THE EXPERIMENTAL STUDY OF RESIDUAL RADIOACTIVITY INDUCED IN ELECTROSTATIC DEFLECTOR

by

Chong XU [1,2]***, Wuyuan LI*** [1,2]***, Junkui XU*** [1]***, Yao YANG*** [1,2]***,***
Wang MAO[1]***, Weiwei YAN*** [1]***, Youwu SU*** [1*]***, and Yaqing YANG***[1]

[1] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China
[2] University of Chinese Academy of Sciences, Beijing, China

Scientific paper
http://doi.org/10.2298/NTRP1703211X

As one of the key components of Sector Focusing Cyclotron at the Institute of Modern Physics, Chinese Academy of Sciences, the electrostatic deflector can be activated by primary and secondary particles, because of a mismatch between the actual value and the design value of the emittance and emergence angle. In addition, it will be struck by more particles, since there is a stray magnetic field and outgas from the surface of the electrostatic deflector. The residual radioactivity in the electrostatic deflector has been studied in two aspects: specific activity and residual dose rate, based on the gamma-ray spectrometry and Fluke 451p ionization chamber, respectively. The specific activity of radionuclides in the main components and the dust on the enclosure have been investigated by using gamma-ray spectrometry. The residual dose rate around the electrostatic deflector has been obtained by Fluke 451p ionization chamber. The results of the study show that there is a non-negligible radiological risk to the staff. This result can be provided as guidance for making a maintenance schedule, so that the dose received by staff can be kept as low as reasonably achievable. Based on the results, advice for "hands-on" maintenance and decommissioning of the SFC have been provided.

Key words: electrostatic deflector, accelerator, induced radioactivity, specific activity, radionuclide

INTRODUCTION

The sector focusing cyclotron (SFC) is the only injector of the heavy ion research facility in Lanzhou (HIRFL), which can provide beam to the experimental terminal directly as well as to the injector of Separated Sector Cyclotron [1]. It can accelerate the charged particles from carbon to uranium. The maximum energy of $^{12}C^{4+}$ is 120 MeV, and the corresponding current is 60 μA, while the maximum energy of $^{238}U^{32+}$ is 19.04 MeV, and the corresponding current is 32 μA. The charged particle will pass the electrostatic deflector before it is extracted from the SFC. The layout of the electrostatic deflector is shown in fig. 1.

The electrostatic deflector will be struck by incident particles provided that the emittance or emergence angle mismatch with the design value. Because of the stray magnetic field and outgas from the surface, there will be more particles deviating from the desired orbit and lost at the electrostatic deflector [2, 3]. When the energy of the incident particles is high enough to overcome the Coulomb repulsion, nuclear reaction will be induced by those particles leading to the production of radionuclides. The incident particles are absorbed by the nucleus of the electrostatic deflector where it deposits its energy in a random manner to many nucleons. If the energy of the incident particles is lower than the Coulomb repulsion, radionuclides will be produced by stripping reaction in which one or more nucleons can be transferred from projectile to the target nucleus when the projectile passes by the target nucleus and continues undeflected in its motion [4]. The level of activity is determined by the rate at which the radioisotopes are produced, combined with the rate at which they decay.

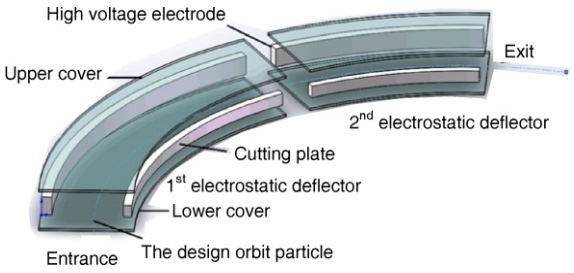

Figure 1. The layout of SFC

In order to reduce the loss of primary particles, the electrostatic deflector should be polished every

* Corresponding author; e-mail: suyouwu@impcas.ac.cn

2~3 months. The residual radioactivity of the electrostatic deflector is a dominant source of occupational exposure to staff. It is one of the main access-restrictions for "hands-on" maintenance in service and in decommissioning. Even though the kinds and the activity profiling of the radionuclide have been studied [5-9], the activation process in the electrostatic deflector of SFC is sophisticated, for the reason that the parameters of the accelerated particles are changeable. Besides, the residual activity induced in the electrostatic deflector has not been studied yet, since it had been put into operation. The main goal of our experimental study was to investigate the induced radioactivity level in the electrostatic deflector. The research has been done in two aspects: specific activity and residual dose rate. In this paper we had: (1) identified the dominating radionuclides contribution to the residual activity in the cutting plate, the high voltage electrode and the dust outside the enclosures; (2) measured the residual dose rate at different point around the electrostatic deflector. The cutting plate and the high voltage electrode are the two main components of the electrostatic deflector. According to the results, appropriate advice will be provided for maintenance and decommissioning. The method of this study is applicable to assess the residual radioactivity in other accelerators.

