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^{99m}Tc ORGAN DOSES MONITORED BY WHOLE BODY COUNTER

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^{99m}Tc ORGAN DOSES MONITORED BY WHOLE BODY COUNTER

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ABSTRACT

The Whole Body Counter monitorage for the human internal contamination is presented. It is possible to detect gamma emitters with energy higher than 100 KeV with an amount higher than about 100 Bq. The detected spectra can be used to measure the up-take, the retention, the biological decay of radioisotopes and the doses in different organs. An accurate study on the ingestion intake of sodium pertechnetate marked with ^{99m}Tc is discussed.

1. INTRODUCTION

The monitoring of the internal contamination by radioisotopes is an actual research field very useful to protect the human species subjected more and more to this type of risk. The use of radio-drugs and marked molecules in nuclear medicine, the radioisotopes manipulation activities, the nuclear accidents occurring in the world and the consequent radioactive fall-out represent some of the typical risks which we are exposed.

A "whole body counter" (WBC) is a system that measures the activity of radioisotopes into the human body by an external detector. It is very difficult the monitoring of alpha, beta and X-ray radioemitters because its signals are absorbed by the body. Very simple, instead, is the detection of gamma emitters with energy higher than 100 keV.

WBC Investigations

- Determination of the contaminant radioisotope
 - Localization of the radioisotope
 - "Up-take" measurements in organs
 - "Retention" measurements in organs
 - "Biological half-time" measurements in organs
 - Measurements of dose given to organs
 - Measurements of dose given to the whole body
 - Study of metabolic activities
 - Determination and study of particular pathologies
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Tab.I - Possible investigations obtainable using a WBC

A WBC detects the radioactivity of different organs, follows the activity decay and measures the absorbed dose by the organs, as reported in Tab.I.

Generally WBC uses large NaI(Tl) detectors with high detection efficiency and the analysis procedure is standardized [1].

Doses measurements are obtained comparing the activity in the patient with that of a phantom with organs, as equivalent-tissue, filled with a known amount of the investigated radioisotope.

In this paper we will discuss some results obtained using the WBC of the Catania University. Special attention will be devoted to the internal contamination by ^{99m}Tc , a marker radioisotope very useful in nuclear medicine [2].

2. MATERIALS AND METHODS

The used WBC has a configuration so called "standard chair". The patient is seated on a plexiglass chair which is shielded by lead walls (4 inches in thickness). A single NaI(Tl) detector, provided by lead collimator and adjustable jib, can be placed on different patient's organs.

The scintillator dimension are: 5 inches in diameter and 4 inches in thickness. The collimator is cone-shaped with an aperture 3.5 inches in diameter and 2 inches in length.

Fig.1 shows the detection efficiency, as counts per seconds per Bequerels (cps/Bq) of the WBC. Detection efficiency decreases with gamma's energy and at 500 keV is 1.5×10^{-3} cps/Bq.

