RADIATION PROTECTION ISSUES DURING THE TI8 AND SECTOR TESTS

H. Vincke, D. Forkel-Wirth, H. Menzel, CERN, Geneva, Switzerland

ABSTRACT

This paper discusses the radiation protection issues which will arise during the TI8 and the sector test. For both tests two main topics are discusses. The first point concentrates on assessments of the prompt radiation levels during the tests and the necessary access restrictions. The second point analyzes the consequences of the activation along the beam line and its surroundings which are caused by the beam losses at the beam line elements and the beam impact in the TED. For the sector test especially the impact for the LHCb area will be discussed in detail.

TI8 TESTS

Parameters used to estimate the radiological consequences of the tests

In the year 2006 two tests are scheduled. The planned intensities and the momentum of the beam used during the tests are listed in Table 1.

Table 1: Beam intensities and momentum of the two TI8 tests.

	Beam momentum	Total beam intensity of the test	Duration
Test 1 (low intensity)	450 GeV/c	6E13 protons	48 h
Test 2 (high intensity)	450 GeV/c	4E14 protons	48 h

During the test the intensity of the single shots will reach one third of the maximum intensity which will be reached during the LHC operation.

Figure 1 presents the simulation geometry of the TI8/LHC area as it was used in the calculations to asses the radiological consequences of the tests. Compared to the tests in 2004 the additional shielding which was located 2 meters downstream the TED and the 80 cm thick concrete shielding wall in UJ88 at the TI8 exit will not be installed anymore.

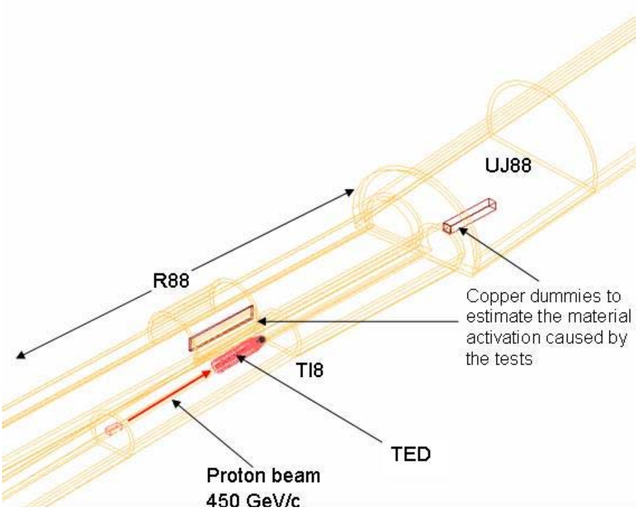

Figure 1: Beam line geometry used to simulate the TI8 tests.

Access restrictions during the test caused by dose rate levels due to prompt radiation

The access to areas where the accumulated dose integrated over the whole test period is higher than 3 uSv has to be blocked. 3 uSv is about one third of 10 uSv, which is considered as the so called “optimization limit”. If “non-radiation workers” in the LHC get a dose less than 10 uSv due to their work in the LHC per year, the working procedure is considered automatically as optimized. In 2006 three tests (two TI8 tests and one sector test) are planned to be carried out. The maximum possible dose per test is limited to 3 uSv. Therefore, non-radiation workers will not get a dose higher than 10 uSv by all tests performed.

Figure 2 presents the accumulated dose contributions caused by the various particle types produced by the beam impact in the TED beam stopper. These pictures present correctly only the forward cascade. Due to limited CPU time the parts of the cascade pointing towards Point 1 were suppressed during the simulation procedure in order to save CPU time.

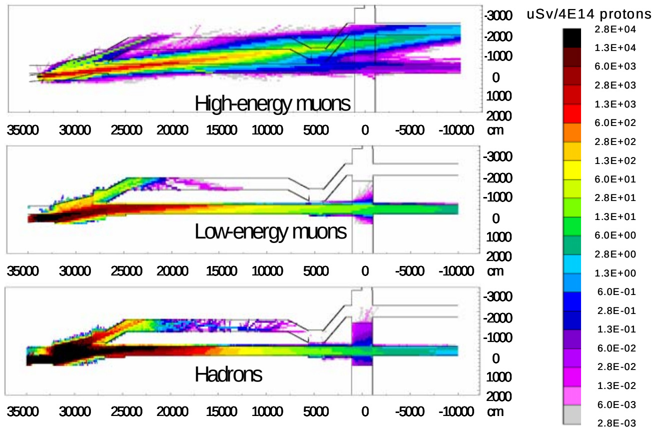

Figure 2: Contribution of the various particle components to the total dose accumulated during the high intensity TI8 test.

