INDUCED ACTIVATION IN THE FUTURE CHARGE-EXCHANGE INJECTION SYSTEM OF THE PS BOOSTER

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ABSTRACT

CERN's Linac2 currently injects protons with a kinetic energy of 50 MeV into the PS Booster (PSB). Linac2 will be replaced by Linac4 which will inject H^- ions with a kinetic energy of 160 MeV into the PSB. In order to enable the PSB for charge-exchange injection, it will be equipped with a new injection system.

The proposed charge-exchange injection system will use carbon foils (one for each of the four PSB rings) to remove the electrons from the H^- ions. The remaining protons will then be merged with the already circulating proton beam. Two percent of the injected beam are expected to be either incompletely stripped or unstripped, and will be sent to 4 internal H^0/H^- injection dumps (one per PSB ring).

This paper focuses on the induced activation in the future injection region. The radiological impact of proposed material choices for the internal dumps has been assessed by establishing Work and Dose Plannings for the most important foreseen interventions. The expected ambient dose equivalent rates at the various work locations have been obtained by FLUKA Monte Carlo simulations.

In addition, the activation of the carbon foils and the derived need of protection measures during foil exchanges are discussed.

KEYWORDS
Activation, Residual Radiation

1. INTRODUCTION

The CERN Linac2 currently injects protons with a kinetic energy of 50 MeV into the PS Booster (PSB). After its connection to the PSB, the future Linac4 will inject H^- ions with a kinetic energy of 160 MeV into the PSB. Therefore a new injection system for the PSB will be installed for its connection to Linac4.

The proposed charge-exchange injection system will use carbon foils to remove the electrons from the H^- ions, thereby activating the foils themselves, and the remaining protons will be merged with the already circulating proton beam. Since the stripping efficiency of this setup is assumed to be 98%, approximately 2% of the beam from Linac4 will not be usable for the PSB. This fraction of the beam will be sent to 4 internal dumps (one per PSB ring), denoted H^0/H^- dumps or *injection dumps*.

The material choice for these 4 injection dumps has evolved over the past years. This paper compares the radiological impact of Silicon Carbide (SiC) and Titanium as material for the injection dumps to the limits and objectives defined by the CERN Radiation Protection group. SiC had been selected as baseline material in the past mainly because of its low influence on the magnetic field if placed inside a magnet and because of its moderate activation properties. However, it has been discovered that SiC might suffer from serious swelling problems due to radiation. This would drastically shorten the expected life-time and therefore increase the number of replacement interventions and the corresponding effective dose to intervening personnel. As an alternative, Titanium has been proposed as dump material. These 4 injection dumps will be located inside the beam vacuum in the vicinity of the BSW 4 injection magnet.

2. FUTURE CHARGE-EXCHANGE INJECTION SYSTEM

A 3D model of the future injection region is shown in Fig. 1. The injection magnets (BSW1-4) for the 4 rings are located between the 2 green dipole magnets. The BSW4 magnets containing the injection dumps are placed at the leftmost locations.

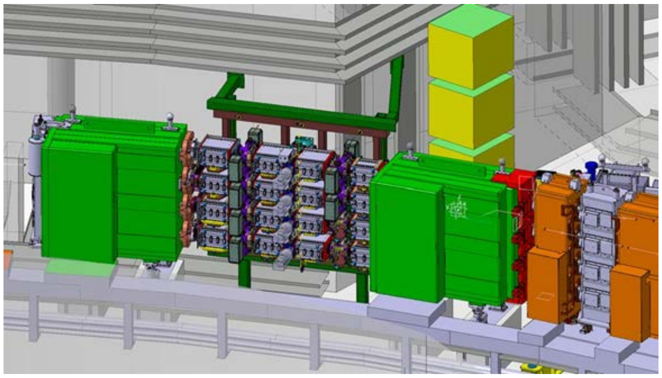

Figure 1. 3D model of the future injection region.

