STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

Belgian Nuclear Research Centre
Environment, Health and Safety
Radiation Protection Dosimetry and Calibration
Boeretang 200
2400 Mol

Extremity Doses of Medical Staff for Complex Interventional Procedures and in Nuclear Medicine ExDos

Final report 2010

L. Struelens & S. Krim
F. Vanhavere

Contents

Executive Summary

In Belgium hardly any extremity and/ or eye lens doses are recorded on a routine basis for interventional procedures. However, the phenomena of cataract as a consequence of the exposure to ionizing radiation is a big issue and it is considered to reduce the dose limit for eye lens doses.
In nuclear medicine sometimes a ring or wrist dosemeter is used routinely. These dosemeters, however, can underestimate the maximum skin dose per square centimeter with a factor 4 to 10, depending on the position of the dosemeter and the procedure.

For the 7th framework program of the EC, a new project (ORAMED www.oramed-fp7.eu) was proposed and one of the major objectives was to determine extremity doses for interventional procedures and in nuclear medicine.The European project consists of 12 partners and in every participating country, measurements were performed in 3 and 2 hospitals for the interventional radiology/cardiology procedures and in nuclear medicine, respectively.
To obtain a more global overview of the situation in Belgium on the problematic of extremity doses and to be able to introduce the necessary radiation protection measures it was recommended to increase the number of hospitals. These extra measurements were performed within the Belgian ExDos project.
The Exdos project can be divided into 2 groups, classified according to the type of procedures that are considered:

A. Extremity / eye lens dosimetry for interventional procedures
B. Extremity dosimetry in nuclear medicine

I- Extremity / eye lens dosimetry for interventional procedures

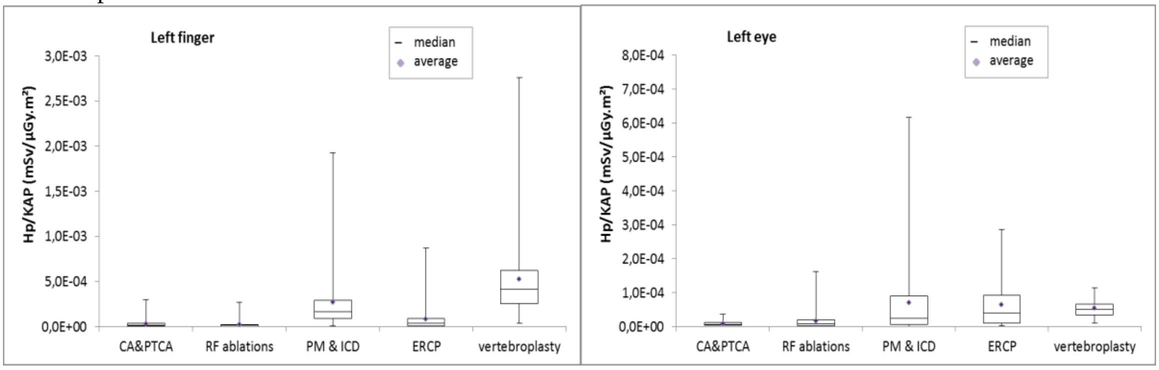
Within ExDos dose measurements are performed for:

- CA & PTCA
- RF Ablations
- Pacemakers and ICD implantation
- ERCP
- Vertebroplasties/kyphoplasties

For CA & PTCA, RF ablations and ERCP, measurements are performed in 9 different Belgian hospitals. PM and ICD implantations are monitored in 8 hospitals. Vertebroplasty procedures are performed less frequently and measurements were performed in 5 hospitals. In total, 354 measurements werecollected.
Dose measurements were performed using thermoluminescent dosemeters (TLDs)LiF crystals, doped with magnesium, copper and phosphore (LiF:Mg,Cu, P).The TLDs were sealed in small plastic bags and taped on the parts of the body to be monitored. 8 TLDs were used: 1 on each ring finger and wrist,1 on each leg about 5 cm below the lead apron, 1 between the eyes and 1 on the side near the left or right eye. Next to these dose measurements, also useful information about the X-ray system, the protection measures, KAP (Kerma-Area-Product) and the working procedure are collected, using well-established measurement protocols.

From all monitored procedures we observed that highest Hp(0.07)/KAP doses were obtained for the PM & ICD implantations and for the vertebroplasty/kyphoplasty procedures. For PM & ICD implantations, the operators are standing at the shoulder of the patient close to the X-ray beam. We also observed that in most cases no ceiling shield is used to protect the eyes and hands of the operator. Moreover, it was regularly observed during the measurement campaign that the hands were inside the primary X-ray beam. The same accounts for the vertebroplasty and kyphoplasty procedures. Also with these procedures no ceiling shields are used as they tend to obstruct the operator in its working practice. Another option for this specific procedure is to use a novel cement delivery system from a distance.
The lowest Hp(0.07)/KAP are obtained for the CA & PTCA procedures and RF ablations. For these procedures operators are more and more aware of radiation protection issues and radiation protection shielding is commonly used. The ERCP procedure has in general low absolute Hp(0.07) dose values because a small amount of radiation is used during this procedure (the lowest KAP values are obtained). However, for these procedures often X-ray systems are used with tube-above configurations and again protected shielding is not commonly used. This resulted in reasonable Hp(0.07)/KAP values for the eyes. In the figures below, an overview is given

of the extremity doses per unit of KAP for all hospitals together on the left finger and the left eye, respectively for each procedure.



Comparison of Hp(0.07)/KAP for each procedures at the left finger (left) and left eye (right)

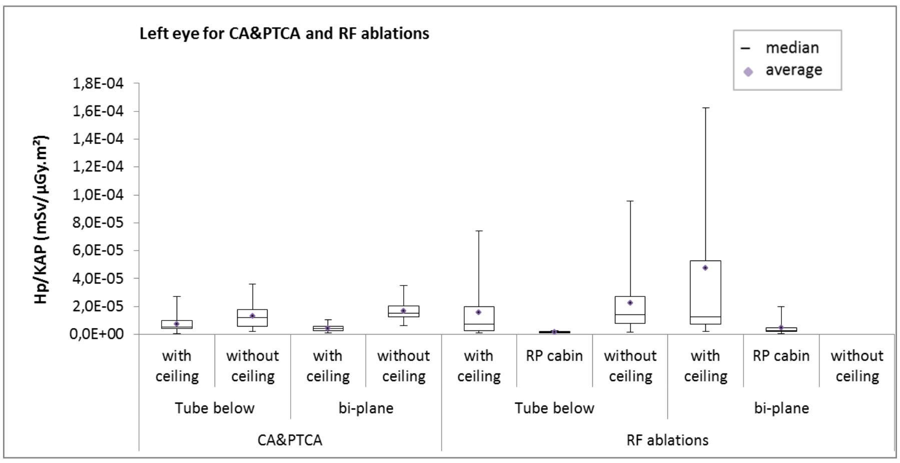
It is obvious that the use of radiation protection screens like the table shield, ceiling shield and RP cabin will decrease extremity doses to the legs, hands and eye lens doses, respectively.

The large database of the ExDos project makes it possible to make a representative assessment of how large this reduction is. For the PM & ICD procedures it was determined that the use of the table shield reduces the doses to the legs with 58%. For the ERCP leg doses were reduced with 70% and even 85% if only the tube-below configurations were taken into account. For the RF ablations and CA & PTCA procedures a reduction of 80% to the leg doses is determined when table shielding is used.

The use of a ceiling suspended shield has the largest effect on the eye doses. If well positioned, also the doses to the hands can be reduced. For RF ablations and CA & PTCA procedures, the eye doses are on average reduced with 80% by using a ceiling suspended shield. This kind of shielding was not used for ERCP, PM & ICD implantations and the verbroplasty & kyphoplasty procedures.

For the RF ablations, 2 hospitals used the RP cabin protection. Eye and finger doses decrease with 67% and 58%, respectively, compared to the procedures where a ceiling shield was used. The leg doses are further reduced with 80% compared to the use of a table shield.

In the figure below, the doses to the eye lens are presented for CA&PTCA procedures and RF ablations, for different tube configurations and compared between no use of ceiling shield, with the use of ceiling shield and when the RP cabin is used.



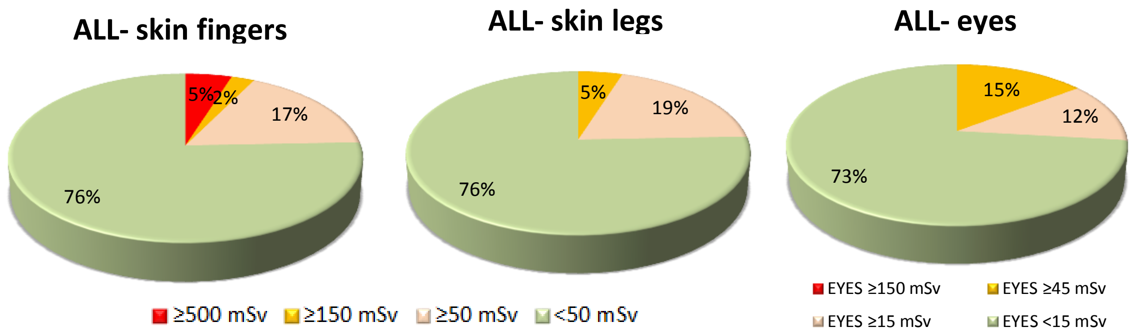
The effect of the tube configuration and protective equipment
on the dose to the left finger for CA & PTCA procedures and RF ablations

The annual dose limit for deterministic effects to the skin is set to 500 mSv averaged over 1cm² area of skin regardless of the area exposed. The annual dose limit for deterministic effects to the eye lens is set to 150 mSv. When 3/10th of the limit is reached, it is legally required that doses are routinely monitored.

For the operators monitored during this project an estimation is made of the annual dose by multiplying the average dose obtained for a certain procedure with his workload (number of procedures) of one year.

In appendix B, the annual doses for each operator are presented, together with information regarding the tube configuration and room protective equipment.

In the figure below, a frequency distribution is given of how many times a certain dose is exceeded for all procedures together.



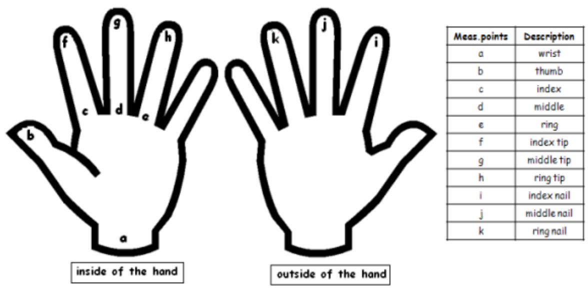
For the hands and legs, routine monitoring is necessary for doses > 150 mSv. For the eye lens, routine monitoring is necessary for doses > 45 mSv.
From the control of annual doses to different operators, we would recommend that routine monitoring is certainly useful for some interventional procedures. For PM & ICD implantations and vertebroplasty & kyphoplasty a routine monitoring of hand doses is required. Routine monitoring of eye lens doses is needed for all procedures, if the limit will be reduced.
For bi-plane systems and for tube-below configurations leg doses become high if no table shield is used, or when it is not properly used. If the table shield is always used, leg doses can be reduced significantly and no routine monitoring would be necessary.

A strong point of the ExDos project is that we have an overview of extremity and eye lens doses for a large number of hospitals. The obtained database is really representative for Belgium.
In general, extremity and eye lens doses can be reduced significantly with the use of protective shielding. However, the correct positioning of this shielding is one of the issues in practice at the moment. Especially the ceiling suspended shield is often not used effectively.

II- Extremity dosimetry for nuclear medicine

An extensive measurement program was performed with unified protocols in 13 different nuclear medicine departments distributed in Wallonia, Flanders and Brussels.

For diagnostics, two radionuclides were considered: F^{18} used for PET examinations and Tc^{99m} used for planar and SPECT examinations. For therapy, three of the most frequent treatments Zevalin, DOTATOC and SIRS labeled with Y^{90} were retained.
The objectives in ExDos were to carry out measurements in 8 hospitals for Tc^{99m} and F^{18}. For therapy applications, as many procedures as possible were followed. Series of 4 or 5 measurements for two different technicians for each one of the selected procedures were programmed.
The protocols specific to the labeling or the administration were adapted to diagnostic and therapeutic applications. Complementary information about the worker's dominant hand, his experience and the applied radiation protection equipment were collected for each monitored worker in order to correlate it with the measured extremity doses. To measure the skin dose across the hands, special gloves were designed with high sensitivity thermoluminescent dosemeters (TLD) placed at a minimum of 11 different positions on each hand. The positions are labeled a-k for the non-dominant (ND) hand, and A-K for the dominant (D) hand.



The results from EXDOS were used to have an overview of the extremity doses in Belgium. Within the ORAMED project, the results (together with results from other European countries and from simulations) will be analysed to make recommendations for better radiation protection.

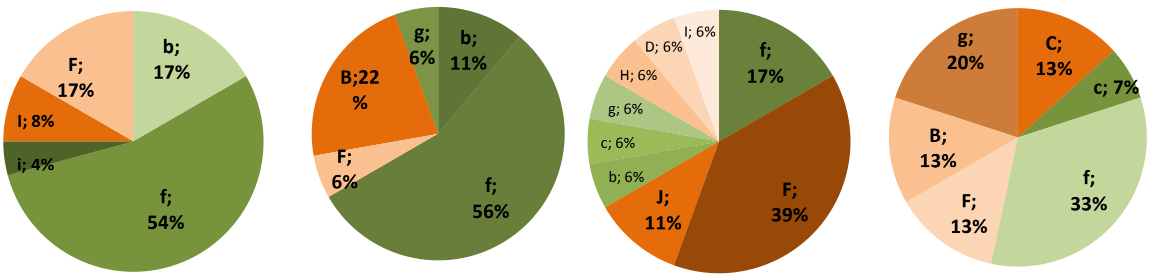
In total, 378 measurements werecollected and used for the analysis, from which

- 117 measurements from preparation of Tc^{99m} (18 workers)
- 90 measurements from administration of Tc^{99m} (18 workers),
- 84 measurements from preparation of F^{18} (18 workers),
- 66 measurements from administration of F^{18} (15 workers),
- 19 measurements for therapy with Y^{90} (preparation),
- 11 measurements for therapy with Y^{90} (administration),

All data were collected over a period of 24 months (from November 2008 until November 2010). The therapies with Y^{90} are non-frequently performed procedures and only a few were followed.

Firstly, this extensive Belgian study on extremity dosimetry in nuclear medicine helped in assessing the locations of the maximal doses on the hand of the worker for the different types of procedure.

In the following pies are given -averaged per worker- the frequency and the location of the maximum doses respectively for the preparation and administration for both Tc^{99m} and F^{18}.



Frequency and the location of the maximum doses respectively for Tc Prep – Tc Adm – FDG Prep – FDG Adm

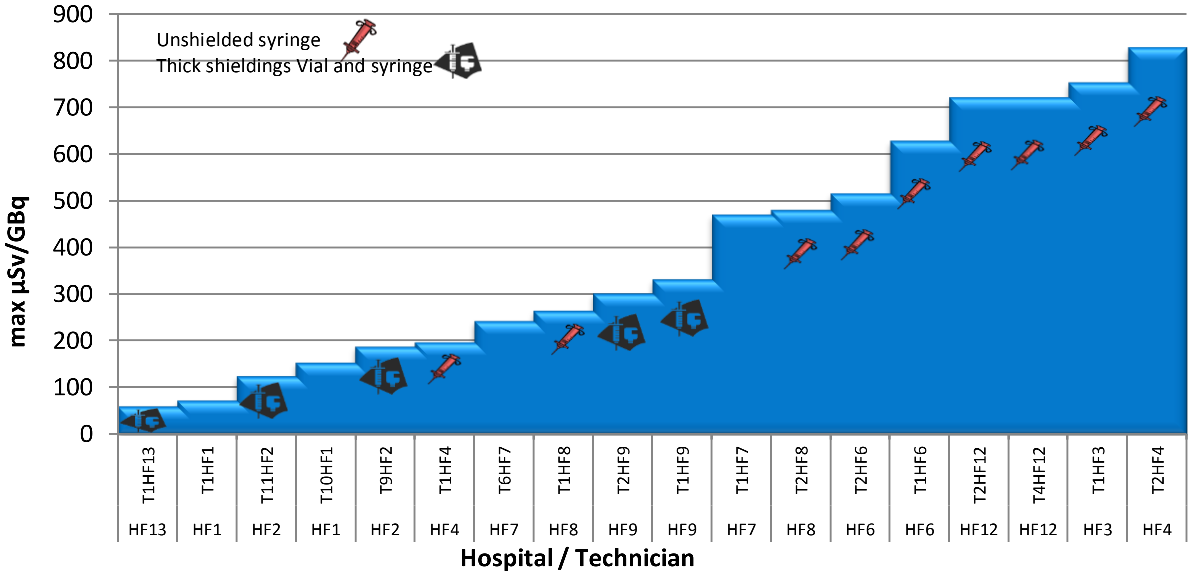
At first glance, the non dominant hand (green slices) is more frequently exposed than the dominant hand for most of the workers for both preparation and administration of Tc^{99m}. In the controry, the dominant hand (orange slices) is clearly more exposed for the preparation of F^{18} whereas for the administration it is not so evident.

For both preparation and administration of Tc^{99m}, workers receive the highest exposure on the index tip of the non dominant hand (around 55% of the workers). The thumb is the second problematic position : for 20% of the workers the largest doses were found on the thumb of the non dominant hand for the preparation of Tc^{99m} and from 11% to 22% depending on the hand for its administration.

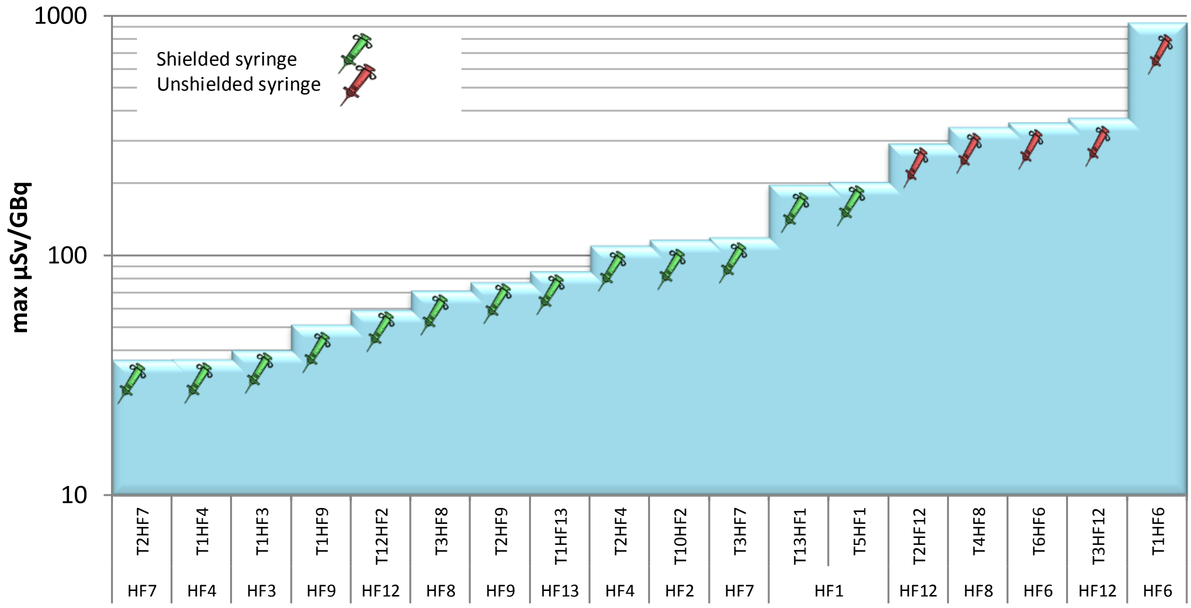
For preparation of F^{18}, the index tip on the dominant hand is more frequently the location where the highest doses were measured for 39% of the workers.
For administration of F^{18}, the index tip and the thumb are the positions where the maximum doses were measured. Nethertheless, it is not clear which hand receives most often the highest exposure, it seems that it depends on the worker and on the way he administrates the radioactive solution to the patient.

Secondly, the results normalized per manipulated activity can be used to have an overview of the maximum doses one can expect for the different types of procedure.

The two following charts show the maximum doses measured per worker respectively for the preparation and the administration of Tc^{99m}.



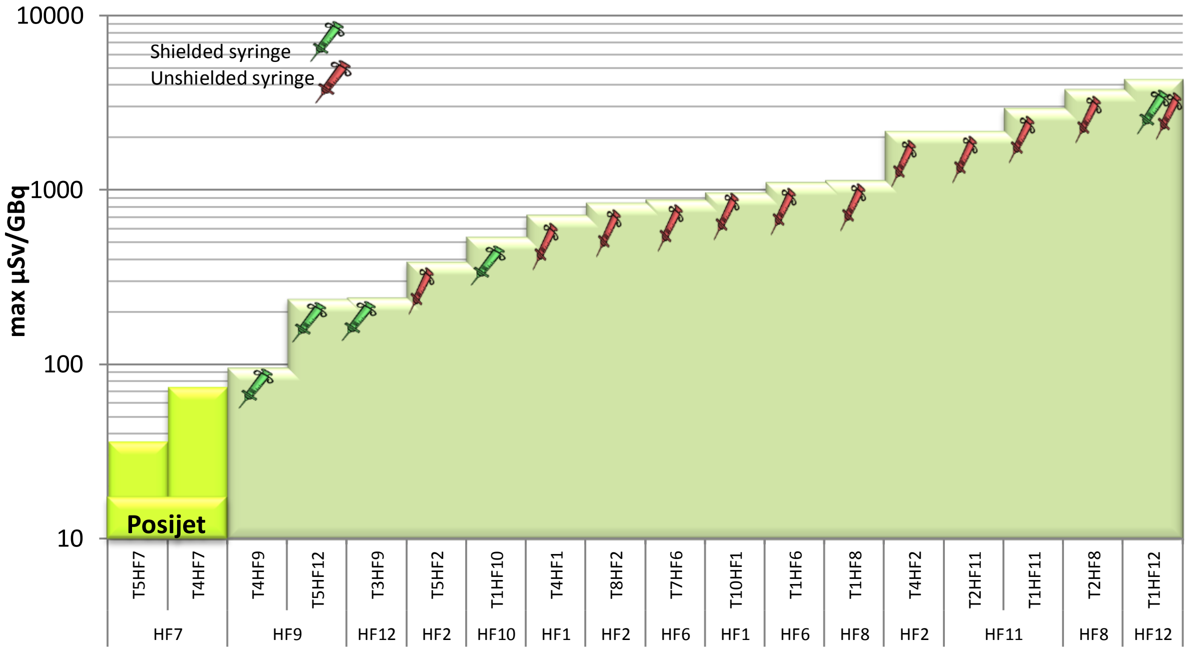
Maximum normalized doses per worker for preparation of Tc^{99m}



Maximum normalized doses per worker for administration of Tc^{99m}

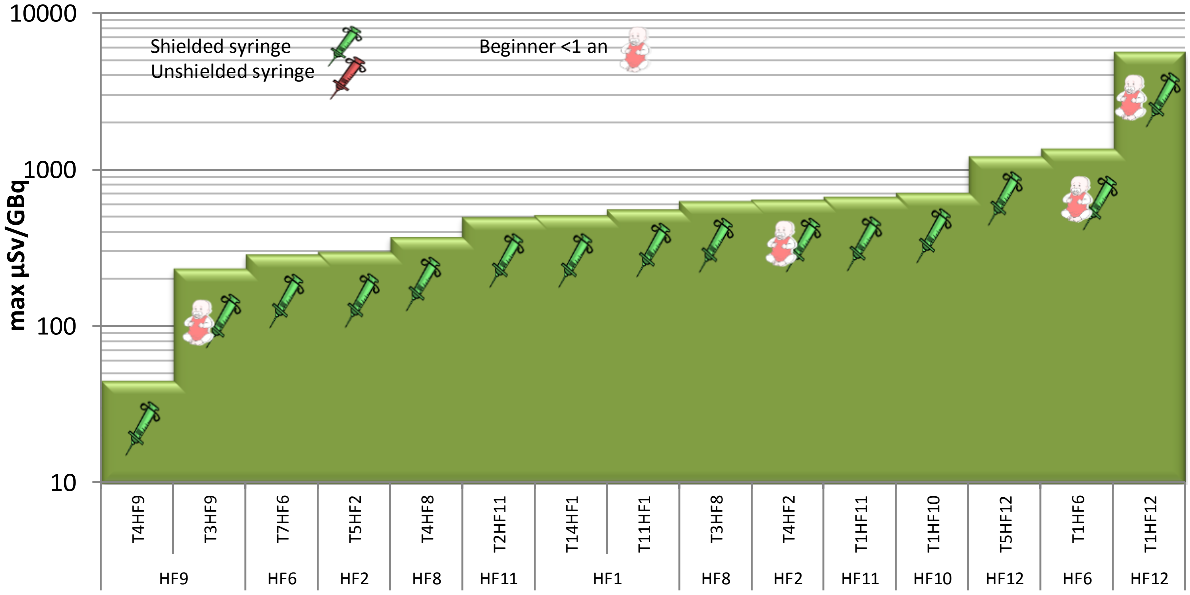
On the left part of the charts are situated the workers with good working practice. The workers using unshielded syringes are clearly situated on the right side for both the preparation and the administration of Tc^{99m}.

The two following charts give the maximum doses measured per worker respectively for the preparation and the administration of F^{18}.



Maximum normalized doses per worker for preparation of F^{18}

For the preparation of F^{18}, workers using thick shielding for syringes receive unmistakably lower doses. The use of a shielded syringe is clearly considered as a main factor in reducing the doses to the hands.



Maximum normalized doses per worker for administration of F^{18}

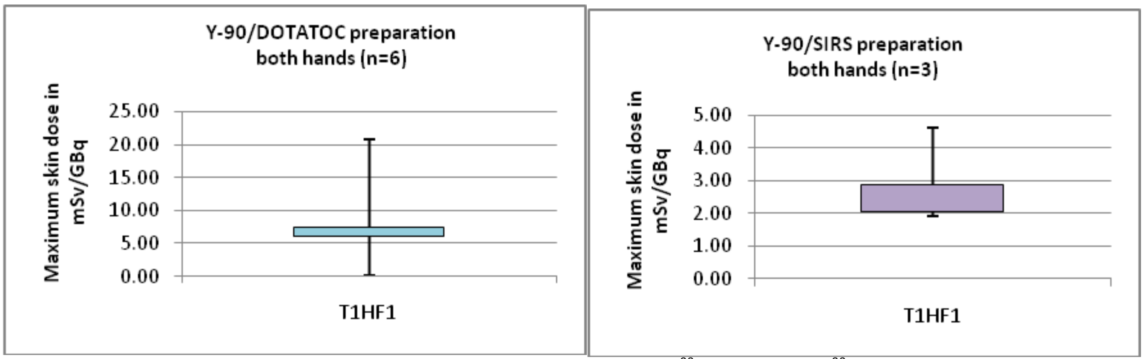
For the administration of F^{18}, all workers that participated to the measurements used a shielded syringe. Workers with less than one year experience were considered as beginner. In this subgroup, two persons -T1HF12 and T1HF6- received higher doses while injecting the F^{18} to the patients than the rest of the workers despite using adequate shielded syringe. In some cases, it seems that the experience of the worker can be considered as a factor influencing the extremity doses but in practice it is difficult to establish its statistical significance. This was demonstrated within the detailed analysis of ORAMED.

The results of the measurements campaign highlight large variations among procedures and workers.

Although the doses normalized by the manipulated activity might be different in absolute value due to the different workload, F-18 procedures are likely to give more exposure than Tc^{99m} when the doses are normalised by the relevant activity. Also, the preparation steps induce more radiation for the skin of the worker than the administration.

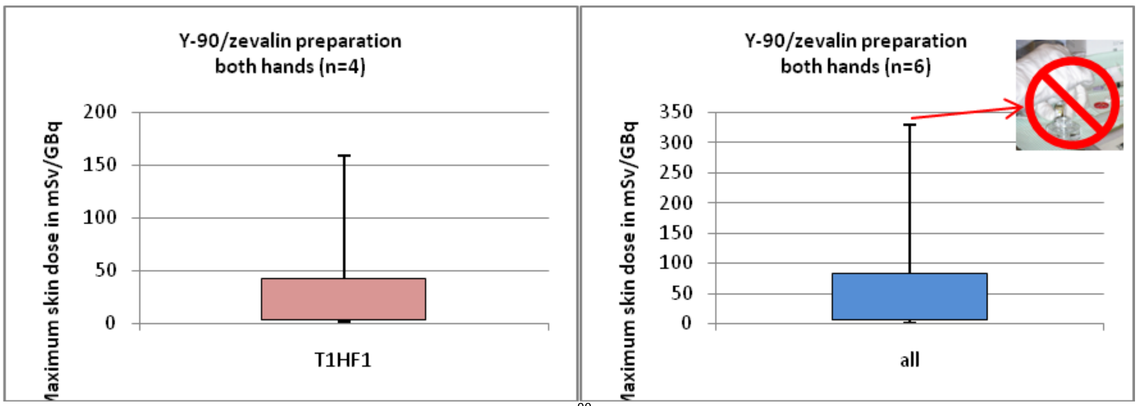
To some extent, the spread of the doses, even within the same procedure, is the expected consequence of the nature of the problem (betas or positrons emitters, orientation of the syringe, distance to the radioactive solution, time of manipulation etc….).
However, the very wide range of maximum doses observed (from some tenths of µSv/GBq up to one thousand for Tc^{99m}, from some tenths of µSv/GBq up to more than five thousand for F^{18} and from few mSv/GBq to more than hundreds mSv/GBq for Y^{90}) is an indication that good and bad practices were performed and thus, that workers with larger doses could actually optimize their working procedures or habits in order to decrease the dose.
Three factors were associated to those workers with higher doses, contamination (in that case the measurements were not considered), working without shielding and direct contact with the source container.

The following charts give the maximum skin dose measured with the associated range (median, mean, minimum and maximum) respectively for the preparation of Y^{90}DOTATOC, Y^{90}SIRS and Y^{90}Zevalin for the same worker.



Maximum doses per worker for preparation of Y^{90}DOTATOC and Y^{90}SIRS

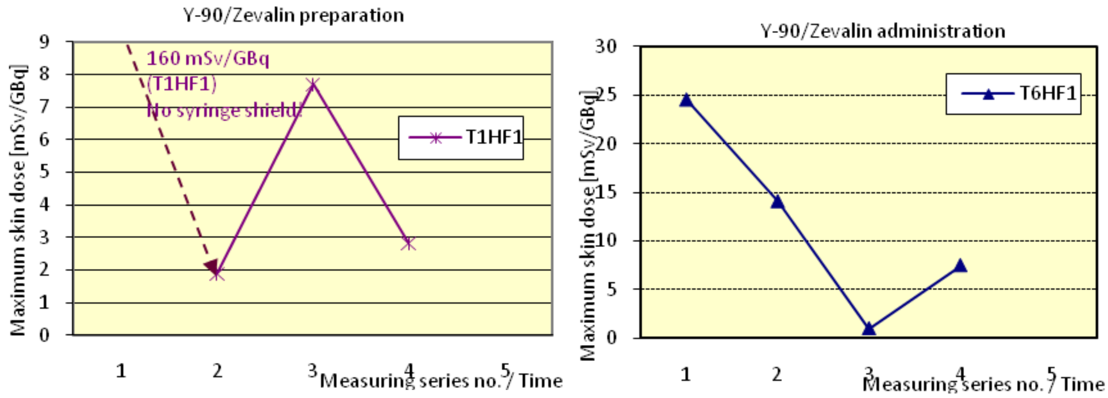
The labeling of Y^{90}Dotatoc can also induce high doses up to 20 mSv/GBq.
During the labeling of Y90/Zevalin (left hand side chart below) severe exposure was measured during the preparation of Y^{90}Zevalin where dose up to 160 mSv/GBq was measured for worker T1HF1 (left chart below) and even up to 300 mSv/GBq due to a bad handling of the reaction vial for another worker (right hand side chart below, in the associated picture : one can see the hand in direct contact with the reaction vial).



Maximum doses per worker for preparation of Y^{90}Zevalin (left worker T1HF1, right all workers)

It should be stressed that optimisation of the exposition is possible. Doses as low as a few mSv/Gbq can be reached for the same therapy. As the therapies are very low in frequency, the worker is not familiarized with betas emitters of high energy and should receive first adequate training. Moreover proper shieldings should also be used in the correct way.
For instance, the reaction vial should remain inside its shield and the syringes should be shielded during all steps of the labeling.

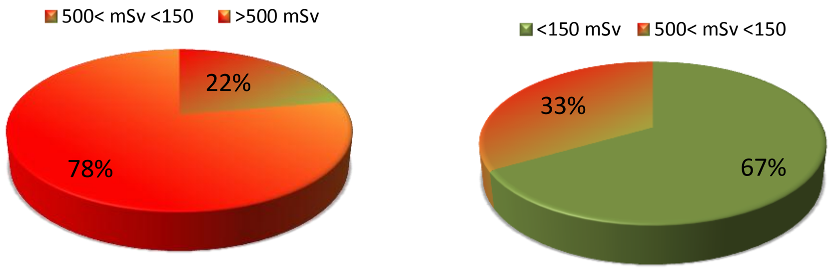
Due to changed awareness regarding beta radiation exposure in hospital HF1, some optimisation was done in order to reduce the exposure of the workers.
The charts below give the dose histories for 2 workers after the 1st, 2nd , 3rd and 4th therapy.



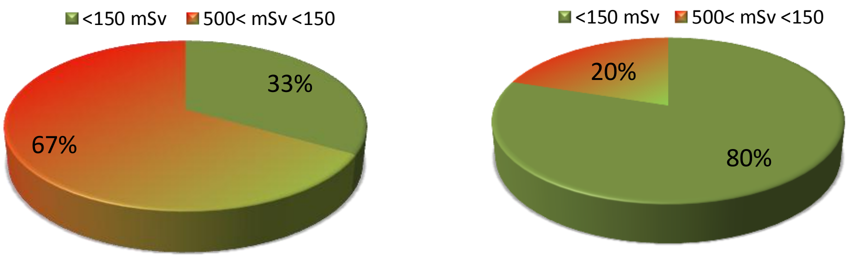
Dose history for Y90/zevalin respectively for workers T1HF1 (prep) and T6HF1 (adm)

Several handlings were corrected and proper shields (e.g. made of 1 cm thick lead glass at least) but also twizers were used. The maximum doses measured drop from 160 mSv/Gbq and 25 mSv/GBq to a few mSv/GBq for respectively the preparation and administration of Y^{90}Zevalin for the same workers.

The annual dose limit for deterministic effects to the skin is set to 500 mSv averaged over 1cm² area of skin regardless of the area exposed. When 3/10th of the limit is reached, it is legally required that doses are routinely monitored. The annual manipulated activity was assessed by each center for their relevant workers depending on the annual activity prepared and administrated and on their working days.
The estimation of the annual dose for a worker performing only one type of procedure was obtained by multiplying the maximum, among all positions in the hand, of his mean normalized doses from all his measurement series by his annual manipulated activity.
The annual dose were thus estimated for 29 different operators for the procedures for which real measurements were available (Appendix E).
Even considering this criteria, it is found that the extrapolated doses are in the range between the 3/10th of the annual limit and the annual limit itself, indicating once again that the monitoring of the extremity doses is clearly a requirement in nuclear medicine. In the figures below, a frequency distribution is given of how many times a certain dose is exceeded for each procedure.



Estimation of the annual doses respectively: Tc^{99m} Prep (9wkr) – Tc^{99m} Adm(9 wkr)



Estimation of the annual doses respectively: F^{18} Prep (12 wkr) – F^{18} Adm (10 wkr)

The preparation of Tc^{99m} is likely to give the largest contribution to the annual dose given its frequency and the activities handled by the workers.

Introduction

In Belgium hardly any extremity and/or eye lens doses are recorded on a routine basis for interventional procedures. However, the phenomena of cataract as a consequence of the exposure to ionizing radiation is a big issue and it is considered to reduce the dose limit for eye lens doses. For medical staff that does not follow the radiation protection measures, the dose limits to the fingers can be reached. In the literature study of the EC FP6 CONRAD project extremity doses are reported for interventional cardiology procedures (ex. PTCA, CA), interventional radiology (ex. embolisations, TIPS, stents, angioplasty) and orthopedic procedures (ex. vertebroplasty)[1].
In nuclear medicine sometimes a ring or wrist dosemeter is used routinely. These dosemeters, however, can underestimate the maximum skin dose per square centimeter with a factor 4 to 10, depending on the position of the dosemeter and the procedure. In the literature study of the CONRAD project extremity doses are evaluated for conventional nuclear medicine (mainly the use of Tc^{99m}, gamma emitter), PET examinations (use of ^{18}F, positron emitter) and for nuclear therapeutic procedures (use of Y^{90}, Re^{186} etc., beta emitters). In all cases, the dose limits can be exceeded.

For the 7th framework program of the EC, a new project was proposed and one of the major objectives was to determine extremity doses for interventional procedures and in nuclear medicine. The project (ORAMED www.oramed-fp7.eu) is coordinated by the SCK•CEN. The European project consists of 12 partners and in every participating country, measurements were performed in 3 and 2 hospitals for the interventional radiology/cardiology procedures and in nuclear medicine, respectively.
To obtain a more global overview of the situation in Belgium on the problematic of extremity doses and to be able to introduce the necessary radiation protection measures it was recommended to increase the number of hospitals. These extra measurements were performed within the Belgian ExDos project.
The ExDos project was launched in parallel with the European project ORAMED, therefore partly the same procedures were evaluated and the same measurement protocols were used. The protocols were prepared within ORAMED and remain the property of the ORAMED consortium group.
They were used for ExDos purposes and the measurement results from ExDos will be used for the ORAMED analyses.

The Exdos project can be divided into 2 groups, classified according to the type of procedures that are considered:

A. Extremity / eye lens dosimetry for interventional procedures
B. Extremity dosimetry in nuclear medicine

For both groups a steering committee has been established, to assist in the measurements and follow up the analysis of the measurements.

For the first group, the steering committee consisted of representatives from SCK-CEN (F. Vanhavere, L. Struelens and S. Krim) and from UZ-Brussel (D. Berus). For the second group the steering committee consisted of representatives from SCK-CEN (F. Vanhavere, L. Struelens and S. Krim), Cliniques Saint Luc (F. Jamar), UZ-Brussel (P. Covens) and Belnuc (J-L. Marques). Also the FANC-AFCN was invited to the meetings of the steering committee.

I. Extremity / eye lens dosimetry for interventional procedures

1. Selection of procedures

Within ORAMED, 5 typical IR and 3 IC procedures in3 hospitals were studied.The list of procedures that were followed was set within the ORAMED project:

- CA & PTCA
- RF Ablations
- Pacemakers and ICD implantation
- DSA & PTA of lower limbs
- DSA & PTA of carotid arteries
- DSA & PTA of renal arteries
- Embolisations
- ERCP

However, in the past a large study on extremity dosimetry has already been conducted in Belgium in the framework of the national study on interventional radiology[2]. Therefore, the ExDos project only considered an extension of the number of hospitals for the 3 selected IC procedures and thegastro-enterology procedure. From literature, indications were also found that doses could be high for specific orthopaedic procedures, like vertebroplasty and kyphoplasty. These procedures were not selected within the ORAMED project because of their low frequency, but we decided to include them in the ExDos project.
Within ExDos dose measurements are performed for:

- CA & PTCA
- RF Ablations
- Pacemakers and ICD implantation
- ERCP
- Vertebroplasties/kyphoplasties

2. Overview of procedures

- Interventional cardiology:
    - **CA & PTCA**

      Coronary angiography is a procedure that uses dye and x-rays to show the inside of the coronary arteries. The coronary arteries supply blood and oxygen to the heart. The procedure can involve placement of a long tube (a catheter) into an artery in order to inject the dye right next to the heart (cardiac catheterization), or the dye can be injected into a vein without the use of a catheter. The image(s) that are obtained are called a coronary angiogram.

      A material called plaque can build up on the inside walls of the coronary arteries and cause them to narrow. When this happens, it is called coronary artery disease (CAD) or atherosclerosis of the coronary arteries. CAD can prevent enough blood from flowing to the heart leading to angina (chest discomfort or pain) and heart attack. Coronary angiography is used to diagnose CAD.
      Percutaneous transluminal coronary angioplasty (PTCA) is performed to open blocked coronary arteries caused by coronary artery disease (CAD) and to restore arterial blood flow to the heart tissue without open-heart surgery. A special catheter (long hollow tube) is inserted into the coronary artery to be treated. This catheter has a tiny balloon at its tip. The balloon is inflated once the catheter has been placed into the narrowed area of the coronary artery. The inflation of the balloon compresses the fatty tissue in the artery and makes a larger opening inside the artery for improved blood flow.The use of fluoroscopy assists the physician in the location of blockages in the coronary arteries as the contrast dye moves through the arteries.

- **Radiofrequency (RF) ablations**

  Radiofrequency energy is used to destroy abnormal electrical pathways in heart tissue or normal parts that are contributing to a cardiac disrhythmia. It is used in recurrent atrial flutter, atrial fibrillation, supraventricular tachycardia and some types of ventricular disrhythmia.The energy emitting probe (electrode) is at the tip of a catheter which is placed into the heart, usually through a vein. The practitioner first "maps" an area of the heart to locate the abnormal electrical activity (electrophysiology study) before the responsible tissue is eliminated. RF ablations are performed under image guidance by a cardiac electrophysiologist, a subspecialty of cardiologists.

- **Pacemakers and defibrillator implantation**

  A pacemaker is typically inserted into the patient through a simple surgery using either local anesthetic or a general anesthetic. In most cases the pacemaker is inserted in the left shoulder area where an incision is made below the collar bone creating a small pocket where the pacemaker is actually housed in the patient's body. The lead or leads (the number of leads varies depending on the type of pacemaker) are fed into the heart through a large vein using a fluoroscope to monitor the progress of lead insertion. A temporary drain may be installed and removed the following day. The actual surgery may last 1 to 2 hours and it is done most often in an operating room or in a cardiac catheterization laboratory.
  A pacemaker stimulates the heart muscle with precisely timed discharges of electricity, causing the heart to beat in a manner that mimics a naturally occurring heart rhythm.
  In many cases, an implantable cardioverter-defibrillator (ICD) is implanted rather than a pacemaker. The pacemaker component of the ICD helps the heart beat regularly, and the defibrillator shocks the heart back into rhythm if it does not beat within a certain period of time.

- Interventional gastro-enterology procedures

  - **Endoscopic retrograde cholangiopancreaticography (ERCP)**

    ERCP is a technique that combines the use of endoscopy and fluoroscopy to diagnose and treat certain problems of the biliary or pancreatic ductal systems, including gallstones, inflammatory structures (scars), leaks (from trauma and surgery), and cancer. A flexible camera (endoscope) is inserted through the mouth, down the esophagus, into the stomach, through the pylorus into the duodenum. The region can be directly visualized with the endoscopic camera while various procedures are performed. A plastic catheter is inserted and radiocontrast is injected into the bile ducts, and/or pancreatic duct. Fluoroscopy is used to look for blockages, or other lesions such as stones.

- Interventional orthopaedic procedures

  - **Vertebroplasty and kyphoplasty**

    Vertebroplasty and kyphoplasty are minimally invasive procedures for vertebral compression fractures (VCF), which are fractures in vertebra, the small bones that make up the spinal column.When a vertebra fractures, the usual rectangular shape of the bone becomes compressed and distorted, causing pain.
    In vertebroplasty, physicians use image guidance to inject a special cement mixture through a hollow needle into the fractured bone. In kyphoplasty, a balloon is first inserted through the needle into the fractured bone to create a cavity or space to control where delivered cement goes, it may also restore some of the compressed height of the vertebra. Once the balloon is removed, the cement mixture is injected into the cavity where the balloon was.

3. Overview of hospitals

For CA & PTCA, RF ablations and ERCP, measurements are performed in 9 different Belgian hospitals. PM and ICD implantations are monitored in 8 hospitals. Vertebroplasty procedures are performed less frequently and measurements were performed in 5 hospitals.
Following hospitals contributed to the measurement campaign:

- RF ablations
  - Hospital A
  - Hospital B
  - Hospital C
  - Hospital E
  - Hospital F
  - Hospital G
  - Hospital H
  - Hospital I
  - Hospital J

- CA/PTCA
  - Hospital A
  - Hospital B
  - Hospital C
  - Hospital E
  - Hospital F
  - Hospital G
  - Hospital H
  - Hospital I
  - Hospital J

- PM/ICD
  - Hospital A
  - Hospital B
  - Hospital C
  - Hospital E
  - Hospital F
  - Hospital G
  - Hospital H
  - Hospital J

- ERCP
  - Hospital A
  - Hospital B
  - Hospital C
  - Hospital D
  - Hospital E
  - Hospital F
  - Hospital H
  - Hospital I
  - Hospital J

- Vertebroplasty
  - Hospital E
  - Hospital K
  - Hospital L
  - Hospital M
  - Hospital N

4. Number of measurements

In every hospital we aimed to perform 10 patients per procedure. However, in some hospitals the frequency could be very low, especially for the RF ablations and PM/ICD implantations. Often these procedures were also not performed in the same service within the hospital. Moreover, in some rooms no DAP-meter was available. In those cases a DAP-meter from SCK was used. This external DAP-meter needed to be calibrated on site and could be used only in 1 room at a time.

In total, 354measurements werecollected, from which

- 39 patients from vertebroplasties procedures
- 77 patients for the ERCP procedures,
- 80 patients for RF ablations,
- 94 patients for CA/PTCA,
- 64 patients from PM /ICD

All data were collected over a period of 24 months (from November 2008 until October 2010).

5. Material and methods

Dose measurements
Dose measurements were performed using thermoluminescent dosemeters (TLDs)LiF crystals, doped with magnesium, copper and phosphorus (LiF:Mg,Cu, P).
A TLD measures ionizing radiation exposure by measuring the amount of visible light emitted from the crystal in the detector when the crystal is heated after exposure. The amount of light emitted is dependent upon the radiation exposure. TLDs are tissue equivalent.
The type of TLDs used in this project are very sensitive with a detection threshold of 50 nGy. The photon energy dependence is less than 20% for energies from 30 keV to 1.3 MeV.
During the measurement campaign, the TLDs were calibrated at the secondary calibration laboratory of SCK•CEN. The calibration was performed with the calibration detectors in a plexi holder and irradiated with a Cs-source (0,667 MeV). Specific correction factors relative to the place of measurement (eyes, fingers, wrists or legs) and the energy were applied. Background TLDs were kept for every measurement and the background signal was subtracted from the measured thermoluminescence signals. Every TLD-reading was also corrected for the individual sensitivity of the respective TLD.
After each measurement, the TLDs were reset by annealing them at 240°C for 12min.

The TLDs were sealed in small plastic bags and taped on the parts of the body to be monitored. 8 TLDs were used: 1 on each ring finger and wrist,1 on each leg about 5 cm below the lead apron, 1 between the eyes and 1 on the side near the left or right eye.

Measurement protocol
The protocol includes detailed instructions on the detector positions

- TLDs on ring fingers and wristson the palmar side when the tube is under the table and on the dorsal side for over couch interventions
- TLDson the side near the left or right eye, depending if the tube is on the left or right side of the physician respectively.

It also includes useful information on the type of equipment, the work procedure and the protective measures used:

- Personal protective equipment (apron, thyroid collar, lead glasses)
- Room protective equipment
- Type of detector and configuration (tube-above, tube-below, bi-plane)
- Position of the physician with respect to the X-ray beam
- Complexity of the procedure
- Access of the catheter
- Experience of the operator
- Radiation field parameters, like tube voltage, current, projections, …
- The total air kerma area product (KAP)

6. Overview of the results

A. Comparison of the different procedures

In figure 1, an overview is given of the KAP-values that were monitored for the different procedures. The least radiation is used for the ERCP procedures (median KAP = 907 µGy.m²) and the largest KAP values were observed for the CA & PTCA procedures (median KAP = 5426 µGy.m²) and vertebroplasty/kyphoplasty procedures (median KAP = 3760).

The data are presented as boxplots, where minima and maxima values, 1st and 3rd quartiles (presented by the box) and median (−) and average values (◆) are shown.

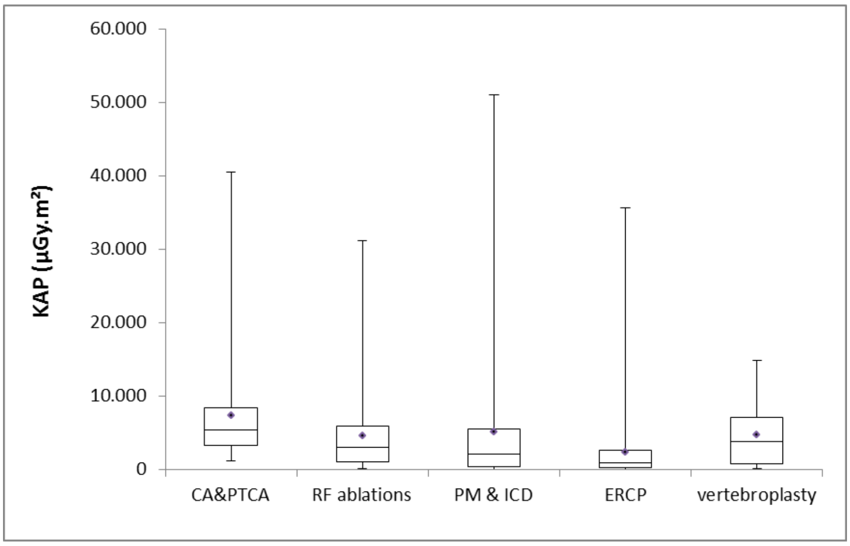


Figure 1: Overview of the KAP-values for each procedure

In figure 2 (a-e), an overview is given of the extremity doses per unit of KAP for all hospitals together on every monitored location for each procedure. The data are shown on a logarithmic scale as a large variation in dose data are observed over all hospitals.

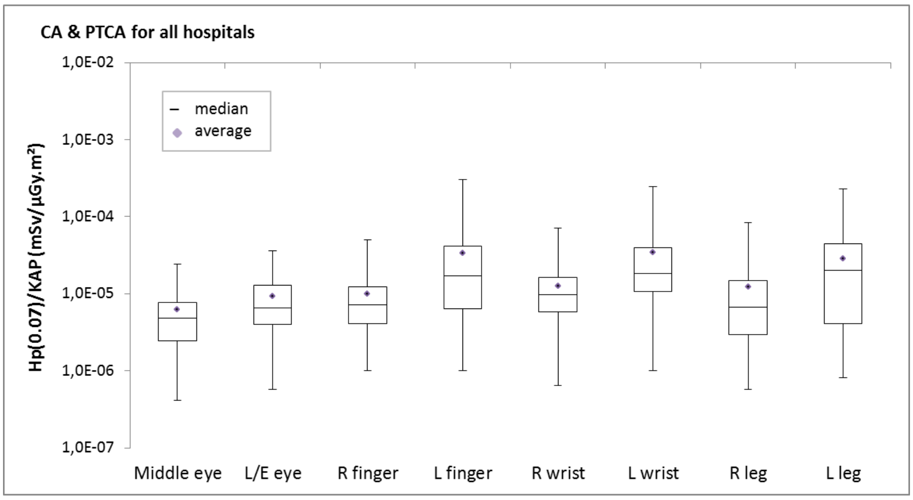


Figure 2a: Hp(0.07)/KAP for CA & PTCA procedures where data from all hospitals are included

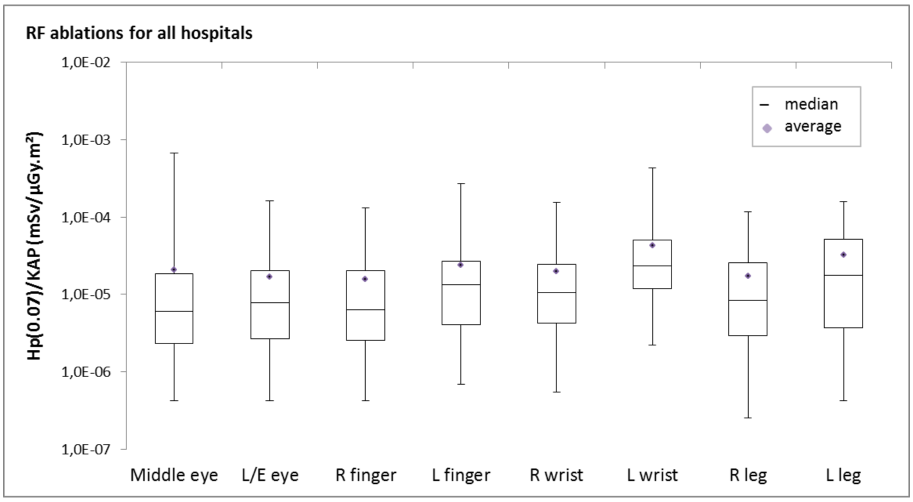


Figure 2b: Hp(0.07)/KAP for RF ablation procedures where data from all hospitals are included

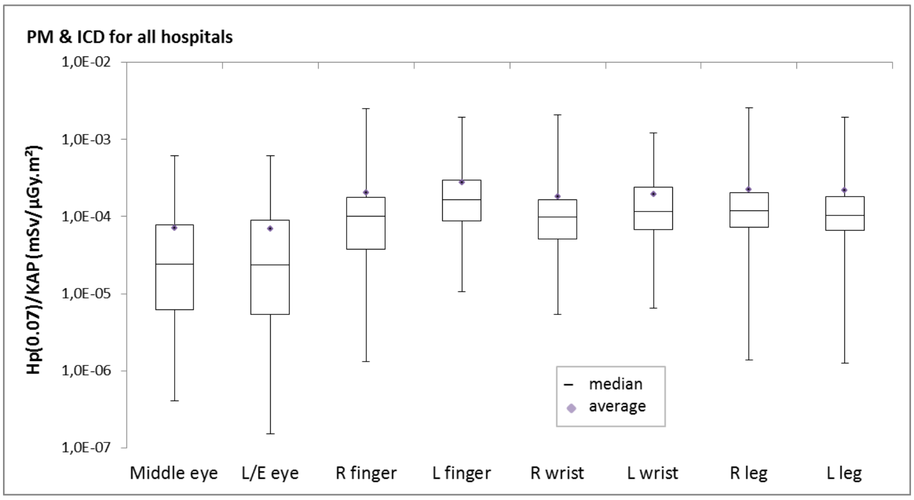


Figure 2c: Hp(0.07)/KAP for PM & ICD implantations where data from all hospitals are included

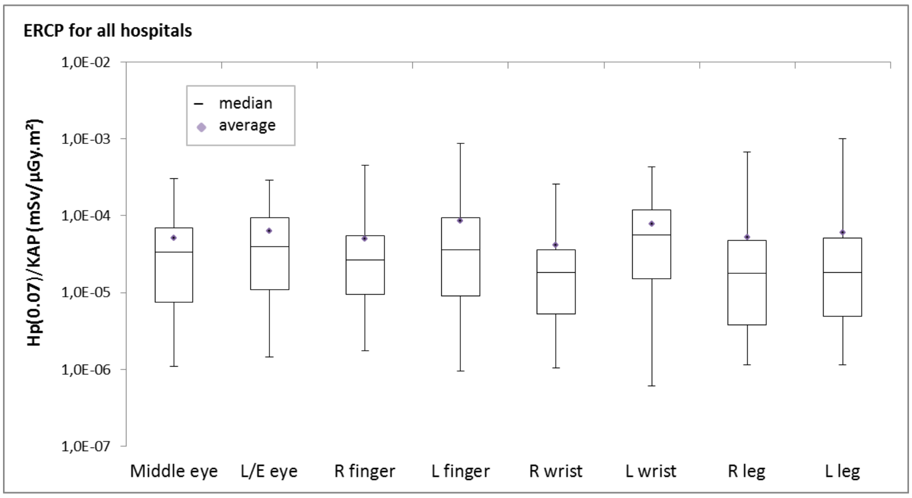


Figure 2d: Hp(0.07)/KAP for ERCP procedures where data from all hospitals are included

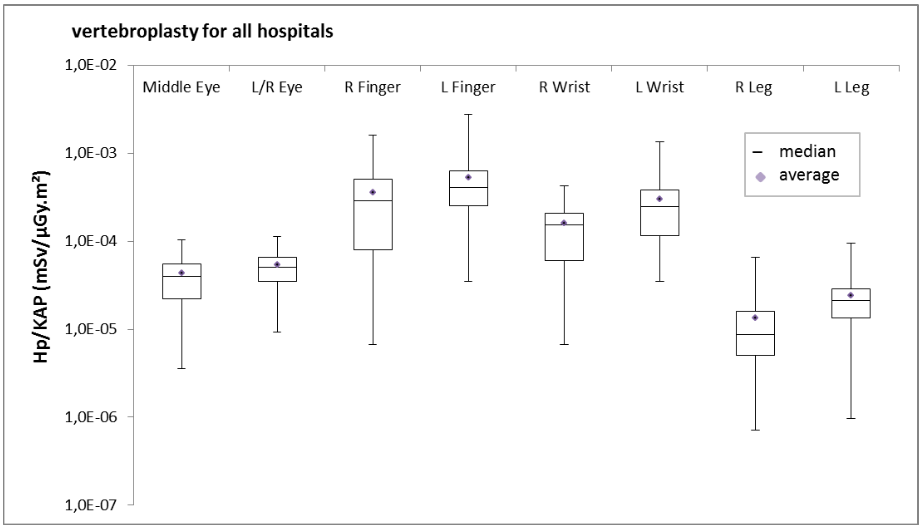
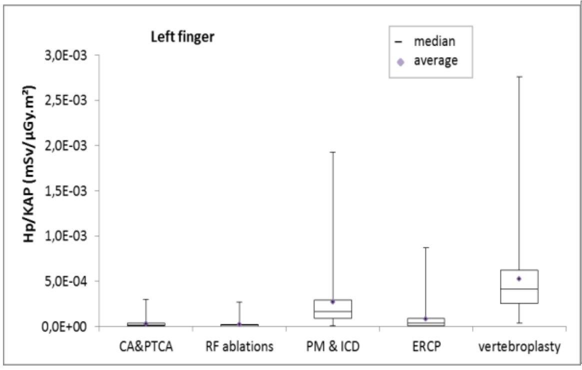
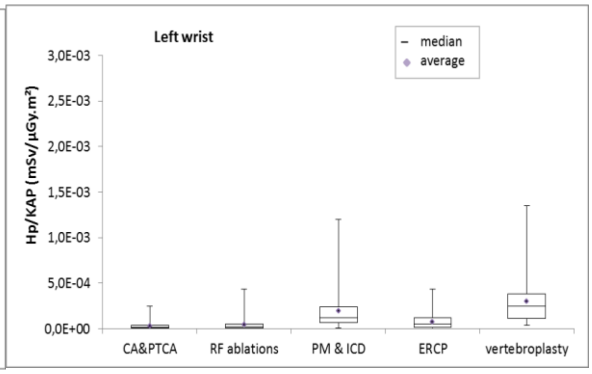


Figure 2e: Hp(0.07)/KAP for vertebroplasty procedures where data from all hospitals are included

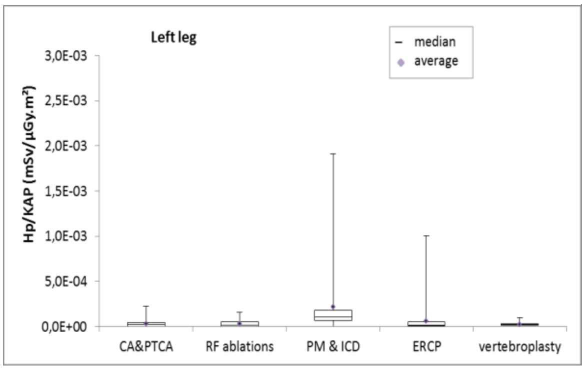
For every procedure, we can observe that the highest doses are monitored on the left side of the different locations (left finger, left hand, left leg and left eye). Therefore, in figure 3 (a-d) the different procedures are compared directly per monitored left location.