The consequence of the expected dose levels accumulated during the high intensity test on the access limitations is as follows:

- Access has to be denied 300 meters from Point 8 into the direction Point 7
- Access has to be denied several 100 meters from UJ88 in the direction to Point 1.
- Access in Point 8 has to be denied. One can only consider access to locations behind the shielding wall under the condition that the shielding wall is already fully installed and that the access to the other side of the wall is made impossible during beam operation periods (either access doors or blocking access by insuperable means like concrete blocks)

Figure 3 presents the access system applied to the area during the TI8 tests in 2004. These access restrictions will be appropriate to guarantee save operation during the TI8 tests in 2006.

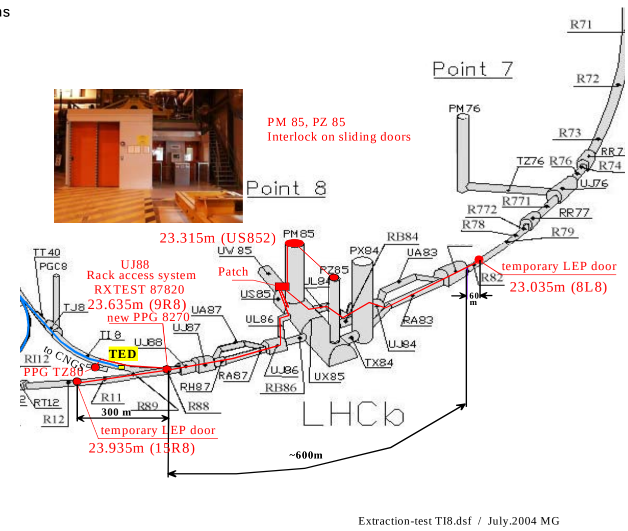

Figure 3: Access system used in 2004 during the TI8 tests[*]. The area where access is prohibited during the TI8 test is indicated by double-arrows and the position of the access doors are indicated by red circles.

Dose rate levels after the TI8 tests

In order to estimate the dose rate caused by material activation after the TI8 test, dedicated FLUKA simulations were performed. Although the duration of both tests will last 48 hours the beam impact time was shortened to 12 hours in the simulation. This approach considers the pessimistic case that the main intensity of the test has to be shifted towards the end of the scheduled beam time. For both tests five different cooling times were considered. The cooling times were as follows: 1 hour, 4 hours, 12 hours, 1 day and 1 week. Figure 4 shows the dose rate distribution in the area of TI8, R88 and UJ88 for four different cooling times. Due to CPU limitations only the activation contributions originating from the walls and the copper dummies in R88, UJ88 and locations downstream the TED in TI8 were considered in the simulations.