3. ACTIVATION OF THE INJECTION SYSTEM DUE TO THE INTERNAL BEAM DUMPS

3.1. Methodology

The following methodology has been used to compare the SiC and Titanium options and to assess the viability of the Titanium option in terms of its radiological impact:

1. FLUKA simulations [1,2] of the future injection area have been performed to estimate the residual radiation levels for SiC and Titanium as dump material.
2. Work and Dose plannings (WDP) for all important intervention scenarios have been constructed. They have been used together with the residual radiation levels to assess the following radiological quantities:
    a. Collective effective dose per intervention
    b. Maximum individual effective dose per intervention
    c. Collective annual effective dose
    d. Maximum individual annual effective dose
3. These effective dose estimates have been compared to the goal of maximum 2 mSv individual annual dose, the design constraint of maximum 2 mSv individual dose per intervention and the goal of not significantly deteriorating the long term collective annual dose for the PSB related interventions.

The current radiological situation of the PSB and especially the injection region can be summarized as follows: The surveys during technical stops show ambient dose equivalent rates above 1-2 mSv/h in the injection region. The collective annual effective doses of all interventions in the PSB have been between 6 mSv and 13 mSv in the past years.

3.2. Setup and Simulation Parameters

A sufficiently detailed geometry of all 4 rings of the PSB including the injection dumps has been constructed for the FLUKA simulations. The geometry has been based on 3D-models and drawings obtained from the CERN design office.

The kinetic energy of the protons impinging on the dump is 160 MeV and the annual number of protons is $5.78\text{x}10^{18}$ per injection dump corresponding to a stripping efficiency of 98%. The FLUKA simulations for the residual ambient dose equivalent rates have been performed for 8 operational years of 300 days each followed by various cool-down times.

3.3. Work and Dose Planning of Interventions

For all the important intervention scenarios, a Work and Dose Planning (WDP) has been established by a common effort of all the various equipment groups involved. In total, 10 intervention scenarios have been identified and they have been investigated for cooling-times of 8 hours, 12 hours, 1 day and 7 days respectively. The planning of these 10 intervention scenarios has led to the definition of 15 locations where personnel will work. These locations are shown in Fig. 2. The assumed annual recurrences of the various intervention scenarios are given in Tab. 1. The reduced expected life-time of the SiC dumps due to radiation induced swelling is reflected in the much higher annual recurrence for the replacement of the BSW4 magnet compared to the Titanium option.

Table I. Annual recurrences of the interventions.

Scenario	Annual recurrence	
	SiC	Titanium
Replacement of BSW4 magnet	2.7	0.5
Replacement of BSW2-BSW3 magnet	1	1
Replacement of BSW1 magnet	1	1
Replacement of stripping foils without foil loader replacement	4	4
Replacement of stripping foils with foil loader replacement	1	1
Replacement of BTV motor	2	2
Replacement of BTV screen	2	2
Replacement of Camera	3.3	3.3
Replacement of Lights	3.3	3.3
Replacement of Filter wheel	1	1

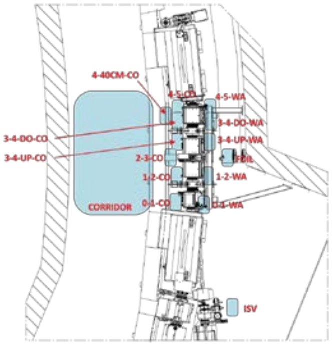

Figure 2. Work locations used for the Work and Dose plannings.

Each intervention has been subdivided into the various tasks that need to be performed. The number of persons and expected time for each task has been attributed to the specific location for the given task. Together with the ambient dose equivalent rates at a given cooling-time, the ambient dose equivalent for each intervention has been calculated by summation over all the involved tasks.

3.4. Residual Radiation

The residual ambient dose equivalent rates for SiC (left) and Titanium (right) after 8 years of operation followed by a cool-down time of 8 hours are shown in Fig.3 as an example. From these data, the residual ambient dose equivalent rates for the 15 work locations have been extracted. The residual ambient dose equivalent rates are typically a factor 2-3 higher for Titanium than for SiC for the most important locations close to the injection dumps.

