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SPATIAL DISTRIBUTION OF STRAY RADIATIONS AROUND A SLOW-POSITRON FACILITY AND A COMPACT ELECTRON STORAGE RING AT THE ELECTROTECHNICAL LABORATORY

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ABSTRACT

A slow-positron facility will soon come into operation at the Electrotechnical Laboratory. At an experimental room, neighboring to the facility, is progressed a different program to utilize a compact electron storage ring. In order to confirm that a variety of experiments, which will be performed in an area existing between the two rooms, would be little bothered with background radiations, stray radiations were measured by the use of Mg_2SiO_4: Tb TLD's at several positions. Energy spectra of x rays were also observed with high-purity Ge coaxial detectors. These measurements proved the effectiveness of the radiation shields made of powdered iron ore.

INTRODUCTION

A slow-positron beam becomes recognized to be a powerful probe in solid state physics, materials science, etc. A new project to generate high-intensity slow positrons by the use of an electron linac was started at the Electrotechnical Laboratory (ETL) in the last fiscal year.[1] In the year before starting the construction of the slow-positron facility, a compact electron storage ring, named NIJI-1, succeeded to store electrons.[2] NIJI-1 is a facility to examine that how low can be the energy of electrons to be injected to a storage ring and that how small the size of a storage ring can be.

Both the slow-positron facility and NIJI-1 locate in Wing C of the ETL Linac Building: the former, in the Low-Energy Experimental Room, and the latter, in the Medium-Energy Experimental Room. (Let us call, hereafter, the above rooms merely as low-energy room and medium-energy room, respectively.) The both facilities share the Measurement Room locating between the above two experimental rooms. In fact, a pair of Anger cameras are planned to be positioned in the measurement room to detect 0.511-MeV γ rays generated with positron annihilations in a sample. This means that it is strictly required to keep radiation backgrounds in the measurement room as low as possible.

The present group has measured (i) radiation doses at several positions both inside and outside the low-energy room by the use of thermoluminescence dosimeters (TLD's) whose phosphor is terbium-activated magnesium orthosilicate[3] (Mg_2SiO_4 : Tb) while intense electrons hit an electron-to-positron converter and (ii) radiation doses at several positions inside the medium-energy room while electrons are injected to and stored in NIJI-1. Energy spectra of x rays have also been observed at the places, where the Anger cameras will be set, with high-purity Ge coaxial detectors. This note reports the measured spatial distribution of radiation doses and observed energy spectra of stray radiations for some typical cases.

RADIATIONS AROUND SLOW-POSITRON FACILITY

The main part of the ETL slow-positron facility is schematically shown in Fig. 1. Marks in the figure stand for:

(a) Final part of the electron-transporting system to the low-energy room;
(b) Electron-to-positron converter and positron moderator;
(c) Radiation shields made of iron blocks containing iron-ore powder;
(d) Linear storage section to stretch pulsed beams of slow positrons;
(e) Brightness enhancement section;

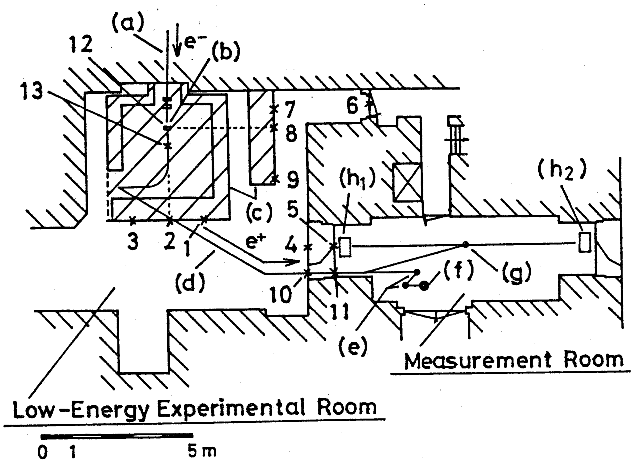

Fig. 1. Plan view of the ETL slow-positron facility.

