PRACTICAL RADIATION-CONTROL AT KEK

Takenori Suzuki, Radiation Science Centre & J-PARC Project Division
High-energy Accelerator Research Organization (KEK),Tsukuba, Ibaraki, 305-0801, Japan

Abstract

At a high-energy proton accelerator facility, radioactivities are induced in the accelerator components due to the loss of primary beams; these radioactivities produce an area of high radiation. From experience at the 12-GeV proton accelerator of KEK, due to beam loss at the septum magnets, a high radiation level was observed. For hands-on maintenance, these magnets must be cooled down for a few weeks or months in order to reach the working exposure radiation level employed at KEK. The major exposure of radiation workers at a high-energy proton accelerator facility is due to maintenance work in the beam-line tunnel after the beam has stopped.

1 INTRODUCTION

The radiation-control scheme during operation at high-energy proton accelerator facilities is different from that during non-operation. During operation, a loss of the primary beam causes interactions with the accelerator components (magnet, beam duct, shielding and collimator) inside the beam-line tunnel, and, then, secondary particles, such as neutrons, are produced. The radiation level outside of the accelerator facilities increases due to these neutrons. The radiation-shielding design aims to reduce the radiation level to below the standard determined by the Government.

The radiation level inside laboratories, where radiation workers and experimentalists work during operation, must be reasonably lower than the standard. The radiation level at the boundaries of the radiation-control areas for non-radiation workers on the site and outside the site boundary for the public must be designed to be much lower than the standard determined by law, since, in Japan, the influence of radiation on the environment for the public must be controlled to be quite low.

On the other hand, during the non-operation period, the radiation-control scheme to restrict maintenance inside the beam-line is important. The radiation exposure caused by maintenance work inside the beam-line is the major part at high-energy proton accelerator facilities.

Radiation emitted from induced radioactivities due to beam loss in the accelerator components is the major cause of exposure. If the radiation level is quite high after stopping the beam, a long cooling period must be necessary, since hands-on maintenance can not be done, because of the high radiation level.

Although it is important to reduce the beam loss during beam acceleration by developing beam-control technology, any unnecessary parts of the beam must be scraped off in order to improve the beam quality. It is also necessary to shape the size of the beam so as to meet the purposes of the experimental users. In such a case, activation of the scraper and collimator becomes extremely high. Moreover, since magnets installed along the entire beam-line are used to tune and control the beam, a small portion of the primary beam is always expected to hit the magnets. Hence, a small amount of activation of these magnets can not be avoided. In order to conduct hands-on maintenance, the beam-control technology must be improved so as to reduce the radiation level of the accelerator components. It is also important to localize activation in the limited space, or limited materials, by designing shielding and the beam optics. A maintenance scenario of the highly activated components must be considered in detail before constructing the accelerator.

This paper gives an outline of the radiation-control at KEK and activation of the accelerator components, which causes trouble for maintenance inside the beam-line tunnel.

2 OUTLINE OF RADIATION-CONTROL AT KEK

Radiation-control at high-energy proton accelerator facilities can be summarized as follows: (1) radiation dose-rate control, (2) access control, (3) radioactive-substance control, and (4) radiation-exposure control. These control plans are different during and after operation, and can be outlined as follows:

(1) The radiation dose rate is continuously monitored according to the standard of the dose rate given in Tables 1 and 2; many monitors are placed at the boundaries and radiation-controlled areas. The radiation-control centre conducts a detailed survey of the radiation-controlled areas once in each cycle. During operation, the major radiation which influences exposure is high-energy neutrons, which penetrate thick concrete shielding. The energy of neutrons is distributed from a low energy to

Table 1: Dose Rate for Various Areas (Japanese Law)

Radiation-controlled Area	1.3mSv/3m
Working Area within Radiation Controlled Area	1mSv/w
Within Site Boundary	250μSv/3m

Note: The dose rate per one hour can be calculated using 500h/3m and 40h/w.

Table 2: Dose Rate for Various Areas (KEK)

Radiation-controlled Area	Forbidden	>100mSv/h
	Restricted	> 20μSv/h
	General	> 1.5μSv/h
Warning Area		> 0.2μSv/h
Non-Controlled Area within Site		≤ 0.2μSv/h
At the Site Boundary		≤ 50μSv/h

a high energy of about 100 MeV. Besides, muons are observed downstream of the beam dump and target, if they are not injected towards the earth, and causes exposure. It is important to confine these radiations inside the shielding and earth.