[*] Taken from talk given by M. Grill in the Safety Working group in 2004

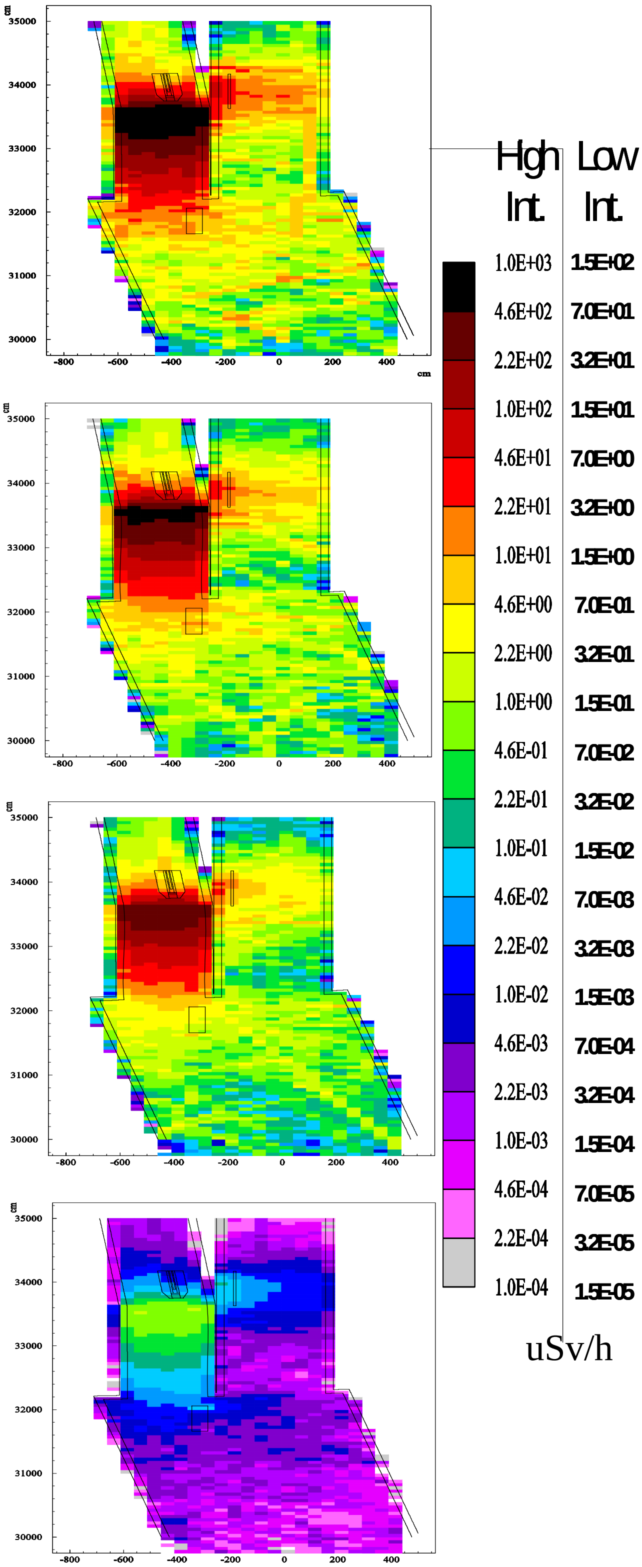

Figure 4: Dose rate (average over an height of 2 m) after an irradiation of 4E14 (high Int.) and 6E13 protons respectively calculated for cooling times of 1(first picture), 12, 24 hours and 1 week (last picture).

After 1 hour of cooling after the high intensity TI8 test, the dose rate in the tunnel R88 adjacent to the TED and at the exit of the TI8 tunnel can be found to be in the range of 50 uSv/h. The main contribution to the radiation originates from Na-24 which is produced in concrete. This isotope decays with a half life of 15 hours. Therefore, the maximum dose rates in these areas declines within one day to a level of about 20 uSv/h. Within a week the radiation is further reduced to a dose rate of 0.1 uSv/h.

Activation of the copper dummies

In order to give first estimates concerning the activity produced during the tests in the two copper dummies, the consequences of a singular impact of 4E14 protons on the TED were calculated for a cooling time of 1 hour. The main specific activity in the copper dummies originates from Cu-64, which has a half life of 12.7 hours. The average specific activity in the dummy in R88 is 7E5 Bq/kg and the average specific activity found in the first 10 cm of the copper dummy in UJ88 is 1.9E7 Bq/kg. These values are clearly above the Swiss Exemption Limit for specific activity. Beside this isotope also several long lived isotopes like Mn-54 and Co-60 will be produced in the copper dummies.

Activation of the TED cooling water

For the simulation the TED was assumed to be cooled with dematerialized water. The impact of the proton beam causes production of tritium and Be-7 in the water circuit. However, the total radioactivity production caused by the test is below the limit above which the water is considered as radioactive.

Consequences of the TI8 tests

Already after the first TI8 test the areas UJ88 and R88 have to be declared as radiation areas. During the first two days (low intensity test) and the first week (high intensity test) respectively the area will be defined as controlled area. The consequence of that will be the following:

- Access only with personal and active dosimeter
- Job and dose planning is required during this time
- Material which will be removed from the area has to be radiologically controlled

After this first period the area classification can be changed from "Controlled Area" into "Supervised Area". This lowers the restrictions such that neither active dosimeter nor a job and dose planning is required when entering these areas.

All calculations are based on the aforementioned conservative irradiation pattern during the test. In case the irradiation is equally distributed over the 48 hours which are foreseen for the test, the dose rate which will be seen at the first day of cooling will be significantly lower.

