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NEW RADIATION PROTECTION CALIBRATION FACILITY AT CERN

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The CERN radiation protection group has designed a new state-of-the-art calibration laboratory to replace the present facility, which is >20 y old. The new laboratory, presently under construction, will be equipped with neutron and gamma sources, as well as an X-ray generator and a beta irradiator. The present work describes the project to design the facility, including the facility placement criteria, the 'point-zero' measurements and the shielding study performed via FLUKA Monte Carlo simulations.

INTRODUCTION

The CERN Radiation Protection (RP) group is in charge of the RP calibration laboratory. In 2010 the RP group was tasked to consider the technical constraints for the replacement of the current ageing facility, its proximity to office spaces and site boundaries, changes to CERN's infrastructure and space management. From these considerations a consolidation plan was approved for the renewal of this facility[(1)].

PLACEMENT CRITERIA AND BACKGROUND MEASUREMENTS

To choose the best location for such a facility various criteria were taken into account. According to CERN's agreements with the host states, the ambient dose rate provided by CERN's activities outside its borders must be <300 μSv y^{-1}. Therefore, placing the facility sufficiently far away from the borders contributes to respecting this limit. Another criterion to be considered is the laboratory size to minimise neutron scattering inside the irradiation room. ISO 8529-2[(2)] recommends that the room should be such that scatter contributions are as low as possible, but in any case they should not cause an increase in instrument reading of >40 % at the calibration point. The minimum size varies with the detector and the irradiation source; for instance, if one considers a small Bonner sphere (5.08 cm) irradiated by an Am–Be source (source-to-detector distance equal to 75 cm), the side length of the room should be 8.2 m. Moreover, a calibration facility has to be located in a place not being influenced by other radiation sources, e.g. particle accelerators (see next section). According to the above-mentioned requirements a suitable location was chosen on the CERN Prévessin site, sufficiently far away from the fence and from other CERN buildings.

Background measurements: set-up and results

The laboratory location is close to the extraction line of the 400 GeV c^{-1} Super Proton Synchrotron (SPS) and its experimental areas. Since the main secondary radiation at hadron accelerators is the neutron field generated by the interaction of the beam particles with the accelerator components[(3)], neutron background measurements were performed in order to assess the influence that the SPS extraction line would have on the calibration complex. The measurements were performed with a WENDI-2 neutron remcounter[(4)] under the following beam conditions:

(1) SPS extracting 400 GeV c^{-1} protons into a target cave (t_{meas}~40 h).
(2) SPS accelerating lead ions with momentum <100 GeV c^{-1} nucleon^{-1} ($t_{meas}\sim 16$ h).
(3) SPS beam off to assess the influence of the natural background ($t_{meas}\sim 14$ h).

The data from the WENDI-2 were analysed off-line and correlated with the SPS beam intensity. The uncertainty was calculated as the statistical uncertainty of the integrated counts and the WENDI-2 calibration uncertainty (8 % systematic error). The average count value over the beam period was multiplied by the counts-to-dose calibration factor. Finally, the average dose rate and the associated standard deviation were calculated. The results are the following:

(1) Neutron $H^*(10)$ during the proton beam period: (15.9 ± 1.7) nSv h^{-1}.
(2) Neutron $H^*(10)$ during the lead ion beam period: (15.6 ± 1.8) nSv h^{-1}.
(3) Neutron background $H^*(10)$: (14.5 ± 1.7) nSv h^{-1}.

It is evident that there is no noticeable influence from neutrons originating from the accelerator or the experimental areas at the planned location of the calibration facility. These measurements will also be useful in the future to evaluate any possible influence of the facility operation on the natural background.

