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RADIATION SAFETY CONSIDERATIONS FOR AREAL ELECTRON LINAC WITH BEAM DIAGNOSTIC SYSTEM

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Abstract

The AREAL linear accelerator will produce electron beam with 5 MeV energy and further upgrade up to 20 MeV. At the first stage of the operation the construction of the beam diagnostic section of complex shape and layout is planned thus making the radiation source definition difficult. FLUKA particle tracking simulation code was used to calculate produced radiation dose rates and define an appropriate radiation shielding.

INTRODUCTION

The AREAL linear electron accelerator equipped with RF gun is capable of producing 5 MeV beam with beam current equal to 200 pC [1]. Along with laser driven RF gun two acceleration structures will permit electron beam energy to reach the energy of 20 MeV. Secondary radiation sources rose due to interaction of the beam electrons with the matter of beam dump target, vacuum chamber walls, beam detectors and diagnostic equipment. Radiation doses are calculated applying FLUKA particle tracking code [2]. Concrete walls of the machine tunnel as well as movable shielding walls constructed of Led and concrete bricks contribution to radiation level outside of tunnel well below the natural background.

Travelling straight beam line, electron beam will be terminated by beam dump making it the main source of the secondary neutron and gamma radiation that safety system should cope with. Electrons will interact with the pieces of the beam diagnostic system set up for beam charge, profile and emittance measurements [1]. Beam bend magnet installed to measure beam momentum and momentum spread by creating dispersion makes beam chamber walls a potential source of the parasitic radiation.

BEAM DUMP

The beam dump will consist of iron core with lateral and downstream shielding. Iron target will be 30 cm long cylinder with 5 cm thickness. Ten cm Led shields will surround iron core (laterally and downstream) and 50 cm thick concrete brick wall will compose outer shielding of the beam dump.

Dose produced at beam dump Standard-Target and shielding calculations are based on the algorithms and formulae contained in SHIELD11 computer code [3], as well as simulated by FLUKA particle tracking code. The angular and energy distribution of the gamma radiation emitted directly in shower core at iron target can be expressed by the following formula [3]:

$$D_\gamma = \left(\frac{EI}{q_e}\right) \times \left(\begin{array}{c}3.031 E e^{-0.959\sqrt{\vartheta}} \times 10^{-13} \\ +7.5 e^{-\vartheta/72.2} \times 10^{-8}\end{array}\right).$$

Here D_γ is the gamma dose rate at the radiation source in the units of [Sv/h], I/q_e is the beam particles fluence(It reaches to value 1.25×10^9), E is the beam energy in [MeV]s and ϑ is radiation angle in degrees with respect to beam direction. For $E = 20$MeV and $\vartheta = 90$degrees one gets $D_\gamma = 0.538$Sv/h. Figure 1 illustrates direct gamma radiation dose per electron distribution at beam dump target for 20 MeV beam. Maximum of radiation lays in forward direction and increases with electron energy nearly linearly.

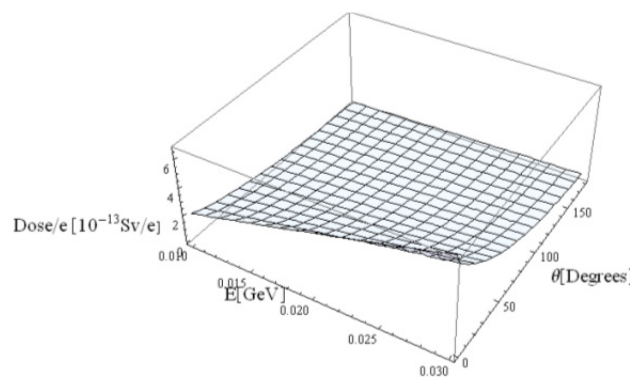

Figure 1: Direct gamma radiation dose per electron at standard target.

The composition of the radiation (in the units of particles/cm3 per primary) produced by 20 MeV electrons incident on Iron target core is given in Table 1.

Table 1: Beam Target Radiation Composition

	particles/cm^3/primary	Accuracy
Neutrons	0.0035	4.6 %
Electrons	1.40	0.0019 %
Photons	10.0	0.024 %

The shielding has to be dimensioned to keep the ambient dose equivalent rate below the limit of 0.125 µSv/h (the sum of both, the neutron- and γ-dose rates) [3,4]. The parameters of the some common shielding materials are given in Table 2. The mean free path λ [g/cm^2] is the parameter that defines materials ability to absorb radiation $F = F_0 e^{-\lambda/d}$, where F is the fluence and d [g/cm^2] is the material thickness. Neutrons are

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effectively being absorbed by concrete, since it contains hydrogen (in bounded water molecules). For the attenuation of the gamma radiation high Z materials (like Led) are being applied (Table 3)

Table 2: Density and removal free path for used shielding materials.

