FEED-FREE MONITORING OF INTENSE HIGH-ENERGY BREMSSTRAHLUNG*

V.I. Nikiforov, V.A.Shevchenko, I.N.Shlyakhov, A.Eh.Tenishev, V.L. Uvarov#, NSC KIPT, Kharkov, 61108, Ukraine

Abstract

High-intensity ($\geq 10^3$W/cm^2) bremsstrahlung sources produced on the basis of electron linacs of energy E_0 up to 100 MeV find use in accelerator-driven subcritical assemblies, in photonuclear isotope production, activation analysis, etc. These processes, as a rule, call for maintaining a stable bremsstrahlung flow for one or more days. Therefore the diagnostic means of the radiation must function reliably under conditions of high-absorbed doses ($\geq 10^8$Gy).

To solve the problem, it is proposed to use a direct charge detector (DCD). It consists of two vacuum gap-spaced metal plates of different thickness. For bremsstrahlung intensity monitoring, measurements are taken of the differential plate current arising due to the difference in Compton electron flows.

The simulation method based on the software PENELOPE/2006 was used to investigate the conditions of equilibrium e,X-radiation formation in the area of detector location, the dependence of detector sensitivity in its standard geometry on the atomic number Z of the plate material and the gammas energy at E_0 ranging from 20 to 100 MeV.

The realization of the method has been demonstrated by experiment with the use of the DCD prototype. The proposed detector requires no external power supply, is easy to operate and has a high radiation resistance.

INTRODUCTION

The dosimetry of intense γ-radiation fields in reactors employs the technique based on the use of a direct-charge detector (DCD) as a monitor [1]. The detector consists of two metal plates of different thickness fixed on the insulator and separated by a vacuum gap. On exposure to γ-radiation, owing to the difference between the charge flows, one plate acquires a positive charge (emitter), and the other plate assumes a negative charge (collector), and their differential current is proportional to the radiation intensity.

The present communication deals with the DCD application conditions for monitoring high-intensity bremsstrahlung (BS). The studies were performed by the computer simulation method with the use of the program system PENELOPE/2006 [2], and also, by experimentation.

CONFIGURATION OF OUTPUT DEVICES

To produce the BS flux with a minimum admixture of electrons, a filter-absorber is placed behind the converter. Its optimum dimensions can easily be estimated through expressing the thickness of output devices of the accelerator in the region of (e,X) radiation formation in terms of the range of electrons in the continuous slowing-down approximation (stopping thickness unit - stu). In particular, with this approach it has been possible to demonstrate that the electron equilibrium of radiation is attained at the total thickness of output devices ranging between 1.2 and 1.4 stu [3]. These data were taken into account when simulating the BS monitoring conditions (Fig.1).

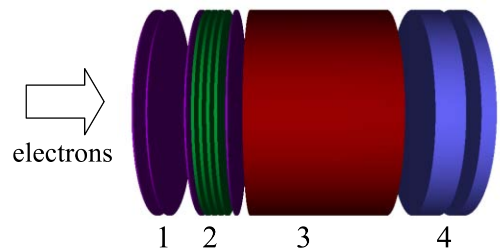

Figure 1: Configuration of output devices of the electron accelerator for BS generation and monitoring.

The region of (e,X) radiation formation includes the exit window **1**of the accelerator, the converter unit **2**, the filter **3** and the BS detector **4**. The exit window **1** consists of the input and output foils (Ti, 0.05 mm), the spacing between which (4 mm) is filled with cooling water. The converter unit **2** is composed of the input and output foils (Ti, 0.05 mm), four plates (Ta, each 1 mm thick) separated by 1.5 mm spacings with cooling water. The filter **3** presents an aluminum cylinder, 10 cm in diameter. For each electron energy value, the cylinder height was chosen such that the total stopping range of the output devices should equal 1.4 stu. The DCD **4** consists of two 10-cm Ø plates with a 2 mm vacuum gap between them. In the computations, we took into account the electron density distribution in the beam close to the conditions of the accelerator KUT-30 created at the NSC KIPT for photonuclear production of isotopes [4].

SIMULATION DATA

For better understanding of the processes of charge formation in the DCD plates, detailed calculations were made at the electron energy E_0=40 MeV for a copper detector having the plates of different thickness. Table 1 gives the characteristics of radiation detected on the near plane of the DCD.

Table1: Radiation parameters (E_0=40 MeV)

Total kW/mA	Photons kW/mA	Electrons kW/mA	Pozitrons kW/mA
9.131 ± 0.035	8.805 ± 0.036	0.2398 ± 0.0079	0.0824 ± 0.0049

Figures 2 and 3 show the charge values in the 1st and 2nd

* Work is supported by STCU under Project # 3151
# uvarov@kipt.kharkov.ua

plates of the detector versus thicknesses of the 1st plate and the 2nd plate, respectively.