BUILDING DESIGN

The facility will consist of three irradiation rooms, storage and control rooms, offices and two technical rooms (Figure 1). Irradiation room 1 will house a 10 TBq ^{60}Co source to perform radiation damage studies on electronic components. The room shielding design was optimised as discussed in the study below. This had the goal of achieving the RP requirements explained in the next section. Irradiation room 2 has a surface area of 3.35 m × 4.95 m. This room does not have any particular shielding requirements. The room will be dedicated to the dosemeter calibration with a dedicated self-shielded irradiator. The calibration hall is the main part of the facility. It is a 13 × 13 × 13 m^3 concrete vault, half of which will be underground to take advantage of the natural shielding provided by the earth. It will be fitted with a neutron panoramic irradiator placed in the geometrical centre of the room at the ground level. From their garage position on the bottom of the vault, the neutron sources (^{238}Pu–Be, ^{241}Am–Be and ^{252}Cf) will be raised to the irradiation position at the floor level via an air-compressed system along a pipe of 7 m long. The floor will be made of a metallic grid to minimise neutron scattering. The neutron irradiator will be placed at the centre of two benches 6 m long, one of which will be shared with the photon irradiator. The latter will have a 30° irradiation angle and house the following gamma sources of different activities:

(1) ^{137}Cs: 873 GBq, 75 GBq, 10 GBq, 1 GBq, 153 MBq, 25 MBq, 249 kBq and 23 kBq.
(2) ^{60}Co: 4 GBq, 9 MBq, 7 kBq and 2 kBq.
(3) ^{241}Am: 176.90 GBq, 494 MBq, 359 MBq, 783 Bq, 91 Bq, 18 Bq.

The main advantage of this neutron and photon irradiator configuration is that it will allow performing simultaneous gamma/neutron measurements to test, e.g. the sensitivity of neutron survey meters to gamma radiation, as mixed fields are very common at CERN. The calibration hall will also house an X-ray generator with a 4 m long bench for X-ray calibrations. The X-ray tube will operate at 320 kV with a tungsten anode. The facility will also be equipped with a beta irradiator. All irradiators and the alignment system will be remotely controlled from the control room.

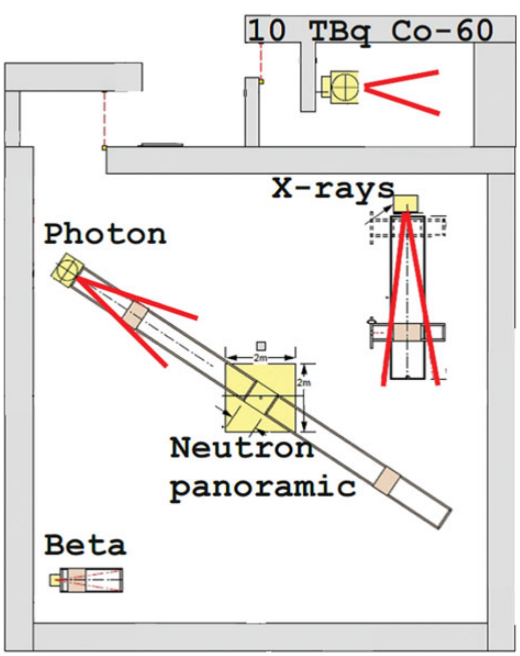

Figure 1. Top view of the calibration hall with the four irradiators and of irradiation room 1 with the photon irradiator.

SHIELDING STUDIES

The shielding studies were carried out for the calibration hall and irradiation room 1 via both Monte Carlo simulations with the FLUKA code[5, 6] and analytical calculations with the RadPro calculator software (www.radprocalculator.com/Gamma.aspx). The shielding requirements were established according to CERN's RP regulations on the following area classifications (see Table 1):

(1) Non-designated areas: offices, the control room, the two technical rooms and the area outside the facility.
(2) Supervised areas: the storage area.
(3) Prohibited areas: the calibration hall, irradiation rooms 1 and 2.

Shielding study for the calibration hall

The design was optimised by shielding studies in order to fulfil both civil engineering and RP requirements. Different building options were considered and compared. In this section the shielding study for the final geometry will be illustrated.

To define the shielding requirements of the facility, the sources providing the highest dose rates were considered. Among the neutrons sources the 1.85 TBq ^{238}Pu–Be (activity in 1973) was considered to be the largest contributor. Among the gamma sources the highest dose rate will be generated by the 872.73 GBq ^{137}Cs source (activity in 2012). The calculations performed for these two sources are conservative

Table 1. CERN area classification scheme.