(f) Sample chamber for experiments of Low-Energy Positron Diffraction, Positron Energy-Loss Spectroscopy, and Reflection High-Energy Positron Diffraction;
(g) Sample chamber for experiments of Two-Dimensional Angular-Correlation of Annihilation Radiations;
(h) Pair of Anger cameras to detect γ rays generated through annihilations of positrons with a sample located in (g).

Table 1. Spatial distribution of radiation doses measured inside and outside the Low-Energy Experimental Room when 75-MeV electrons of average current of 50 μA impinged upon the electron-to-positron converter. Values are given in R/Hr units.

Location	Height relative to incident electron level		
	0 cm	+ 60 cm	- 60 cm
(1)	$4.59 \cdot 10^{0}$	$8.01 \cdot 10^{0}$	$6.28 \cdot 10^{0}$
(2)	$3.96 \cdot 10^{0}$	$6.41 \cdot 10^{0}$	$4.33 \cdot 10^{0}$
(3)	$3.02 \cdot 10^{0}$	$2.76 \cdot 10^{0}$	$3.09 \cdot 10^{0}$
(4)	$7.00 \cdot 10^{-1}$	$7.90 \cdot 10^{-1}$	$6.46 \cdot 10^{-1}$
(5)	(a)	*	*
(6)	(b)	*	*
(7)	$1.45 \cdot 10^{-1}$	$1.70 \cdot 10^{-1}$	$1.25 \cdot 10^{-1}$
(8)	$1.76 \cdot 10^{-1}$	$2.05 \cdot 10^{-1}$	$1.56 \cdot 10^{-1}$
(9)	$3.56 \cdot 10^{-1}$	$3.56 \cdot 10^{-1}$	$2.98 \cdot 10^{-1}$
(10)	*	*	$5.79 \cdot 10^{-1}$ (c)
(11)	*	*	$5.00 \cdot 10^{-4}$ (c)
(12)	*	$6.35 \cdot 10^{0}$ (d)	*
(13)	*	$6.49 \cdot 10^{0}$ (d)	*

At positions marked with *, TLD's were not placed.
(a) Undistinguished from natural backgrounds.
(b) A little larger than natural backgrounds.
(c) Values obtained at the hole drilled in the shielding door.
(d) Values obtained on the top of the shielding blocks.

The background radiations may be induced mainly by bombardment of the electron-to-positron converter, a tantalum cylinder, with intense electron beams. The main radiation shields, (c) above, enclose a cubic space whose side is about 3 m long. In the cubic space, there exist the electron-to-positron converter, a positron moderator (tungsten ribbons), and an initial part of a transporting system of slow positrons. The measurement room is, as a matter of course, separated from the low-energy room with a thick radiation-shield wall. There are some concerns, however, that a very small fraction of generated x rays and neutrons might reach the measurement room; because the positron-transporting system pass through a hole drilled in the shielding door.

For the purpose of reinforcing the shielding power, a local shield was put so as to surround the electron-to-positron converter with lead bricks and borated polyethylene bricks: total thickness of lead was about 15 cm and that of borated polyethylene was about 10 cm. Table 1 gives a typical example of radiation doses measured with Mg_2SiO_4 : Tb TLD's at 13 locations marked in Fig. 1. The figures tell x-ray dose rates in R/Hr units when 50-μA electrons of 75-MeV energy fall upon the converter.