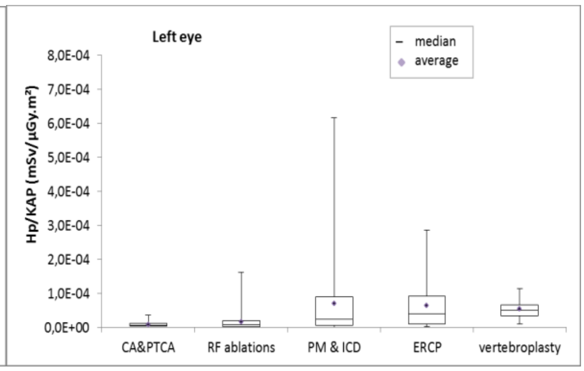
(a)



(b)



(c)



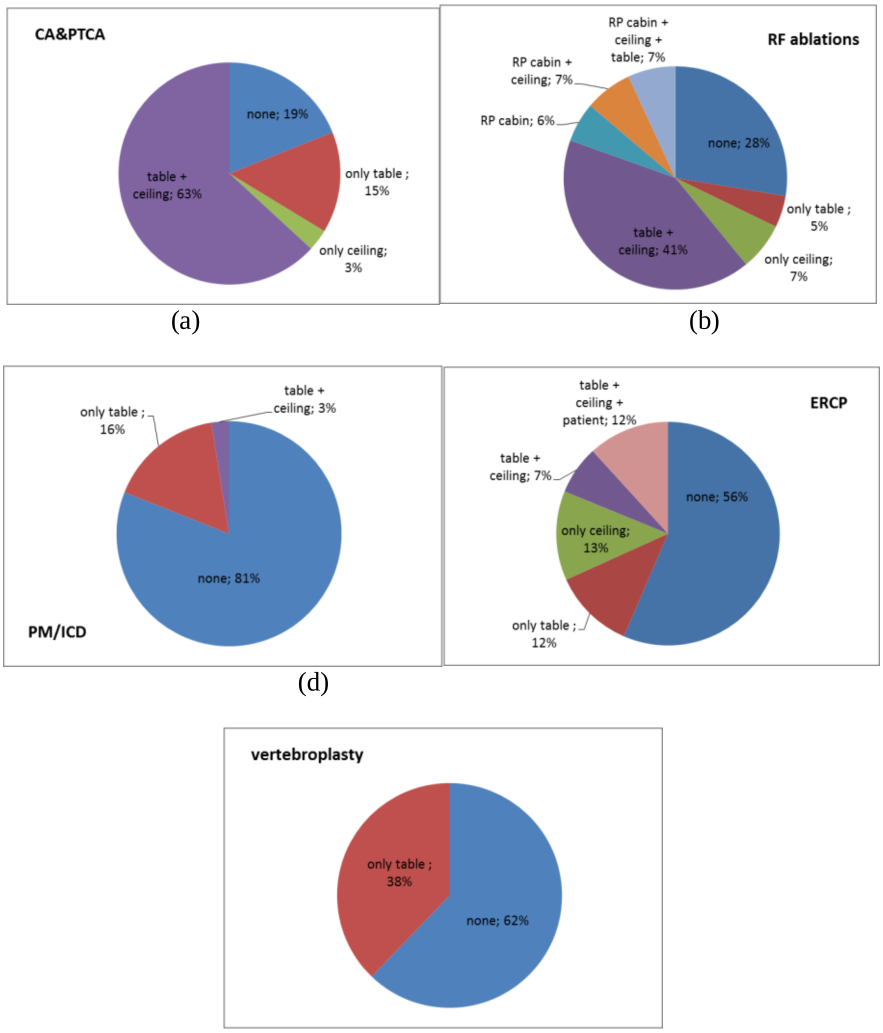
(d)

Figure 3: Comparison of Hp(0.07)/KAP for each procedures at the left finger (a), left wrist (b), left leg (c) and left eye (d)

For the **left finger and left wrist**, the highest doses are observed for the PM/ICD implantations and the vertebroplasty/kyphoplasty procedures. For the left finger median Hp(0.07) values of 279 µSv and 1495 µSv and maximum values up to 6564 µSv and 7309 µSv are obtained during the PM/ICD implantations and vertebroplasty/kyphoplasty procedures, respectively. For the left wrist median Hp(0.07) values of 175 µSv and 784 µSv and maximum values up to 3588 µSv and 4635 µSv are obtained during the PM/ICD implantations and vertebroplasty/kyphoplasty procedures, respectively.
For the **leg doses**, highest doses are observed for PM/ICD implantations with a median value of 158 µSv with a maximum up to 4996 µSv.
For the **doses to the eyes**, the highest doses are monitored at the PM/ICD implantations, ERCP procedures and vertebroplasty/kyphoplasty procedures with median values of 75 µSv, 62 µSv and 335 µSv and maxima up to 1083 µSv, 1083 µSv and 836 µSv, respectively. These values are considerably lower than those to the hands and legs, but we should emphasize that the annual limit for the eyes (150 mSv) is lower than the annual limit for the skin (500 mSv).

B. The influence of protective equipment and tube configuration

The largest influence on the monitored Hp(0.07)/KAP extremity doses is the use of protective equipment in the room and the tube configuration (tube-above the table, tube-below the table or bi-plane configuration).
For each procedure a general overview of the room protective equipment used in all hospitals is given in figure 4. In figure 5 a picture is shown on the different types of protective equipment used. An overview of the tube configuration is given in figure 6.



(a) (b)
(c) (d)
(e)

Figure 4: Overview of the use of room protective equipment for each procedure

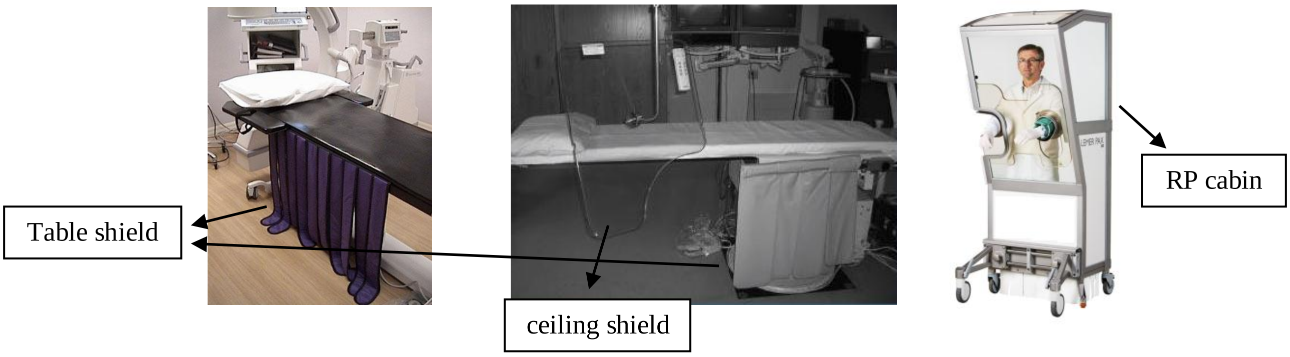


Figure 5: Room protective equipment used in the rooms

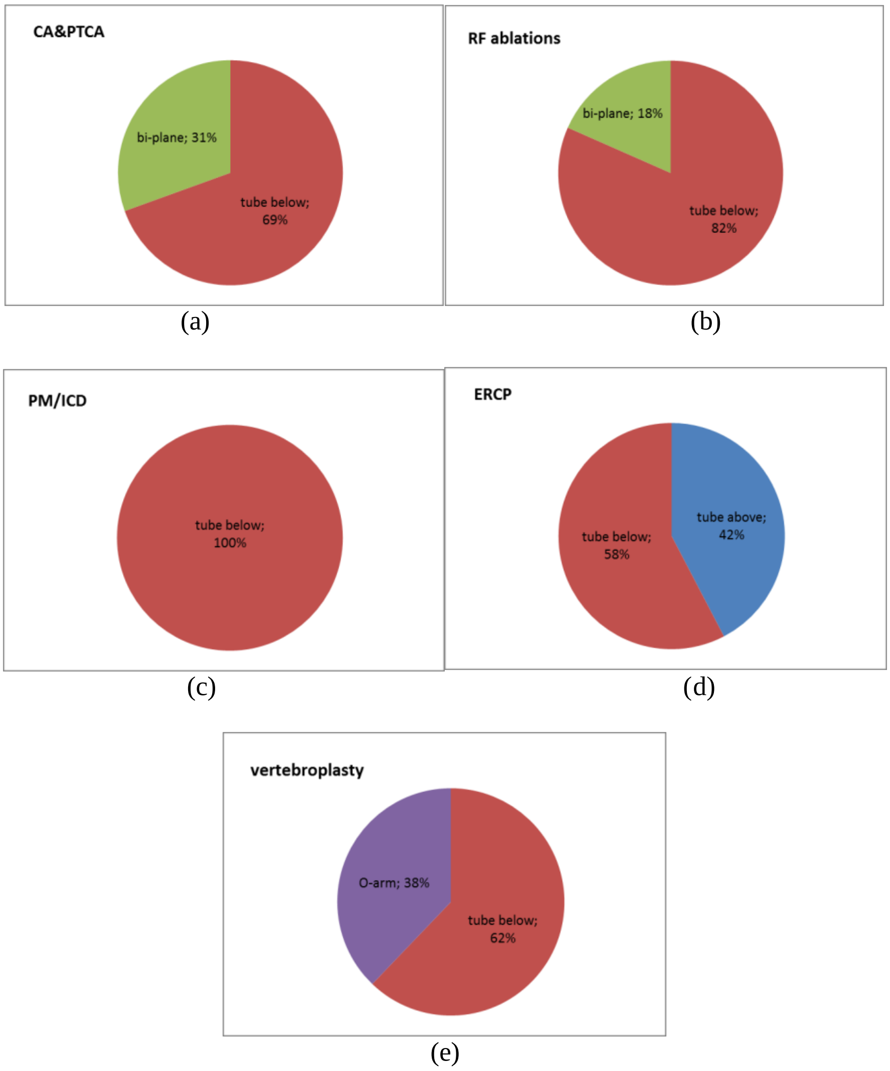


Figure 6: Overview of the tube configuration for each procedure

The highest doses observed at the fingers and wrists for PM/ICD implantations and vertebroplasty/kyphoplasty procedures are caused by a lack of protective equipment. No ceiling suspended shields are used. It also explains the higher doses to the eyes for these procedures.

The use of these types of shields is not trivial for both kind of procedures. For the PM/ICD implantations the operator is positioned near the shoulder of the patient where the PM/ICD is implanted (figure 7). The use of a ceiling suspended shield is experienced as an obstruction to access the patient. Moreover, the operator is really

close to the X-ray beam, which explains why doses to the hands can be very high. Also for the vertebroplasty procedures ceiling suspended shieds are never used for the same reason. They are considered as a burden when the needles need to be inserted in the vertebrae of the patient.It was seen regularly that the hands of the operator were in the X-ray beam for both types of procedures.

Figure 7: The position of the operator during a PM/ICD implantation

For the PM/ICD implantations,in 19% of the cases at least a table shield was used. In figure 8, the doses to the left leg are compared when a table shield is used and when it was not used.

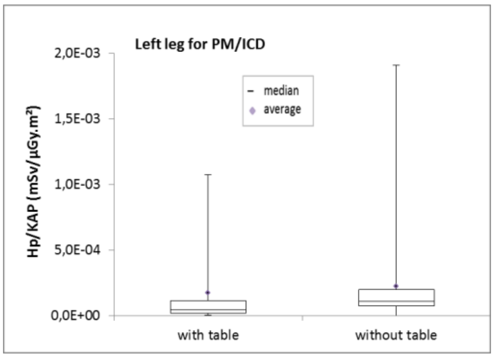


Figure 8: The effect of the table shield on HP(0.07)/KAP to the legs for PM/ICD implantations

For the ERCP procedures, the doses to the eyes are comparable with those measured during PM/ICD implantations and vertebroplasty/kyphoplasty procedures (figure 3d). One explanation is the use of a tube-above configuration in 42% of the ERCP procedures monitored. Moreover, the ceiling suspended shield is not used in 68% of the cases. In figure 9, the doses to the left eye are compared for tube above and tube below configurations and with and without ceiling suspended shield. Unfortunately, no data were available, where ceiling suspended shields are used with tube-above configurations. For tube-below configurations, the effect of the ceiling shield on eye doses is not present. This phenomena was observed for most of the procedures. The tube-above configuration is responsible for the higher doses to the eyes (normalised to KAP) for ERCP procedures.
However, the amount of radiation used during this procedure is low (median KAP-value of 907 µGy.m²). The median absolute Hp(0.07) value obtained for this procedure to the left eye is 13 µSv (36 µSv for tube-above and 8 µSv for tube-below configurations) with a maximum up to 1083 µSv. This maximum value is obtained for a procedure performed on a tube-above configuration when no protective equipment is used in the room.

The lowest doses are observed for the CA & PTCA procedures and RF ablations (figure 3). For these procedures a good tendency is present to use protective measures in the room (figure 4). Of all monitored procedures, 19% and 28% did not use any protective measures for CA & PTCA and RF ablations, respectively. In figure 10 and 11, the influence of the tube configuration (tube-below or bi-plane) and the use protective equipment (ceiling and RP cabin) is shown on the left eye and left finger, respectively for CA & PTCA and RF ablations. The use of the ceiling shield results in a significant reduction of the eye dose. For bi-plane configuration the effect is larger than for the tube-below configuration. For the bi-plane configuration, the ceiling shield protects the operator's eyealso

from the lateral tube. For RF ablations, 2 hospitals use the RP cabin (figure 5), which results in the smallest doses to the eyes and fingers.
The effect of the ceiling shield to the fingers is smaller than to the eyes and for the tube below configurations, there is no effect.

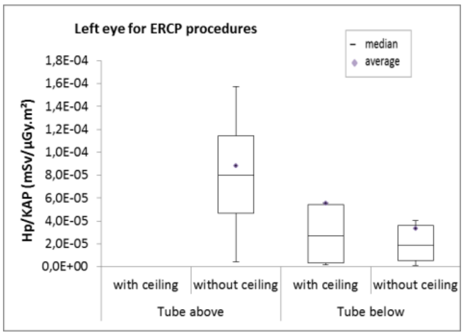


Figure 9: The effect of the tube configuration and ceiling suspended shield on the dose to the left eye for ERCP procedures

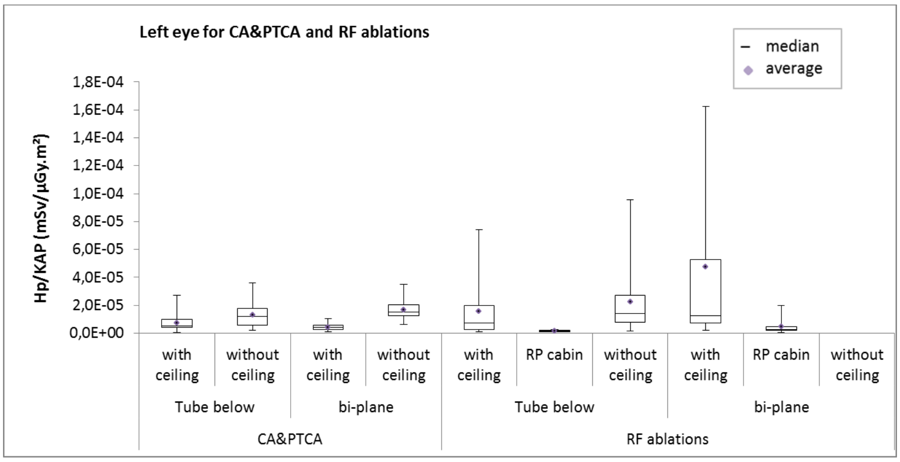


Figure 10: The effect of the tube configuration and protective equipment on the dose to the left eye for CA & PTCA procedures and RF ablations

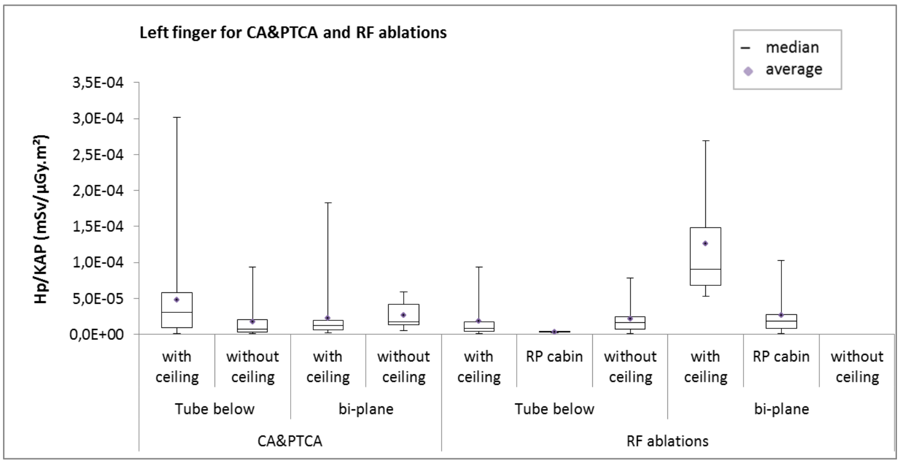


Figure 11: The effect of the tube configuration and protective equipment on the dose to the left finger for CA & PTCA procedures and RF ablations

In figure 12, an overview is given from the doses to the left leg for CA & PTCA procedures and RF ablations. Again the influence of tube configuration and the use of a table shield is investigated.
A reduction of leg doses when the table shield is used can be seen for the tube-below configurations (no data was available without table shield for the bi-plane configuration). Again the lowest doses are observed when the RP cabin is used. The leg doses are in this case also protected from the side.

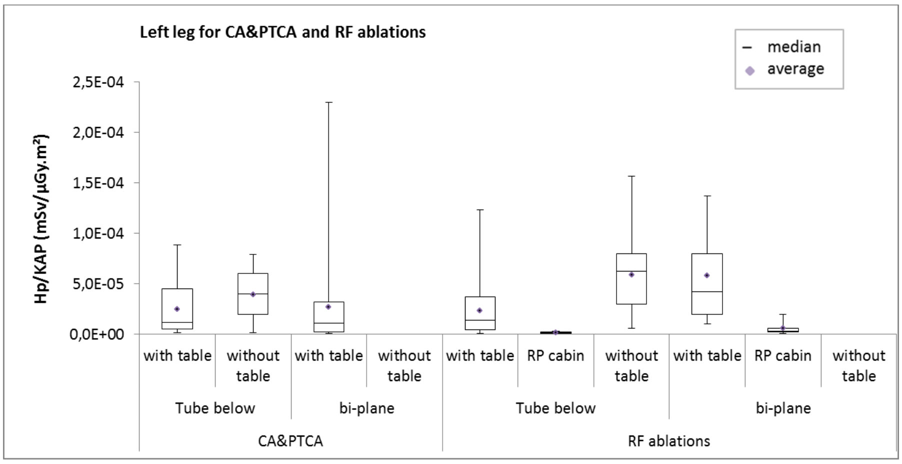


Figure 12: The effect of the tube configuration and protective equipment on the dose to the left leg for CA & PTCA procedures and RF ablations

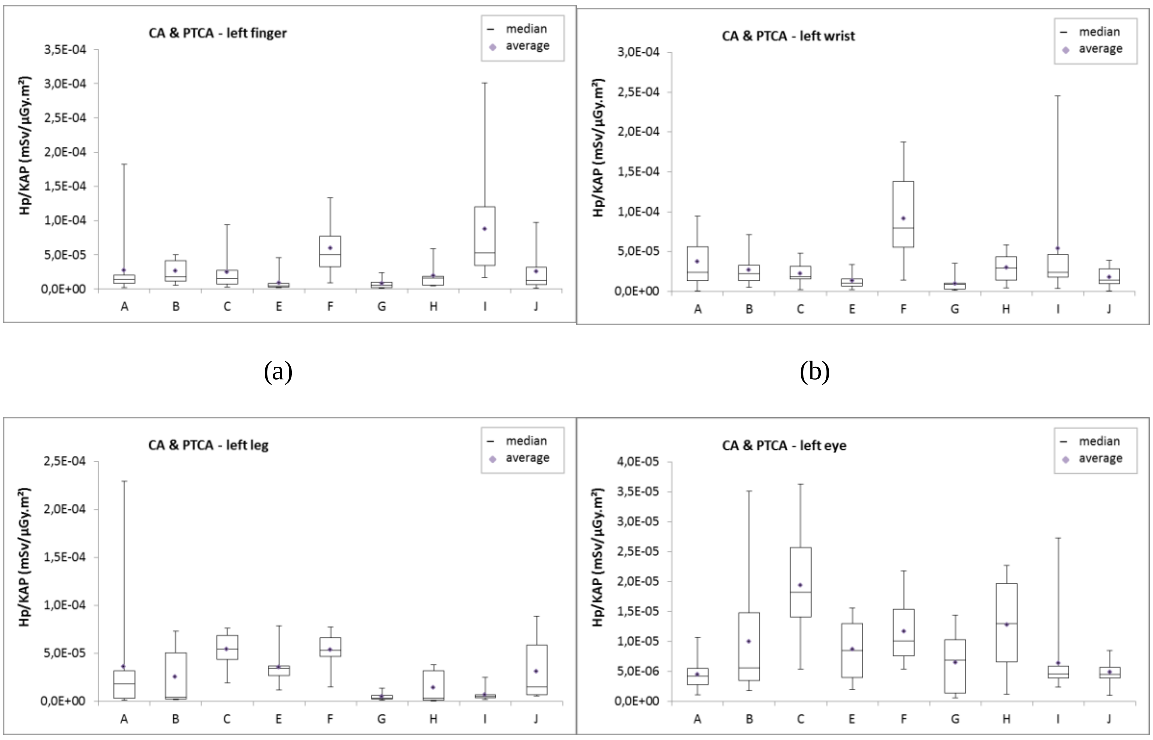
In table 1, an overview is given of the maximum obtained Hp(0.07) value on every monitored location for each procedure and it is mentioned which tube configuration is used and if protection equipment is used.

	Left finger	**Right finger**	**Left wrist**	**Right wrist**	**Left leg**	**Right leg**	**Left eye**	**Middle eye**
Procedure	CA & PTCA							
Maximum Hp(0.07) [µSv]	1170	316	1775	579	1567	761	630	318
Tube configuration	below	bi-plane	bi-plane	bi-plane	bi-plane	bi-plane	bi-plane	bi-plane
Table	/	/	/	/	yes	yes	/	/
Ceiling	no	yes	no	yes	/	/	no	no
Procedure	RF ablations							
Maximum Hp(0.07) [µSv]	896	446	1838	530	931	432	1045	752
Tube configuration	bi-plane	below	bi-plane	below	below	below	below	below
Table	/	/	/	/	yes	no	/	/
Ceiling	yes	no	yes	no	/	/	no	no
Procedure	PM & ICD implantations							
Maximum Hp(0.07) [µSv]	6564	4328	3588	3825	4996	4046	1286	962
Tube configuration	below	below	below	below	below	below	below	below
Table	/	/	/	/	no	no	/	/
Ceiling	no	no	no	no	/	/	no	no
Procedure	ERCP procedures							
Maximum Hp(0.07) [µSv]	1983	218	828	166	862	250	1286	755
Tube configuration	above	above	above	below	below	below	above	above
Table	/	/	/	/	yes	yes	/	/
Ceiling	no	no	no	no	/	/	no	no
Procedure	Vertebroplasty & kyphoplasty							
Maximum Hp(0.07) [µSv]	7309	7673	4635	3357	337	327	993	1096
Tube configuration	below	below	below	below	below	below	below	below
Table	/	/	/	/	yes	yes	/	/
Ceiling	no	no	no	no	/	/	no	no

Table 1: An overview of the maximum Hp(0.07) values measured on every location for each procedure

C. Comparison of the different hospitals

In figure 13 (a-d), the doses in the different hospitals are compared for the CA & PTCA procedures for the left finger, left wrist, left leg and left eye.



(a) (b)

(c) (d)

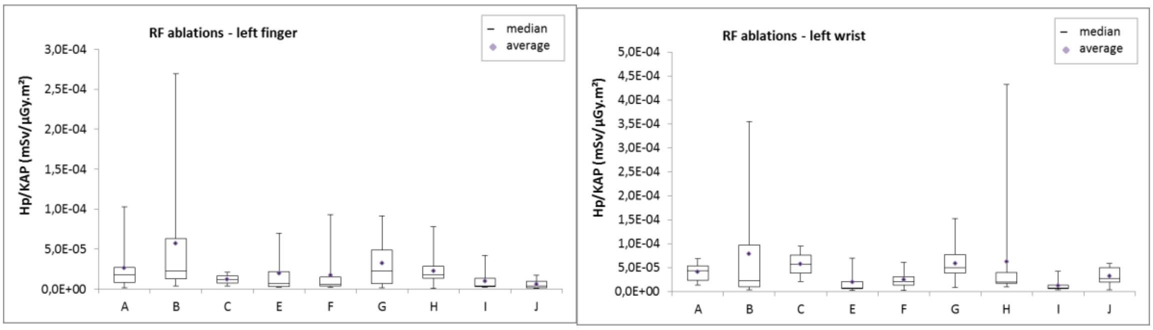
Figure 13: Comparison of the different hospitals for CA & PTCA procedures for the left finger (a), left wrist (b), left leg (c) and left eye (d)

For the **left finger and left wrist**, the highest doses are obtained in hospital F and I. Both hospitals have a tube-below table configuration and even use the ceiling shield. However, in hospital I the catheter is inserted through the arm (radial access), which means that the operator is closer to the X-ray beam. Although the ceiling shield seems not to reduce the doses to the hands, it reduced the doses to the eyes in both hospitals. The position of the ceiling shield can be very different from one hospital to another and will have an influence wether or not it reduces the doses to the hands. The lowest doses to the hands are attained in hospital E and G. In hospital G, a ceiling shield is used, but in hospital E it is not used.

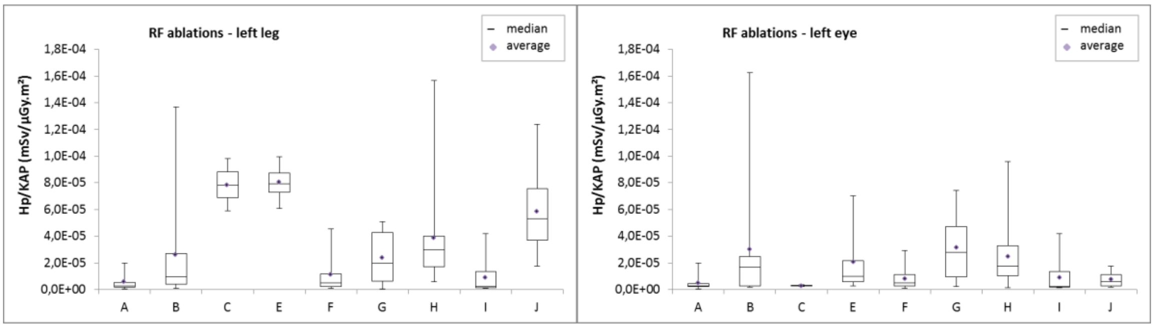
The **leg doses** are highest in hospital C and F. In hospital C, no protective equipment is used in the room in combination with a tube-below configuration. In hospital F, however, the table shield is used, but again it seems not to reduce the doses to the legs. The lowest doses are obtained in hospital G and I. Both hospitals use the table shield.

The lowest **doses to the eyes** are obtained in hospital A, I and J. All three hospitals use the ceiling shield. Hospital A has a bi-plane configuration, while in hospital I and J a tube-below configuration is used. The highest doses are observed in hospital C, where no protective equipment was used.

In figure 14 (a-d), the doses in the different hospitals are compared for the RF ablations for the left finger, left wrist, left leg and left eye.



(a) (b)

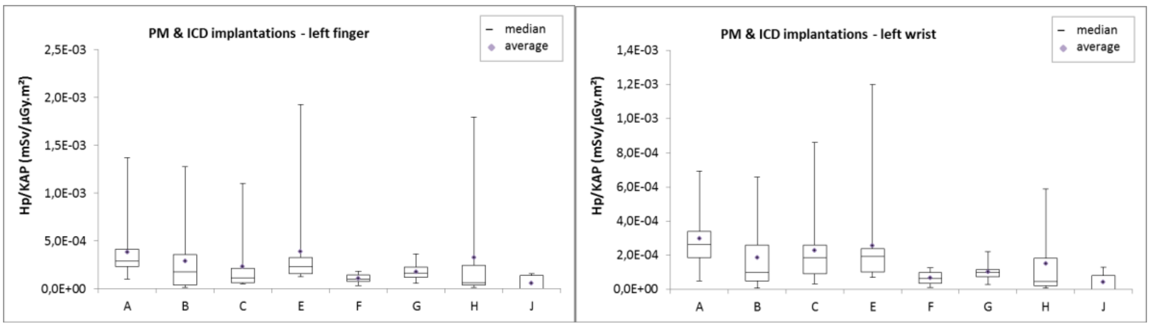


(c) (d)

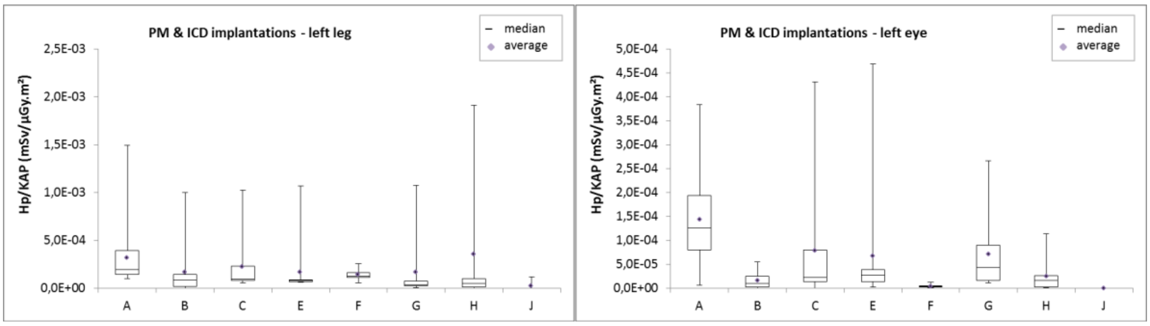
Figure 14: Comparison of the different hospitals for RF ablations for the left finger (a), left wrist (b), left leg (c) and left eye (d)

The most obvious result are the very high doses to the legs for hospital C, E and J compared to the other hospitals. All three hospitals use a tube-below configuration, but in hospital C and E no table shield is used. In hospital J, there is a table shield present, but it was much smaller than usual and not always well positioned.
In hospital A and I, the RP cabin is used during RF ablations. Moreover, in hospital I, next to the RP cabin, also a ceiling shield is used to protect the hands. We can indeed see that doses to the legs and eyes are very small in hospital A and I, while in hospital I also the doses to the finger and wrist is low.
For the eyes the higher doses are observed for hospital G and H. In hospital H, there is no ceiling shield, although in hospital G it was used.

In figure 15 (a-d), the doses in the different hospitals are compared for the PM & ICD implantations for the left finger, left wrist, left leg and left eye.



(a) (b)

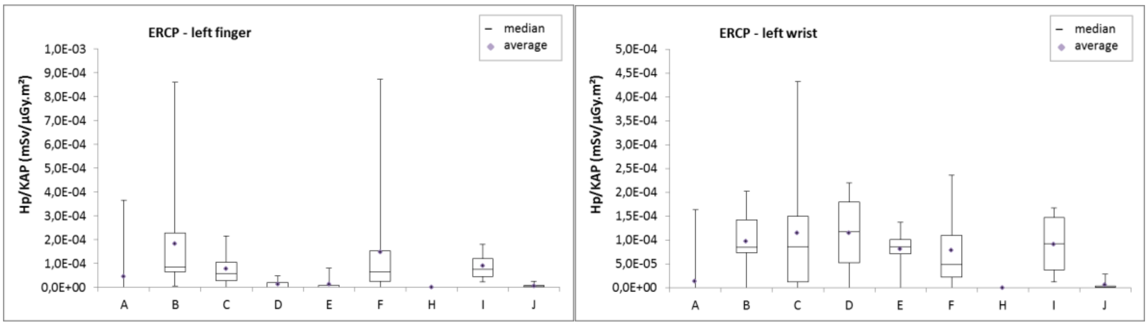


(c) (d)

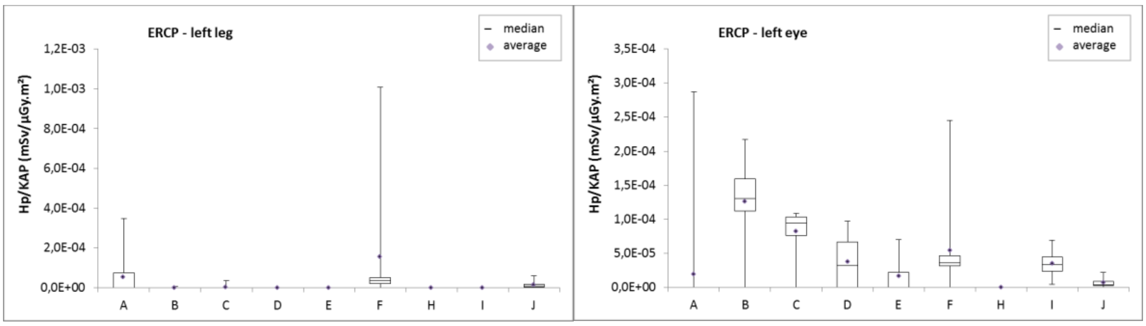
Figure 15: Comparison of the different hospitals for PM & ICD implantations
for the left finger (a), left wrist (b), left leg (c) and left eye (d)

6 out of the 8 contributing hospitals didn't use any room protective equipment in the room. Only a table shield was used in hospital G and J. Doses to the legs in these 2 hospitals are low. In hospital J, doses are in general low. A very small amount of radiation was used (very low KAP-values), such that almost all doses are below the detection limit of the dosemeters. In most of the hospitals it was reported several times that the hands had been in the beam during the procedure.

In figure 16 (a-d), the doses in the different hospitals are compared for the ERCP procedures for the left finger, left wrist, left leg and left eye.



(a) (b)



(c) (d)

Figure 16: Comparison of the different hospitals for ERCP procedures
for the left finger (a), left wrist (b), left leg (c) and left eye (d)

The Hp(0.07) doses of a very large part of the monitored ERCP procedures dit not exceed the detection limit of the dosemeter (8 µSv), because not much radiation (low KAP-values) is used for these procedures compared to the other interventional procedures. For those hospitals were no box plot is observed in one of the graphs of figure 16, it means that all data were below the detection limit.

In hospital A, F, H and J a tube-below configuration is used and for these hospitals, except hospital H; doses to the legs were measured. In hospital F no protection is used, in hospital A and J sometimes a table shield is used.

In hospital H, a continuous lead shield is used from the image intensifier all the way down to the X-ray tube, therefore zero doses were measured in that hospital for all monitored locations.
Hospitals B, C, D, E and I performed the ERCP procedures on a tube-above configuration and no protection equipment was used in the room. For these hospitals measurable doses were obtained for the hands and the eyes.

In figure 17 (a-d), the doses in the different hospitals are compared for the vertebroplasty & kyphoplasty procedures for the left finger, left wrist, left leg and left eye.

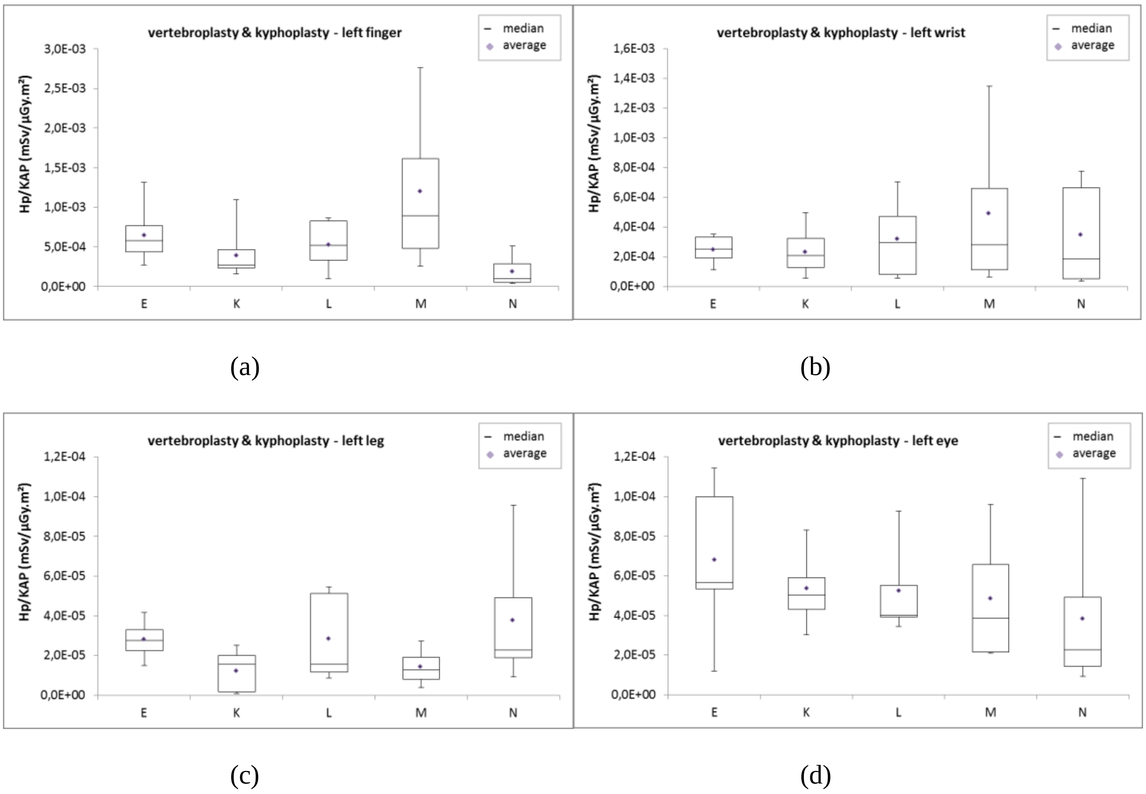


Figure 17: Comparison of the different hospitals for vertebroplasty and kyphoplasty procedures for the left finger (a), left wrist (b), left leg (c) and left eye (d)

Hospital E, K and M perform these orthopedic procedures on the same equipment as used for the interventional vascular procedures (C-arm with tube-below configuration). In hospital K no protective equipment is used in the room, while in hospital E and M a table shield is used. The effect of the table cannot be observed on the leg doses between these 3 hospitals in figure 17c.
The effect of the type of equipment (O-arm compared to C-arm) could not be observed for the doses to the hands and eyes. The O-arm system tends to give higher doses to the legs.
In hospital L, a new system is used for some procedures which enables the operator to place the needles and insert the cement from a distance. From figure 18, it can be observed that the difference between direct injection and injection from a disctance mainly has an influence on the doses to the fingers and wrists.
More measurements needs to be performed for these procedures.

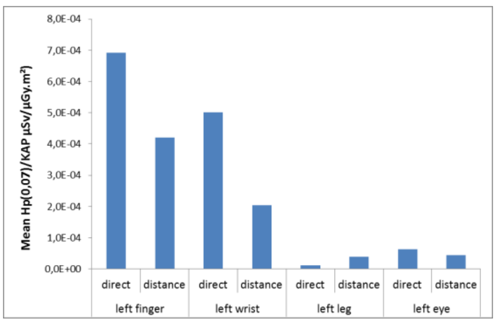


Figure 18: Comparison between direct injection and injection from a distance for vertebroplasty & kyphoplasty

The measured Hp(0.07)/KAP values of each hospital separately for each monitored location are given in appendix A. Also an overview of the tube configuration and the use of protection measures are indicated.

7. Annual doses

The annual dose limit for deterministic effects to the skin is set to 500 mSv averaged over 1cm² area of skin regardless of the area exposed. The annual dose limit for deterministic effects to the eye lens is set to 150 mSv. When 1/10 of the limit is reached, it is legally required that doses are routinely monitored.

For the operators monitored during this project an estimation is made of the annual dose by multiplying the average dose obtained for a certain procedure with his workload (number of procedures) of one year. If more than 1 type of procedure is performed by the same operator, the doses from each procedure are stacked to obtain the total sum. In appendix B, the annual doses for each operator are presented, together with information regarding the tube configuration and room protective equipment.

In total, information on the annual workload is gathered from 48 physicians (10 for CA & PTCA; 11 for RF ablations; 8 for PM & ICD implantations; 15 for ERCP procedures and 4 for vertebro- & kyphoplasty).
In figure 19, a frequency distribution is given of how many times a certain dose is exceeded for all procedures together. A similar distribution is given in figure 20, 21, 22, 23 and 24 for CA & PTCA, RF ablations, PM & ICD implantations, ERCP procedures and vertebro- & kyphoplasty, respectively.
For the doses to the hands and legs we divided the distribution in

- ≥ 500 mSv (= limit) ;
- ≥ 150 mSv (= high doses and 3/10th of limit) ;
- ≥50 mSv (= 1/10 of limit) ;
- < 50 mSv

For the doses to the eyes we divided the distribution in

- ≥ 150 mSv (= limit)
- ≥ 45 mSv (= high doses and 3/10th of limit)
- ≥ 15 mSv (= 1/10 of limit)
- < 15 mSv

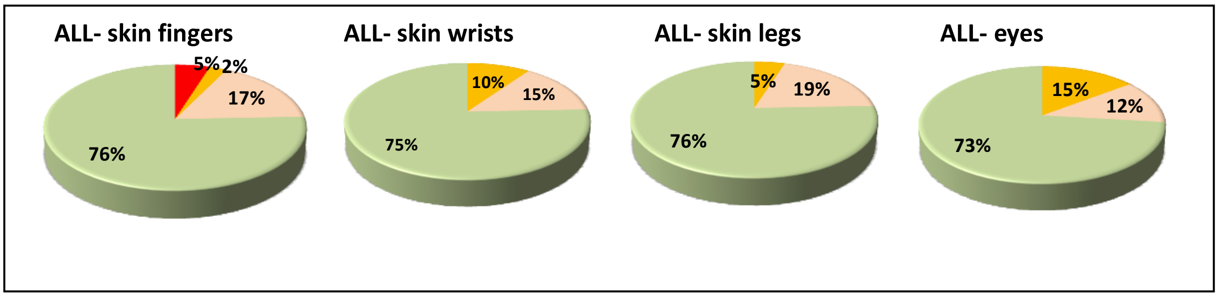


Figure 19: The frequency distribution of how many times a certain dose is exceeded for all procedures

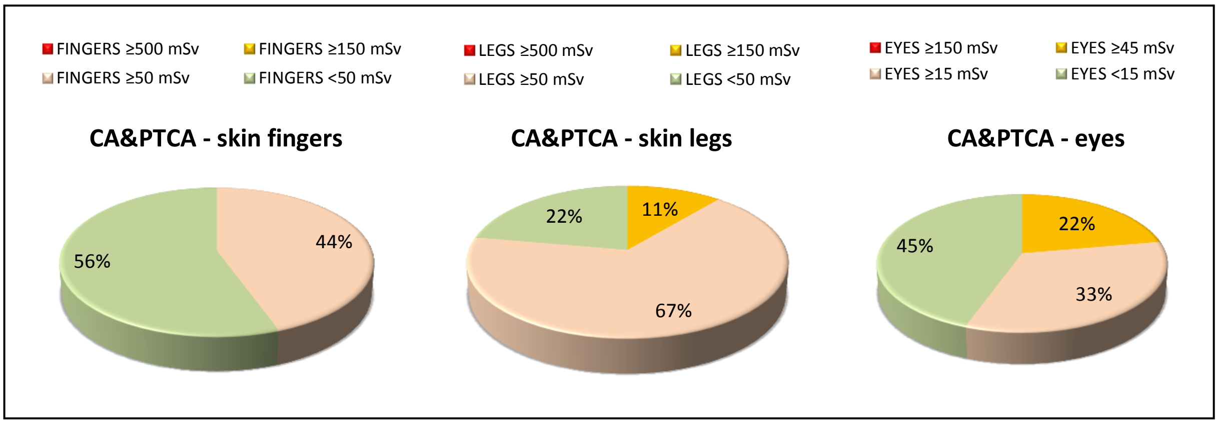


Figure 20: The frequency distribution of how many times a certain dose is exceeded for CA & PTCA

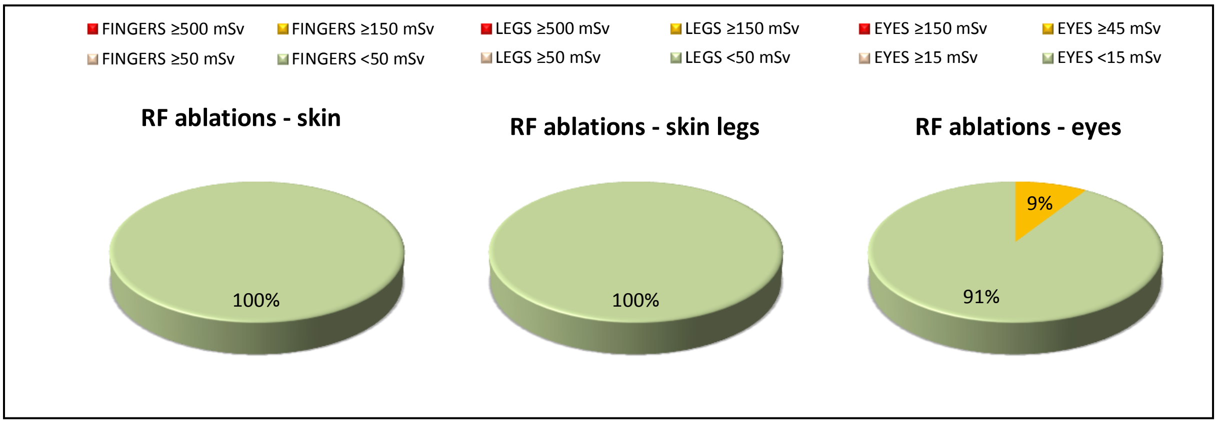


Figure 21: The frequency distribution of how many times a certain dose is exceeded for RF ablations

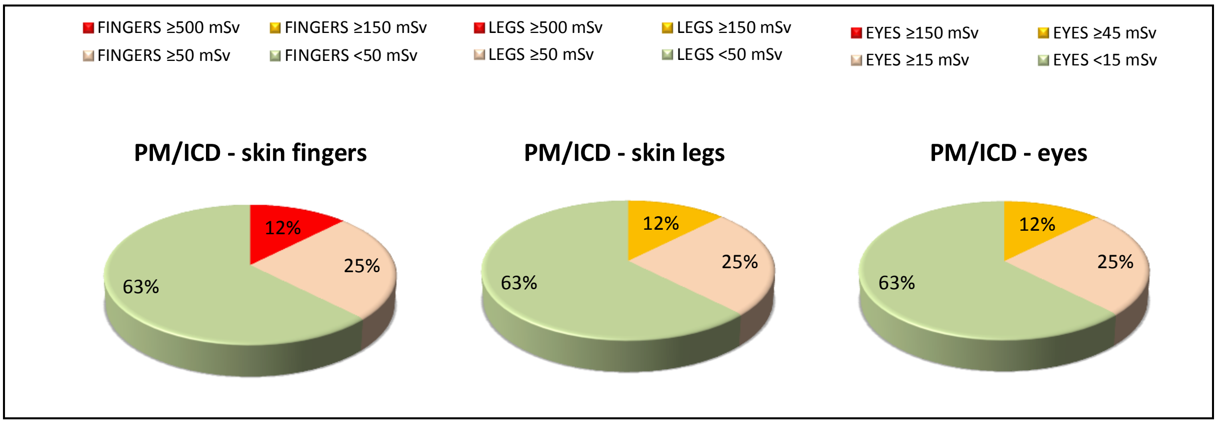


Figure 22: The frequency distribution of how many times a certain dose is exceeded for PM & ICD implantations

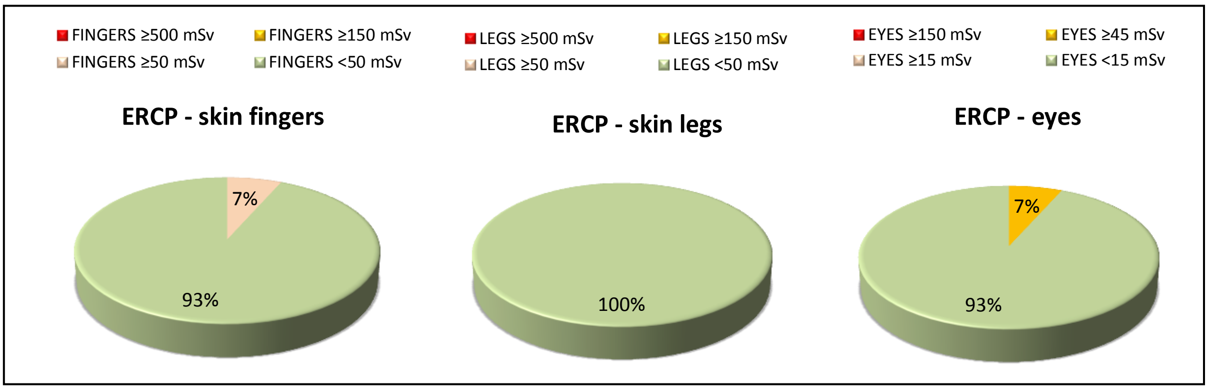


Figure 23: The frequency distribution of how many times a certain dose is exceeded for ERCP procedures

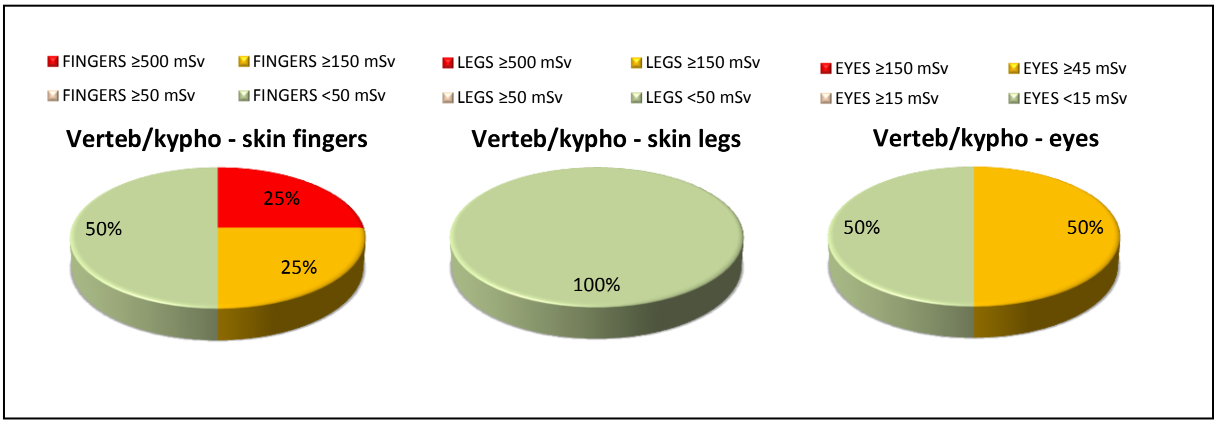


Figure 24: The frequency distribution of how many times a certain dose is exceeded for vertebro- & kyphoplasty

5% of the monitored people, received skin doses to the hands larger than the annual limit. These were operators performing PM & ICD implantations or vertebroplasty & kyphoplasty procedures. Doses to the legs and the eyes never exceeded the respective limit. However, it should be mentioned that the distribution is given for each procedure separately. Therefore, operators performing different types of procedures, might not exceed the limit for each procedure separately, but might be if the sum of the different procedures is considered.
From this data, we could recommend that for CA & PTCA procedures hands, legs and eyes are routinely monitored. Especially, the legs for which 11% of the doses are larger than 3/10th of the limit. From the graphs for each operator in appendix B, it is clear that these high doses are mainly reached when bi-plane systems are used or tube-below configurations without any table shield.
For the RF ablations, routine monitoring seems only usefull for the eyes (9% exceeded 3/10th of the limit). For PM & ICD implantations and vertebro-/kyphoplasty procedures, certainly the doses to the hands should be monitored. However, also in 12% and 50%, respectively the eyes received doses larger than 45 mSv and therefore, require monitoring. Especially, if we bear in mind that most probably the annual limit for the eye lens will decrease in the future.
For ERCP procedures, routine monitoring of the eyes is usefull if tube-above configurations are used.

8. Summary

A strong point of the ExDos project is that we have an overview of extremity and eye lens doses for a large number of hospitals. The obtained database is really representative for Belgium.
From all monitored procedures we observed that highest Hp(0.07)/KAP doses were obtained for the PM & ICD implantations and for the vertebroplasty/kyphoplasty procedures. For PM & ICD implantations, the operators are standing at the shoulder of the patient close to the X-ray beam. We also observed that in most cases no ceiling shield is used to protect the eyes and hands of the operator. Moreover, it was regularly observed during the measurement campaign that the hands were inside the primary X-ray beam. The same accounts for the vertebroplasty and kyphoplasty procedures. Also with these procedures no ceiling shields are used as they tend to obstruct the operator in its working practice. Another option for this specific procedure is to use a novel cement delivery system from a distance.
The lowest Hp(0.07)/KAP are obtained for the CA & PTCA procedures and RF ablations. For these procedures operators are more and more aware of radiation protection issues and radiation protection shielding is commonly used.The ERCP procedure has in general low absolute Hp(0.07) dose values because a small amount of radiation is used during this procedure (the lowest KAP values are obtained). However, for these procedures often X-ray systems are used with tube-above configurations and again protected shielding is not commonly used. This resulted in reasonable Hp(0.07)/KAP values for the eyes.

It is obvious that the use of radiation protection screens like the table shield, ceiling shield and RP cabin will decrease extremity doses to the legs, hands and eye lens doses, respectively. At least when they are correctly used.
The large database of the ExDos project makes it possible to make a representative assessment of how large this reduction is. For the PM & ICD procedures it was determined that the use of the table shield reduces the doses to the legs with 58%. For the ERCP leg doses were reduced with 70% and even 85% if only the tube-below configurations were taken into account. For the RF ablations and CA & PTCA procedures a reduction of 80% to the leg doses is determined when table shielding is used.

The use of a ceiling suspended shield has the largest effect on the eye doses. If well positioned, also the doses to the hands can be reduced. For RF ablations and CA & PTCA procedures, the eye doses are on average reduced with 80% by using a ceiling suspended shield. This kind of shielding was not used for ERCP, PM & ICD implantations and the verbroplasty & kyphoplasty procedures.
For the RF ablations, 2 hospitals used the RP cabin protection. Eye and finger doses decrease with 67% and 58%, respectively, compared to the procedures where a ceiling shield was used. The leg doses are further reduced with 80% compared to the use of a table shield.

From the calculation of annual doses to different operators, we would recommend that routine monitoring is certainly usefull for these interventional procedures. For PM & ICD implantations and vertebroplasty & kyphoplasty a routine monitoring of hand doses is required. Routine monitoring of eye lens doses is needed for all procedures, especially if the limit will be reduced.
For bi-plane systems, doses to the legs should be monitored and for tube-below configurations leg doses become high if no table is used, or when it is not properly used.