Area	Dose limit (y)	Ambient dose equivalent rate limit	
		Permanent occupancy ($8\ h\ d^{-1}$)	Low occupancy ($<1.6\ h\ week^{-1}$)
Non-designated	1 mSv	0.5 $\mu Sv\ h^{-1}$	2.5 $\mu Sv\ h^{-1}$
Supervised	6 mSv	3 $\mu Sv\ h^{-1}$	15 $\mu Sv\ h^{-1}$
Simple	20 mSv	10 $\mu Sv\ h^{-1}$	50 $\mu Sv\ h^{-1}$
Limited stay	20 mSv		2 $mSv\ h^{-1}$
High radiation	20 mSv		100 $mSv\ h^{-1}$
Prohibited	20 mSv		$>$100 $mSv\ h^{-1}$

estimates for the other sources of lower activities, as well for the X-rays that will be generated by the X-ray irradiator.

FLUKA simulations and results

The geometry considered in the simulations (Figure 1) reproduced a concrete hollow cube $13\times13\times13\ m^3$, half of which lies underground. The simulated soil composition and density were chosen to be similar to the soil in Prévessin[7]. The room entrance is a maze closed by a 5 cm thick polyethylene shielded door. The hall walls and roof are made of 80 cm thick and 40 cm thick concrete, respectively. Due to fire protection requirements there is a 2 m^2 aperture on the roof. This aperture is mandatory in order to provide smoke extraction in the case of fire, but it represents a neutron escape path. To minimise the dose rate generated by this aperture, it was decided to place a 2 m^2 polyethylene slab of 5 cm thickness above it to attenuate the resulting ambient dose equivalent rate. The neutron spectrum of the 1.85 TBq ^{238}Pu–Be (neutron emission rate of $1.46{\cdot}10^8$ neutrons s^{-1}) source was reproduced in FLUKA with a dedicated source routine. The source was placed close to the centre of the room in the future irradiation position. The facility was located inside an air sphere sufficiently large to reproduce the skyshine effect (20 km in diameter). In the DEFAULTS card, option PRECISIOn[6] was chosen as default. This sets the transport of neutrons down to thermal energies and the tracking of electromagnetic particles down to 33 keV for photons and 100 keV for electrons and positrons. Scoring of the ambient dose equivalent rate was performed with the card USRBIN every 20 cm in a cube of $20\ m\times20\ m\times20\ m$ volume around the facility.

Figures 2 and 3 show that the ambient dose equivalent rate generated by the Pu–Be source around the calibration hall is everywhere $<0.2\ \mu Sv\ h^{-1}$; this value is fully compliant with the CERN RP

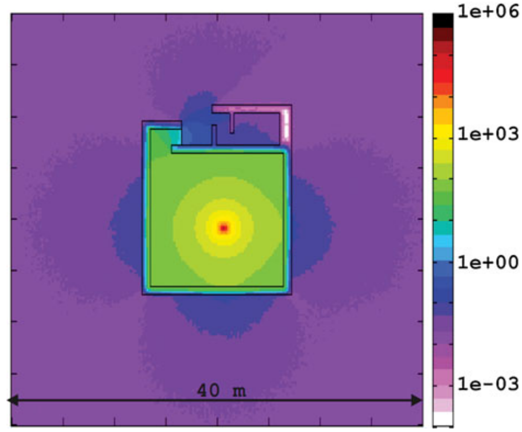

Figure 2. Top view of geometry showing the ambient dose equivalent rate caused by the Pu–Be source operation. The plane is cutting at the source level. The legend scale is in $\mu Sv\ h^{-1}$. For clarity in the black and white version only the dose rates between 0.001 and 2.5 $\mu Sv\ h^{-1}$ are shown.

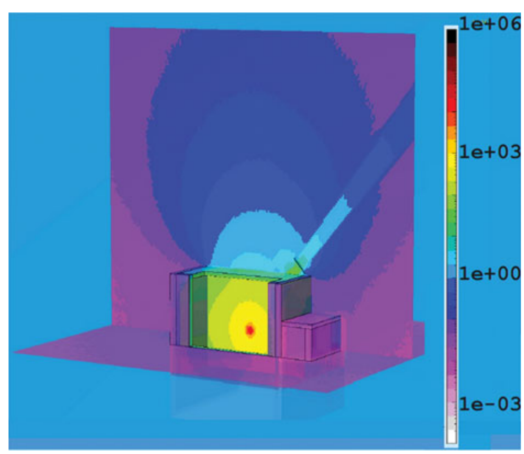

Figure 3. Side-view of the geometry showing the ambient dose equivalent rate cause by the Pu–Be source operation. The plane is cutting at the source level. The legend scale is in $\mu Sv\ h^{-1}$. For clarity in the black and white version only the dose rates between 0.001 and 11 $\mu Sv\ h^{-1}$ are shown.