(2) Access to the primary beam-line tunnel must be restricted at high-energy proton accelerator facilities. Before maintenance work, an application form must be submitted in advance. On the form, the details must be written, such as the name of the person in charge, the work place, the contents of the work and prediction of the working hours. When radiation workers enter the beam-line tunnel, they must carry a personal key assigned to each individual and an alarm dosimeter. The personal key notifies the accelerator control centre about who enters the beam-line tunnel and what kind of work is being done; also, the key prohibits operation of the accelerator. During operation, access to the beam-line tunnel is prohibited, and any change in the status of the entrance door or the personal key terminates operation of the accelerator by an interlock system.

(3) In the control of radioactive substances, attention must be paid to articles like tools, accelerator components, and shielding, which are left inside the beam-line tunnel during operation. Any radioactive articles must not be brought out from the beam-line tunnel. When these articles are needed to be removed, a gate monitor is used to measure the activities automatically. If the gate monitor can not be used because of the size or other reason, the radiation-control centre must be notified to survey the articles.

(4) Exposure control is conducted in accordance with the standards (Table 4) of KEK, which are designed to be lower than that of government law (Table 3). Furthermore, the working levels for a day, a week, and a year are employed for practical radiation-exposure control (Table 5), which are lower than the KEK standard; this is intended to prevent large exposure within a short period.

In most cases, exposure problems occur during maintenance work inside the beam-line tunnel after stopping the beam. Therefore, before maintenance work, the status of the radiation level around the beam-line is measured, and a radiation map is posted in front of the entrance gate to notify radiation workers of the dose map in advance. Also, warning signs are posted at places of high radiation levels along the beam-line. If it is unnecessary to come close, signs notify workers to keep away from the place. On some occasions, it is necessary to do maintenance work on the highly activated components, on the order of several tens of mSv/h. In such cases, in order to reduce the exposures and to avoid large doses to specific individuals, a working plan must be submitted in advance to deal with the situation.

In the next chapter, the radiation levels of the accelerator components observed in the 12-GeV-PS and the related facilities are introduced.

Table 3: Dose Limits for Radiation Workers (Japanese Law)

Radiation Worker	(1) 100mSv/5y and (2) 50mSv/y
Woman	5mSv/3m+(1)&(2) above, 2mSv/ gestation

Table 4: Dose Limits Employed at KEK

Radiation Worker	20mSv/y
Woman	6mSv/y, 2mSv/3m
General Public	150µSv/3m

Table 5: Working Levels for Daily Control

Man	Woman
0.5mSv/d 1.0mSv/w 7.0mSv/y	0.3mSv/d 0.5mSv/w 2.0mSv/y

3 RADTION LEVELS DUE TO INDUCED RADIOACTIVITIES AT THE 12-GEV-PS AND RELATED FACILITIES

The KEK12-GeV-PS has two modes: fast extraction and slow extraction, because of user requests. For neutrino experiments, the fast-extraction mode is used to transport 3×10^{12}pps of 12-GeV protons to an Al target (65cm×2cmϕ). When this beam is extracted from the PS, about 10% of the beam loss occurs at the septum magnets. Since the slow-extraction mode has a much larger beam loss than the fast-extraction mode, less of the beam than in the fast-extraction mode is extracted to keep the same beam loss as that for the fast-extraction mode. It is reported that extraction loss induces radioactivities and, in order to conduct hands-on maintenance, the loss for any mode of extraction must be kept lower than about 400W [1,2]. Proton numbers equivalent to the 400 W beam loss are about 0.2×10^{12}pps (32nA), and the maximum dose rate around the loss point is about 30-40mSv/h, with an average of 10mSv/h [1,2].

The recent record (Dec. 2002) of the dose rate due to a loss of about 580W after a half-day cooling showed about 80mSv/h at the highest point, 30~40mSv/h at 30 cm away from the point, and then 10~20mSv/h around these high-radiation areas (Fig. 1). After 3 weeks of cooling, the dose rate decreased down to 15mSv/h at the highest point and 1mSv/h near to the area (Fig. 2). Considering the exposure limit at KEK, a few minutes of work is allowed near to the highest point in a day, and a few days of this kind of work are allowed in one week. This suggests that it is necessary to cool down the radioactivities significantly before maintenance work. Moreover, many people must participate in such radiation work in order to avoid a large dose to a specific person, and distribute the exposure among many radiation workers. To achieve this kind of radiation work, the maintenance procedure must be planned in advance.

