Project title: Radiation risk appraisal for detrimental effects from medical exposure during management of patients with lymphoma or brain tumour (SINFONIA)

Grant Agreement: 945196

Call identifier: NFRP-2019-2020

Topic: NFRP-2019-2020-14 Improving low-dose radiation risk appraisal in medicine

D3.6: Field survey of staff dosimetry practice in PT centers

Lead partner:	SCK CEN (3)
Author(s):	Marijke De Saint-Hubert, Alexandru Dasu, Lara Struelens
Work Package:	3
Delivery as per Annex I:	Month 18 (28.02.2022)
Actual delivery:	Month 20 (30.04.2022)
Type:	Report
Dissemination level:	Public

"This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945196"

Contents

1. Introduction

Deliverable 3.6 is part of Task 3.4. entitled ‘Staff doses in proton radiotherapy’, which is a task within WP3 on ‘Dose and risk assessment of staff, comforters, the public and the environment’.

The aim of this work was to collect data of staff exposure in proton therapy (PT), which is of concern due to the potential exposure of staff related to creation of high energy neutrons, which travel a long distance before depositing their dose, with high biological effectiveness. Moreover, activation of materials in proton therapy makes the technique subjected to fear and doubts related to the risks of staff. It is therefore essential to monitor neutrons on different positions around accelerator and to monitor staff accordingly.

Although dose monitoring of personnel is in place in proton therapy centers in accordance with national regulations, documentation of proton (PT) staff dosimetry data is limited, which further complicates addressing radiation protection concerns in daily practice across PT centers. Moreover, an in-depth knowledge on the detector response is needed to ensure accurate dose assessment. Not only the angular and energy response of detector systems is important, but it is also essential to know the dose-rate dependency of these detectors. In general, response data are not always known and/or not always considered in the calibration protocols. This can potentially lead to under- and overprotection of staff depending on their working environment and tasks (nurses, medical physicists, maintenance, and technical personnel).

In order to get a clear picture of the current practices and doses measured for staff in PT centers in Europe, we planned to execute a survey on the current doses and practices in European PT centers in relation to the following items:

- What type of personnel & ambient monitoring systems is used?
- Who is wearing dosemeters?
- Are neutron doses considered? And how is calibration performed (e.g., is energy and angular dependence considered?)

From this survey we will evaluate for which specific scenarios site-specific measurements and simulations have to be performed to allow for an accurate assessment of the neutron and total staff doses. Using survey results, SINFONIA will improve staff dosimetry in proton therapy and answer some essential questions in radiation protection of staff, including maintenance and technical personnel: a) are the concerns for pregnant women justly or exaggerated? b) should precautions and guidelines be followed more strictly in certain locations?

Finally, we will report on staff doses and set guidelines for different types of personnel (nurses, medical physicists, maintenance, and technical personnel) related to their exposures.

Table 1. Overview of EU PT centers addressed, and final responses received.

	COUNTRY	WHO, WHERE	Completed/ not completed
1	**Austria**	MedAustron, Wiener Neustadt	Completed
2	**Belgium**	UZ Leuven Particle Proton Center, Leuven	Completed
3	**Czech Republic**	PTC Czech r.s.o., Prague	Completed
4	**Denmark**	Dansk Center for Partikelterapi, Aarhus	Completed
5	**France**	CAL/IMPT, Nice	Completed
6	**France**	CPO, Orsay	Completed
7	**France**	CYCLHAD, Caen	Not completed
8	**Germany**	HZB, Berlin	Not completed
9	**Germany**	HIT, Heidelberg	Completed
10	**Germany**	WPE, Essen	Completed
11	**Germany**	UPTD, Dresden	Completed
12	**Germany**	MIT, Marburg	Not completed
13	**Italy**	INFN-LNS, Catania	Completed
14	**Italy**	CNAO, Pavia	Not completed
15	**Italy**	APSS, Trento	Completed
16	**Poland**	IFJ PAN, Krakow	Completed
17	**Spain**	Quironsalud PTC, Madrid	Completed
18	**Spain**	CUN, Madrid	Completed
19	**Sweden**	The Skandion Clinic,Uppsala	Completed
20	**Switzerland**	CPT, PSI, Villigen	Not completed
21	**The Netherlands**	UMC PTC, Groningen	Completed
22	**The Netherlands**	HollandPTC, Delft	Not completed
23	**The Netherlands**	ZON PTC, Maastricht	Completed

2. Methodology

All European proton therapy centers were asked to complete a survey (Table 1) on the current practice and doses measured for their staff. The survey was set-up using the LimeSurvey software tool provided by CESGA (CESGA is a SINFONIA partner) to allow for an online completion of the survey.

https://enquisas.cesga.es/index.php/734288?lang=en

The 1st page of the questionnaire included the following text:

This survey aims to document current staff doses and dosimetry practices in PT and report on the applied regulations for occupational exposures in PT centers.

