RADIATION MONITORING IN A SELF-SHIELDED CYCLOTRON INSTALLATION

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INTRODUCTION

As nuclear medicine is approaching a new era with the spectacular growth of PET diagnosis, the number of medical cyclotrons installed within the major hospitals is increasing accordingly. Therefore modern medical cyclotron are highly engineered and highly reliable apparatus, characterised with reduced accelerating energies (as the major goal is the production of fluorine 18) and often self-shielded. However specific dedicated monitors are still necessary in order to assure the proper radioprotection. At the Careggi University Hospital in Florence a Minitrace 10 MeV self-shielded cyclotron produced by General Electric has been installed in 2000. In a contiguous radiochemistry laboratory, the preparation and quality control of ^{18}FDG and other radiopharmaceuticals takes place.
Aim of this work is the characterisation and the proper calibration of the above mentioned monitors and control devices.

MATERIAL AND METHODS

The air contamination level in the cyclotron room and the exposure levels both in the cyclotron room and in the radiochemistry room are under a continuos control by means of suitable probes connected to a centralised control and display system. The pass through area towards the cyclotron and the radiochemistry rooms is furnished with a hand-foot monitor in order to assess any possible surface contamination of the personnel on their way out. An overview of the installation layout is reported in Fig. 1.

Environmental exposure probes (Probes 1 & 2)

The probes are low dose rate Gm counters produced by SEA GmbH. Their calibration has been performed using a ^{18}F source of nominal activity 158 MBq, as measured by means of a standard dose calibrator, positioned at a distance of about 2 meters from the probes and the simply comparing their readings with that of a calibrated (by the National Calibration Service) ionisation chamber (Victoreen 450P) positioned in close proximity to each probe.

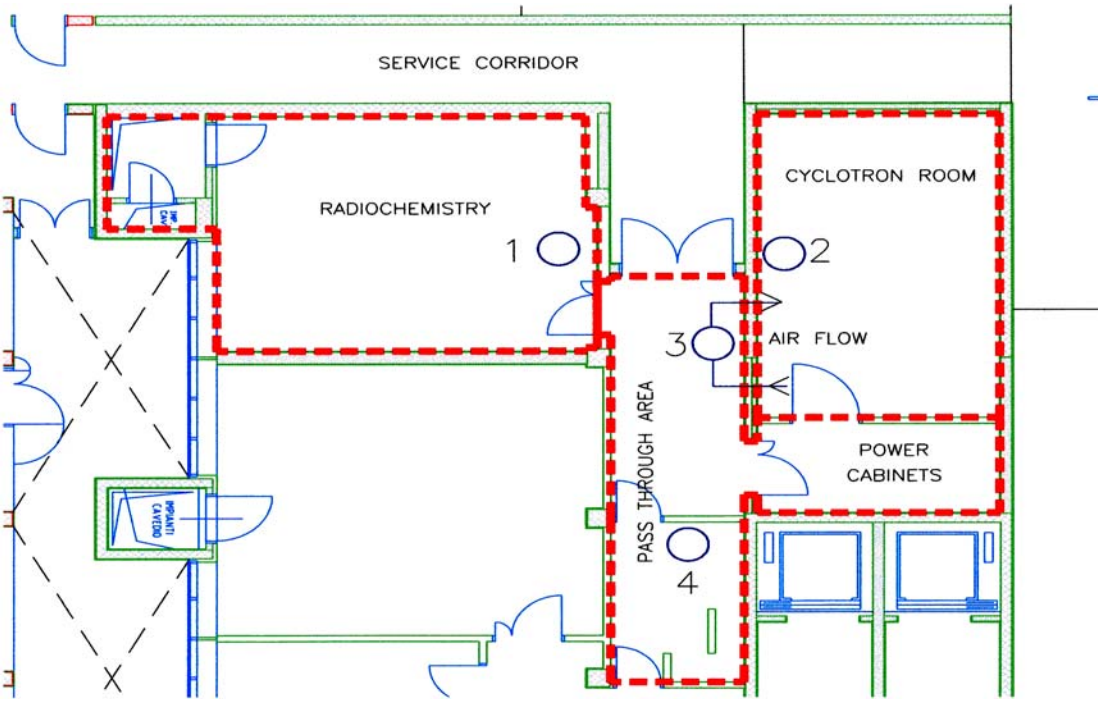

Fig. 1 - location of the radioprotection monitors inside the installation
1 & 2 – exposure level GM monitors
3 – cyclotron air contamination monitor
4 – hand-foot monitor