As can be seen in Table 1, the present configuration of radiation shield can sufficiently reduce stray radiations in the measurement room. The radiation doses measured outside the low-energy room are small enough to pass regulations made by the Japanese government; it is desired to obtain information of the energy distribution of the stray radiations and the origin of them. Two high-purity Ge coaxial detectors were set at points (h_1) and (h_2) shown in Fig. 1. An energy spectrum was measured at (h_1) when electron beams impinged upon the converter; and then the "pure background" was measured when the linac is turned off. The "net spectrum" of x rays was obtained by subtracting the pure background data from the first data after equating the data acquisition time. The resultant net spectrum is shown in Fig. 2. A distinct peak at 0.511 MeV is probably due to annihilations of positrons, which are generated by stray x rays through pair-creation processes in aluminum cover of the Ge crystal. These x rays are certainly produced when the converter is bombarded with primary electrons. In this project, quasi-continuous beams of slow positrons will be generated by the use of the linear storage method, the anti-coincidence technique with a gate pulse of a few μsec long will suppress the affection of the x-ray burst without much difficulty.

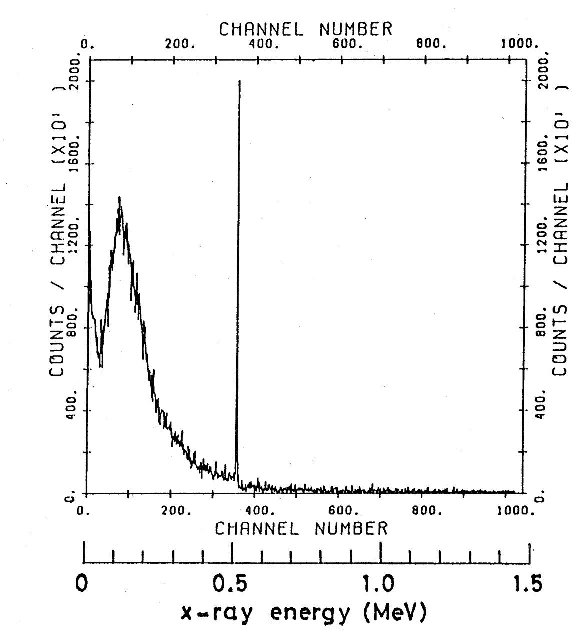

Fig. 2. Energy spectra of x rays measured at position (h_1) shown in Fig. 1. Data acquisition time is equivalent to about 11 hours.

RADIATIONS AROUND STORAGE RING NIJI-1

When electrons are injected to NIJI-1, a fraction of them being out of accelerating phase fail to continue revolving in it. These electrons emit bremsstrahlung x rays when they hit vacuum chambers made of stainless steel. It is required to enclose these x rays within the medium-energy room to keep the measurement room clean in terms of radiation backgrounds. For NIJI-1, several amount of radiation shielding materials are stacked to prevent most x rays and neutrons from reaching the usual exit as shown in Fig. 3. In this figure, B-n's stand for bending-magnet sections and L-n's, long insertion sections. Other marks in parentheses stand for:

(a) Septum magnet;
(b) Kicker magnet;
(c) RF cavity to accelerate stored electrons;
(d) Radiation shields made of iron blocks containing iron-ore powder;
(e) Local radiation shields made of heavy-concrete blocks, iron blocks, lead blocks, paraffin blocks, etc.;
(f) Electrical equipments such as power supplies to the septum and kicker magnet, rf-power source, etc.

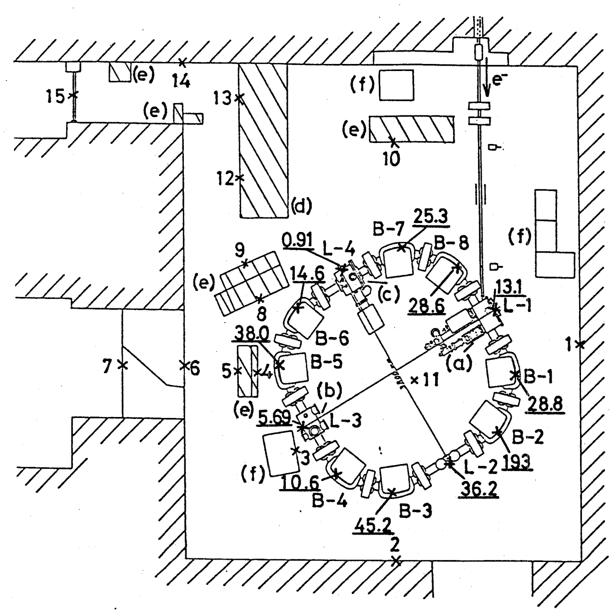

Fig. 3. Plan view of the Medium-Energy Experimental Room. Underlined figures mean integrated radiation doses caused by stored electrons in units of mR for an extraordinary case (see text).

