The
CERN
Neutrino Beam
to Gran Sasso
Project

Calculation of Intervention Doses for the CNGS Facility

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Abstract

The purpose of the CNGS (CERN Neutrinos to Gran Sasso) project is to generate at CERN a powerful artificial muon-neutrino beam aimed at the Gran Sasso Laboratory in Italy. There, detectors will detect those neutrinos and try to disentangle those, which on their 730 km trip have changed their flavour. During the operating lifetime of the neutrino beam facility some interventions are required. These maintenance operations have to be planned in advance to define the guidelines of design and operational procedures in order to keep the doses received by personnel As Low As Reasonably Achievable (ALARA-principle). A calculational method developed for the Monte Carlo simulation program FLUKA has been used, which allows one to compute dose equivalent rates from induced radioactivity for different cooling times in the regions of the human intervention. In this paper the method of calculation is described, the results of dose equivalent rate in the areas of interventions are summarized and discussed and finally, these results are applied to estimate doses received by personnel during interventions.

1. Introduction

The proton beam of 400 GeV/c ejected from the SPS (Super Proton Synchrotron) is transported in a transfer line TT41 through 73 dipole and 28 quadrupole magnets to the CNGS target T40 [1,2]. The target consists of 13 graphite rods. Among many other particles, positive pions and kaons are produced in the target as a consequence of the proton collisions. They are focused into a parallel beam by a system of two pulsed magnetic lenses, called horn and reflector (Fig. 1). A 1-km-long evacuated decay pipe allows the pions and kaons to decay into their daughter particles, particularly into muon-neutrinos and muons. The remaining hadrons (protons, pions and kaons) are absorbed in an iron beam dump with a graphite core. The muons are monitored in two sets of detectors downstream of the dump. Further downstream, the muons are absorbed in the rock while the neutrinos continue their travel towards Gran Sasso.

Fig. 1 Schematic layout of the CNGS elements at the CERN site

In Gran Sasso two big neutrino detectors, ICARUS and OPERA, are being built to detect the neutrinos interactions and possible pinpoint those due to ν_τ produced as a result of oscillations of neutrino of type ν_μ , which can only occur if the neutrinos possess a mass.

2. Replacing the Horn

In the CNGS facility one of the most critical interventions in a high-radioactive environment is the replacement of the horn. A schematic view of the

horn, stripline, “Fast Coupling System” (FCS) and shielding is shown in Fig. 2. The horn is installed approximately 1 meter downstream of the target and is fully shielded with (from inside to outside) a 30 cm shield of marble, a 20 cm shield of iron and finally a 30 cm shield of concrete (above the horn, there is a roof shielding made of iron).

Changing the horn consists of a number of steps, some of which are planned to be performed by a human intervention rather than a robot. In order to replace the horn, a crane is used to lift it. Prior to that, the horn has to be released manually from the stripline part 1. The stripline connects the horn to the pulse transformer located in the service gallery (gallery located parallel to the aisle see Fig. 3) and consists of several sections of parallel plates, in general of aluminum. In order to disconnect the horn, five bolts have to be unscrewed in the FCS, an operation that is estimated to take 4 minutes (see [3] for a more detailed description).

Fig. 2 Horizontal longitudinal schematic view of the FCS region

The FCS is a special segment built of copper. This segment allows to disconnect/connect quickly the horn and the striplines. Afterwards the link section located in the trench (passage located below the collimator) has to be removed. This operation is expected to take 14 minutes. Finally, the stripline 1 can be moved downstream 150 mm, which takes approximately 3 minutes.

Once the horn is released from the electrical connections, the crane is used first to remove the roof shielding, part of the left lateral shielding and then the horn itself. Afterwards the horn is transported

with a trailer up to the storage chamber. A spare horn is carried with the trailer down to the horn area and the same operations as before are repeated but in inverse order.

3. Calculational Method

Primary and secondary particles activate the materials of the surrounding regions producing residual nuclei and then these nuclei decay during the irradiation plus cooling time. To simulate this a two-step approach has been used and linked to FLUKA [7,8] by means of user routines (see [4,5,6] for a more detailed description of the method and benchmarks). First, the FLUKA input for the first step is read and parameters concerning the magnetic field, the regions involved in the activation calculation and the cooling times are stored. In this step the magnetic field in the horn is activated (this is not the case in the second step). Residual nuclei are obtained as a result of hadronic inelastic collisions during the FLUKA Monte Carlo simulation. The FLUKA subroutine USRSUW_EVO [6] calculates the decay (β^+ , β^- and γ decay) of each radioactive residual nucleus into the next generations during the irradiation and cooling time selected by the user. As a first approximation for the isomer production equal sharing is assumed among all states. The radioactive (β^+ , β^- and γ emitters) isotopes are stored (together with their mass, charge, position, activity and weight) in an external file and the FLUKA output is generated, including some parameters for the second step.