EXPERIMENTAL SET-UP

SFC operating conditions

The SFC cyclotron at the Institute of Modern Physics (IMP) has been put into operation since 1987, and the electrostatic deflector was replaced in 1997. The study was performed 8 hours after the operation. $^{36}Ar^{11+}$ with the energy of 194.40 MeV and the current of 2.2 μA had been accelerated for 9 days before this study. All of the charged particles had been accelerated in the last six months are shown in tab. 1.

Method of analysis

In order to assess the level of residual radioactivity, the identification of radionuclides and the measurement of the activity were carried out by HPGe gamma-ray spectrometer. The residual dose rates around each component of the electrostatic deflector were acquired by Fluke 451p ionization chamber before the sampling from the electrostatic deflector. The cutting plate is made of TU2 and the high voltage electrode is made of TC4. TU2 is an alloy of copper and silver, and its composition is listed in tab. 2. TC4 is a titanium alloy and its composition is listed in tab. 3.

The samples of the metal powder, from the cutting plate and the high voltage electrode, were obtained by sandpaper. The sample of the dust outside

Table 1. The parameters of charged particles accelerated in SFC

Nuclides	Energy [MeV]	Extract current [μA]	Commission time [d]
$^{112}Sn^{26+/35+}$	414.40	2.0	5
$^{32}S^{9+}$	172.80	1.40	4
$^{32}S^{9+}$	128.00	1.20	11
$^{4}He^{1+}$	16.00	2.50	5
$^{86}Kr^{17+/26+}$	197.80	2.00	12
$^{209}Bi^{31+}$	188.10	0.14	19
$^{12}C^{4+/6+}$	84.00	2.60	12
$^{12}C^{3+}$	50.40	4.00	16
$^{16}O^{5+/8+}$	86.40	2.50	8
$^{40}Ar^{11+}$	188.00	4.00	4
$^{16}O^{6+}$	123.20	2.00	14
$^{56}Fe^{17+}$	352.80	1.20	7
$^{12}C^{4+/6+}$	84.00	4.00	7
$^{40}Ar^{12+/17+}$	248.00	3.00	8
$^{209}Bi^{31+}$	188.10	0.20	17
$^{58}Ni^{19+/25+}$	359.60	1.70	20
$^{36}Ar^{11+}$	194.40	2.00	9

Table 2. Isotopic composition of TU2

Isotopic	Mass fraction [%]	Isotopic	Mass fraction [%]
Cu + Ag	99.95	Ni	0.002
P	0.002	Pb	0.004
Bi	0.001	Sn	0.002
Sb	0.002	S	0.004
As	0.002	Zn	0.003
Fe	0.004	O	0.003

Table 3. Isotopic composition of TC4

Isotopic	Ti	Fe	C	N	H	O	Al	V
Mass fraction [%]	88.035	0.3	0.1	0.05	0.015	0.2	6.8	4.5

electrostatic deflector was collected by non-woven fabrics. The diameter of the sample is Ø75mm. The weight of the dust sample is 4.7 g, while that of TC4 and TU2 is 62.8 mg and 54 mg, respectively. The semiconductor HPGe detector (Ortec GEMX) was used in this study, with 60 % efficiency relative to 3 × 3 NaI and FWHM of 2.30 KeV at 1.33MeV. The diameter of the crystal is 67.20 mm and the length of the crystal is 71.10 mm. The thickness of the dead layer outside the crystal is 0.30 m, while that inside the crystal is 700 m. The carbon fiber absorbing layer is 0.90 mm. The gamma ray spectrum has been acquired by the commercial software GammaVision. The measurement time of each sample is 10 hours. The energy and efficiency calibration of detector have been done based on the combination of experimental measurement and MCNP simulation [10].

