Romanian Reports in Physics, Vol. 68, Supplement, P. S885–S945, 2016

RADIATION PROTECTION AND SAFETY AT ELI-NP

I. O. MITU[1,*], C. IVAN[1, 2], F. NEGOIȚĂ[1, 2], D. ARANGHEL[1, 2], S. BERCEA[2], E. ILIESCU[2], C. PETCU[1], M. GUGIU[1, 2], M.A. POPOVICI[3], C.A. UR[1], S. GALES[1], N.V. ZAMFIR[1, 2]

[1]Extreme Light Infrastructure – Nuclear Physics, ”Horia Hulubei” National Institute for Physics and Nuclear Engineering, P.O.Box MG-6, RO-077125 Bucharest-Magurele, Romania

[2]”Horia Hulubei” National Institute for Physics and Nuclear Engineering, P.O.Box MG-6, RO-077125 Bucharest-Magurele, Romania

[3]Physics Department, University Politehnica of Bucharest, Splaiul Independenței nr. 313, RO-060042, Bucharest, Romania

[*]Corresponding author *Email:* iani.mitu@eli-np.ro

Abstract. In the present report we propose radiological protection and dosimetry technical systems for ELI-NP facility. The study includes assessments of the facility's radiological installations and experimental areas, as well the location and nature of detectors/instruments that should be appropriate to cover the three main areas of dosimetry for ELI-NP: personnel dosimetry, area dosimetry and environment dosimetry. The devices dedicated to the above first three items must fulfill the legal requirements provided by the regulatory bodies in this field, and will also serve to obtain the operational licenses from the Romanian Nuclear Authority (CNCAN). In order to fulfill the regulatory requirements (Romanian and International) we consider mandatory to consult calibration facilities and methods for the dosimetric systems special characteristics. We identified the structure required in Romania and European countries and a common organizational plan to efficiently design, supervise and monitor all aspects of safety, radiological protection and dosimetry for ELI-NP, as well the required budget and personnel.

Key words: Radioprotection, radiation safety, Monte Carlo calculations, dosimetry, beam dump design, regulatory body, radiation monitoring system, control access

1. INTRODUCTION

This document summarizes technical proposals in the field of Dosimetry and Radiological Protection which are needed to operate the ELI-NP installations, protect all personnel (staff and external users) and public, and insure monitoring of the environment according to the best national and EU practices.

All the requirements related to other hazards like wastes management or pollution, and safety issues like chemical safety, biosafety, machinery safety, design safety, electrical safety, or any other negative impact that the construction of ELI-NP facility may generate, are fulfilled according to the building permit obtained in 2012 from the Romanian regulatory body and according to organizational chart that is in compliance with national legal frame.

The aim of this document is to identify and to present the documents and design issues to be followed for ELI-NP installation in the domain of nuclear safety, radioprotection and dosimetry as well as the related ionizing radiation metrology for ELI-NP. Any analysis on this subject must have as a starting point the main types of ionizing radiation and the energy of the particles which constitute these radiation fields at ELI-NP.

The ELI-NP is in the building process at Măgurele, Romania. Constituting one of the three arms of the European Extreme Light Infrastructure project, the facility will use a high intensity laser (up to 10^{23}-10^{24} Wcm^{-2}) and a high energy, low bandwidth gamma beam system. This infrastructure will create a new European laboratory with a broad range of science covering frontier fundamental physics, nuclear physics and astrophysics, as well as applications in nuclear materials, radioactive waste management, material science and life science.

For the ELI-NP project, which will host experiments that generate ionizing radiations fields of characteristics very different from those which are commonly met at other research facilities, dedicated technical proposals have to be elaborated in the field of safety, radiological protection and dosimetry. In general there are no radiation protection regulations regarding the specific conditions to be encountered in the ELI-NP, therefore these special conditions occurring in the ELI-NP experiments are approached similar to the ones met at known radiological installations.

The specific regulations in the area of radiological protection do not include the lasers in the radiological installations class. Still, the experiments performed with high power lasers, which involve laser beam interaction with various target materials, are generating very intense and complex ionizing radiation fields. Therefore, a special attention is required from radiological protection point of view.

Radiation fields and radiological protection aspects encountered in the experiments with the gamma source are known due to the existence of similar types of these sources worldwide. This is also true for the experiments that involve the 0.1 PW and 1 PW laser systems. For 10 PW lasers, the researchers who contributed to ELI-NP project implementation made considerable efforts to estimate the source terms generated in these experiments extrapolating the results from existing facilities limited currently to 1 PW.

A good knowledge of the field is difficult to obtain, including particle composition (protons, neutrons, electrons, photons, etc.) and the distribution of the fluency of each component in position, angle, energy and time, is very difficult to estimate: however even a partial description is often useful, since much of missing information can be derived from physical judgment, calculation or other a priori experience. In practice, information about field composition is obtained by the combined use of two or more detectors, each with high sensitivity to only one specific radiation component. However, it is not always sufficient, since the dosimetric and shielding characteristics of some radiation components are strongly variable with energy. Therefore, in order to obtain an accurate estimation of fields characteristics, the performed calculations have to be compared with experimental measurements for validation to be done during operation.

2. DOSE ASSESSMENTS AT ELI-NP

The radiation beams and fields that will be produced in the ELI-NP Bucharest facility are strongly different from all the applications of dosimetry developed in Romania until now. Starting from the ELI-NP White Book, the international Working Groups for experiments at ELI-NP have identified the main types of radiation sources generated in the proposed experiments and their characteristics. The evaluation of the necessary dosimetry systems should be based on the present analysis of ELI-NP expected sources, location of beams losses and beam dumps as described in the produced technical design reports (TDRs), existing experience in the working groups from similar experimental facilities, gamma, electron and others ions facilities as well as research reactor facilities (CERN, RAL/STFC, CEA, ESFR, DESY, ILL, GSI-FAIR, GANIL-SPIRAL2, etc.)

One aspect of the program will be the collaboration with similar facilities, especially with the other pillars of ELI facility, in order to identify the needed safety documents and rules, the detectors and dosimetric systems adequate for different fields of applications in the ELI-NP facility, as well as for the radiological protection.

2.1 Dose constrains at ELI-NP

A number of experimental areas within the ELI-NP facility will involve firing lasers at solid and gaseous targets, which will result in the emission of high energy particles (protons and electrons) and photon radiation. The physical parameters of all ionizing radiation generated by the instruments within the ELI-NP facility are presented in chapter 2.2. The provision of beam dumps will ensure that the majority of this high energy radiation is absorbed local to the target. Bulk shielding provisions around experimental areas, such as walls and doors, will further ensure that dose accrual by personnel working in the surrounding areas is both acceptable and ALARA.

The dose uptake criteria for professional exposed personnel based on which the shielding calculations have been performed are only 10% of the legal limits, as following:

- The criteria for individual effective dose shall be less than 2 mSv in a year. However, in special circumstances, a higher effective dose may be authorized in a single year, provided that the average over five consecutive years does not exceed 2 mSv per year;
- The criteria for equivalent dose to the lens of the eye is less than 15 mSv in a year;
- The criteria for equivalent dose to the skin shall be less than 50 mSv in a year averaged over any 1 cm^2 area of skin, regardless of the area exposed;
- The criteria for equivalent dose to the extremities such as hands, forearms, feet and ankles shall be less than 50 mSv in a year

In addition to the dose limits outlined above, the project will further constrain doses to members of the public to a tenth of the dose limits for the public outlined in Romanian and European legal frame. Thus the limit for effective dose to a member of the public shall be 0.1 mSv in a year.

2.2 The main specifications of the two ELI-NP machines

ELI-NP facility will host two radiological installations: one is a 10 PW laser system and the other is a high energy gamma source.

The High Power Laser System (HPLS) of ELI-NP will produce laser pulses of up to 300 J energy with 30 fs duration at a repetition rate of 0.017 Hz (1 pulse per minute) on two parallel amplification chains: they provide simultaneous the power of 10 PW for each arm of the laser, with a remarkable spatial and temporal quality of the beam; this allows to reach an intensity of 10^{23}-10^{24} W/cm^2 on a target., The laser system will have two outputs for intermediate power of 100 TW provided simultaneously in the associated experimental areas, with a repetition rate of 10 Hz and it will have also two outputs for intermediate power of 1 PW, provided simultaneously in other experimental areas, with a repetition rate of 1 Hz. HPLS will have also a double front-end in order to ensure a reduced maintenance time and an increased availability of the beam time. The front-ends will serve, one at a time, both arms of 10 PW.

The γ source belonging to the ELI-NP infrastructure will be produced by reverse Compton incoherent scattering of the light of an optic laser (TW class at 100 Hz repetition rate) on an intense beam of relativistic electrons produced by an electron accelerator "Warm LINAC" type (maximum energy of the electrons of about 720 MeV). There will be two interaction points: the first one will produce a gamma beam with the maximum energy of 3.5 MeV, corresponding to the interaction of the laser with the electron beam of 320MeV; the second interaction area will produce a gamma beam with the maximum energy of 20 MeV corresponding to the interaction of the optic laser of TW class with the electron beam of 720 MeV. In order to increase the total intensity, the laser beam is recirculated at interaction point and the electron beam has a structure of 32 micro-bunches separated by 16 ns each.

The main characteristics of the gamma beam are: the band width (BW) better of 2x 10^{-3}, the total flux of maximum 10^{11} p/s at 100% BW, the peak brilliance higher than 10^{21} p/mm^2/mrad^2/s (0.1 % BW).

2.3 Source terms

The ionizing radiations that are generated at the ELI-NP facility are split in two classes: primary sources of ionizing radiations and residual radiation sources. First category includes electron beam from the linear electron accelerator (LINAC), the gamma beam and neutral and charged particles resulted following the high power laser interaction with target material (protons, electrons, neutrons, electromagnetic radiations (X rays and gammas, etc.). Residual radiation sources include the ionizing radiation fields coming from the activation of targets, reactions chambers, beam guiding systems, apertures, beam dumps, experimental equipment or radiological protection shielding, following the action of the primary sources.

Table 1
Source terms at ELI-NP [1, 2]

Area		**Particle**	**Mean Energy (GeV)**	**Particles/ Pulse**	**Freq. (Hz)**	**Divergence (Degrees)**	**Distribution**	**FWHM (GeV)**
E1	**A**	Proton	0.5	1.40E+12	0.017	+/- 20	Rectangular	0.05
		Electron	1.5	8.00E+10	0.017	+/- 20	Gaussian	0.15
	B	Proton (via TNSA)	Mean energy is around 40 MeV for a thermal TNSA spectrum, with a maximum energy of 250 MeV.	6.00E+12	0.017	+/- 25	Boltzmann	n/a
	C	Electron	38	8.61E+10	0.017	+/- 0.5	Gaussian	0.001

	D	Photon	n/a	3.14E+14	0.017	+/- 20	*Thermal	n/a
	E	Electron	0.145	5.00E+12	0.017	+/- 25	Maxwellian	n/a
E6	**F1**	Photon (bremsstrahlung from target)	n/a	n/a	0.017	The divergence angle depends upon the electron reflux within the target. If there is no reflux, then assume 50-60 degrees. If refluxing, then assume 360 degrees.	Maxwellian	n/a
	F2	Photon (synchrotron)	Energy ranges from 0.01 MeV to 30 MeV, with an average energy of 10 MeV.	1.00E+14	0.017	Total divergence of 80° in both forwards and backwards directions (see comments).	Rectangular	0.01
E6	**G1**	Proton	Mean energy is around 40 MeV for a thermal TNSA spectrum, with a maximum energy of 250 MeV.	6.00E+12	0.017	50° for TNSA, directed along the normal to the target foil. The normal to the target foil can be 12°-30° from the direction of the pump laser and therefore 12°-30° from the axis of the beam dump.	Boltzmann	n/a
	G2	Proton (via RPA or BOA type processes)	0.5	1.00E+12	0.017	+/- 2.5	Quasi-mono energetic	0.05
E4	**H**	Proton	0.01	1.20E+11	10	+/- 20	Rectangular	0.01
		Electron	0.05	3.60E+10	10	+/- 20	Rectangular	0.01
	I	Electron	0.5	1.80E+09	10	+/- 0.5	Gaussian	0.01
E5	**J**	Proton	2-60 MeV with an average energy of 20 MeV.	7.57E+12	1	+/- 20	Boltzmann	n/a
		Electron	n/a	3.08E+07	1	+/- 1.45	*Thermal	n/a

	K	Electron	2	8.05E+07	1	+/- 0.12	Gaussian	0.01
	L	Photon	n/a	8.34E13 for 0.035 MeV 7.6E12 for 0.58 MeV 6.8E10 for 8.8 MeV	1	+/- 20	*Thermal	n/a
E7	**M**	Electron	0.72	1.88E+10	1	n/a	Gaussian	0.00072
		Electron	0.1	6.25E+10	0.017	+/- 0.286	Gaussian	0.01
		Photon	0.0195	1.00E+11	100	+/- 0.0575	Parabolic	n/a
		Electron	2.5	n/a	n/a	+/- 0.143	Gaussian	0.05
ERA	**N**	Electron	0.72	1.00E+11	100	0.05	Gaussian	0.00036
AE1	**O**	Electron	0.14	1.00E+11	100	0.05	Gaussian	0.00014
		Electron	0.32	1.00E+11	100	0.05	Gaussian	0.0003
		Photon (not collimated)	0.0035	1.00E+09	100	+/- 0.0575	Parabolic	n/a
E2/E8	**P**	Photon (not collimated)	0.0035	1.00E+09	100	+/- 0.0575	Parabolic	n/a
E8		Photon (not collimated)	0.0195	1.00E+09	100	+/- 0.0575	Parabolic	n/a
E2	**Q**	Positron	1.40E-04	1.20E+08	100	n/a	n/a	n/a
		Electron	1.18E-03	6.89E+08	100	n/a	n/a	n/a
		Photon	1.16E-03	8.46E+08	100	n/a	n/a	n/a
E3		Positron	5.00E-05	1.00E+05	100	n/a	Gaussian	n/a
GSR	**R**	Photon (not collimated)	0.0195	1.00E+09	100	+/- 0.0575	Parabolic	n/a

***Note:** Definitions of the Thermal components are:
All spectra are divided in thermal components, quasi-monochromatic components and, if required, a cut-off. For each thermal component *i*, is given the total number of particle (or photon) per steradian N_i^T and the temperature T_i in MeV. The quasi-monochromatic components consider a Gaussian shape, defined in terms of the number of the particle per steradian N_j^G, the central energy E_j^G in MeV and the FWHM of that component ΔE_j^G in MeV. In case of a cut-off**,** is given the energy value E^{MAX} in MeV. Within this scheme, the spectrum is represented by this formula:

$$N(x) = \begin{cases} 0 & \text{for } x \geq E^{MAX} \\ \sum_i \frac{N_i^T}{T_i} \exp\left(-\frac{x}{T_i}\right) + \sum_j 2 \frac{N_j^G}{\Delta E_j^G} \sqrt{\frac{2 \ln 2}{\pi}} \exp\left[-4 \ln 2 \left(\frac{x - E_j^G}{\Delta E_j^G}\right)^2\right] & \text{for } x < E^{MAX} \end{cases}$$

If T_i is not provided, it is supposed to be infinity, and N_i^T will became number of proton per steradian per MeV.
** From Vulcan (300J) data, the number of particles has been multiplied by 2/10 (at ELI-NP there are 2X30J for the 2X1PW experiments – cave "C-E5").

