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THE PRODUCTION AND RELEASE OF RADIOACTIVITY IN THE AIR OF THE LOW-BETA REGIONS CLOSE TO LHC EXPERIMENTS

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Abstract

This report completes the estimation of the release of radioactivity in the air from the high-luminosity experimental caverns of the LHC by considering the production of radioactivity in the low-beta regions of the accelerator tunnel. Radionuclides are formed in the air by the cascades generated in the magnet string by high-energy, very forward secondaries produced in the p-p collisions. The FLUKA code was used to simulate the hadronic cascades initiated by the secondaries. 39 different radionuclides are considered; their production was estimated from the hadron track-lengths in the air. The release of the radionuclides has been estimated using a model which assumes the direct transfer of radioactivity from its point of creation to the release point. The effect of these releases has been evaluated by determining the off-site doses and dose rates due to the radioactive emissions calculated using the procedures described by the Swiss HSK.

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1. Introduction

This report completes the estimation of radioactivity in the air close to the high-luminosity experimental regions of the LHC [Huh96]. In that report no estimation was made of the radioactivity produced in the accelerator tunnel outside the experimental region by the cascades initiated in the low-beta magnet string by high-energy secondaries from the p-p collisions.

As in the previous study, 39 different radionuclides are considered here. [Huh96]. Radionuclide production has been estimated from the hadron track-lengths in the air and the consequence of the release of the radionuclides from the tunnel evaluated as in [Huh96] by determining the off-site doses and dose rates due to the radioactive emissions, calculated using the procedures described in a document issued by the Swiss HSK (Hauptabteilung für die Sicherheit der Kernanlagen) [HSK95].

2. The FLUKA Simulations

Description of the Geometry

The geometry of the low-beta region implemented in FLUKA for these calculations is shown in Figure 1. The walls and rock surrounding the tunnel were assumed to have the same composition – that of concrete having a density of 2.35 g / cm^3.

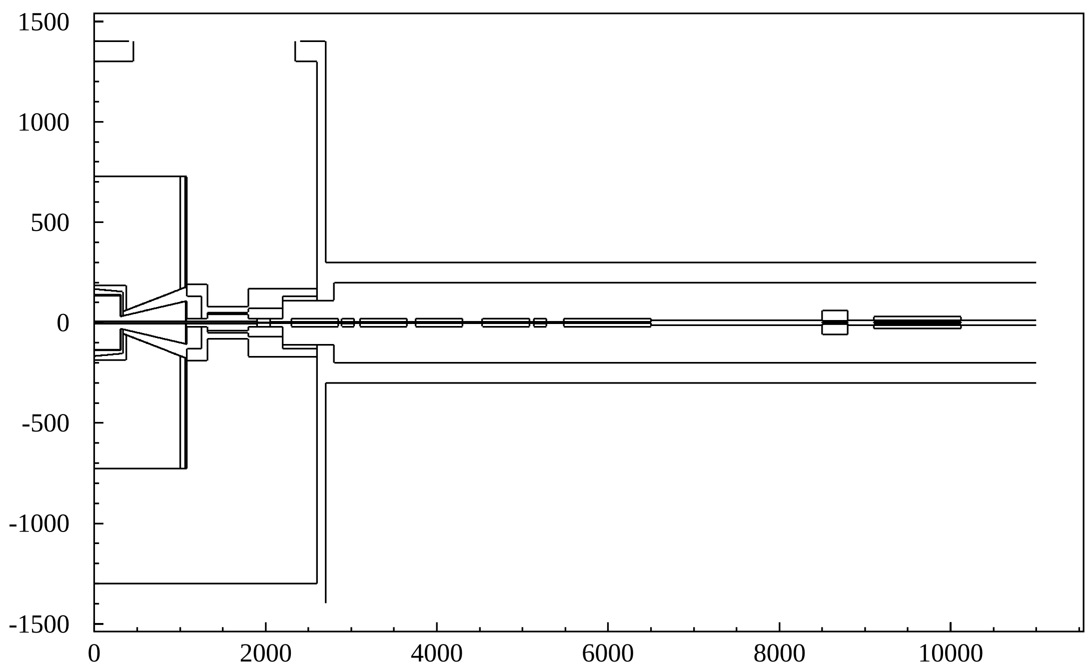

Figure 1: The geometry of a low-beta region used in the FLUKA simulations.

