Gy/h.

The concrete wall surrounding the DAΦNE Hall is evidently insufficient to reduce the doses to the values envisaged by the project aims for the new installation. Therefore we add some lead locally in strategic locations. This additional lead thickness is also required to reduce, inside the Hall, the doses to acceptable levels, with regard to accidental exposures of a short duration. Such exposures are however improbable because the access to the Hall is interdict during operations with stored beams.

We have decided to intercept, at the end of each machine section, the gas bremsstrahlung "spots" with 20 cm of lead, introducing an attenuation factor in the range 10^3-10^4 (Es86, Ba89).

10.2 TRANSVERSE SHIELDING

Once the machine is set up, an excellent injection quality and beam losses lower than 5%, located in the injection septa, are expected. In the calculations made to test the general shielding effectiveness, beam losses have been located exactly in correspondence of these magnets (see S1 and S2 in fig. 5).

On the basis of the results obtained by applying the methodology described in the preceding paragraphs, we have decided that, in the 0° direction, a lead shield 20 cm thick has to be added in both cases. With regard to S2, it is necessary the further addition of a lateral lead shield 10 cm thick.

In these conditions, the doses in the areas most exposed to the radiation field generated in the septa appear to be very low in normal operating conditions, as shown in table III.

Table III also shows the dose rates expected in the same places, in the event of catastrophic loss of the injected beams at the septa. These doses can be considered fully acceptable, taking into account the surely modest frequency of the hypothesized event, as well as the fact that most of the areas involved will not usually be accessible to the personnel during injection operations.

Table III Results of the calculations of the doses produced by beam losses in the injection septa in normal operating conditions and in the case of catastrophic beam loss.

Septum S1	Septum S2	
Areas exposed at 0°	Det. Ass. Hall	Cable Gallery
Dose rate for p=5% (μSv/h)	0.14	2.23
Dose Equivalent (μSv/y)	6.97	112
Dose rate for p=100% (μSv/h)	2.80	44.6
Areas exposed at 90°	Leale fenced area	Cable Gallery
Dose rate for p=5% (μSv/h)	1.26	2.67
Dose Equivalent (μSv/y)	63	133
Dose rate for p=100% (μSv/h)	25.3	53.4