RESULTS

The gamma-ray spectra have been measured in a standard way inside a low-background lead shield-

ing-chamber. The evaluation and distinguishing of gamma spectra is a complicated undertaking because of the complexity of multi-peak [11]. The activities obtained from these spectra were checked by re-calculating backwards in time to the time-point at the end of irradiation using the characteristic decay-constant of a given isotope. The activities given out at the end of irradiation for the decay time of removal from the cyclotron have been corrected. The measurement of the residual dose has been done before the "hands-on" of maintenance. The results are described in four aspects as follows because of different sampling locations and measurement methods.

Identified isotopes and residual activity in the cutting plate

The samples of cutting plate had been measured at the time of 12 hours, 30 hours, 13 days, and 60 days end of irradiation. The radionuclides identified in the cutting plate are shown in the tab. 4. The kind of those radionuclides has been arranged in order of specific activity. The evolutions of the radionuclides induced in the cutting plate are shown in fig. 2. It can be seen from the results that the radionuclides with the half-life less than 1 day induced in the cutting plate are ^{44}Sc, ^{48}Cr, ^{87}Y, ^{87m}Y, ^{90}Nb, ^{95}Tc, and ^{97}Ru. The long-lived radionuclides with the half-life more than 70 days are ^{22}Na, ^{46}Sc, ^{54}Mn, ^{56}Co, ^{58}Co, and ^{75}Se.

Table 4. Activation products in cutting plate

Nuclides	Half-life [d]	Specific activity [Bqg^{-1}]	Error [%]	The ratio to total activity
^{44}Sc	0.16	9.746 10^{6}	13.18	9.649 10^{-1}
^{58}Co	70.86	9.284 10^{4}	5.35	9.192 10^{-3}
^{75}Se	119.78	4.143 10^{4}	5.51	4.102 10^{-3}
^{89}Zr	3.27	3.812 10^{4}	5.36	3.774 10^{-3}
^{48}Sc	1.82	2.872 10^{4}	21.84	2.844 10^{-3}
^{51}Cr	27.70	2.562 10^{4}	14.48	2.537 10^{-3}
^{95}Tc	0.83	2.301 10^{4}	5.48	2.278 10^{-3}
^{90}Nb	0.61	1.661 10^{4}	7.23	1.645 10^{-3}
^{87}Y	0.82	1.471 10^{4}	6.18	1.456 10^{-3}
^{44m}Sc	2.44	1.365 10^{4}	7.80	1.351 10^{-3}
^{54}Mn	312.30	1.255 10^{4}	5.44	1.243 10^{-3}
^{56}Co	77.27	8.753 10^{3}	6.49	8.666 10^{-4}
^{48}Cr	0.96	8.704 10^{3}	12.26	8.618 10^{-4}
^{22}Na	949.69	7.915 10^{3}	7.24	7.837 10^{-4}
^{87m}Y	0.56	7.770 10^{3}	10.86	7.693 10^{-4}
^{97}Ru	0.86	6.688 10^{3}	5.61	6.622 10^{-4}
^{46}Sc	83.79	5.485 10^{3}	8.44	5.431 10^{-4}
^{57}Co	271.79	6.260 10^{2}	5.05	6.198 10^{-5}
^{48}V	15.97	5.548 10^{2}	5.57	5.493 10^{-5}
^{60}Co	1924.61	2.910 10^{2}	7.64	2.881 10^{-5}
^{65}Zn	244.26	4.414 10^{1}	6.47	4.370 10^{-6}

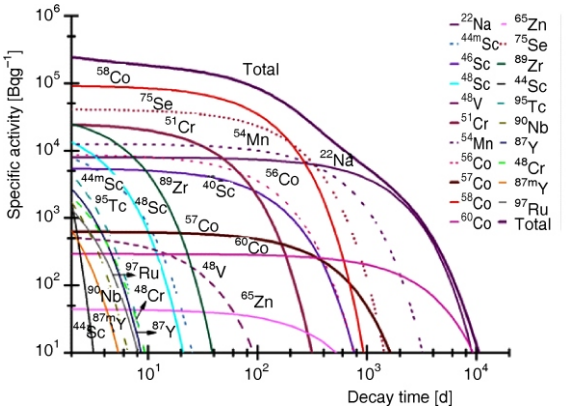

Figure 2. Evolution of the specific activity in cutting plate

Identified isotopes and residual activity in the high voltage electrode

The measurement of the samples came from the high voltage electrode and has been performed in 4 time-points at the end of irradiation: 12 hours, 30 hours, 12 days, and 107 days, respectively. The distinguished radionuclides and its specific activity are listed in tab. 5. The evolutions of the radionuclides identified in the high voltage electrode are shown in fig. 3. The half-life of each radionuclide identified in the high voltage electrode is more than 15 days. The long-lived radionuclides with the half-life more than 70 days are ^{65}Zn, ^{54}Mn, ^{57}Co, and ^{60}Co.