2.4 ELI-NP biological shielding description

All the radiological protection walls for experimental areas are mixt (fixed walls and movable concrete blocks) and they are designed to fulfill next requirements:

- to ensure the required radiological protection thickness;
- to be sufficiently stable to ensure equipment protection in case of an eventual earthquake;

Needed height is 5 m in accelerator hall, areas for individual experiments and areas for accelerator equipment, except experimental area E1/E6 where the height is 6.5 m because of the beam dump dimension proposed for the E1 experiments. Shielding walls, floor and roof for the accelerator halls (Accelerator Bays 1 & 2) are made of concrete with 1.5 m thickness. For experimental area E3 and storage of radioactive materials area the shielding thickness is 1 m horizontally and 1.5 m vertically.

For experimental areas E1/E6 and E8 radioprotection shielding are designed to be 2 m thick horizontally and 1.5 m vertically. For experimental areas E4, E5, E7 and ERA the thickness of the walls is 1.5 m both horizontal and vertical. The access in the experimental areas will be done by concrete doors for both personal and equipment. All access doors must ensure the same protection as the walls. During operation personal presence is restricted in the experimental areas, basement and roof of the facility. Access in these areas is permitted only based on special procedures.

Protection to electromagnetic pulse (EMP) generated in the experiments with the high power lasers will be ensured through different methods: special supplemental gates at the entrance in experimental area E1/E6, E7, E4 and E5, special gaskets at the concrete doors designed for radioprotection, etc. (more details in chapter 2.7). Lasers, accelerator and all experimental areas will lie on the same armed concrete plate, which will dump efforts and will be isolated against vibration through a matrix of springs and dumpers installed between the building foundation and concrete plate where equipment lie. Also, “Photo – fission interaction laser lab.”, „NRF Interaction laser lab.” and „Photo – drive laser lab.” areas will lie on the same concrete plate, isolated for vibrations. The distance between the inferior side of the concrete plate where the experiments lie and the general grating of the foundation is 3 m to allow mounting in the basement most part of installations (ventilation, fluids piping, wiring) and some other equipment, as well as their inspection and maintenance by authorized personal.

Under all accelerator and experimental areas, beside the floor thickness of 1.5 m, building foundation will have a thickness of 1.5 m of concrete, which will ensure supplemental radioprotection to avoid underground water and soil activation.

2.5 Dose calculations for the ELI-NP experimental areas

The radiological protection studies indicate that in order to efficiently shield the experiments performed within the ELI-NP facility dose assessments should be conducted using complex simulations and calculations using specialized computer codes. Given the source terms presented in the above chapter, these assessments have been performed and have been found the proper shielding requirements that should be designed for each experimental setup in order to fall within the dose criteria assumed. The shielding provisions include the concrete walls, floor, roof and doors (presented in 2.3), beam dumps assigned to each experiment type and all the additional shielding required to reduce the cold side doses within criteria. All the proposed experimental setups have to ensure the radiological protection requirements are implemented as recommended in this Technical Design Report.

2.5.1 Experimental area 1 (E1)

Initial scoping calculations showed that, besides the concrete walls, roof and floor, a beam dump (see Figure 2) was necessary in order to reduce cold side dose rates within the acceptable criteria [2] and to avoid shielding activation. A calculation was required to confirm the bulk shielding thicknesses, by assessing the cold side dose rates on the roof. The roof was deemed bounding for all other walls for the following reasons:

a. The roof offers the least protection against radiation (1.5 m concrete, with respect to the walls which offer 2.0 m concrete).

b. The roof is the surface closest to the beam dump, where all secondary radiation is created.

c. From initial scoping calculations, it was found that the dominant source of radiation is due to secondary neutrons created in the beam dump. Neutron flux spectra were sampled at various points across the room and this showed that the most onerous spectra were that closest to the roof.

Additionally, dose calculations were taken at the corresponding locations indicated in Figure 1 and the dose rate at the roof was the highest.

The resulting calculations (see Table 2) indicate that the cold side dose rates in surrounding corridors and on the roof [2] would not fall within dose rate design criteria because of the following factors:

- Consideration of the aluminum interaction chamber walls proved that contributions due to secondary particles (photons and neutrons) generated in the aluminum are very important.
- The divergence of proton source is very large
- In order to have enough space for experimental equipment the beam dump cannot be installed very close to interaction chamber.

An analysis of implementing a thin window into the interaction chamber wall has been performed [2]. The results (Source A* from Table 2) indicated that in order to significantly reduce the cold side dose rates a 0.5 cm thick Inconel-718 window may be used. Although the results are significantly lower, they should be interpreted with caution, because: a) at this time, the presence of apparatus within the interaction chamber and in the path of the particle beam has not been considered, therefore the estimated reduction in prompt doses obtained by using a window may be overestimated; b) The effect a window may have on residual dose rates is important as residual dose rates may be a more significant factor than prompt dose rates in total, overall dose accrual of personnel. Therefore, further optimization [2] was required in order to provide an ALARA solution.

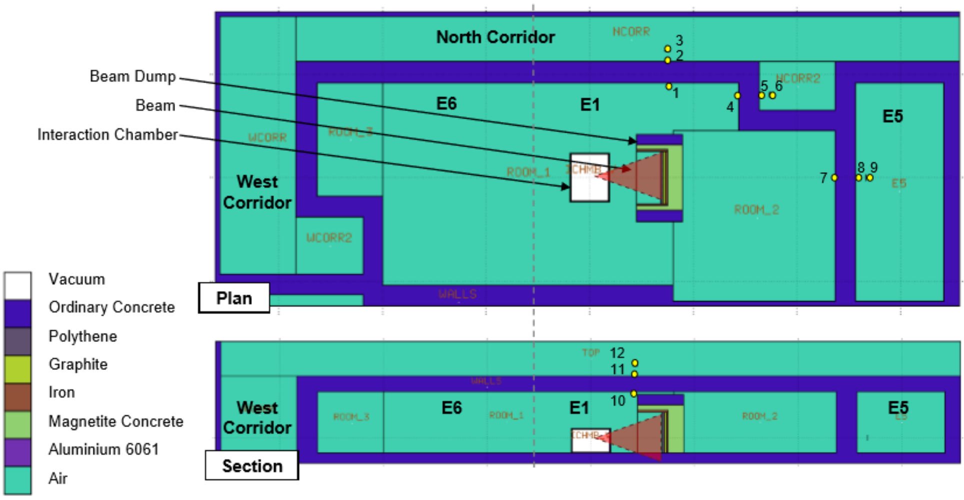


Fig. 1 - Experimental area E1 layout [2]. Dose points are indicated (see Table 2).

Table 2
Summary of peak calculated dose rates for E1

Dose point (see Fig. 1)	Location	Distance (cm)	Total dose rate (μSv/h)		
			Source A	Source B	Source A*
1	E1	Hot side	3.31E+03	4.32E+02	7.54E+02
2	North corridor	1	7.9	0.1	1.3
3	North corridor	100	5.6	0.05	1.1
4	E1	Hot side	1.91E+02	-	-
5	North corridor	1	0.3	-	-
6	North corridor	100	0.2	-	-
7	E1	Hot side	9.43E+01	-	7.97E+01
8	E5	1	1.1	-	1.3
9	E5	100	0.8	-	1.1
10	E1	Hot side	1.73E+04	2.53E+03	4.50E+03
11	Gantry	1	66.6	0.9	13.3
12	Gantry	100	43.6	0.6	10.7
13	E2/GSR Roof	Waist height	0.7	-	-
14	E2/GSR Roof	Head height	0.4	-	-

Further analysis indicate that a supplemental shielding (concrete walls), positioned inside E1 experimental area, can be used to reduce the cold side dose rates on corridors and adjacent areas. Reduction of repetition rate of laser pulse is another practical method to reduce the dose. One should mention also that most the experiments will generate weaker primary radiation fields compared to source term A which is an optimistic extrapolation for 10 PW laser power of current results for proton acceleration at laser power below1 PW, and is requested by a small number of proposed experiments in E1 area.

2.5.2 Experimental area 6 (E6)

The experiments performed in E6 area require a beam dump (see Figure 2) in order to stop the secondary particles generated following the 10 PW lasers interaction with target materials. The beam dump is also required in order to reduce the dose rates from the cold side of the experimental area shielding walls and to avoid as much as possible the shielding and experimental setup activation.

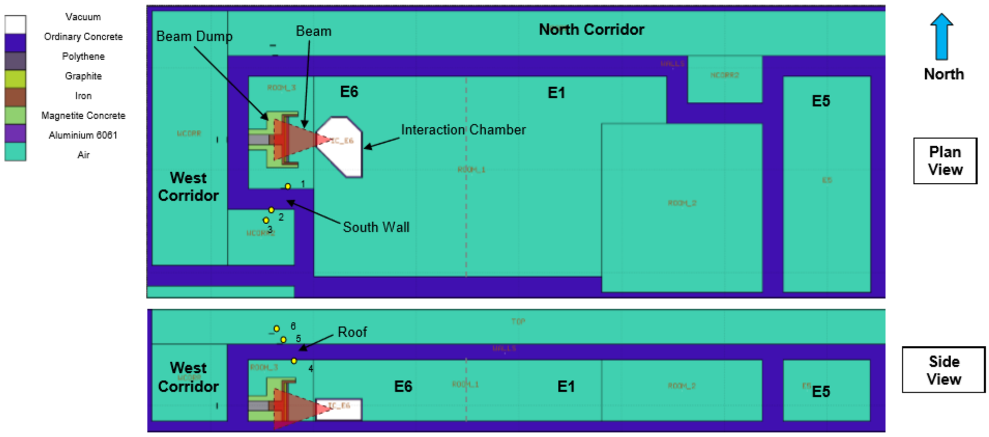


Fig. 2 - Experimental area E6 layout [2]. Dose scoring points are indicated (see Table 3).

The dose levels external to E6 area were calculated with the beam dump design proposed in [2]. The results are presented in Table 3. The dose is driven by gamma rays, neutrons and both muons and anti-muons produced in the beam dump; given the mean free path of muons in matter is typically very high, this is not a problem that can be practicably resolved by an increase in the thickness of the concrete bulk shielding.

Similar to experimental area E1, an analysis has been performed in order to determine the effect of using a thin window in the interaction chamber for reducing the energy loss by primary protons into the interaction chamber walls. The window used in calculations was made of Inconnel-718 of 0.5 cm thick. Its dimensions had been chosen depending on the beam divergence and source distance from the interaction chamber wall so that all the beam particles will pass through the window.

Table 3

Summary of peak calculated dose rates for E6

Dose points Figs. 2 and 3	Location	Distance (cm)	Total dose rate (μSv/hour)						
			C	E	F1	F2	G1	G2	
								Without window	With window
1 (Fig. 2)	South wall	Hot side	-	n/a	n/a	n/a	-	4210	923
2 (Fig. 2)	South wall	1	-	n/a	n/a	n/a	0.16	9.83	1.66
3 (Fig. 2)	South wall	100	-	n/a	n/a	n/a	0.07	4.42	0.65
4 (Fig. 2)	Roof	Hot side	-	13300	9200	52700	483	9870	2580
5 (Fig. 2)	Roof	1	-	0.26	0.41	1.28	1.16	51.30	7.47
6 (Fig. 2)	Roof	100	-	0.09	0.27	0.60	0.57	25.30	4.63
3 (Fig. 3)	West wall	1	0.11	-	-	-	-	-	-
4 (Fig. 3)	West wall	1	0.5	-	-	-	-	-	-

Further calculations show that in order to reduce the dose from muons external to the facility, 7 meters of iron shielding would be required (see Figure 3). This would result in < 0.5 μSv/hour at the end of the muon shielding in the beam direction and approximately 1.5 μSv/hour at the wall. Contributions to dose from additional photons and neutrons produced in the iron shielding by the muons are small.

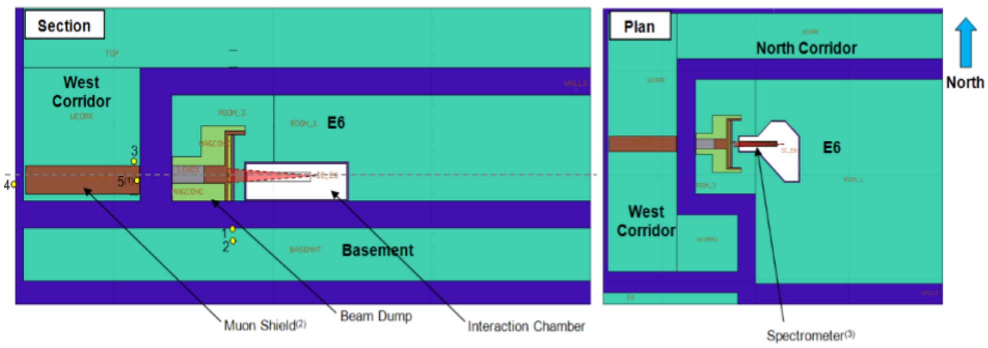


Fig. 3 - Muon shielding external to E6 [2]. Dose points are indicated.

2.5.3 Experimental areas 2 and 8 (E2 and E8)

The beam dumps for the experiments performed in E2 and E8 areas are both positioned in E8 area [2]. A movable beam dump for low energy gamma beam similar to the one positioned in E8 area will be placed in AB2. The photon sources (low and high energy gamma beams) are incident upon the west wall of E8 and in this instance the beam dump arrangements have been incorporated into the west wall.