Simulations

Primary p-p events were generated with the DTUJET93 [Aur94] event generator which includes diffractive scattering. However the position of the secondaries in the file was randomized so that sequential interrogation of the file could take place from any starting point and always yield secondaries from "average" events. Secondaries were transported in the magnet system (with magnetic fields) using the FLUKA95 code [Fas93, Fas94]. Track-lengths of protons, charged pions and neutrons as a function of energy were scored in the air volume of the low-beta region. The simulation method was adopted from [Huh95], *i.e.* the source was divided into very-forward ($\theta > 732\mu$rad) and "central" contributions. Eight runs, each treating 5000 "central" tracks and another eight treating 500 forward tracks were performed.

The calculations were performed using the geometry for the CMS detector, but since the low-β regions for ATLAS and CMS are almost identical, the results obtained in the present calculations should be applicable to both experiments

3. Determination of track-lengths

In these simulations track-length was scored on a region basis using a logarithmic energy binning with ten bins per decade. The upper energy limit for scoring was taken to be 10 TeV. The lower limit for charged hadrons was 10 MeV. Low-energy neutrons were scored in the 72-group structure of FLUKA. Since the upper bound of the low-energy neutron group structure is 19.6 MeV, 57 logarithmic bins will have a factor width of 1.2593, which is close to $10^{0.1}$ = 1.2589. By default FLUKA normalizes track-lengths by assuming that all regions have a volume of 1 cm^3.

4. The production and release of radionuclides

The 39 radionuclides of interest in this study are listed in Table 1 together with their half-lives taken from [ICRP83]. The track-lengths determined using the FLUKA simulations were multiplied by the energy-dependent cross-sections for the production of these radionuclides used in [Huh96]. The radionuclide production per p-p collision in one of the two low-beta regions associated with an experiment is given in column 3 of Table 1.

The half-lives of the isotopes considered are all greater than about 30 seconds. Since the air passing through the tunnel will take of the order of 100 seconds to pass through the low-beta region, the simplest assumption for these radionuclides is that there will be no decay during the time of irradiation. Also, since the air will only take about 30 seconds after irradiation before it is vented to the atmosphere, one obtains a realistic upper estimate of the release by assuming that there is no decay after irradiation. Höfert *et al.* suggested that an average inelastic p-p collision rate of 10^9 s^{-1} over 24 hours should be taken for assessing environmental effects of the LHC experiments. For 180 days of p-p operation of the LHC this leads to a total of 1.6×10^{16} inelastic interactions per year. Thus in order to obtain the time variation of the collision rate in an experiment, values determined using Equation (1) have been scaled by the factor of $10^9 / 7.5 \times 10^8$ = 1.33.

The calculated annual release of radioactivity from one of the low-beta regions close to the high-luminosity ATLAS or CMS experiments is given in column 4 of Table 1. These releases from