Results of this questionnaire will be kept confidential and will be used to map staff doses and risks within PT. Moreover, we will compare occupational dosimetry practices between centers and assess radiation protection concerns. We will not share data with third-parties. An explicit question is raised before entering the survey to make sure they read the information and are eligible to complete the survey.

Clicking on the 'next' button indicates that:

- You have read the above information
- You voluntarily agree to participate
- You are at least 18 years of age

The survey (Annex 1) was organized in 5 parts as follows:

1) Which dosimeters are used to monitor staff in proton therapy?
   Provide options (TLD, OSLD, RPLD, Track detectors, Bubble detectors, …) and ask for specific manufacturer
   Information on calibration and detection limits

2) What type of personnel is wearing such a dosimeter and what is his/her dose received?
   a) Medical Physicist

b) Nurses
c) Caring staff
d) Medical Doctors from outside of PT center (e.g. anesthetists)
e) Cleaning personnel
f) Maintenance personnel
g) Radiation Oncologist
h) administrative personnel
i) other

From the above-mentioned personnel types we would like to know the typical range of doses on a yearly basis.

3) <u>Which types of ambient dose monitoring systems are used?</u>
   a) Fixed monitors
      i) Type and manufacturer
      ii) More information on calibration, detection limits etc.
      iii) Rooms monitored and sharing of dose records
   b) Transportable monitors
      (1) Type and manufacturer
      (2) More information on calibration, detection limits etc.

4) <u>Radiation protection regulations</u>
   a) Are visitors monitored and how is this organized?
   b) Are pregnant women able to continue their work and what is the regulation for pregnant staff?
   c) How was commissioning derived
   d) How are room doors controlled?

5) <u>Collaboration with the SINFONIA</u>
   a) Ask if and for what there is interest in SINFONIA project and if there is interest to host measurements/calculations to be performed within their PT center.

3. Timeline

The survey was sent to 24 EU-PT centers on **20-April-2021.** In the beginning, participation was limited mainly due to high workload of PT centers. In addition, covid crisis has impacted the centers' organization imposing new regulations and safety measures. Also, staff shortage made it difficult to reach the right people to fulfill the survey. Regular reminders were sent and a targeted approach was used to contact persons on an individual basis..

In **December 2021** the response rate was 66%. A final reminder was sent with a deadline **end of February 2022**, which resulted in few more responses. For this reason, an extension of 2 months was requested to write the final report of deliverable 3.6. **end of April 2022** (M20) instead of end of February 2022 (M18). Nevertheless, the delay of the deliverable has no impact on the work conducted in WP3 and task 3.4.

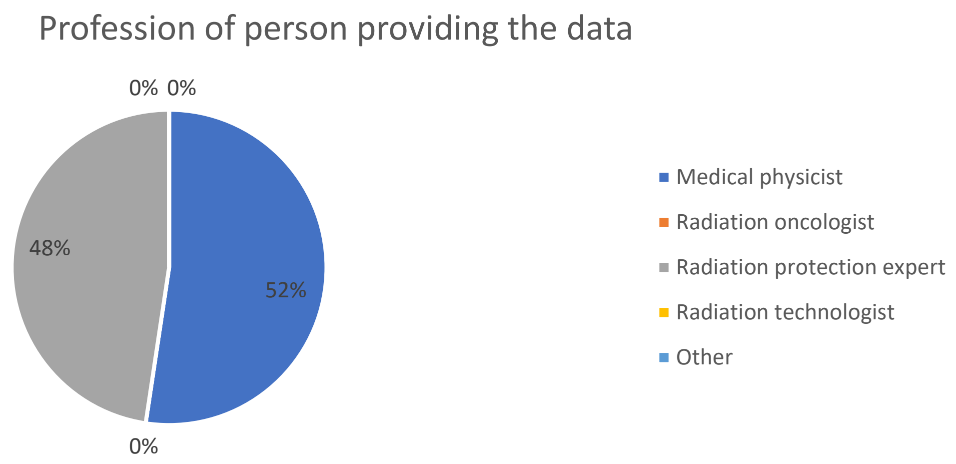
By the extended deadline, we received 17 responses . As RPTC Munich is not anymore operational today, we removed them from the list of proton therapy centers in Europe. In total 23 centers are operational and 17 centers replied to the survey, which resulted in a <u>74% response rate</u> to the survey (Table 1).