	Concrete	Fe	Pb
ρ [g/cm^3]	2.35	7.87	11.35
Neutrons [g/cm^2], ([cm])	30, (12.8)	47, (5.97)	97,(8.55)
Gamma [g/cm^2], ([cm])	42, (17.9)	33.6 (4.27)	24,(2.11)

Figure 2 depicts dose outside tunnel vs. concrete shielding thickness. Dotted line shows target level of equivalent dose ($0.125\mu Sv/h$).Additional 10cm Led shielding around beam dump target effectively reduces gamma dose. One should notice that concrete shielding total thickness is the sum of tunnel wall thickness and that of removable shielding wall round the radiation source.

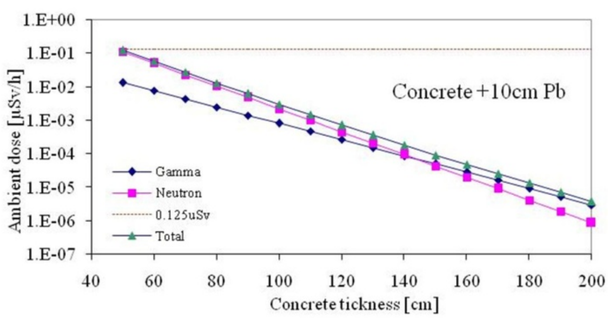

Figure 2: Ambient dose outside tunnel vs. concrete shielding thickness. Dotted line shows target level of equivalent dose.

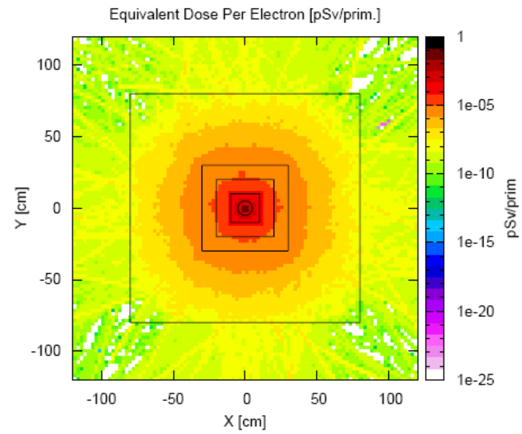

Figure 3: Equivalent dose per electron in picoSieverts in the beam dump vicinity for 20 MeV beam energy (FLUKA simulation).

Figure 3 demonstrates spatial distribution (in the plain perpendicular to the beam direction) of the Equivalent dose per electron in picoSieverts in the beam dump vicinity for 20 MeV beam energy simulated by FLUKA.

RADIATION FROM BEAM DIAGNOSTIC EQUIPMENT

At the AREAL linac Faraday Cups will be inserted into electron beam path to measure the beam charge. Faraday Cup is made of stainless steel and will collect the complete charge of the train of the o 200 pC bunches becoming the source of the secondary radiation. A DC voltage is applied to reduce the number of electrons leaving the surface so that the emitted radiation almost completely consists of gamma quanta. YAG:Ce scintillation screens will be used for the beam profile measurements.

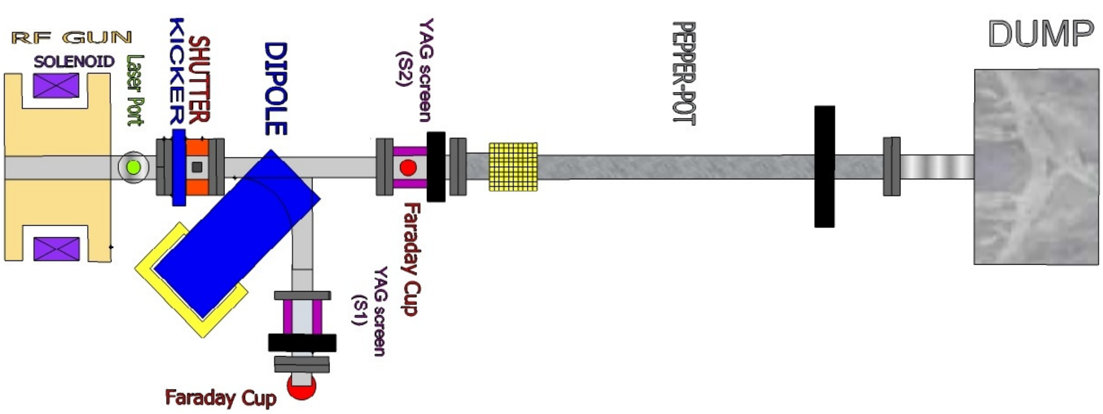

Figure 4: Layout of AREAL gun section with diagnostics (phase 1, beam energy is 5 MeV).