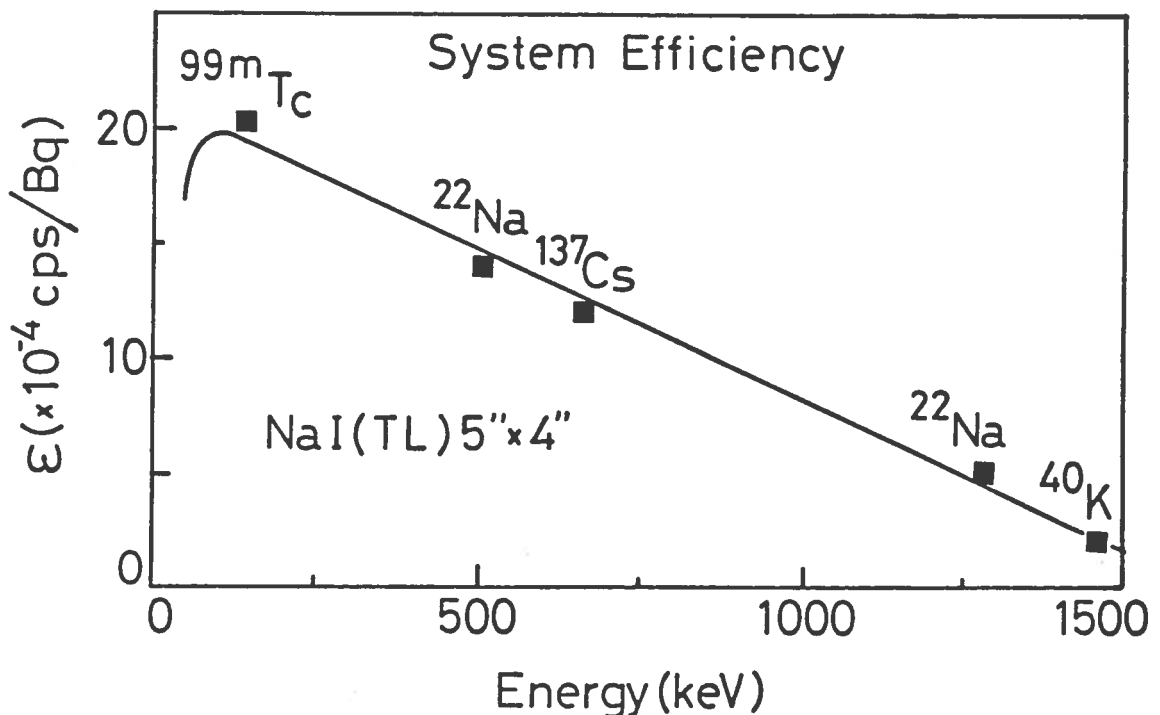


Fig.1: WBC detection efficiency as a function of the gamma's energy

The minimum detectable amount (MDA), measured with a 3σ significance rule of the standard deviation of the background signal, depends on the following parameters [3]:

$$MDA = (3 / \varepsilon) \sqrt{C / t} \quad (1)$$

where ε is the system detection efficiency (cps/Bq) for the examined radionuclide, C is the count rate (cps) measured in the energy interval ΔE of the background spectrum for an uncontaminated patient and t is the spectrum acquisition time (sec).

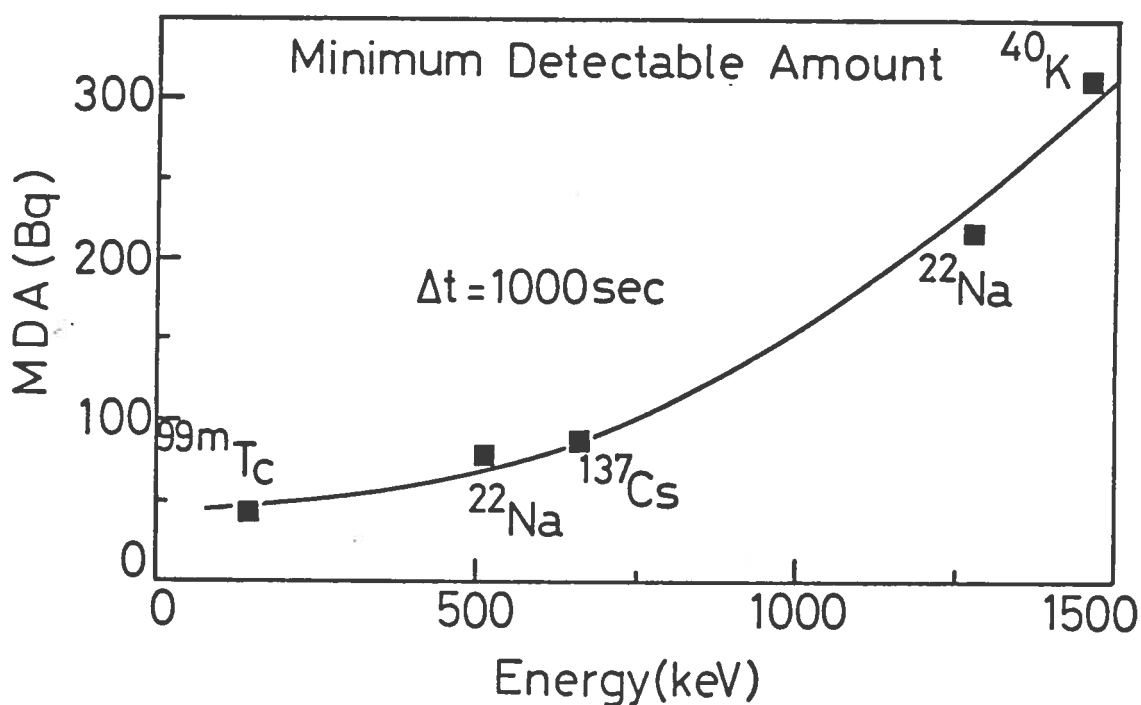


Fig.2: Minimum detectable amount as a function of the gamma's energy

High sensitivity is obtained increasing the acquisition time and reducing the background signal. Acquisition times of about 1000 sec are sufficient to have a low MDA value and are acceptable for the patient.