Identified isotopes and residual activity in the dust

The samples of dust outside the electrostatic deflector have been measured at the time of 30 hours and 1776 hours end the irradiation, respectively. The radionuclides are listed in tab. 6. Figure 4 describes the temporal evolution of radionuclides. The radioactivity isotope identified in the dust is the isotope with the half-life more than 5 days. The kinds of long-lived radionuclides, with the half-life longer than 70 days induced, in the dust are the same as that in the high voltage electrode and cutting plate. Nonetheless, the specific

Table 5. Activation products in high voltage electrode

Nuclides	Half-life [d]	Specific activity [Bqg^{-1}]	Error [%]	The ratio to total activity
^{65}Zn	244.26	5.228 10^{5}	5.01	3.707 10^{-1}
^{58}Co	70.86	5.042 10^{5}	11.26	3.575 10^{-1}
^{54}Mn	312.30	1.637 10^{5}	5.02	1.161 10^{-1}
^{57}Co	271.79	1.074 10^{5}	5.00	7.616 10^{-2}
^{56}Co	77.27	6.936 10^{4}	5.04	4.919 10^{-2}
^{46}Sc	83.79	3.525 10^{4}	5.01	2.500 10^{-2}
^{60}Co	1924.61	4.095 10^{3}	5.27	2.904 10^{-3}
^{48}V	15.97	2.289 10^{3}	10.62	1.623 10^{-3}
^{51}Cr	27.70	1.077 10^{3}	11.17	7.637 10^{-4}

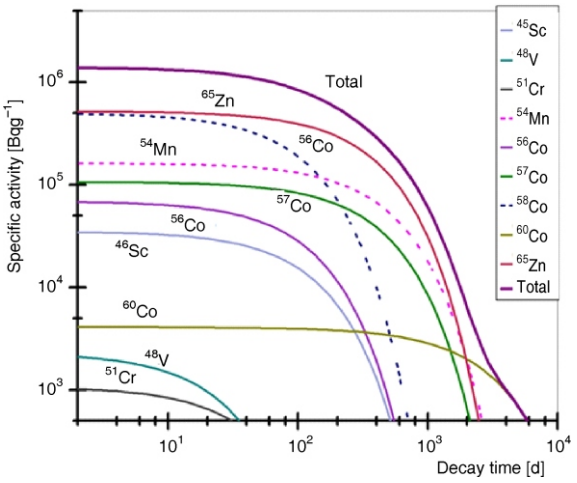

Figure 3. Evolution of the specific activity in high voltage electrode

Table 6. Activation products in dust outside the electrostatic deflector

Nuclides	Half-life [d]	Specific activity [Bqg^{-1}]	Error [%]	The ratio to total activity
^{65}Zn	244.26	1.370 10^{2}	5.05	7.116 10^{-1}
^{7}Be	53.12	1.814 10^{1}	6.46	9.423 10^{-2}
^{46}Sc	83.79	1.060 10^{1}	5.41	5.506 10^{-2}
^{22}Na	949.69	7.350	5.46	3.818 10^{-2}
^{58}Co	70.86	7.140	6.01	3.709 10^{-2}
^{54}Mn	312.3	5.180	5.15	2.691 10^{-2}
^{57}Co	271.79	1.530	5.05	7.947 10^{-3}
^{88}Y	107	1.370	11.68	7.116 10^{-3}
^{75}Se	119.78	1.293	5.13	6.716 10^{-3}
^{56}Co	77.27	1.230	9.93	6.389 10^{-3}
^{60}Co	1924.06	9.300 10^{-1}	8.90	4.831 10^{-3}
^{52}Mn	5.59	6.200 10^{-1}	9.93	3.220 10^{-3}
^{51}Cr	27.70	1.200 10^{-1}	5.51	6.233 10^{-4}
^{48}V	15.97	1.400 10^{-2}	9.40	7.272 10^{-5}