Radiation Monitors used during and after the TI8 tests

All access doors will be equipped with high-pressure ionization chambers (IG5) during the beam operation. These chambers will be in the interlock of the TI8 extraction. In case too high beam values will be measured during the operation the beam will be stopped.

During and after the TI8 test air ionization chambers (PMI) will be installed in the area of the TED, in R88 and in UJ88 close to highly activated locations in order to measure the dose rate caused by activation.

Along the whole TI8 beam line TL and High Level Dosimeters will be installed in order to measure the dose which is given to the material by the test operation.

SECTOR TEST

This chapter studies the radiological consequences of the Sector Test in which 3E13 protons with a momentum of 450 GeV/c will be sent over the injection tunnel TI8 into the LHC tunnel to the TED beam stopper located at the beginning of Point 7. The main intensity of the single shots will be 5E9 protons and the highest intensity will go up to 1E11 protons per shot. The maximum loss rate expected during the test will be in the range of 1 %. A more likely loss ratio will be 10^{-4}. For the sector test the same radiation assessment as for the TI8 test was performed. A prompt radiation levels during the test and the consequences originating from the activation were studied. Moreover, a closer look to the LHCb area in terms of possible activation of equipment was undertaken.

The radiological requirements of the tests are as follows: During the test the prompt radiation should be kept within the limits applied on areas which can be accessed by non radiation workers. The area between Point 8 and 7 should be reclassified after the test to a non-designated area. Moreover, no radiological consequences for the LHCb area should arise from the test.

In order to assess all consequences of the test FLUKA simulations were either performed or old calculation results were extrapolated by applying the new irradiation and geometry conditions.

Access restrictions during the test based on dose rate levels due to prompt radiation

The access to areas where the accumulated dose integrated over the whole test period is higher than 3 uSv has to be blocked. 3 uSv is about one third of 10 uSv, which is considered as the so called “optimization limit”. If “non-radiation workers” in the LHC get a dose less than 10 uSv due to their work in the LHC per year, the working procedure is considered automatically as optimized. In 2006 three tests (two TI8 tests and one sector test) are planned to be carried out. The maximum possible dose per test is limited to 3 uSv. Therefore, non-radiation workers will not get a dose higher than 10 uSv by all tests performed.

The consequence of this restriction in accumulated dose can be concluded in terms of access constraints as follows:

- Access has to be denied 1 km downstream the TED beam stopper (into direction Point 6)
- Access has to be denied several 100 meters from UJ88 in the direction to Point 1.
- Access in Point 8 has to be denied. One can only consider access to locations behind the shielding wall under the condition that the shielding wall is already fully installed and that the access to the other side of the wall is made impossible during beam operation periods (either access doors or blocking access by insuperable means like concrete blocks)

Dose rate levels after the Sector Test

After the Sector Test activation of the beam line elements and their surroundings will remain in the area. In the area of the TED the surrounding concrete walls, the beam line elements and the TED itself will contribute the most to the dose rate seen in the area. The dose rate seen after the test in the area will depend strongly on the irradiation pattern and on the cooling time after the irradiation.

After the test it is planned to remove the TED in order to reclassify the area to a non designated area. In order to estimate the radiation levels after the test and to estimate the earliest moment at which it is save to remove the TED without taking too much dose, FLUKA simulations according the following parameters were performed:

- The irradiation time was assumed to be 12 hours. Although the test itself will last 14 days, this conservative assumption takes into account that beam line related problems might occur at the beginning of the test resulting in a shift of the main beam intensities towards the end of the test period.
- The total intensity was assumed to be 3E13 protons.
- The dose rate after the test was calculated for cooling times of 1 day, 4.5 days and 1 week.

The simulation results are also supposed to predict whether it will be possible to reclassify the area after the test to a non designated area. Figure 5 presents the dose rate levels calculated for the aforementioned irradiation conditions for three different cooling times in the surroundings of the TED. For this calculation the tunnel geometry consisted only of the tunnel itself, the TED and an iron/concrete absorber located downstream the TED. For each cooling time the total dose rate and the dose rate originating from the concrete walls only are plotted.