Table 1: Production and release of radionuclides from one low-beta region

Radionuclide	Half-life	Production (nuclei per p-p collision)	Annual Release (Bq)
^{3}H	12.35 y	1.16×10^{-1}	3.31×10^{6}
^{7}Be	53.3 d	3.13×10^{-2}	7.55×10^{7}
^{10}Be	1.60×10^{6} y	5.33×10^{-2}	1.17×10^{1}
^{11}C	20.38 m	6.69×10^{-2}	6.06×10^{11}
^{14}C	5730.0 y	1.51×10^{2}	9.24×10^{6}
^{13}N	9.965 m	1.12×10^{-1}	2.07×10^{12}
^{14}O	71.0 s	3.94×10^{-3}	6.15×10^{11}
^{15}O	122.24 s	6.13×10^{-2}	5.57×10^{12}
^{19}O	27.1 s	2.62×10^{-6}	1.07×10^{9}
^{18}F	109.77 m	6.00×10^{-5}	1.01×10^{8}
^{23}Ne	28.0 s	6.64×10^{-6}	2.63×10^{9}
^{24}Ne	3.38 m	1.38×10^{-6}	7.57×10^{7}
^{22}Na	2.602 y	2.36×10^{-5}	3.19×10^{3}
^{24}Na	15.0 h	3.53×10^{-5}	7.25×10^{6}
^{25}Na	60.0 s	1.24×10^{-5}	2.28×10^{9}
^{27}Mg	9.5 m	1.74×10^{-5}	3.39×10^{8}
^{28}Mg	20.91 h	7.84×10^{-6}	1.16×10^{6}
^{26}Al	7.16×10^{5} y	3.40×10^{-5}	1.67×10^{-2}
^{28}Al	2.24 m	1.01×10^{-4}	8.30×10^{9}
^{29}Al	6.6 m	3.94×10^{-5}	1.10×10^{9}
^{31}Si	157.3 m	6.55×10^{-5}	7.70×10^{7}
^{32}Si	450.0 y	4.05×10^{-5}	3.16×10^{1}
^{30}P	2.499 m	2.84×10^{-5}	2.10×10^{9}
^{32}P	14.29 d	3.61×10^{-4}	3.24×10^{6}
^{33}P	25.4 d	6.34×10^{-4}	3.20×10^{6}
^{35}P	47.4 s	5.59×10^{-5}	1.31×10^{10}
^{35}S	87.44 d	6.93×10^{-4}	1.02×10^{6}
^{37}S	5.06 m	2.30×10^{-4}	8.41×10^{9}
^{38}S	2.87 h	1.28×10^{-4}	1.38×10^{8}
^{34m}Cl	32.0 m	1.86×10^{-5}	1.08×10^{8}
^{36}Cl	3.01×10^{5} y	1.79×10^{-3}	2.09×10^{0}
^{38}Cl	37.21 m	1.48×10^{-3}	7.35×10^{9}
^{39}Cl	55.6 m	2.42×10^{-3}	8.05×10^{9}
^{40}Cl	1.4 m	4.30×10^{-4}	5.67×10^{10}
^{37}Ar	35.02 d	9.96×10^{-3}	3.65×10^{7}
^{39}Ar	269.0 y	1.01×10^{-2}	1.33×10^{4}
^{41}Ar	1.827 h	3.33×10^{-1}	5.62×10^{11}
^{38}K	7.636 m	1.10×10^{-5}	2.66×10^{8}
^{40}K	1.28×10^{9} y	5.35×10^{-5}	1.47×10^{-5}

the caverns are compared with the present CERN Release Constraints in Table 2 where it will be seen that the relases for most of the categories of radionuclides are well below the CERN Constraints. However the release for the short-lived isotopes from one low-beta region could approach 10% of the appropriate Constraint value.

Table 2: Annual release of radioactivity in the air from one Low-Beta Region (Bq)

Nuclide	CERN Constraint (Bq)	Annual Release Zero delay (Bq)
^{3}H	4×10^{12}	3.31×10^{6}
^{7}Be	4×10^{11}	7.55×10^{7}
All β/γ with $T_{1/2} < 1$ day	1.2×10^{14}	9.54×10^{12}
Other β/γ with $T_{1/2} > 1$ day	4×10^{10}	5.32×10^{7}

5. Off-site doses and dose rates

The off-site doses and dose rates resulting from the releases were calculated using the procedures described in a draft document issued by the Swiss HSK [HSK95] as adapted for the CERN site [Mor96].

The annual dose rate was calculated using the annual releases of Table 1 and the yearly distribution of wind speeds and directions. The total dose due to releases from a single cycle were also calculated but using adverse atmospheric conditions as in [Huh96]. The centre line doses and dose rates in the most likely wind direction summed over all radionuclides are shown as a function of distance in Figures 2 and 3. The doses are also shown for decay times of 25 seconds and 20 minutes between production and release. As is to be expected, the shorter decay time gives little or no reduction in dose; the 20 minute decay time is completely unrealistic given the closeness of the production to the release point. Thus these doses provide realistic upper bounds to the doses from the release of radioactive air from a low-beta region.

Figures 4 and 5 show the sum of the doses for two low-beta regions and the CMS experimental cavern, the latter taken from [Huh96]. It can be seen that for distances greater than 100 m the average total annual dose rate never exceeds 5 μSv per year. The dose from a single fill cycle never exceeds 1 μSv.

6. Conclusions

The present calculations of the production and release of radionuclides via the air of the low-beta regions close to high-luminosity experiments have shown that the activities released from one region in one year are less than 10% of the current CERN Release Constraints.