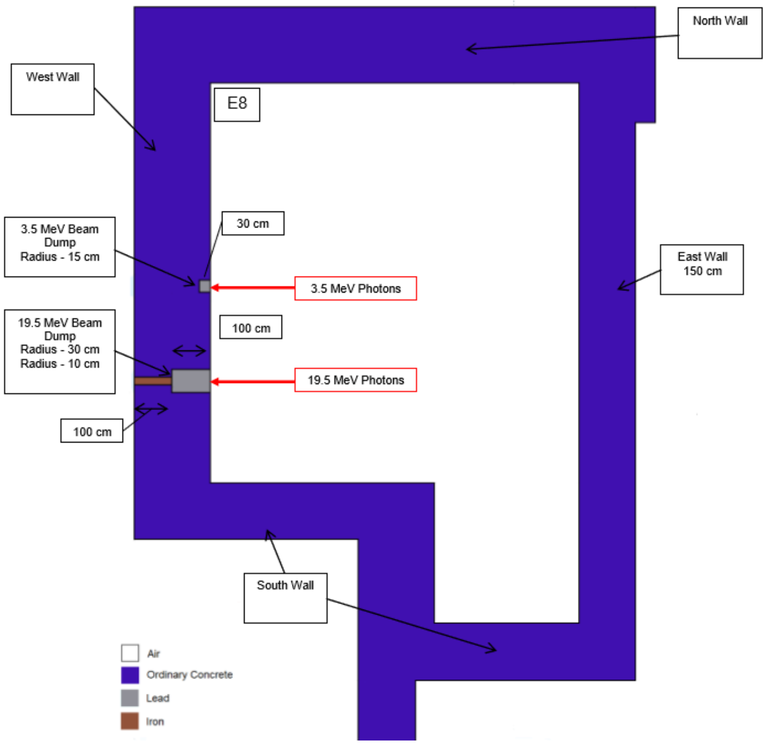


Fig. 4 - Experimental area 8 layout, including beam dumps positions [2].

The calculated doses for the beam dumps in E8 are presented in Table 4. All calculated radiation doses meet acceptance criteria for the beam dump designs.

Table 4
Summary of peak calculated doses for E8 area

Dose point		Peak dose rates (µSv/hour)
West wall	Contact	7.85E-02
	1 m	4.90E-02
Roof	Contact	1.22E-02
	1 m	7.76E-03

2.5.4 Experimental area 4 (E4)

The calculations undertaken [2] have demonstrated that dose rates at the cold side of the walls and roof of E4 will be within the 1 µSv/hour criterion during normal operations. Peak dose rates have been calculated in contact with cold side of the bulk shielding and at 1 m from contact.

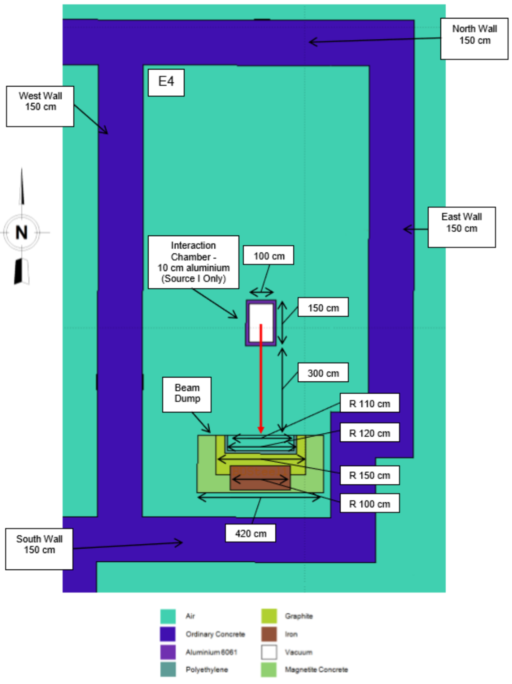


Fig. 5 - Experimental area E4 layout [2].

Table 5
Summary of peak calculated dose rates for E4

Source	Dose point		Dose rate (μSv/hour)
H	North Wall Hot Side	Contact	3.07E+02
	West Wall Hot Side	Contact	1.35E+03
	Roof Hot Side	Contact	1.24E+03
	Roof Cold Side	Contact	9.69E-03
		1 m	6.68E-03
I	North Wall Hot Side	Contact	8.57E+01
I	Roof Hot Side	Contact	2.86E+03
	Roof Cold Side	Contact	2.69E-01
		1 m	1.43E-01
I	West Wall Hot Side	Contact	2.07E+03
	West Wall Cold Side	Contact	2.43E-01
		1 m	1.48E-01

2.5.5 Experimental area 5 (E5)

The calculations undertaken have [2] demonstrated that dose rates at the cold side of the walls and roof of E5 will be within the 1 μSv/hour criterion during normal operations. Peak dose rates have been calculated in contact with cold side of the bulk shielding and at 1 m from contact.

Table 6
Summary of peak calculated dose rates for E5

Source	Dose point		Dose Rate (μSv/hr)
J	Roof Hot Side	Contact	3.35E+04
	Roof Cold Side	Contact	1.16E-01
		1 m	7.25E-02
	North Wall Hot Side	Contact	6.78E+03
	East Wall Hot Side	Contact	2.11E+04

	East Wall Cold Side	Contact	5.51E-02
		1 m	4.08E-02
K	Roof Hot Side	Contact	4.00E+01
	Roof Cold Side	Contact	1.27E-02
		1 m	3.72E-03
	North Wall Hot Side	Contact	3.79E+00
	East Wall Hot Side	Contact	3.46E+01
L	Roof Hot Side	Contact	5.77E+05
	North Wall Hot Side	Contact	1.07E+04
	South Wall Hot Side	Contact	5.45E+05
	South Wall Cold Side	Contact	2.81E-01

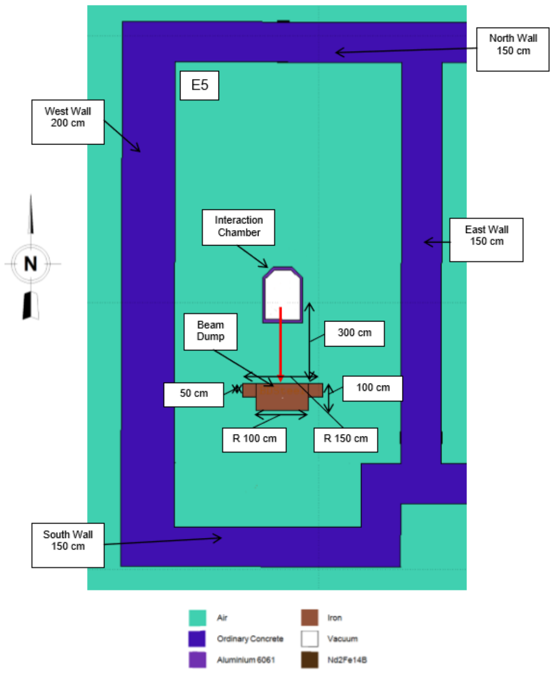


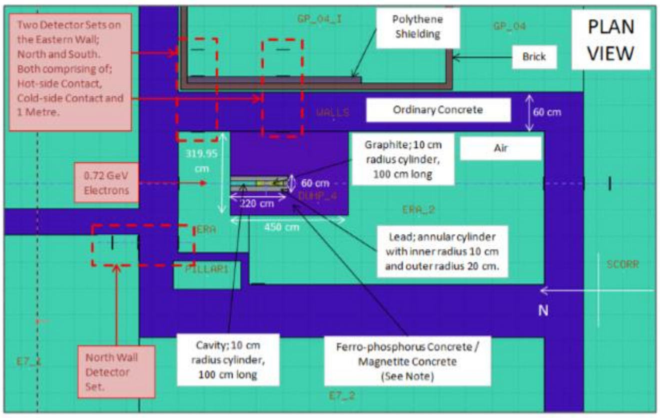
Fig. 6 - Experimental area E5 layout [2].

2.5.6 Electron Recovery Area (ERA)

The calculations presented in this report are assuming a beam dump design [2] which should efficiently shield the primary electron beam and secondary particles generated following their interaction in the beam dump materials, in order to fall within the acceptance criteria with the cold side dose rates. Though, the beam dump will be constructed by the GBS contractor, EuroGammaS. The design they propose is not identical with the following one, therefore EuroGammas provided calculations to demonstrate compliance with the dose criteria for the new design [3].

Dose rates in neighboring areas have been judged to be below the design criteria for a beam dump mainly comprised of magnetite concrete, with the exception of the East room. An enhanced shield design implementing a Ferro-concrete beam dump and 25 cm of polythene shielding at the cold side of the east wall, has been shown to reduce cold-side dose rates such that the relevant criterion is achieved. It is recommended that for the magnetite beam dump design, consideration be given to prohibiting access within the East room adjacent to the ERA when it is operational. Alternatively, if the source intensity cannot be reduced, consideration may need to be given to implementation of a Ferro-concrete beam dump and additional polythene shielding on the cold-side of the partition wall in the East room.

The beam dump is required to be very large due to the continuous operation of the electron beam.



Note: This arrangement presents the additional Polythene shielding on the cold-side of the eastern wall. In this calculation the main material within the beam dump was Ferro-phosphorus Concrete, however, all other calculations used Magnetite Concrete.

Fig. 7 - ERA layout [2]. Additional case also presented (supplemental add of polythene and Ferro-phosphorus concrete).

Table 7
Summary of peak calculated dose rates for ERA

Position	Location	Total dose rate (μSv/hour)	
		Magnetite	Ferro-phosphorus and polythene shielding
East Wall North	Hot-side Contact	1.67E+04	1.60E+04
	Cold-side Contact	8.28E-01	1.05E-01
	Cold-side 1 m	6.80E-01	8.72E-02
East Wall South	Hot-side Contact	1.22E+03	2.29E+02
	Cold-side Contact	3.84E+00	3.74E-01
	Cold-side 1 m	1.95E+00	2.00E-01
North Wall (E7)	Hot-side Contact	1.15E+04	-
	Cold-side Contact	3.43E+00	-
	Cold-side 1 m	1.43E+00	-

The peak dose rate in the neighboring East room was calculated to be 3.84 μSv/hour. It is a peak dose rate only present on a small portion of the wall and the East room is expected to be low occupancy. It is therefore judged that any impact on dose accrual due to this slightly elevated dose rate will be negligible and the 1.5 meters thick concrete walls for the ERA are acceptable.

Through the use of a magnetite beam dump, the bulk shielding of the walls and roof of the ERA have been demonstrated to adequately reduce cold side dose rates to within the relevant criteria, with the exception of the east wall. Through the implementation of a ferroconcrete beam dump and 25 cm of polythene shielding at the cold side of the east wall, dose rates were reduced to < 1 μSv/hr and hence within the criteria.

2.5.7 Accelerator Bay 1 (AB1)

The calculations presented in this report are assuming a beam dump design [2] which should efficiently shield the primary electron beam and secondary particles generated following their interaction in the beam dump materials, in order to fall within the acceptance criteria with the cold side dose rates. An issue has been raised by the fact that the beam dump position and electron beam direction are headed towards the control room of the accelerator. In order to decrease the dose rates to a minimum, more supplemental shielding had to be added around the beam dump.

It was found that dose rates from AB1 were generally below the design criteria. However the peak dose rate through the north wall was found to be ~ 5 μSv/hr, falling off to less than 3 μSv/hour at 1 m from the wall. Although the immediate cold-side dose rates are in excess of the 1 μSv/hour design criterion for the north wall area it is considered that it will be manageable because:

- The area of elevated dose rate is highly localized to the corridor next to E3 and dose rates fall off quickly with distance.

- Occupancy in the corridor during AE1 operations is expected to be low.

Overall it is not expected that the elevated dose rate at the North Wall area of AE1 will result in any significant dose accrual. All other areas resulted in dose rates within the design criteria. In order to achieve these dose rates beam dumps will be required for Sources O & Q. The materials and dimensions assumed for the beam dumps in this assessment are shown in [2].

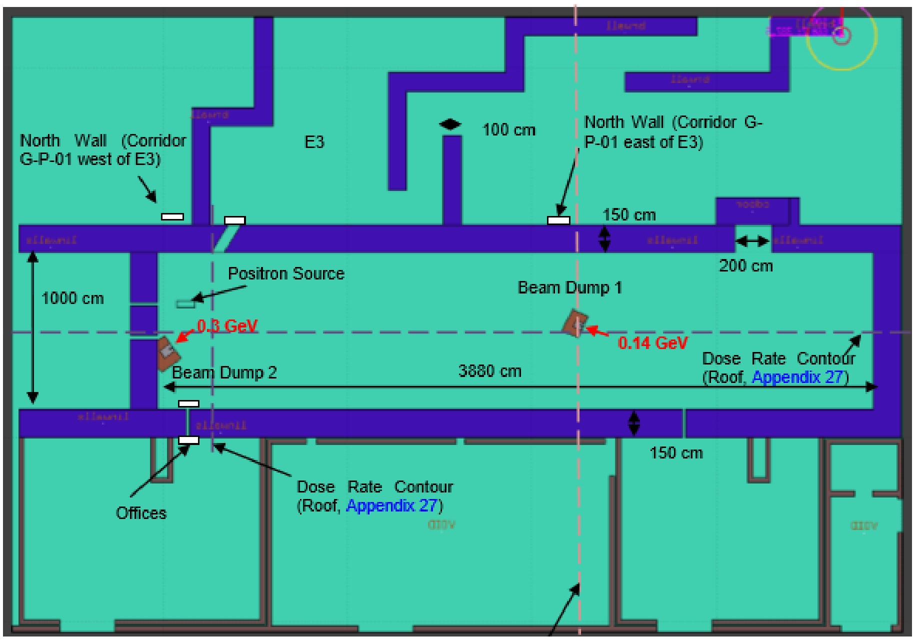


Fig. 8 - Layout of AB1. Beam dumps positions are indicated [2].

Peak dose rates through bulk shielding for the south wall, north wall and roof are summarized in Table 8.

Table 8
Summary of peak calculated dose rates for AB1

Location	Distance	Total dose rate (μSv/hour)	
		Source O	Source Q
North Wall (Corridor G-P-01 west of E3)	Hot-side (1 cm)	6.59E+05	3.58E+02
	Cold-side (1 cm)	5.18E+00	-
	Cold-side (100 cm)	2.93E+00	-
North Wall (Corridor G-P-01 east of E3)	Hot-side (1 cm)	1.67E+05	7.98E+00
	Cold-side (1 cm)	3.60E-01	-
Laser Lab G-P-07	Hot-side (1 cm)	2.18E+05	-
	Cold-side (1 cm)	9.23E-01	-
Roof	Hot-side (1 cm)	4.87E+05	-
	Cold-side (1 cm)	8.19E-01	-

Due to the lack of space in the beam dump region, the contractor of the GBS is proposing to bend the electron beam towards the basement where the beam dump should be positioned. The preliminary calculations for this scenario indicate that the assessed dose rates at the ground level fall within the accepted criteria. Also, optimization of beam dump will avoid the underground water and soil activation. The preliminary design of the beam dump to be positioned in the basement and dose assessments are presented in [3].