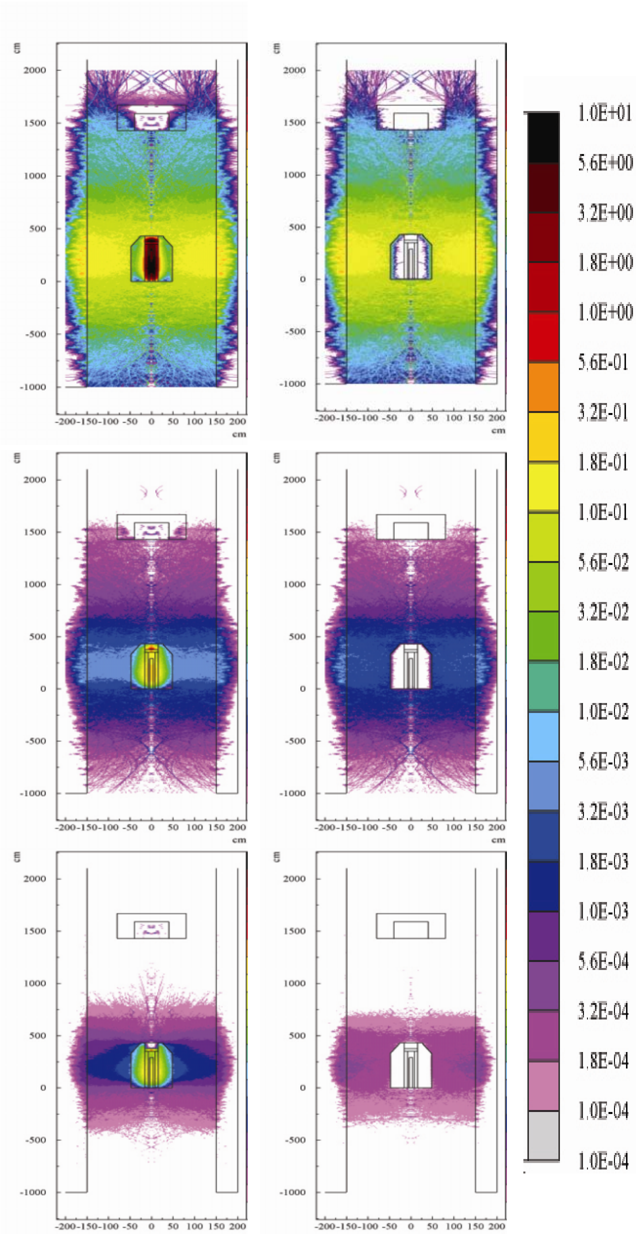

Figure 5: Dose rate after an irradiation of 3E13 protons on the TED and a cooling time of 1 day (upper picture), 4.5 days and 1 week (lower picture). The left column of pictures shows the total dose rate whereas the right column presents the dose rate contribution of the walls only.

The dose rate after one day of cooling can be found in the range of 180 uSv/h between the TED and the concrete walls. The main contribution comes from the concrete surrounding the TED. The radiation contribution of the TED to the total dose is minor at that time. The radiation during the first days after the beam was switched off is dominated by the decay of Na-24. This isotope has a half life of about 15 hours and occurs mainly in concrete. After a cooling time of 4.5 days a major part of the Na-24 isotopes are already decayed and the maximum total dose rate is reduced down to a level of about 6 uS/h. About one half of the total dose rate close to the TED originates now from the TED itself. At that dose rate in the area it will become possible to remove the TED from the beam line. After 7 days of cooling time the dose rate (3.2 uSv/h) originates mainly from the TED. The contribution from the wall is in the range of 0.3 uSv/h, which is only 10 % of the total dose rate.

Further precautions to keep radiation levels in the sector sufficiently low after the Sector test

Like during the TI8 injection test in 2004 a second absorber has to be installed downstream the TED in order to absorb high-energy particles leaving the TED. This installation will prevent an activation of downstream located elements. The dimensions of the iron core of the second absorber will be 80 cm x 80 cm x 160 cm (beam direction) which has to be surrounded by 80 cm of concrete in order to capture low energy neutrons leaving the inner absorber.

Moreover, no massive equipment should be present close to the TED in order to prevent activation.

The beam losses upstream the TED have to be kept at an absolute minimum. After the TI8 tests in 2004, which were carried out with similar intensities, several beam line elements upstream the TED showed elevated dose rates above 2.5 uSv/h. In case similar losses occur during the sector test there are two possibilities to reduce the dose rate in the area to a value below 2.5 uSv/h. The first possibility is to remove temporarily the element which shows the elevated dose rate. The second possibility can be found in a local shielding of the element.