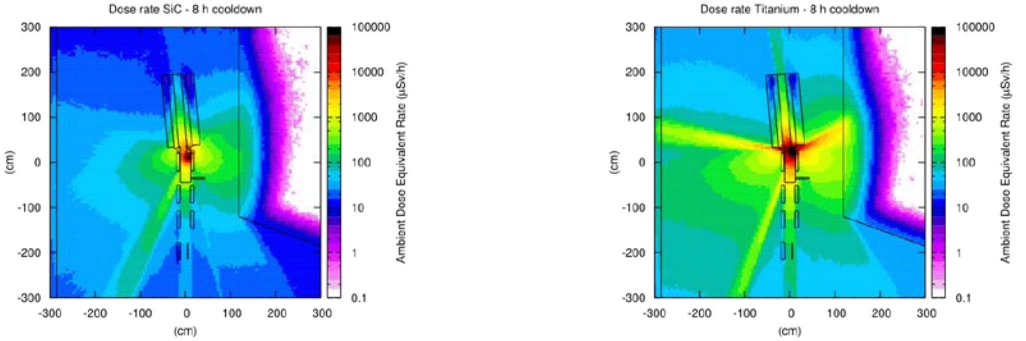

Figure 3. Residual ambient dose equivalent rates for SiC (left) and Titanium (right) after a cool-down time of 8 hours.

3.5. Dose Estimates

The collective ambient doses equivalents per occurrence for the various cool-down times are shown in Fig. 4. The highest collective dose per occurrence is 2.22 mSv for the *Replacement of BSW4 magnet* scenario with Titanium as dump material and a cool-down time of 8 hours. This is below the collective ambient dose equivalent for similar interventions in the last years in the injection area. The maximum individual ambient dose equivalent for the *Replacement of BSW4 magnet* scenario is 570µSv, i.e. well below the design constraint of maximal 2 mSv individual dose per intervention.

Applying the annual recurrences of the interventions as defined in Tab. 1 yields the average annual collective dose that are shown in Fig. 5 (left). Because the annual recurrence for the *Replacement of BSW4 magnet* for Titanium is 0.5, i.e. below 1, the annual collective dose with the annual recurrence for the *Replacement of BSW4 magnet* for Titanium set to 1 instead of 0.5, i.e. for a year when the intervention is actually performed, is shown in Fig. 5 (right). The annual recurrence for the *Replacement of BSW4 magnet* for SiC has also been set to 3 instead of 2.7. This quantity is denoted by *annual collective dose with unit minimal occurrence*.

The estimated annual collective doses are in the range of 2-5 mSv, with comparable average annual collective doses for SiC and Titanium. These values are also lower than the collective annual effective doses of all interventions in the PSB in the last years. As a consequence, both SiC and Titanium are acceptable material choices for the injection dumps with respect to their radiological impact.

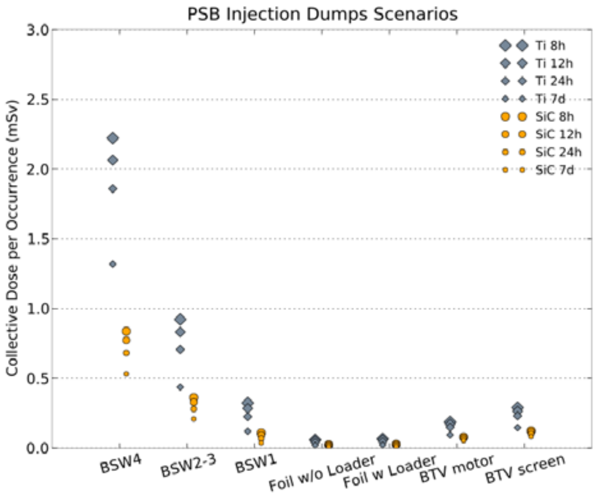

Figure 4. Collective dose per occurrence.