Fig. 2 shows the MDA values, in Bq units, of our WBC system as a function of the gamma's energy. With 1000 sec acquisition time the MDA for 140 keV is of about 50 Bq.

^{99m}Tc was prepared by a ^{99}Mo reactor and used to investigate on the internal contamination [4]. The half-time of the ^{99m}Tc is 6 hr, the emitted gamma ray energy is 140 keV, the investigated marked molecule was the NaO_4Tc (sodium pertechnetate), which is largely used in nuclear medicine.

A solution containing 200 μCi of $^{99\text{m}}\text{Tc}$ per 100 cc of H_2O has been given, by ingestion, to a voluntary, adult and healthy patient (1.7 m tall and 70 Kg weight).

WBC investigations were performed repeating the analysis on different organs at different times from the intake. An acquisition time of 320 sec was used for each organ monitoring.

Measurements of biological decay, τ_b , were obtained by the known physical decay of the $^{99\text{m}}\text{Tc}$, $\tau_f = 521\text{min}$, and by the experimental effective decay in the analysed organ, τ_e , according the relation [5]:

$$\tau_e = (\tau_f \times \tau_b) / (\tau_f + \tau_b) \quad (2)$$

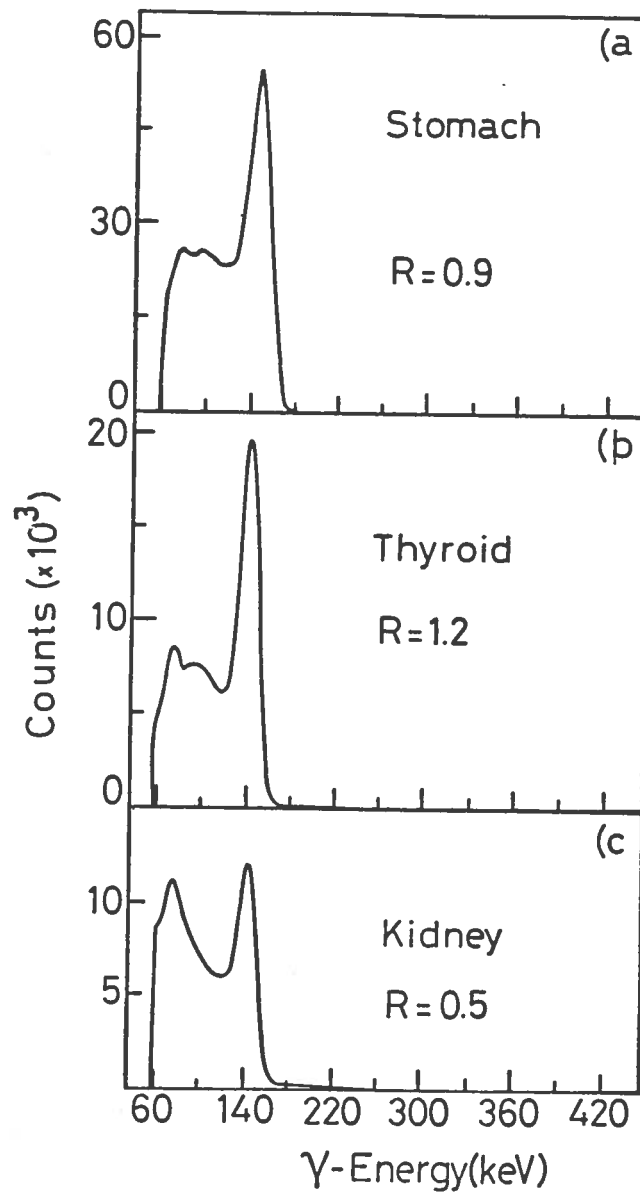


Fig.3: Spectra for $^{99\text{m}}\text{Tc}$ intake by stomach (a), thyroid (b) and kidney

3. RESULTS

Fig. 3 shows three typical spectra obtained monitoring the radioisotope activity in the stomach (a), thyroid (b) and kidney (c). Each spectrum indicates clearly the detection of a photopeak at 140 keV energy and of a Compton background which is dependent on the analysed organ.