2.5.8 Experimental area 7 (E7)

It was found that the sources envisaged for E7 are generally much less intense than those of other areas within the ELI-NP facility. Furthermore, E7 is unique within ELI-NP in that it is the only Experimental Area that is adjacent to the general access corridor through the south and partially to the west walls, but there is a considerable distance of these walls from the source and beam dump location. Therefore, with the exception of the roof, the dose rate design criteria for the cold-side locations are typically less stringent than for some other areas.

The assessments concludes that dose rates from E7 sources, using the recommended beam dumps, will all be significantly below the dose rate design criteria for all adjacent areas. Peak dose rates in adjacent areas are presented in Table 9.

Table 9
Summary of peak calculated dose rates for E7

Source	Dose point	Total dose rate (μSv/hour)
M1 720 MeV Electrons	East 1 cm Cold-side	5.10
	East 100 cm Cold-side	3.20
	Roof 1 cm Cold-side	0.33
	Roof 100 cm Cold-side	0.24
M1 100 MeV Electrons	East 1 cm Cold-side	< 0.1
	East 100 cm Cold-side	< 0.1
	South 1 cm Cold-side	< 0.1
	South 100 cm Cold-side	< 0.1
M2 2.5 GeV Electrons	100 cm from Beam Dump	4.50

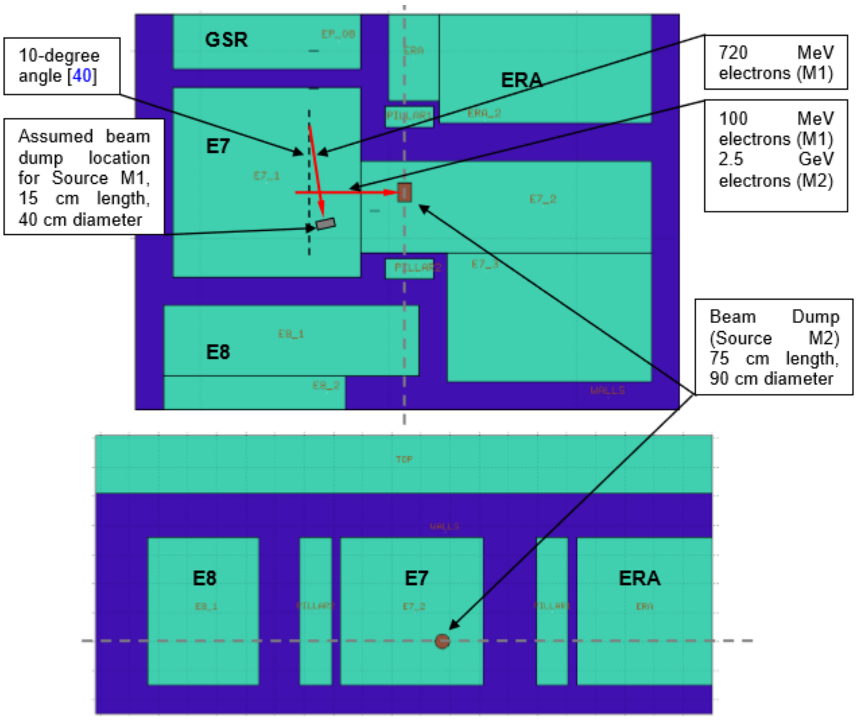


Fig. 9 - Layout of E7. Sources locations are indicated [2].

2.5.9 Experimental area 3 (E3)

The positron source within E3 was not expected to result in significant dose rates on the cold-side of the bulk shielding. The results of the assessments confirm this expectation, with calculated dose rates being very much less than 1 μSv/hr, both through the bulk shielding and from the door aperture.

In summary, using very conservative assumptions [2], it can be shown that dose rates in neighboring areas from source terms within E3 are typically very much lower than the design criteria.

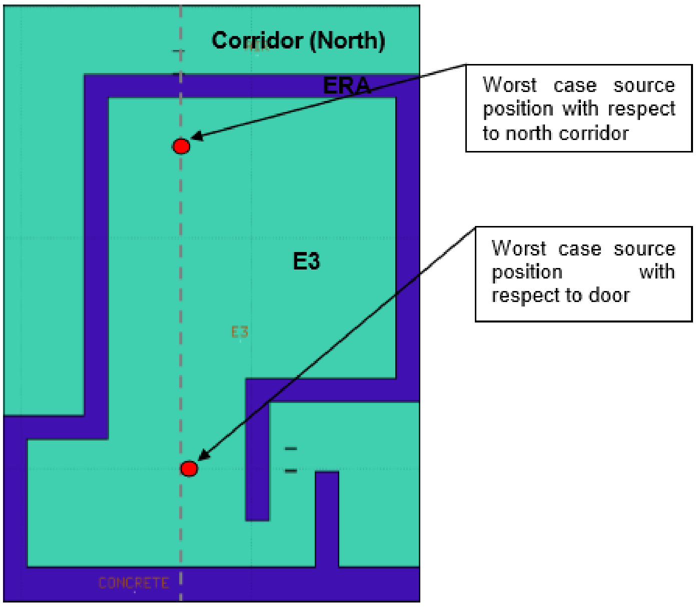


Fig. 10 - Layout of E3. Source positions are indicated [2].

All calculated dose rates on the cold-side of E3 were found to be significantly below the criterion of < 1 μSv/hr. The dose points considered on the north wall of E3 will bound the roof and all other walls of E3.

2.5.10 Conclusions on dose assessments

Bulk shielding of the active areas within the ELI-NP facility plays a key role in the reduction of personnel dose uptake [4]. The shielding provided by structural walls has been subject to a preliminary assessment to ensure adequacy with respect to a basic design criterion.

In reality, the doses accrued within these areas are expected to be lower for more realistic source configurations combined with more representative operator positions and bulk shielding material densities and compositions. Furthermore, in some areas of the facility, daily doses significantly below criteria have been calculated. This provides further confidence that the annual dose criteria are achievable [4]. The bulk shielding around the Experimental Areas performs a shielding safety function that limits the dose accrual in surrounding, accessible areas such as control rooms and access corridors. The residual radioactivity (of accelerator components or experimental equipment) is potentially the major part of the dose uptake, especially for the personnel involved in operation and maintenance of concerned equipment. Remote control capabilities for operations such as positioning and alignment or component replacement should be implemented as much as reasonably practicable.

2.6 Secondary radiation fields characteristics and monitoring devices

For all radiation monitoring systems proposed to be installed in ELI-NP should be taken into account the characteristics of the secondary radiation fields produced following the primary beams particles interaction in the beam dumps.

For an efficient choice of the radiation monitors one should take into account the cold side spectra presented in [2] for each experimental area.

The ionizing radiations field characteristics and dosimetry requirements for each experimental area are presented in Tables 10 and 11. These were chosen according to the dose assessments made.

A number of radiation dose detectors have been proposed for the ELI-NP experimental areas monitoring. These devices were chosen according to the characteristics of the secondary radiation fields produced in experiments, in order to efficiently monitor the radiation doses that personnel can encounter. The detectors proposed to be installed are mainly for gamma and neutron doses monitoring as these are the main types of ionizing radiations that leave the experimental areas shielding. Exception makes the detectors for muons, proposed for the exterior of experimental area E6 and the radioactive gases detectors proposed to be installed on the chimney of the facility.

The detectors proposed should cover the estimated particle energy and dose ranges and, for pulsed field measurements, the maximum dose per pulse to be measured [5]. There are proposed detectors for measurement of dose rates – active dosimeters, and for measurement of integrated dose – passive dosimeters. For the cases where the actual detector technology does not cover the estimated field's characteristics, this being true for the active detectors, the detectors should be doubled by passive ones. The active detectors will be fixed in certain locations on the corridors and experimental areas, chosen in the estimated dose hot spots (see Figures 19-24). Passive detectors will be positioned near the active ones as well as in a dense network of points near the high occupancy areas as shown in the section 4.1. The same type of passive detectors will also be used as personal dosimeters. Besides the fixed detectors, the radiation monitoring will also be done with mobile detectors used mainly for monitoring the radiation doses inside experimental areas before the entrance of the personnel.

2.6.1 Types of radiological protection instruments

In radiological protection, in conformity with the regulations and practice, the following kinds of measurements are needed:

1. Area monitoring
   - fixed instruments (monitors) must cover:
     - dosimetry monitoring for X, γ- ray and neutrons
     - activity monitoring
   - The fixed instruments (monitors) should be accompanied by passive dosimeters (TLD or OSL)
   - fixed monitors (to the chimney) for radioactive gaseous effluents
   - mobile monitors for radioactive gases – for environmental measurements
   - portable instruments
2. Personnel monitoring
   - portable dosimetric systems/instruments :
     - dosimetric films
     - TLD or OSL – dosimeters
     - personnel electronic (dose/dose rate meters)

The data from the monitoring equipment must be sent:
- in the control room for laser beam
- in the control room for gamma beam
- in the control room for BMS

Only the active detection systems located inside the experimental areas must go into operation only after the experiments stopped. The active detection systems from all the other areas must operate continuously. Special requirements could be necessary regarding the aging and hardness of the components of these systems, due to the irradiation during the experiments. The monitoring system must have thresholds which must be set.

To the access doors in the experimental area, have to be provided devices to display the values of the dose rate inside the experimental area. The detection assemblies of the fixed area monitors must have optical and acoustic warning devices. The radiation monitoring systems must display the values of the dose rate.

The safety procedures must state that the dosimetry officer must check the values of the dose rate before approving the access in the experimental areas and must calculate the maximum access time.

Table 10

Field characteristics and dosimetry requirements for each experimental area

Item	**Position**	**Radiation type**	**Energy range**	**Dose rate range**	**Special conditions**	**Obs.**
1	E1/E6 inside	Gamma *1;2	0.01 – 20 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1 nSv)	Permanent monitoring (switched off during experiment)	Attenuation ≥60 dB 10 MHz – 30 GHz
2	E1/E6 outside	Gamma *1;2	0.01 – 300 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1 μSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level
3	E1/E6 outside	Neutrons *3;4	10^{-3} eV – 400 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1μSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level
4	E4 inside	Gamma *1;2	0.01 – 20 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1 nSv)	Permanent monitoring (switched off during experiment)	Attenuation ≥60 dB 10 MHz – 30 GHz
5	E4 outside	Gamma *1;2	0.01 – 20 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1nSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level
6	E4 outside	Neutrons *3;12	10^{-3} eV – 100 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1 nSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level

7	E5 inside	Gamma *1;2;13	0.01 – 20 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1 nSv)	Permanent monitoring (switched off during experiment)	Attenuation ≥60 dB 10 MHz – 30 GHz
8	E5 outside	Gamma *1;2	0.01 – 300 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1 µSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level
9	E5 outside	Neutrons *3;4	10-3 eV – 200 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1µSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level
10	E7 inside	Gamma *1;2;13	0.01 – 20 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1 nSv)	Permanent monitoring (switched off during experiment)	Attenuation ≥60 dB 10 MHz – 30 GHz
11	E7 outside	Gamma *1;2	0.01 – 20 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1nSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level
12	E7 outside	Neutrons *3;4	10-3 eV – 10 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1 nSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level
13	E2 and E8 inside	Gamma *1;2;13	0.01 – 20 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1 µSv)	Permanent monitoring (switched off during experiment)	
14	E2 and E8 outside	Gamma *1;2	0.01 – 20 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1µSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level
15	E2 and E8 outside	Neutrons *3;12	10-3 eV – 12 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1 nSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level
16	E3 inside	Gamma *1;2;13	0.01 – 3 MeV	10^{-7} – 10^{-2} Sv/h (dose per pulse:1nSv)	Permanent monitoring (switched off during experiment)	

17	E3 outside	Gamma *1;2	0.01 – 3 MeV	$10^{-7} – 10^{-2}$ Sv/h	Permanent monitoring (during and following the beam operation)	
18	E3 outside	Neutrons *3;4;5	10^{-3} eV – 3 MeV	$10^{-7} – 10^{-2}$ Sv/h (dose per pulse:1 µSv)	Permanent monitoring (during and following the beam operation)	
19	ERA inside	Gamma *13;1;2	0.01 – 12 MeV	$10^{-7} – 10^{-2}$ Sv/h (dose per pulse:1µSv)	Permanent monitoring (switched off during experiment)	Pulsed regime Pulse length: ns level
20	ERA outside	Gamma *1;2	0.01 – 60 MeV	$10^{-7} – 10^{-2}$ Sv/h (dose per pulse:1 nSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level
21	ERA outside	Neutrons *3;4;5	10^{-3} eV – 811MeV	$10^{-7} – 10^{-2}$ Sv/h (dose per pulse:1nSv)	Permanent monitoring (during and following the beam operation)	Pulsed regime Pulse length: ns level

Note: Gamma- Energy range certified on market for 30 keV – 7 MeV; Neutrons – Energy range certified on market thermal to 100 MeV
*****See Table 11

Table 11

Instruments for radiation protection dosimetry found on market or other laboratories

Item	Instrument	Type of radiation	$\dot{H}$ measure range	$E_{min} – E_{max}$	Special conditions
1	GMS295	Gamma	10 nSv/h – 1µSv/h	30 keV – 7 MeV	
2	SCIONIX	Gamma	1µSv/h – 10 mSv/h	30 keV – 7 MeV	Shot/frequent pulse
		Gamma	10 mSv/h – 1 Sv/h	30 keV – 7 MeV	
		Gamma	10 nSv/h – 1Sv/h	30 keV – 7 MeV	
3	NMS017ng	Neutron	0.72 cps/µSv/h	0 – 14 MeV	
4	SCIONIX	Neutron	0.56 cps/µSv/h	Am-Be	