Air contamination control (Probe 3)
As a consequence of the low beam energy and of the selfshield around the cyclotron the neutron flux in the surrounding environment is very low. From neutron dose measurements it has been calculated being less than 2 neutrons s^{-1} cm^{-2}. Therefore the cyclotron doesn't give rise to any problem connected with the activation of ^{40}Ar within the air (nor for the activation of other elements in the same room). However, as a possible event of air contamination still exists, as it is the case of explosion of the (liquid) target during the irradiation, the monitoring of the environmental air is necessary in order to verify the accessibility or not of the personnel to the room. The air contamination monitoring is performed by means of a thin window GM counter, also produced by SEA GmbH, positioned within a sealed box having a volume of 6.5 litres. Such a box is located in the pass through area outside the cyclotron room where the irradiation level due to the cyclotron itself is negligible. The air is pumped inside the box from the cyclotron room by means of an internal ventilation system.
The calibration has been performed using two planar sources of ^{36}Cl and ^{137}Cs, both having dimensions 15x10 cm^2 and activity 21.5 Bq/cm^2, to simulate the ^{18}F beta and gamma emissions respectively.
In table I a comparison of the energy and abundance of the beta and gamma emissions of ^{36}Cl and ^{137}Cs vs. those of ^{18}F is reported.

Table I

Comparison of the abundance and the energy of β and γ emissions of ^{18}F ^{36}Cl and ^{137}Cs																
^{18}F						^{36}Cl						^{137}Cs				
β^+		100%	250	keV		β^-		98%	279	keV		β^-		95%	173	keV
γ		200%	511	keV								β^-		5%	426	keV
												γ		95%	662	keV

The ^{137}Cs source was shielded with a 5 mm PMMA plate in order to completely stop the beta emission. Measurements have been performed with the source located in different positions (see Fig. 2) around the probe in order to evaluate an average geometrical response, as the distribution of activity in the gas inside the box is supposedly uniform.

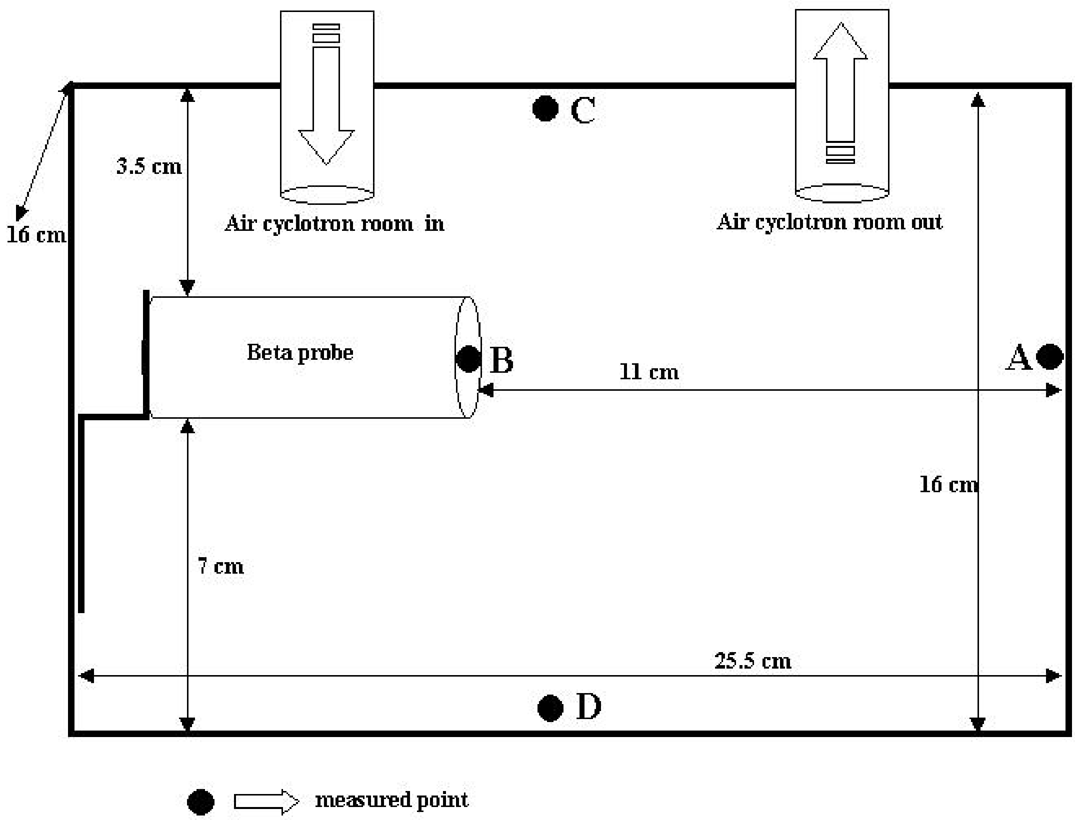

Fig.2 – detector set up for the cyclotron air contamination monitoring.