4. Results

1) Profession of person providing the data

Out of 17 responders, 52% were medical physicists and 48 %radiation protection experts. No oncologists or technologists responded.

Figure 1. 2D pie chart of the profession of person providing the data in the survey.



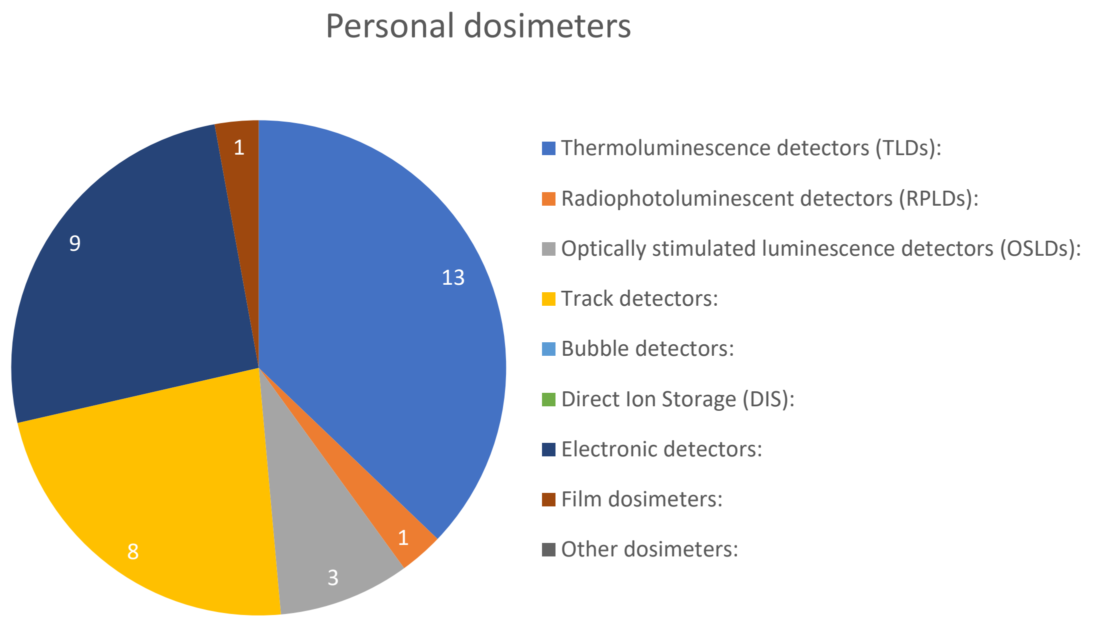
2) Which dosimeters are used to monitor staff in proton therapy?
   a) Detector types
      - Response showed that from the **luminescence detectors**, namely thermoluminescence detectors (TLDs), radiophotoluminescent detectors (RPLDs) and optically stimulated luminescence detectors (OSLDs) the mostly used are TLDs (Figure 2). Interestingly, at least one of these detector types were always used with 13, 1 and 3 centers using TLDs, RPLDs, and OSLDs respectively.
      - One group (Trento) is using TLDs as well as a **film dosimeter** (Tecnorad).
      - 2 centers indicated the use of **Albedo TLD** detectors (MedAustron and UPTDresden) which combines LiF-6 and LiF-7 type of TLDs with several combinations of filters, to account also for the neutron dose.
      - Besides that, almost half of the centers (8 out of 17) make use of **track detectors** to measure neutrons (see figure 2).
      - Therefore, we can conclude that in at least **10 out of the 17 centers neutrons are monitored** during the monitoring of their staff.
      - The use of **electronic detectors** is reported in 53% of centers, which is mostly used as alarm dosimeters or for information purposes besides the mandatory personalized staff monitoring systems.