5	Plastic scintillators	Neutron		Fast neutron	Difficult pulsed fields (ex. Rutherford Laboratory)
6	EJ-410, Scintillator shielded with Pb	Neutron			On-shot n and high energy X-ray flux monitoring
7	Activation monitoring NaI detectors				Activation monitoring of chamber & high yield components
8	BTI FNS-100 Fast neutron spectrometer	Neutron	Efficiency absolute $3 \cdot 10^{-4}$ for 1 MeV	0.1 – 5.1 MeV	
9	BD-PND	Neutron	1 – 5.35 mSv	200 keV – 15 MeV	Personal neutron dosimetry
10	BDT	Neutron	1.1 – 112 µSv	Thermal neutron	Personal neutron dosimetry
11	BDS	Neutron	535 µSv (0.1 – 0.2 bub/µSv)	10 - 10000 keV	Personal neutron dosimetry
12	Berthold LB 6411, 2 variants: LB6411 + LB123 Umo =>portable monit LB6411+LB111 =>stationary measuring instrument	Gamma, neutron	0.1 µSv/h – 100 mSv/h	1 – 10 MeV	Used as portable and/or stationary monitor in accelerators research γ-sensitivity: < 40 µSv/h in 10 mSv/h, ^{137}Cs gamma-field
13	CANBERRA IP67, EcoGamma g	Gamma	10 nSv/h -10 Sv/h	30 keV-5 MeV	Environmental Gamma Radiation Monitor
14	CANBERRA TAM 100D/DSI	Tritium	0.5 to 10^6 µCi/m^3 (18 kBq/m^3 to 3.7 x 104 MBq/m3)		High Sensitivity Wide range Digital Tritium in Air monitor
15	CANBERRA TAM 73 D/3DSI	Beta in gaseous form (Tritium, Noble Gas, etc.)	Six decade range from 1µCi/m^3		Portable Digital Tritium in Air Monitor
16	CANBERRA CAM 100G	Noble gas and other radioactive gases	1.0 x 10^{+4} to 1.0 x 10^{+14} Bq/m3 (2.7 x 10^{-7} ~ 2.7	0.15 – 1 MeV	Radioactive Gas Monitor Continuously, accurately and

			x 10^{+3} μCi /cc)		reliable monitor the activity of noble gas and other radioactive gases in a variety of ambient, ducted and effluent applications
17	CANBERRA OLM-H	Gamma	3.7 x 10^{3} to 3.7 x 10^{9} Bq/m3 (1 x 10^{-7} to 1 x 10^{-1} μCi/cc).		On-line Process Monitoring Systems- Continuous measurement of the quantity of radioactive gamma activity in a gaseous stream
Note for items 8,9,10,11: Zero gamma sensitivity, energy independent above threshold, dose-rate independent, tissue-equivalent dose measurement, neutron measurements around LINAC's, insensitive to electrons and photons					

2.7 EMP characteristics

The electromagnetic pulse (EMP) [6] is an issue that should be taken into account when finding proper instrumentation for monitoring doses in areas where laser experiments are performed. At the moment, information about the strength of EMP inside experimental areas is not complete. One should expect, after the preliminary evaluations made, an EMP magnitude inside experimental area with the lowest estimate of approximately 700 V/m, and the highest one up to 50 kV/m. It should be noted that depending on the experimental setup and shielding strategy this values can change.

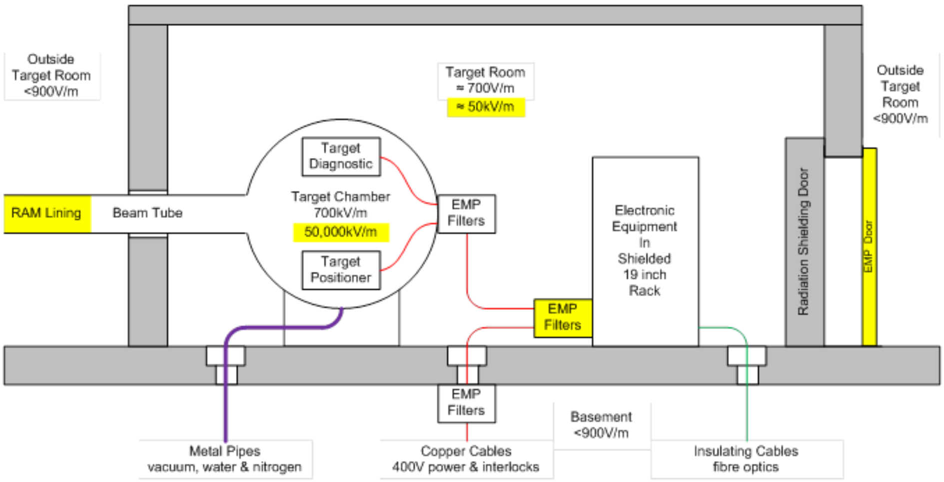


Fig. 11 - Shielding strategy and EMP magnitude [6].

2.8 Calculated doses external to the facility

The shielding provisions of the ELI-NP facility will ensure that dose rates in contact with the exterior of the facility will be less than 0.1 μSv/hr. Given that ELI-NP is to be located on a licensed site, it is highly unlikely that members of the public will spend time at this location and therefore doses are expected to be negligible. However it is recommended that regular monitoring at the facility administrative boundary is undertaken throughout the facility lifetime to ensure that doses to the public remain negligible [2, 4].

Besides the prompt doses initiated by the secondary particles generated within the ELI-NP experiments, a study [8] has been conducted to estimate the residual activity concentration created. For each experimental area has been performed this assessment in order to identify the specific radionuclides generated [7]. These had to take into account that for all experimental areas, the air exchange rate provided by the venting system is 5 changes/hour. Also, the venting system in all the experimental areas have a depression working regime in order to collect the air from adjacent areas to inside experimental areas. E1/E6 has the highest level of depression due to the increased level of residual concentration determined in comparison to all other experimental areas. The venting system has the property of not recirculating the volume of air. Only fresh air will be pumped in the facility. The subtracted air from the experimental areas will pass through a chimney that is foreseen with special filters and a radioactive gas detector before being exhausted in the atmosphere.

The main objective of the study [8] was the assessment of the regulatory compliance of the normal, technological atmospheric releases from the combined operations of ELI-NP and IFIN-HH facilities.

The annual activity of 1.53E+11 Bq estimated to be released to atmosphere by ELI-NP [7] exceeds by approximately two orders of magnitude the 9.87E+09 Bq of the most conservative estimation of the activity released by the IFIN-HH facilities at the operational level of the year 2014. Due to the nature of the generated radionuclides from ELI-NP activities (small half-life times), the average Annual Effective Dose potentially induced to the Critical Group by ELI-NP was found to be three orders of magnitude below the Annual Effective Dose resulting from IFIN-HH operations, and by two order of magnitude lower, under less conservative assumptions.

The cumulated atmospheric releases of the combined ELI-NP + IFIN-HH system under a normal operation regime will comply by a comfortable margin with the Legal Dose Constraint, of 100 μSv per year to persons of the general population, legally set for IFIN-HH. The calculated annual Total Effective Dose to a person of the Critical Group would range from 25.58 μSv/a under the most conservative assumptions, down to 5.77 μSv/a in the least conservative case (major contributions from IFIN-HH), to be compared with 9.43 μSv/a determined by measurements.

On the other hand, since the most conservative evaluation involving all 19 ELI-NP sources operating simultaneously and an IFIN equivalent source releasing at 22 mAG (meters Above Ground) indicates a cumulated annual Total Effective Dose of ca. 25 μSv on the Air Exposure Path only, the 10% Legal Dose Constraint allocation to the Air Path currently in effect – and attributable to IFIN facilities only – may need to be revised upwards, from the current 10% to a minimum of 25.5%, in order to accommodate the ELI-NP advent into the overall system-allocated Legal Dose Constraint.

The results of the radiological assessment conducted on the potential health and environmental effects on the general population, of the atmospheric releases from combined ELI-NP and IFIN-HH operations indicate that neither the annual, nor the acute exposures would bear any significant consequence, from a regulatory standpoint.

2.9 Assessment of penetrations– access control and delimitations

Doses have been assessed at the cold side location where it is expected that the maximum dose will be experienced due to penetrations [9]. Prompt doses in excess of the dose criteria at the cold-side of a penetration may be considered acceptable if it can be demonstrated that the doses at the nearest reasonable location of an operator are within the dose criteria.

The calculated dose rates and any subsequent shielding requirements for the major penetrations across the ELI facility, by experimental area, are presented in [9].

Calculations have been conducted to assess penetrations in the fabric of the bulk shielding of the ELI Nuclear Physics facility. The calculations show that the cold side dose criteria will be achieved provided that the recommendations and shielding requirements outlined in [9] are implemented.

The ELI-NP penetrations within the experimental areas will be used according to experimental setups requirements. All the penetrations that will remain unused will be covered by concrete or similar density materials plugs. Shielding of used penetrations has to also be considered in case there is additional space between the equipment and existing shielding. This document is proposing to implement this measure to all experimental areas.

Due to penetrations, there is some localized increasing in the dose rate of the neighboring experimental area. It will be installed an interlocking system or controlled access system having the purpose to limit the access in experimental areas and in technical basement depending on the activities running.

2.9.1 Access control system

The access control system is intended to prevent any unauthorized or accidental entry into experimental areas. An access control system is composed by physical barriers (doors, shields, hutches), signs, audible or visual warning devices, etc. by an active system able to allow people a safe entry in controlled areas, counting them in the same time and by a body of administrative procedures that defines conditions where entry is safe.

General requirements include but are not limited to:

- Minimize exposure of personnel to any risk factors, radiological or other.
- Minimize impact of access control procedures on the machine effective beam-time
- Use a single access card for all areas inside the ELI-NP building
- Keep a unified log record and history of user access
- Allow easy maintenance and policy changes to be implemented in the future

Due to particularities of ELI-NP project timeline and administrative constraints, implementation of the access control system will take place in 2 phases.

First phase represents the baseline solution for access control. It takes place during ELI-NP building construction, ending on commissioning date. At that moment the building will have installed a Building Management System that includes functionality for general access control and interlock of all areas, based on control and monitoring of the large radioprotection doors and also the doors of other technical rooms.

Second phase aims for increased flexibility in the access modes, by using additional equipment and logic, in order to support certain operating modes of the Laser and Gamma machines which are not covered by the first-phase solution.

New/modified equipment is proposed to avoid the limitations described above:

• Additional physical barriers (light secondary doors, fences, turnkeys) installed in front of the large radioprotection doors will allow enforcement of new access modes (e.g. ‘controlled’), in which the radioprotection doors remain open but only selected personnel can enter an area.

Ideally these should be commanded by the same card reader & keyboard as the one used for the radioprotection doors, but separate ones will also work. The turnkeys must be able to count the number of accesses in/out of the room. Due to geometrical layout constraints in the building plans, some of them will need to be dismountable, to allow circulation of large equipment:

• Modified interlock key panels (or, alternatively, replacement with multi-position switches) to permit selection of these additional access modes from the control rooms

• Search buttons for additional verification of human presence inside some experimental areas

• New/modified automation stations to implement the signal processing needed for the new access matrix

• Communication posts installed next to each access door, outside the experimental rooms, to contact the control room.

The access system proposed to ELI-NP foresee that the routine entrance inside each of the experimental areas should be allowed through a turnstile and a gate controlled by a magnetic card reader. Any of the ELI-NP sources/beam may not be able to start/operate if there is no parity between entries and exits. The entrance is possible only for personnel equipped with a personal magnetic card. The system is conceived such that only a person at a time both in entrance and in exit is allowed to pass.

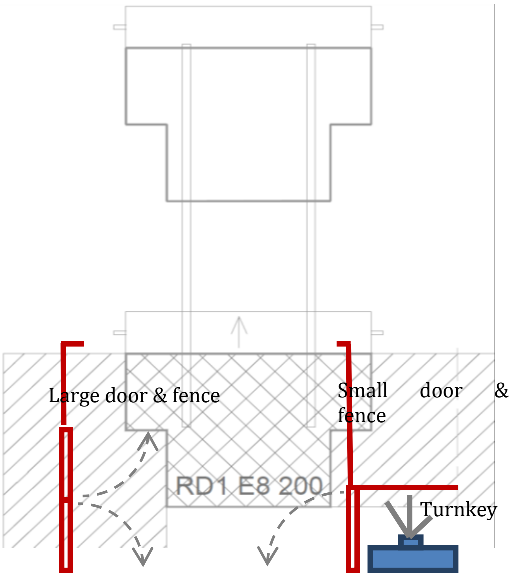


Fig. 12 - Schematic layout of physical barriers for room E8.

Fig. 13 - Example of access control equipment in DAΦNE, LNF, Italy.

3. BASIC SAFETY REQUIREMENTS

3.1 Radiation Safety requirements [10 - 60]

1. Basic safety principles for ELI-NP

2. Basic norms regarding safety for ELI-NP

The safety program for ELI-NP should refer to the following:

- radiological protection of the equipment
- radiological protection of the workers
- radiological protection of the environment
- radiological protection of the population

All the requirements regarding the safety for ELI-NP as well as the actions to be done in order to fulfill these requirements should be included in the Quality Management System (QMS) of ELI-NP. The safety part of the QMS should be based on:

- laws standards (national/international)
- norms (guidelines)

It should include the following documents:

- rules
- procedures
- work instructions

3. Nuclear legislation structure

4. Classification of the ELI-NP areas

5. Authorizations

The authorizations will be issued by the Romanian authorities (e.g. CNCAN, public health authorities, or environment protection authorities).

The authorizations issued by the nuclear authority (CNCAN) should refer to:

- plants
- equipment
- instruments
- practices
- personnel (staff)

Exemption should be taken into account.

6. Radiological protection for ELI-NP

The radiological protection system of ELI-NP should include responsibilities for:

a. the titular holder of the authorization

b. the board for the Radiological Protection

- organization chart
- competence

c. radiological protection responsible

d. head of laboratories

e. head of experimental areas

f. persons in charge for experiments, workers

7. Administrative rules/procedure:

- the license for the use of the radiation beam/source
  - the license for the nuclear activities
  - classification of the radiological risk employment

8. Integrated risk management

The integrated risk management should refer to:

a. the identification of risks for: - laser equipment
- radiological installations
- radioactive sources

b. risk assessment

c. management of the risk, by:
- optimization
- justification
- restriction of the activities.

A study must focus to identify possible vulnerabilities at ELI-NP facility and how can be analyzed the risks.

The following risks can be predicted at ELI-NP:

• Unauthorized worker / observer enters restricted access area during experiment set-up / dismantling;

• Worker / observer enters restricted access area during experiment;

• Worker / observer enters restricted access area after experiment but not complying the access procedures;

• Worker / observer present in restricted access area immediately prior to an experiment and who remains in the restricted access area during the experiment.