The maximum annual dose from such releases has been estimated and shown that the total average annual dose rate from two low-beta regions together with the release from an experimental cavern never exceeds 5 μSv per year for distance greater than 100 m. This is still less than the 20 μSv per year CERN norm for exposure of members of the population to radioactive air coming from CERN's installations.

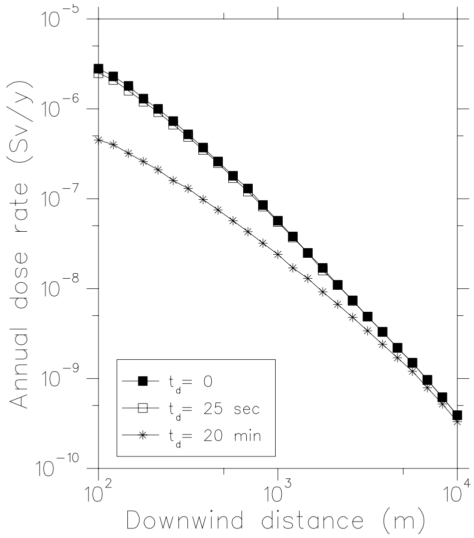

Figure 2: Annual dose rate from chronic releases in Sv / y for one low-beta region.

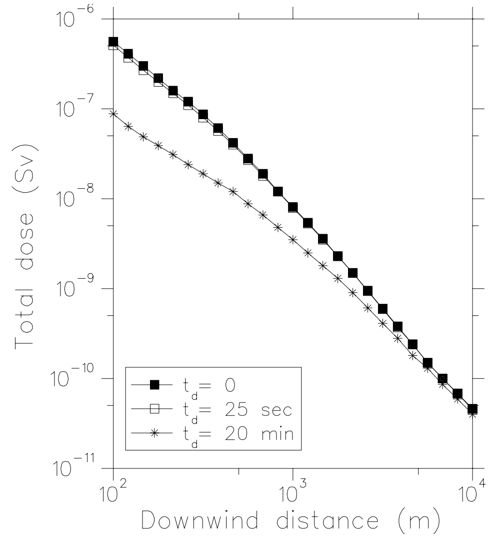

Figure 3: Total dose for release from one cycle in Sv for one low-beta region.

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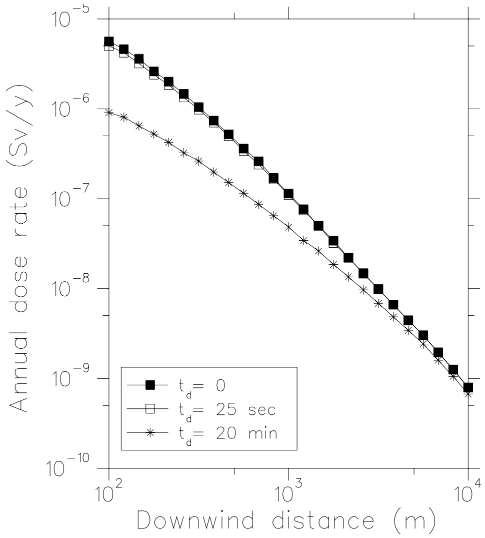

Figure 4: Annual dose rate from chronic releases in Sv / y for two low-beta regions plus an experimental cavern.

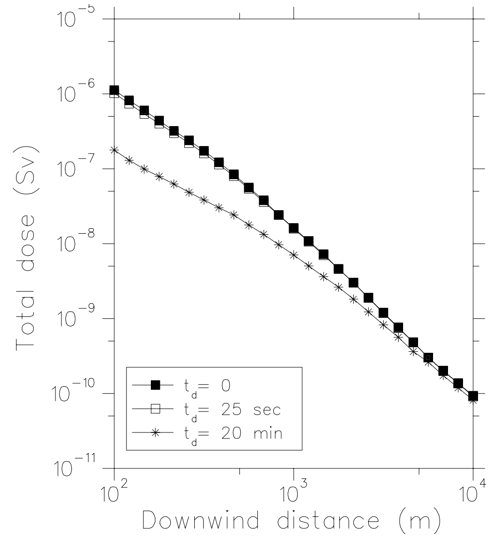

Figure 5: Total dose for release from one cycle in Sv for two low-beta regions plus an experimental cavern.

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