For each measurement point we calculated the calibration factors f (Bq/cps) both for ^{36}Cl and for ^{137}Cs (γ only):

$$f_{Cl}^{\beta} = \left(\frac{activity}{cps}\right)_{Cl} \qquad\qquad f_{Cs}^{\gamma} = \left(\frac{activity}{cps}\right)_{Cs}$$

For ^{18}F we obtain then:

$$f_{F}^{\beta} = \left(\frac{activity}{cps}\right)_{Cl} \cdot \varepsilon_{Cl/F} \qquad\qquad f_{F}^{\gamma} = \left(\frac{activity}{cps}\right)_{Cs} \cdot \varepsilon_{Cs/F}$$

where $\varepsilon_{Cl/F}$=98/100 and $\varepsilon_{Cs/F}$=95/200.
Finally the calibration factor f_F (Bq/cps) for ^{18}F is obtained from the relationship
$1/f_F = 1/f_F^{\beta} + 1/f_F^{\gamma}$

Hand – foot monitor (probe 4)
The sensitive devices of the monitor are four ZnS large area flat detectors (left and right hand, left and right foot) simultaneously measuring the surface contamination in Bq/ cm ^{2} The same ^{36}Cl and ^{137}Cs sources and a very similar procedure as for the calibration of the probe for the air contamination were used, but the position of the sources which, in this case, was (obviously) always the same for each of the four detectors. An additional correction was eventually added taking into account for the ratio between the area of the detectors and the area of the planar sources.

RESULTS
In table II, III and IV are reported the results of the calibrations described in the above section.
For the hand-foot monitor only the final results are reported.

Tab. II
Calibration of the environmental exposure probes

(All data in µSv/h)	Probe1 (cyclotron room)	Probe 2 (radiochemistry room)	Ionisation Chamber Victoreen 450P
Background	0,05	0,05	0,01
158 MBq ^{18}F source 2m apart	6,91	6,82	7,2

Tab. III

Calibration of the air contamination probe

(letters A, B, C and D refer to the locations of the sources correspondingly shown in Fig. 1)

	A (cps)	**B (cps)**	**C (cps)**	**D (cps)**
^{36}Cl 3230 Bq/150 cm^2	4.7	29.7	4.2	3
^{137}Cs 3230 Bq/150 cm^2	0.2	0.8	0.5	0.3
	A f (Bq/cps)	**B f (Bq/cps)**	**C f (Bq/cps)**	**D f (Bq/cps)**
f^{β}_{Cl}	687	109	769	1077
f^{γ}_{Cs}	16150	4038	6460	10767
f^{β}_{F}	673	107	754	1055
f^{γ}_{F}	7671	1918	3069	5114
f_F (Bq/cps)	619	101	605	875
f_F (Bq/cps)	**550 (average between positions A, B, C and D)**			

Tab. IV

^{18}F Calibration factors f_F (Bq/cps) for the hand - foot monitor

LH	**RH**	**LF**	**RF**
15.1	19.9	7.8	6.8

Such factors are then divided by the hand or foot area (by default assumed to be equal to 150 cm^2), so that the final result displayed by the monitor is expressed in Bq/cm^2 .
The alarm threshold for ^{18}F is set at 8 Bq/cm^2, corresponding to about 1/3rd of the limit for removable contamination for professional workers as calculated according to (2).

CONCLUSIONS

There is a good agreement (within 6%) between the two environmental probes and the calibrated ionisation chamber. Moreover their sensitivity is well adequate, with an alarm threshold properly set above the background, to detect any abnormal or unpredicted residual activity within the target container as well as to detect the presence of radioactive sources in the radiochemistry room outside their schieldings.

The apparatus for controlling the air contamination is very simple though its sensitivity is high enough to assure the instantaneous detection of ^{18}F concentrations well below $1x10^6$ Bq/m^3 assumed as investigation level (1). In such a circumstance the activity in the detection box would be 6500 Bq, corresponding to 12 cps. Setting the alarm threshold to 1 cps (natural background being about 0.1 cps) allows therefore the prompt detection of air concentrations of ^{18}F below $1/3^{rd}$ of the IL, even in the worst case of an overestimation of the calibration factor up to 100%.

Similar considerations apply for the hand – foot monitor as its sensitivity for ^{18}F resulted well above the derived limits for the skin surface (2).

As a general remark, we can state that modern selfshielded medical cyclotrons require monitoring systems which are reduced in number, rather inexpensive and not difficult to be calibrated.

REFERENCES

(1) ICRP 78 – Individual Monitoring for Internal Exposure of Workers, Annal of the ICRP vol.27 n°3/4 1997.

(2) Radionuclide and Radiation Protection Handbook 1998, Rad. Prot. Dos, Vol 76, Nos. 1 – 2, 1998.