• Loss of interaction chamber containment when performing experiments involving radioactive or other hazardous materials;

• Loss of vacuum generation system containment during or after performing experiments involving radioactive or other hazardous materials;

• Loss of cryogenic cooling system containment;

• Failure of cryogenic cooling system;
• Loss of water cooling system containment (if included in design);
• Failure of water cooling system (if included in design);
• Loss of facility power;
• Faults due to unwanted effects of NIR;
• Release of radioactive or other hazardous materials to the environment;
• Worker faults when handling radioactive or other hazardous experimental materials (including clean-out and maintenance of interaction chambers).

There are shields included in most areas of the ELI-NP to meet the dose criteria for the public and for workers outside the experimental areas.

The majority of the faults listed in above relate to failures of Plant and Equipment (P&E).

A Layers of Protection Analyze (LOPA) study has been performed respecting BS EN 61508 and BS EN 61511, in order to give an indication of the suitability of the types of safety measures that may be used in ELI-NP, based on the safety measures used in some of similar facilities.

LOPA is a semi quantitative assessment technique that uses an estimate of severity and initiating event frequency to indicate the required risk reduction for a particular hazard. The risk reduction is estimate by selecting suitable, independent safety measures or Protection Layers. An RRF (Risk Reduction Factor) is then assigned to each safety measure or Protection Layer, and the combined RRF from these layers is contrasted to the risk reduction required for the hazard severity. Additional safety measures or layers of defense can then – if necessary – be defined to ensure the overall risk for the scenario is acceptable.

LOPA stands for layer of Protection analysis. LOPA is process to evaluate risk with explicit risk tolerance for specific consequences. It's about creating value without taking unnecessary risk. The level of risk acceptance is expressed in terms of tolerable frequency. This tolerable frequency is the decision criteria for design and operational changes. The higher the consequence means that we have the lower the tolerable frequency. LOPA can be break down into seven steps:

a. Identify a single consequence to analyze (this is commonly done during the HAZOP to screen out high risk scenarios for LOPA). A Hazard and Operability study (HAZOP) is a systematic approach to investigate each element of a process to identify all of the ways in which parameters can deviate from the intended design conditions and create hazards or operability problems.

b. Define the tolerable frequency for the consequence.

Table 12
Consequences frequencies

Multiple fatality:	0.00001/year or 0.001%/year
Single fatality:	0.0001/year or 0.01%/year
Hospitalized injury:	0.001/year or 0.1%/year

c. Assess the probability of the initiating event (this could be identified during the HAZOP as causes)

d. Identify independent protection layers and assign a risk reduction factor

Important: The protection layer must be independent from the initiating event and independent for other safeguards used for this consequence.

e. Calculate the expected frequency of the consequence scenario

Expected frequency = initiating event frequency x probability of failure of safeguards

f. Decide if risk is acceptable based on the tolerable frequency.

g. Determine the additional safeguards to reduce the risk to meet the tolerable frequency.

A hazard is defined as a "Condition, event, or circumstance that could lead to or contribute to an unplanned or undesirable event." More often an accident or operational failure occurs as the result of a sequence of causes. A hazard analysis will consider system state, for example operating environment, as well as failures or malfunctions.

While in some cases, safety or reliability risk can be eliminated; in most cases a certain degree of risk must be accepted. In order to quantify expected costs before the fact, the potential consequences and the probability of occurrence must be considered. Assessment of risk is made by combining the severity of consequence with the likelihood of occurrence. Risks that fall into the "unacceptable" category (e.g., high severity and high probability) must be mitigated by some means to reduce the level of safety risk. There are software that are centered around the hazard analysis and functional based safety process.

Table 13
Severity definitions – Safety Related

Severity	Definition
Catastrophic	Results in multiple fatalities and/or loss of the system
Hazardous	Reduces the capability of the system or the operator ability to cope with adverse conditions to the extent that there would be: • Large reduction in safety margin or functional capability

	• Crew physical distress/excessive workload such that operators cannot be relied upon to perform required tasks accurately or completely • Fatal injury to ground personnel and/or general public
Major	Reduces the capability of the system or the operators to cope with adverse operating conditions to the extent that there would be: • Significant reduction in safety margin or functional capability • Significant increase in operator workload • Conditions impairing operator efficiency or creating significant discomfort • Major occupational illness and/or major environmental damage, and/or major property damage
Minor	Does not significantly reduce system safety. Actions required by operators are well within their capabilities.
No Safety Effect	Has no effect on safety

The paper "Risk criteria in EU" by V.M. Trbojevic focuses a risk criteria used in the EU for population living in vicinity of hazardous facilities. It is known from this work that there is a credible fatal accident risk for certain faults at high-energy facilities. On this basis, it is necessary to set targets and limits for risk that reflect this, and the paper describes how the frequency target of 10-6/ year and 10-5/ year appropriate. Not every fault has a credible fatal accident risk, however, and the risk from these non-fatal hazards will be allocated a frequency target of 1x10-4/yr and limit of 1x10-3/yr, mirroring figures used when considering radiological faults with minor consequences (typically <1-2 mSv, where treatment of some description will be required for affected personnel but the short-term risk of death is minimal).

In the case of the LOPA assessment performed on the ELI-NP design, the criteria are as defined in the paper "Risk criteria in EU". The severity of the event described can be one of three categories:

- Extensive (multiple fatalities);
- Serious (multiple significant injuries, possibility of single fatality), or
- Minor (one or more minor injuries).

Will follow discussions with specialist engineers point of the identified events, the impact event description and the calculation of the risk estimate.

9. Monitoring of the radiation fields, should be done by the monitoring of:
- the plants
- the equipment
- the areas
- the staff
- the effluents
- the population
- the environment

10. Radiation sources:
- lasers (according the specific legislation)
- radiological installations(facilities)
- radioactive sources
- radioactive wastes

This part of the safety system should be also refer to:
- radioactive sources management
- radioactive sources storage and handling

11. Training of the staff

12. Equipment for the protection of the staff:
a.radiological protection
b. collective radiological protection (shields)
c. individual radiological protection:
- clothing (overalls, dressing gown)
- footwear
- gloves
- goggles
- respirators (gas mask), where necessary

13. Radiological mapping
The radiological mapping should refer to:
- radiological risk areas (RRA)
- demarcation of the RRA
- marking of the RRA
- monitoring of the RRA
- access control to the RRA

14. Limits and operational levels, dose constraints
For normal activity:
external exposure – A class staff
– B class staff

internal exposure – A class staff
– B class staff
combined exposure – A class staff
– B class staff
For emergency (potential exposure)

15. Requirements regarding the areas (laboratories, working areas, forbidden areas, safety areas, leisure area).

These requirements should refer to:

- access
- specific facilities (electric power, drinking water, technological water, ventilation, air conditioning, drainage)

The use of specialized electrical power systems, however, may mean that additional measures are required to ensure electrical safety beyond those specified in the relevant Romanian and European standards. Furthermore, the non-ionizing radiation (NIR) generated by the instruments may be hazardous to health.

15a) Management of Electrical Safety

For the most part, national and international standards for electrical safety tend to address the supply types used for domestic and industrial equipment, and do not consider nonstandard supplies such as those that may be used al ELI-NP. Indeed, the European Commission (EC) Machinery Directive specifically excludes experimental systems; hence it is suggested that US Department of Energy guidance is used as this a document specifically written for organizations involved in research and development activities that use high-power electrical devices. If additional information is needed, there may be benefit in referring to the publications of a number of the International Electro technical Commission (IEC) Technical Committees (TCs), however few if any of the relevant TCs' publications have been approved as standards, so the publications should only be considered as potentially- useful guidance:

TC 44 – Safety of machinery, electro technical aspects;

TC 66 – Safety of measuring, control and laboratory equipment;

TC 99 – System engineering and erection of electrical power installations in systems with nominal voltages above 1kV a.c. and 1.5kV d.c. particularly concerning safety aspects.

It is known that power for the central instruments in ELI-NP will originate from a 220V, 50Hz single-phase a.c. supply. The national transmission network supplies the urban distribution network via 110kV/ 20kV transformers. This is then supplied on to the IFIN-HH site where it is applied across 20kV / 0.4Kv transformers. The 0.4kV is distributed via substations to the various on-site facilities including ELI-NP. Safety for the on-site connections would be the responsibility of the contractor if this were to be necessary, and would not be expected to feature in the ELI-NP safety report.

15b) Management of Non-Ionizing Radiation

The Activity Report on July includes a list of the types of NIR hazards that may occur in ELI-NP. The most dangerous form of NIR within ELI-NP will be emissions from the lasers, and the risks posed by laser emissions are well understood – as are the means of controlling them. It is noted that IEC TC 76 covers optical radiation safety and laser equipment, but since none of its publications are ready for approval as standards, this may be used only as guidance if required. Preparation of the laser system will require personnel to work in the laser and experimental areas when low power alignment lasers are operating and this will be controlled by a combination of procedural controls and PPE.

Apart from the clear hazards posed by emissions from the lasers, the significance of NIR as a hazard to health is not as clear as it is for ionizing radiation. It is still a potential hazard, however, and so should be controlled – although it is possible that the measures put in place to protect electronic equipment from the effects of NIR will also work to protect workers and the public. This will depend largely on whether it is more effective to install electromagnetic (EM) shielding throughout the sections of the experimental areas that contain instruments responsible for generating the NIR, or whether it is better the EM-harden individual items of electronic equipment. This should become clear as the design for ELI-NP progresses through the Construction Phase, at the details will be included in the Operational Phase Safety Report.

15c) Management of other conventional safety hazards

It is anticipated that conventional safety hazards other than from electrical hazards and NIR will be managed in a similar way as in other industrial or laboratory settings. If there are any situations or hazards in ELI-NP that are not specifically covered by workplace safety, it would be appropriate to seek advice from the European Agency for Safety and Health at Work (EU-OSHA). This will be included in the Operational Phase Safety Report.

16. Radioactive sources handling and transport inside ELI-NP limits.

17. Radioactive waste disposal:
- solid waste
- liquid waste
- gaseous waste

18. Decontamination of the:
- personnel
- equipment
- instruments
- devices

19. Response to emergencies:
- identification of emergencies and classification
- emergencies plan (approved by CNCAN)
- preparing and training of the staff
- first aid

20. Public and environment exposure

Public and environment exposure should refer to the:
- derived emission levels
- monitoring plan for radioactive effluents
- environment monitoring plan (approved by CNCAN)

The main hazards envisaged for ELI-NP are as follows:

a) External and internal dose hazards

b) Conventional safety hazards

c) Environmental hazards

These hazards will be necessary to perform Probabilistic Risk Assessment (PRA) on the safety systems that will be implemented in ELI-NP. There are a variety of different hazards which all need to be managed to ensure risks are ALARA. To assist with this, the following criteria will be used:
- Dose criteria
- Criteria regarding the use of electrical systems
- Any non-ionizing radiation that is generated will be compared to the limits set out in International Commission on Non-Ionizing Radiation Protection

This study is to describe how radiological safety will be assumed during normal operations at ELI-NP.

For the shielding assessment, it has been agreed that the maximum doses for Professional Exposed Individuals (PEIs) at ELI-NP will be set at 2 mSv per year (10 times lower than the maximum national legal limits for the professional exposed personnel). Total Effective Dose Equivalent (TEDE), apart from in exceptional circumstances where 5 mSv is permitted in a single year sa long as the average TEDE over five years is not more than 2 mSv. This is 10 % of the 20 mSv Professional Exposed Individual annual dose quoted in CNCAN documentation. Maximum doses to the public from ELI Beam lines are limited to 10% of the CNCAN limits for the public. It should be noted that the CNCAN limits are equal to or lower than the equivalent European Atomic Energy Community (EUROATOM) limits, and so there is no detriment to radiological safety in using the Romanian national limits rather than the European ones as the benchmark for the Eli-NP dose criteria.

There are additional Committed Effective Dose Equivalent (CEDE) values for specific organs and areas of the body. Values equivalent to 10% of the CNCAN values will apply for CEDE received by the public from ELI-NP.

Table 14
These values are set as the criteria for the ELI-NP facility as summarized below

		ELI-NP criteria (mSV /an)	CNCAN limit (mSV /an)
Professional	TEDE	2	20
	CEDE lens of eye	15	150
	CEDE per cm^2 of skin	50	500
	CEDE for hands, feet	50	500
Public	TEDE	0.1	1
	CEDE lens of eye	1.5	15
	CEDE per cm^2 of skin	5	50
	CEDE for hands, feet	5	50
Pregnant women	TEDE	0.1	1
Persons under 16 years old, during preparation	TEDE	0.1	1
	CEDE lens of eye	1.5	15
	CEDE per cm^2 of skin	5	50
	CEDE for hands, feet	5	50
Persons 16 to 18 years old, during the training	TEDE	0.6	6
	CEDE lens of eye	5	50
	CEDE per cm^2 of skin	15	150
	CEDE for hands, feet	15	150
Persons over 18 years during training	TEDE	1	20
	CEDE lens of eye	15	150
	CEDE per cm^2 of skin	50	500
	CEDE for hands, feet	50	500

The most significant hazards in ELI-NP will occur when the instruments are operating, and it is assumed that to experimental areas be prohibited at these times.

It is anticipated that the operations will follow a generic pattern of:

- Experiment preparation;
- Confirmation that experiment areas are cleared of personnel;
- Undertaking the experiment
- A delay before re-entry whilst irradiated material decay to acceptable levels;
- Re-entry to the experiment areas.

Before and after experiments take place it will be necessary to access the instruments and interaction chambers. Because these areas may have high dose rates (after an experiment has taken place), it will be necessary to ensure that dose uptake can be measured and controlled to ensure doses are ALARA.

Workers will be prohibited from accessing experimental areas during normal operations in ELI-NP, so there will be no need for additional personal protective equipment in these areas.

It is intended, that the facility design will allow the dose rate targets to be achieved. Shielding design is based upon both the dose rate design targets defined within the Radiological Classification of Areas and the worse-case source terms.

The dose rate targets will be achieved through a combination of shielding design and access restrictions and this is the approach that has been successfully adopted in other high power laser facilities elsewhere such as ELI Beam lines.

In conclusion, there are no foreseen issues with radiological safety for ELI-NP for normal operations.

Next it will review non radiological risks.

21. Plan for decommissioning of ELI-NP

22. Signaling, marking, warning of the hazards in the working areas

23. General rules for the activity

24. Record of the announcements and reports

25. Safeguards

The Law no. 111/1996 republished establishes the Legal framework for National Committee on Control of Nuclear Activities (CNCAN) as Regulatory Body of Romania.