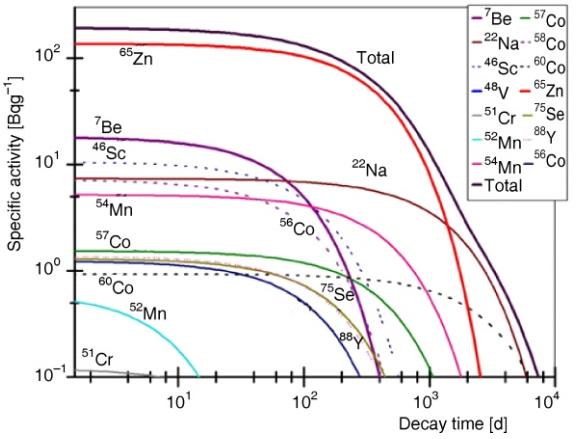

Figure 4. Evolution of the specific activity in dust outside the electrostatic deflector

activity of each isotope in dust is several orders of magnitude lower than that in the cutting plate and high voltage electrode, respectively. ^{65}Zn in the dust makes the largest contribution to the total specific activity for its highest proportion. Due to the long-time accumulation of the aerosol inside the hall, the concentration of ^{7}Be in the dust is higher than the average concentration of ^{7}Be in the aerosol of Lanzhou at the moment of wiping assuming the volume of dust diffusion uniform is 1 m^{3}. The activity of ^{7}Be in the aerosol of Lanzhou area ranges from 3.10 10^{-4} to 1.78 10^{-2} Bq per cubic meter [12]. The partial RMS errors of activities are shown in tab. 4, tab. 5, and tab. 6. Those errors are obtained as a quadratic sum of two components: (1) efficiency calibration error and (2) net-peak-area error.

Measurement of residual dose rate

Before the "hands-on" of maintenance, the residual dose rates around the electrostatic deflector have been measured 8 hours end of irradiation by Fluke 451p ionization chamber with 10 % accuracy. The distance between the ionization chamber and the surface of the component is 5 cm. The measured values of the dose rates are shown in tab. 7. It can be concluded from the measurement results that: (1) the dose rate at the entrance are higher than that at the exit both for the cutting plate and the high voltage electrode along the direction of beam transmission, (2) the charged particles lost on the upper and the lower cover are less than that on the cutting plate and the high voltage electrode, respectively.

DISCUSSION

The residual radioactivity in the electrostatic deflector depends on the kinds, the current and the energy of the incident particles and the composition of

Table 7. Residual dose rate of electrostatic deflector

Location	Dose rate [Svh^{-1}]	Location	Dose rate [μSvh^{-1}]
Entrance of 1st electrostatic deflector	750.24	Entrance of 1st lower cover	7.55
Exit of 1st electrostatic deflector	300.79	Middle of 1st lower cover	18.47
Entrance of 2nd electrostatic deflector	80.43	Exit of 1st lower cover	13.22
Exit of 2nd electrostatic deflector	30.58	Entrance of 2nd lower cover	10.24
Entrance of high voltage electrode	38.74	Middle of 2nd lower cover	12.66
Exit of high voltage electrode	19.85	Exit of 2nd lower cover	9.57
Entrance of upper cover	1.19	Middle of upper cover	3.62
Exit of upper cover	2.67		

the target materials. The required cooling time of the main components and the dust used for the decay of the residual radioactivity, can be determined based on the exemption value, the specific activity and the half-life of each radionuclide. Based on the experimental results above, the induced radioactivity in the electrostatic deflector has been discussed as follows.

On one hand, ^{44}Sc, with its half-life of 0.16 days is the dominant short-lived radionuclide to be found in the cutting plate. It would decay at a fast rate 1 day after irradiation with the largest proportion 0.9649 of the total radioactivity. The short-lived radionuclides found in the cutting plate are ^{89}Zr, ^{95}Tc, ^{90}Nb, and ^{87}Y. Those are produced by $^{36}Ar^{11+}$. The specific activity of those radionuclides would be lower than the exemption value pointed in GB18871 [13] 10 days after irradiation. The exemption value of ^{58}Co, ^{22}Na, and ^{54}Mn are 1 10^1 Bqg^{-1}, while the value of ^{75}Se is 1 10^2 Bqg^{-1}. So it will be needed more than 10 years for the those radionuclides in the cutting plate to achieve the clearance level, based on the exemption values of each radionuclide and the total specific activity limited by EURATOM Council Directive 2013/59 [14].