In general, extremity and eye lens doses can be reduced significantly with the use of protective shielding. However, the correct positioning of this shielding is one of the issues in practice at the moment. Especially the ceiling suspended shield is often not used effectively.

II. Extremity dosimetry in nuclear medicine

1. Selection of procedures

As a consequence of the definition that the dose limit for the skin has to be applied to ‘the dose averaged over any area of 1 cm² regardless of the area exposed’ it is advisable to measure the local skin dose at the location with presumably the highest exposure. This requirement is the central dilemma of extremity dosimetry and causes severe practical difficulties. In daily practice in nuclear medicine, it is very difficult to predict which part of the hand will receive the highest dose. Moreover, the dose distribution over the hand may vary during a single process as well as when several people perform the same procedure.
The procedures were selected according to their frequency in the collaborative hospitals, the doses that can be delivered and covered the three different types of emitters used in nuclear medicine, i.e. positron, beta and gamma. For diagnostics, two radionuclides are considered: F^{18} used for PET examinations and Tc^{99m} used for planar and SPECT examinations. For therapy, three of the most frequent treatments are Zevalin, DOTATOC and SIRS labeled with Y^{90}, but others using different drugs labeled with other radionuclides (I^{131}, Sm^{153}…) were also considered but not reported in this report. The accent will be put on the preparation and the administration.

Within ORAMED, 2 hospitals were included per radionuclide. In ExDos, the objectives extended the number of hospitals to 10, which means measurements in 8 hospitals within ExDos for Tc^{99m} and F^{18}. For therapy applications, as many procedures as possible will be followed. Therapies are performed with low frequency and only in a few hospitals. Therefore, a total of 10 hospitals per therapy nuclide is not feasible in practice. For every selected radionuclide the necessary procedural parameters (activity, use of protective measures, …) were recorded.
The results from ExDos were used to have an overview of the extremity doses situation in Belgium. Within the ORAMED project, the results (together with results from other European countries and from simulations) will be analysed to make recommendations for better radiation protection.

2. Number of measurements

In total, 387 measurements werecollected and used for the analysis, from which

- 117 measurements from preparation of Tc^{99m},
- 90 measurements from administration of Tc^{99m},
- 84 measurements from preparation of F^{18},
- 66 measurements from administration of F^{18},
- 19 measurements for therapy with Y^{90} (preparation),
- 11 measurements for therapy with Y^{90} (administration),

All data were collected over a period of 24 months (from November 2008 until November 2010). The therapies with Y^{90} are non-frequently performed procedures so only a few were followed.

3. Overview of procedures

Imaging with labeled Tc^{99m}

Technetium-99m or Tc^{99m} ("m" indicates that this is a metastable nuclear isomer) is used in radioactive isotope medical tests: for example, as a radioactive tracer that medical equipment can detect in the human body. It is well-suited to the role because it emits readily detectable 140 keV gamma rays, and its half-life is only about six hours. It dissolves in aqua regia, nitric acid, and concentrated sulfuric acid, but it is not soluble in hydrochloric acid of any strength. Klaus Schwochau's book Technetium lists 31 radiopharmaceuticals based on Tc^{99m} for imaging and functional studies of the brain, myocardium, thyroid, lungs, liver, gallbladder, kidneys, skeleton, blood, and tumors.
Technetium-99m is used in 20 million diagnostic nuclear medical procedures every year. Approximately 85 percent of diagnostic imaging procedures in nuclear medicine use this isotope. Depending on the type of nuclear medicine procedure, the Tc^{99m} is bound to a pharmaceutical that transports the Tc^{99m} to its required location. For example, when Tc^{99m} is chemically bound to exametazime, the drug is able to cross the blood-brain barrier and flow through the vessels in the brain for cerebral blood flow imaging. This combination is also used for labeling white blood cells to visualize sites of infection. Tc^{99m} Sestamibi is used for myocardial perfusion imaging, which shows how well the blood flows through the heart. Imaging to measure renal function is done by attaching Tc^{99m} to Mercapto acetyl triglycine (informal acronym: MAG3); this procedure is known as a MAG3 scan.

The preparation of any Tc^{99m} pharmaceutical is performed by using a cold kit and adding the required Tc^{99m} activity in a certain volume of Tc^{99m} eluate (pertechnetate).

Labeling

Tc^{99m} is eluted from the generator as a pertechnetate anion. It must be reduced to a lower valency state in order to be chemicaly reactive for labeling.
Cold kits which are prepacked sets of sterile ingredients are used for the preparation of a specific radiopharmaceutical. The kit contains the active ingredient, a reducing agent and may contain authorized excipients and other additives. The contents of the kit before preparation are not radioactive. However, after the sodium pertechnetate Tc^{99m} injection is added, adequate shielding of the final preparation must be maintained. The active ingredient is the compound to be labeled with the radionuclide.

Protective caps should be removed from the pharmaceutical vials; and the vials should be placed in the appropriate labeled vial shields. When introducing Tc^{99m} solution or saline to a vial, it may be necessary to equalise pressure by withdrawing an equivalent volume of air at the same time. This can be done gradually as the solution is added.

The rubber septum of each pharmaceutical vial should be swabbed with alcohol.

Shielded 10ml or 5ml syringes capped with 21G needles are generally used to reconstitute the pharmaceuticals. The appropriate activity of Tc^{99m} solution should be added to each shielded pharmaceutical vial; and the pharmaceutical should be allowed to incubate for the specified length of time.

After the recommended incubation time has elapsed, patient activities are withdrawn using shielded 2ml syringes. The activity and volume of Tc^{99m} solution added to each pharmaceutical should be recorded in the laboratory log book.

Dispensing

Patient injections are usually prepared in a volume of 2 ml. Saline may be used to increase the volume if the volume in which the required activity is obtained is below 1ml.
Once the patient injection is prepared, a needle of appropriate gauge should be used and the air in the syringe must be expelled. Each patient activity must be measured and recorded in the radiopharmacy log.

Tc^{99m} radiopharmaceuticals have a short shelf life (about 6h) they are used straight after preparation.

Injection :

The tracer is injected intravenously through a catheter preferably positioned in an anticubital vein. The injected dose depends on the type of camera and organs to be visualised.The suggested dose ranges employed for various diagnostic indications in the average adult patient (70 kg) are as follows:

Bone scan imaging: 740-925 MBq
Myocardial imaging: 185 OR 740-925 MBq (^{99m}Tc-MIBI or –Tetrofosmin)
Vesico-ureteral imaging: 18.5 to 37 MBq (0.5 to 1 mCi)
Brain imaging: 370 to 740 MBq (10 to 20 mCi)
Thyroid gland imaging: 37 to 370 MBq (1 to 10 mCi)
Salivary gland imaging: 37 to 185 MBq (1 to 5 mCi)
Blood pool imaging: 370 to 1110 MBq (10 to 30 mCi)
Nasolacrimal drainage system: Maximum dose of 3.7 MBq (100 μCi)

Imaging with F^{18}DG[4]

[18F]FDG is the principal radiotracer for clinical PET imaging. F^{18} is produced in a cyclotron, and the radiopharmaceutical is usually then synthesized locally by simple radiochemistry. Due to its relatively short half-life (110 minutes), many centers now have the cyclotron facility and camera on site to ensure a supply of [18F]FDG. However, manufacturers can deliver [18F]FDG to locations within a certain distance, and a delivery system is already established in some countries.
FDG is trapped within the metabolically active tumor cells, which provides the basis for functional imaging. FDG imaging is usually performed with dedicated PET scanners.

PET examination of patients with MTC is performed at least 2 months after initial treatment, when tumor markers are usually elevated and conventional imaging modalities are either negative or inconclusive to detect recurrent or metastatic disease. PET images are routinely obtained 40 to 60 minutes after 5-6 MBq/kg of FDG is given intravenously to patients in a fasting state. Fasting is necessary to minimize competitive inhibition of FDG uptake by blood glucose. At least 4 hours of fasting is recommended by many investigators. At some centers, serum glucose is measured before the tracer injection; if it is higher than 200 mg/dl, the PET scan is deferred until the patient's glucose level is normal. In diabetic patients, the blood sugar should be controlled by either oral hypoglycemic agents or insulin before scanning. In a standard protocol of cancer imaging, the patient should be relaxed prior to and after the injection of FDG. Tension of the neck muscles can result in focal uptake, which can be misinterpreted as nodal metastases. Patients should avoid talking and chewing to avoid uptake of FDG in the laryngeal, facial, pharyngeal, and masticatory muscles, which can also affect interpretation of the images.

Whole-body scans are usually performed to evaluate patients with known malignancy. However, metastasis is rarely seen in the legs. Emission scans typically take 40 minutes to cover 100 cm. Emission scans are adjusted for signal attenuation by applying a correction derived from a 68Ge/68Ga transmission scan of the same region. In case of PET-CT, the CT carries out the transmission scan. Transmission scans are typically acquired for 18 minutes. Images are viewed in the transaxial, coronal, and sagittal planes from a computer monitor that allows coregistration of all three orthogonal views. Since PET images cannot accurately display the anatomical location of tumors, CT or MRI is usually correlated to interpret FDG images. Maximum-intensity projection images are sometimes helpful in determining abnormal focuses of tracer uptake. PET-CT devices that arecommonly used nowadays are able to provide, in one session, metabolic information about tumor behavior and precise anatomic localization of the disease.

Dispensing :

For dispensing a prescribed amount of radioactivity, it is necessary to determine the total activity and the radioactivity concentration of the radiopharmaceutical. A single dose may be withdrawn aseptically from the multidose vial by using a suitable syringe.
Once the patient injection is prepared, a needle of appropriate gauge should be used and the air in the syringe must be expelled. Each syringe must be measured in the dose calibrator to verify the prescribed amount of radioactivity for a patient.

Injection :

The tracer is injected intravenously through a catheter preferably positionedin an anticubital vein. The injected dose is dependent of the type of PET camera that is being used.

The recommended dose for 3D systems is between 150 and 300 MBq,whereas for 2D systems a dose of 370 MBq is proposed. For studies limitedto brain imaging, half of these doses should be used. The doses may beadjusted in function of weight (6MBq/kg for 2D systems) for instance in children or very obese patients.

Therapies with Zevalin Y^{90}

Zevalin (Ibritumomab tiuxetan) was the first radioimmunotherapy treatment to be approved by the U.S. Foodand Drug Administration (FDA) for the treatment of non-Hodgkin lymphoma (NHL). Zevalin has been approvedfor the treatment of patients with relapsed or refractory lowgrade, follicular, or transformed B-cell NHL, including patients with follicular NHL who are no longer responding to treatment with Rituxan (rituximab), a monoclonal antibody therapy.

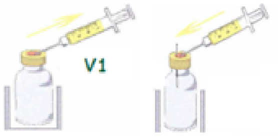
Zevalin is different in many ways from conventional chemotherapy or external beam radiation therapy. Zevalincombines the cell targeting ability of a monoclonal antibody with the additional cell killing ability of a radioactive particle, or radioisotope, called yttrium-90. Treatment with the Zevalin regimen can be completed within a week on an outpatient basis. It is generally well tolerated by patients, without the hair loss and nausea that often accompany chemotherapy treatments. The most common side effect is a temporary reduction in blood cell counts.

Labeling of Zevalin with Y^{90}:

The rubber stopper of all cold kit vials and the yttrium-90 chloride vial are cleaned with a suitable alcohol swab and allowed to air dry. The cold kit reaction vial is placed in a suitable dispensing shield (plastic enclosed in lead).

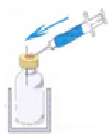
Step 1: The sodium acetate solution is transferred to the reaction vial (not radioactive yet)

Step 2: Y^{90} chloride is then tranferred to the reaction vial and appropriate shielding must be used



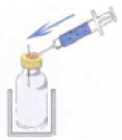
A volume V1 of 1500 MBq of Y^{90} chloride is drawn and then tranfered to the reaction vial containing the sodium acetate solution transferred in step 1 using a 1ml sterile syringe. The solution is then mixed completely by coating the entire inner surface of the reaction vial and then by inversion or rolling the container.

Step 3: the ibritumomab tiuxetan solution is tranferred to the reaction vial



1.3 ml ibritumomab tiuxetan solution is transferred to the reaction vial. The whole solution is then mixed completely by coating the entire inner surface of the reaction vial and then by inversion or rolling the container.The Y^{90} chloride/acetate/ibritumomab tiuxetan solution is then incubated at room temperature for five minutes.

Step 4: the formulation buffer is added to the reaction vial



The formulation buffer is drawnusing a 10-ml syringe with a large bore needle, that will result in a combined total volume of 10 ml. After the 5-minute incubation period, the same volume of air as the formulation buffer to be added must be withdrawn from the reaction vial in order to normalise pressure and immediately thereafter the formulation buffer is added down the side of the reaction vial.

Step 5: the Y^{90} radiolabeled Zevalin solution is analyzed for its specific radioactivity

Radiochemical purity of the radiolabelled preparation applies as long as more than 95% of Y^{90} is incorporated into the monoclonal antibody. Before administration to the patient, the percent

radioincorporation of the prepared Y^{90}radiolabeled Zevalin must be checked by Instant Thin Layer Chromatography (ITLC).

Administration of Zevalin with Y^{90}:

During the injection of Y^{90} radiolabeled ZEVALIN, proper shielding barriers should be in place. Y^{90} Zevalin is injected intravenously (I.V.) over a period of 10 minutes. The prescribed administered dose of Y^{90} Zevalin are usually :

- 0.4 mCi/kg (14.8 MBq/kg) actual body weight for patients with a platelet count > 150 000 cells/mm³,
- 0.3 mCi/kg (11.1 MBq/kg) actual body weight for patients with a platelet count of 100 000-149 000 cell/mm³

Therapies with DOTATOC Y^{90}

DOTA-D-Phe1-Tyr3-octreotide (DOTATOC) is a newly developed somatostatin analogue which can be stably labelled with the β-emitter yttrium-90.
The crossfire of betaparticles can destroy both somatostatin receptor-positive and receptor-negative tumor cells. Many reports show the usefulness of peptide receptor radionuclide therapy (PRRT) in neuroendocrine functioning tumors and thus Y^{90}-DOTATOC can be used for receptor-mediated internal radiotherapy.

Labeling of Dotatoc with Y^{90} :

To label dotatoc with Y^{90},several steps must be followed:

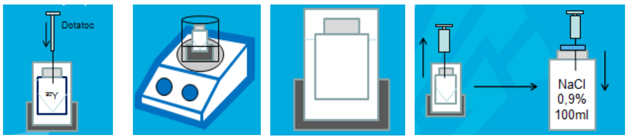


Figure 1 - Directions for labelling dotatoc with yttrium 90

First the peptide is added to the Y^{90} chloride then the reaction vial is placed in an oil bath of 90 degrees for 30 minutes .
Afterwards, the solution is kept at room temperature for at least 2 minutes to cool down. Finally, the concentrated Y^{90} DOTATOC solution is then sterile filtered in a sterile vial containing 100 ml of saline.
A sample is taken for quality control.

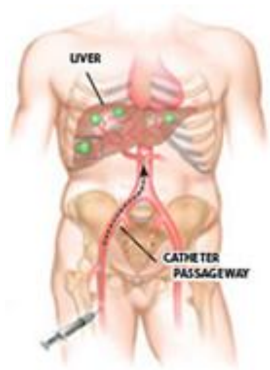
Labeling of Dotatoc with Y^{90}:

Leak free connections were used to avoid contamination in the therapy room. All tubings are pre-filled with saline before connecting them.


Figure 2 – Connecting the tubings for a safe administration with Y90/dotatoc

Once the pump and infusion system are tested for 5 minutes, the therapy is started without touching the tubing, filled with Y^{90}. After administration of Y^{90} the tubing are rinced with saline for 15 minutes.[5]

Therapies with SIR-Spheres Y^{90}



SIR-Spheres microspheres are an innovative means of treating liver cancer. In cases where it is not possible to surgically remove the liver tumors, SIR-Spheres microspheres can be used to deliver targeted, internal radiation therapy directly to the tumor.

This technique uses millions of tiny polymer beads or microspheres which contain a radioactive element called yttrium-90. SIR-Spheres microspheres are very small, approximately 32 microns in size, and are about one-third the diameter of a strand of hair. SIRT is usually administered as an outpatient procedure by a specially trained physician known as an interventional radiologist. A small catheter is guided into the liver and the SIR-Spheres microspheres are infused through the catheter.

The microspheres with the radioactive yttrium-90 are carried by the bloodstream directly to the tumors in the liver where they preferentially lodge in the small vessels feeding the tumor and deliver their dose of radiation. Unlike conventional external beam radiation, which can only be applied to limited areas of the body, SIR-Spheres microspheres selectively irradiate the tumors and therefore have the ability to deliver more potent doses of radiation directly to the cancer cells over a longer period of time.

Labeling of SIRSpheres® with Y^{90}:

The center of aluminum seal from sterile glass v-vial is removed with forceps, and therubber top is cleaned with alcohol swap.
2 mL room air are drawned into a shielded 5 mL syringe attached with a 20 gauge Huber point needle, and quickly drawn back and forth several times in order to mix the SIR-Spheres@ thoroughly through the rubber top of the SIR-Spheres@ delivery vial.

Figure 3 – Withdrawing the activity for Y90/SIRS

The lead pot containing the SIR-Spheres@ vial is lead at approximately 45" angle and the pre-calculated activity of patient dose iswithdrawn quickly, and transferred into the glass-v vial in the otherlead pot.
The glass-v vial containing the confirmed patient dose is put into the dedicated Perspex shield (figure 4).

Figure 4 – Perpex shieldfor Y90/SIRS

4. Overview of hospitals

		Tc		FDG	
Hospital	**Technician**	**Prep**	**Adm**	**Prep**	**Adm**
HF1	T1HF1	6			
	T4HF1			10	
	T14HF1(*)				5*
	T5HF1		5		
	T10HF1	5		5	
	T11HF1(*)				5
	T13HF1		5		
HF2	T4HF2			3	5
	T5HF2			4	4
	T8HF2			3	
	T12HF2		7		
	T9HF2	5			
	T10HF2		5		
	T11HF2	5			
HF3	T1HF3	10	5		
HF4	T1HF4	10	5		
	T2HF4	10	5		
HF6	T1HF6	5	5	5	5
	T2HF6	5			
	T7HF6			5	5
	T5HF6				
	T6HF6		5		
HF7	T1HF7	10			
	T2HF7		5		
	T3HF7		5		
	T4HF7				5
	T5HF7				5
	T6HF7	10			
HF8	T1HF8	5		5	
	T2HF8	4		5	
	T3HF8		5		5
	T4HF8		5		5
HF9	T1HF9	5	4		
	T2HF9	6	5		
	T3HF9			5	5
	T4HF9			5	5
HF10	T1HF10			5	5
HF11	T1HF11(*)			5*	5*
	T2HF11(*)			5*	5*
HF12	T1HF12			5	5
	T2HF12	5	5		
	T3HF12		5		
	T4HF12	5			
	T5HF12			4	4
HF13	T1HF13	5	5		

Table 1 – Number of measurements for diagnostic procedures

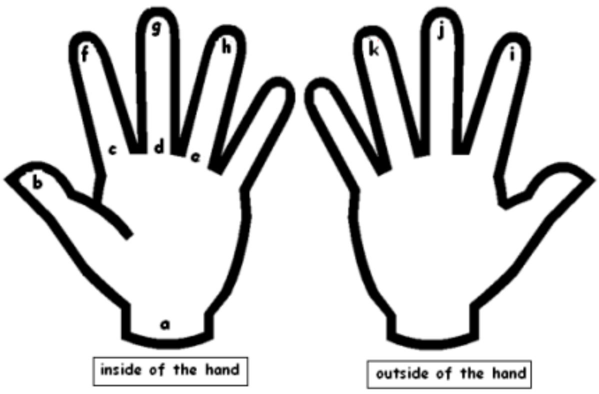
Problems and delays :

- The TLDs for beta emitters are very fragile. A non negligible number of them were broken during the measurements. The preparation of the gloves as well as the unpacking of the TLDs taped on the gloves are very time consuming.
- The measurements were delayed for several months in hospitals HF2 and HF6 where new hotrooms were installed.
- In hospital HF3, only one person was monitored as it is a very small center.

- In hospital HF1, all 5 scheduled measurements for administration of FDG were done but due to the teamwork, 3 workers did the measurements (only 2 measurements for worker T14HF1(*) instead of the 4-5 required per worker).
- Workers T1HF11, T2HF11 still need at this date to send back 4 measurements each to complete their serie of 5 measurement for the preparation and administration of F^{18}.
- In hospitals HF13 and HF10, only one worker agreed to be monitored, the second one declined participating to the measurements after one or two measurements.
- In hospital HF5, all workers declined participating to the measurements after 3 measurements performed.In general, the refusal was notified only after that the gloves were prepared and 2 to 3 months later. This resulted in delay in contacting and starting the measurements in other centers.
- Also regarding F^{18}, the measurements in the 10^{th} hospital could not be completed as the partner in charge lacked time.

5. Materials and method

An extensive measurement program was performed in 13 different nuclear medicine departments distributed in Wallonia, Flanders and Brussels with unified protocols.
The protocols, property of the ORAMED group, were used for ExDos purposes and the measurement results from ExDos will be used for the ORAMED analyses.
The protocols specific to the labeling or the administration were adapted to diagnostic and therapeutic applications.
Using such unified protocols, the measurements are homogenized and all data can be compared and evaluated.
Series of 4 or 5 measurements for two different technicians for each one of the selected procedures were programmed. Complementary information about the worker's dominant hand, his experience and the radiation protection equipment used were collected for each monitored worker in order to correlate it with the measured extremity doses.
To measure the skin dose across the hands, special gloves were designed with high sensitivity thermoluminescent dosemeters (TLD) placed at a minimum of 11 different positions on each hand. The positions are labelled a-k for the non-dominant (ND) hand, and A-K for the dominant (D) hand as shown in Figure 5.
Moreover, TLDs were welded in thin plastic bags to reduce the material in front of the TLD and measure adequately the quantity Hp(0.07). Another important point was to ask all the operators to check their gloves for contamination after each measurement.



Meas.points	Description
a	wrist
b	thumb
c	index
d	middle
e	ring
f	index tip
g	middle tip
h	ring tip
i	index nail
j	middle nail
k	ring nail

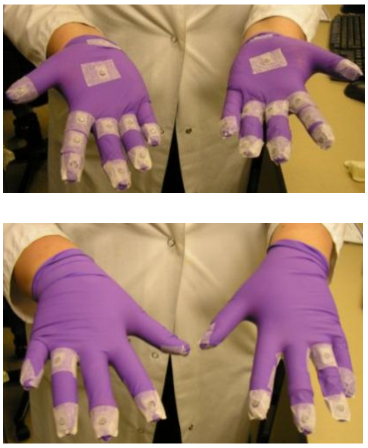


Figure 5 – Positions of measurements (left) – Gloves for beta emitters (right)

The TLDs used for this project are LiF crystals, doped with magnesium, copper and phosphore (LiF:Mg, Cu, P) for the measurements with gamma emitters and LiF crystalswith graphite, doped with magnesium, copper and phosphore for beta emmitters (LiF, graphite :Mg,Cu, P).

Figure 6 – MCP-N (LiF:Mg,Cu,P)

The new thin layer MCP-Ns (LiF:Mg,Cu,P) TL dosimeters, used to measure personal dose equivalent Hp(0.07) in fields of weakly penetrating radiation consist of two layers : a thin radiation sensitive part bonded to a thick base made of not activated LiF to which 2% of graphite was added in order to suppress any spurious luminescence.

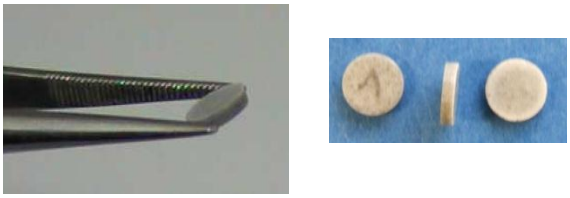


Figure 7 – MCP-Ns graphite (LiF:Mg,Cu,P)

Commercial name	*Material*	*Effective Material thickness*	*Dimension of the circullar pellets*	*LLD * (mGy)*	*Supplier*
MCPNs graphite (N for natural abundance)	LiF : Mg, Cu, P - graphite	10 mg/cm²	4.5 mm ⌀ * 0.9 mm	0.019	TLD POLAND
MCPN (N for natural abundance)	LiF : Mg, Cu, P	240 mg/cm²	4.5 mm ⌀ * 0.9 mm	0.008	TLD POLAND

Table 2 – characteristics of MCP-N and MCP-Ns

During the measurement campaign, the TLDs were calibrated at the secondary calibration laboratory of SCK-CEN. Specific correction factors relative to the place of measurement and the energy were applied.

For this purpose, TLDs wrapped in thin plastic bags were placed on two different phantoms and irradiated with Cs^{137}(γ 667 keV), Sr/Y^{90} (β^- 0.546 keV and 2 282 keV) and N150. Corresponding factors were calculated and were used for correcting the response of the TLD when exposed to the following radionuclides F^{18} (γ 511 keV, β^+ 634 keV) ; Y^{90} (β^- 2 282 keV) and Tc^{99m} (γ 140 keV) .

Both phantoms used are right circular cylinders 30 cm in length made of PMMA. The pillar phantom, associated with calibration of wrist is 7.3 cm in diameter. The rod phantom, associated with calibration of ring dosemeters, is 1.9 cm in diameter.

Background TLDs were kept for each measurement and the background signal was substracted from the measured TL signals. Each TLD-reading was also corrected for the individual sensitivity of the respective TLD. After each measurement, the TLDs were reset by annealing them at 240°C for 12 min.

- Validation of the TLDs

Before launching the measurement campaign, an intercomparison was performed within ORAMED in order to assess the methodology of the dosemeters' calibration used for the measurements. The main goal of this intercomparison was to establish a common basis for the measurement campaign among all participants. Two different irradiation fields were used in the intercomparison: Cs^{137} and Kr^{85}.
Standard TLDs (LiF:Mg:Cu:P and LiF:Mg:Ti, up to 240 mg•cm^{-2}) which will be used for gamma ray measurements, were irradiated with Cs^{137} and thin TLDs (8-10 mg•cm^{-2}), used for positron and beta pharmaceuticals, were irradiated with Kr^{85}. All participants reported results within 10% of the reference value.

- Lowest limit of detection

The lowest limit of detection was calculated after each set of calibrated TLD (same annihilation date and same date of reading). 2 or 3 tlds were kept for the background (per set of 100 TLDs) and the correspondant readings were corrected by their relevant individual factors. The lowest limit of detection was estimated by multiplying the averaged reading for the background with its relative standard deviation and correctedwith the calibration factor. 2 sigmas were kept as confidence level.
For both types of TLDs (MCPN and MCPNs), the lowest limit of detection was then averaged on 10 different values taken from the measurements from the files and we ensured that every hospital was included (table 2).

- Activity used for normalisation

In ORAMED, the measured doses were normalized to the manipulated activity to allow comparison between different departments. This manipulated activity refers to the “multidose activity” for normalisation in the case of Tc^{99m} and to the prepared activity to be administrated for F^{18}.

6. Overview of the results

A. Overview of collected data relative to radiation protection

Information relative to the different radiation protection devices used is summarized below for the different radionuclides and procedures.

a) Preparation of Tc^{99m} (18 workers)

All workers used a lead-shielded vial for Tc^{99m} .
During the preparation of Tc^{99m} only half of the workers (56%) acknowledged using also a shielding for the syringe (chart 1).

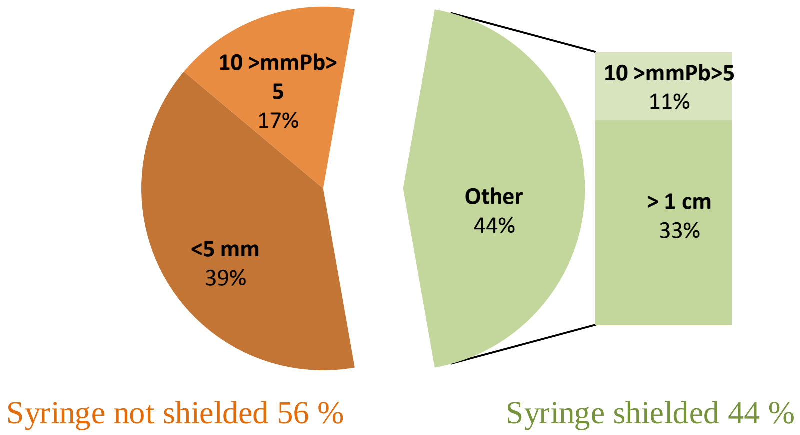


Chart 1 – Shielding used for Tc99m Preparation

In general, the use of a thin shield for the vial (below 5 mm of Pb) is also associated with the use of an unshielded syringe. Parallelely, most of the workers that used a shielded syringe used also a thick shielded vial.

b) Administration of Tc^{99m} (18 workers)

78% of the workers inject with a shielded syringe (13 workers out of 18) from 10 different centers.

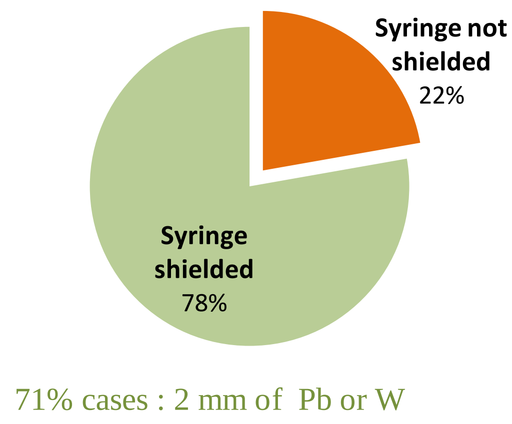


Chart 2 – Shielding used for Tc99m Administration

The syringe is usually shielded by 2 mm of Pb or W for 71% of the workers that declared using a shield for the syringe.

c) Preparation of F^{18} (18 workers)

69% of the workers prepare the dose for the patient with an unshielded syringe (8 hospitals: 11 workers). The multi-vial is shielded in all cases. Most of the centers use 3 cm to 5 cm of lead as shielding for the vial (figure 8a and 8b).
In hospital HF9 (figure 9c), the syringe is placed in a 2 cm lead container and the activity is then adjusted through the connected tubings while the "multi-vial" remains shielded in all steps in a 5 cm thick shield. This syringe lead container is also kept while the syringe is carried away to the room of injection and during the injection.

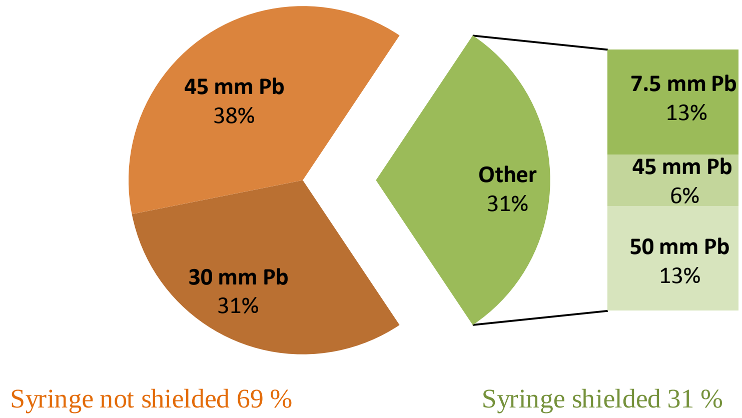


Chart 3 – Shielding used for the vials during F^{18}Preparation

The hospital HF12 using tungsten for shielding has also a system with 45 mm of lead that is used only when their usual Trasis® sytem is not working (figure 8a).

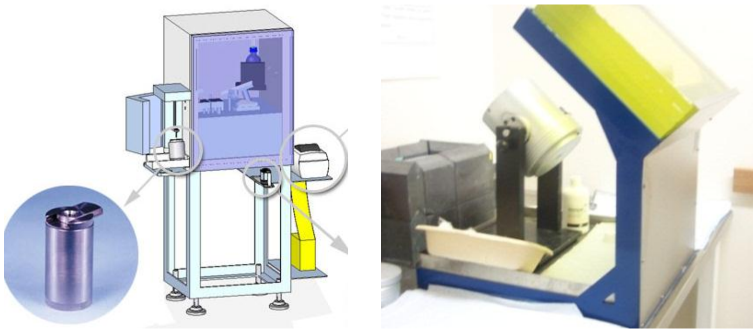


Figure 8a and 8b – Respectively : hospital dispensing unit,Trasis ® (hospital HF12) and most commonly used vial shielding of 45 mm Pb

d) Administration of F^{18} (15 workers)

All workers use a shielded syringe while injecting the patient either made of lead or tungstene (respectively 4 hospitals: 8 workers, 4 hospitals: 7 workers).

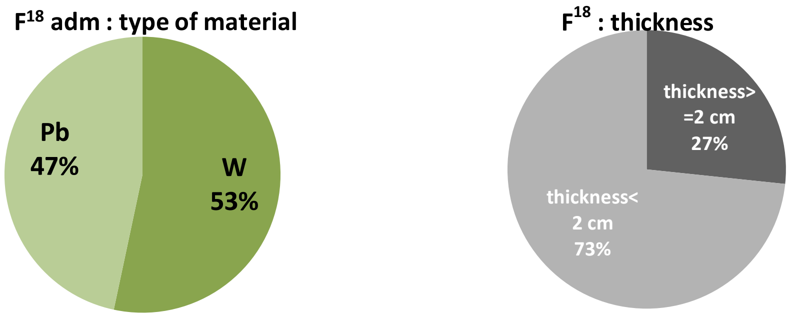


Chart 4 – Material and thickness of the shields used for F^{18} Administration

When a shielded syringe is used, the thickness is 2 to 4.5 cm lead equivalent (2 hospitals: 4 workers). The shield is typically 5 to 7 mm thick for syringes of thickness below 2 cm.

Hospitals HF6, HF8, HF9 (6 workers) used very specific thick shielding for the syringe (figures 9b and 9c). In hospital HF6 and HF8, the shielded syringe remains on a mobile table and thus is not carried by the worker (figure 9b) whereas in hospital HF9 the syringe is placed in a 2 cm lead container that can be carried away (figure 9c).

Figure 9a – HF12: 7 mm W-eq shield (trasis ®)

Figure 9b – HF6 : Pb 4.5 cm

Figure 9c– HF9 : Pb 3 cm

In hospital HF12, when the Trasis® system is used, the syringe is actually shielded twice : the first shield consists of a 7 mm thick tungsten wall (figure 9a) and the second of a 3 cm tungsten equivalent thick injection tool (figure 10a and 10b).

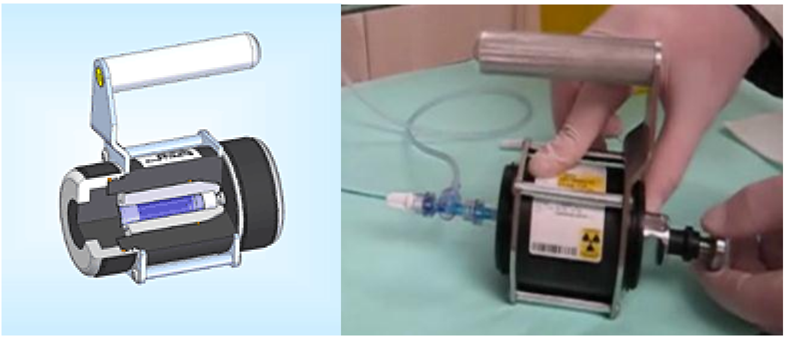


Figure 10a-10b Shielded syringe itself inserted into the additional lead pig for injection Trasis®

- Posijet® (figure 11): Full automatic dispensing and injection unit used in hospital HF7 (2 workers)

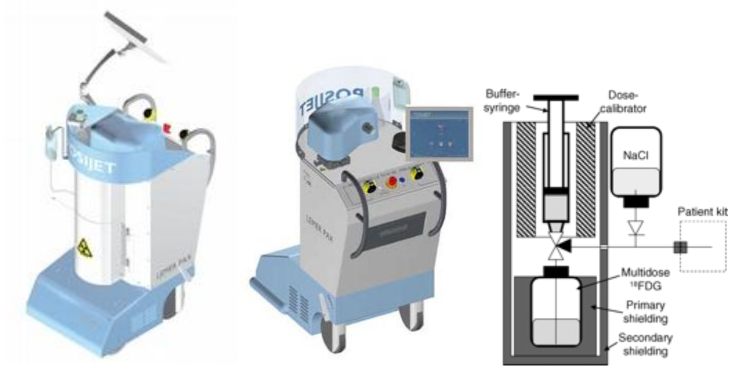


Figure 11 – Posijet ® (hospital HF7)

The dispensing and administration is automatically done. The system requires very limited manipulations of the worker.

e) Therapies with radionuclide Y^{90}

Below are only reported the appropriate shieldings that should be used as the low number of therapies monitored do not allow calculating any percentage or frequency for the shieldings that were used.

- Y^{90}Dotatoc

Therapies with Y^{90}DOTATOC were done in only one hospital. Different shielding were used as after the first measurement, optimisation was done in order to reduce the exposure of the workers.

Tweezers were used to enlarge the distance and a special tubing system was developed in house to transfer the concentrated Y^{90}DOTATOC solution to the vial with saline (figure 12 at the left).

Figure 12 – Shieldings used for Y^{90}DOTATOC preparation : 1 cm lead glass shield for vial and syringe

The formulated therapy is stored in a special aluminum cover to protect for beta radiation.

Figure 13 – Shieldings used for Y90/Dotatoc storage before administration

- Y^{90}SIRS

Therapies with Y^{90}SIRS were monitored in only two hospitals. The preparation of the dose to be administrated to the patient was done in a similar way in both hospitals. The shieldings used for syringe and vial are made of 1 cm thick lead glass for both vial and syringe.

Figure 14 – Shieldings used for Y^{90}SIRS preparation: 1 cm lead glass for vial and syringe or 1 cm lead for vial

- Y^{90}Zevalin

Therapies with Y^{90}Zevalin were monitored in 3 hospitals. For hospital HF1, different shielding were used as after the first measurement, optimisation was done in order to reduce the exposure of the workers (hospital HF1).

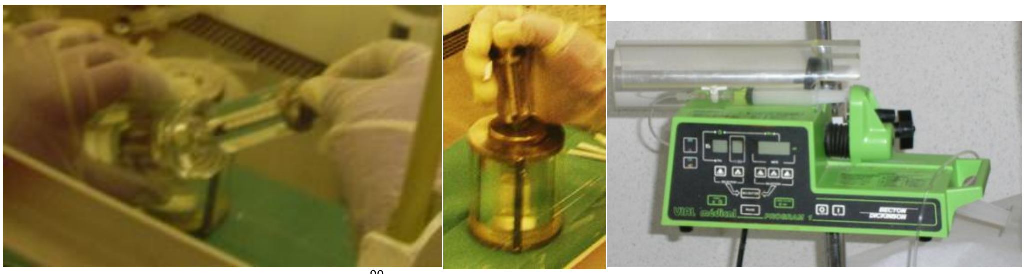


Figure 15 – Shieldings used for Y^{90}ZEVALIN preparation (left) and administration (right) in hospital HF1

In hospital HF6, workers prepare the dose to be administrated in a shielded vial, that will also be used for the administration (no syringe). As the step involving the dispensing in the 10mL syringe does not take place it induces less manipulations of the reaction vial thus less exposure for the worker.

Figure 16 – Shieldings used for Y^{90}ZEVALIN preparation in hospital HF6

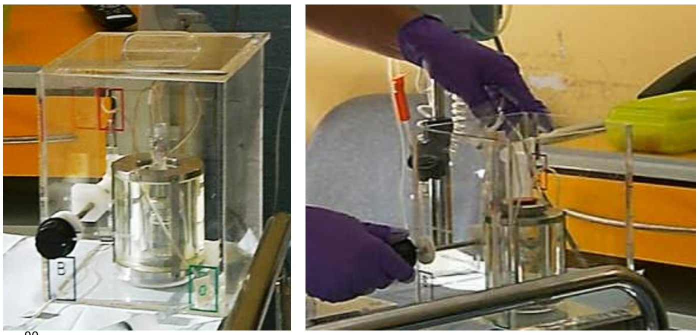


Figure 17 – Shieldings used for Y^{90}ZEVALIN administration in hospital HF6 : vial shield of 2 cm lead glass and Perplex box from SIRS®

B. Comparison of the maximum doses per worker

a) Preparation of Tc^{99m}

117 measurements were collected from 18 workers (10 different centers). The doses were normalized by the activity of the multi-vials and averaged by position. In chart 4, the maximum of the averaged doses per position were plot with their specific standard deviations for each worker.

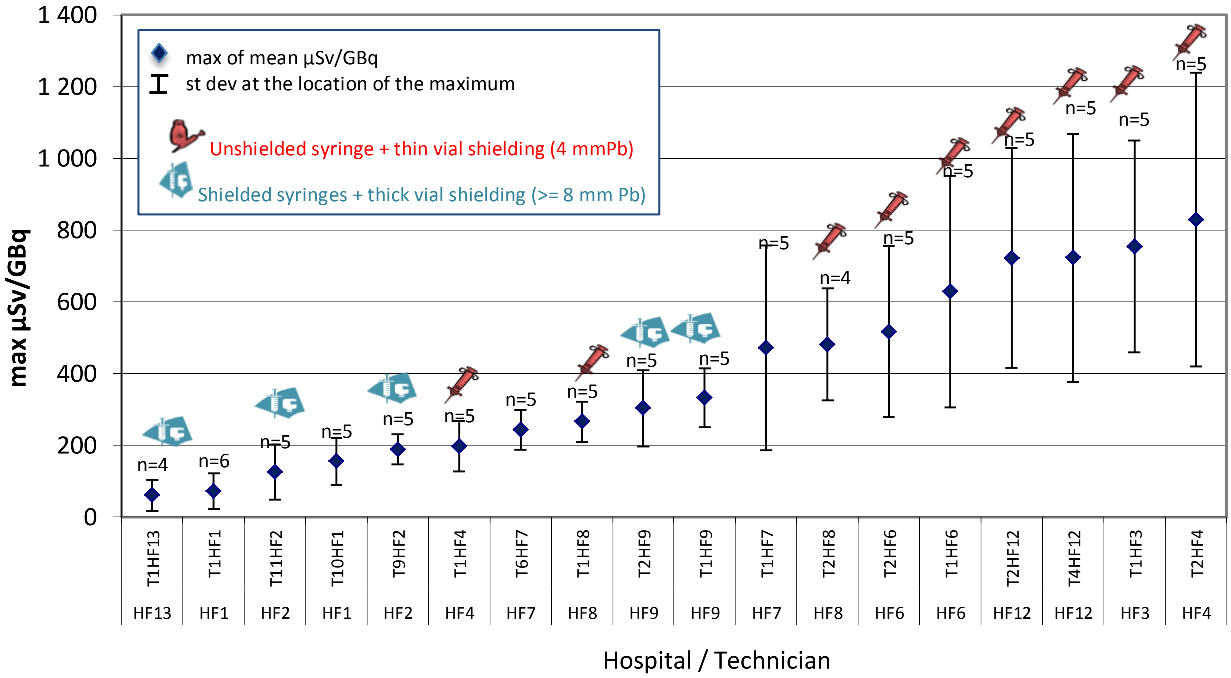


Chart 4 – Tc^{99m} : Preparation Maxima of the means per worker

The workers with good working practice are situated on the left part of the charts. The workers using unshielded syringe are clearly found on the right side for the preparation of Tc^{99m}. The use of shielded syringe is unmistakably considered as a main factor in reducing the doses to the hands.

A part of the measurements for the preparation could be done splitting the preparation of the vials and the syringes: 28 measurements were done only for the preparation of the vials (6 Workers) and 25 measurements while preparing the doses for the patients (5 workers). The doses were normalized by the activity of the multi-vials for the preparation of the vials and by the activity of the prepared syringes for the dispensing part. Results were then averaged by position.

In chart 5, the maximum of the averaged doses per position were plot with their specific standard deviations for each worker.

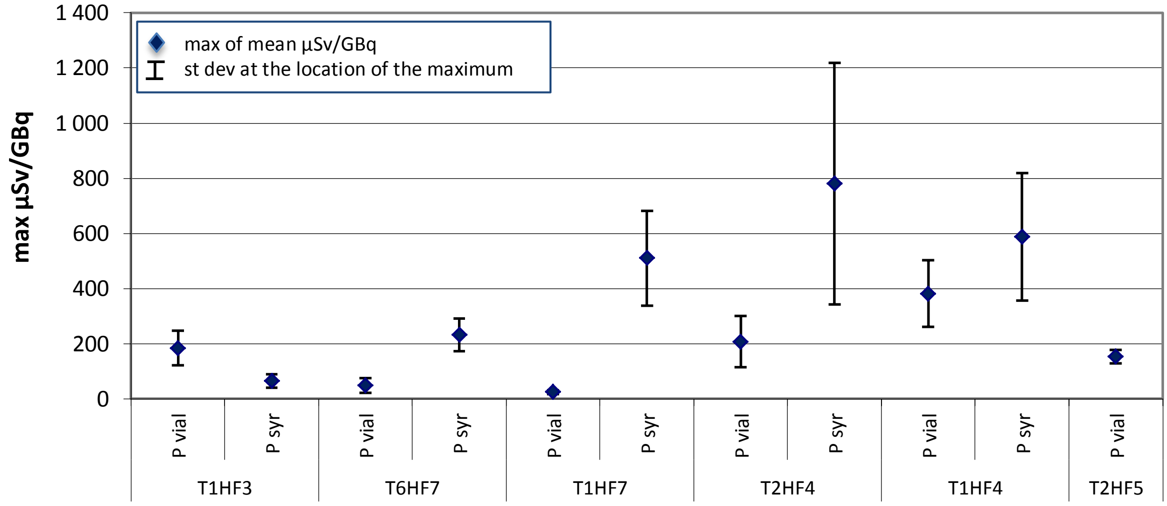
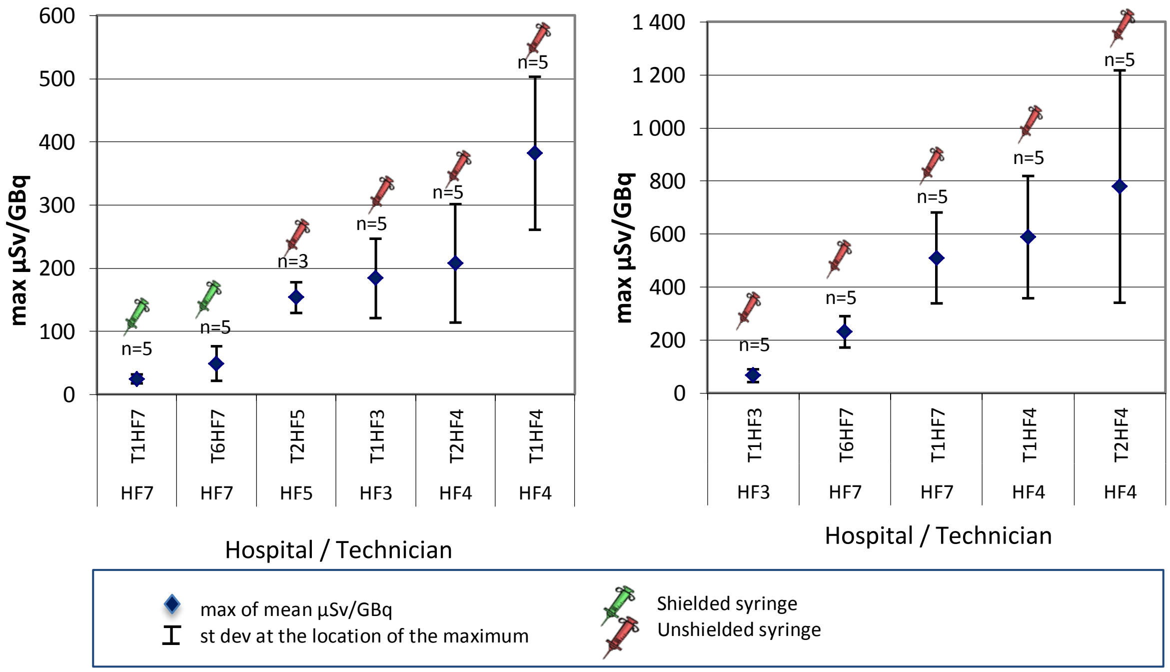


Chart 5– Maxima of the means per worker for preparation Vials and preparation Syringes

In charts 6a and 6b are given separatly the maximum of the averaged doses per position respectively for the labeling and the dispensing of Tc^{99m} for each worker.



Charts 6a and 6b – Maxima of the means per worker for respectively : preparation Vials, preparation Syringes

On the left part of the charts are situated the workers with good working practice. Again, the workers using unshielded syringe are clearly situated on the right side (chart 6a).

b) Administration of Tc^{99m}

90 measurements were collected from 18 workers (10 different centers). The doses were normalized by the activity of the syringes administrated and averaged by position. In chart 7, the maximum of the averaged doses per position were plot with their specific standard deviations for each worker.

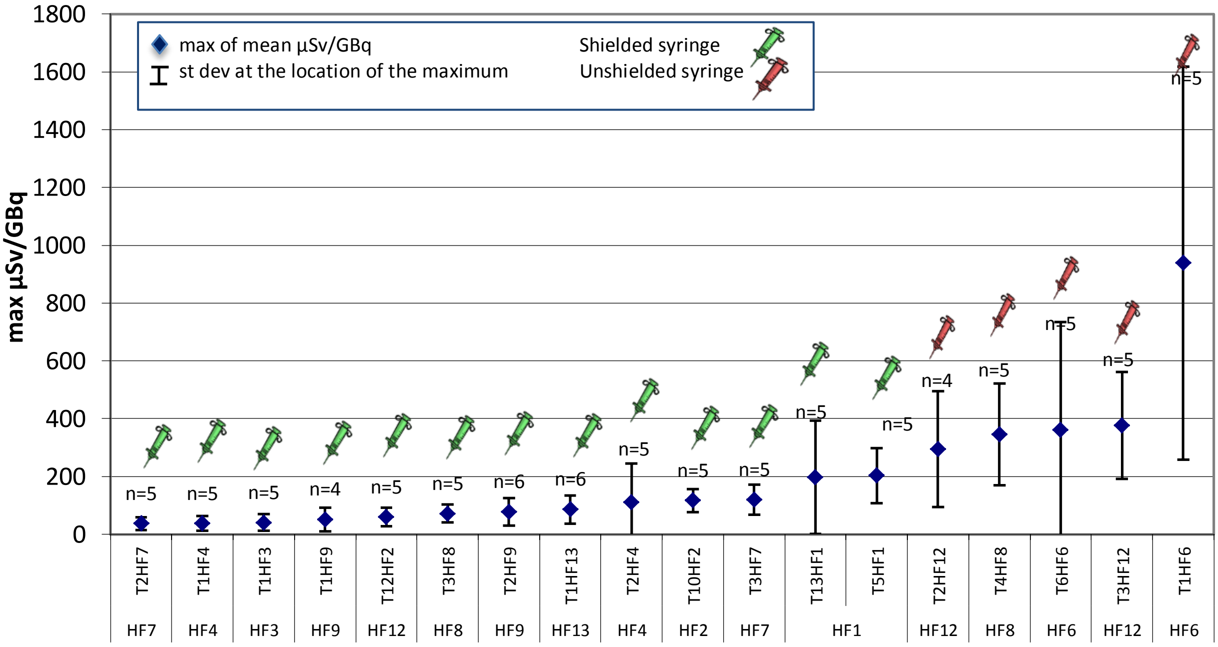


Chart 7 – Maxima of the means per worker for administration of Tc^{99m}

On the left part of the charts are situated the workers with good working practice. The workers using unshielded syringe are clearly situated on the right side for the administration of Tc^{99m}. The use of shielded syringe is evidently considered as a main factor in reducing the doses to the hands.
Chart 8, zoom of chart 7 shows the results for workers using a shielded syringe.

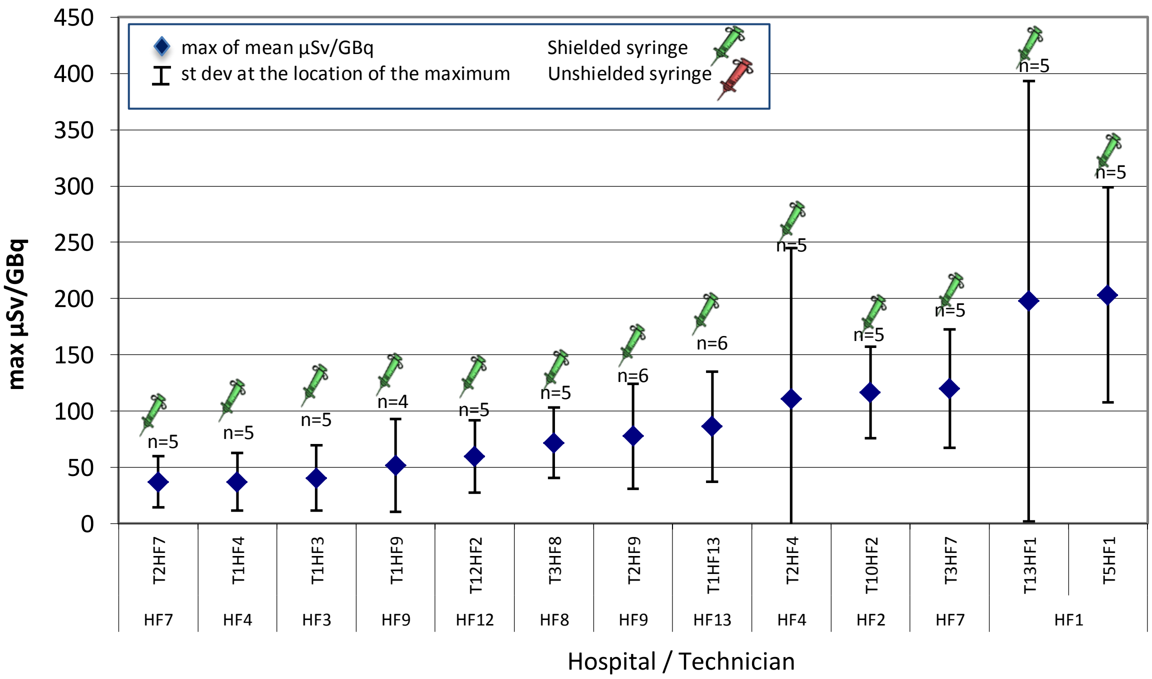


Chart 8 – Maxima of the means per worker for administration of Tc^{99m}(Zoom)

c) Preparation of F^{18}

84 measurements were collected from 18 workers (9 different centers). The doses were normalized by the activity of the prepared syringes and averaged by position. In chart 9, the maximum of the averaged doses per position were plot with their specific standard deviations for each worker. The multi-vial was shielded in all cases.

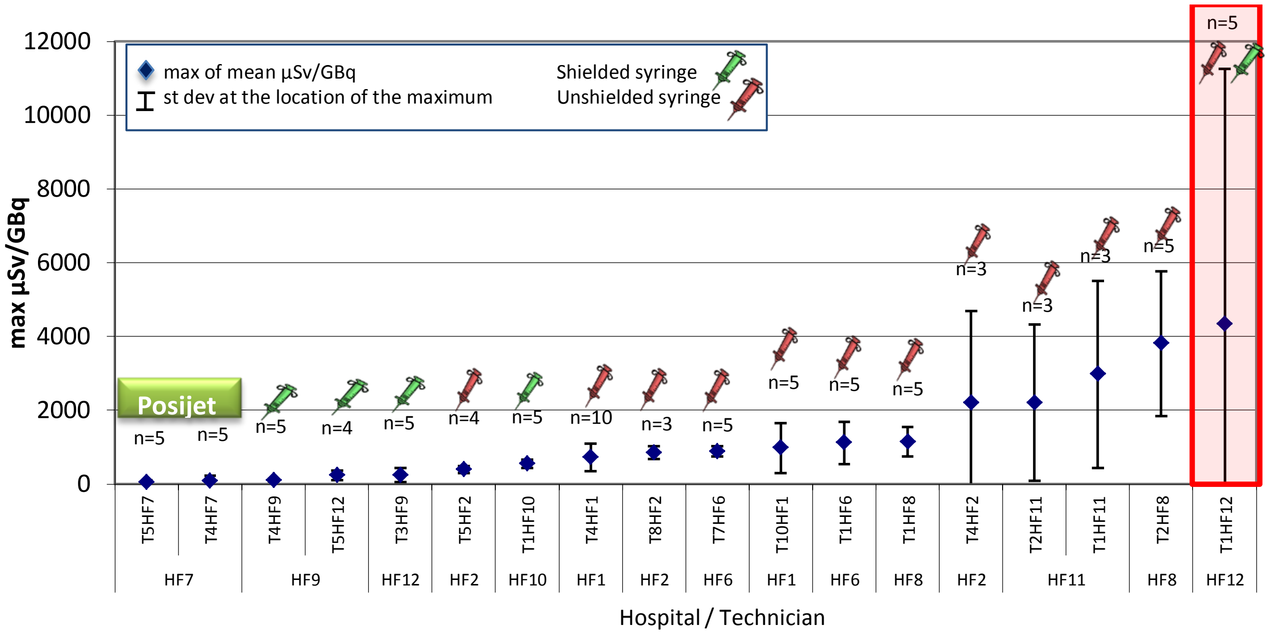


Chart 9 – Maxima of the means per worker for preparation of F^{18}

Regarding worker T1HF12, the large spread is due to the fact that the measurements were done in two different ways, one using the dispensing system in place in the hospital and the other done manually but the tools provided induced very bad manipulations with the syringe (the dispensing system was out of order at that time). Chart 10, zoom of chart 9 shows the results for workers within the 3rd quartile for the maximum doses during the preparation of F^{18} (below 1900 µSv/GBq).