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Radiation sources related to beam diagnostic system (Fig. 4)are the followings:

- Faraday Cup for beam current measurement at the end of arc section;
- Faraday Cup for beam current measurement at the end of 'pepper pot';
- Scintillation screen for the beam profile measurements;
- Scintillation screen for the beam energy and energy profile measurements;
- Scintillation screen for the beam emmitance measurements;
- 'Pepper pot' Tungsten mask for beam emittance measurements;
- Beam chamber walls at the bending magnet.

20μm thick YAG: Ce scintillation screens do not emit significant amount of radiation to pose a problem from the radiation safety point of view. The radiation produced by 'Pepper pot' Tungsten mask for beam emittance measurements is effectively screened by 'Pepper pot's coating. Beam chamber walls at the bending magnet produce radiation only when magnet is not operating in stationary condition and beam hits or scraps vacuum chamber walls. The main sources of radiation are Faraday Cups at the ends of spectrometer arm and 'pepper pot'.

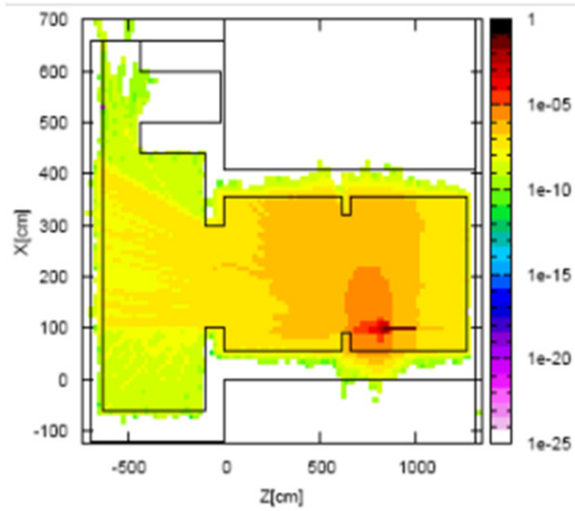

Figure 5: Equivalent dose distribution in the Tunnel in picoSieverts per electron hitting the Faraday Cup at the 95cm distance from the electron gun for 5 MeV beam energy (FLUKA simulation). Radiation penetrated tunnel walls carries 7.6x10-5 MeV energy per electron.

Faraday Cups consist of a hollow stainless steel cylinder of 15 mm diameters, closed at the base, with an appropriately-sized aperture for collecting the electrons. An outer, grounded cylinder provides shielding.

Only 10^{-5} part of energy per electron incident on Faraday Cup escapes the tunnel as a gamma background radiation.

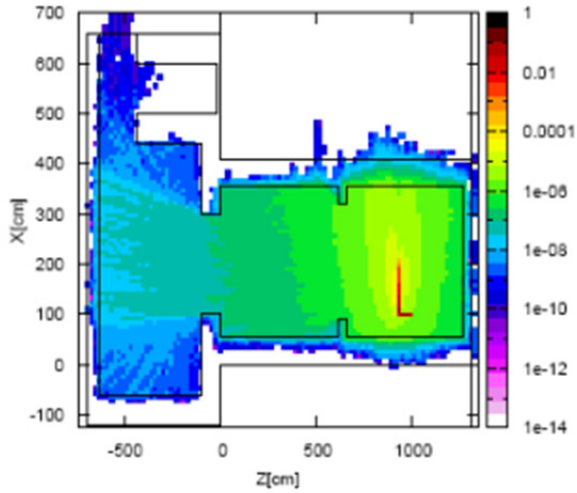

Figure 6: Equivalent dose distribution in the Tunnel inpicoSieverts per electron hitting the Faraday Cup at the end of bend section for 5 MeV beam energy (FLUKA simulation). Radiation penetrated tunnel walls carries 5.5x10^{-5} MeV energy per electron.

CONCLUSIONS

Ones we aim to get ambient dose of 0.125 microSvieverts/hour outside machine tunnel, 100cm total thickness of concrete shielding will suffice (50cm dump shielding plus 50 cm wall). The insertion of 10 cm Led shielding around dump reduces concrete thickness to 50 cm. It includes also contingency that takes into account possible deviations of the concrete parameters from the design values, e.g. density, homogeneity, isotropy and chemical composition.

REFERENCES

[1] B. Grigoryan, et al, "Advanced Research Electron Accelerator laboratory based on Photocatode RF Gun", Proceedings of IPAC2011, San Sebastian, Spain, pp 1066-1068.
[2] A Ferrari, P.R. Sala, A. Fassò, and J. Ranft, "FLUKA: a multi-particle transport code", CERN 2005-10 (2005), INFN/TC_05/11, SLAC-R-773.
[3] W.R. Nelson, The SHIELD11 Computer Code, T.M.Jenkins, SLAC-R-737, UC-414.
[4] SwissFELRadiation Protection Report for SwissFEL-CDR, FEL-FU96-008-0.
[5] K. Nakamura et al., JPG 37, 075021 (2010), http://pdg.lbl.gov