Material removal from the area after the test

In order to allow the removal of equipment (material) from the area without being radiologically controlled, it has to be guaranteed that the area did not become radioactive by the test. One procedure to guarantee this condition can be found in distributing material samples at expected critical loss points. In case these samples do not show significant radioactivity, the rest of the area can be declared as conventional, meaning that material transport can be permitted without radiological control.

RADIOACTIVITY PRODUCTION IN THE AREA OF THE LHCB EXPERIMENT

Maximum dose rate close to the beam loss point after the sector test in the LHCb area

First assessments of the dose rate which will occur after the sector test close to the beam line were made. Baseline of this estimate was a studies of a beam loss in a collimator, which consists of a carbon, steel and copper. A picture of the collimator can be found in Figure 6. Detailed results of these studies can be found in [1]. The number of lost protons was assessed with 3E11, which correlates with the estimated maximum loss during the Sector Test. In order to be conservative the loss of these protons were assumed to occur all at the same moment.

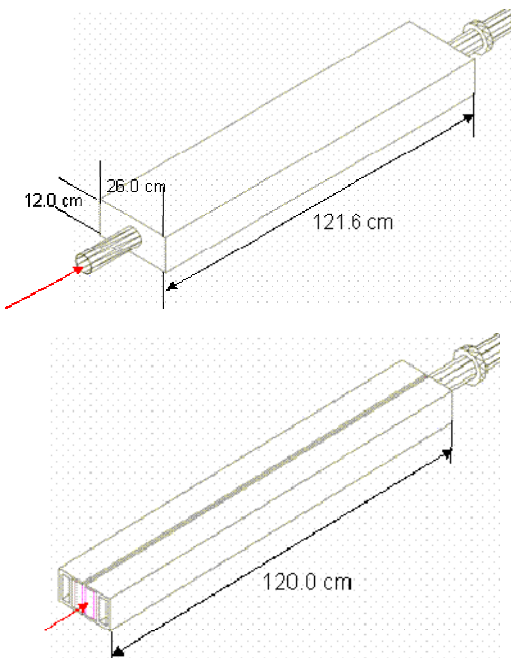

Figure 6: Outer and inner design of the collimator which was used to calculate the dose rate caused by an impact of 3E11 protons for various cooling times.

The beam momentum used for these calculations was 450 GeV/c, which is the same which will be used for the sector test. Figure 7 shows the calculated dose rates caused by material activation after the aforementioned beam impact conditions for five cooling times.

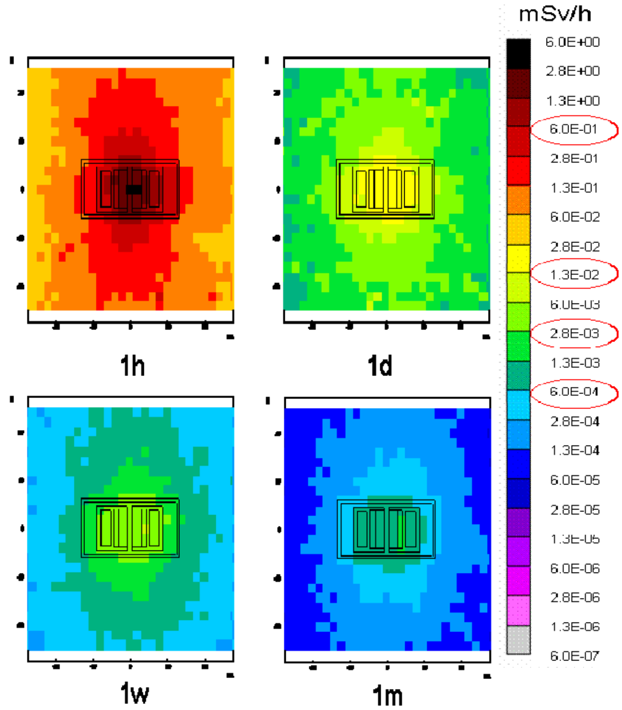

Figure 7: Dose rate after an impact of 3E13 protons calculated for cooling times of 1 hour (upper left), 1 day (upper right), 1 week (lower right) and 1 month.