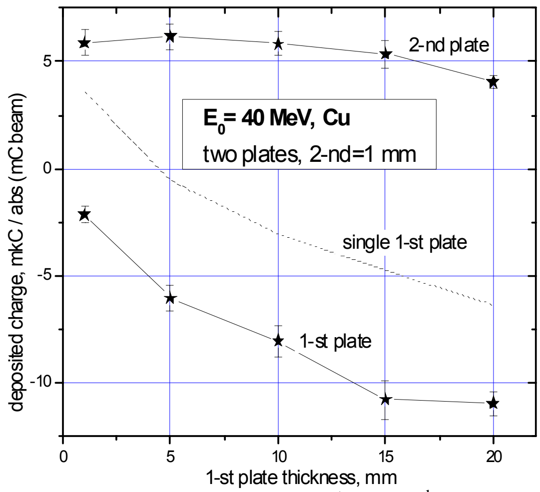

Figure 2: Charge formed on the 1st and 2nd copper plates versus 1st plate thickness at a constant thickness (1 mm) of the 2nd plate. The dashes show the charge on the first single plate.

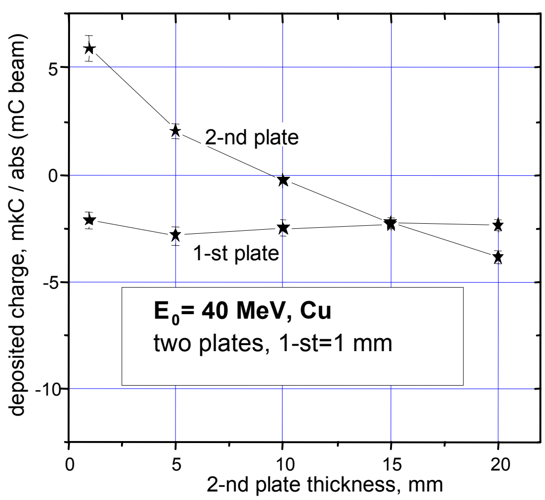

Figure 3: Charge formed on the 1st and 2nd copper plates versus 2nd plate thickness at a constant thickness (1 mm) of the 1st plate.

To investigate the dependence of the DCD sensitivity on the radiation energy and the plate material, calculations were made to determine the charges on the plates from Al (Z=13), Cu (Z=29), Zn (Z=40) and Ta (Z=73) at E_0=20, 40, 60, 80 and 100 MeV (see Figs. 4, 5). In the calculations, the 1st and the 2nd plates were put to be 20 mm and 1 mm thick, respectively.

EXPERIMENT

For the demonstration experiment, a power cermet triode GS-4V (the 50-ies of the XX century) was used (see Fig. 6). Its "anode-insulator-grid" structure practically corresponds to the DCD conditions. The insulator has been made from the radiation-resistant $2MgO{\cdot}SiO_2$ ceramics, and the electrodes were made from copper. The anode thickness was much greater than the grid thickness.

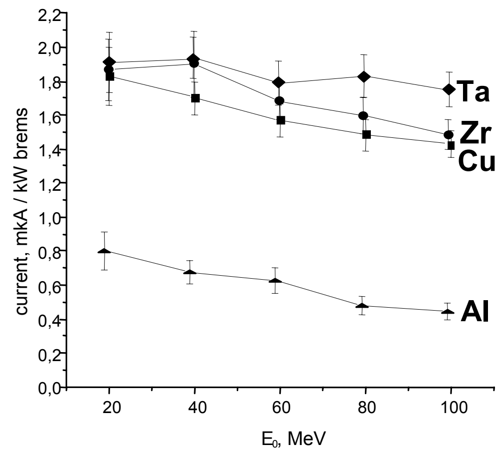

Figure 4: DCD output current versus electron energy E_0.

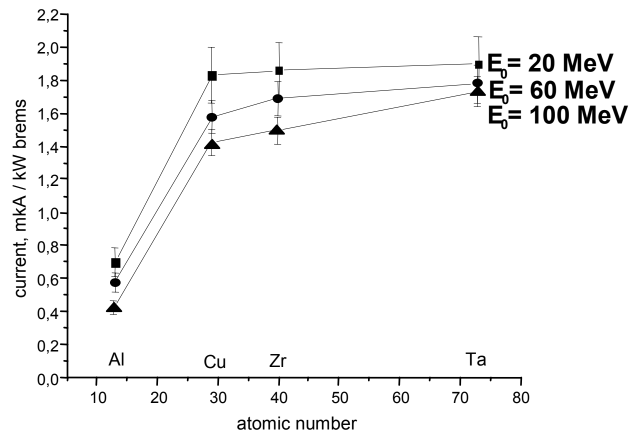

Figure 5: DCD sensitivity versus Z of the plate material.