requirement for non-designated areas. The ambient dose equivalent rate in the storage area stays between 0.02 and 2.5 $\mu Sv\ h^{-1}$, which is the lowest limit for a supervised area. On the roof the dose rate reaches a maximum value of 6 $\mu Sv\ h^{-1}$. For general safety and RP reasons the roof will be fenced and accessible only under special conditions. It should be mentioned that the shielding would allow hosting a Pu–Be source twice as intense.

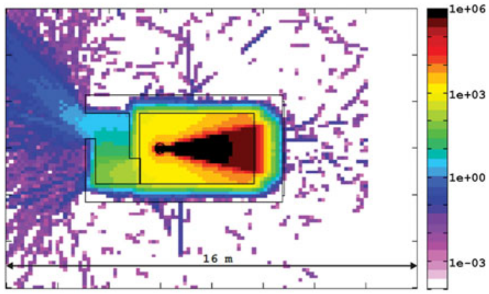

Figure 4. Top view of the geometry showing the ambient dose rate cause by the Co-60 source operation. The plane is cutting at the source level. The legend scale is in μSv h^{-1}. For clarity in the black and white version only the dose rates between 0.001 and 2.5 μSv h^{-1} are shown.

RadPro calculations

To calculate the ambient dose equivalent rate outside the facility during irradiations with the ^{137}Cs source, a dose rate calculation was carried out with the RadPro code. The following source parameters were defined: source ^{137}Cs; activity: 872.73 GBq; source-to-detector distance: 10 m (conservative); shielding material and thickness: concrete with a thickness of 80 cm.

The dose rate obtained outside an 80 cm concrete shield at a 10 m distance was equal to 7 nSv h^{-1}. If one compares this value to a mean value of 80 nSv h^{-1} of the natural background, one can conclude that the dose rate coming from the ^{137}Cs source is negligible.

Shielding study for irradiation room 1

The design of irradiation room 1 was also optimised via shielding studies in order to optimise the available volume for radiation tests and fulfil at the same time both civil engineering and RP requirements. This room presents especially important constraints from the RP point of view because of the high activity of the ^{60}Co source.

FLUKA simulations and results

The geometry considered in the simulation reproduced the irradiation room with dimensions of $3\times4.65\times3$ m^3. The room entrance is a maze closed by iron shielding door of 2 cm thickness. The maze walls are of 40 cm thickness, the side walls are made of concrete of 80 cm thickness and the wall in front of the irradiator is composed of two layers: 110 cm concrete and 10 cm stainless steel; the roof is made of concrete of 40 cm thickness. The 10 TBq ^{60}Co source was placed inside the dedicated lead irradiator, based on manufacturer drawings, in the future irradiation position. The FLUKA parameters were the same as in the previous section. Scoring of the ambient dose equivalent rate was performed with the card USRBIN in a 13 m $\times$ 14 m $\times$ 7 m volume mesh around the facility. Figure 4 shows that the ambient dose equivalent rate around irradiation room 1 is $<10^{-4}$ μSv h^{-1}; this value complies with the CERN RP requirements for non-designated areas. The dose rate just beside the maze entrance, i.e. in the storage area, stays between 0.02 and 2.5 μSv h^{-1}, which is the lowest limit applicable to a supervised radiation area at CERN. On the roof the dose rate reaches the maximum value of 0.5 μSv h^{-1}. For general safety and RP reasons the roof will be fenced and accessible only under special conditions.

CONCLUSIONS

This paper describes the project, the shielding study and the background measurements performed for the new CERN RP calibration facility. The neutron measurements show that the chosen location is well suited for the laboratory. The shielding study and the design met the RP area classification requirements as well as the calibration needs. The neutron and gamma irradiator configuration will also allow the gamma sensitivity of neutron survey meters to be tested in a mixed field.

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