In the second step from each of the isotopes obtained before, photons, positrons and electrons generated during the radioactive decay at a certain cooling time are sampled. It is assumed that particles are emitted isotropically and their energy and energy spectra are obtained from a database [9,10]. This information is used by FLUKA for the simulation of the electromagnetic cascade induced by these particles. Finally, the values of fluence obtained by FLUKA are converted in values of Dose Equivalent Rate (DER) at any point of interest and for each cooling time. The ICRP74 and Pelliccioni data [11] are used to perform this conversion.

4. Results of Accumulated Doses

For the calculations an irradiation time of 200 days of operation per year and a proton intensity of 8.0×10^{12} protons per second have been considered. To obtain similar statistics for both small and large regions in the contribution to the total DER the above-mentioned method has been applied separately to 10 different parts of the geometry (e.g. concrete of the target chamber, horn shielding etc.). Fig. 3 and 4 represent the sum of these ten different contributions to the total DER for two different cooling times. Results are represented in a horizontal section at the level of the beam line. The interventions will take place in three locations; two are situated in the aisle (locations 1 and 2 in Fig. 3) near the FCS and one in the trench (location 3).

Fig. 3 Values of DER after a cooling time of 1 day

Fig. 4 Values of DER after a cooling time of 1 month

For these locations the values of DER in mSv/h are shown in Table 1 (see also [13,14]). Large variations of DER around the region of the intervention are observed for cooling times up to one week but for longer cooling times the variations are small.

Cooling time	D.E.R. in 1	D.E.R. in 2	D.E.R. in 3
1 day	2.44996E+01	9.44221E+01	9.69182E+01
1 week	7.65812E-01	2.88675E+00	3.54678E+00
1 month	5.76408E-01	1.87096E+00	2.22899E+00
2 months	5.09522E-01	1.57431E+00	1.84111E+00
4 months	4.43196E-01	1.18112E+00	1.37052E+00
6 months	3.97334E-01	1.02066E+00	1.16386E+00

Table 1 DER in mSv/h for the locations in Fig. 3

Different shielding materials and configurations for the shielding in front of the FCS (Fig. 2) have been studied with FLUKA [13]. A 50% reduction of the DER near the FCS after 1-month cooling time was obtained for a sandwich-shielding configuration in comparison with a no-shielded configuration. It was also recommended to shield the opening for the electrical connections in the horn shielding as much as possible [13] to reduce the radiation levels in the aisle.

The accumulated doses (for the duration of each operation) for each of the human interventions necessary to replace the horn are shown in Table 2. Interventions performed before a cooling time of 1 day reach prohibitive values of accumulated dose.

Intervention Step	Location	Duration (min)	Accumulated dose (μ Sv)			
			1day	1week	1month	2months
Install lights	2	1.	1573	48	31	26
Open fast coupling connection	3	4.	6461	236	148	122
Remove stripline link section in trench	1	14.	5716	178	134	118
Slide stripline downstream	1	3.	1224	38	28	25
Slide stripline upstream	1	6.	2449	76	57	50
Close fast coupling connection	3	6.	9691	354	222	184
Take dimensions of new stripline link section	1	2.	816	25	19	16
Install stripline link section in trench	1	20.	8166	255	192	169
Remove lights	2	1.	1573	48	31	26
Total			37700	1260	870	740

Table 2 Values of accumulated doses (μ Sv) for the interventions to replace the horn

This estimation of accumulated doses in the areas of the intervention allows one to adopt the design accordingly, to establish the necessary measures of

radioprotection for the personnel performing the interventions and also helps to decide the timing for these operations in accordance with the radioprotection regulations.

5. Radioprotection Constraints

The DER received during any consecutive 12-month period for professionally exposed workers must not exceed 20 mSv [15]. In addition, if during a one-month period a worker receives more than 2 mSv CERN has to report to the Swiss authorities and give detailed justification. These limits cannot be directly applied during the construction and interventions in the accelerator. Therefore a design criterion of 2 mSv per person and per intervention was introduced [16], that ensures that these limits will not be exceeded.

6. Conclusion

Considering the CERN design criterion of 2mSv per person and per intervention and the obtained results of accumulated doses (Table 2) as well as the fact that the individual and collective doses have to be kept As Low As Reasonable Achievable (ALARA), it has been concluded that the interventions to exchange the horn have to be performed after at least a cooling time of 1 month.

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