On the other hand, the kinds of all of the long-lived radionuclides identified in the high voltage electrode are the same as that in the cutting plate. But no short-lived radioactivity isotope with the half-life shorter than 1 day has been distinguished in the high voltage electrode. ^{65}Zn is the most important radionuclide that has been identified in the high voltage electrode with the maximum proportion of the total radioactivity. According to the evolution of the specific activity in the high voltage electrode, it can be deduced that it needs approximately 7 years for the high voltage electrode to achieve the exemption values after moving out of the SFC.

Moreover, the dust is also a radioactive source which is formed by natural erosion and wear on the electrostatic deflector. The dust will be adsorbed on the enclosure of electrostatic deflector with indoor airflow. All of the radionuclides identified in the dust outside the enclosure are the long-lived radionuclides, which also have been distinguished in the cutting plate and the high voltage electrode. In addition, ^{65}Zn in the dust should be given more attention because it has the largest proportion of the total radioactivity. ^{7}Be in the aerosol produced by thermal neutrons tend to uniformly fill a room should be taken in particular concern, since it may be higher than the background.

The cooling time is required at different workplaces, based on the kinds of radionuclides to be distinguished. The storage time of component before decommissioning will be influenced by the activity of long-lived radionuclides with the half-life longer than 70 days. The required cooling time before the "hands-on" maintenance is mainly limited by the short-lived radioactivity isotope. The kind of the short-lived radioactivity isotope induced in the electrostatic deflector after operation would be affected by the parameters of the accelerated particles. The relative importance of a particular isotope from the view of its contribution to the local dose rate depends on its half-life and the radiation emitted when it decays. Beta radioactivity represents a significant source of exposure to personnel via the skin of individuals engaged in maintenance after the accelerator is shut down, for the reason that some of the radionuclides identified in the electrostatic deflector decay by beta emission or, by positron emission or, by capturing an orbiting electron.

In order to reduce the risk of external and internal exposure, the following advice should be paid much attention. First of all, the residual dose rate of the electrostatic deflector must be measured during the maintenance and the received dose of each working time should be recorded so that the total dose received within one year by each staff member is lower than the personal dose limits for occupational exposure. The maximum working time should be limited within 1.11 hours per time based on the management limit of 5 mSv per year of one person [15], supposing that the maintenance is conducted every two months. Beyond that, the polish should be applied within a confined space and the metal dust should be cleaned at the end of maintenance so as to reduce the risk of internal exposure. Last but not least, staff must wear dust masks during work.

CONCLUSIONS

The electrostatic deflector of SFC has been activated by the lost particles, due to the stray magnetic field and the unstable vacuum. The radionuclide inventory in the components of electrostatic deflector and the dust outside the electrostatic deflector enclosure was under investigation by gamma-ray spectroscopy and ionization chamber, respectively. The method can be applied to evaluate the residual radioactivity of the accelerator both in commissioning and decommissioning. Investigation results show that the kinds of the radionuclides induced in the cutting plate are higher than in the high voltage electrode for the reason that $^{36}Ar^{11+}$ is lost in the cutting plate. The residual radioactivity in the components of electrostatic deflector exhibited that there is a non-negligible radiological risk to the relevant staff. The cooling time under different situation has been analyzed according to the exemption value, the specific activity and the half-life of each radionuclide. The residual radioactivity of the dust outside the electrostatic deflector can not be ignored because the ^{65}Zn and ^{7}Be may be inhaled. The results of the study can be provided as a guidance for making maintenance schedule so that the residual dose received by the staff is kept as low as reasonably achievable. Nevertheless, a further work should be done to assess the risk of internal exposure.

AUTHORS' CONTRIBUTIONS

The idea for the study was put forward by C. Xu, Y. W. Su, and Y. Q. Yang. The samples were prepared by C. Xu, W. W. Yan, and W. Mao. The measurements were carried out by C. Xu and J. K. Xu. The discussion was carried by C. Xu, W. Y. Li, and Y. Yang. The manuscript and figures were prepared by C. Xu.

ACKNOWLEDGEMENTS

We thank the members of Magnet and Mechanical Group for the help with sampling.