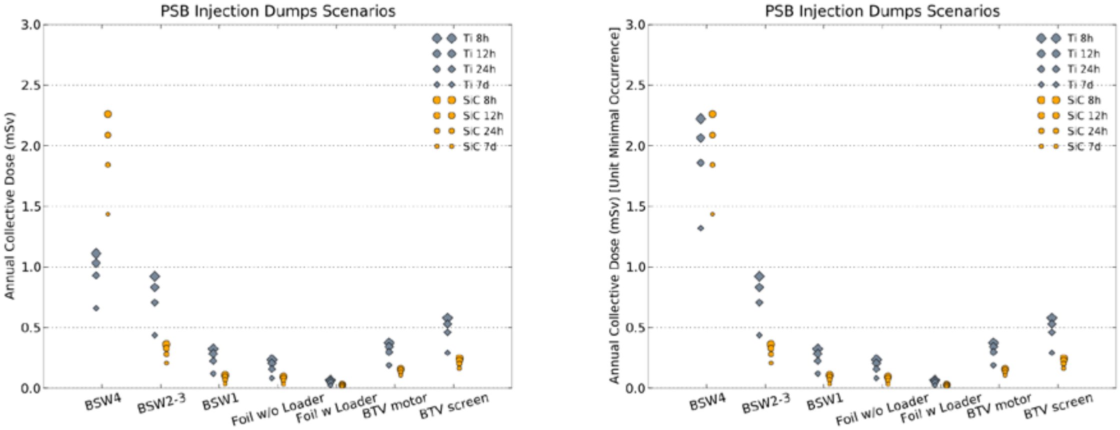

Figure 5. Average annual collective dose (left) and annual collective dose with unit minimal occurrence (right) for various cool-down times.

4. ACTIVATION OF THE STRIPPING FOILS

The injected H^- ions and the already circulating proton beam will activate the 250 µg/cm^2 thick carbon stripping foils. For the most pessimistic case, continuous operation at maximum Linac4 intensity for 300 days is assumed, i.e. 10^{14} H^- per pulse at 1.11 Hz together for the 4 PSB rings. This yields an average beam intensity of 2.75×10^{13} H^-/s/ring. Furthermore it has been assumed that each injected proton passes 62.5 times on average through the stripping foil during the injection phase. The kinetic energy is assumed to be 160 MeV during the whole injection phase.

The minimum required waiting time before any access to the PSB tunnel is 30 minutes, i.e. the duration of the air flush. Therefore the foil activities are computed for a cool-down time of 30 minutes and are presented in Tab. 2 for the various radionuclides. The production cross sections of the radionuclides for protons at 160 MeV on Carbon have been taken from the TENDL 2010 library [3]. The committed effective doses due to accidental inhalation or ingestion of a foil have been computed by applying the inhalation and ingestion dose conversion coefficients (DCC) from the Swiss Radiation Protection Ordonnance [4]. The contribution from ^3H can be considered to be negligible due to its relative long half-life and the diffusion from the foil into the vacuum.

The estimate for the committed effective dose due to inhalation is 25 mSv and for the committed effective dose due to ingestion it is 17 mSv. These values are well above the limits for radiation workers as well as above the design limit of 2 mSv maximum individual dose per intervention. Therefore protective measures are required to prevent the accidental intake of a foil by the intervening personnel.

Table II. Stripping foil activation at the start of the access and resulting committed effective doses due to accidental inhalation or ingestion.

Radionuclide	**Half-life**	**DCC**		**Activity**	**Comm. Eff. Dose**	
		Inhalation	**Ingestion**	**at access**	**Inhalation**	**Ingestion**
		Sv/Bq	**Sv/Bq**	**Bq**	**Sv**	**Sv**
Be-7	53.22d	4.6e-11	2.8e-11	5.48e+08	0.0252	0.0154
Be-10	1.6e6y	1.9e-08	1.1e-09	8.05	1.53e-07	8.85e-09
C-11	20.37m	3.2e-12	2.4e-11	4.93e+07	0.000158	0.00118
N-13	9.967m	3.2e-12	2.4e-11	2.93e+04	9.38e-08	7.04e-07
Total					0.0254	0.0165

5. CONCLUSIONS

The proposed charge-exchange injection system for the PSB will use carbon foils with a stripping efficiency of 98% to remove the electrons from the H^- ions. Approximately 2% of the beam from Linac4 will not be usable for the PSB and will be sent to 4 internal injection dumps (one per PSB ring).

The radiological impacts of Silicon Carbide and Titanium as material for the injection dumps have been compared to the limits and objectives defined by the CERN Radiation Protection group. Silicon Carbide and Titanium are both acceptable material choices for the injection dumps with respect to their radiological impact and Titanium has been selected as baseline material choice.

The committed effective dose due to accidental stripping foil intake has been estimated to be 25 mSv requiring protective measures to prevent an accidental intake of a foil by the intervening personnel.

ACKNOWLEDGMENTS

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