The experimental monitoring of the BS was performed at the accelerator KUT-30 at the following beam parameters:

electron energy, MeV	38;
beam current (pulse value), mA	440;
pulse duration, μs	3.7.

Figure 6: Cermet triode as a DCD prototype.

The typical DCD signal is shown in Fig. 7.

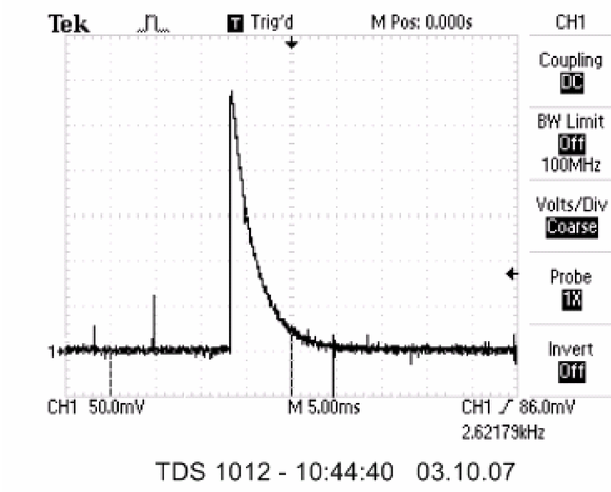

Figure 7: DCD prototype signal.

DISCUSSION

At a stopping length of the output devices of the accelerator (exit window+converter+filter) greater than 1.4 stu, the radiation comprises practically no beam electrons, and consists only of secondary particles, i.e., braking photons, Compton electrons and positrons. The spectra of all forward-flying particles are shifted towards low energies. Their average values make 10% to 15% of the accelerated electron energy. It is obvious that the resulting charge of the irradiated plate is equal to the sum of charges (taken with the corresponding signs) of electrons and positrons incident on the plate and escaping from it.

The choice of the detector plate thickness is determined by the path length of secondary electrons. The plate having the thickness less than the path length is considered to be "thin", and if greater – then it is considered to be "thick". The shortest path of electrons (1.17 mm) is observed in tantalum at E_0=20 MeV, and the greatest path (2.07 cm) – in aluminum at E_0=100 MeV. Therefore, the choice of 1 mm thickness of the plate-emitter and 20 mm thickness of the plate-collector is optimal for all the materials in the accelerated electron energy range under consideration.

The present results show that in the two-plate detector, where the 1st plate is thick and the 2nd plate is thin, the thick plate is always charged negatively, and the thin plate – positively. The greatest positive charge is attained on the thin plate from copper and zirconium, and the greatest negative charge – on the thick tantalum plate. Apparently, the detector with the thick tantalum plate and the thin copper or zirconium plate is the best choice, because the charge difference is expected in this case to be the greatest.

If the plate dimensions are smaller than the transverse size of the radiation flux, then the detector is subjected to all-round irradiation due to a substantial divergence of the radiation. As a result, even the thick plate can get positively charged and lose its role of the collector.

CONCLUSION

- The direct-charge detector (DCD) can be applied for passive continuous monitoring of high-energy high-power (≥1 kW) bremsstrahlung. The DCD can be used in two modes of operation:
  - • for monitoring the total BS power. In this case, the diameter of the detector plates must be greater than the transverse dimension (cross-sectional size) of the radiation flux;
  - • for monitoring the relative level of high-energy BS intensity. For this purpose, a small-size detector remote from the radiation source can be used.
- The DCD sensitivity varies only slightly with an increasing atomic number of the plate material for Z>30. As Z increases, the dependence of the detector sensitivity on the braking photon energy decreases.
- Considering that the radiation is of pulsed character, the output signal value of the DCD is in real practice ~ 3 orders of magnitude higher than the values shown in Figs.4,5. This provides a reliable registration of the signal without its additional amplification.
- In view of high BS intensity values, the choice of the material for detector plates is not critical for photonuclear technologies. The main factor criterion here is evidently its minimum activation.

REFERENCES

[1] R.Hosemann, H.Warrinkhoff. Nucleonics. 22 (1964) 51.

[2] F.Salvat, J.M.Fernandez-Varea and J.Sempau, "PENELOPE-2006 A Code System for Monte Carlo Simulation of Electron and Positron Transport" (OECD Nuclear Energy Agency, Issy-les-Moulineous, France, 2006).

[3] A.N. Dovbnya, V.I. Nikiforov, V.L. Uvarov, N.A. Dovbnya, "Electron Linac Based e,X-Radiation Facility", EPAC'06, Edinburgh, June 2006, WEPCH143, p.2257 (2006); http://www.JACoW.org.

[4] M.I.Aizatskiy, E.Z.Biller, V.N.Boriskin et al, "High-Power Electron S-band Linac for Industrial Purposes", PAC'03, Portland, May 2003, RPAB070, p.2878 (2003); http://www.JACoW.org.