REFERENCE

[1] Zhan, W. L., *et al*., HIRFL Today, *Nuclear Physics A, 805* (2008), 1-4, pp. 533c-540c
[2] Calandrion, R., *et al*., Decommissioning Procedures for an 11 MeV Self-Shielded Medical Cyclotron After 16 Years of Working Time, *Health Physics, 90* (2006), 6, pp. 588-596
[3] Wang, Y. F., *et al*., Physical Design of the New Extraction System for SFC, *High Energy Physics and Nuclear Physics, 30* (2006), 1, pp. 147-149
[4] Williams, W. S. C., Nuclear and Particle Physics, Oxford University Press, New York, USA, 1991
[5] Fertman, A., *et al*., First Results of an Experimental Study of the Residual Activity Induced by High-Energy Uranium Ion in Steel and Copper, *Nuclear Instruments and Methods in Physics Research B, 260* (2007), 2, pp. 579-591
[6] Magistris, M., Ulrici, L., The Fingerprint Method for Characterization of Radioactive Waste in Hadron Accelerators, *Nuclear Instruments and Methods in Physics Research A, 591* (2008), 2, pp. 343-352
[7] O'Donnell, G. R., *et al*., Measurement of the Residual Radioactivity Induced in the Front Foil of a Target Assembly in a Modern Medical Cyclotron, *Applied Radiation and Isotopes, 60* (2004), 2-4, pp. 539-542
[8] Pohorecki, W., *et al*., Measurement and Calculations of long-Lived Radionuclide Activity Forming in the Fast Neutron Field in Some ITER Construction Steels, *Fusion Engineering and Design, 89* (2014), 7-8, pp. 932-936
[9] Yashima, H., *et al*., Induced Radioactivity in Cu Targets Produced by High-Energy Heavy Ions and the Corresponding Estimated Photon Dose Rates, *Radiation Protection Dosimetry, 112* (2004), 2, pp. 195-208
[10] Conti, C. C., *et al*., A Detailed Procedure to Simulate an HPGe Detector with MCNP5, *Progress in Nuclear Energy, 66* (2013), July, pp. 35-40
[11] Chadvick, B. M., *et al*., ENDF/B-V II.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology, *Nuclear Data Sheets, 107* (2008), 12, pp. 2931-3060
[12] Wu, J. L., *et al*., Concentration of ^{7}Be in Atmospheric Aerosol in Lanzhou, *Chinese Journal of Radiological Health, 20* (2011), 3, pp. 333-334
[13] Pan, Z. Q., *et al*., Basic Standards for Protection Against ionizing Radiation and for the Safety of Radiation Sources (GB18871-2002), Beijing, 2002
[14] ***, Council Directive 2013/59/EURATOM of 5 December 2013, Laying Down Basic Safety Standards for Protection Against the Dangers Arising from Exposure to Ionising Radiation, Luxemburg, *Official Journal of the European Union, L 13* (2014), p. 50, Luxemburg

Received on March 10, 2017
Accepted on July 13, 2017

Чунг СЈУ, Вујуен ЛИ, Ђуенкуеј СЈУ, Јао ЈАНГ, Ванг МАО, Вејвеј ЈЕН, Јоуву СУ, Јаћинг ЈАНГ

ЕКСПЕРИМЕНТАЛНО ОДРЕЂИВАЊЕ ЗАОСТАЛЕ РАДИАКТИВНОСТИ ИНДУКОВАНЕ У ЕЛЕКТРОСТАТИЧКОМ УСМЕРИВАЧУ

Елекростатички усмеривач представља једну од кључних компоненти SFC циклотрона у Институту за модерну физику Кинеске академије наука. У току рада може доћи до његове активације примарним и секундарним честицама услед одступања стварне од пројектоване вредности угла емитовања и излазног угла. Додатно, усмеривач ће бити погођен већим бројем честица услед лутајућег магнетног поља и ослобођеног гаса са површине електростатичког усмеривача. Заостала радиоактивност у електростатичком усмеривачу проучавана је са становишта специфичне активности – спектрометријом гама зрачења, и јачине дозе – применом јонизационе коморе Fluke 451P. Гама спектрометријском анализом утврђена је специфична активност радионуклида у главним компонентама усмеривача и прашини на кућишту. Јачина дозе око електростатичког усмеривача измерена је јонизационом комором Fluke 451P. Резултати испитивања показују да постоји незанемарљив радијациони ризик за особље, те се могу употребити као смернице у припреми плана и распореда одржавања, чиме би се доза за особље свела на минималну могућу. На основу резултата, дати су и практични савети за одржавање и декомисију SFC циклотрона.

Кључне речи: електростатички усмеривач, акцелератор, индукована радиоактивност, специфична активност, радионуклид