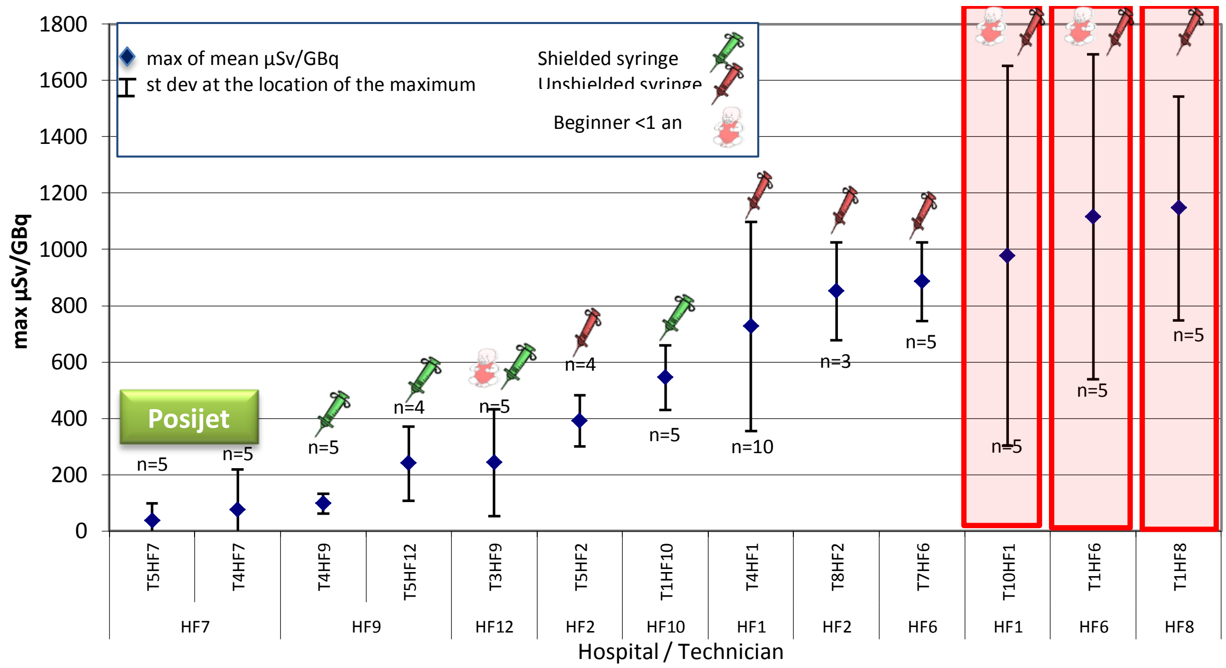


Chart 10 – Maxima of the means per worker for preparation of F^{18} (zoom)

On the left part of the charts are situated the workers with good working practice. The workers using unshielded syringe are clearly situated on the right side.

The use of a shielded syringe is clearly considered as a main factor in reducing the doses to the hands.

d) Administration of F^{18}

66 measurements were collected from 15 workers (10 different centers). The doses were normalized by the activity of the syringes administrated and averaged by position. In chart 11, the maximum of the averaged doses per position were plot with their specific standard deviations for each worker.

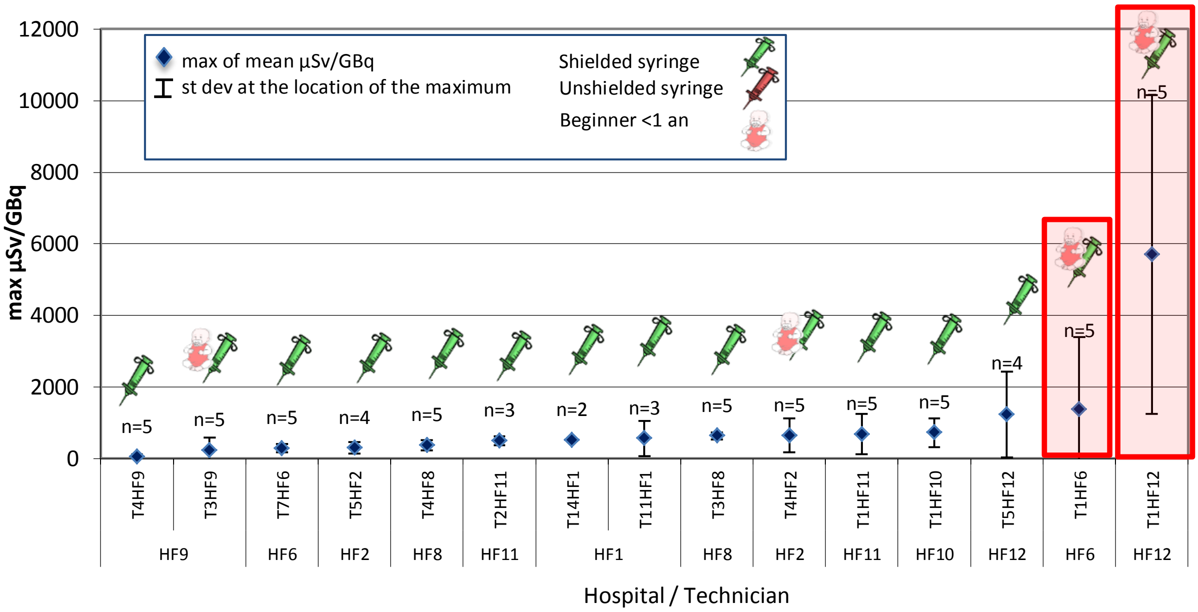


Chart 11 – Maxima of the means per worker for administration of F^{18}

For the administration of F^{18}, all workers that participated to the measurements used a shielding for the syringe. 2 workers considered as beginner with less than one year experience received higher doses while injecting the F^{18} to the patients despite using adequate shielded syringe. It seems that the experience of the worker can be considered as a factor influencing the extremity doses but in practice it is difficult to establish its statistical significance. This was also demonstrated within the detailed analysis of ORAMED.

Chart 12, zoom of chart 10 shows the maximum of the averaged doses per position for all except worker T1HF12 for the administration of F^{18}.

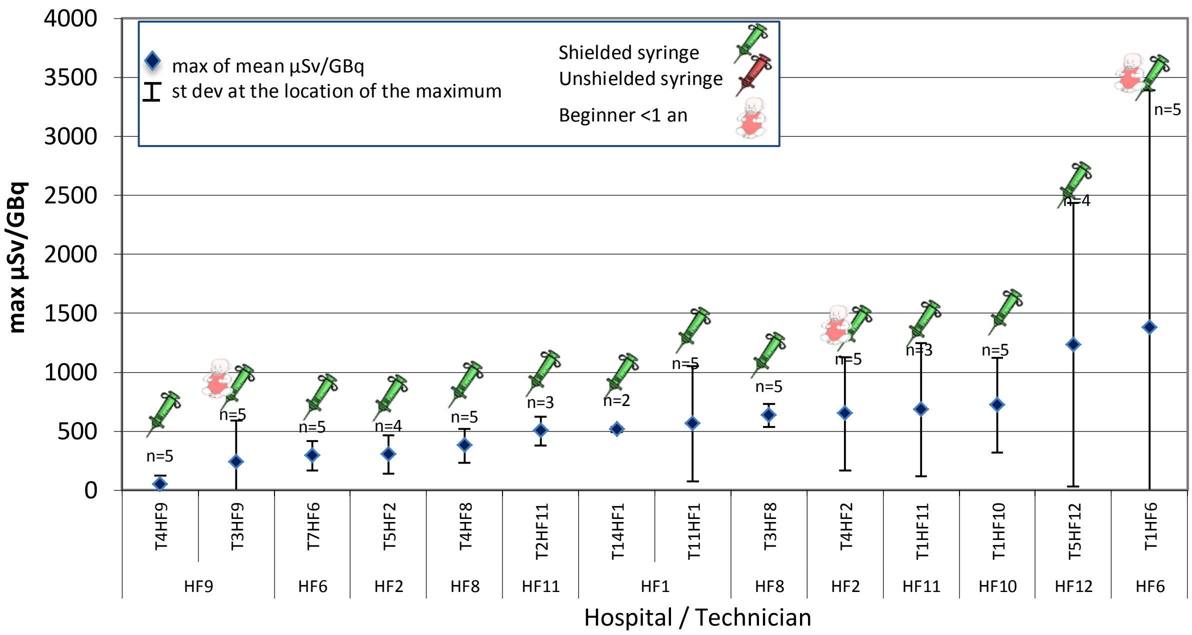
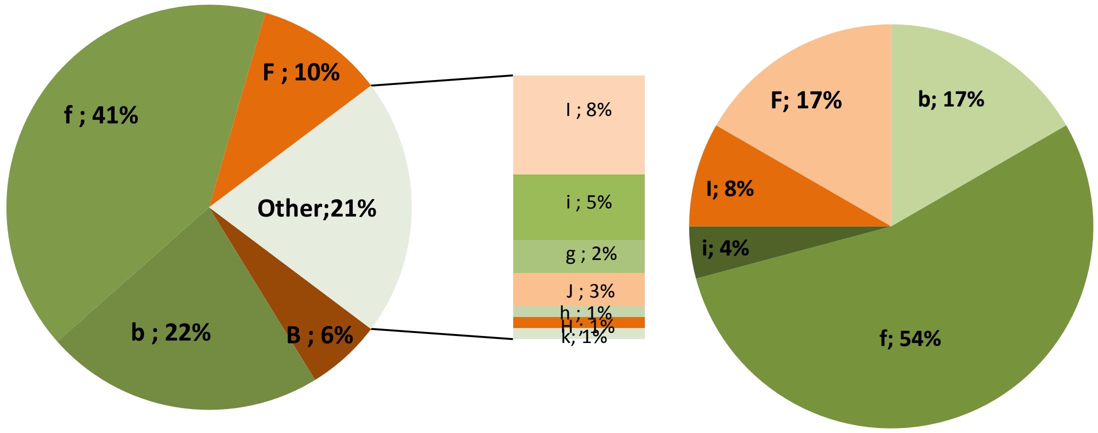


Chart 12 – Maxima of the means per worker for administration of F^{18}

C. Frequency and position of the maximum doses

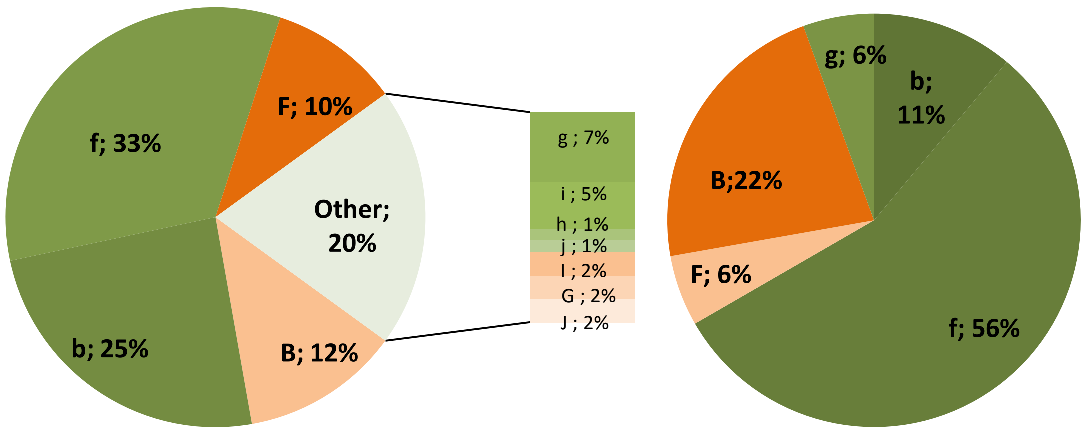
a) Preparation of Tc^{99m}



Charts 13a and 13b – Tc^{99m} Prep : Respectively frequency and position of maximum for all measurements and averaged per worker

In charts 13a and 13b are given respectively per measurement and averaged per worker the frequency and the position of the maximum doses.
All measurements considered altogether, the maximum dose is found at the index tip (51 %) , thumb (28 %) most frequently on the non dominant hand.
For preparation of Tc^{99m}, 71 % of the workers receive the highest exposure on the index tip most often on the non dominant hand (54% of the workers).

b) Administration of Tc^{99m}

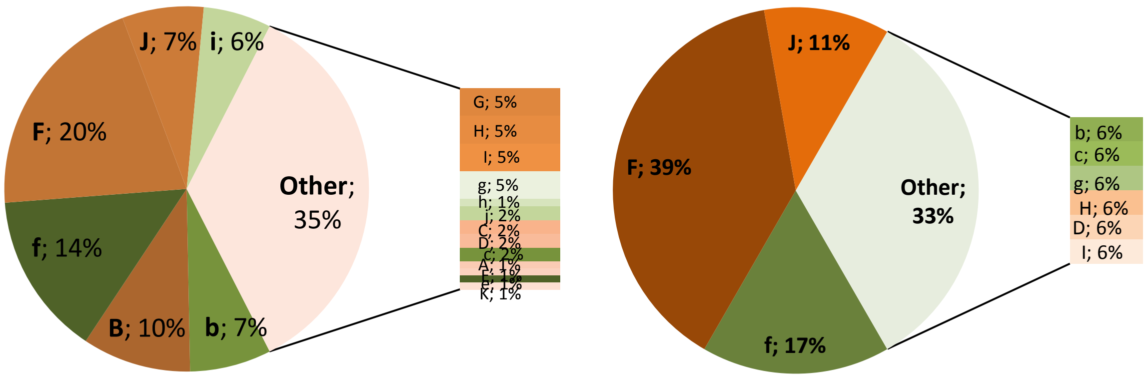


Charts 14a and 14b – Tc^{99m} Adm : Respectively frequency and position of maximum for all measurements and averaged per worker

In charts 14a and 14b are given respectively per measurement and averaged per worker the frequency and the position of the maximum doses.
All measurements considered together, the maximum dose is found on the index tip (43 % of the measurements) and on the thumb (37 %) most frequently on the non dominant hand.

For administration of Tc^{99m}, the largest doses were measured on the index tip for 62 % of the workers most often on the non dominant hand (56 % of the workers). The second location where the maximal doses were more frequently found is the thumb for 33 % of the workers usually on the dominant hand (22%).

c) Preparation of F^{18}

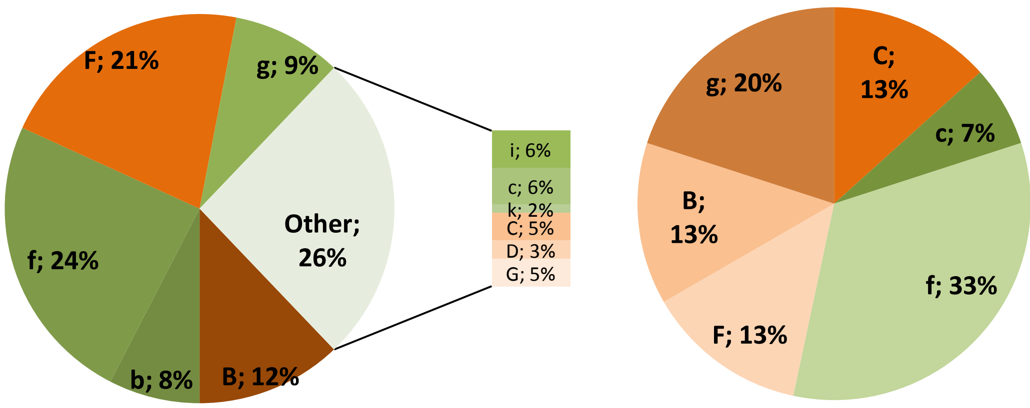


Charts 15a and 15b – F^{18} Prep : Respectively frequency and position of maximum for all measurements and averaged per worker

In charts 15a and 15b are given respectively per measurement and averaged per worker the frequency and the position of the maximum doses.
All measurements considered together, the maximum dose is found at the index tip (34 % of the measurements), then at the thumb (17 %) most frequently on the dominant hand.

For preparation of F^{18}, 46% of the workers receive the highest dose most frequently on the index tip and on the the middle nail usually on the dominant hand.

d) Administration of F^{18}



Charts 16a and 16b – F^{18} Adm : Respectively frequency and position of maximum for all measurements and averaged per worker

In charts 16a and 16b are given respectively per measurement and averaged per worker the frequency and the position of the maximum doses.
All measurements considered together, the maximum dose is found most often at the index tip (35 % of the measurements), then at the thumb (20 %).
For administration of F^{18}, the maximum doses were measured most often on the index tip for 46% of the workers usually on the non dominant hand.
However, in the case of the administration of F^{18}, the locations where the highest doses were found were quite various. It is not clear which hand receives most often the largest exposition. Its seems actually to be more complex and to depend more on the worker and how he usually processes the different steps of the injection (distances, angles and directions of his hand relative to the syringe).

D. Ratios

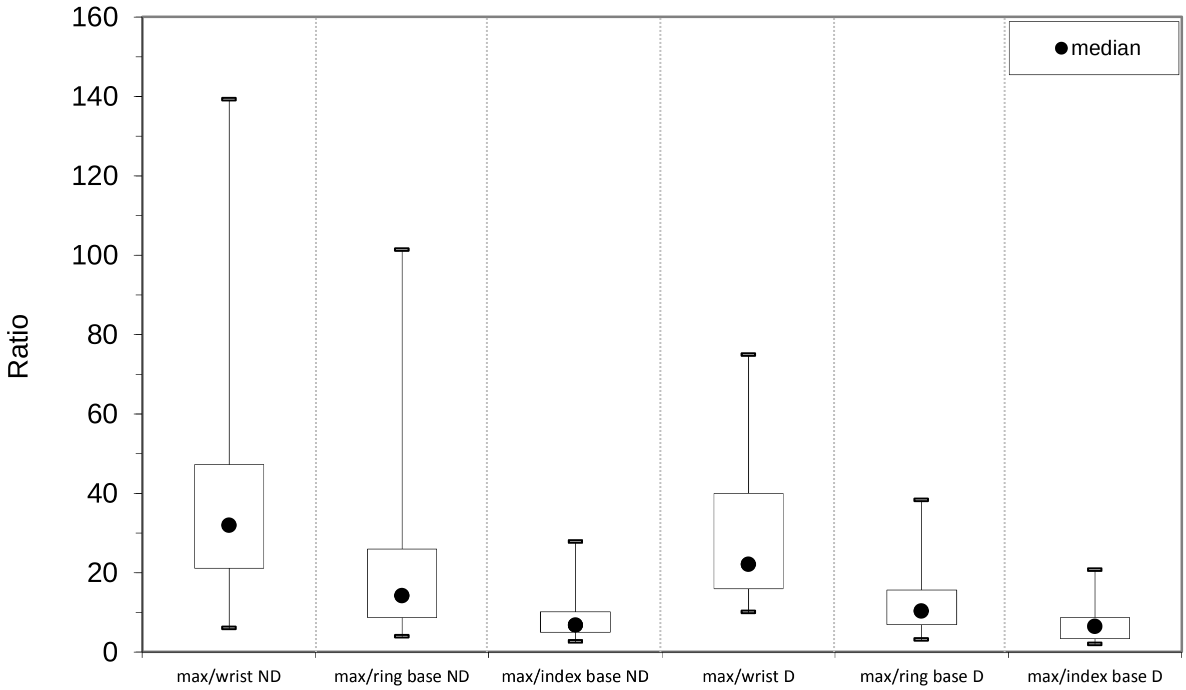
The impact of placing the routine monitoring dosemeter at a different position than the one corresponding to the maximum skin dose has been estimated by calculating the following correction factors for both non dominant (nd) and Dominant hand (D) :

- Hpmax/Hpbase ring,
- Hpmax/Hpwrist,
- Hpmax/Hpbase index,
- Hpmax/Hpindex tip,

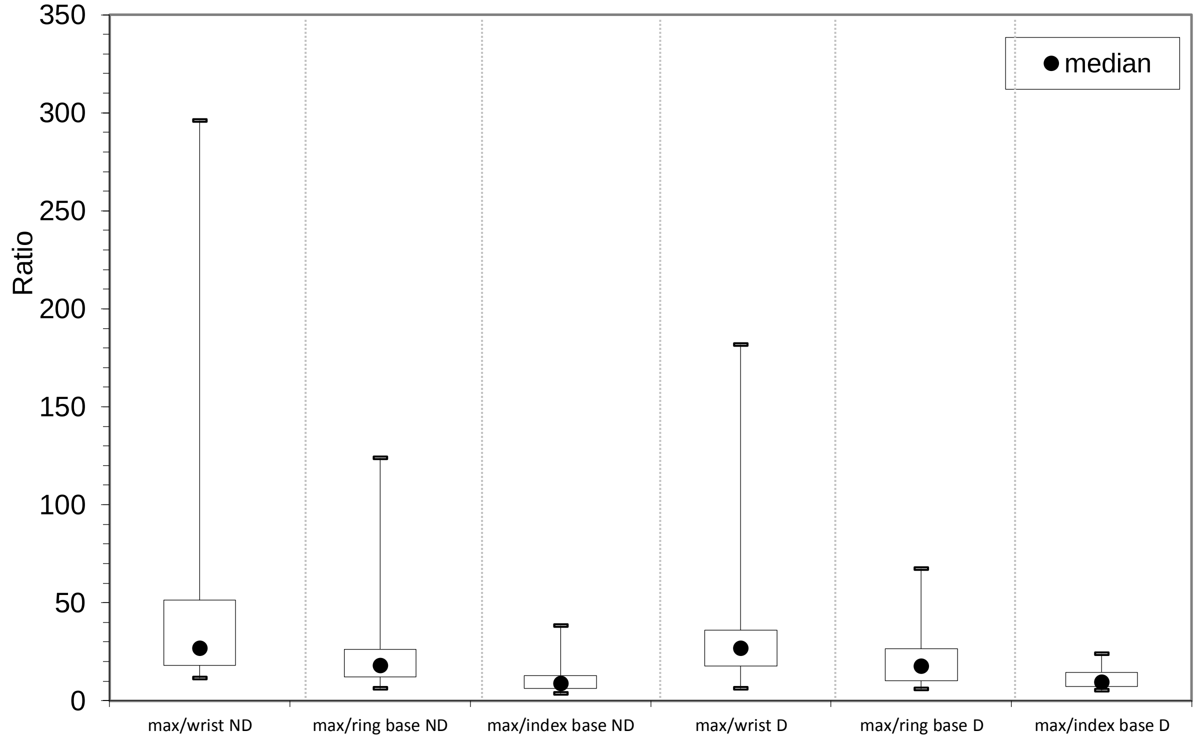
These correction factors are evaluated by considering the following ratios where Hpmax is the maximum of the mean Hp(0.07) (µSv/GBq) when both hands are considered simultaneously, Hpbase ring, Hpwrist, Hpbase index and Hpindex tip are the mean dose at the base of the ring finger, the wrist, the base of the index and the tip of the index, respectively, for the nd and D hands.

It was not calculated for therapy considering the small number of measurements available.

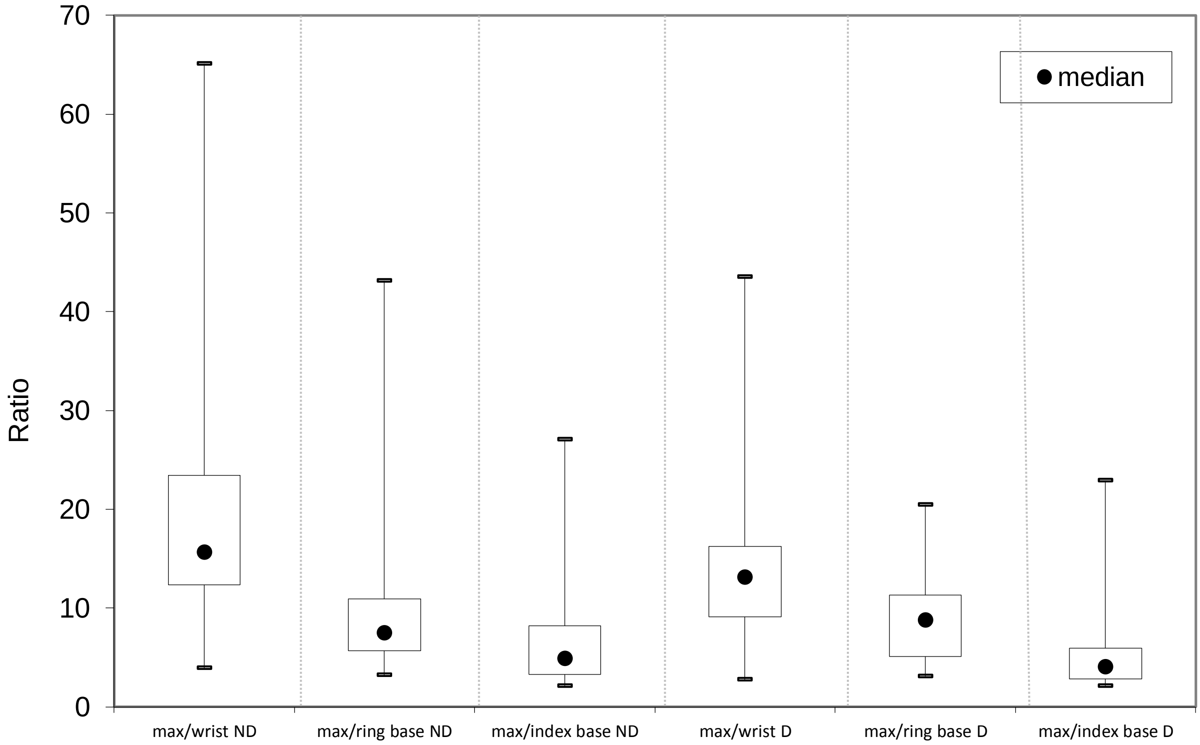
In charts 17a, 17b, 18a and 18b are given the box plots showing the mean, median, minimum and maximum values of these correction factors for each procedure for diagnostic procedures.



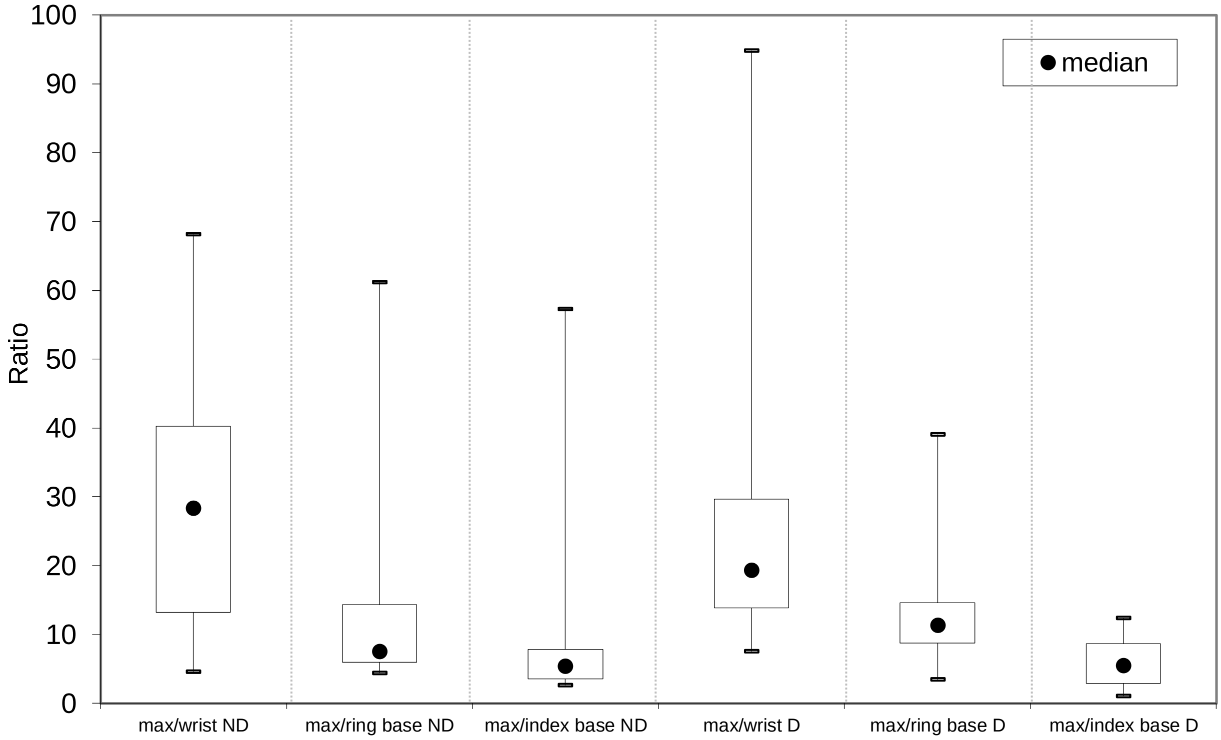
Charts 17a–ratios max/other positions for Tc^{99m} prep



Charts 17b – Respectively ratios max/other positions for Tc^{99m} adm



Charts 18a–ratios max/other positions for F^{18} prep



Charts 18b –ratios max/other positions for F^{18} adm

The mean value of the ratio of the maximum dose and the dose at the base of the index for the different tested diagnostic procedures is the lowest. It is also associated with the thinnest range from 3 to 10.

Also, the base of the index finger of the non dominant hand seems to be the more practical position for routine extremity monitoring in nuclear medicine. This position has shown more similar correction factors as regards the maximum dose for the different diagnostic procedures, lower values and also smaller variability than other positions.

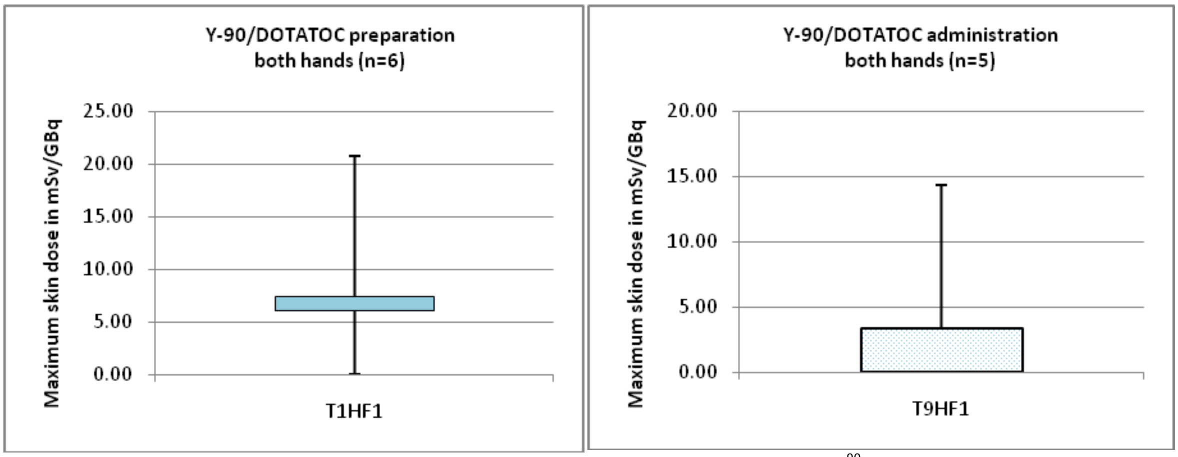
Taking a mean value from the four diagnostic techniques, one should be able to calculate a good approximate of the maximum dose equivalent from the ring dosemeter worn in the base of the index of the non dominant hand.

E. Comparison of the maximum doses therapy with Y^{90}

Given the small number of therapies that could be monitored, only maximum doses normalized per activity to be administrated were calculated.

1. Y^{90}DOTATOC

In charts 19a and 19b, are given the maximum doses normalized per activity to be administrated for Dotatoc therapies with Y^{90} (range : median, mean, min and max). 2 workers were monitored in one hospital, worker T1HF1 (6 measurements) and worker T9HF1(5 measurements).

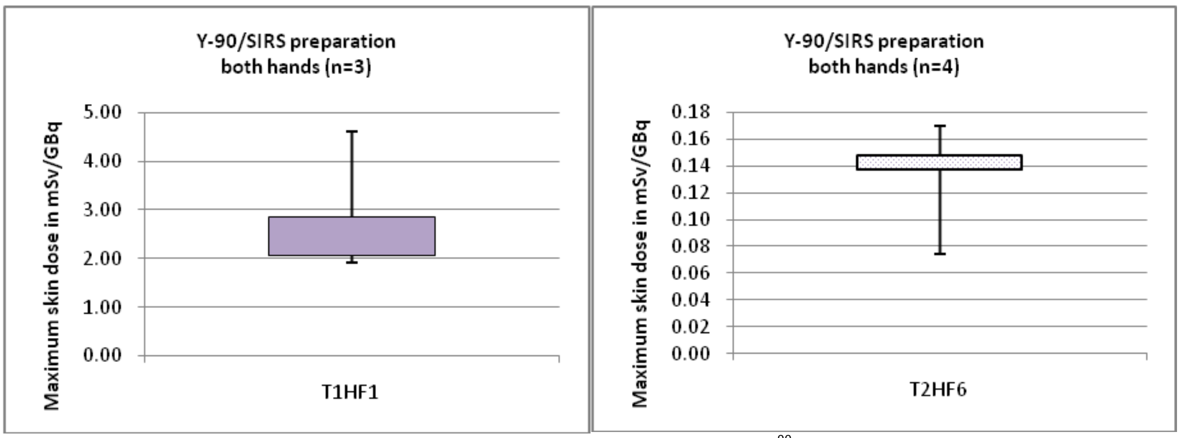


Charts 19a and 19b – Respectively maximum doses normalised per activity for Y^{90}Dotatoc Prep and Adm

The labeling of Y^{90}Dotatoc can induce high doses up to 20 mSv/GBq (chart19a).

2. Y^{90}SIRS

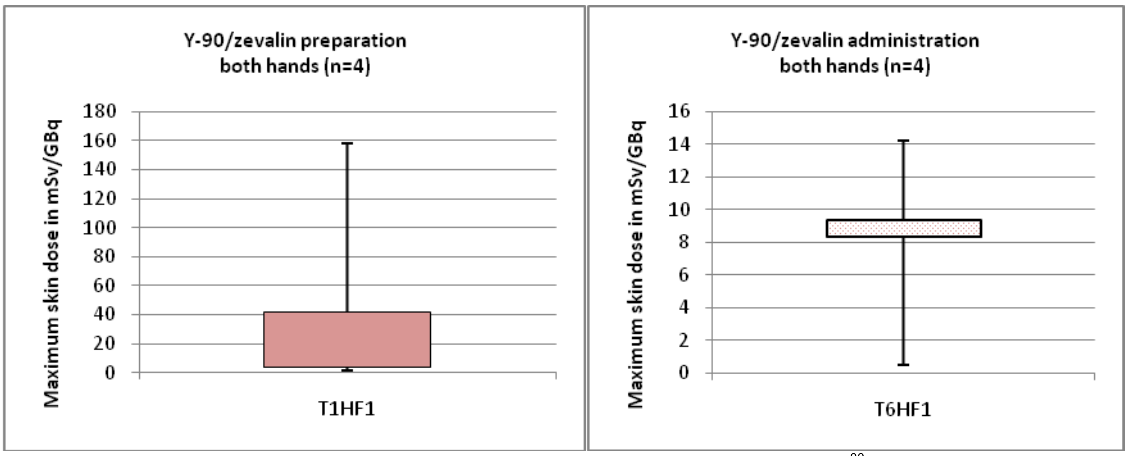
In charts 20a and 20b, are given the maximum doses normalised per activity to be administrated for SIRS therapies with Y^{90} (range : median, mean, min and max). 2 workers were monitored in 2 hospitals, worker T1HF1 (3 measurements) and worker T2HF6 (4 measurements).



Charts 20a and 20b – Respectively maximum doses normalised per activity for Y^{90}SIRS Prep for worker T1HF1 and T2HF6

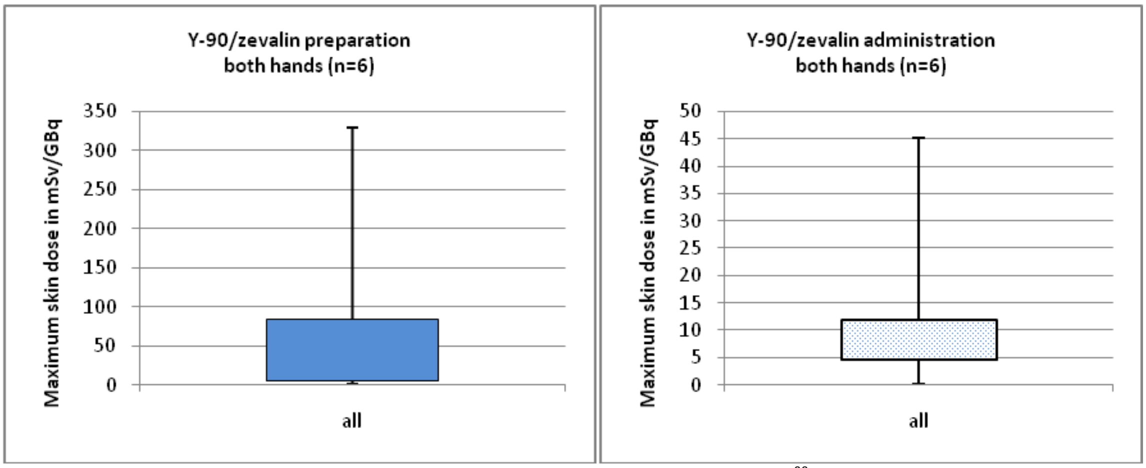
3. Y^{90}ZEVALIN

In charts 21a and 21b, are given the maximum doses normalised per activity to be administrated for Zevalin therapies with Y^{90} (range : median, mean, min and max). 2 workers were monitored in hospital HF1, worker T1HF1 (4 measurements) and worker T6HF1 (4 measurements).



Charts 21a and 21b – Respectively maximum doses normalised per activity for Y^{90}Zevalin Prep and Adm

In charts 22a and 22b, are given the maximum doses normalised per activity to be administrated for Y^{90} Zevalin therapies (range : median, mean, min and max) for all workers. 3 workers were monitored for the preparation (workers T1HF1; T2HF6 and T6HF2 respectively : 4, 1 and 1 measurements) and for administration worker T6HF1 (4 measurements).



Charts 22a and 22b – Respectively maximum doses normalised per activity for Y^{90}Zevalin Prep and Adm (all workers)

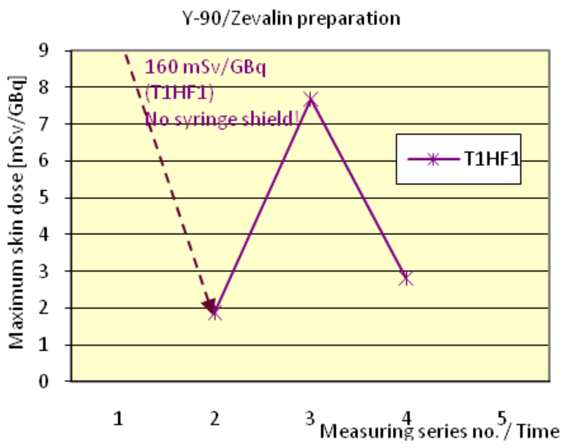
During the labeling of Y^{90}Zevalin (chart 22a) severe exposure was measured during the preparation of Y^{90}Zevalin where dose up to 160 mSv/GBq was measured for worker T1HF1 (left chart below) and even up to 300 mSv/GBq for another worker due to a bad handling of the reaction vial (figure 18).

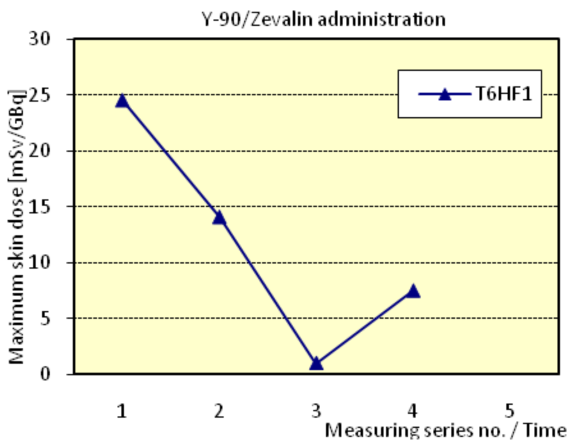
Figure 18 – Direct contact with the Y^{90} hot reaction vial

It should be stressed that optimisation of the exposition is possible. Doses as low as a few mSv/Gbq can be reached for the same therapy. As the therapies are very low in frequency, the worker is not familiarized with betas emitters of high energy and should receive first adequate training. Moreover proper shieldings should also be used in the correct way.
For instance, the reaction vial should remain inside its shield and the syringes should be shielded during all steps of the labeling.

Dose history for workers T1HF1 and T6HF1

Due to changed awareness regarding beta radiation exposure, optimisation was done in order to reduce the exposure of the workers. In charts 23a and 23b are given the dose history for worker T1HF1 and T6HF1 for their serie of 4 measurements after the 1st, 2nd , 3rd and 4th therapy.





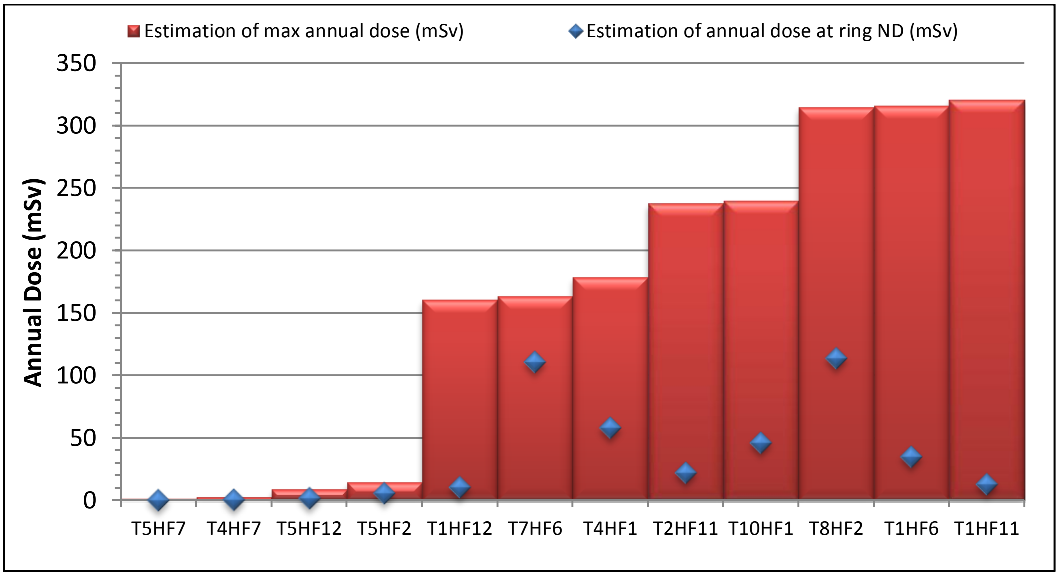
Charts 23a and 23b – Respectively dose history for Y^{90}ZEVALIN for workers T1HF1 (prep) and T6HF1 (adm)

Several handlings were corrected and proper shields (e.g. made of 1 cm thick lead glass at least) as well as twizers were used.
The maximum doses measured drop from 160 mSv/Gbq and 25 mSv/GBq to a few mSv/GBq for respectively the preparation and administration of Y^{90}Zevalin for the same workers.

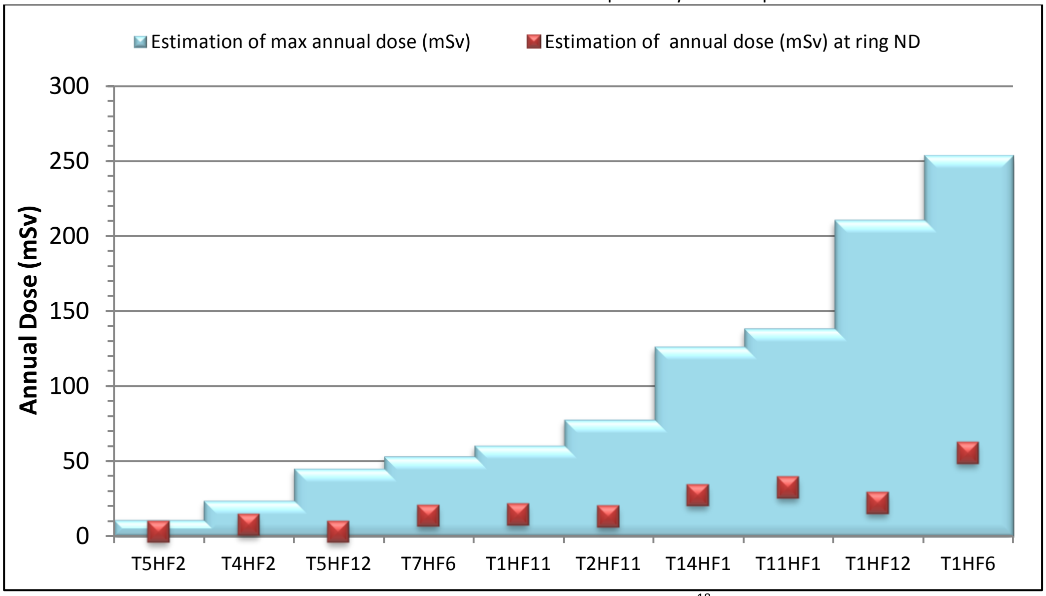
7. Estimation of the annual doses

The annual dose limit for deterministic effects to the skin is set to 500 mSv averaged over 1cm² area of skin regardless of the area exposed. When 3/10th of the limit is reached, it is legally required that doses are routinely monitored.
The annual manipulated activity was assessed by each center for their relevant workers depending on the annual activity prepared and administrated and on their working days (short questionnaire).
The estimation of the annual dose for a worker performing only one type of procedure was obtained by multiplying the maximum, among all positions in the hand, of his mean normalized doses from all his measurement series by his annual manipulated activity.
The annual dose were thus estimated for 29 different operators for the procedures for which real measurements were available (Appendix E).

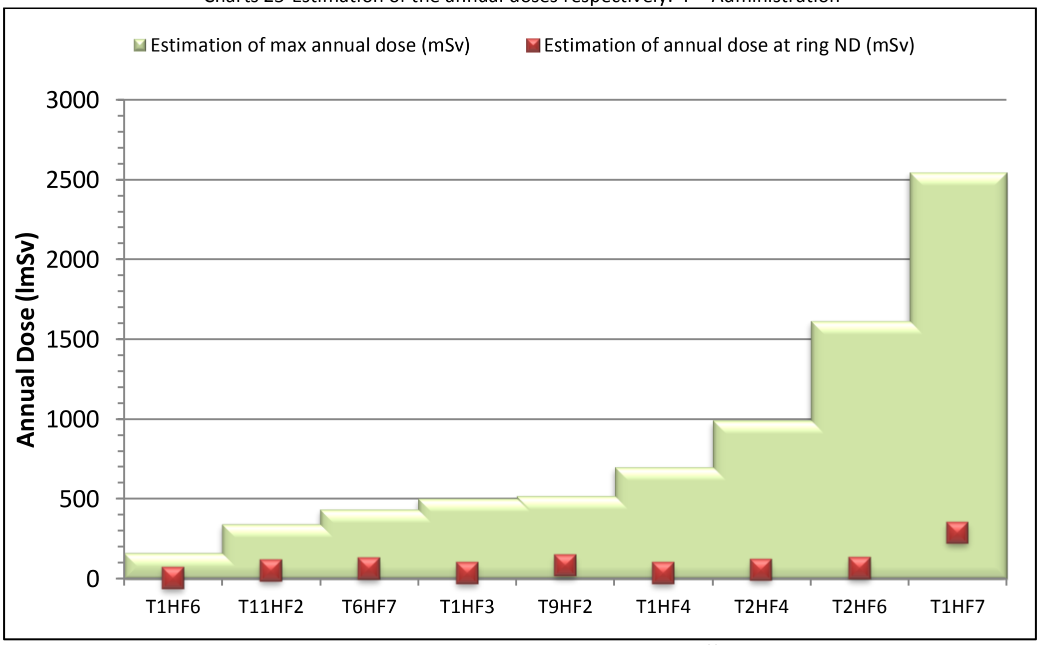
The following charts 24 to 27 give the estimated maximum annual dose for different workers as well as an indication of the annual dose at the ring position on the non dominant hand for each type of procedure.



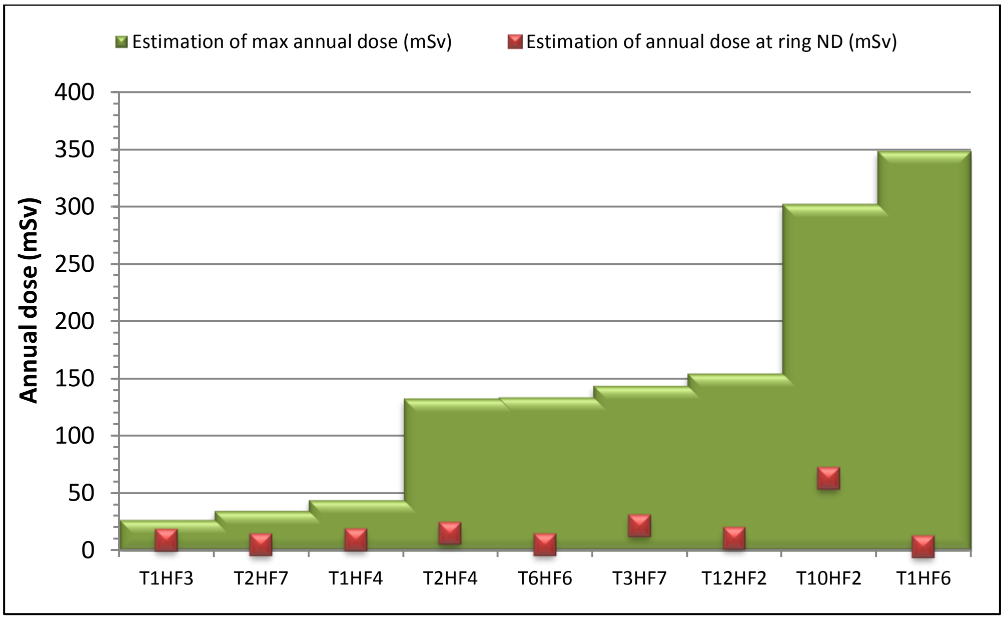
Charts 24- Estimation of the annual doses respectively : F^{18} Preparation



Charts 25-Estimation of the annual doses respectively: F^{18} Administration



Charts 26-Estimation of the annual doses respectively: Tc^{99m} Preparation

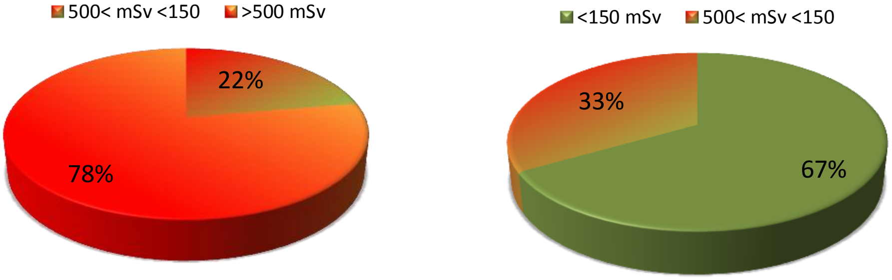


Charts 27-Estimation of the annual doses respectively: Tc^{99m} Administration

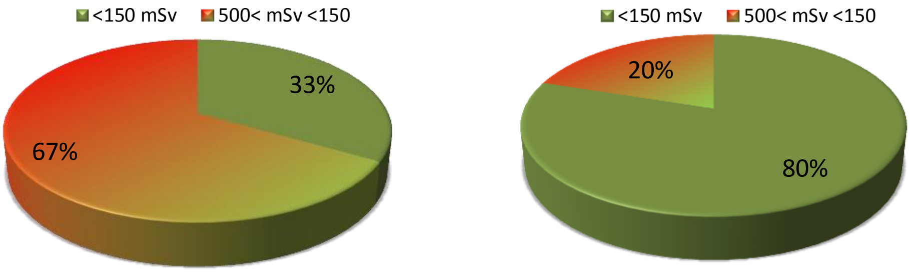
As expected, there is a large underestimation of the maximal annual dose when one does the evaluation based on the dose found at the ring position on the non dominant hand.

Some workers were monitored for only one type of procedure (e.g. Tc^{99m} preparation) when actually they performed more (e.g. plus Tc^{99m} administration, plus F^{18} preparation and administration, plus therapy). In these cases, the estimation of the annual dose was calculated only considering the monitored procedures, from which real measured values were available.
Extrapolating doses from one worker to another for a given procedure was considered very risky and not realistic due to the large variation observed between workers performing the same procedures, even in the same hospital.
Even considering this criteria, it is found that the extrapolated doses are in the range between the 3/10th of the annual limit and the annual limit itself, indicating once again that the monitoring of the extremity doses is clearly a requirement in nuclear medicine.

In the figures below, a frequency distribution is given of how many times a certain dose is exceeded for each procedure.



Charts 28a-28b Estimation of the annual doses respectively: Tc^{99m} Prep (9wkr) – Tc Adm(9 wkr)



Charts 29a-29b Estimation of the annual doses respectively: F^{18} Prep(12 wkr) – FDG Adm (10 wkr)

For most of workers (78%), just the preparation itself of Tc^{99m} can induce an annual dose above the annual limit although it was seen when normalised by the activity that F^{18} procedures are likely to give more exposure than Tc^{99m} . This is mainly due the large activities manipulated and the workload involved in Tc^{99m} .

The estimation of the annual doses was done considering each kind of procedure separately whereas in reality a worker can perform more than one (e.g: preparation and administration of Tc^{99m}). Thus, these percentages might be underestimated.

8. Summary

This extensive Belgian study on extremity dosimetry in nuclear medicine helped in assessing the locations of the maximal doses on the hand of the worker for the different types of procedure.

The results of the measurements campaign highlighted large variations among procedures and workers.
To some extent, the spread of the doses, even within the same procedure, is the expected consequence of the nature of the problem (betas or positrons emitters, orientation of the syringe, distance to the radioactive solution, time of manipulation etc….).
The dose distribution over the hand depends first on the characteristics of the radionuclide; it is highly inhomogeneous for Y^{90} and more homogeneous for F^{18} and especially for Tc^{99m}. It also depends on the distance between the source and the hand and on whether the source is shielded or not. Moreover it depends on the manipulations performed. Therefore, even performing the same procedure with the same devices, it may strongly vary from one worker to another. However, some trends were found among the monitored workers for all procedures. Thus, the dose at the non dominant hand is usually higher than the dose at the dominant hand and the index tip is most frequently the most exposed position on the hand.[6]

However, the very wide range of maximum doses observed (from some tenths of µSv/GBq up to one thousand for Tc^{99m}, from some tenths of µSv/GBq up to more than five thousand for F^{18} and from few mSv/GBq to more than hundreds mSv/GBq for Y^{90}) is an indication that good and bad practices were performed and thus, that workers with larger doses could actually optimize their working procedures or habits in order to decrease the dose.
In particular, the use of shielded syringe was clearly evaluated as a main factor in reducing the doses to the hands. [7]

Staff handling Y^{90} has to be aware of the fact that the skin dose rate can be considerably higher for the same activity and distance to the source when no radiation protection measure is taken. For instance, just a common plexiglas syringe shield can provide an attenuation factor of more than two orders of magnitude for Y^{90} (Appendix D).
When appropriate training is given and the suitable radiation protection measures are used, doses can be reduced to an acceptable level when repeating the procedure. The annual dose limit for deterministic effects to the skin is set to 500 mSv averaged over 1cm² area of skin regardless of the area exposed. When $3/10^{th}$ of the limit is reached, it is legally required that doses are routinely monitored. The annual doses were here estimated for 29 workers for the procedures for which real measurements were available.
Even considering this criteria, it is found that the extrapolated doses are in the range between the $3/10^{th}$ of the annual limit and the annual limit itself for the preparation and administration of F^{18} as well as the administration of Tc^{99m}.
This indicates once again that the monitoring of the extremity doses is clearly a requirement in nuclear medicine.

Whereas in the case of the preparation of Tc^{99m}, 7 workers out of 9 were estimated to receive most likely an annual dose above 500m Sv. The preparation of Tc^{99m} is likely to give the largest contribution to the annual dose given its frequency and the activities handled by the workers.

References

1. **First multi centre study to investigate high-dose X-ray procedures in Belgium, subproject 3: Calculation of effective dose to staff using Monte-Carlo simulations and extremity doses to personnel**
   Buls N., Clerinckx P., Vanhavere F., et al., Project report, financed by the Federal Agency of Nuclear Control, Belgium 2005

2. **An overview on extremity dosimetry in medical applications**
   F. Vanhavere, E. Carinou, L. Donadille, M. Ginjaume, J. Jankowski, A. Rimpler, and M. Sans Merce,. Radiat Prot Dosimetry, March-April 2008; 129: 350 – 355

3. **Extremity and eye lens doses to the staff of interventional cardiology and radiology procedures – Preliminary results**
   Koukorava, E. Carinou, J. Domienik, J. Jankowski, S. Krim, D. Nikodemova , L. Struelens and F. Vanhavere, Abstract submitted to the World Congress 2009 on Medical Physics and Biomedical Engineering to be held at Munich, September 7 – 12, 2009.