The Compton scattering is increased by the large organ dimensions, by the organ depth in respect to the body surface and by the small dimensions of the detector collimator.

The photopeak/background signals ratio, R , is high (>1) for small and superficial organs, such as the thyroid. Large and deep organs, such as kidneys and intestine, instead, show a low R ratio (<1) due to the high contribution of the scattered photons.

Fig. 4 shows the experimental activity measured in the thyroid as a function of the time. The plot indicates the initial uptake phase and the successive decay time of the marked molecules inglobed in this organ. Uptake and decay depends mainly by the hematic flux in the thyroid.

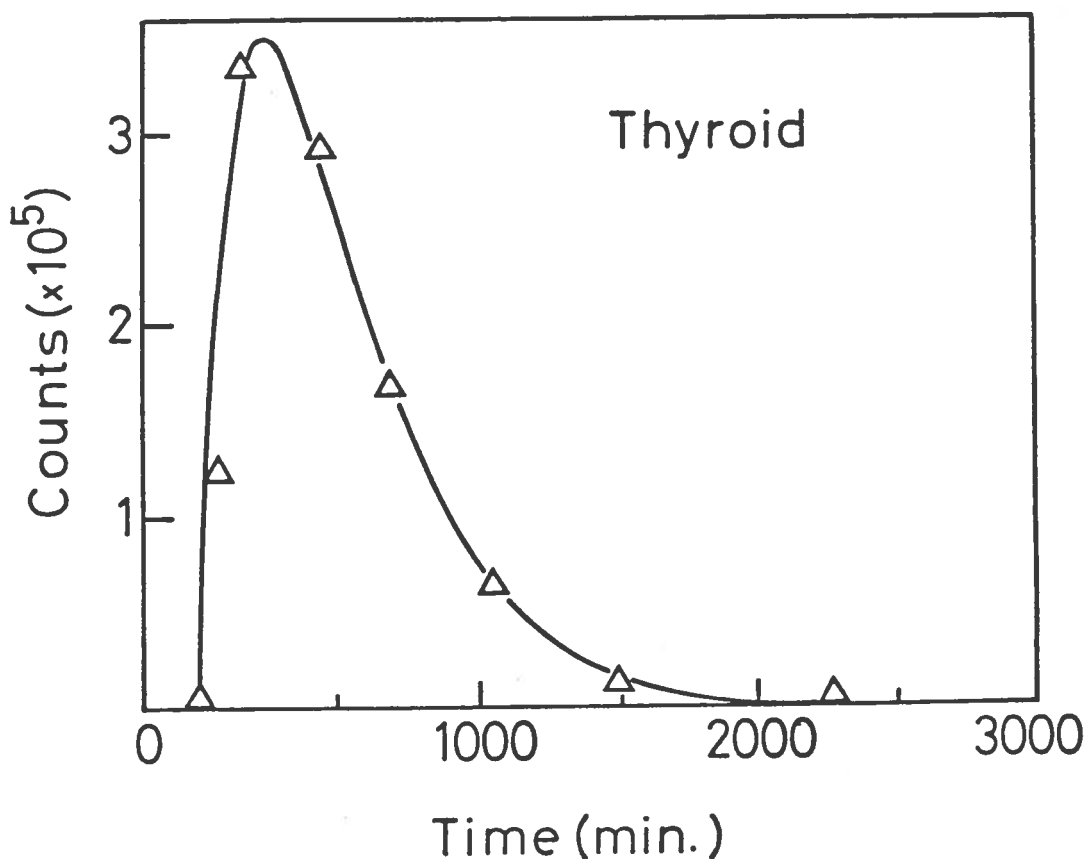


Fig.4: ^{99m}Tc activity detected in the thyroid as a function of the time

Similar measurements have been performed on different organs of the same patient : stomach, bladder, kidney, intestin and head.