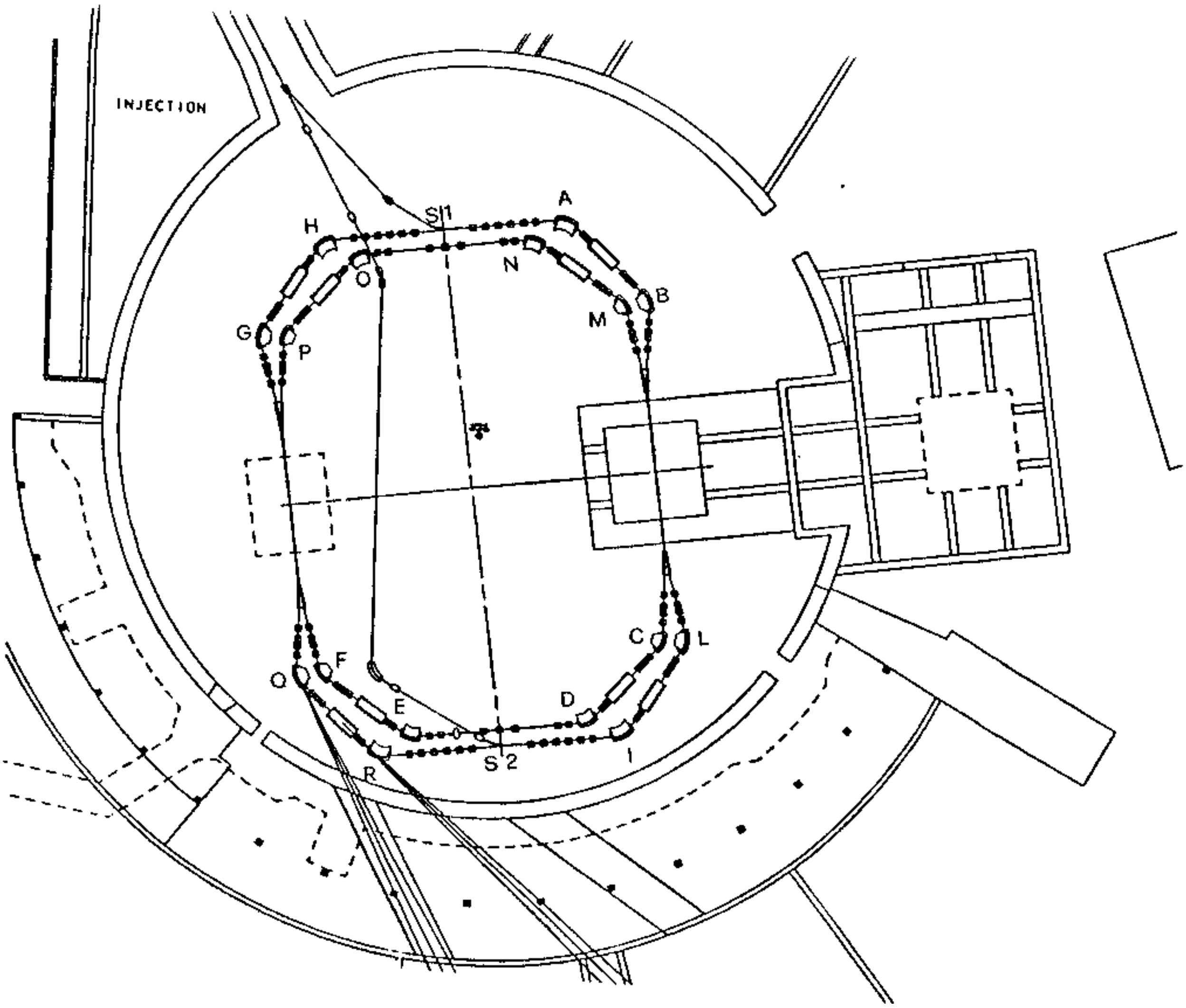

Fig. 5 - Main Rings layout.

Beam losses during the injection phase in the machine sections differing from those housing the septa are expected to be negligible. However, the possibility that they may occur has been examined. Also in this case the assumption has been made that the losses do not exceed 5% and they are localized in a single magnets. However such beam losses could never occur at the same time in all the magnets. The additional lead shielding, 20 cm thick, in the forward direction provided for the gas bremsstrahlung appears to be effective in all cases, also to reduce the doses produced during injection. For some magnets (D, E, I, L, Q, R in fig. 5) it might be useful to also install a 10 cm lead lateral protection, if low dose rates are desired such as those assumed in the project aims in the Cable Gallery, which however is not supposed to be frequented during the machine operation. A decision in this connection will be taken during the commissioning. A 5-10 cm thick lead shield will be placed between the B and S2 magnets and the Detector Assembly Hall.

Shields so arranged also solve the problems caused by the beam losses due to the life time of the stored beams, which are expected to be uniformly distributed all along the machine. In each machine section a beam fraction proportional to its length will therefore be lost. In calculations, these beam losses have been, for precaution, assumed to be concentrated in correspondence with the magnet placed nearest to the shielding.

According to these assumptions, the most relevant doses are expected to come from magnet I, due to both to the greater length of the tract to which it belongs and to its proximity to the concrete shield. In the side direction only 2.25 m separate such magnet from the Cable Gallery, while the forward distance is only about 5 m. With the additional shielding proposed above (included the lead 10 cm thick lateral protection), the expected dose rates in the Cable Gallery appear to be negligible and the relevant annual doses is equal to 280 μSv in the forward direction and to 970 μSv in the 90° direction.

10.3 ROOF SHIELDS

The heiger level areas examinated in this paragraph are the Adone Control and Counting Rooms, that will be subdivided into 2nd Detector Counting Room, Control Room and DC Power Supplies Area, and the Detector Building Control Room.

For the dose evaluation in the above rooms the eq. (6), (8), (9) and (10) have been modified in order to account the different source terms arising because of the different emission angles of the radiation.

The same assumptions used in the preceding paragraph have been maintained for beam losses distribution.

Table IV shows the results obtained by considering, for each room, the most significant beam losses locations and by supposing that in each point 5% of the injected beam is lost. It has further been supposed that the machine has no covering. The data shown include the dose rates and the annual foreseen doses in normal working conditions, as well as the dose rates likely to occur in case of catastrophic beam losses of the injected beam.