1. **Principles and Practice of PET/CT - Part 1 A Technologist's Guide**
   European Association of Nuclear Medicine
   Technologist Committee and Technologist Education Subcommittee

2. **Optimization of the preparation and administration of ^{90}Y-DOTATOC: practical aspects**
   C. Terwinghe B. Vanbilloen K. Baete N. Bergans S. Krim S. Van Binnebeek
   Presentation held at the EANM'10 Annual Congress of the European Association of Nuclear Medicine , Vienna, Austria October 9-13, 2010.

3. **Extremity Exposure in NM diagnostic with F^{18} and Tc^{99m} labeled radiopharmaceuticals. Results of the ORAMED project**
   A. Carnicer, S. Baechler, I. Barth, L. Donadille, P. Ferrari, M. Fulop, M. Ginjaume, G. Gualdrini, S. Krim, X. Ortega, A. Rimpler, N. Ruiz-Lopez, M. Sans Merce and F. Vanhavere
   Presentation held at the Workshop on optimization of Radiation Protection of Medical Staff
   Barcelona, January 20-22, 2011

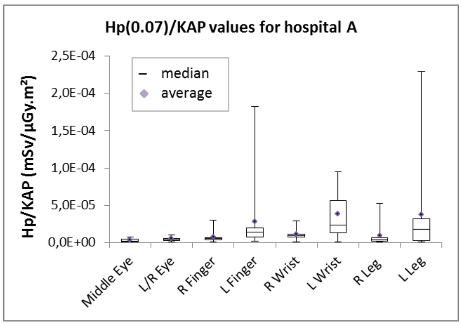
4. **Extremity exposure in nuclear medical therapy with Y^{90} labeled substances**
   A. Rimpler, I. Barth, P. Ferrari, S. Baechler, A. Carnicer, L. Donadille, M. Fulop, M. Ginjaume, M. Mariotti, M. Sans Merce, G. Gualdrini, S. Krim, X. Ortega, N. Ruiz, and F. Vanhavere
   Presentation held at the Workshop on optimization of Radiation Protection of Medical Staff
   Barcelona, January 20-22, 2011

Appendix A:
Overview of the doses to the extremities and eyes for each hospital per procedure

A. CA & PTCA

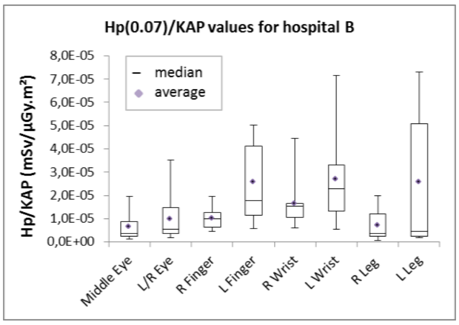
Hospital A:

- Bi-plane configuration
- Ceiling + table
- Mean KAP: 8763 µGy.m²



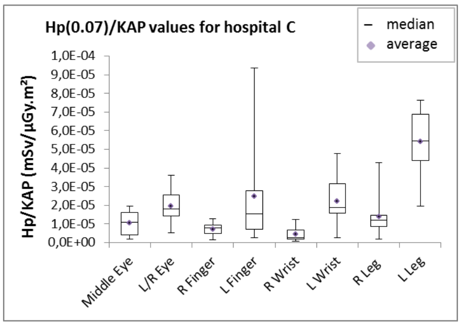
Hospital B:

- Bi-plane configuration
    - o Table + ceiling
- Tube-below configuration
    - o Ceiling (+ table sometimes)
- Mean KAP: 11050 µGy.m²



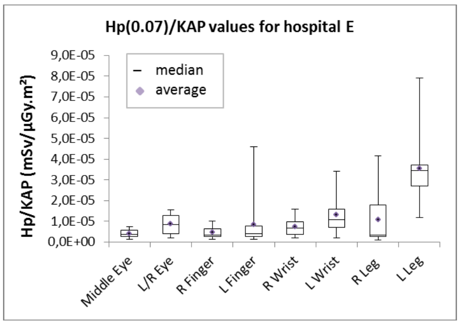
Hospital C:

- Tube-below configuration
- No room protection
- Mean KAP: 7640 µGy.m²



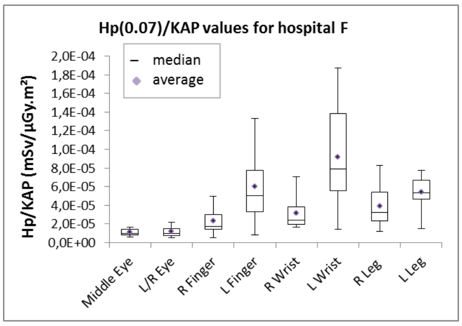
Hospital E:

- Tube-below configuration
- No room protection (table sometimes)
- Mean KAP: 5020 µGy.m²



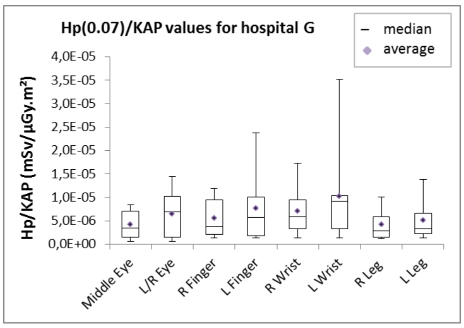
Hospital F:

- Tube-below configuration
- Table + ceiling
- Mean KAP: 3895 µGy.m²



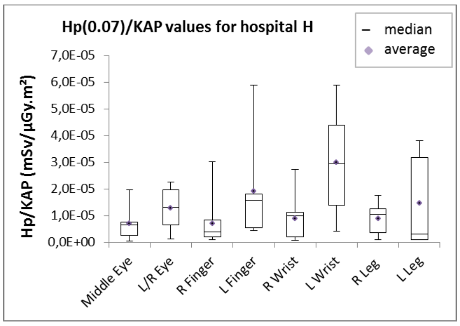
Hospital G:

- Tube-below configuration
- Table + ceiling
- Mean KAP: 5265 µGy.m²



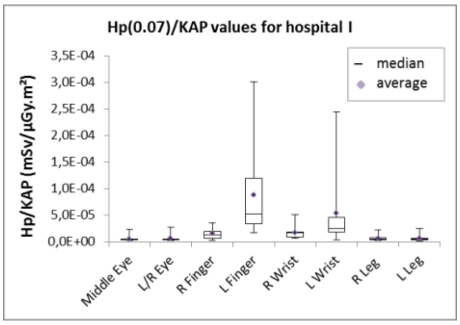
Hospital H:

- Bi-plane configuration
- Table (+ ceiling sometimes)
- Mean KAP: 13210 µGy.m²



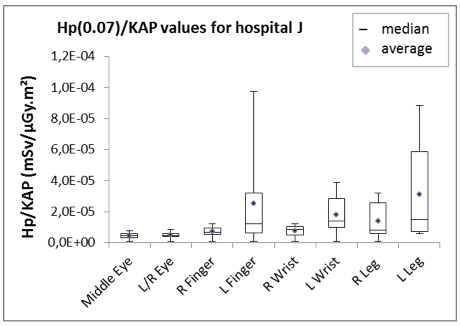
Hospital I:

- Tube-below configuration
- Table + ceiling
- Mean KAP: 3265 µGy.m²



Hospital J:

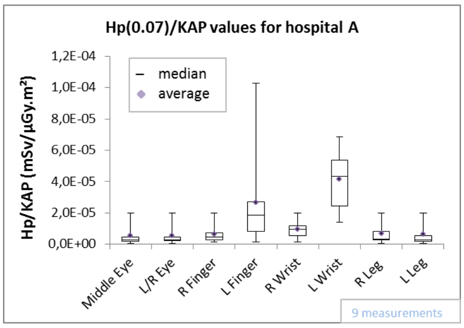
- Tube-below configuration
- Table + ceiling
- Mean KAP: 7435 µGy.m²



B. RF Ablations

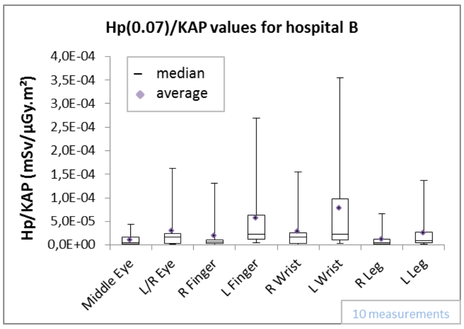
Hospital A:

- Bi-plane configuration
- RP cabin
- Ceiling shield for lateral tube (sometimes)
- Mean KAP : 6895 µGy.m²



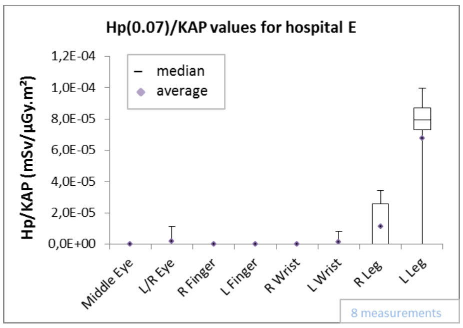
Hospital B:

- Bi-plane configuration
  - Table + ceiling
- Tube-below configuration
  - Table (+ ceiling sometimes)
- Mean KAP: 9050 µGy.m²



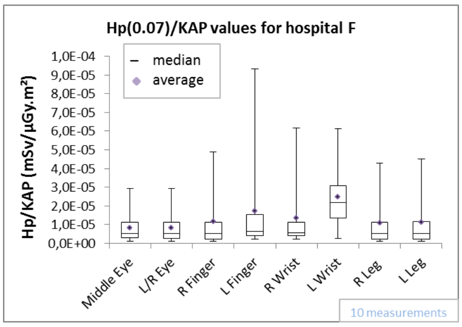
Hospital E:

- Tube-below configuration
- No room protection
- Mean KAP: 1478 µGy.m²



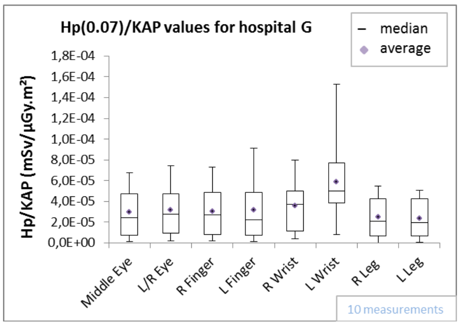
Hospital F:

- Tube-below configuration
- Table + ceiling
- Mean KAP: 2509 µGy.m²



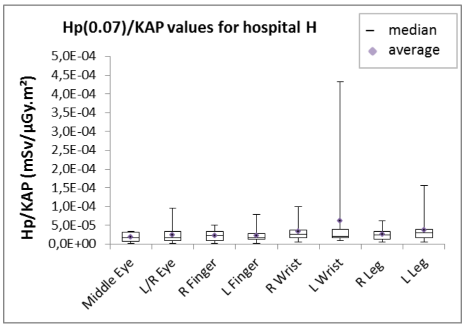
Hospital G:

- Tube-below configuration
- Table + ceiling
- Mean KAP: 4500 µGy.m²



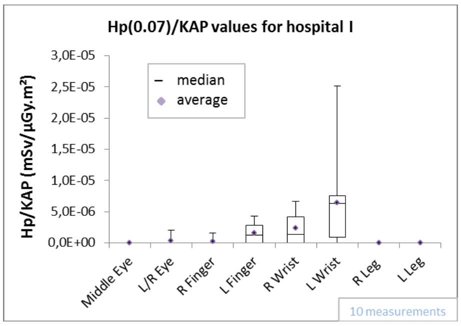
Hospital H:

- Tube-below configuration
- No room protection
- Mean KAP: 3520 µGy.m²



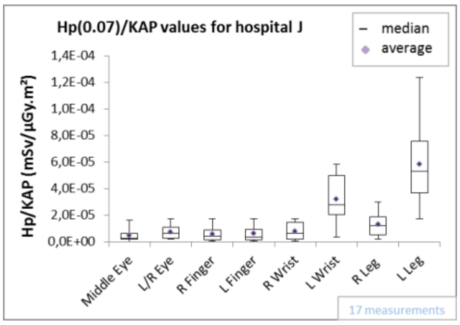
Hospital I:

- Tube-below configuration
- RP cabin + ceiling + table
- Mean KAP: 3771 µGy.m²



Hospital J:

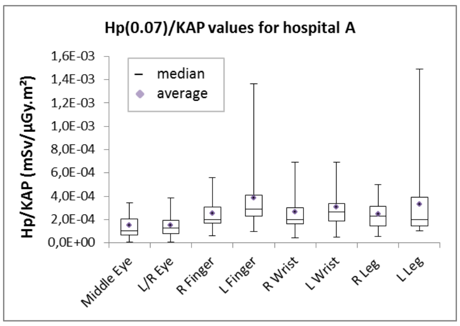
- Tube-below configuration
- Ceiling (+ table)
- Mean KAP: 6940 µGy.m²



C. PM and ICD implantations

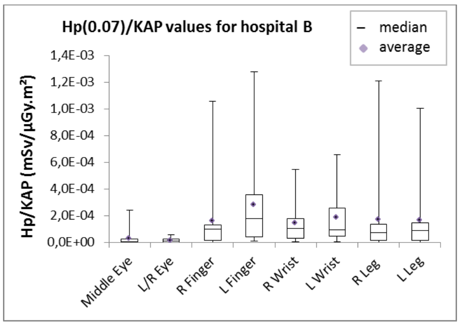
Hospital A:

- Tube-below configuration
- No room protection
- Mean KAP: 635 µGy.m²



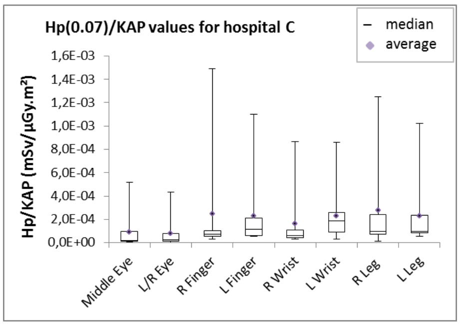
Hospital B:

- Tube-below configuration
- No room protection
- Mean KAP: 15645 µGy.m²



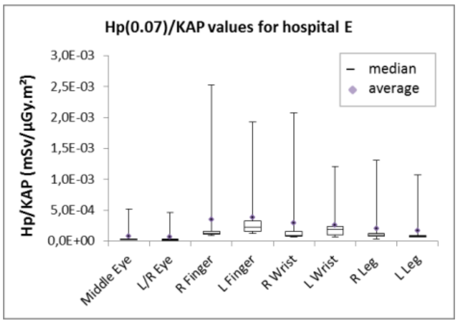
Hospital C:

- Tube-below configuration
- No room protection
- Mean KAP: 7910 µGy.m²



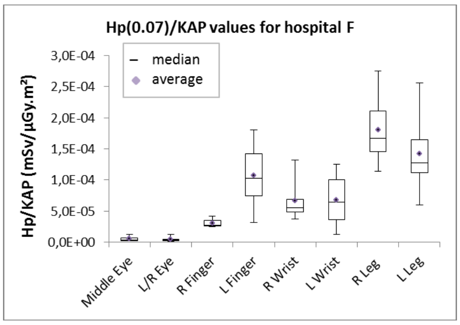
Hospital E:

- Tube-below configuration
- No room protection
- Mean KAP: 2250 µGy.m²



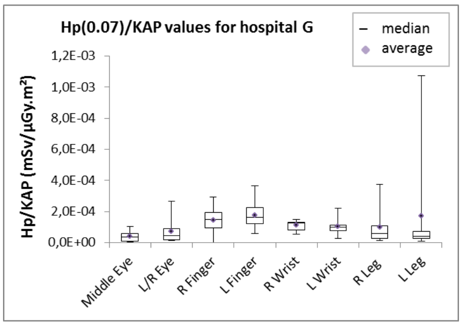
Hospital F:

- Tube-below configuration
- No room protection
- Mean KAP: 3865 µGy.m²



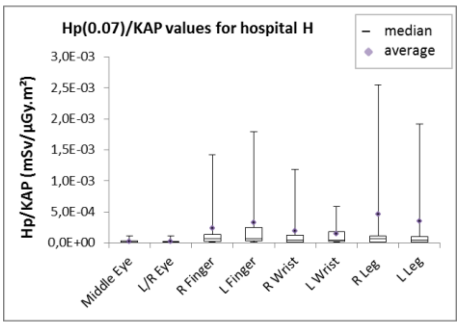
Hospital G:

- Tube-below configuration
- Table shielding
- Mean KAP: 10095 µGy.m²



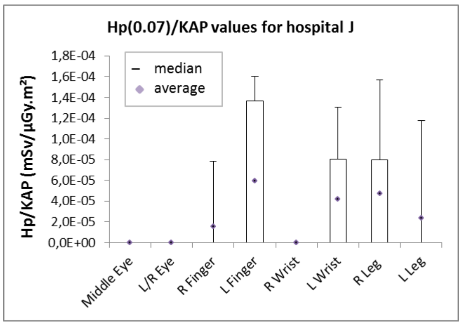
Hospital H:

- Tube-below configuration
- No room protection
- Mean KAP: 4430 µGy.m²



Hospital J:

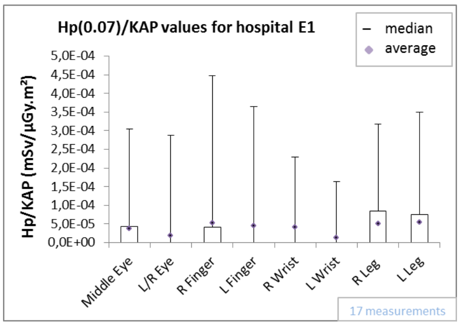
- Tube-below configuration
- Table shielding
- Mean KAP: 655 µGy.m²



D. ERCP procedures

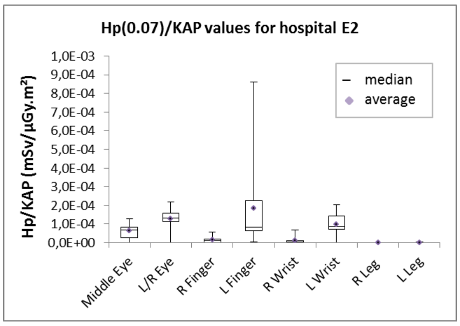
Hospital A:

- Tube-below configuration
- Table (+ ceiling sometimes)
- Mean KAP: 190 µGy.m²



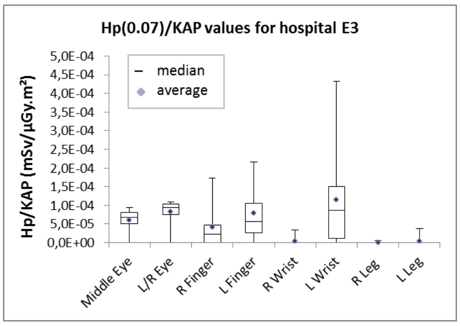
Hospital B:

- Tube-above configuration
- No room protection
- Mean KAP: 3310 µGy.m²



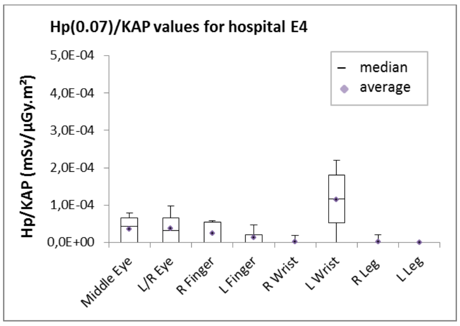
Hospital C:

- Tube-above configuration
- No room protection
- Mean KAP: 590 µGy.m²



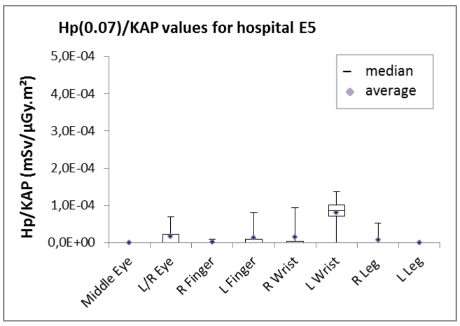
Hospital D:

- Tube-above configuration
- No room protection
- Mean KAP: 340 µGy.m²

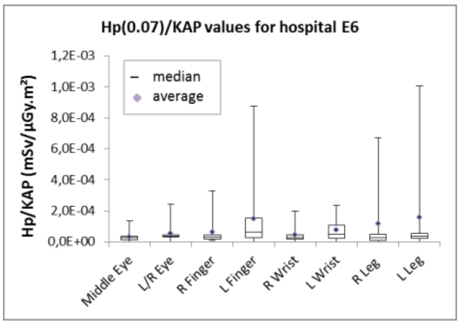


Hospital E:

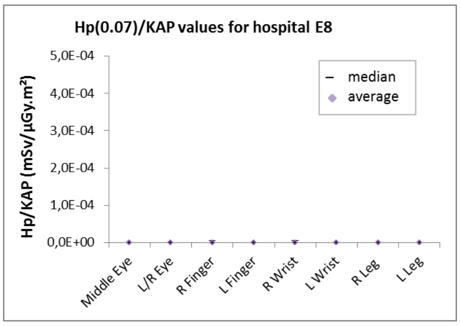
- Tube-above configuration
- No room protection
- Mean KAP: 330 µGy.m²



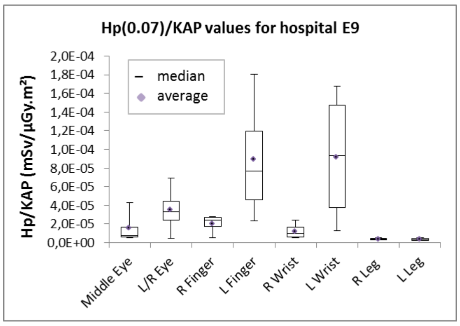
<u>Hospital F</u>:
- Tube-below configuration
- No room protection
- Mean KAP: 1560 µGy.m²



<u>Hospital H</u>:
- Tube-below configuration
- Curtain between tube and detector
- Mean KAP: 3130 µGy.m²

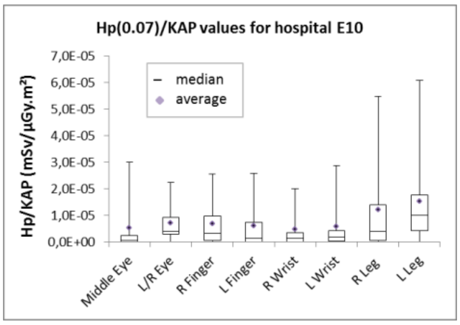


<u>Hospital I</u>:
- Tube-above configuration
- No room protection
- Mean KAP: 2110 µGy.m²



Hospital J:

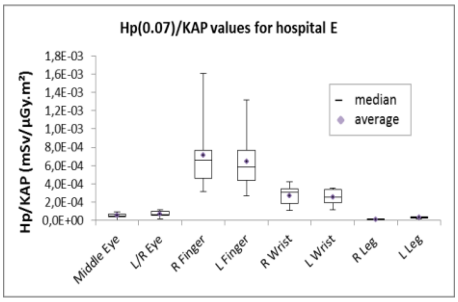
- Tube-below configuration
- Table shielding
- Mean KAP: 9975 µGy.m²



E. Vertebroplasty & kyphoplasty

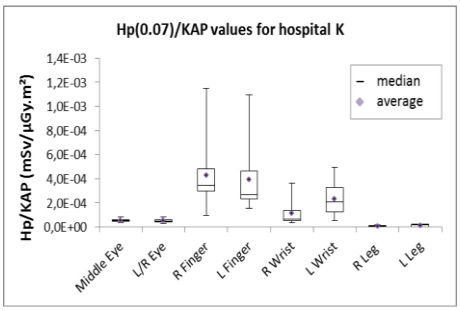
Hospital E:

- Tube-below configuration
- Table shielding
- Mean KAP: 7325 µGy.m²



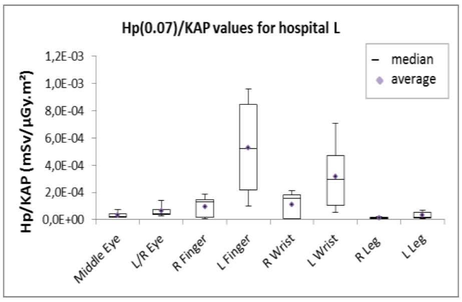
Hospital K:

- Tube-below configuration
- No room protection
- Mean KAP: 6420 µGy.m²



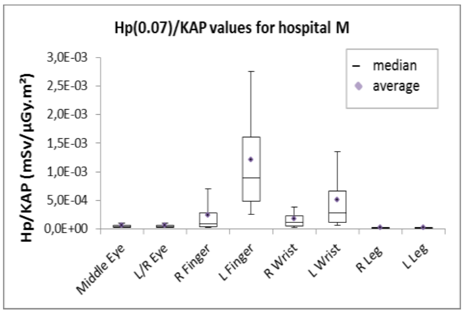
Hospital L:

- O-arm configuration
- No room protection
- Mean KAP: 916 µGy.m²



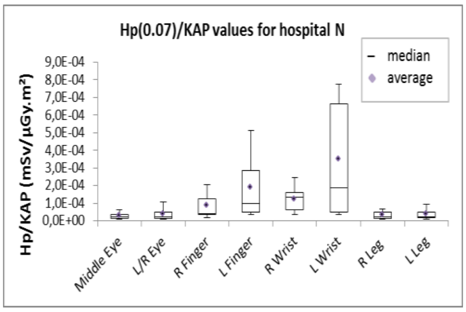
Hospital M:

- Tube-below configuration
- Table shielding
- Mean KAP: 7500 µGy.m²



Hospital N:

- O-arm configuration
- No room protection
- Mean KAP: 420 µGy.m²



Appendix B: Overview of the annual doses to the extremities and eyes for each operator per procedure

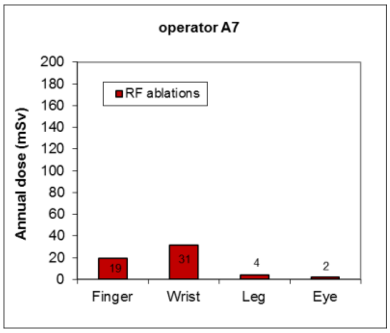
The mean Hp(0,07) value for every monitored location given in this part is the maximum value of the average Hp(0,07) of the left part and right part (middle part for the eyes). Most operators are monitored at least 3 times during the measurement campaign.

A. Annual doses for interventional cardiology procedures

Hospital A

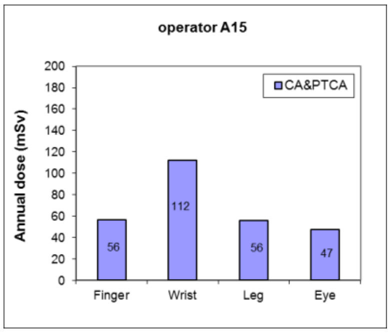
Operator 7

- Procedure: RF ablations
- Annual workload: 160
- Mean Hp(0.07)
  * fingers: 121 µSv
  * wrists: 197 µSv
  * legs: 24 µSv
  * eyes: 14 µSv
- Tube configuration: bi-plane
- Room protection equipment: RP cabin



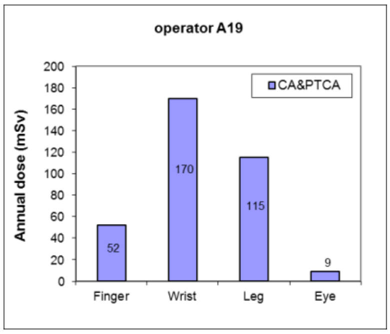
Operator 15

- Procedure: CA & PTCA
- Annual workload: 750
- Mean Hp(0.07)
  * fingers: 75 µSv
  * wrists: 149 µSv
  * legs: 75 µSv
  * eyes: 53 µSv
- Tube configuration: bi-plane
- Room protection equipment: table + ceiling



Operator 19

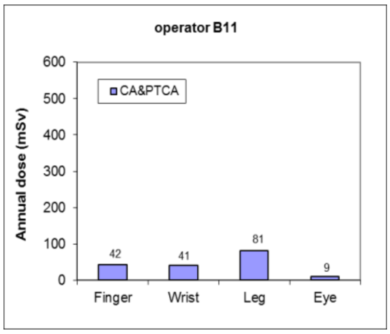
- Procedure: CA & PTCA
- Annual workload: 600
- Mean Hp(0.07)
  * fingers: 86 µSv
  * wrists: 283 µSv
  * legs: 192 µSv
  * eyes: 15 µSv
- Tube configuration: bi-plane
- Room protection equipment: table + ceiling



Hospital B

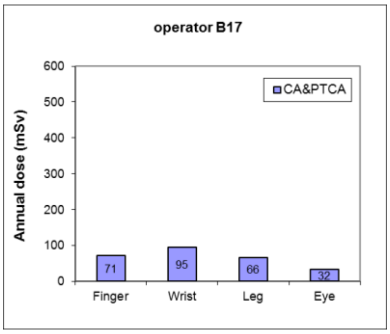
Operator 11

- Procedure: CA & PTCA
- Annual workload: 255
- Mean Hp(0.07)
  * fingers: 164 µSv
  * wrists: 160 µSv
  * legs: 318 µSv
  * eyes: 37 µSv
- Tube configuration: below / bi-plane
- Room protection equipment: none / table + ceiling



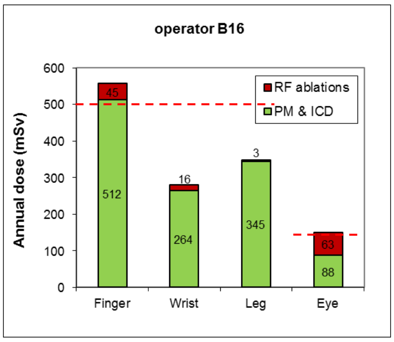
Operator 17

-	Procedure:	CA & PTCA
-	Annual workload:	233
-	Mean Hp(0.07)	* fingers: 307 µSv * wrists: 406 µSv * legs: 283 µSv * eyes: 118 µSv
-	Tube configuration:	bi-plane
-	Room protection equipment:	table + ceiling



Operator 16

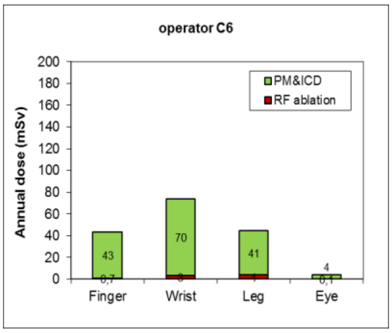
-	Procedure:	RF ablations	PM & ICD
-	Annual workload:	61	151
-	Mean Hp(0.07)	* fingers: 746 µSv * wrists: 206 µSv * legs: 43 µSv * eyes: 880 µSv	* fingers: 3391 µSv * wrists: 7747 µSv * legs: 2283 µSv * eyes: 501 µSv
-	Tube configuration:	below	below
-	Room protection equipment:	table	none



<u>Hospital C</u>

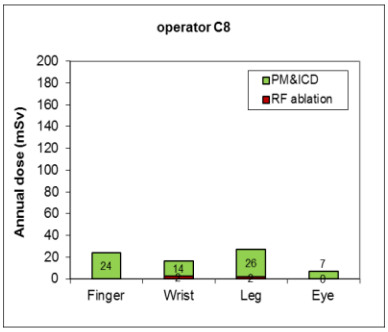
Operator 6

-	Procedure:	RF ablations	PM & ICD
-	Annual workload:	16	40
-	Mean Hp(0.07)	* fingers: 43 µSv * wrists: 199 µSv * legs: 246 µSv * eyes: 8 µSv	* fingers: 1071 µSv * wrists: 1758 µSv * legs: 1013 µSv * eyes: 101 µSv
-	Tube configuration:	below	below
-	Room protection equipment:	none	none



Operator 8

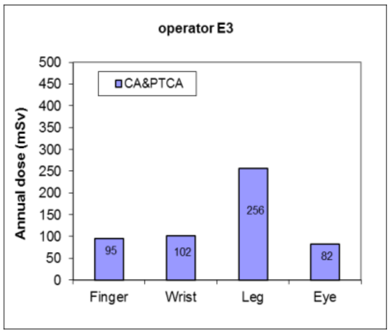
		RF ablations	PM & ICD
-	Procedure:	RF ablations	PM & ICD
-	Annual workload:	16	40
-	Mean Hp(0.07)	* fingers: 43 µSv	* fingers: 1071 µSv
		* wrists: 199 µSv	* wrists: 1758 µSv
		* legs: 246 µSv	* legs: 1013 µSv
		* eyes: 8 µSv	* eyes: 101 µSv
-	Tube configuration:	below	below
-	Room protection equipment:	none	none



<u>Hospital E</u>

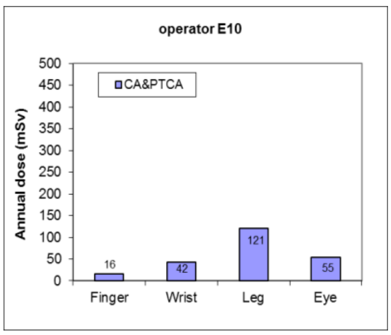
Operator 3

- Procedure: CA & PTCA
- Annual workload: 1157
- Mean Hp(0.07)
  * fingers: 82 µSv
  * wrists: 88 µSv
  * legs: 221 µSv
  * eyes: 59 µSv
- Tube configuration: below
- Room protection equipment: table



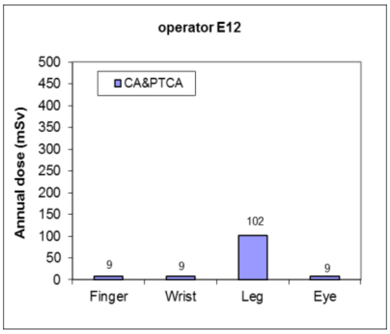
Operator 10

- Procedure: CA & PTCA
- Annual workload: 998
- Mean Hp(0.07)
  * fingers: 16 µSv
  * wrists: 42 µSv
  * legs: 121 µSv
  * eyes: 46 µSv
- Tube configuration: below
- Room protection equipment: none



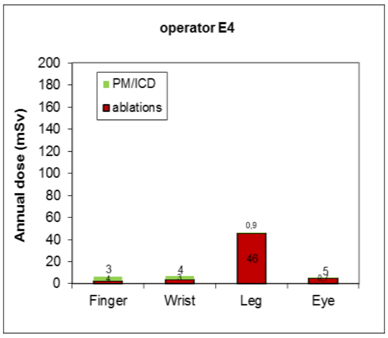
Operator 12

- Procedure: CA & PTCA
- Annual workload: 1067
- Mean Hp(0.07)
  * fingers: 8 µSv
  * wrists: 8 µSv
  * legs: 96 µSv
  * eyes: 8 µSv
- Tube configuration: below
- Room protection equipment: none



Operator 4

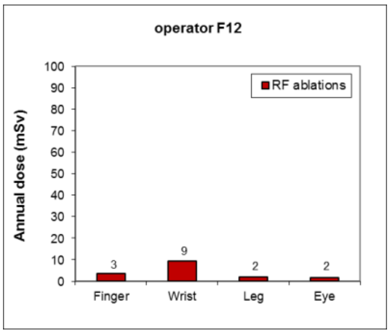
		RF ablations	PM & ICD
-	Procedure:	RF ablations	PM & ICD
-	Annual workload:	350	80
-	Mean Hp(0.07)	* fingers: 8 µSv * wrists: 11 µSv * legs: 130 µSv * eyes: 14 µSv	* fingers: 45 µSv * wrists: 39 µSv * legs: 12 µSv * eyes: 8 µSv
-	Tube configuration:	below	below
-	Room protection equipment:	none	none



Hospital F

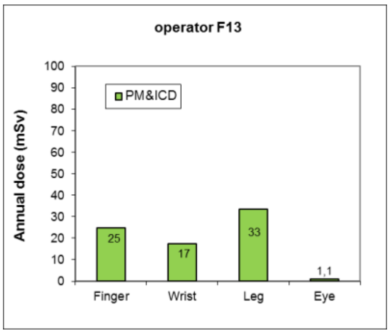
Operator 12

- Procedure: RF ablations
- Annual workload: 183
- Mean Hp(0.07)
  * fingers: 19 µSv
  * wrists: 50 µSv
  * legs: 10 µSv
  * eyes: 9 µSv
- Tube configuration: below
- Room protection equipment: table + ceiling



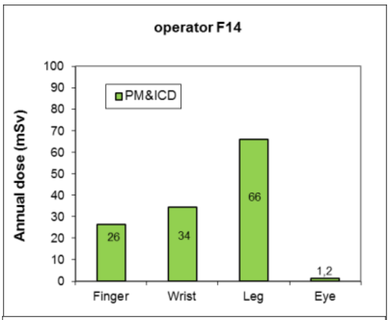
Operator 13

- Procedure: PM & ICD
- Annual workload: 44
- Mean Hp(0.07)
  * fingers: 565 µSv
  * wrists: 394 µSv
  * legs: 757 µSv
  * eyes: 26 µSv
- Tube configuration: below
- Room protection equipment: none



Operator 14

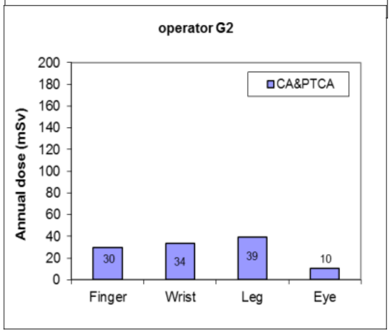
- Procedure: PM & ICD
- Annual workload: 144
- Mean Hp(0.07)
  * fingers: 182 µSv
  * wrists: 238 µSv
  * legs: 458 µSv
  * eyes: 8 µSv
- Tube configuration: below
- Room protection equipment: none



Hospital G

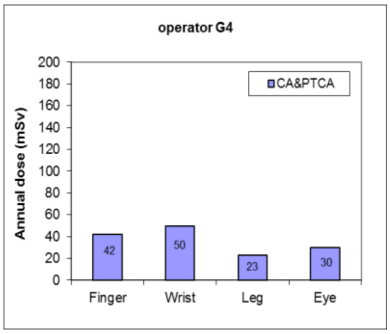
Operator 2

- Procedure: CA & PTCA
- Annual workload: 714
- Mean Hp(0.07)
  * fingers: 42 µSv
  * wrists: 47 µSv
  * legs: 55 µSv
  * eyes: 14 µSv
- Tube configuration: below
- Room protection equipment: table + ceiling



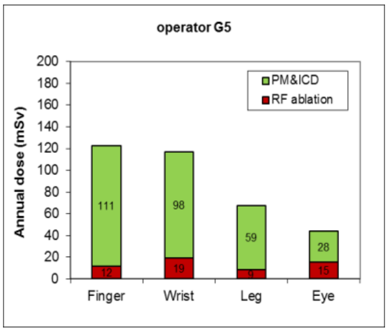
Operator 4

- Procedure: CA & PTCA
- Annual workload: 904
- Mean Hp(0.07)
  * fingers: 46 µSv
  * wrists: 55 µSv
  * legs: 25 µSv
  * eyes: 29 µSv
- Tube configuration: below
- Room protection equipment: table + ceiling



Operator 5

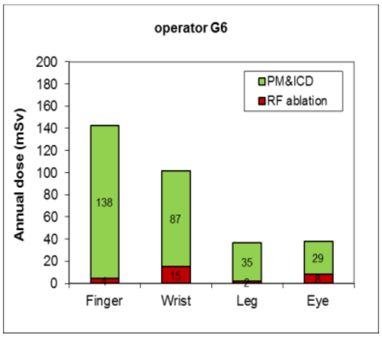
- Procedure:	RF ablations	PM & ICD
- Annual workload:	189	185
- Mean Hp(0.07)	* fingers: 63 µSv	* fingers: 600 µSv
	* wrists: 101 µSv	* wrists: 529 µSv
	* legs: 46 µSv	* legs: 319 µSv
	* eyes: 70 µSv	* eyes: 132 µSv
- Tube configuration:	below	below
- Room protection equipment:	table + ceiling	table



Operator 6

- Procedure: RF ablations | PM & ICD
- Annual workload: 187 | 88
- Mean Hp(0.07)

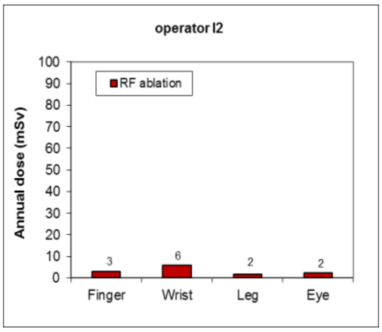
	RF ablations	PM & ICD
Procedure:	RF ablations	PM & ICD
Annual workload:	187	88
Mean Hp(0.07)	* fingers: 24 µSv * wrists: 79 µSv * legs: 11 µSv * eyes: 39 µSv	* fingers: 1565 µSv * wrists: 985 µSv * legs: 394 µSv * eyes: 285 µSv
Tube configuration:	below	below
Room protection equipment:	table + ceiling	table



Hospital I

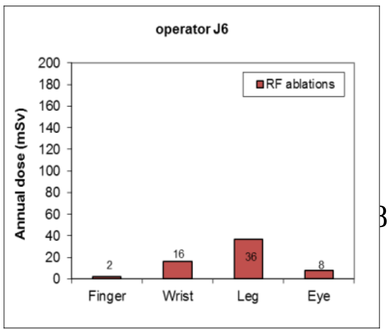
Operator 2

- Procedure: RF ablations
- Annual workload: 209
- Mean Hp(0.07) * fingers: 14 µSv
  * wrists: 28 µSv
  * legs: 8 µSv
  * eyes: 9 µSv
- Tube configuration: below
- Room protection equipment: RP cabin + table + ceiling



Hospital J

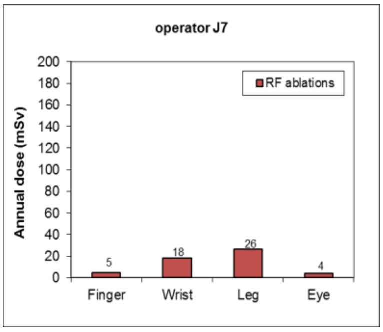
Operator 6



- Procedure: RF ablations
- Annual workload: 100
- Mean Hp(0.07) * fingers: 19 µSv
  * wrists: 163 µSv
  * legs: 364 µSv
  * eyes: 79 µSv
- Tube configuration: below
- Room protection equipment: table + ceiling

Operator 7

- Procedure: RF ablations
- Annual workload: 60
- Mean Hp(0.07) * fingers: 79 µSv
  * wrists: 303 µSv
  * legs: 439 µSv
  * eyes: 68 µSv
- Tube configuration: below
- Room protection equipment: table + ceiling

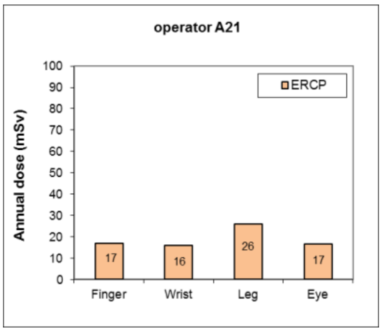


A. Annual doses for ERCP procedures

Hospital A

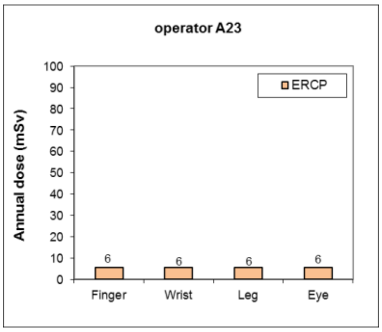
Operator 21

- Procedure: ERCP
- Annual workload: 1281
- Mean Hp(0.07) * fingers: 13 µSv
  * wrists: 13 µSv
  * legs: 20 µSv
  * eyes: 11 µSv
- Tube configuration: below
- Room protection equipment: table + ceiling



Operator 23

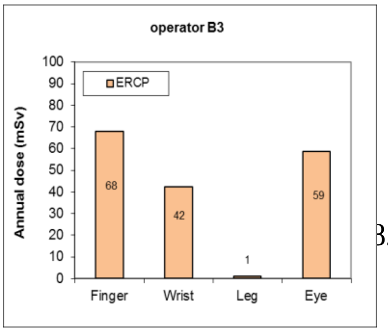
- Procedure: ERCP
- Annual workload: 689
- Mean Hp(0.07) * fingers: 8 µSv
  * wrists: 8 µSv
  * legs: 8 µSv
  * eyes: 8 µSv
- Tube configuration: below
- Room protection equipment: table + ceiling



Hospital B

Operator 3

- Procedure: ERCP
- Annual workload: 100

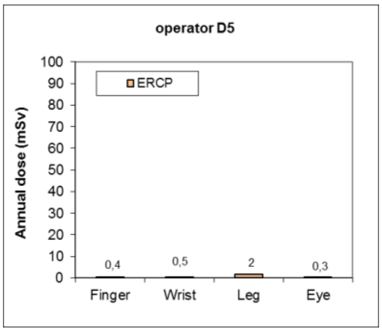


- Mean Hp(0.07) * fingers: 681 µSv
  * wrists: 423 µSv
  * legs: 11 µSv
  * eyes: 504 µSv
- Tube configuration: above
- Room protection equipment: none

Hospital D

Operator 5

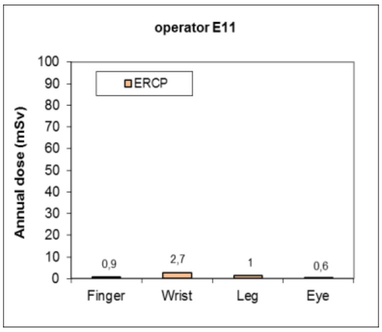
- Procedure: ERCP
- Annual workload: 30
- Mean Hp(0.07) * fingers: 13 µSv
  * wrists: 16 µSv
  * legs: 56 µSv
  * eyes: 9 µSv
- Tube configuration: above
- Room protection equipment: none



Hospital E

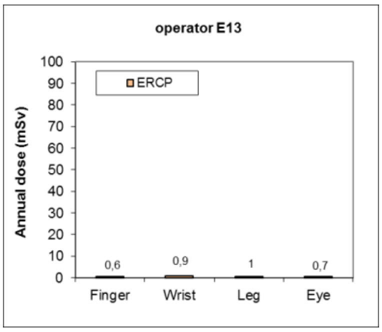
Operator 11

- Procedure: ERCP
- Annual workload: 70
- Mean Hp(0.07) * fingers: 13 µSv
  * wrists: 39 µSv
  * legs: 19 µSv
  * eyes: 8 µSv
- Tube configuration: above
- Room protection equipment: none



Operator 13

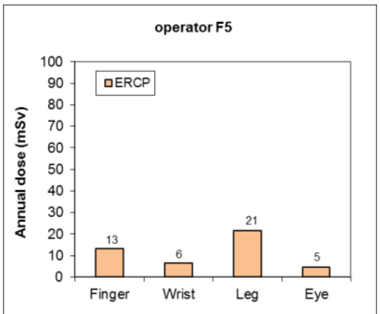
- Procedure: ERCP
- Annual workload: 70
- Mean Hp(0.07) * fingers: 8 µSv
  * wrists: 13 µSv
  * legs: 8 µSv
  * eyes: 10 µSv
- Tube configuration: above
- Room protection equipment: none



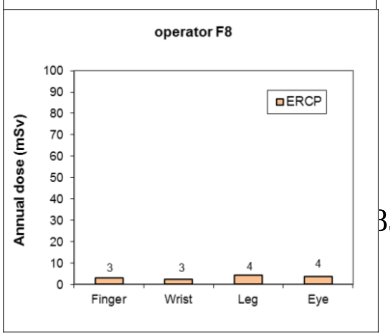
Hospital F

Operator 5

- Procedure: ERCP
- Annual workload: 107
- Mean Hp(0.07) * fingers: 123 µSv
  * wrists: 60 µSv
  * legs: 200 µSv
  * eyes: 42 µSv
- Tube configuration: below
- Room protection equipment: none



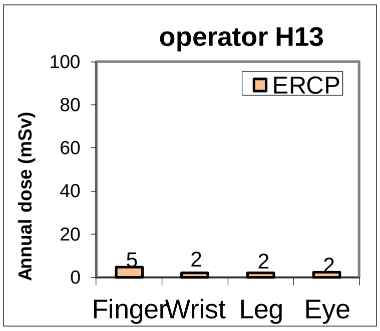
Operator 8



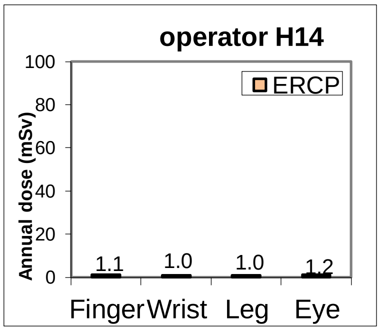
- Procedure: ERCP
- Annual workload: 107
- Mean Hp(0.07) * fingers: 28 µSv
  * wrists: 24 µSv
  * legs: 41 µSv
  * eyes: 36 µSv
- Tube configuration: below
- Room protection equipment: none

Hospital H

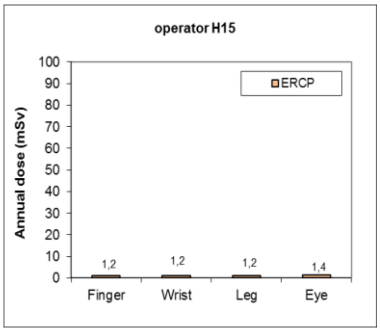
Operator 13
- Procedure: ERCP
- Annual workload: 250
- Mean Hp(0.07) * fingers: 19 µSv
  * wrists: 8 µSv
  * legs: 8 µSv
  * eyes: 10 µSv
- Tube configuration: below
- Room protection equipment: ceiling + table



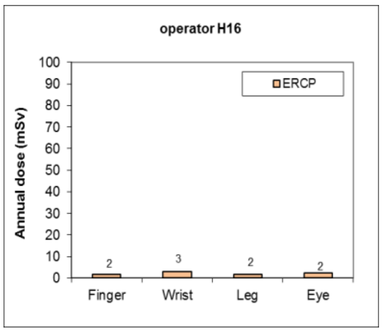
Operator 14
- Procedure: ERCP
- Annual workload: 125
- Mean Hp(0.07) * fingers: 9 µSv
  * wrists: 8 µSv
  * legs: 8 µSv
  * eyes: 10 µSv
- Tube configuration: below
- Room protection equipment: ceiling + table



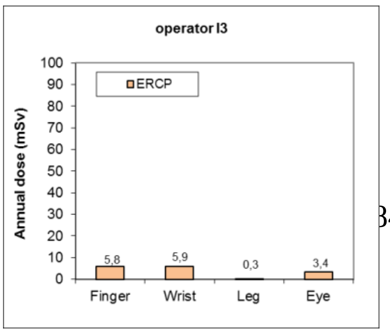
Operator 15
- Procedure: ERCP
- Annual workload: 150
- Mean Hp(0.07) * fingers: 8 µSv
  * wrists: 8 µSv
  * legs: 8 µSv
  * eyes: 10 µSv
- Tube configuration: below
- Room protection equipment: ceiling + table



Operator 16
- Procedure: ERCP
- Annual workload: 230
- Mean Hp(0.07) * fingers: 8 µSv
  * wrists: 13 µSv
  * legs: 8 µSv
  * eyes: 10 µSv
- Tube configuration: below
- Room protection equipment: ceiling + table



Hospital I



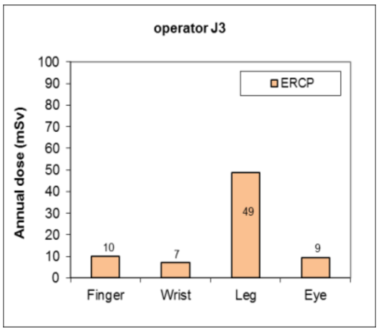
Operator 3

- Procedure: ERCP
- Annual workload: 36
- Mean Hp(0.07)
  * fingers: 162 µSv
  * wrists: 165 µSv
  * legs: 8 µSv
  * eyes: 95 µSv
- Tube configuration: below
- Room protection equipment: none

Hospital J

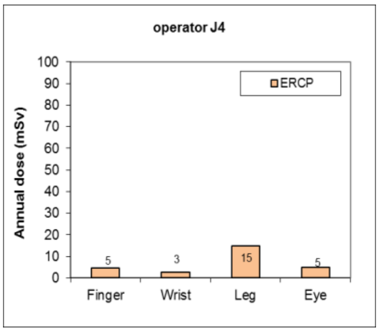
Operator 3

- Procedure: ERCP
- Annual workload: 150
- Mean Hp(0.07)
  * fingers: 67 µSv
  * wrists: 47 µSv
  * legs: 325 µSv
  * eyes: 63 µSv
- Tube configuration: below
- Room protection equipment: table (not well positioned)



Operator 4

- Procedure: ERCP
- Annual workload: 150
- Mean Hp(0.07)
  * fingers: 30 µSv
  * wrists: 18 µSv
  * legs: 99 µSv
  * eyes: 32 µSv
- Tube configuration: below
- Room protection equipment: table (not well positioned)

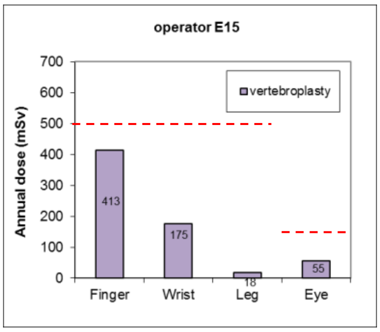


C. Annual doses for vertebroplasty & kyphoplasty

Hospital E

Operator 15

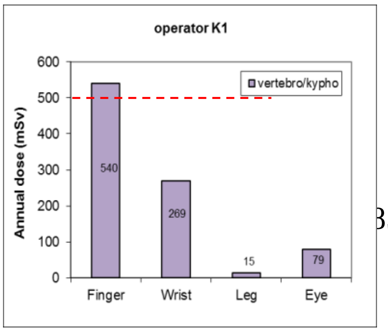
- Procedure: vertebro/kypho
- Annual workload: 95
- Mean Hp(0.07)
  * fingers: 4349 µSv
  * wrists: 1844 µSv
  * legs: 188 µSv
  * eyes: 486 µSv
- Tube configuration: below
- Room protection equipment: table



Hospital K

Operator 1

- Procedure: vertebro/kypho
- Annual workload: 185

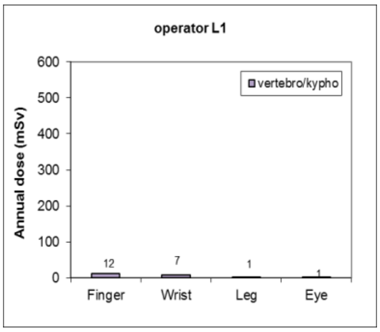


- Mean Hp(0.07) * fingers: 2918 µSv
  * wrists: 1454 µSv
  * legs: 79 µSv
  * eyes: 361 µSv
- Tube configuration: below
- Room protection equipment: none

Hospital L

Operator 1

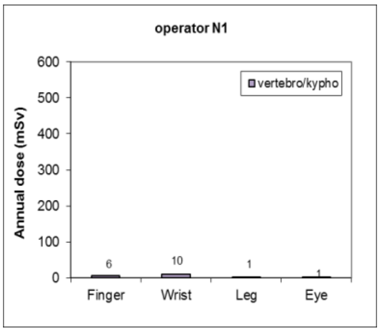
- Procedure: vertebro/kypho
- Annual workload: 25
- Mean Hp(0.07) * fingers: 479 µSv
  * wrists: 300 µSv
  * legs: 30 µSv
  * eyes: 60 µSv
- Tube configuration: O-arm
- Room protection equipment: none



Hospital N

Operator 1

- Procedure: vertebro/kypho
- Annual workload: 50
- Mean Hp(0.07) * fingers: 117 µSv
  * wrists: 193 µSv
  * legs: 11 µSv
  * eyes: 12 µSv
- Tube configuration: O-arm
- Room protection equipment: none



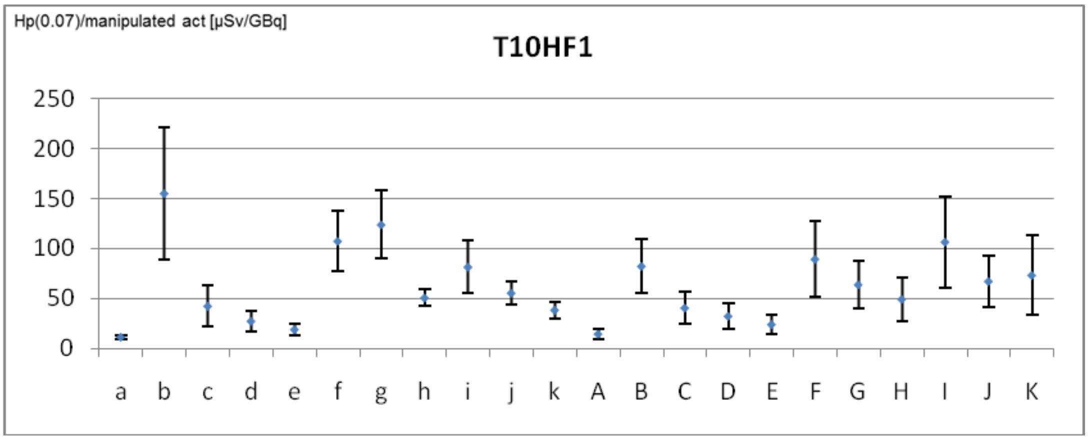
Appendix C
Overview of the doses to the extremities for each worker per type of procedure

The following charts show the mean normalized doses per position with its relevant standard deviation for all workers.