Obtained results indicate that the gastrointestinal intake produces a fast uptake of the stomach ($\tau_u=16$ min) and a slow uptake of the thyroid ($\tau_u=230$ min), as reported in Tab.II. The biological decay times indicate a fast decay in the kidney ($\tau_b=700$ min) and a very slow decay in the intestinal tract ($\tau_b=12400$ min). The data for the "body" are referred to all not examined organs of the patient.

Organ	minutes		
	$\tau_{up-take}$	$\tau_{effective}$	$\tau_{biological}$
Stomach	16	300	700
Bladder	50	340	980
Kidney	200	300	700
Thyroid	230	350	1060
Intestin	90	500	12400
Head	65	320	830
Body	110	350	1060

Tab.II - Measurements of uptake and decay times in different organs

The count rate (cps) measured in different organs is proportional to the amount of absorbed radioisotope. The "true" activity into the organ was measured comparing the experimental count rate detected externally to the body with that detected in a simulated organ of a fantom containing a know activity. As simulated organs were used balloons filled with water with a geometry and mass equivalent to each organ.

The dose rate D (mRem/sec) given to the single organ can be calculated as follow :

$$D = (E_{\gamma} A) / M \quad (3)$$

where E_{γ} is the emitted photon energy (140 keV), A is the measured activity (Bq) and M is the organ mass (Kg).

Tab. III shows the organ masses, the experimental values of the count rate and the dose rates in different organs (at the maximum activity).

Organ	Mass (gr)	Counts/sec (cps)	Dose rate (μ Rem/sec)	Total dose (50hr) (mRem)
Stomach	600	6180	4.3	112
Bladder	250	925	0.64	19
Kidney	150	1170	0.8	21
Thyroid	20	1425	1.0	26
Intestin	3500	865	0.6	26
Head	1500	560	0.4	11
Body	63800	195	0.14	4

Tab. III - Values of the total doses measured in different organs

Generally, the activity of ^{99m}Tc in the investigated organs remains significantly high for times lower than 1000 minutes. The total dose absorbed by each organ has been calculated integrating the dose rate on times up to 50 hours. Obtained values indicate that the maximum absorbed dose is found in the stomach (112 mRem), intestine and thyroid, as reported in Tab.III.

Considering the body as a homogeneous system, the maximum the dose rate should be $D_h = 0.24 \mu\text{Rem/sec}$. Because the system is not homogenous, it is possible to calculate the organ retention, **Ret.**, by the equation:

$$\text{Ret.} = (D_i / D_h)(m_i / M) \quad (4)$$

where D_i is the maximum dose rate in the i-th organ, m_i is the mass of i-th organ and M is the mass of the total body (70Kg).

Fig. 5 shows the retention values within 2 hr from the intake. The 17% of the intake activity is localized in the stomach, the 13% in the intestine tract and only the 0.2% is in the thyroid. In the excrets have been calculated retention values lower than 1%.