After one hour of cooling the dose rate close to the equipment will rise up to a level of a maximum of 0.6 mSv/h. The dose rate after one day will have decreased already to a value of 13 uSv/h. The maximum dose rate levels after a cooling time of one week and one month respectively will be 2.8 uSv/h and 0.6 uSv/h. One has to note that the assumed scenario is a very conservative assumption of the reality. Firstly, the real loss will be very probably distributed equally over the whole test period of 14 days (instead of a singular loss). Moreover, also the loss rate of 1% is a conservative assumption compared to the more likely loss rate of 10^{-4}.

First assessment of the activation of LHCb detector elements

Due to missing information about the beam loss pattern and the materials present to the most likely beam loss points only first very rough estimates about the activation in the range of the LHCb area could be made. For this first estimate the specific activation caused by a proton beam with a momentum of 450 GeV/c and an intensity of 3E11 protons in a material cylinder was calculated. The first material chosen for the simulation was aluminium which is the main component of the LHCb velo. The cylinder had a radius of 3 cm and a length of 50 cm. Two different irradiation patterns and a cooling time of one day were chosen to calculate the consequences of such a beam loss. The first loss pattern is a singular loss of 3E11 protons in the cylinder whereas the second loss pattern assumes a continuous loss of 3E11 protons within 14 days. The main isotopes produced by the two loss scenarios are listed in Table 2.

Table 2: Specific activity caused by the loss of 3E11 protons in an aluminium cylinder (radius: 3 cm, length: 50 cm).

	Singular loss	Loss over 14 days	Half life
Isotope	Bq/kg	Bq/kg	
Na-24	1.01E+05	6.51E+03	15 h
Be-7	2.27E+03	2.09E+03	53 d
F-18	1.96E+02	1.55	110 m
Na-22	1.89E+02	1.88E+02	2.6 y

The Na-24 activation is above the limits below which a material is not considered as radioactive. In case such a loss occurs in aluminium, a cooling time of five days is required until the aluminium can be declared as non radioactive.

The same beam loss simulation was performed for a lead cylinder of 3 cm radius and 20 cm length. The first results showed that about 700 isotopes are produced in lead. Although there are currently no detailed results it can be already assumed that there is a strong risk to produce significant activation in case of a direct beam loss in lead.

Consequences for the LHCb area

The beam losses should be kept at an absolute minimum and all detector parts should be removed from the beam line as far as possible during the test. Before the area can be reclassified to a non designated area, thorough radiation measurements have to be performed. During the test various sets of material samples have to be distributed over the beam line close to the most probable beam loss points in order to allow a measurement of an upper value of possible material activation of the detector.

Radiation Monitors used during and after the Sector test

All access doors will be equipped with high-pressure ionization chambers (IG5) during the beam operation. These chambers will be in the interlock of the TI8 extraction. In case too high radiation values will be measured the test will be interrupted.

During and after the sector test air ionization chambers (PMI) will be installed in the area of the TED and other locations showing elevated activations in order to measure the dose rate caused by activation.

Along the whole LHC and TI8 beam line TLD and High Level dosimeters will be installed in order to measure the dose which is given to the material by the test operation.

CONCLUSION

TI8 Injection tests

After the first TI8 test the areas UJ88 and R88 have to be declared as radiation area. The first week after the high intensity test and after two days after the low intensity test the areas will be declared as Controlled Areas. During this initial period personal and active dosimeter and job and dose planning will be obligatory. After this first period the areas will be declared as Supervised Areas. From that moment onwards only personal dosimeters are obligatory in the areas. Materials which will be removed from the areas require a radiation control before being declassified.

Sector test

In order to prevent activation of the material, losses have to be strongly limited upstream the TED. In case some elements show after the test a dose rate above 2.5 uSv/h local shielding of this elements will be required. A second beam absorber has to be installed downstream the TED to prevent activation of the beam line elements located further downstream the TED. 4 - 5 days after the sector test the TED can be removed. Although there are good chances to reclassify the area to a non designated area one week after the test, radiation measurements have to be undertaken before the reclassification is carried out. In general material has to be controlled before it can be taken out of the area. However, by analyzing material samples placed close to the most probable loss points along the beam line, a reconsideration of that point might be taken into account.

REFERENCES

[1] Helmut Vincke, CERN-SC-2004-018-RP-TN: Remnant dose rates in the area of a TCDI collimator after 200 days of normal operation and after an accidental beam loss