The CNCAN deliver the following types of Authorizations (authorization phases):

1. design;
2. the location (layout);
3. construction and / or assembly;
4. commissioning;
5. test operation;
6. use (operation);
7. repair and / or maintenance;
8. conservation;
9. decommissioning

In Law 111/1996 there are detailed the main responsibilities and duties for

- CNCAN
- Radiation Safety Experts
- Authorization holder

• Radiation Safety officer CNCAN

All activities involving radiation sources should comply with Fundamental Norms on Radiation Safety (NSR-01). These Norms establish the necessity to obtain the CNCAN authorization is prior of practice.

Radiation protection principles are

a) Justification,

b) Optimization and

c) Dose limitation (ALARA principle for working considerations)

Radiation Safety Norms – Authorization procedures (NSR-03)

Authorization is the official document issued by the Committee which entitle the holder to carry out activities in the nuclear field and has the quality of the official registered. Rights acquired under the authorization may not be transferred without the agreement of the Committee.

Authorization is the act whereby proves the legality in the nuclear field of activities.

The authorization is valid only for the holder and only for the nuclear activities or practices for which it was issued.

Compliance with the limits, terms and conditions included in the authorization or in annexes accompanying compulsory.

Individual dosimetry norms (NSR-06)

Each occupational exposure personnel will be monitored with personal dosimetry systems by CNCAN notified laboratory.

For each occupational exposure personnel will be provided electronic dosimeters with high dose rate alarm.

Type of personnel dosimeters and electronic dosimeters are described in Chapter 4.

Norms on issuance of permits to exercise the nuclear activities and the designation of accredited experts in radiological protection (NSR-07)

• Permits for level 1 allows holders to carry out activities in the field and the specialty for which they were issued and to the Authorization holder

• Permits for level 2 allows holders to carry out activities with consistent radiological risk of nuclear material and allows the owners to have responsibilities related to radiation protection in the controlled / surveillance area or lead radiation sources or activities of nuclear installations in the field and specialty for which the permit was issued

• Permits for level 3 CNCAN designates accredited experts in radiological protection specialists who have the knowledge and training needed to provide consultancy for assessment of doses, achieving effective protection of persons and correct use of equipment and radiation protection.

3.2 High Intensity Laser Safety requirements

3.2.1 Classes of Lasers (adopted from ANSI Z-136.1-1993*)

• Class 1

– Not capable of emitting in excess of the Class 1 AEL

– Most lasers in this class are lasers which are in an enclosure which prohibits or limits access to the laser radiation

• Class 2a

– Lasers in the visible region of the spectrum which do not exceed the Class 1 AEL for exposure less than or equal to 10E3 s

– The output of the laser is not intended to be viewed

– An example of a Class 2a laser is a supermarket point-of-sale scanner

• Class 2

– All Class 2 lasers are in the visible region of the spectrum

– Continuous wave lasers which can emit accessible radiant power which exceeds the Class 1 AEL for the maximum duration inherent in the laser, but do not exceed 1 mW

– Pulsed lasers which can emit accessible radiant power which exceeds the Class 1 AEL for the maximum duration inherent in the laser, but not do not exceed the Class 1 AEL for an exposure of 0.25 s

• Class 3a

– Have output that is greater than or equal to 5 times Class 2 AELs

• Class 3b

– Continuous wave – between the Class 3a limits and 500 mW

– Repetitively pulsed – radiant energy between 30-150 mJ per pulse for visible and infrared, otherwise greater than 125 mJ per pulse; average power less than 500 mW

• Class 4

– Limits exceed Class 3b limits.

3.2.2 Laser Safety (class 4)

• Engineering controls

1. protective housing shall be provided
2. interlocks shall be provided on removable parts of the housing
3. service access panels shall be interlocked or require a tool for removal
4. a key-controlled master switch shall be provided

5. when the entire beam in not enclosed, a NHZ shall be established

6. when there exists a partially limited beam path, a NHZ shall be established

7. a permanent beam stop or attenuator shall be provided

8. an alarm, warning light, or verbal countdown shall be used during use or start-up of the laser

9. the controlled area shall:

• be restricted to authorized personnel only
• be designed to allow for rapid emergency egress
• be equipped with a device that allows for deactivation of the laser or reduction of output to below the MPE
• be designed to fulfill Class 3b controlled area requirements
• be designed with entry safety controls

10. the laser should be monitored and fired from a remote location

11. if used outdoors, a Class 4 laser shall:

• have an established NHZ
• be restricted from the presence of unauthorized personnel if the MPE is exceeded
• have appropriate controls if personnel are permitted in the NHZ
• have a beam path that is not at eye level with sitting or standing persons
• be terminated by a beam stop, if possible
• be disabled when not in use
• be operated only by authorized personnel
• be evaluated for necessary personnel protective equipment in inclement conditions
• have warning labels in a conspicuous place
• have a warning system which activates prior to emergence of the beam

12. If the MPE is exceeded:

• viewing portals and/or display screens shall be designed so as not to exceed the MPE
• collecting optics shall be designed so as not to exceed the MPE

• Administrative and procedural controls

1. approved, written standard operating, maintenance, and service procedures shall be required

2. education and training shall be provided for operators, maintenance, and service personnel

3. only authorized personnel shall operate, maintain or service the laser

4. alignment procedures shall ensure that the MPE for the eye is not exceeded

5. eye protection shall be required

6. spectators shall be prevented from the controlled area
7. service personnel shall comply with control procedures
8. the laser safety officer shall take measures to reduce output if the output is considered to be excessive.

4. TECHNICAL PROPOSAL FOR RADIATION PROTECTION AND DOSIMETRY

4.1 Radiation Protection Dosimetry

4.1.1 Personnel Dosimetry

The basic choice for personnel dosimetry is a combination of passive gamma and neutron dosimeters. For gamma radiation the OSL systems provide a larger energy range (up to 40 MeV, Dose Measurement Range: 10 μSv to 10 Sv) for operation compared to others (TLDs, photo dosimeters, etc.). OSL detectors are also sensitive to beta radiation. For neutron radiation, for the energy range consideration (from 0.25 eV to 40 MeV, Dose Measurement Range: 100 μSv to 250 mSv), the CR 39 are proposed. The two types of dosimeters will packed in single badge. The badges are personnel nominal dosimeters. The reading and processing of both will be assured in the ELI-NP Dosimetry Laboratory with specific instruments with periodicity to be defined by the Radioprotection and Safety Documents (typically monthly).

Active dosimeters for personnel (Electronic Personnel Dosimeters - EPD) are also proposed with both gamma and neutron sensitivity with highest possible range. They will be assigned to each team member during an experiment. The EPD should provide acoustic alarm in case that measured dose rate exceeds the predefined threshold. We mention that due to pulsed character of radiation field in laser experiments the prompt indication of the EPD may be underestimated and this is the reason why the passive detectors have been foreseen as basic choice, while active dosimeters are considered very useful for interventions in radiation fields due to activation/contamination/radioactive sources, etc. The reader instrument of the EPD (rather a communication device for data transfer to PC) and the maintenance instrument for periodic checks will be located in the ELI-NP Dosimetry Laboratory.

OSL are reusable passive detectors to be erased (reset) after each reading. The CR39 are single use detector that will be archived according to specific rules.

The archiving of readings of OSL and EPD detector is on the software included in the dosimetry systems.

The recalibration of CR39 and OSL reading instruments, of the OSL and EPD detectors, and of the associated maintenance instruments has to be performed by accredited laboratories. Such accreditations are not foreseen for ELI-NP. Therefore, the activities of recalibration affect only the operational budget. Due to temporary unavailability of some instruments during such recalibration (or for other reasons) the reading/processing instruments for CR39 and OSL have to be doubled.

4.1.2 Area Dosimetry

The basic choice for area dosimetry is the same combination of passive gamma and neutron dosimeters as in case of personnel dosimetry, that is OSL detectors for gamma and CR39 for neutrons, packed in the badge. The distribution of the measurement positions is shown in Figure 14 for ground floor (29 positions) and Figure 15 for basement (15 positions).

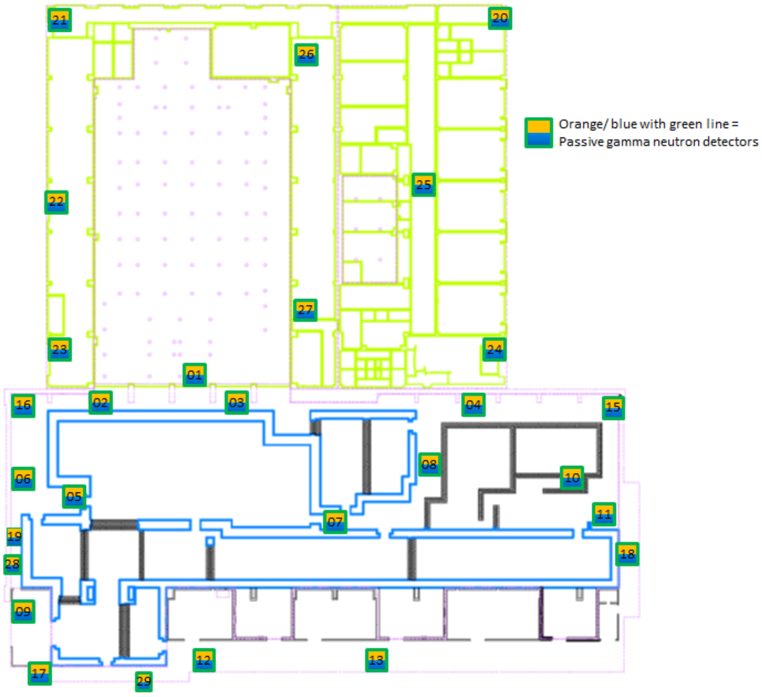


Fig. 14 - Position of passive area monitors at the ground floor.

Fig. 15 - Position of passive area monitors in the basement.

Active dosimetry systems have to take into account the pulsed (short duration) radiation fields specific to laser facilities. Additionally, the detectors installed inside laser experimental areas (E1, E4-E7) should work in high EMP environments. Due to these constraints no commercial active dosimetry system has been identify to be proposed to working inside laser experimental areas when laser beam is ON. Nevertheless, a system is proposed to be turned ON when laser beam is stopped. As it will measure only activation, this system will be sensitive to gamma only. The detectors of this system will be placed near the access door in experimental area as shown in Figure 16 with red line yellow squares (8 measurement positions). The detectors in positions 07 and 08 are placed in experimental rooms where the gamma beam may allow them to work continuously if laser beam is OFF.

Outside experimental areas the EMP is reduced by the shielding provided by the building and active detectors can work continuously. Two types of detectors are foreseen:

- Special detectors to be developed for work in pulsed fields of neutron and gammas will be installed in the hot spots identified by Monte Carlo simulations; 6 measurement positions at ground floor and 2 measurement positions in the basement as marked in the figures 16 and 17.
- Commercially available detectors for gamma ray are proposed in other 24 measuring points (of which 15 on ground floor). We mentioned that prompt contribution to measured doses when laser system is ON might be underestimated by these active detectors, whoever they are useful for the assessment of the presence of activation or other radioactive materials.

The area monitoring systems for the Gamma Beam System (GBS) will be provided together with the accelerator and will be defined by EuroGammaS.

It has been identified that the proposed dosimetry system for the GBS, composed of gamma and neutron detectors, are also able to work within the pulsed fields regime. Consulting the market, we have found that this is the only system most suitable to use for ELI-NP radiation monitoring, especially for the areas where experiments with HPLS are conducted. Technical specifications of the detectors can be found in [61].

The active detectors will be connected to a central unit that will collect, store and send the data for display at least in:

- Laser Control Room
- Gamma Control Room
- BMS (Building Management System) Control room

The Central Unit will display near the doors of each experimental area, outside the area, the dose rate measured by the detector placed inside near the same door. There is not foreseen to interlock the doors with the measured dose rate level.

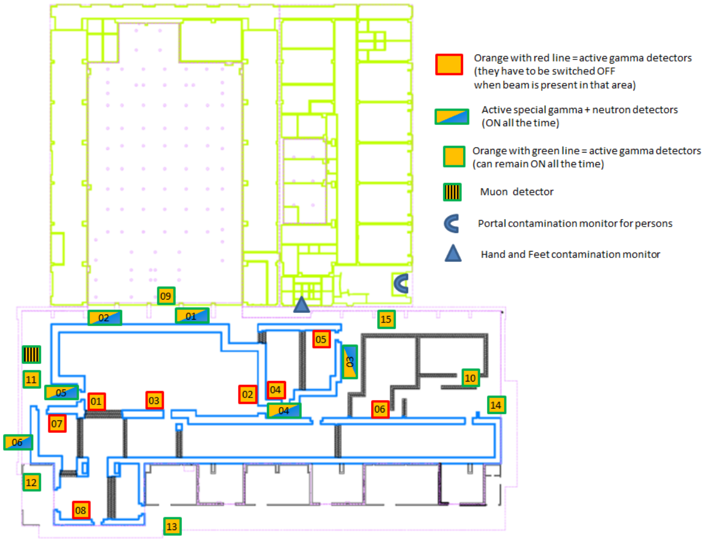


Fig. 16 - Position of active area monitors on the ground floor.

Fig. 17 - Position of active area monitors in the basement.

Additionally we propose 4 portable systems:

- 2 systems with probes for neutrons, gamma (and other for contamination), such as Berthold LB123 Umo
- 2 systems with probes only for gamma, such as Berthold LB123 D-H10

Significant muon contribution to dose is possible only around the beam-dump for E6 experimental area when high energy electrons will be produced. Due to pulsed field character, the muons are interacting all in the same time with the detectors and also the gamma produces by the same primary electrons. A detector able to measure separately only the muon dose is not possible. We proposed a stack detector composed of several plastic scintillators interlaced with thick lead layers such that to be able to extract the gamma contribution using a method based on simulations. A detailed R&D work is needed to size the detector and validate the proposed method.

We mentioned that passive detectors sensitive to beta, including OSL proposed for personnel and area dosimetry are also sensitive to muons. Some studies on TLD at CERN show good correspondence of measured dose with calculated muon dose [60].

4.1.3 Environmental Dosimetry

An environmental dosimetry system (using gamma detectors) is installed in yard of IFIN-HH. One similar system is proposed for ELI-NP to be located in-between Gamma and Experiment Building and Offices Building as shown in Figure 18. This system is equipped with plastic scintillator detectors. They are able to recording the equivalent dose for gamma radiations from environmental in the range 0.1 μSv/h- 10 Sv/h for the energy gamma radiation fields 20 keV - 3 MeV.