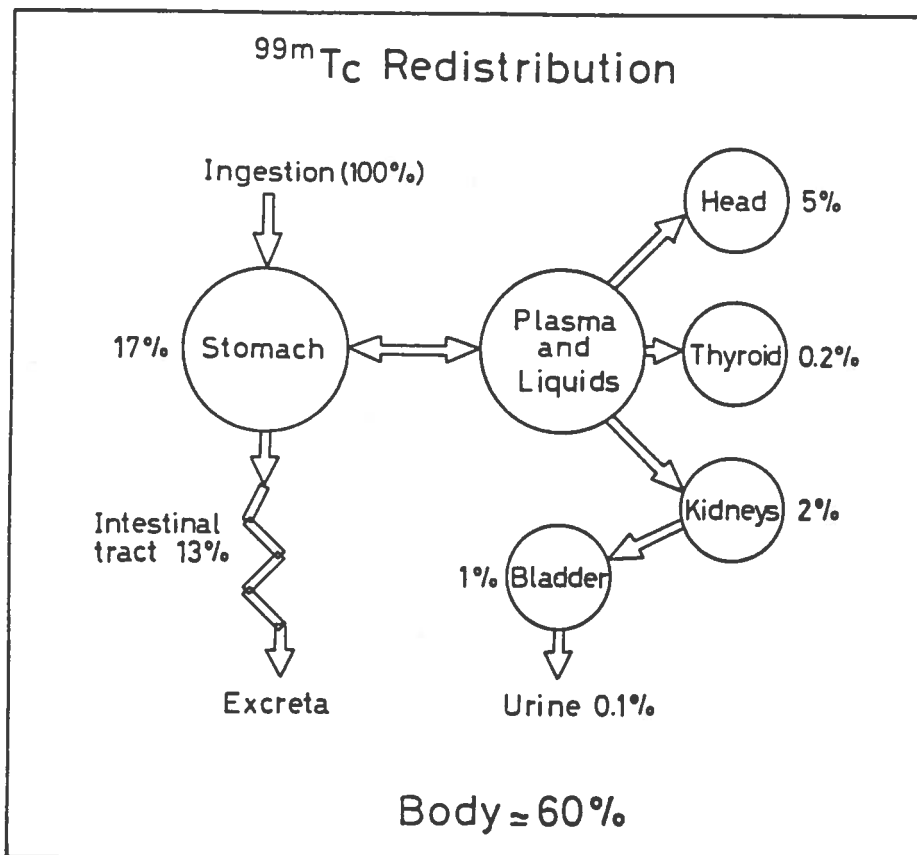


Fig.5: Percentual retention of the radionuclide in the initial phase of internal contamination.

Generally, dose measurements are affected by errors within the 20%. Indeterminations concern: organ masses, activity in the organ, photopeak counting and reciprocal influences between the organs. Such last contribute plays a significative role in the calculation of the correct total dose given to the single organ; it can be valued with the "transfer factors **S**" given by literature for a source organs (high activity) and target organs (lower activity)[6]. The firsts irradiate the seconds and contribute to increase its absorbed doses. The trasfer factors depend essentially on the geometrical-anatomical configuration of the organs and are relative to the radioisotope of interest.

To calculate the total dose absorbed by a single organ, D_t , we shall use the following relationship:

$$D_t = D_o + S D_s \quad (5)$$

where D_o represent the total dose experimentally measured in the organ and D_s is the dose experimentally measured in the stomach (the organ having higher activity).

Relatively to the internal ^{99m}Tc contamination, Tab. IV shows the values of the S -factors for different target organs considering the stomach as a source.

Target Organ	Source Organ (Stomach)
Stomach	0
Intestin UL	0.03
Intestin LL	0.01
Thyroid	7×10^{-6}
Lung	0.01
Liver	0.02
Kidney	0.03
Bones (total)	0.007
Testicles	4×10^{-4}
Egglers	0.004

Tab. IV - Transfer factors S relative to ^{99m}Tc (ingestion intake)

The S -factor is proportional to the distance source-target. To calculate the total dose really absorbed by the kidney, for instance, the measured dose of 21 mRem must be increased by 3% .

4. DISCUSSION AND CONCLUSIONS

Obtained values of absorbed doses by different organs are in well agreement with the Literature data. A comparison of measured doses with Literature data [7] for sodium pertechnetate absorbed by intravenous is shown in Tab. V.

The comparison is normalized to 1mCi administration and shows clearly that the ingestion intake releases a higher dose to the stomach in respect to that produced by intravenous intake.

ORGAN	Irradiation dose (mRem/mCi)	
	Experimental (ingestion)	Literature (intravenous)
Thyroid	130	130
Stomach	560	260
Bone Marrow	30	20
Testicles	15	10
Total body	20	15

Tab. V - Comparison of the absorbed doses between experimental and Literature data

The monitoring of radionuclides into the human body is of high interest for radioprotection aims.

Generally, for a traditional scintigraphy, the activity of used ^{99m}Tc given to the patient are of about 1 - 5 mCi thus the doses to the organs given in Tab.III must be increased by about a factor ten.

Reports of the International Committee for Radio Protection (ICRP) contain many data on the internal contamination but need of continuous revision. Mostly of data concern the models adopted to study the internal contamination for many chemical compounds and for organs as different connected compartments [8].

In this contest our experimental data are original and represent a first approach to investigate on the absorption and release by organs in presence of normal and pathological states. A study on different patients and on different intakes (ingestion, intravenous, inhalation,...) of sodium pertechnetate is in course.

A special interest is devoted to the calibration procedure by fantom. The fantom organs must be very similar to the real organs and the internal contamination must be simulated very correctly. To this, our WBC center is involved in an international network promoting the use of an antropomorphous fantom and common analysis procedures.

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