Table IV Doses produced in heigher level rooms by beam losses at the injection septa and in some other machine locations, in normal working conditions and in the case of catastrophic beam losses (rings without covering).

Magnet Source (Direction)	Exposed area	Dose Rate in n.c. (μSv/h)	Annual Dose in n.c. (μSv)	Dose Rate Cat. Beam Loss (μSv/h)
S2 (18°)	Counting Room	13.4	669	268
S2 (90°)	Counting Room	2.21	110	44.1
R (17°)	Counting Room	13.9	695	278
R (90°)	Counting Room	0.97	48.3	19.3
S1 (22°)	C. R. Detector	1.0	49.7	19.9
S2 (23°)	C. R. Detector	0.97	48.6	19.4
B (90°)	C. R. Detector	0.14	7.1	2.82
L (44°)	C. R. Detector	0.26	13.1	5.25

Annual doses are low enough to do not require roof. If we prefere to keep low the dose rates too in the areas usually frequented by staff, we should have to cover the machine sections near to the S2 and R magnets. If the same criterion has to be applied in the case of a catastrophic beam losses as well, the machine covering should then be extended to S1.

The zone of the S2 injection septum will be covered with a shield equivalent to 10 cm of lead and 50 cm of concrete, while only 50 cm of concrete will suffice on the S1 septum zone and on the R magnet.

We remark that no account has been taken of the effect produced by the two experimental apparatus which, once installed on the machine, will actually represent an effective shielding in many directions.

The doses due to the life time of the stored beams are expected to be negligibile, and in any case such as to require no further shielding addition.

10.4 SKYSHINE EFFECT

Skyshine effect evaluations were made through simulation of the Adone building geometry and of the radiation transport using Morse code (Fa92).

Since beam losses are likely to occur only in correspondence with the septa, calculations have taken into account the catastrophic loss of the injected beam in a thick lead target located in one of the sections where the septa are housed. With the hypothesized target the neutron production has been actually maximized, even though part of the photon component is self-absorbed by the target.

The average ambient dose equivalent rate in the area between 10 and 20 metres from the building wall at 2 metres height is ~ 30.9 μSv/h for the neutron component and 1.7 μSv/h for the photons one. Between 100 and 200 metres such two components drop to 1.5 μSv/h and to 0.1 μSv/h respectively.

With the machine coverings hypothesized in the previous paragraph, these doses go down to negligible levels, as it can be deduced also considering the TVL values in par. 5. Of course, they will be negligible in normal working conditions when the beam losses involved should be only 5%.

11. BEAM TEST

The maximum beam test intensity has been chosen to be 10^3 e^-/s, so that no lateral shields are necessary. Only an absorber of 10 cm of lead at the end of the beam line will be installed. However, an area one metre deep around the beam line will be fenced, in order to avoid accidental exposures.

The safety system will prevent machine operation whenever the intensity exceeds the established current.

Dosimetry evaluations have been performed supposing that the beam hits a target with optimal thickness to produce bremsstrahlung. By applying eq. (1) and (2), negligible dose rates are found outside the fenced area.

12. SUMMARY

The shielding for the new accelerators will require the thicknessess indicated in the following summary. These thicknesses may be replaced by equivalent ones of other materials.

Shields configuration for DAΦNE complex.

Linac	General shields: those of the present Tunnel Beam absorber: 20 cm Pb + 200 cm concrete.
Damping Ring	General lateral shield: 100 cm concrete (after delimiting a 5 m deep area). Supplementary shields: 10 cm Pb around septa 1 and 2. 15 cm Pb in the *a* directions (see fig.4). 20 cm Pb after the Y magnet. Roof: 40 cm concrete.
Main Rings	General shields: those of the existing Adone Hall (with some changes) extended to the Detector Building. Supplementary shields: 20 cm Pb at the end of the machine sections and in correspondence of S1 and S2 in injection direction. 5-10 cm Pb between B and S2 magnets and the Detector Assembly Room (see fig. 5). 10 cm Pb laterally on D, E, I, L, Q, R, S2 magnets (to be confirmed after the first testing). Roof: 10 cm Pb + 50 cm concrete in the S2 zone. 50 cm concrete above S1 and R.
Beam Test	Beam absorber: 10 cm Pb (after delimiting a 1 m deep area).

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