A. Preparation of Tc99m

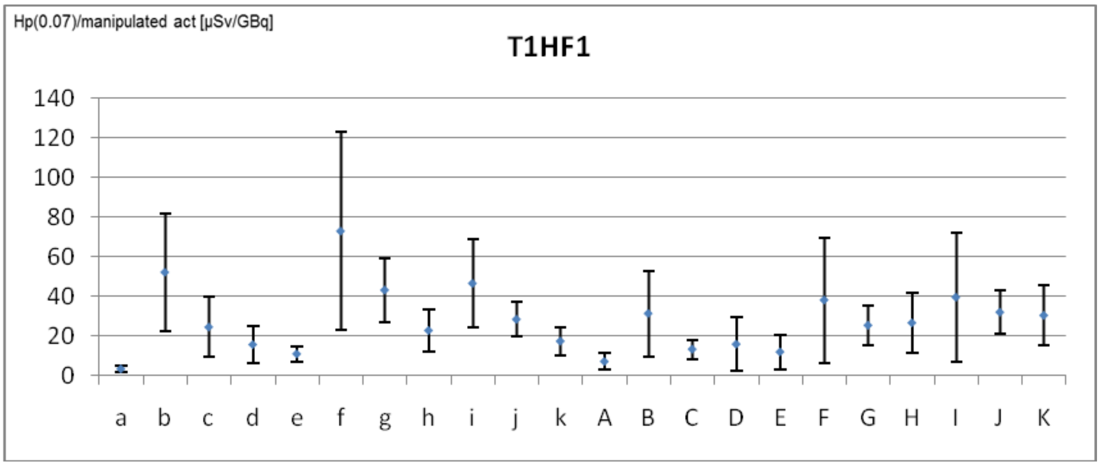
Worker T10HF1 :preparation Tc99m

1 year experience
Shieldings used : Syringe not shielded
Vial 6 mm Pb



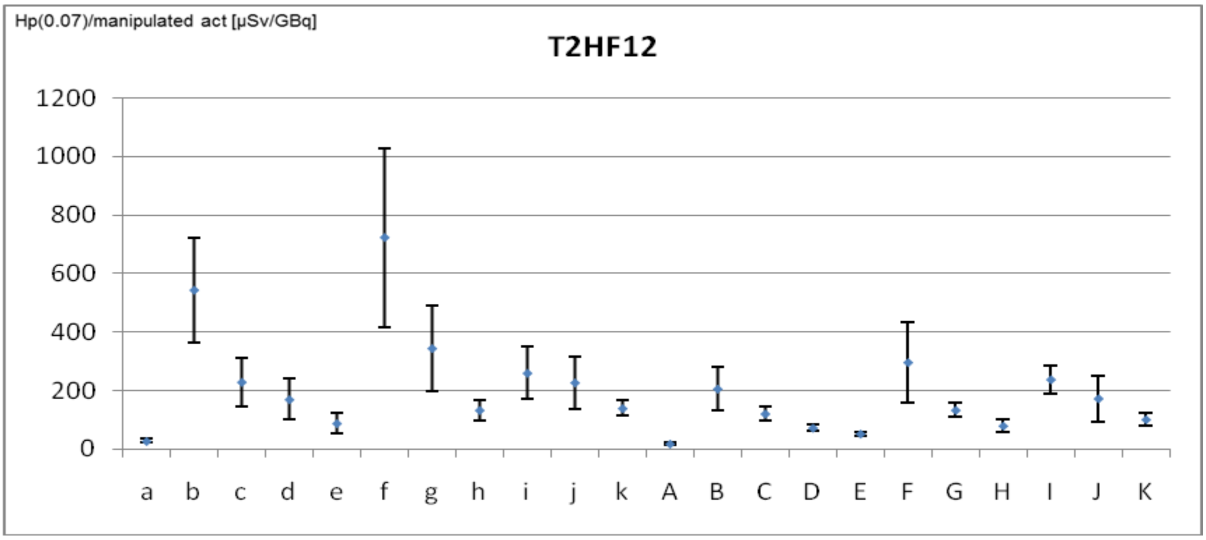
Worker T1HF1 :preparation Tc99m

6 years experience
Shieldings used : Syringe not shielded
Vial 10 mm Pb



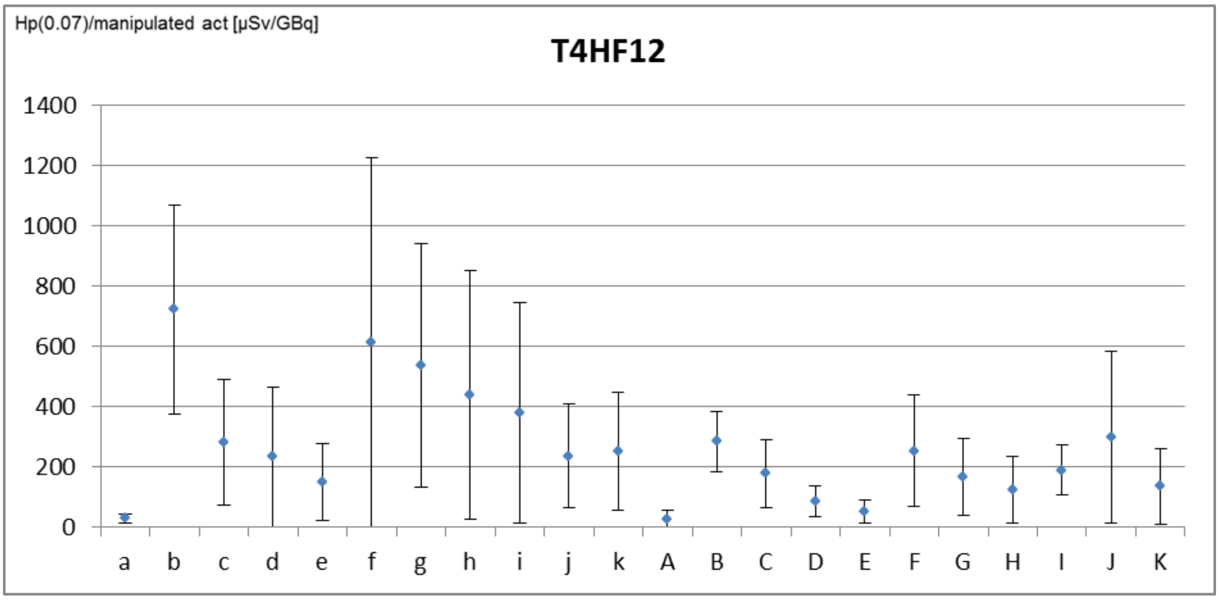
Worker T2HF12 :preparation Tc99m

6months experience
Shieldings used : Syringe not shielded
Vial 4 mm Pb



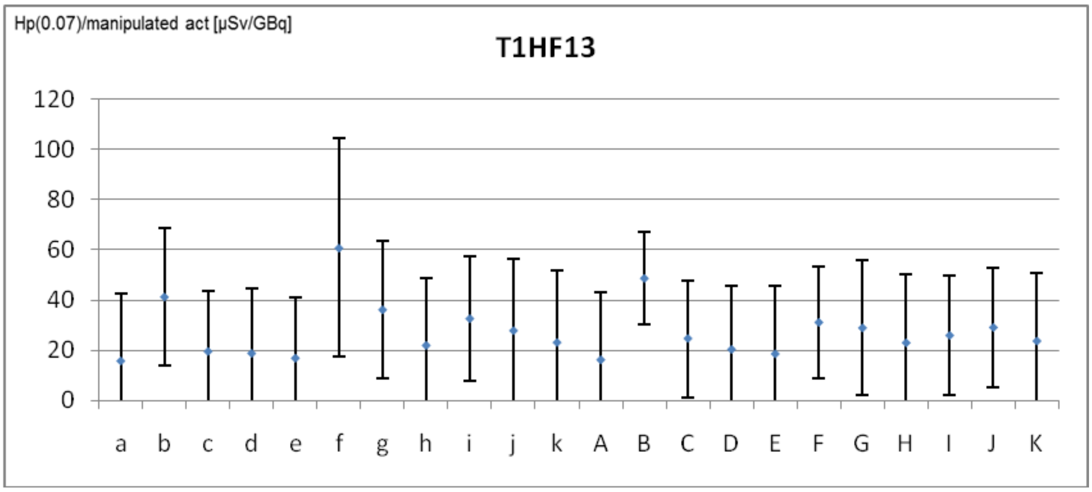
Worker T4HF12 :preparation Tc99m

3 years experience
Shieldings used : Syringe not shielded
Vial 4 mm Pb



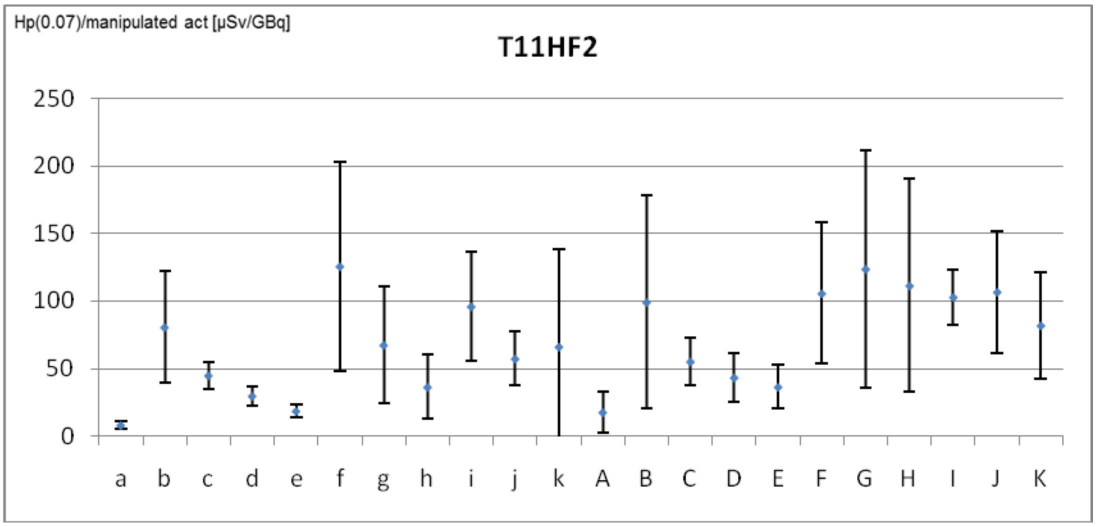
Worker T1HF13 :preparation Tc99m

20 years experience
Shieldings used : Syringe 2 mm W
Vial 8 mm Pb



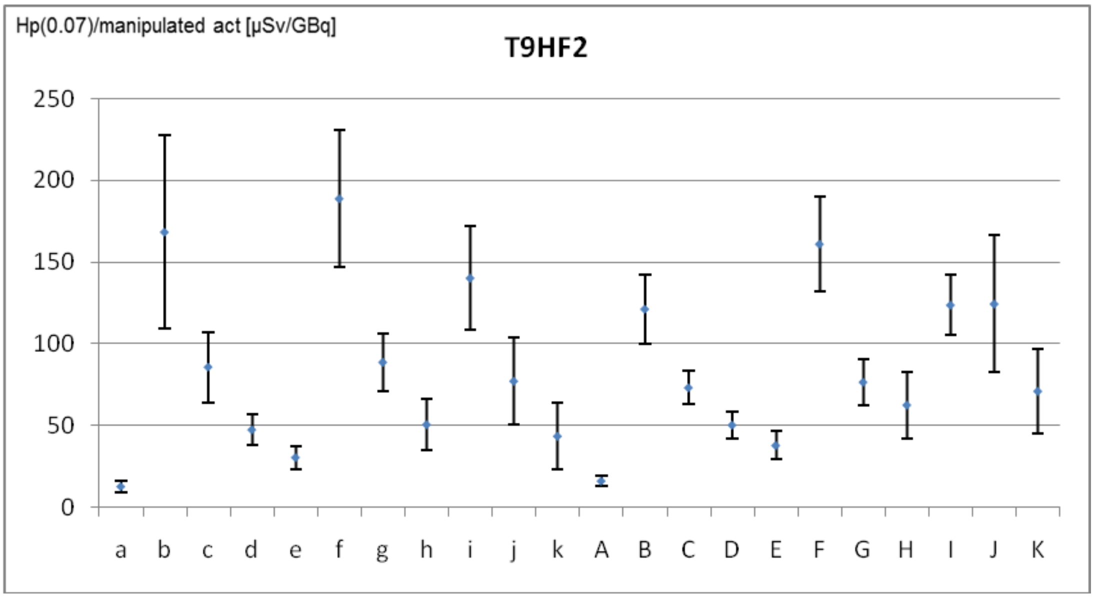
Worker T11HF2 :preparation Tc99m

2months experience
Shieldings used : Syringe 4 mm Pb
Vial 17 mm Pb



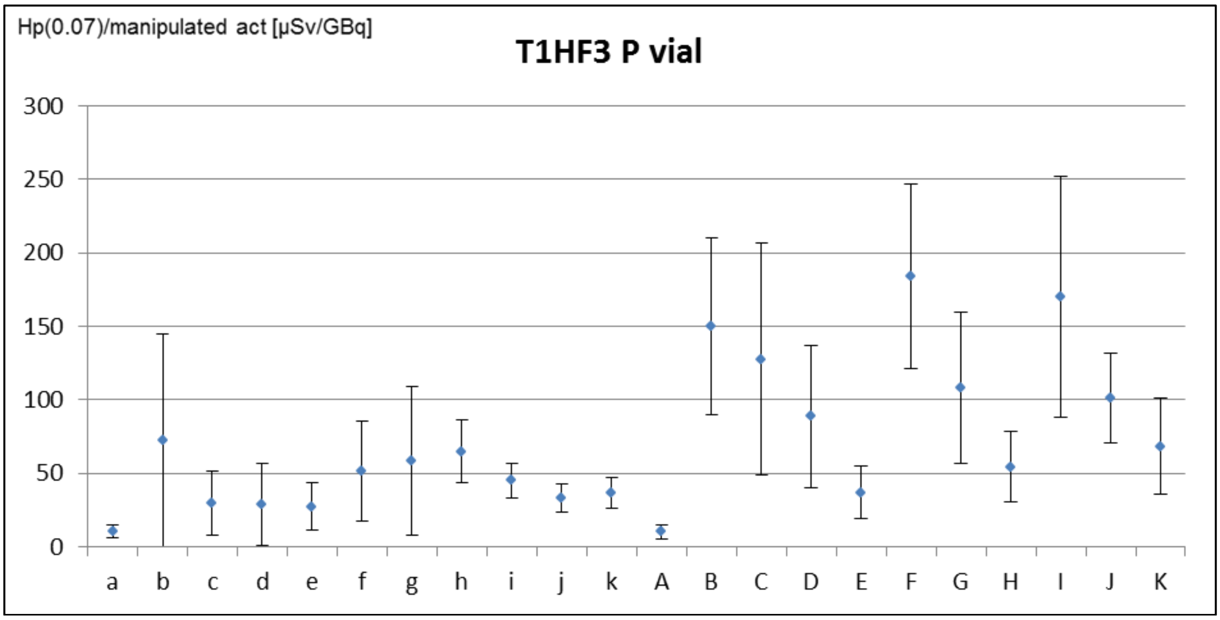
Worker T9HF2 :preparation Tc99m

1year experience
Shieldings used : **Syringe 4 mm Pb**
Vial 17 mm Pb



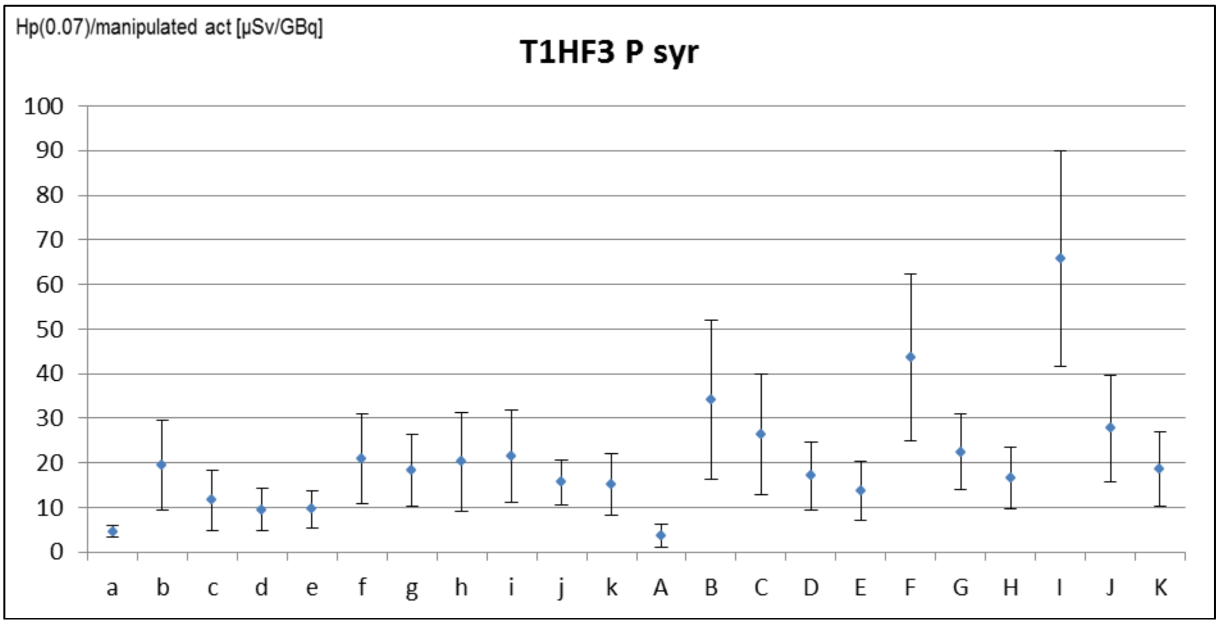
Worker T1HF3 : Preparation Vial Tc99m

13 years experience
Shieldings used : **Syringe not shielded**
Vial 5 mm Pb



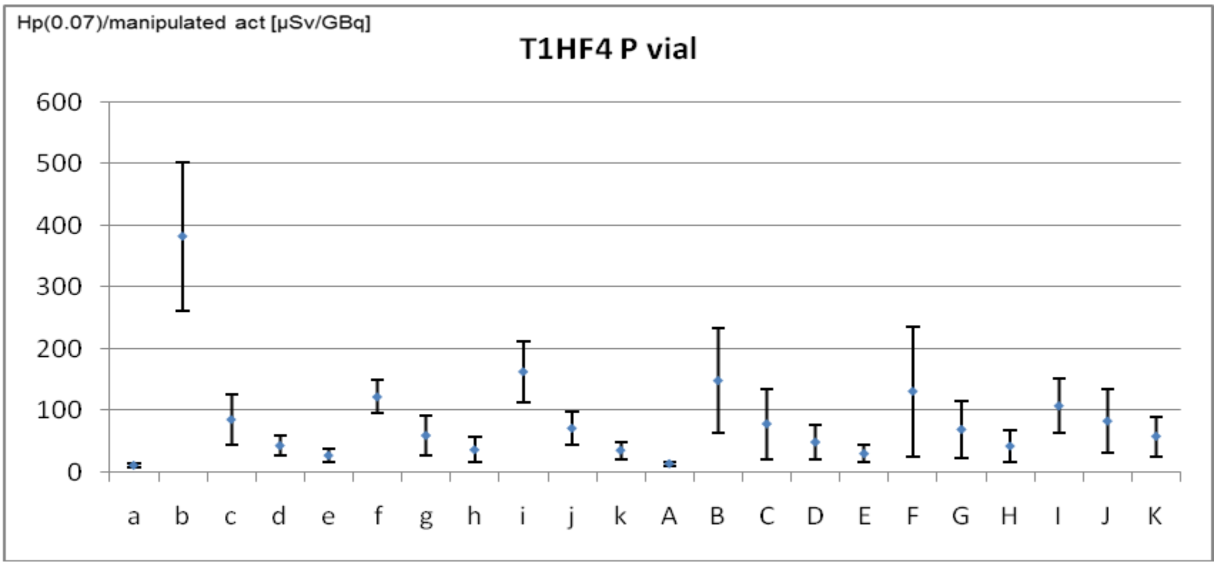
Worker T1HF3 : Preparation Syringe Tc99m

13 years experience
Shieldings used : Syringe not shielded



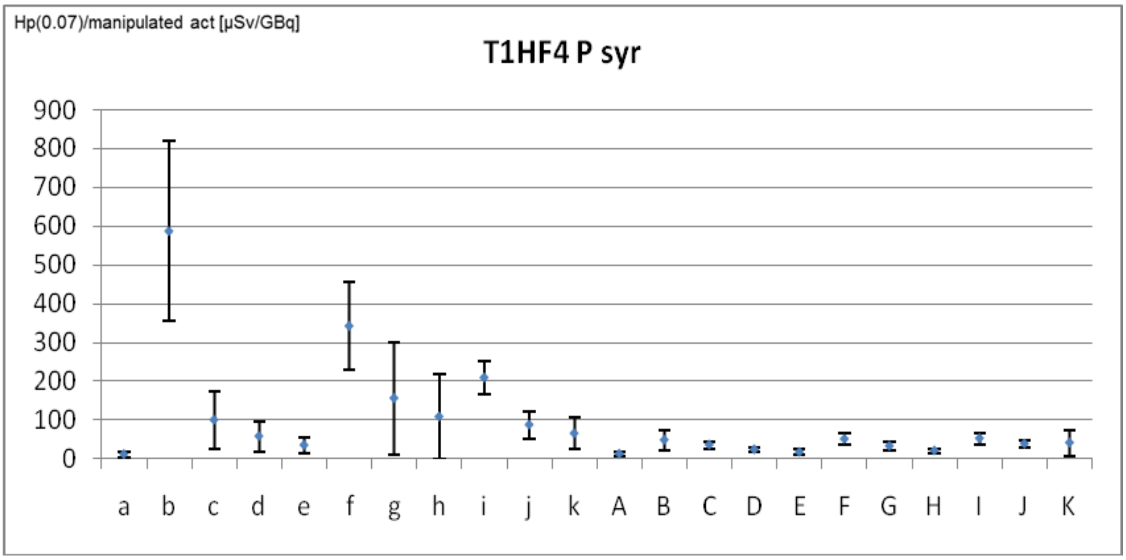
Worker T1HF4 : Preparation Vial Tc99m

25 years experience
Shieldings used : Syringe not shielded
Vial 5 mm Pb



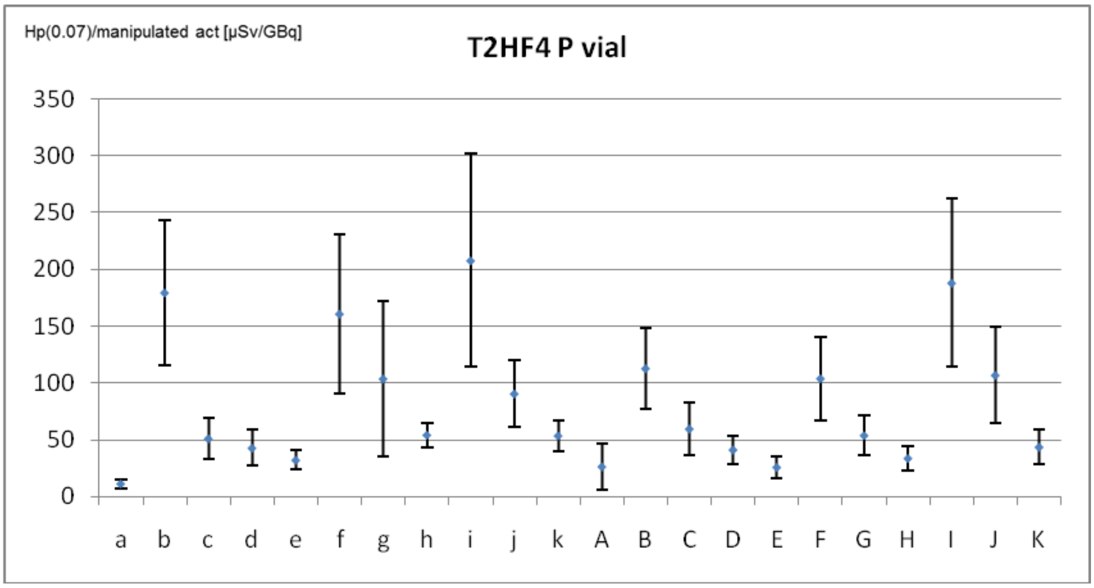
Worker T1HF4 : Preparation Syringe Tc99m

25 years experience
Shieldings used : Syringe not shielded



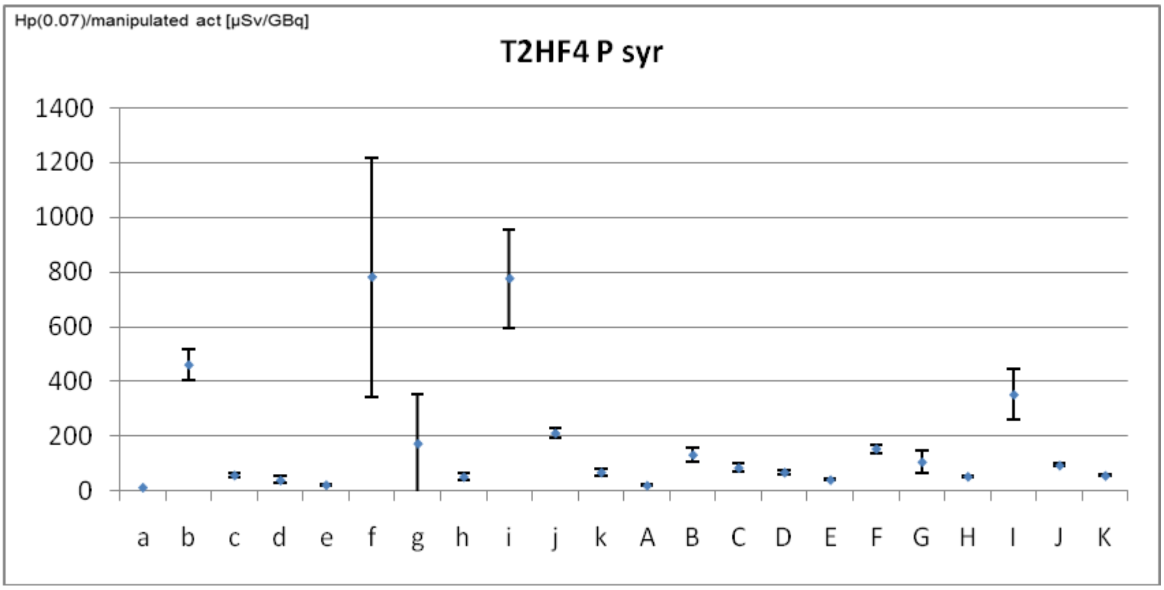
Worker T2HF4 : Preparation Vial Tc99m

5 years experience
Shieldings used : Syringe not shielded
Vial 5 mm Pb



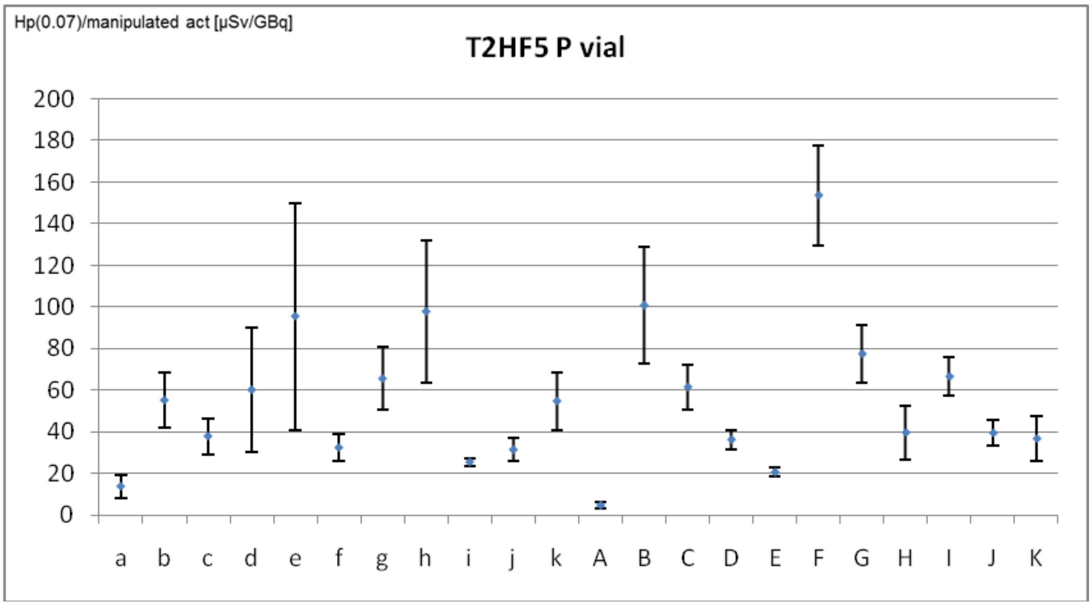
Worker T2HF4 : Preparation Syringe Tc99m

5 years experience
Shieldings used : **Syringe not shielded**



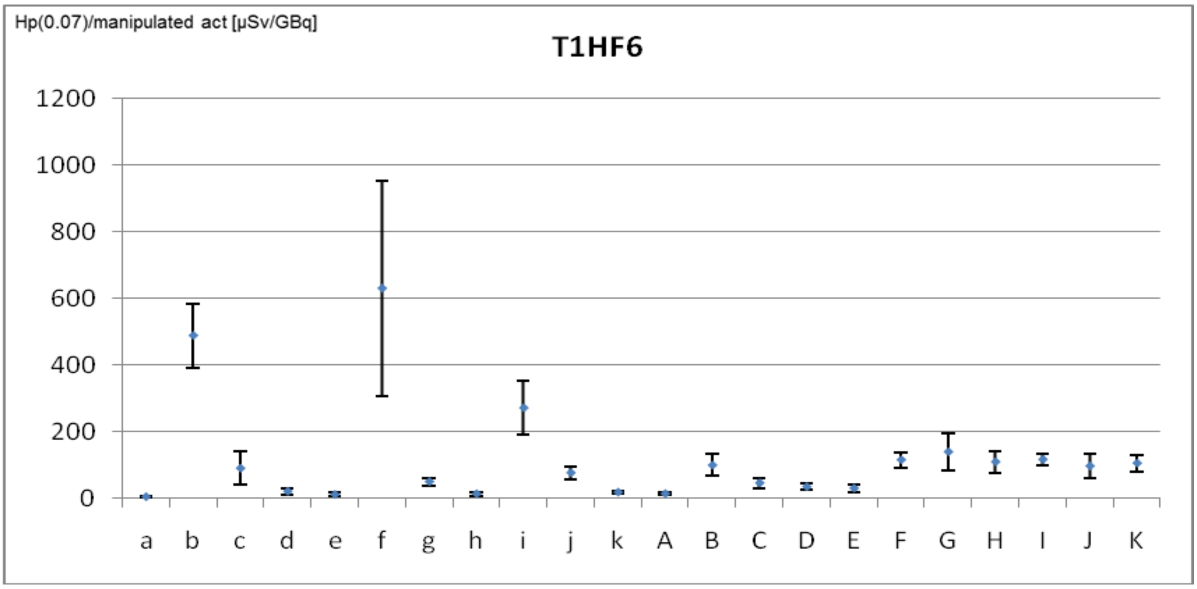
Worker T2HF5 : Preparation Vial Tc99m

20 years experience
Shieldings used : **Syringe not shielded**
Vial ? mm Pb



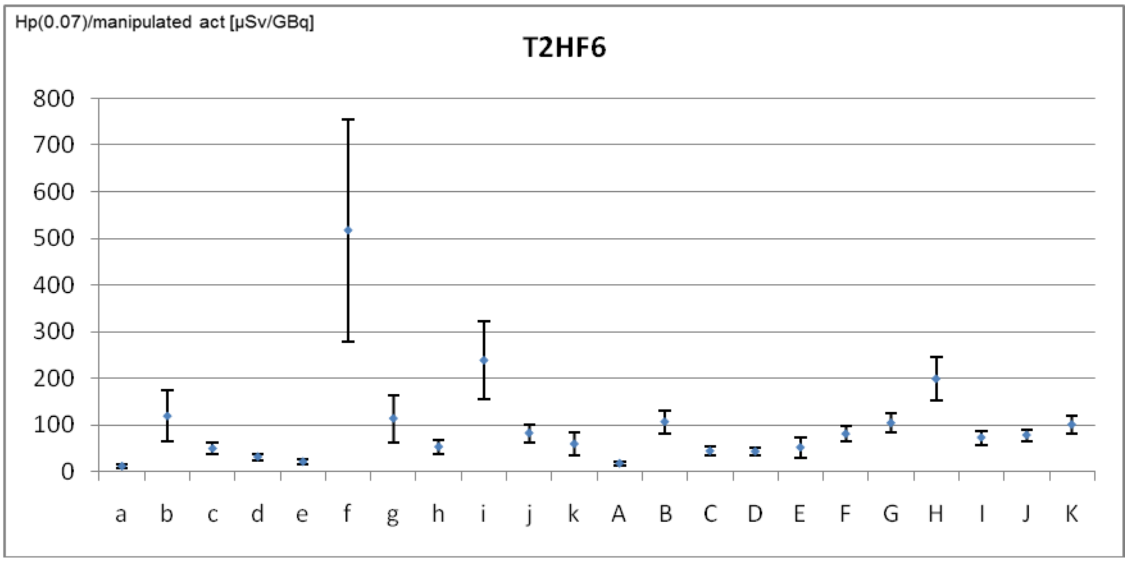
Worker T1HF6 :preparation Tc99m

1 year experience
Shieldings used : **Syringe not shielded**
Vial 4 mm Pb



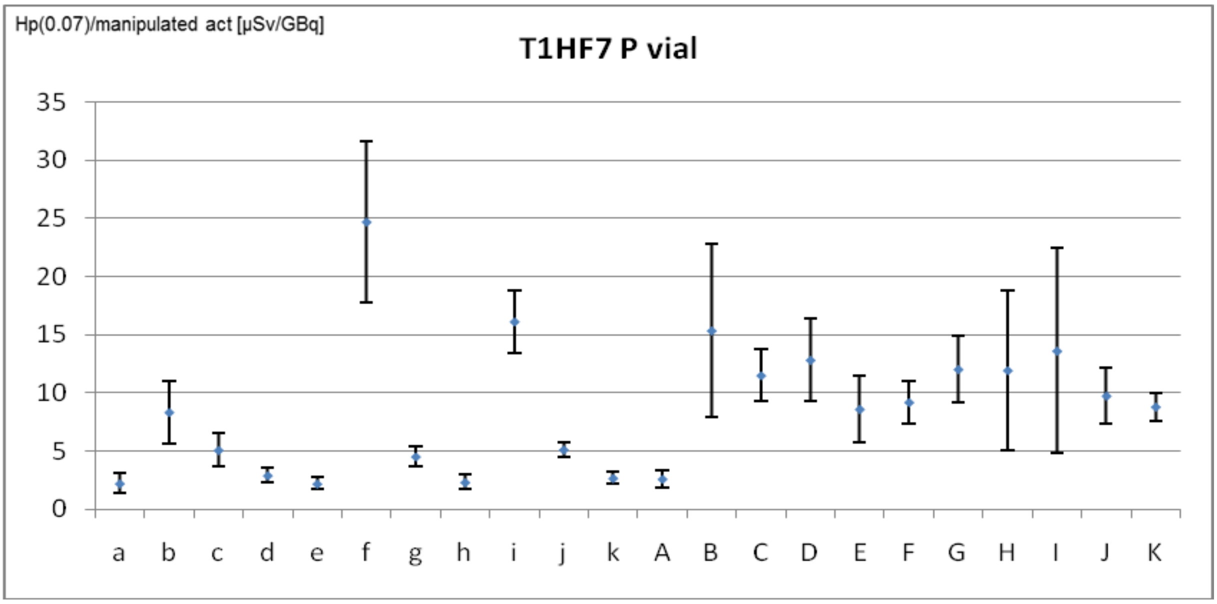
Worker T2HF6 : preparation Tc99m

31 years experience
Shieldings used : **Syringe not shielded**
Vial 4 mm Pb



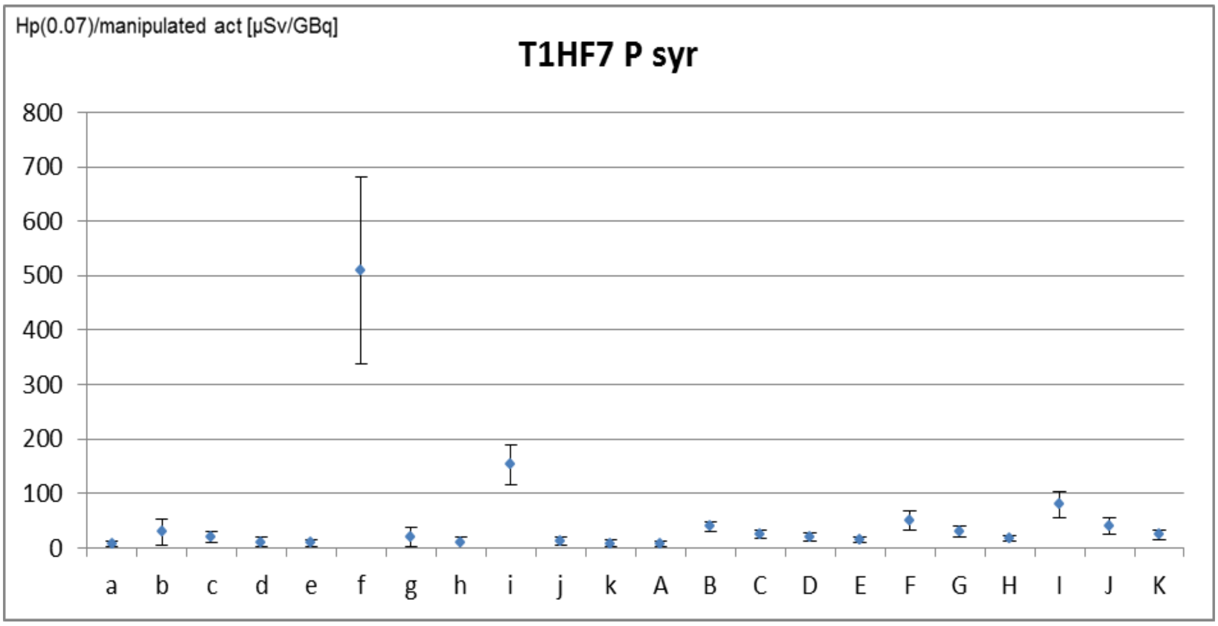
Worker T1HF7 : Preparation vial Tc99m

18 years experience
Shieldings used : **Syringe 2 mm Pb**
Vial 5 mm Pb



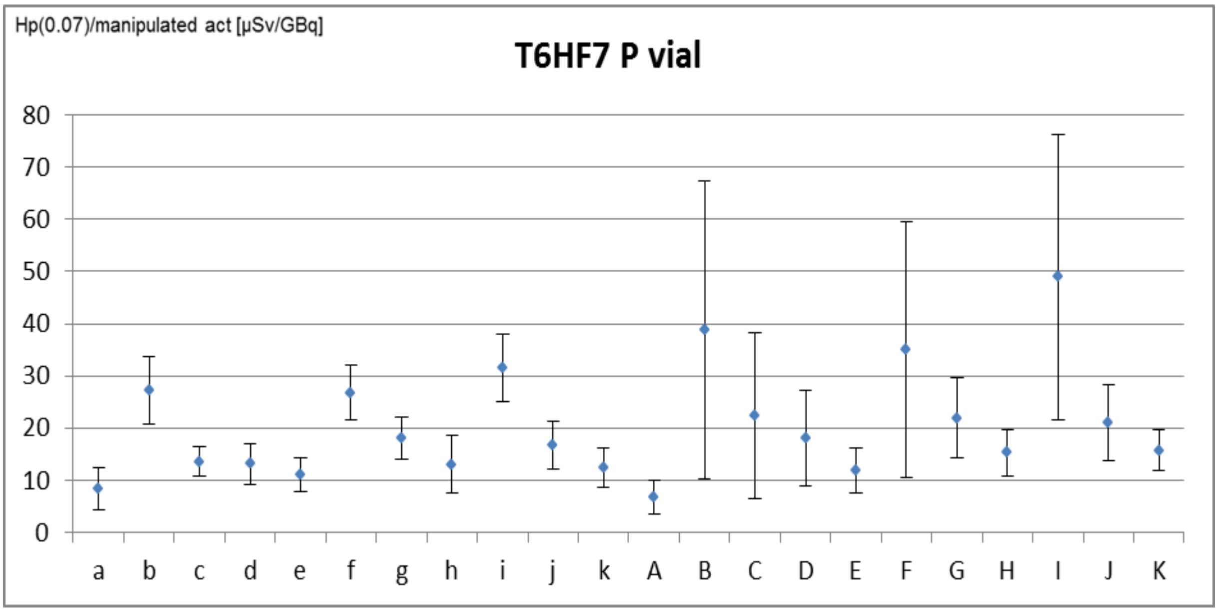
Worker T1HF7 : Preparation syringe Tc99m

18 years experience
Shieldings used : **Syringe not shielded**



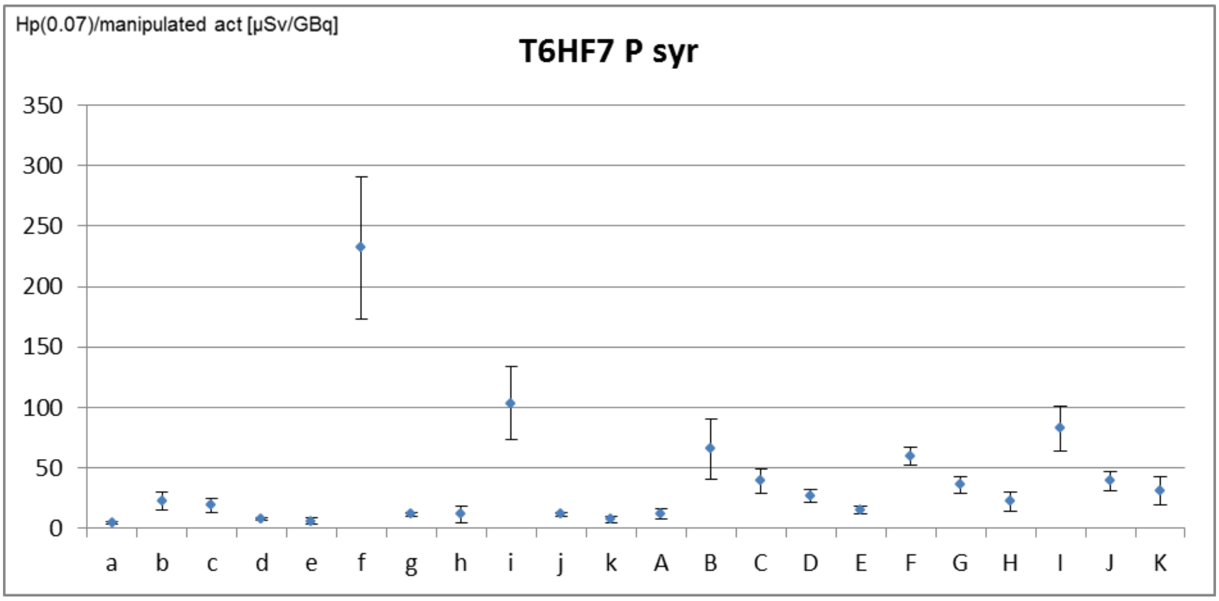
Worker T6HF7 : Preparation vial Tc99m

25 years experience
Shieldings used : Syringe 2 mm Pb
Vial 5 mm Pb



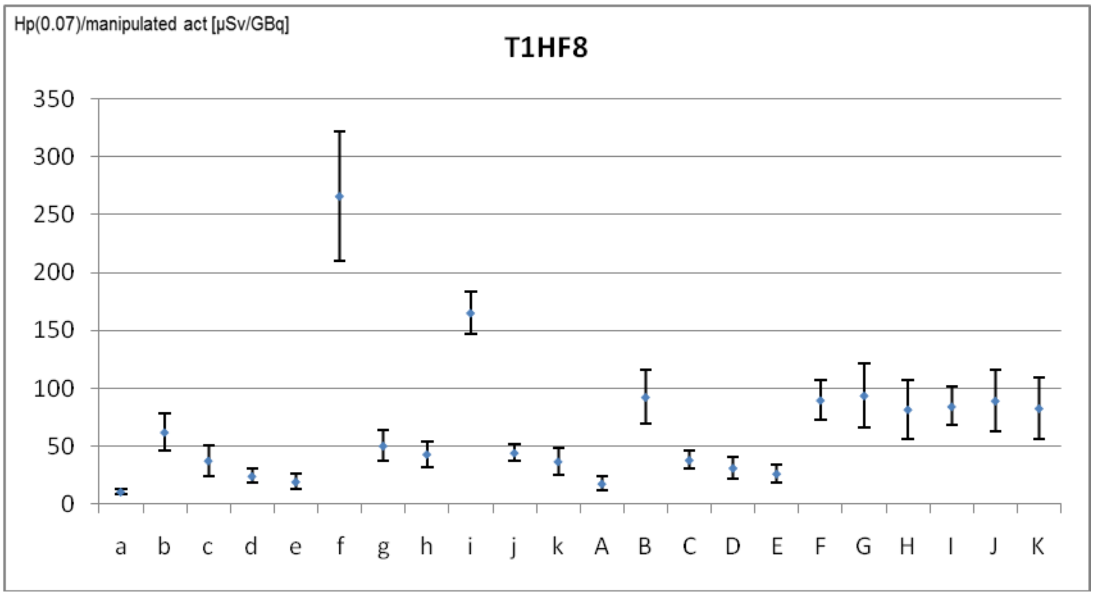
Worker T6HF7 : Preparation syringe Tc99m

25years experience
Shieldings used : Syringe not shielded



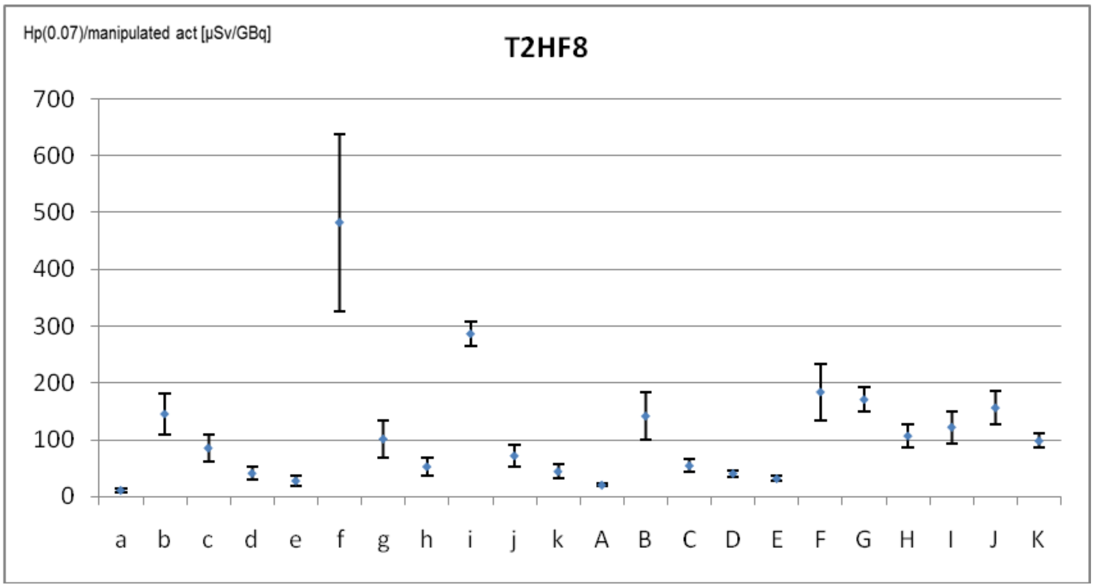
Worker T1HF8 :preparation Tc99m

22 years experience
Shieldings used : **Syringe not shielded**
Vial 2.1 mm Pb



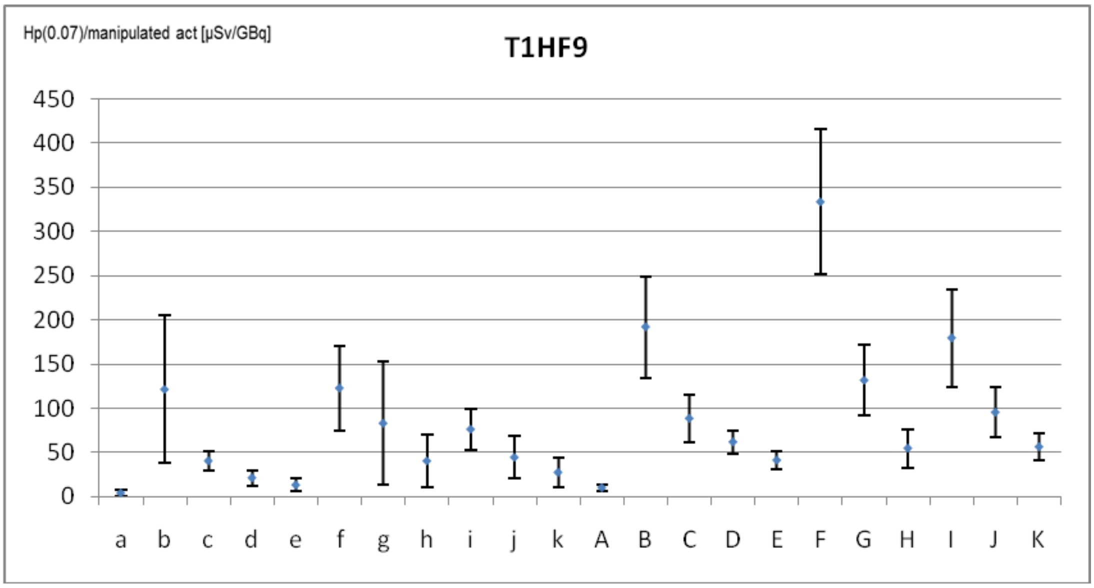
Worker T2HF8 : preparation Tc99m

27 years experience
Shieldings used : **Syringe not shielded**
Vial 2.1 mm Pb



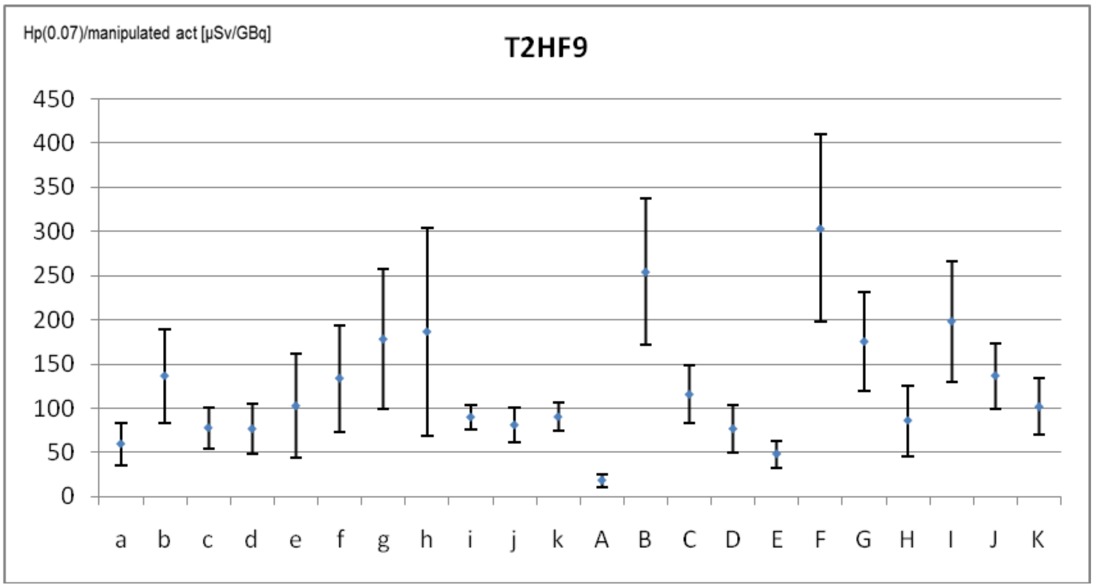
Worker T1HF9 : preparation Tc99m

16 years experience
Shieldings used : Syringe 2 mm Pb
Vial 17 mm Pb



Worker T2HF9 : preparation Tc99m

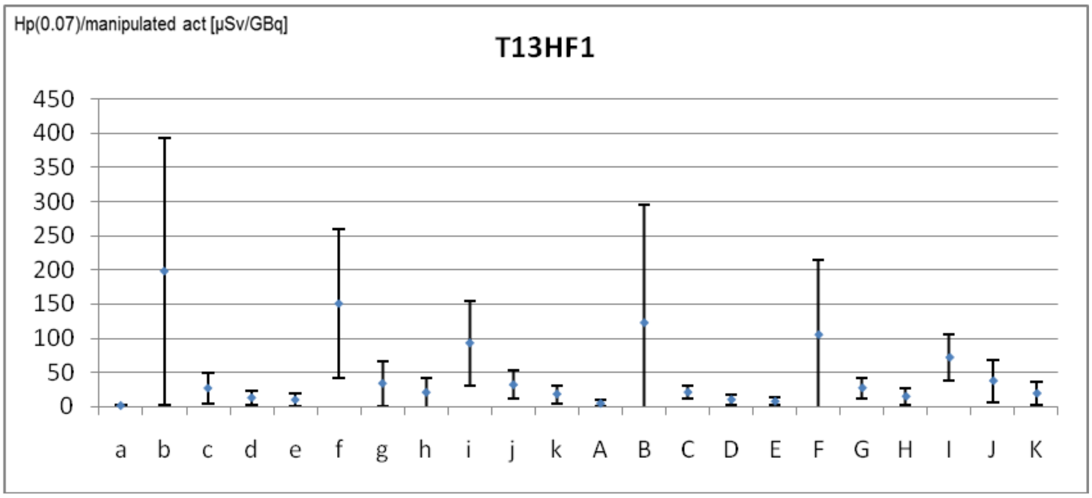
24 years experience
Shieldings used : Syringe 2 mm Pb
Vial 17 mm Pb