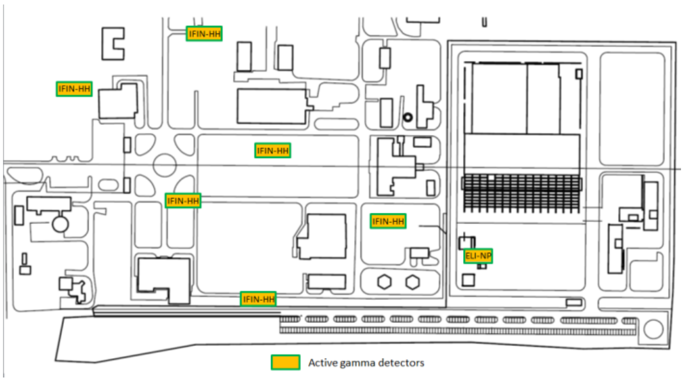


Fig. 18 - Distribution of active detectors within IFIN-HH and ELI-NP yard.

In other 10 measurement positions as shown Figure 19 will be installed the passive gamma and neutron detectors described in section 4.1.1. For the particular case of gaseous effluents, radioactivity measurement will be done as described in section 4.2.4.

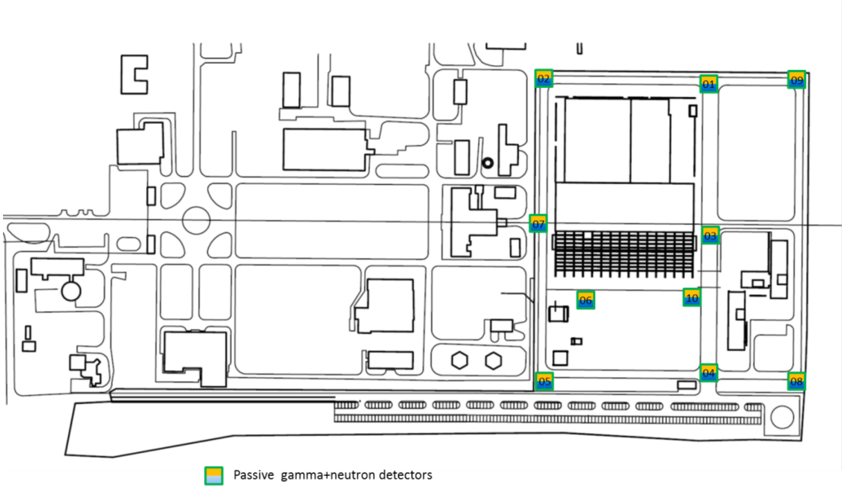


Fig. 19 - Distribution of passive detectors in ELI-NP yard.

4.2 Radioprotection activity measurements

4.2.1 Internal contamination

A whole body counter is already available within IFIN-HH for measurements of internal contamination.

4.2.2 External personnel contamination

A hand-feet counter for personnel will be located at the entrance in the Gamma and Experimental Building coming from Laboratory Building.

One contamination portal (both for personnel and object) will be installed at entrance in the Laboratory Building coming from outside. This will be the only access in the Special Buildings used currently. The other doors/entrances in the Special Buildings will have controlled access.

4.2.3 Area contamination

Area contamination (as well as equipment contamination) will be measured with dedicated probes attached to some of the portable dosimeter mentioned above in section 4.1.2. Probes for beta-gamma and beta-alpha will be available.

4.2.4 Radioactive gases and aerosol

A fixed gaseous monitor, such as Canberra OLM-H, will be installed at the exhaust of ELI-NP ventilation system on the pipe toward the evacuation tower.

The use of heavy ion gaseous targets and an aerosol He-jet transport system are foreseen in E1 interaction chamber. They will be operated only when high vacuum is achieved in E1 chamber and maintained by turbo-molecular pumps backed by a rough vacuum pump. In HPLS-TDR1 is proposed to install at the exit of the backing vacuum pump a radioactive gases cooling tank that can accumulate gases for some time before exhausting in the ventilation system. Turnkey systems are available, and IFIN-HH is running such system installed at the exit of the vacuum system of the radioisotope production cyclotron. The system is equipped with sensors in order to commute automatically the accumulation of the gases in the tank only when a given level of radioactivity is detected at exit of vacuum pump.

A portable monitor for gaseous radioactivity, such as Canberra PGM102, will used inside experimental areas as well as for outdoor measurement. Additionally, a tritium portable monitor, such as TAM73D from Canberra, can be added to be used in the same conditions.

4.3 Dosimetry Laboratory

Dosimetry Laboratory is located in the Workshops and Laboratories Building and has a surface of 93 m^2. The following activities are proposed for this Laboratory:

1. Processing and archiving data from passive detector for both the personnel and area
2. Processing and maintenance of the EPD to be used by personnel
3. Surveying and maintenance of active monitor systems
4. Storage and maintenance of the mobile and portable detectors for area monitoring
5. Storage and management of calibration sources used in experiments.

At least four persons (two safety officers and two technicians) are needed in the staff. The two safety officers will need Level 2 Permit from National Regulatory body.

The Staff of the Dosimetry Unit of ELI-NP will have offices in this Laboratory and will define and implement the Working Procedures specific to above listed activities as part of the QMS (Quality Management System) of ELI-NP. They will take in charge also the ELI-NP Programme for Effluent Discharges Monitoring and the Programme for Environment Radioactivity Monitoring around ELI-NP facilities established according to the Regulations.

The laser experiments TDRs have requested to perform in this Laboratory additional processing of other types of passive detectors: radio chromic films, Image Plates, bubbles detectors. Therefore some space has been allocated for such activities in the Laboratory.

A sketch of the layout of the Dosimetry Laboratory is shown below.

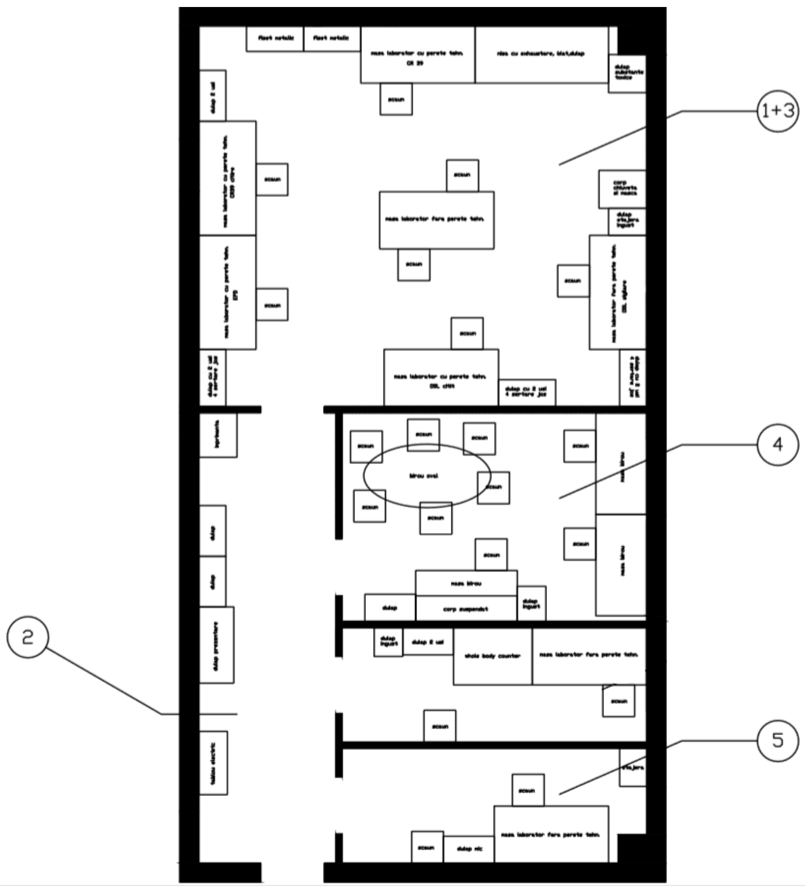


Fig. 20 - The Dosimetry Laboratory of ELI-NP.

5. CONCLUSIONS

The ELI-NP facility will host high power laser systems which will provide intensities reaching 10^{22} – 10^{23} Wcm^{-2} to be achieved for the first time. The main purpose is to use this capability to investigate new physical phenomena at the interfaces of plasma, nuclear and particle physics at ELI-NP. Also, in ELI-NP will be created a unique high brilliance, low divergence, monoenergetic gamma beam source based on the Inverse Compton Scattering of laser light on relativistic electron bunches provided by a warm RF LINAC, aiming to open new dimensions in basic and applied nuclear physics research and material sciences applications.

This document assesses from the radiological protection perspective the experimental conditions proposed to be developed in ELI-NP facility using HPLS, GBS and combined experiments between the two installations. It is considered a reference paper for the radiation safety system to be implemented at ELI-NP and also for the licensing process needed in order to ensure and prove a safe operational regime.

All the radiological protection assessments performed and presented in this paper indicate the compliance of the calculated dose values with the criteria outlined in 2.1 for the ELI-NP project. The locally peak doses that are not falling within the dose constrains are proven to be manageable. Additional work is being performed in order to define the safety procedures for operation of the ELI-NP installations and experiments.

REFERENCES

1. Personal communication from Richard Haley (*Nuclear Technologies*) to Iani-Octavian Mitu.
2. L. C. MacFarlane *et al.*, ELINP-R&D01-I6 (Issue 6), April 2015
3. EuroGammaS report for ELI-NP GBS
4. Adolfo Esposito *et al.*, WP10_23-2-2015
5. S. Wilson *et al.*, ELINP-R&D02-I7 Issue 7, June 2015
6. David Hulse *et al.*, ELINP-R&D05-I2 Issue 2, April 2015
7. Michael Jordan Mead, Report prepared for ELI-NP
8. L. C. MacFarlane *et al.*, ELINP-R&D03-I2 Issue 2, June 2015
9. Dan V. Vamanu *et al.*, IFIN-HH Dept. of Life and Environmental Physics, DFVM, December, 2015
10. L. MacFarlane *et al.*, ELINP-R&D04-I1 Issue 1, April 2015
11. NSR-01, www.cncan.ro
12. Legea 111/1996
13. M.O. nr. 404/2000
14. M.O. nr. 769/2002
15. Norme de securitate radiologica privind radioprotectia operationala a lucratorilor externi, Noiembrie 2001
16. Norme de securitate radiologica privind proceduri de autorizare, Noiembrie 2001

17. Norme fundamentale de transport in siguranta a materialelor radioactive, Februarie 2002
18. Norme de dezafectare a obiectivelor si instalatiilor nucleare, Decembrie 2002
19. Norme de protectie fizica in domeniul nuclear, Noiembrie 2001
20. Norme de control de garantii in domeniul nuclear, Noiembrie 2001
21. Monitorul Oficial al Romaniei, Partea I, nr.936 bis, 20.12.2002
22. Ordinul CNCAN 40/90
23. HG 635/1990
24. M.O. nr. 393/2004
25. Norme de acordare si utilizare a echipamentului individual de protectie la radiatii ionizante, Noiembrie 2005
26. Norme privind sursele orfane si controlul surselor inchise de mare activitate, Decembrie 2005
27. Norme privind monitorizarea emisiilor radioactive de la instalatiile nucleare si radiologice, Septembrie 2005
28. Norme privind monitorizarea radioactivitatii mediului in vecinatatea unei instalatii nucleare sau radiologice, Septembrie 2005
29. Norme privind cerintele de planificare si pregatire a titularului de autorizatie pentru interventia la urgente nucleare sau radiologice, Aprilie 2014
30. IAEA Safety Series nr. 115, Vienna 1996; Part 3, July 2014
31. ICRU S1, 1993
32. ICRU 35, 1982
33. NCRP 65, 1980
34. Safety Reports Series No. 2, IAEA, Vienna, 1998
35. Fundamental Safety Principles No. SF-1, November 2006
36. The Management System for Facilities and Activities Safety Requirements, part I, nr. GS-R-3, July 2006
37. The Management System for Technical Services in Radiation Safety Guide, No. GS-G-3.2, March 2011
38. Criteria for use Response for a Nuclear or Radiological Emergency General Safety Guide, No. GSG-2, March 2011
39. Occupational Radiation Protection Safety Guide, No. RS-6-1.2, November 1999
40. Storage of Radioactive Waste Safety Guide, No. WS-G-6.1, November 2006
41. LA-UR-00-2584/2001
42. Dosimetry and shielding for Roentgen and gamma radiation, Ed. Academiei Romane, Bucuresti
43. Compendium of neutron spectra and detector responses for radiation protection purposes IAEA, Vienna, 2001
44. Monitoring Program for Unrestricted Release Related to Decommissioning of Nuclear Facilities, IAEA, 1992
45. Safety Standards series No. RS-G-1.7, IAEA 2004
46. Office of Environment, Health and Safety, University of California, Berkeley
47. Portland State University – Radiation Safety Guide
48. ICRP- No. 60/1990
49. Hasky, R. *et al.*, W.C.F. “Laboratory Safety Manual” - Sydney 1992
50. 2005 Recommendation of the International Commission on Radiological Protection – ICRP Draft Publication, 2004
51. Martin, A. *et al.*, “An Introduction to Radiation Protection”, London 1996
52. Wiley, J., “Atoms, Radiation and Radiation Protection”, New York 1993
53. Wrixon, A.D. *et al.*, “Radiation, people and the environment”, Vienna 2004
54. Autorisation Phase Safety Report, NT/722500939/R988, Issue 3
55. V.M. Trbojevic, Risk criteria in EU, Risk Support Limited, London, UK, January 2005
56. Anton A. Frederickson, The Layer of Protection Analysis (LOPA) method, April 2002
57. HAZOP, http://www.graphicproducts.com/articles/what-is-hazop.php#ixzz3FBddRsSV
58. Authorization Phase Safety report, NT/722500939/R988, Issue 3

59. Preliminary Bulk Shielding Analysis for the ELI-NP Facility, NT/722500895/R956, Issue 1
60. Shielding Assessment of Penetrations in the Bulk Shielding of the ELI Nuclear Physics Facility, NT/722500939/R1002
61. M. Hofert, Rad. Prot. Dosimetry, vol. 20, no. 3, pp 149-154 (1987)
62. Adolfo Esposito, GBS-2015-03-31-DLV-DL00082-Rev0.1-INFN-LNF