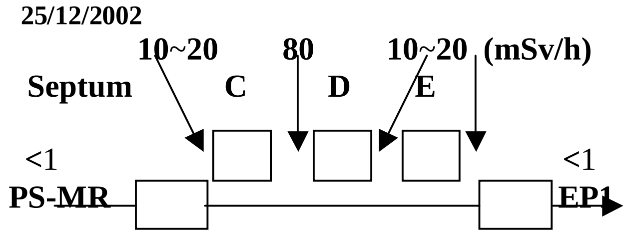

Fig. 1: Dose rate around the septum magnets of the 12-GeV-PS for the fast-extraction point. This was measured on December 25, 2002, after 7 hours of cooling. The beam loss during operation was estimated to be about 580 W.

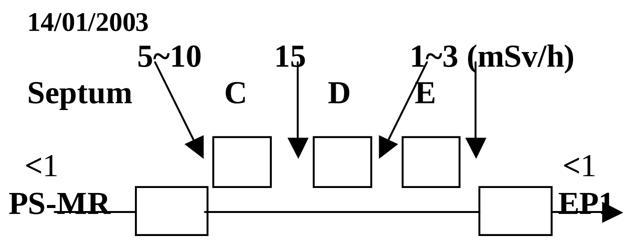

Fig. 2: Dose rate measured on January 15, 2003 after 3 weeks of cooling the extraction point shown in Fig. 1.

There are two Counter Halls: the East Counter Hall (ECH) and the North Counter Hall (NCH), which utilize a beam from the 12-GeV-Ps. The characteristics of NCH are discussed in this section. NCH has a primary beam-line called the "EP1 beam-line". This beam-line is utilized in two ways: (1) transport line to the Target Station, where a proton beam interacts with an aluminium target to produce neutrinos towards Kamiokande; (2) production of secondary particles, like π and K particles, which are used for physics experiments in the K5 and K6 experimental areas of NCH. In the case of (1) above, a primary beam of 3×10^{12}pps extracted by the fast-extraction mode from 12-GeV-PS only pass through the EP1 beam-line. In this case, the beam loss along the beam-line is small, resulting in a dose rate of 1 ~ 5mSv/h after operation. In the case of (2) above, a primary beam of 1×10^{12}pps is extracted by the slow-extraction mode. Two production targets (PT, 6cm$\times$2cmϕ) can be installed on the EP1 beam-line at the T5 and T6 positions. After two weeks of irradiation for physics experiments, the dose rate of the target becomes on the order of 1Sv/h, even after 3 days of cooling. Usually, the beam-line components are highly activated to an order of 50-100mSv/h. Since the space of the beam-line tunnel for maintenance is quite small, it is strictly restricted to enter the tunnel.

Since, from an exposure point of view, access to the primary beam-line is prohibited, the EP1 beam-line tunnel comprises a two-story structure: a primary beam-line tunnel above and a service tunnel below; these tunnels are separated by 2m thick concrete. From the service tunnel, water supply and electric power can be operated. If a repair of beam-line components, such as a magnet is necessary, concrete shielding can be removed from the ceiling of the primary beam-line tunnel; bolts and nuts can be handled far from the top; these components can be handled from the top and transferred to a maintenance area. Thus, exposure due to maintenance work can be effectively avoided.

The neutrino beam-line is located downstream of the EP1 beam-line. The primary proton beam is transported through these two beam-lines, and finally the beam is applied to an aluminium target for neutrino production. After 30 days of irradiation, the dose rates just after the irradiation are expected to be 10~100Sv/h. After cooling for about 100 hours, the dose rate becomes about 100~300mSv/h, since Na-24 (half life 15 hours) induced in the aluminium target decays out quickly. Since the target area is shielded with thick concrete shielding and the influence of the high radiation is quite small, radiation workers inside the target station do not receive a significant amount of exposure from the target. If unnecessary, they do not come close to the area.

4 SUMMARY

Usually, the primary beam-line at high-energy proton accelerator facilities is covered by thick shielding and, thus, the dose rate at the circumference is designed to remain lower during the operation. From the viewpoint of radiation-control, the dose rate of high-energy neutrons is important during operation, and the exposure is kept low by the shielding design. Generally, exposure caused by maintenance work inside the primary beam-line tunnel after operation is of great concerned at high-energy proton accelerator facilities, and a large part of the exposure record of radiation workers is due to maintenance work in the beam-line tunnel. When a beam is extracted from the 12-GeV-PS, beam loss occurs around the extraction septum magnet, resulting in a high radiation area. The dose rate is also high around the target region in the utilizing facility. It is difficult to do hands-on maintenance around these high dose areas. In order to reduce the exposure due to maintenance work, it is important to consider a complete cooling-off period, and the maintenance procedure must be planned in advance.

5 ACKNOWLEDGEMENT

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6 REFERENCES

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