B. Administration of Tc99m

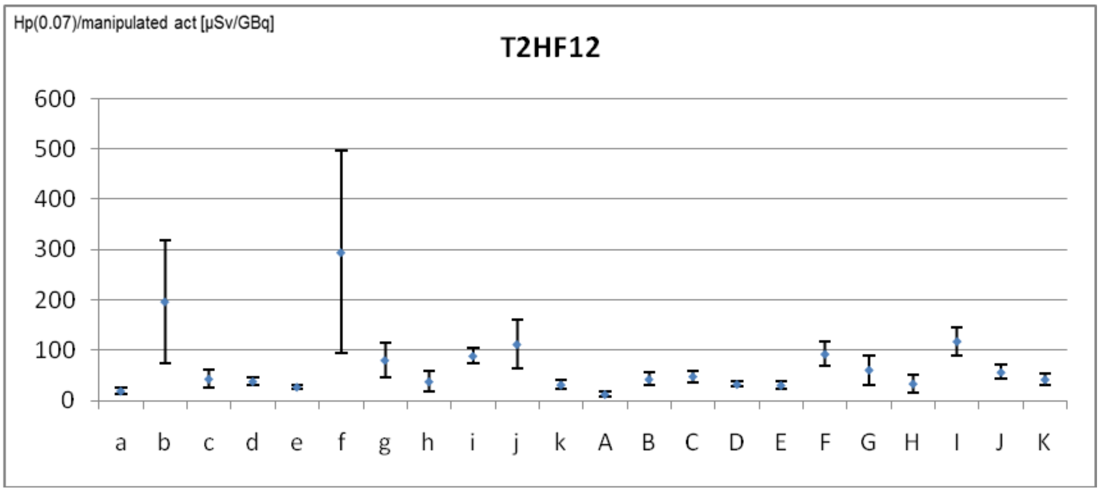
Worker T13HF1 : administration Tc99m

3.5 years experience
Shieldings used : Syringe 2 mm Pb



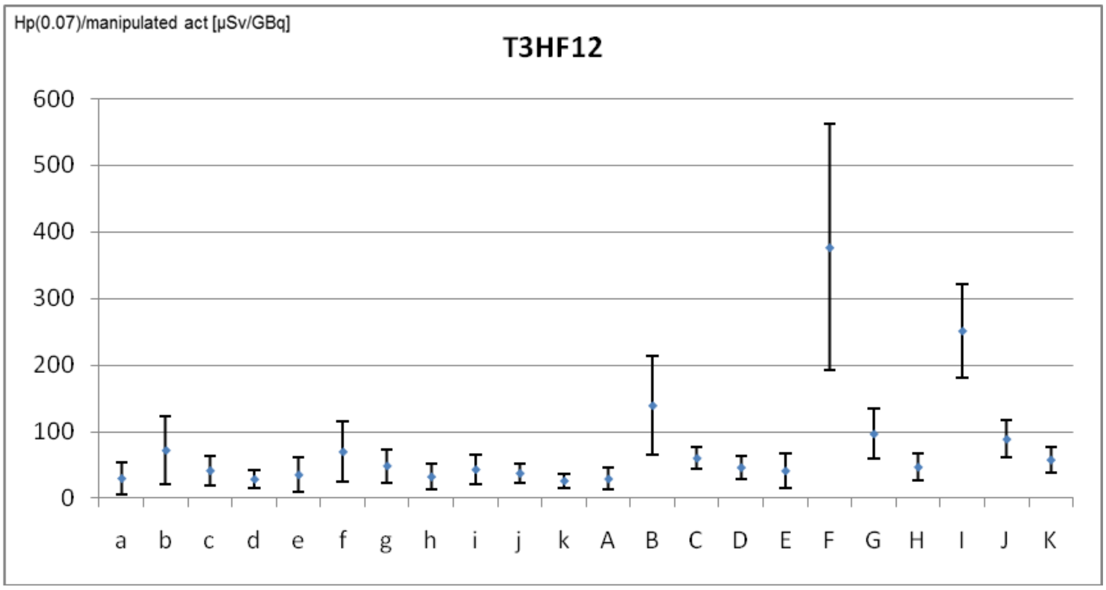
Worker T2HF12 : administration Tc99m

6 months experience
Shieldings used : Syringe not shielded



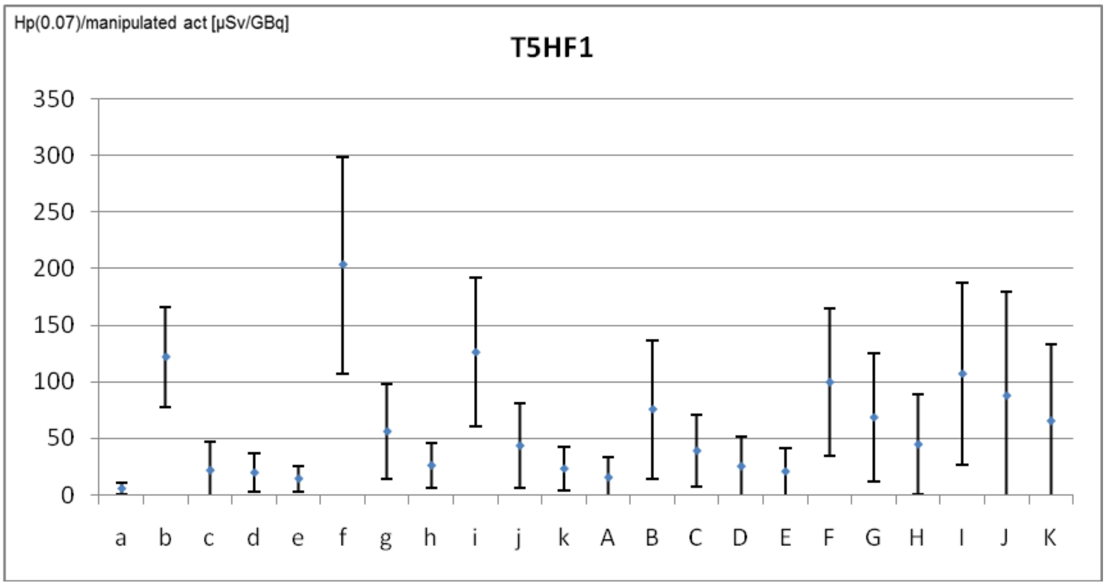
Worker T3HF12 : administration Tc99m

3 years experience
Shieldings used : Syringe not shielded



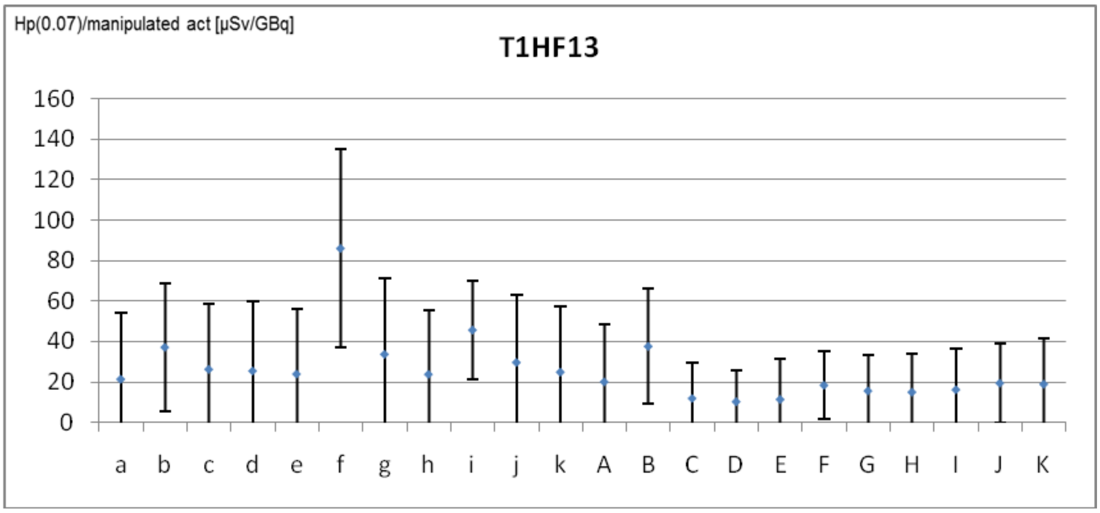
Worker T5HF1 : administration Tc99m

2 years experience
Shieldings used : Syringe 2 mm Pb



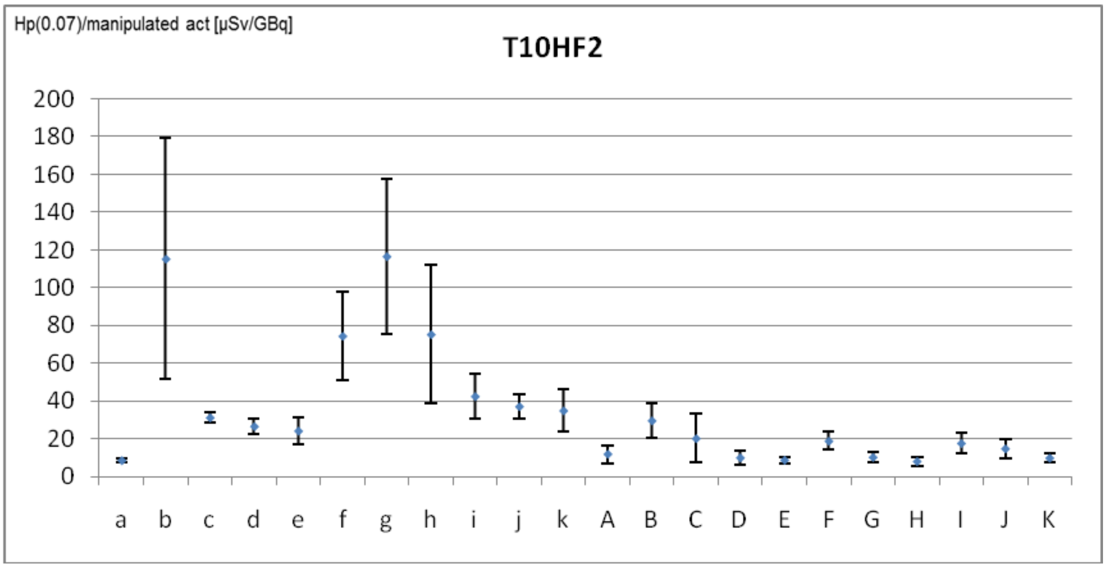
Worker T1HF13 : administration Tc99m

20 years experience
Shieldings used : Syringe 2 mm W



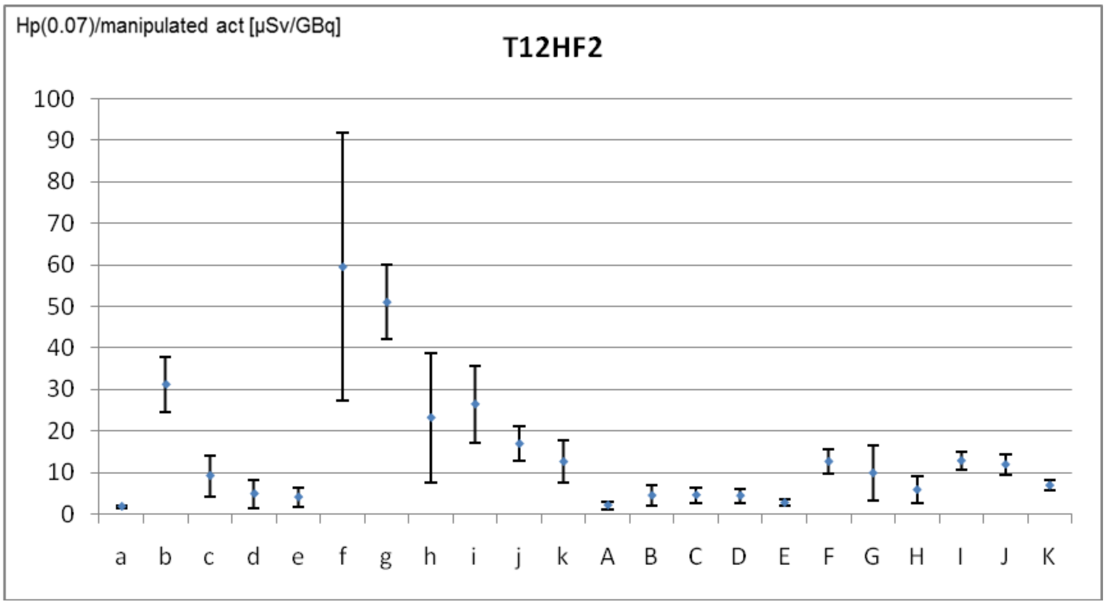
Worker T10HF2 : administration Tc99m

1.5 years experience
Shieldings used : Syringe 4 mm Pb



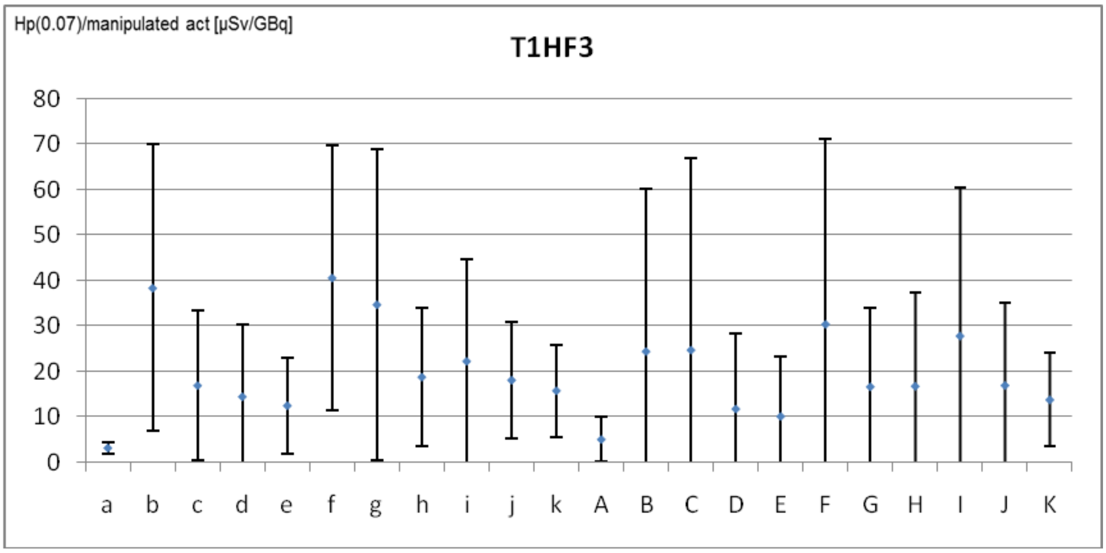
Worker T12HF2 : administration Tc99m

? year experience
Shieldings used : Syringe 1 mm Pb (leaf)



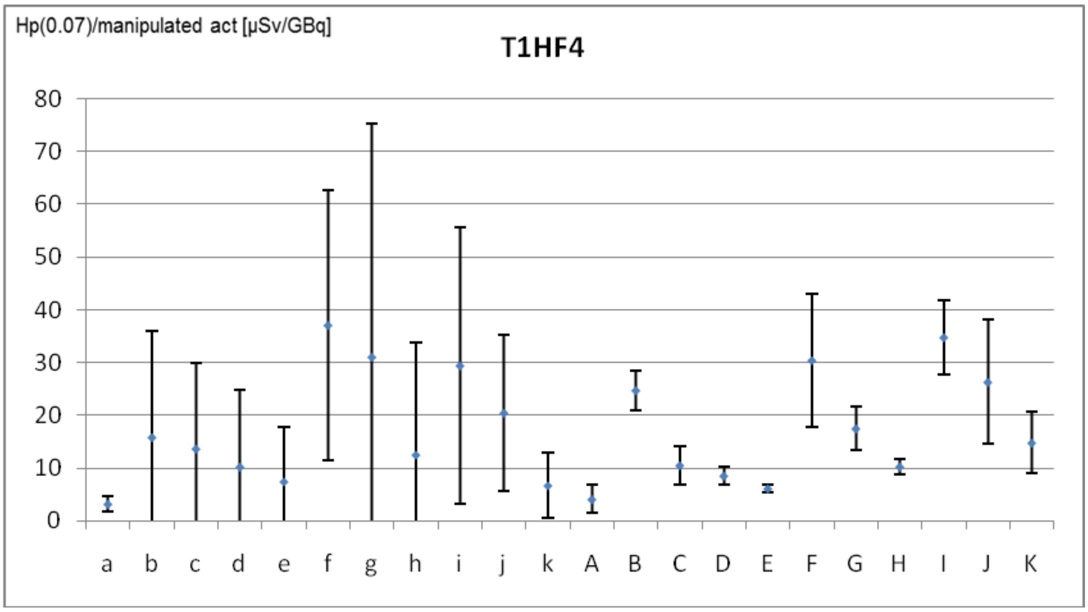
Worker T1HF3 : administration Tc99m

13 years experience
Shieldings used : Syringe 2 mm W



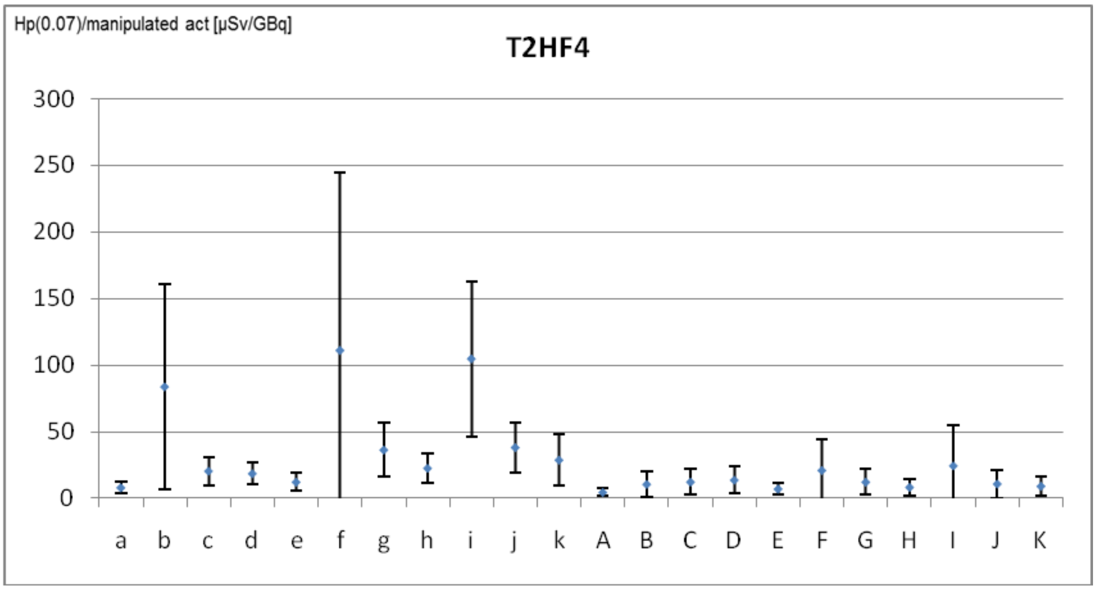
Worker T1HF4 : administration Tc99m

25 years experience
Shieldings used : Syringe 2 mm Pb



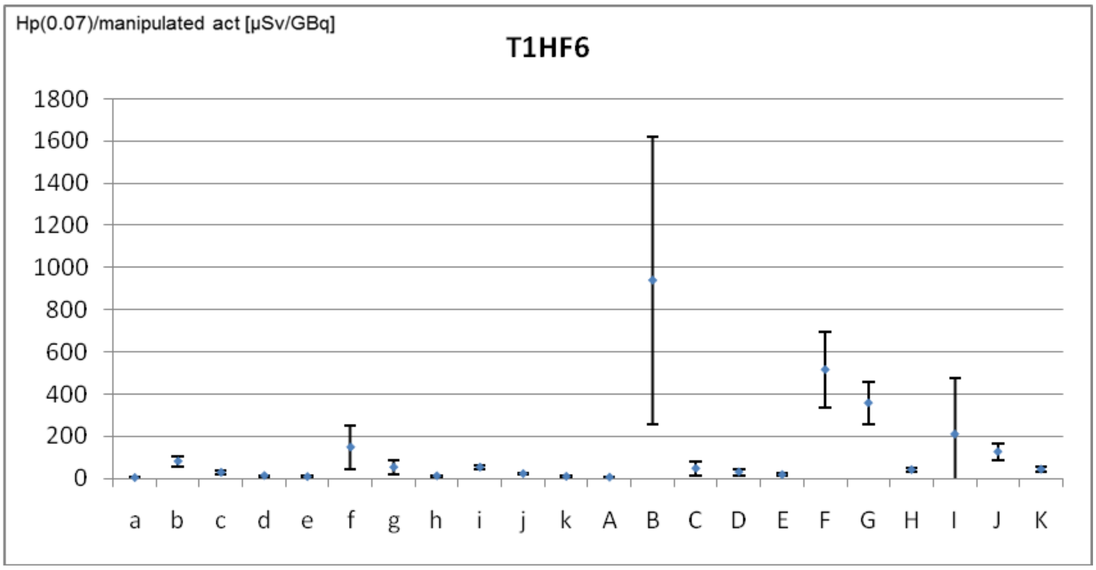
Worker T2HF4 : administration Tc99m

5 years experience
Shieldings used : Syringe 2 mm Pb



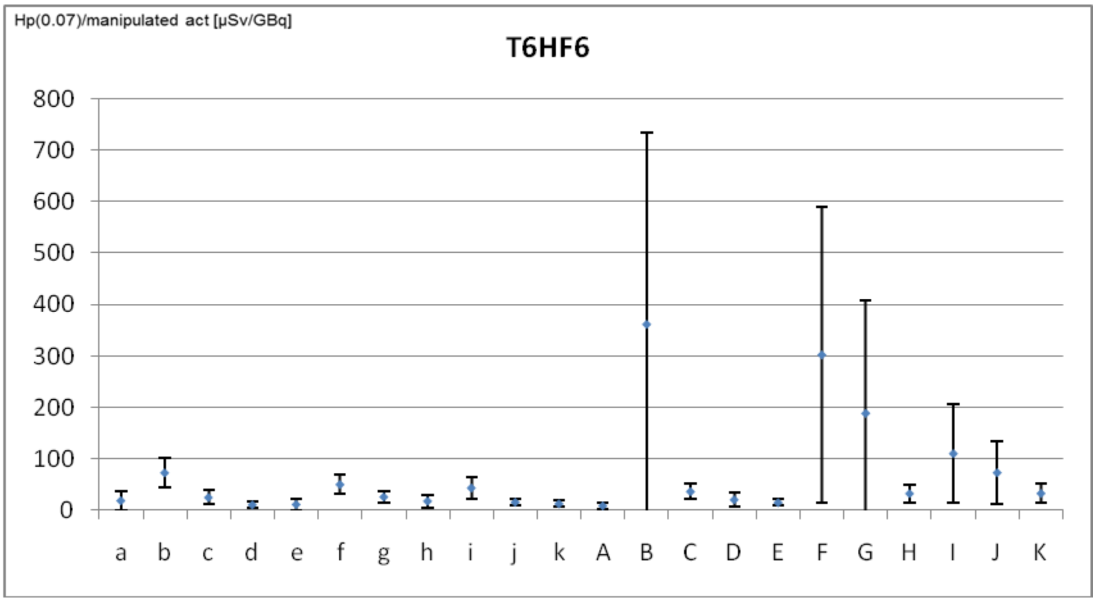
Worker T1HF6 : administration Tc99m

1 year experience
Shieldings used : Syringe not shielded



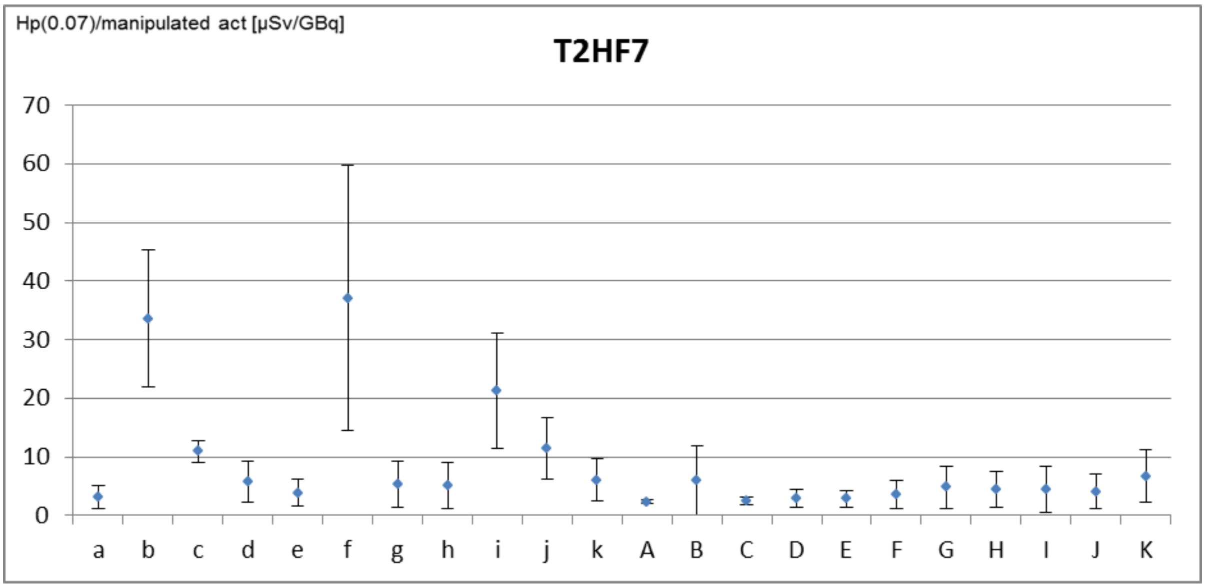
Worker T6HF6 : administration Tc99m

1 year experience
Shieldings used : Syringe not shielded



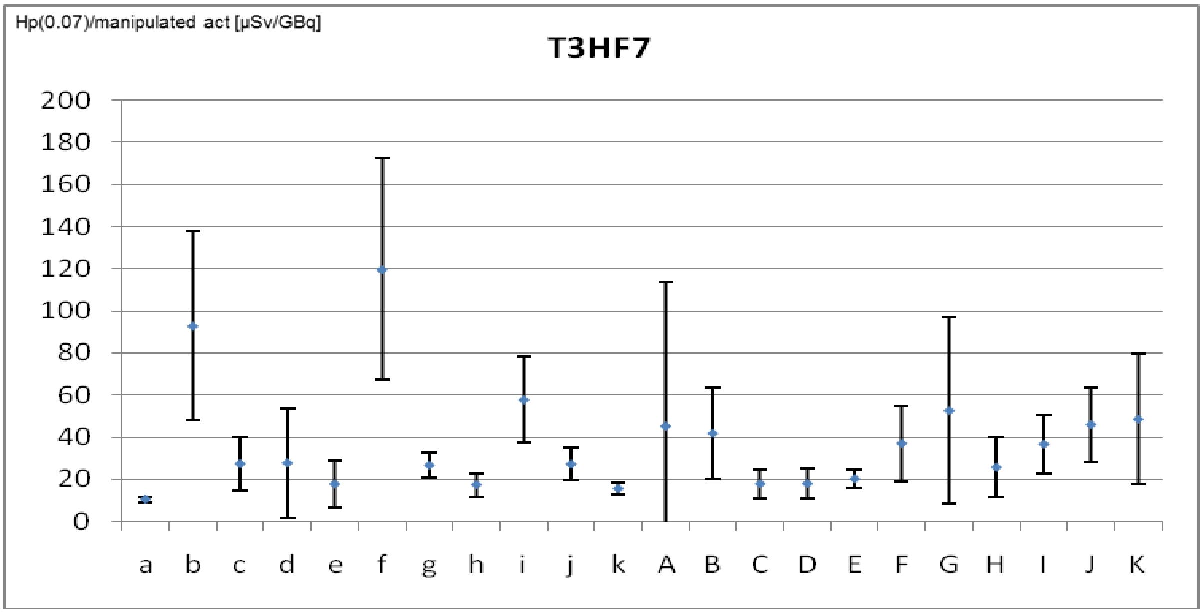
Worker T2HF7 : administration Tc99m

4 years experience
Shieldings used : Syringe 2 mm Pb



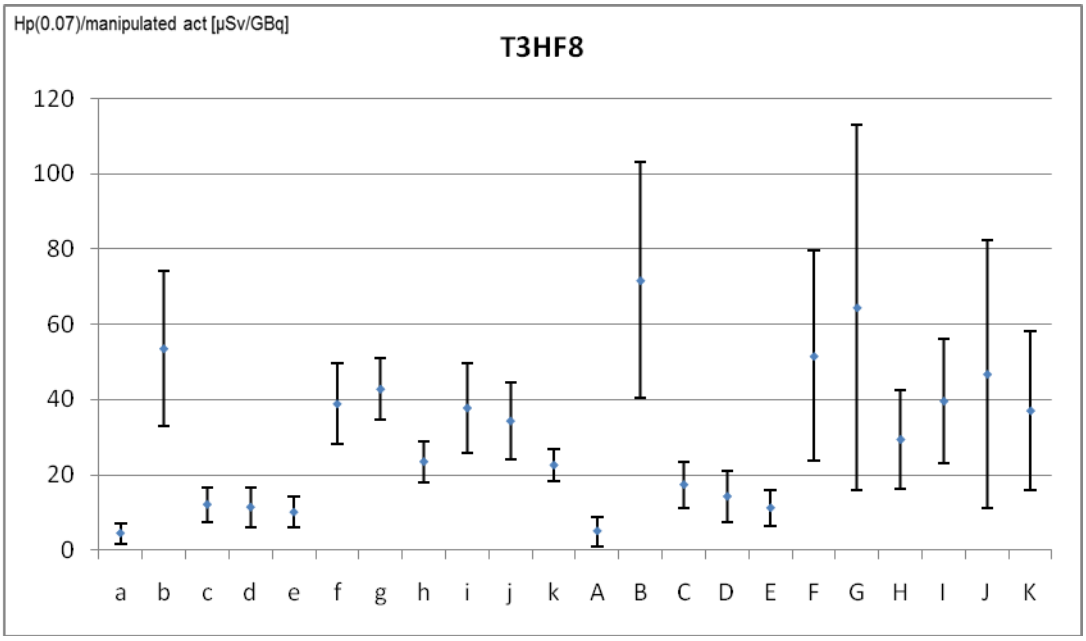
Worker T3HF7 : administration Tc99m

3 years experience
Shieldings used : Syringe 2 mm Pb



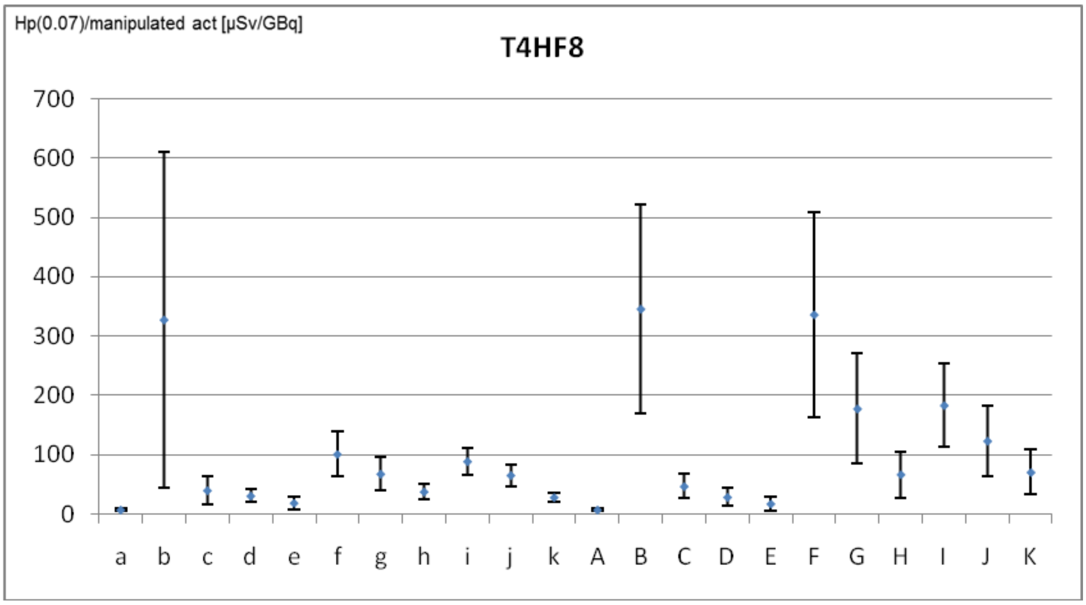
Worker T3HF8 : administration Tc99m

3 years experience
Shieldings used : Syringe not shielded



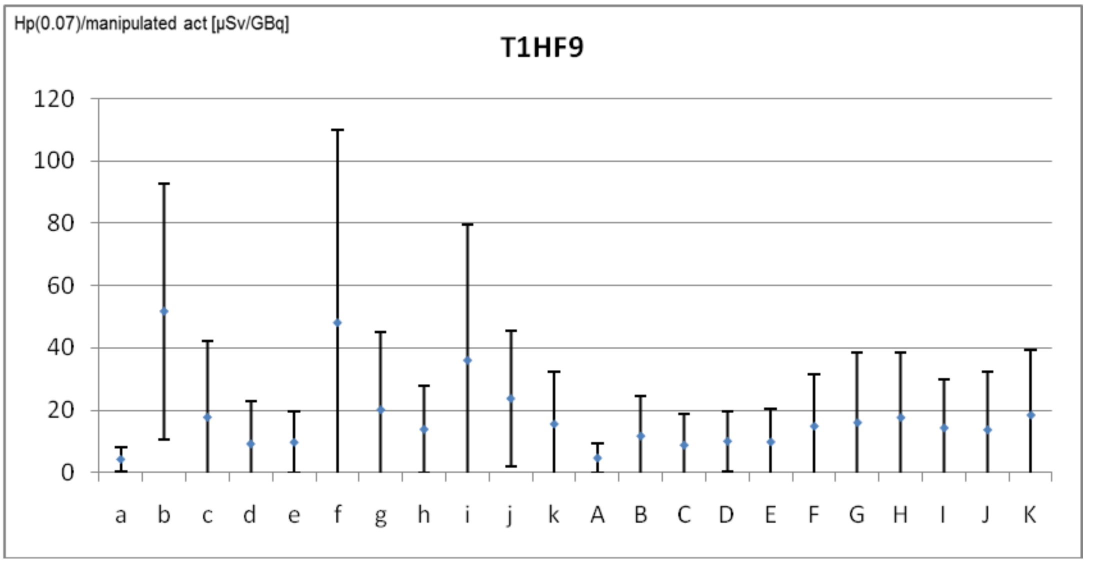
Worker T4HF8 : administration Tc99m

20 years experience
Shieldings used : Syringe 2 mm Pb



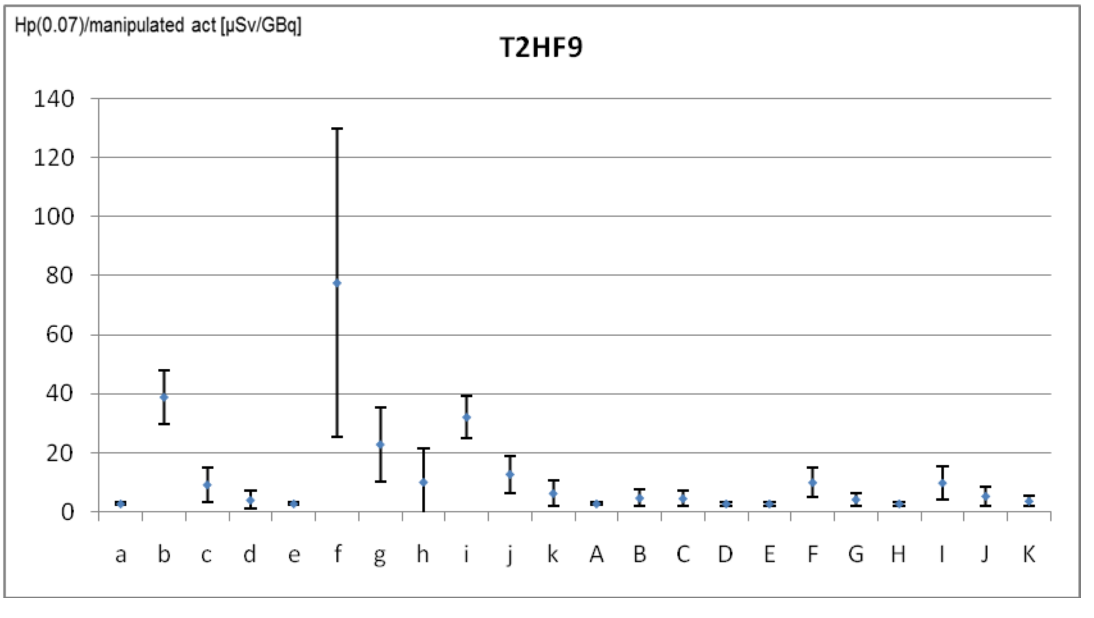
Worker T1HF9 : administration Tc99m

16 years experience
Shieldings used : Syringe 2 mm W



Worker T1HF9 : administration Tc99m

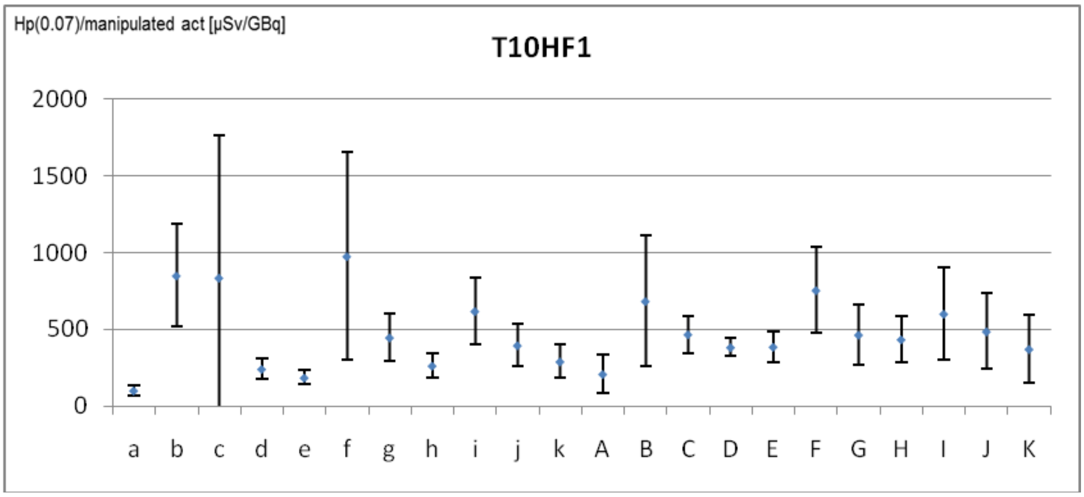
24 years experience
Shieldings used : Syringe 2 mm W



C. Preparation of FDG

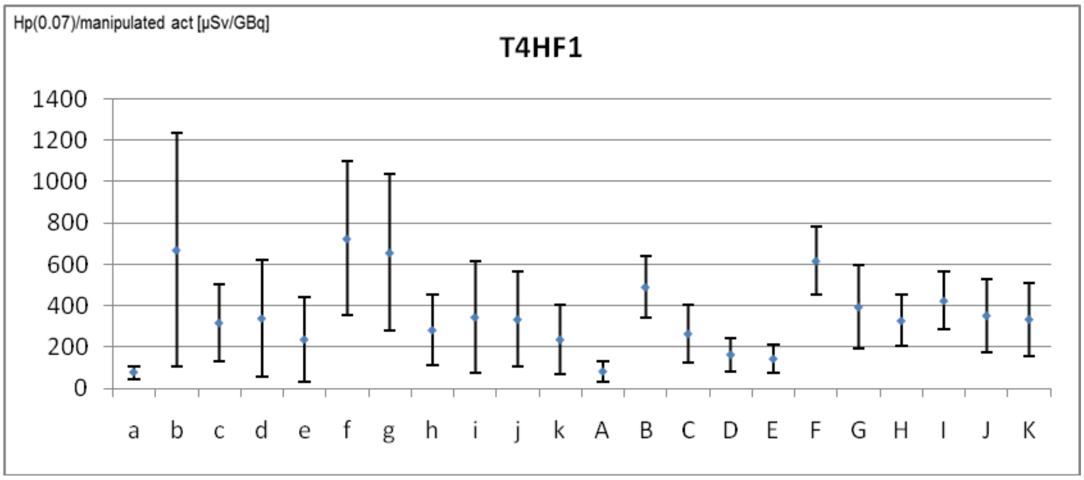
Worker T10HF1 : preparation FDG

1 year experience
Shieldings used : Syringe not shielded
Vial 45 mm Pb



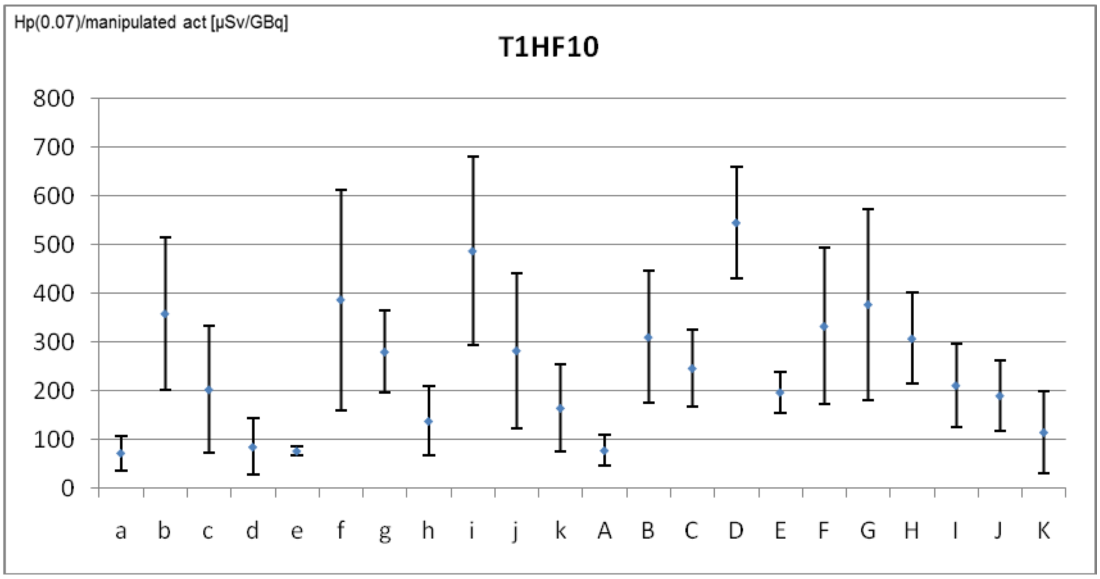
Worker T4HF1 : preparation FDG

15 years experience
Shieldings used : Syringe not shielded
Vial 45 mm Pb



Worker T1HF10 : preparation FDG

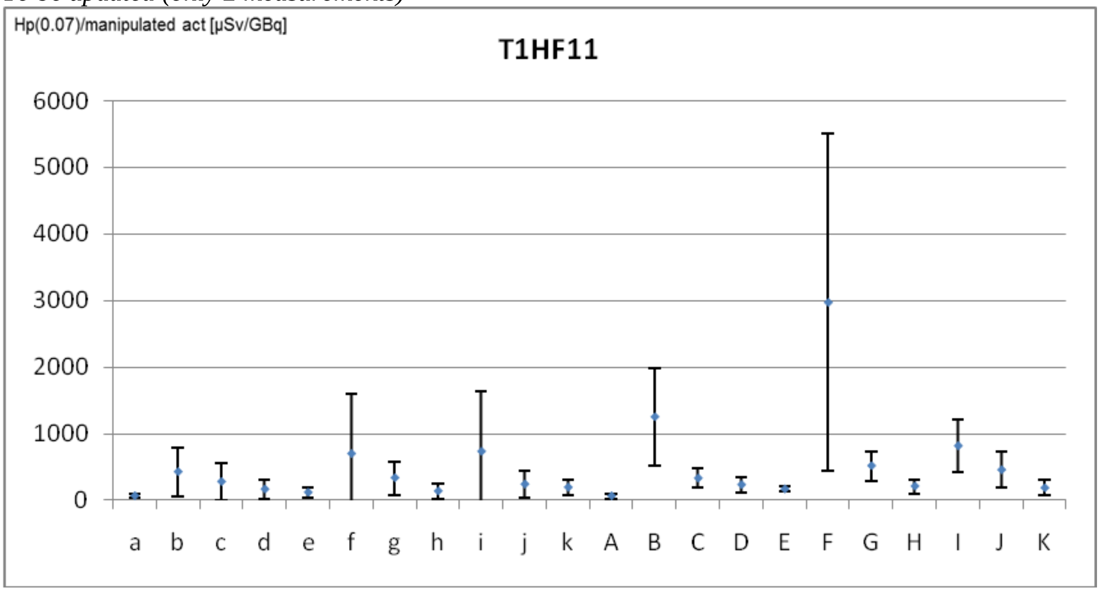
18 years experience
Shieldings used : **Syringe 7 mm Pb**
Vial 45 mm Pb



Worker T1HF11 : preparation FDG

5 years experience
Shieldings used : **Syringe not shielded**
Vial 30 mm Pb

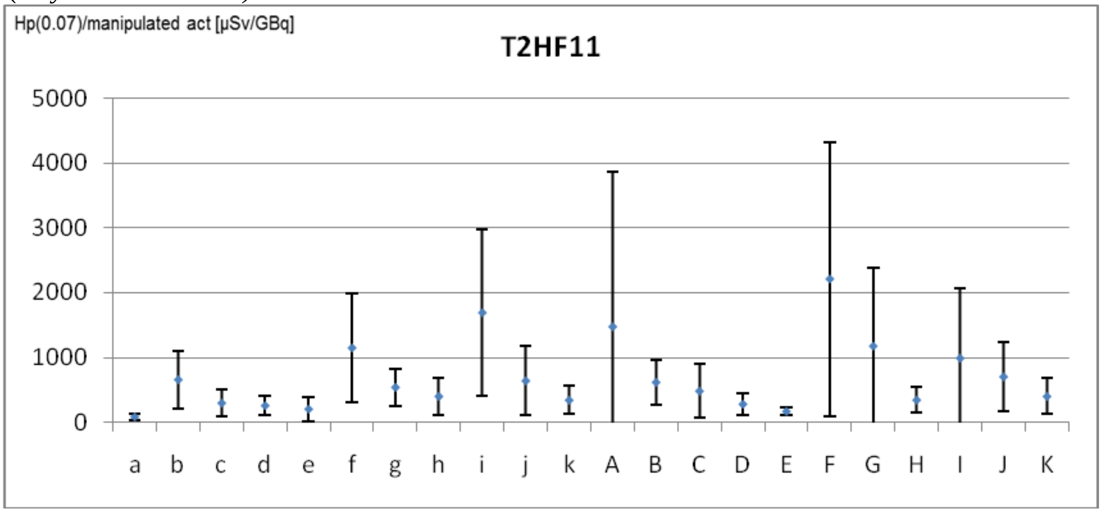
To be updated (only 2 measurements)



Worker T2HF11 : preparation FDG

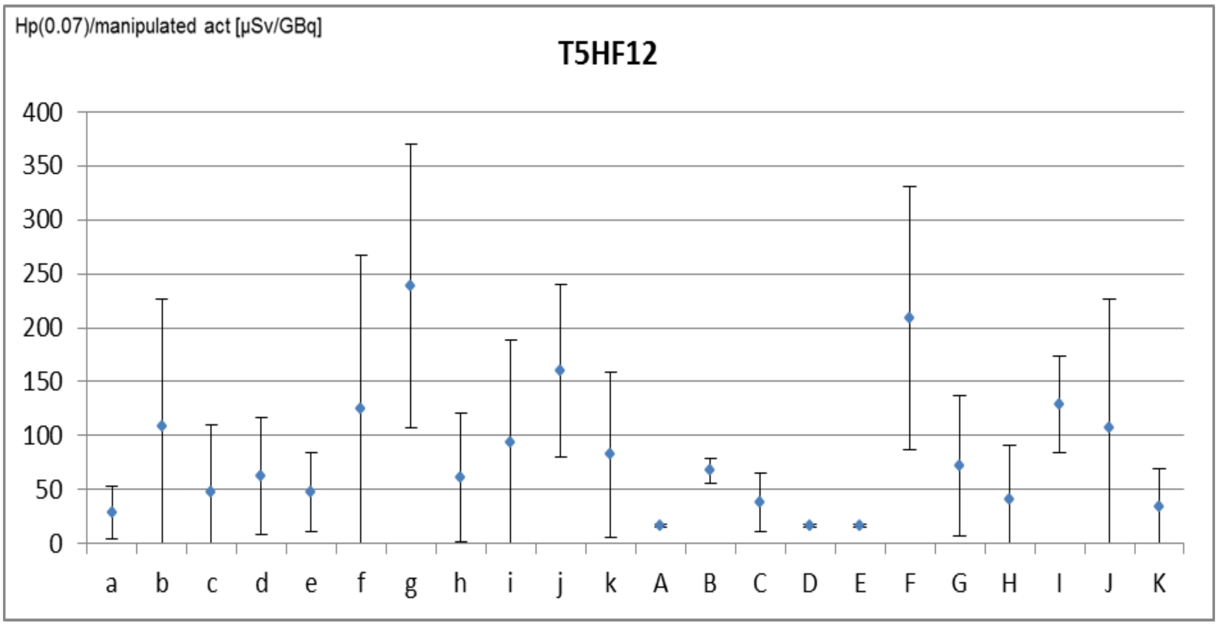
3 years experience
Shieldings used : Syringe not shielded
Vial 30 mm Pb

(only 2 measurements)



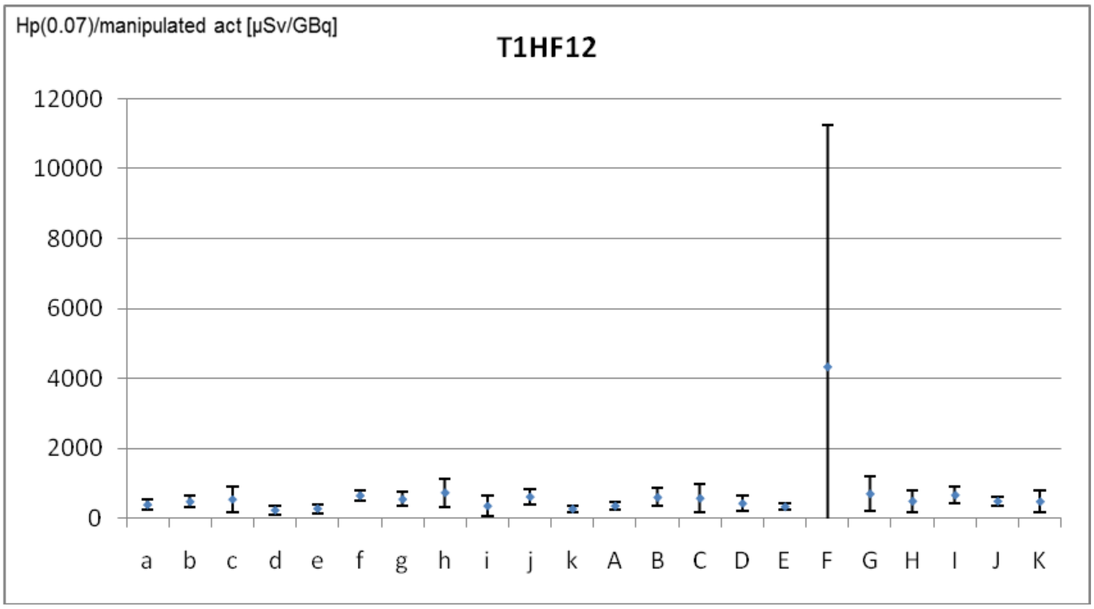
Worker T5HF12 : preparation FDG

6 years experience
Shieldings used : Syringe 30 mm W
Vial 16 mm W



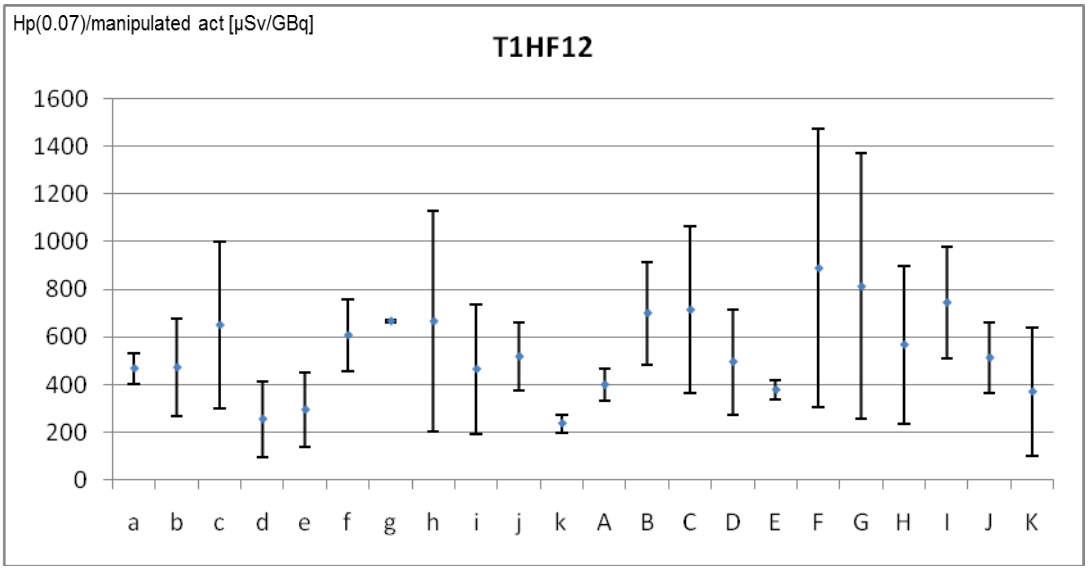
Worker T1HF12 : preparation FDG

10 months experience
Shieldings used : Syringe 30 mm W // 4 mm Pb (manual)
Vial 16 mm W // 45 mm Pb (manual)



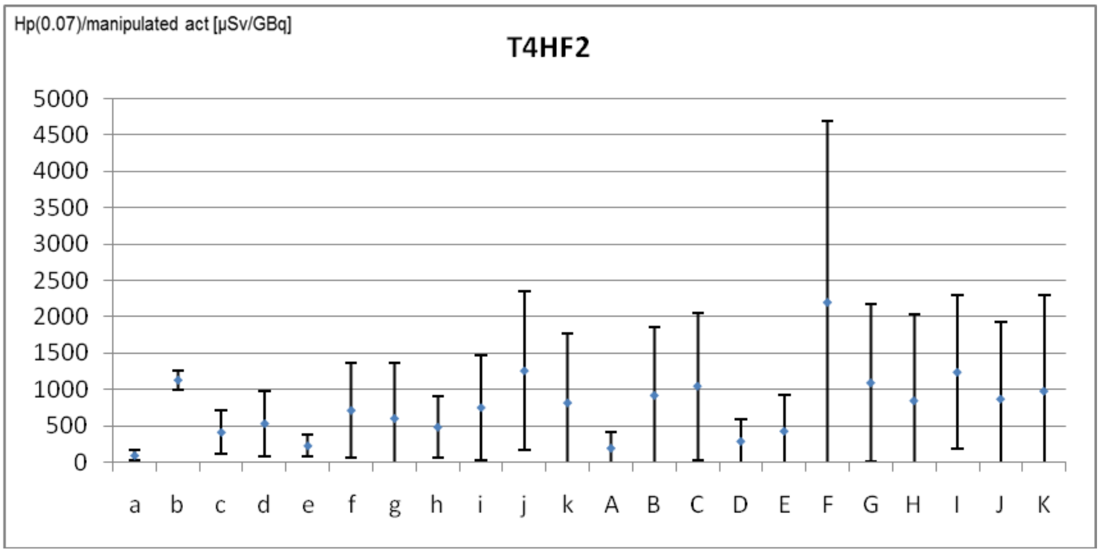
Worker T1HF12 : preparation FDG (outlier removed)

10 months experience
Shieldings used : Syringe 30 mm W // 4 mm Pb (manual)
Vial 16 mm W // 45 mm Pb (manual)