In order to examine the effectiveness of the stacked radiation shields, radiation doses were measured at 15 positions marked in Fig. 3 with Mg_2SiO_4 : Tb TLD's. Typical results are given in Table 2: In this case, all the TLD's were set at the height of the level of injected electrons for about 15 min of injection. These results show that the stacked shields effectively prevent radiations from straying out even through the usual exit.

While stored electrons are revolving in NIJI-1, x rays may be generated due to collisions of them with residual gas molecules inside the vacuum chambers as well as due to the radioactivity of the chambers themselves induced by injected electrons. These stray radiations also need to be reduced as possible to protect personnels working around NIJI-1 from unnecessary irradiations. As an example, measured radiation doses are also shown in Fig. 3 with underlined figures. These values were obtained with the following conditions:

(a) TLD's were set about 6 min after ramping up the electron energy from 160 MeV, initial energy of in-

jected electrons, to 220 MeV;
(b) It took about 10 min for setting 12 sets of TLD's; during this period, the amount of stored electrons decreased at a rate of about 2.6 mA/min;
(c) About 2 hours after the positioning of TLD's 45 mA of stored electrons disappeared all at once;
(d) The gross decay rate was about 1 mA/min for the above 2 hours.

Table 2. Radiation doses for 15 min of injection at 15 positions marked in Fig. 3.

Position	Rad. Dose for 15 min	Position	Rad. Dose for 15 min	Position	Rad. Dose for 15 min
(1)	5.13 R	(6)	100 mR	(11)	1.98 R
(2)	2.97 R	(7)	——	(12)	5.04 mR
(3)	388 mR	(8)	8.60 R	(13)	3.28 mR
(4)	1.38 R	(9)	189 mR	(14)	3.54 mR
(5)	31.0 mR	(10)	242 mR	(15)	0.13 mR

Value at (7) is indistinguishable from natural backgrounds.

At some positions, enormously large values of integrated radiation doses were observed. This is, however, one of the worst cases from the health physics points of view: One usually enters the medium-energy room when several tens of minutes have passed after the fill of electrons to NIJI-1; In this case, the main bending magnets were suddenly inactivated caused by mis-operation of electric power supply to the magnets (cf. (c) above).

Energy spectra of x rays were also measured by the use of the high-purity Ge coaxial detectors in the measurement room while electrons were injected to NIJI-1. Comparing to the spectrum of pure background, no significant difference was observed at either position (h_1) or (h_2) shown in Fig. 1.

CONCLUDING REMARKS

Radiation doses were measured by the use of Mg_2SiO_4: Tb TLD's inside and outside the low-energy room while intense electrons bombarding the electron-to-positron converter. With adding lead and borated polyethylene bricks to cover the converter and positron moderator, background radiations in the measurement room were decreased to a large extent. The energy spectra of stray radiations were observed with high-purity Ge coaxial detectors at places where Anger cameras would be set. A distinct peak at 0.511 MeV was observed, the origin of which was probably pair-creation process of x rays streamed through a hole drilled in the thick shielding door to guide transporting system of slow positrons.

Also radiation doses were measured around the compact electron storage ring NIJI-1 for two cases: both electron-injection mode and electron-storage mode. The stacked radiation shields located very close to NIJI-1 effectively suppressed radiation doses even at the door of the usual exit. The thick shielding door almost completely absorbs radiations generated during electron injection to NIJI-1; no significant difference, therefore, was observed between energy spectrum taken in injection mode and that of pure background.

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