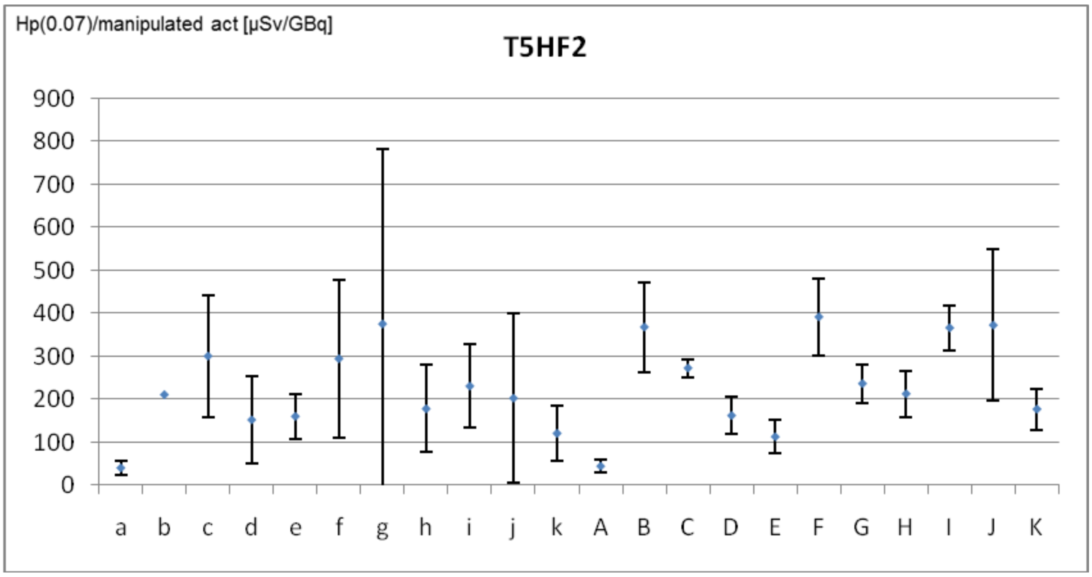
Worker T4HF2 : preparation FDG

1? year experience
Shieldings used : Syringe not shielded
Vial 45 mm Pb



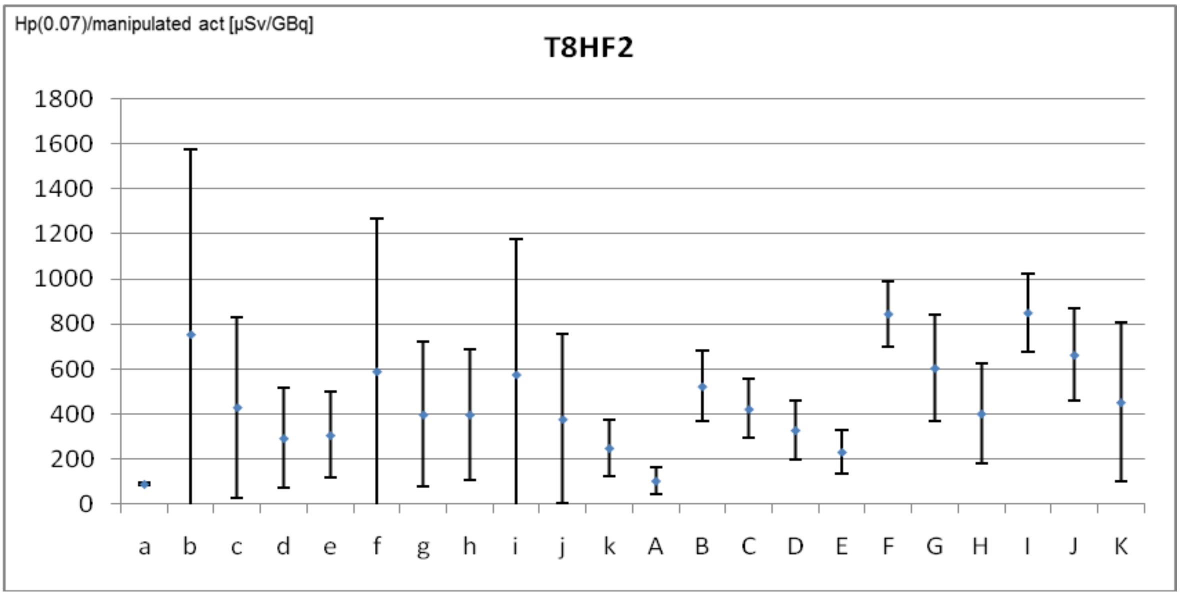
Worker T5HF2 : preparation FDG

>5? years experience
Shieldings used : Syringe not shielded
Vial 45 mm Pb



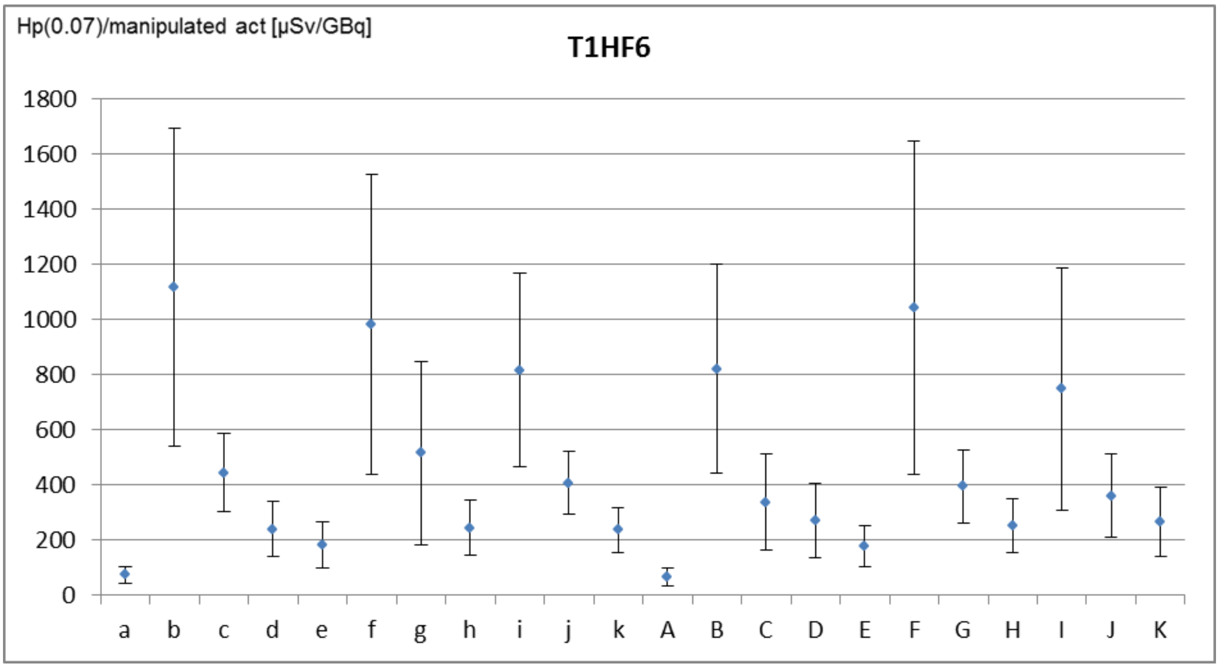
Worker T8HF2 : preparation FDG

2.5 years experience
Shieldings used : Syringe not shielded
Vial 45 mm Pb



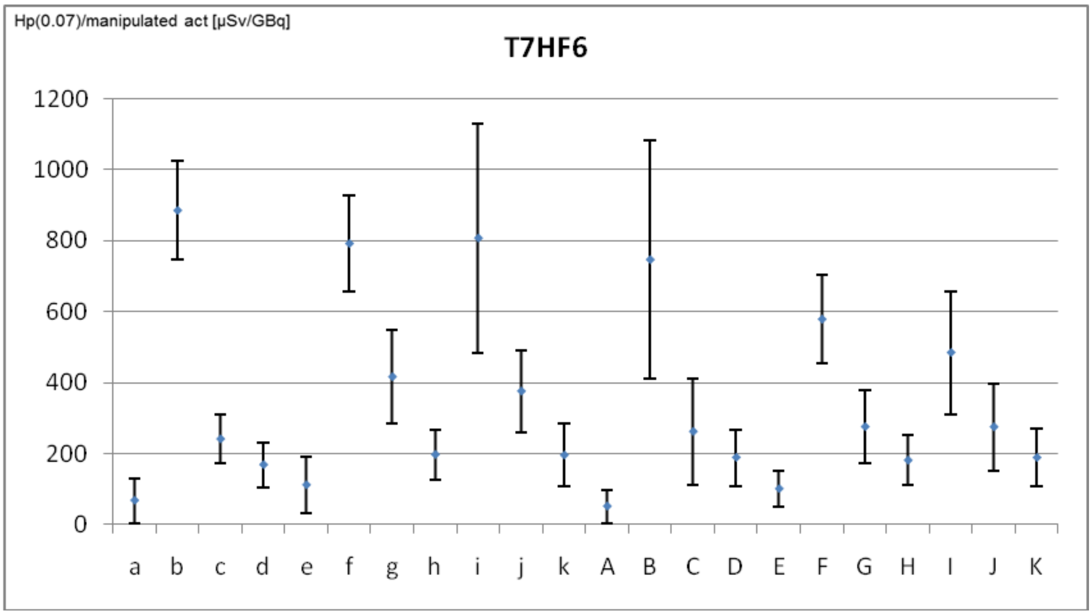
Worker T1HF6 : preparation FDG

1 year experience
Shieldings used : Syringe not shielded
Vial 45 mm Pb



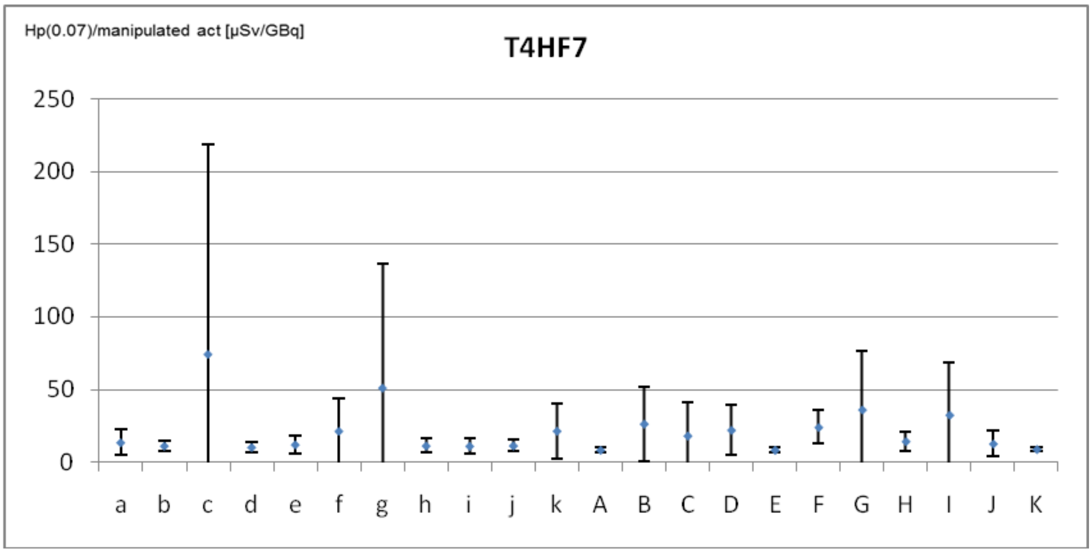
Worker T7HF6 : preparation FDG

>5 years experience
Shieldings used : Syringe not shielded
Vial 45 mm Pb



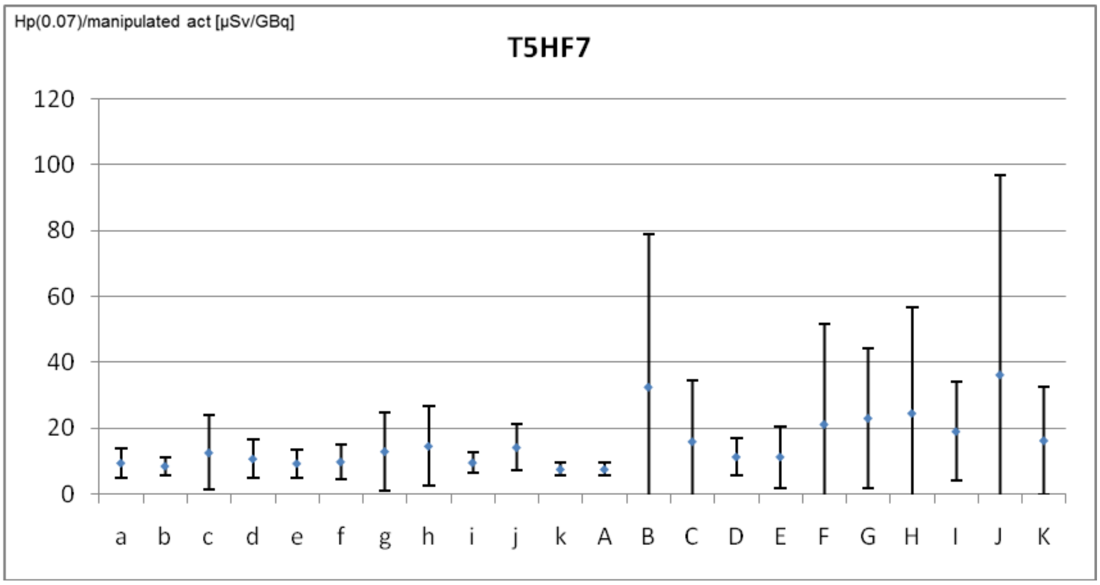
Worker T4HF7 : preparation FDG

1 year experience
Shieldings used : Full automatic system for dispensing and injection Posijet®



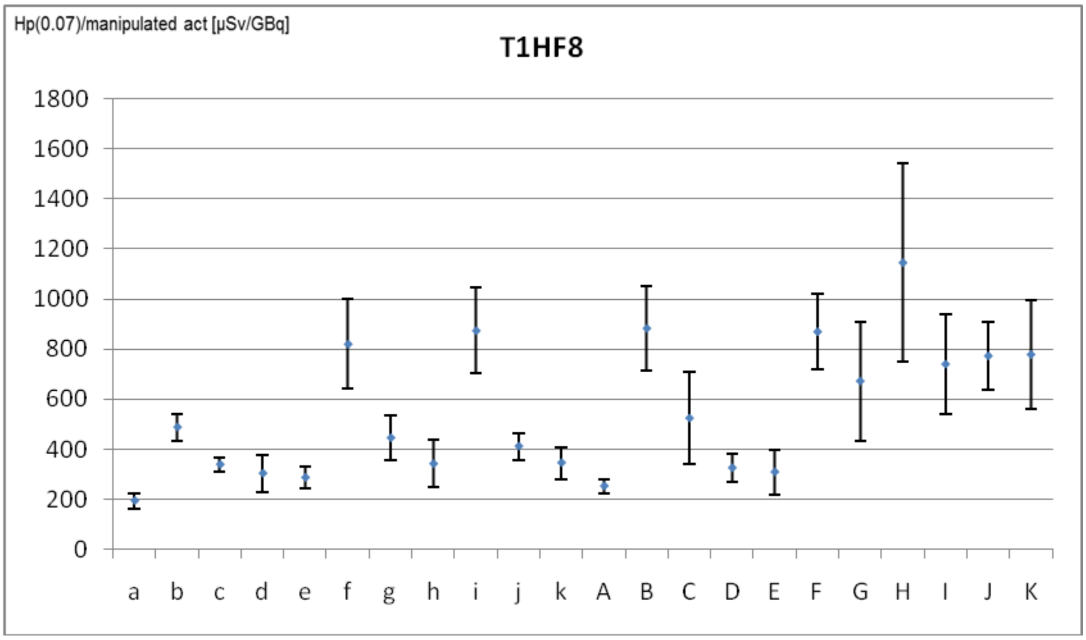
Worker T5HF7 : preparation FDG

1 year experience
Shieldings used : **Full automatic system for dispensing and injection Posijet®**



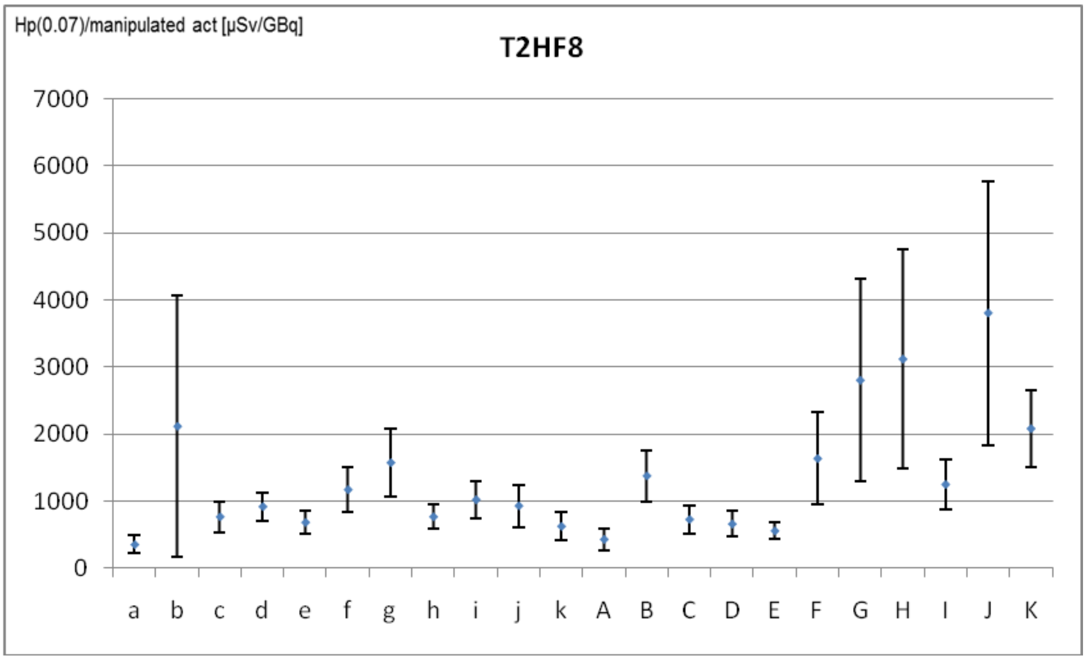
Worker T1HF8 : preparation FDG

22 years experience
Shieldings used : **Syringe not shielded**
Vial 45 mm Pb



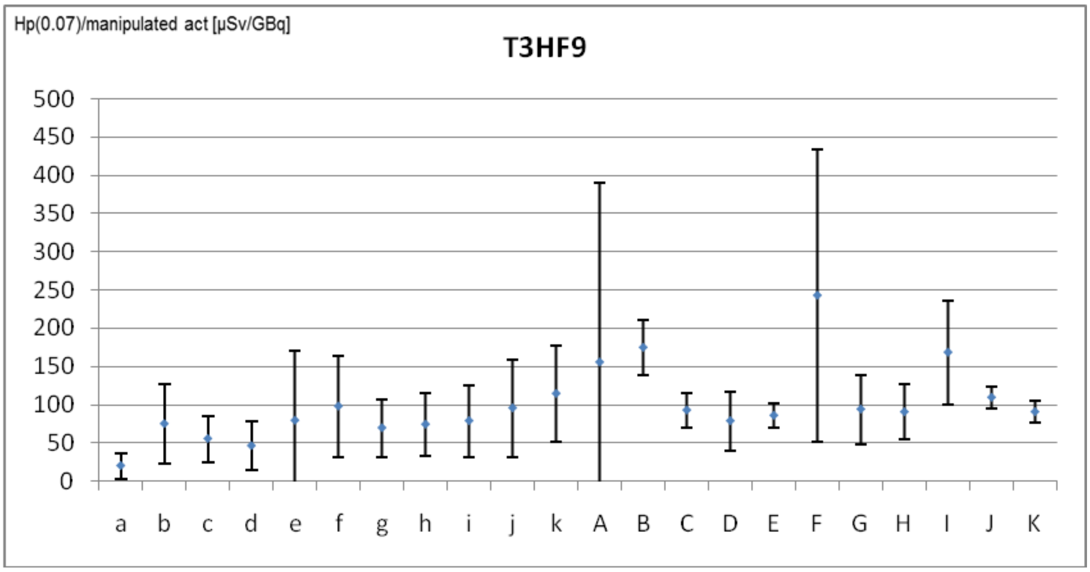
Worker T2HF8 : preparation FDG

27 years experience
Shieldings used : Syringe not shielded
Vial 45 mm Pb



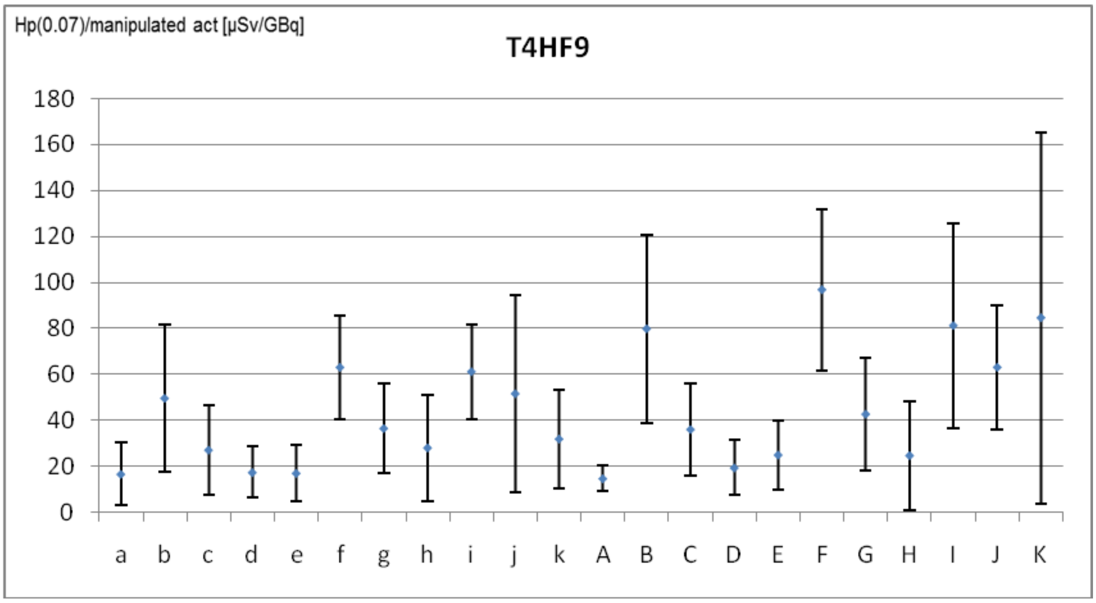
Worker T3HF9 : preparation FDG

1 year experience
Shieldings used : Syringe 20 mm Pb
Vial 50 mm Pb



Worker T4HF9 : preparation FDG

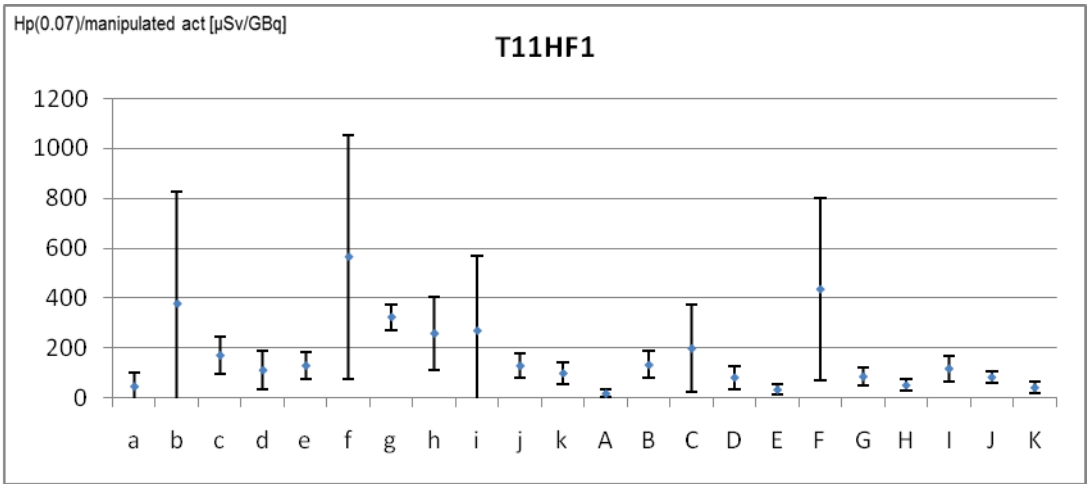
>5 years experience
Shieldings used : Syringe 20 mm Pb
Vial 50 mm Pb



D. Administration of FDG

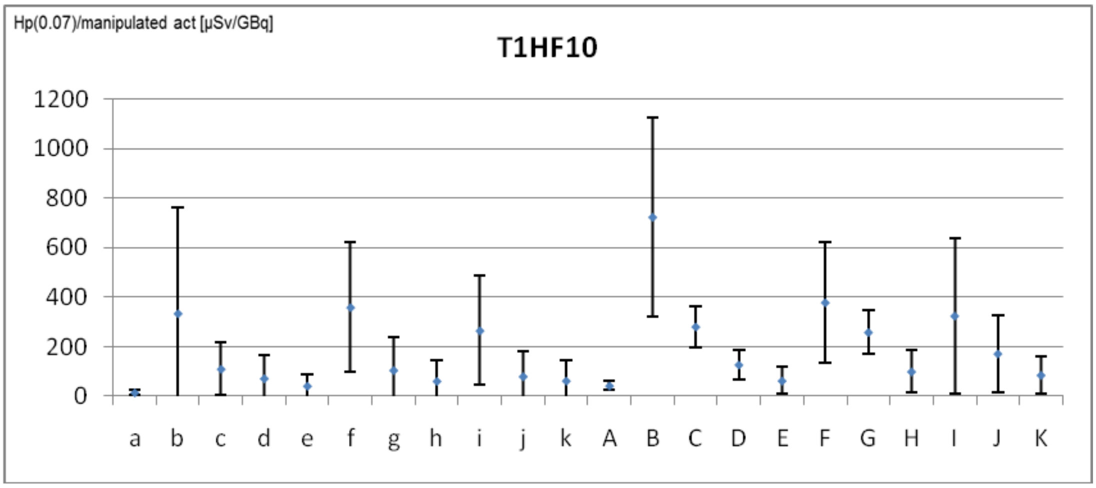
Worker T11HF1 : administration FDG

11 years experience
Shieldings used : Syringe ? mm W



Worker T1HF10 : administration FDG

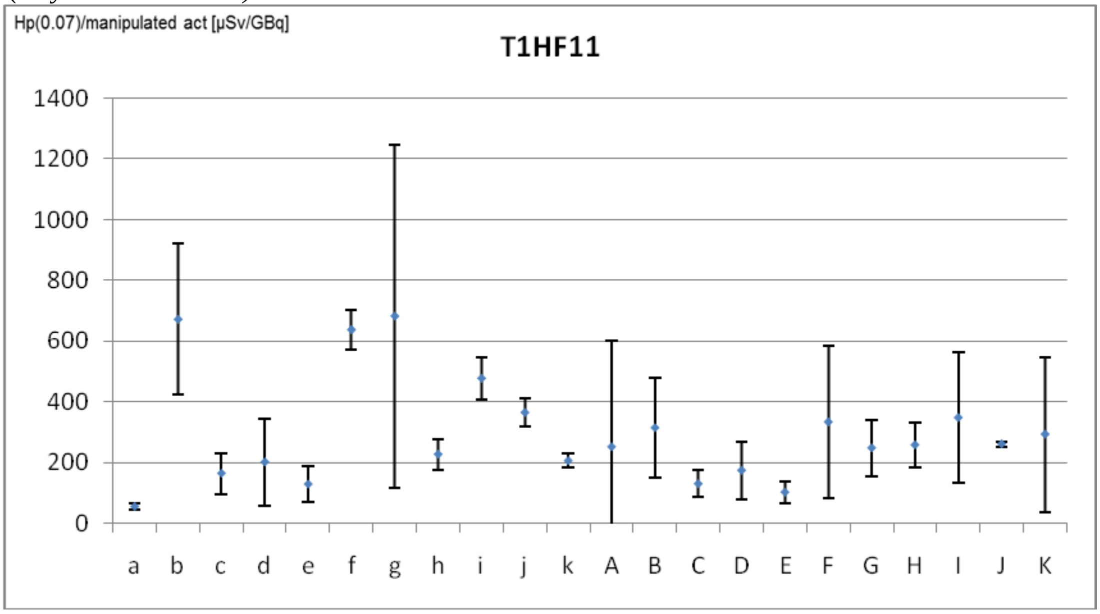
18 years experience
Shieldings used : Syringe 7 mm Pb



Worker T1HF11 : administration FDG

5 years experience
Shieldings used : Syringe 5 mm Pb

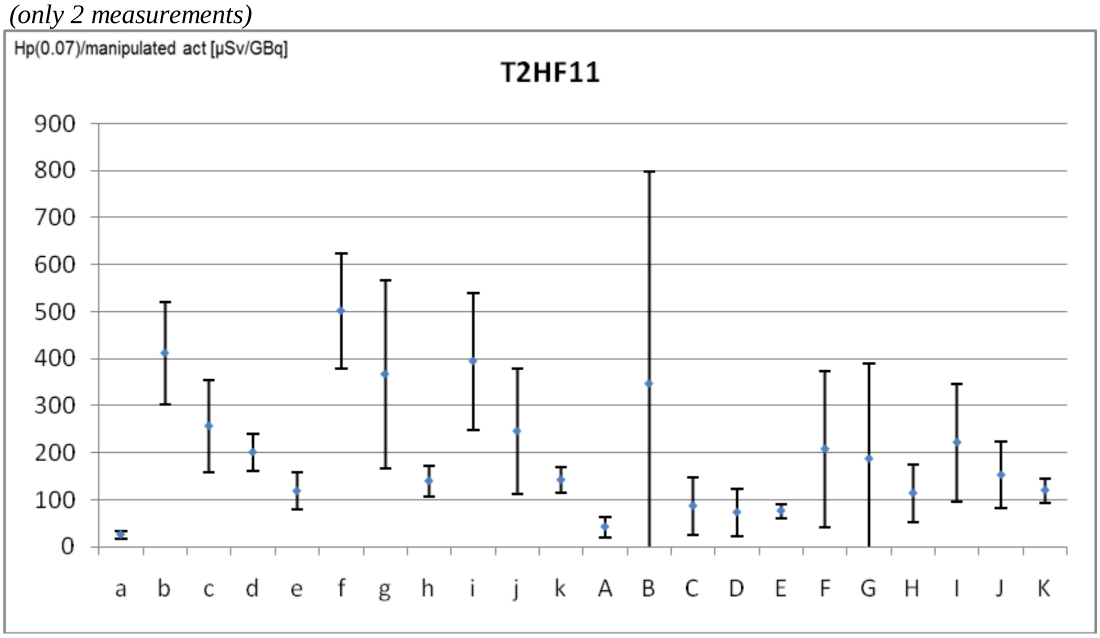
(only 2 measurements)



Worker T2HF11 : administration FDG

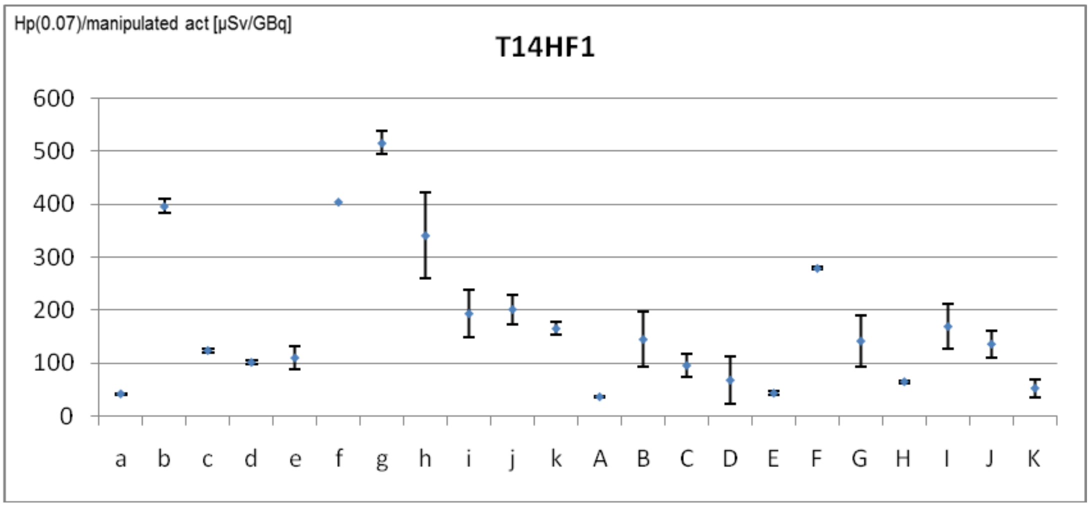
3years experience
Shieldings used : Syringe 5 mm Pb

(only 2 measurements)



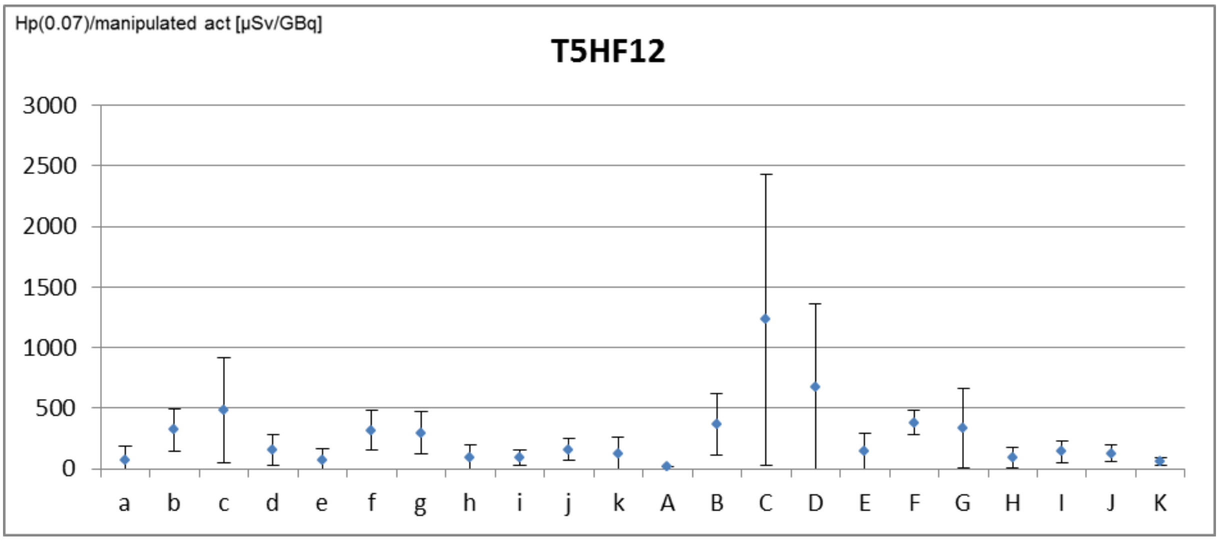
Worker T14HF1 : administration FDG

1.5 years experience
Shieldings used : Syringe ? mm W



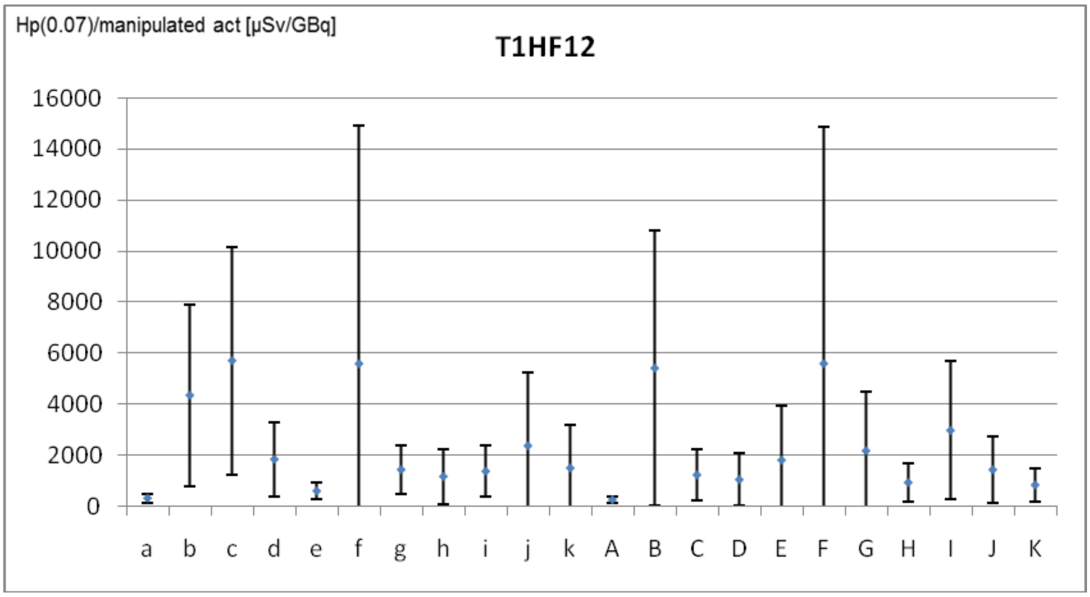
Worker T5HF12 : administration FDG

6 years experience
Shieldings used : Syringe 30 mm W



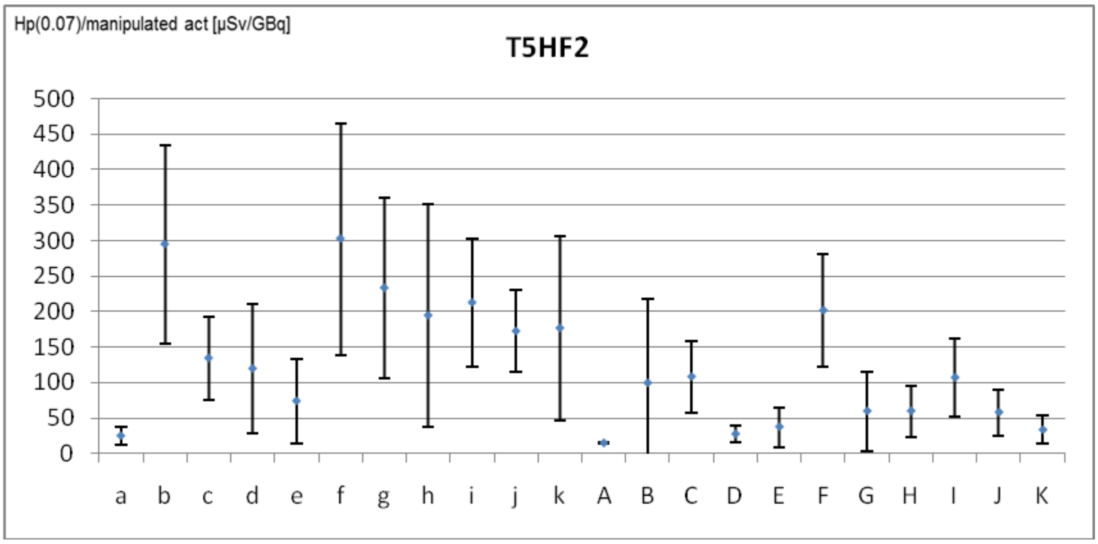
Worker T1HF12 : administration FDG

10 months experience
Shieldings used : Syringe 30 mm W



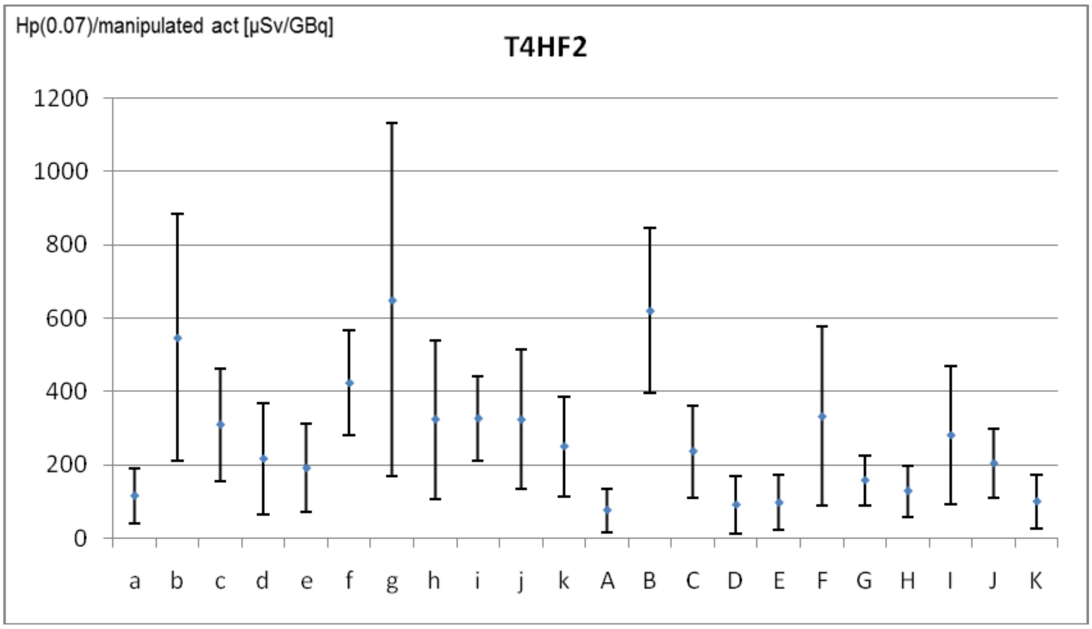
Worker T5HF2 : administration FDG

>5 years experience
Shieldings used : Syringe 5 mm W



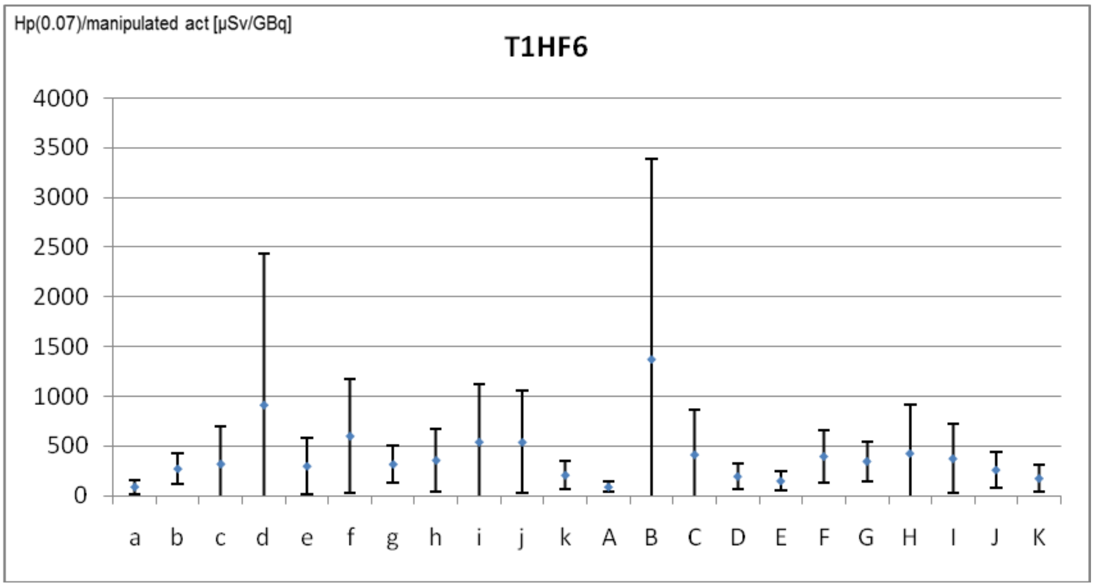
Worker T4HF2 : administration FDG

1? year experience
Shieldings used : Syringe 5 mm W



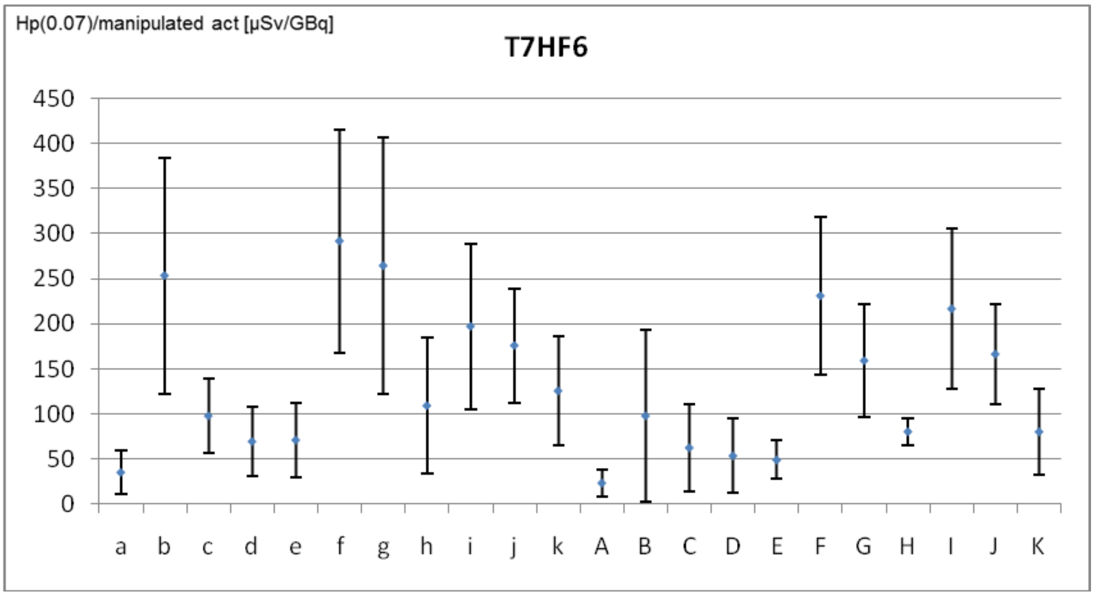
Worker T1HF6 : administration FDG

1 year experience
Shieldings used : Syringe 45 mm Pb



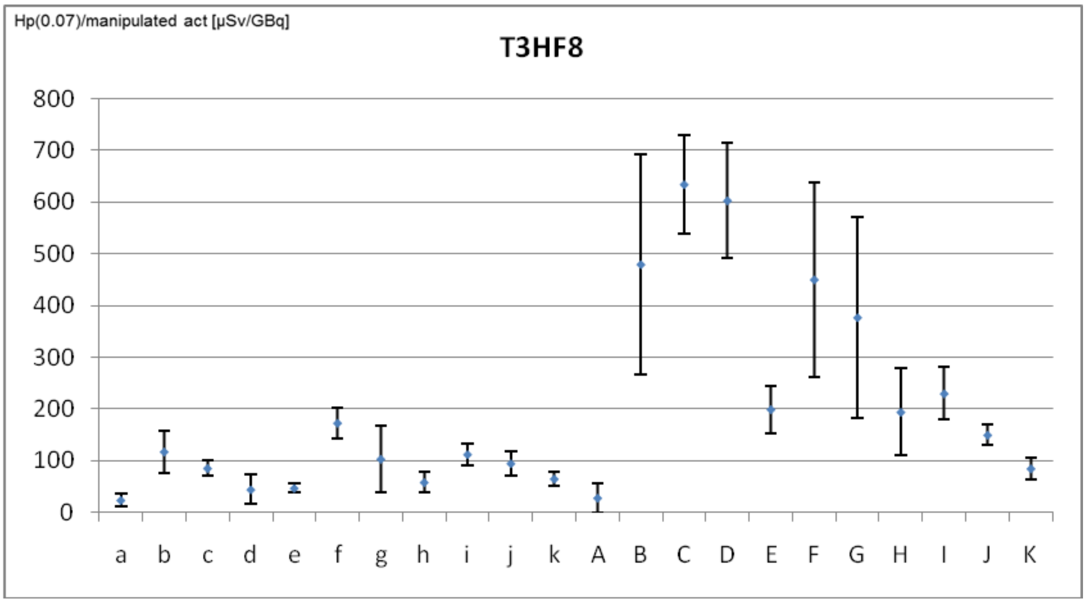
Worker T7HF6 : administration FDG

>5 years experience
Shieldings used : Syringe 45 mm Pb



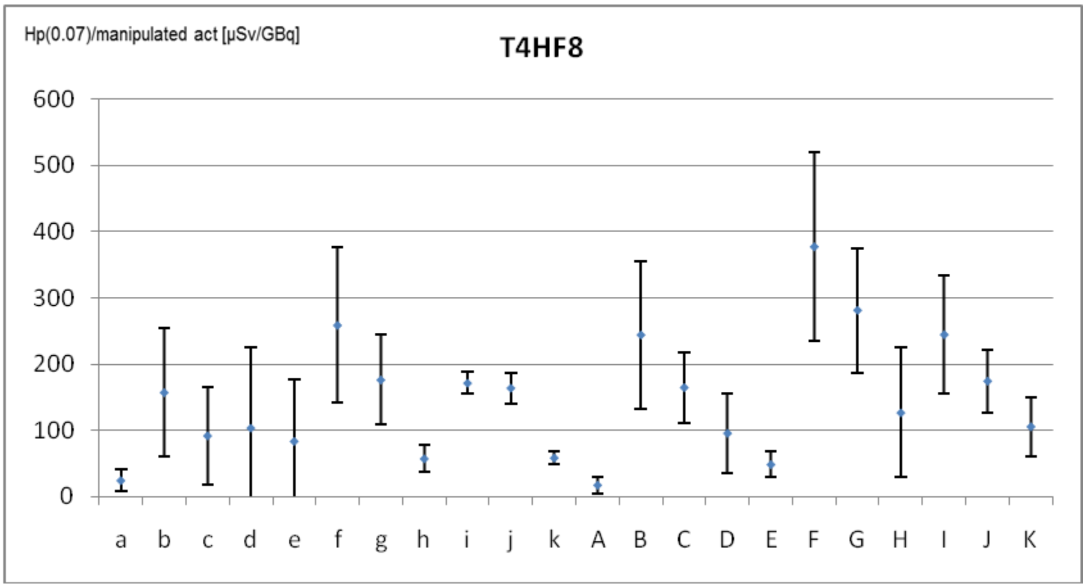
Worker T3HF8 : administration FDG

3 years experience
Shieldings used : Syringe 7 mm W



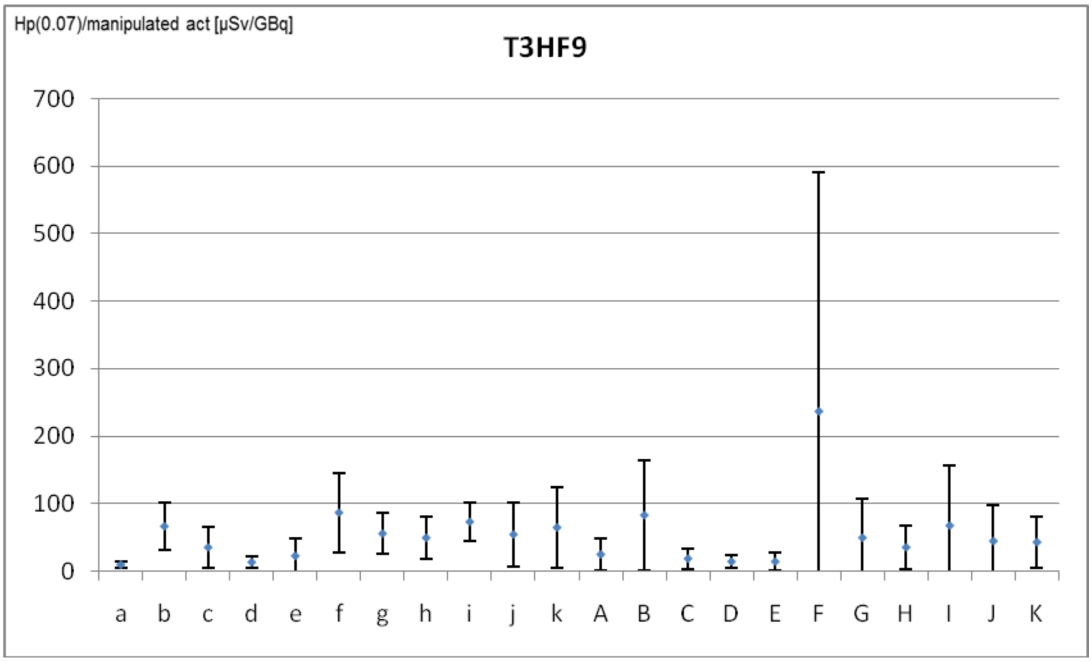
Worker T4HF8 : administration FDG

20 years experience
Shieldings used : Syringe 7 mm W



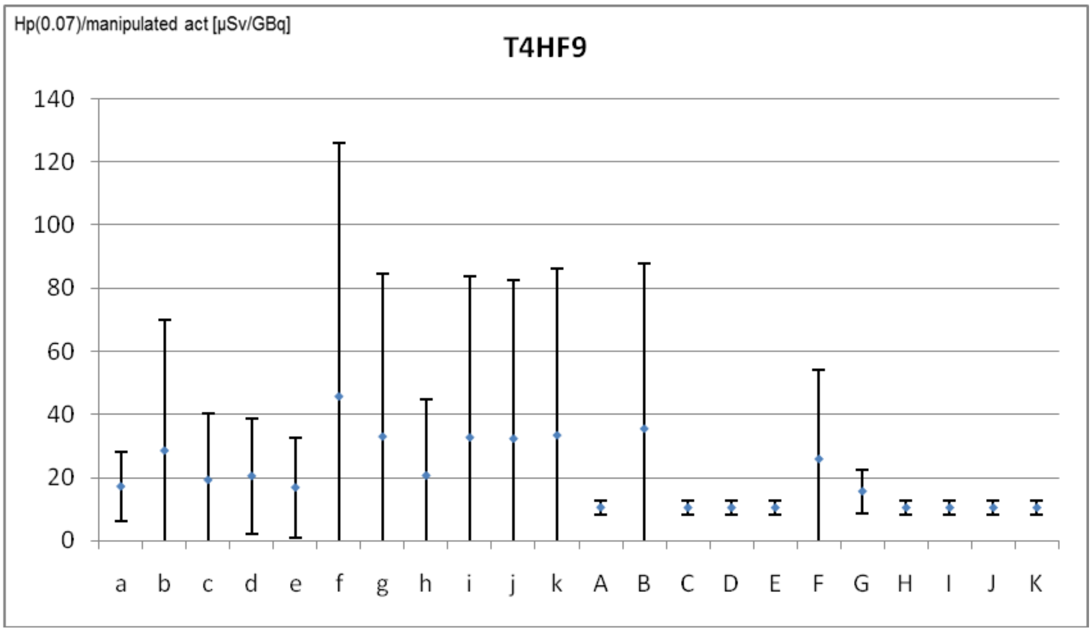
Worker T3HF9 : administration FDG

1 year experience
Shieldings used : Syringe 20 mm Pb



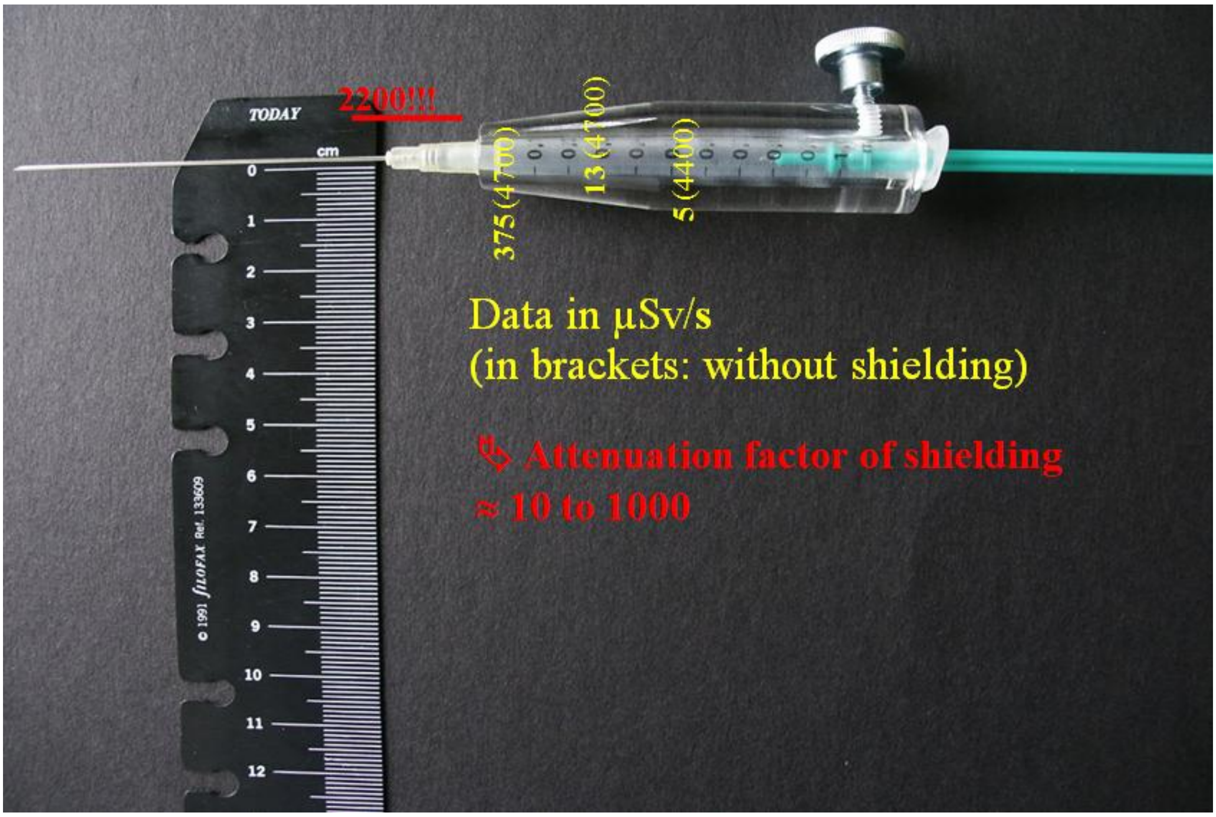
Worker T4HF9 : administration FDG

>5 years experience
Shieldings used : Syringe 20 mm Pb



Appendix D: Dose rate at the syringe and shielding (185 MBq Y^{90})

Courtesy of A. Rimpler and I. Barth (Bundesamt für Strahlenschutz (BfS), Berlin, Germany)



Appendix E : Overview of the annual doses to the extremities and for each operator

Worker	Radionuclide – Procedure	A manip/year (GBq)	Max dose (µSv/GBq)	position max	Estimation dose at ring non dom (mSv)	Estimation max annual dose (mSv)	% of annual limit considering only this radionuclide	Comments
T4HF2	FDG adm	37	649	g	7	24	5%	does only adm F^{18}
T5HF2	FDG prep	37	391	F	6	14	3%	left hosp 1 year ago
	FDG adm	37	302	f	3	11	2%	
T8HF2	FDG prep	370	851	I	114	315	63%	Prep Tc + does also Tc
T12HF2	Tc Adm	2590	60	f	10	154	31%	only adm Tc
T9HF2	Tc prep	2775	189	f	84	524	105%	Prep Tc + does also F^{18}
T10HF2	Tc Adm	2590	117	g	63	302	60%	only adm Tc
T11HF2	Tc Prep	2775	126	f	52	349	70%	Prep Tc + does also F^{18}
T1HF3	Tc prep Vials	888	184	F	24	163	33%	
	Tc prep Syr	672	66	I	6	44	9%	
	Tc Prep	888	754	b	48	670	134%	
	Tc adm	672	41	f	8	27	5%	
T1HF4	Tc prep Vials	2700	382	b	72	1587	317%	Point b >2 Sv
	Tc prep Syr	1200	588	b	42	458	92%	
	Tc Prep	2700	198	F	78	1587	317%	
	Tc adm	1200	37	f	9	44	9%	
T2HF4	Tc prep Vials	2700	208	i	64	561	112%	
	Tc prep Syr	1200	780	f	28	936	187%	
	Tc Prep	2700	829	f	124	995	199%	
	Tc adm	1200	111	f	15	133	27%	
T6HF7	Tc prep Vials	3000	49	I	33	147	29%	
	Tc prep Syr	1800	232	f	11	417	83%	
	Tc Prep	3000	244	f	110	733	147%	
T1HF7	Tc prep Vials	9000	25	f	20	222	44%	Point f =3 Sv !
	Tc prep Syr	5400	510	f	46	2754	551%	
	Tc Prep	9000	472	i	482	4248	850%	
T2HF7	Tc Adm	1200	29	b	5	35	7%	
T3HF7	Tc Adm	1200	120	f	21	144	29%	
T5HF7	FDG P+A posijet	36	36	J	0	1	0%	adm F^{18} + Tc ?
T4HF7	FDG P+A posijet	36	74	c	0	3	1%	adm F^{18} + Tc ?
T1HF11	FDG prep	108	2974	F	13	321	64%	
	FDG adm	108	564	f	14	61	12%	
T2HF11	FDG prep	108	2202	F	22	238	48%	
	FDG adm	108	722	B	13	78	16%	
T1HF6	Tc prep	266	629	f	3	168	34%	point B : 602 mSv
	Tc adm	371	938	B	3	348	70%	
	FDG prep	185	1709	f	34	316	63%	point f : 484 mSv
	FDG adm	185	1375	B	55	254	51%	
T2HF6	Tc prep	3130	517	f	67	1618	324%	Point f >1 Sv
	Zevalin	6	4748	h	3	31	6%	
	SIRS	51	107	i	1	5	1%	
T7HF6	FDG prep	185	885	b	20	164	33%	does also Tc adm
	FDG adm	185	292	f	13	54	11%	
T6HF6	Tc adm	371	360	B	4	134	27%	
T4HF1	FDG prep	246	726	f	58	178	36%	only F^{18} P
T10HF1	FDG prep	246	977	f	46	240	48%	does also Tc P
T14HF1	FDG adm	246	516	g	27	127	25%	does also Tc A
T11HF1	FDG adm	246	564	f	32	139	28%	does also Tc A
T1HF1	DOTATOC therapies	162	9387	f	134	1519	304%	since 2009 only Y90 dotatoc labeling no RP
		162	1716	F	19	278	56%	since 2009 only Y90 dotatoc labeling RP
T5HF12	FDG prep	37	239	g	2	9	2%	only F^{18}
	FDG adm	37	1233	C	3	46	9%	only F^{18}
T1HF12	FDG prep	37	4339	F	11	161	32%	only F^{18}
	FDG adm	37	5701	c	22	211	42%	only F^{18}