   b) Detector calibration
      - **Dosimetric quantities** were always measured by a detector in Hp(10) quantity while also Hp(0.07) was measured in 77%, 37.5% and 66% for TLDs, track edge detectors and electronic dosimeters, respectively.
      - The **radiation quality** used for calibration depended largely on the detector type used. For TLDs mostly Cs-137 was used (54%) while Co-60 and Cf-252 were used in only 2 centers. In one case Cf-252 was combined with Cs-137 and in another it was combined with Cs-137 plus Co-60. The

radiation quality for track detectors was either not known/displayed (75%) or it was Cf-252 (25%). For electronic dosimeters the use of Cs-137 was again most prominent with 78% of centers versus 22% Co-60 while for 55% of centers this was combined with Am-Be, Sr90, Kr-85 and/or x-ray calibrations.

- Regarding **specific correction factors** in most cases the responding person did not know if corrections were applied for neutron energy or neutron angular distributions and mostly the corrections for background were mentioned here.

Figure 2. Pie chart of the detector types used to monitor staff in proton therapy centers.



3) Which type of personnel is wearing a dosimeter and what dose levels are measured?
   a) Figure 3 shows the different **types of personnel** wearing a detector. In almost all centers medical physicists are monitored as well as nurses while other staff taking care of the patient or administrative personnel are rarely monitored. Medical doctors and radiation oncologists are monitored in 58% and 70% of the centers respectively. In some centers it was reported that the decision to exclude these professional categories from systematic monitoring was taken after analyzing the risks to receive a significant dose. Cleaning personnel and maintenance personnel are monitored in 52% and 76% of centers respectively and some centers have indicated that these types of personnel are not managed by the clinic and, therefore, also dose records were not available.
   b) Figure 4 shows the **dose levels** measured in different types of personnel with 3 different categories: measurable dose, dose below limit or not known. In most cases, except for maintenance personnel, the dose levels were lower than detection limits. From the answers the individual doses provided by the centers, the doses, when measurable, were always below 1 mSv/year. No remarkable difference was observed between different types of staff and there was also no large difference observed between centers. This suggests that the center's practice to monitor staff (for example involving or not involving the monitoring of neutron contributions to the total dose), does not affect the final doses measured in staff. Overall, we can conclude that the staff doses measured in proton therapy are very low and there is little concern about their associated risks.

Figure 3. Bar plot of personnel wearing a dosimeter.

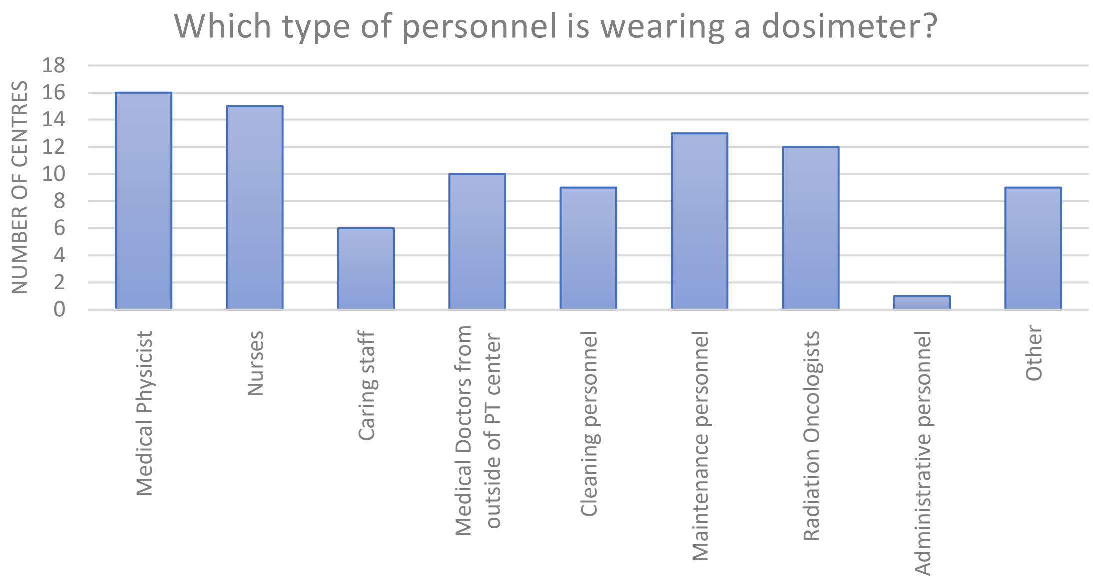
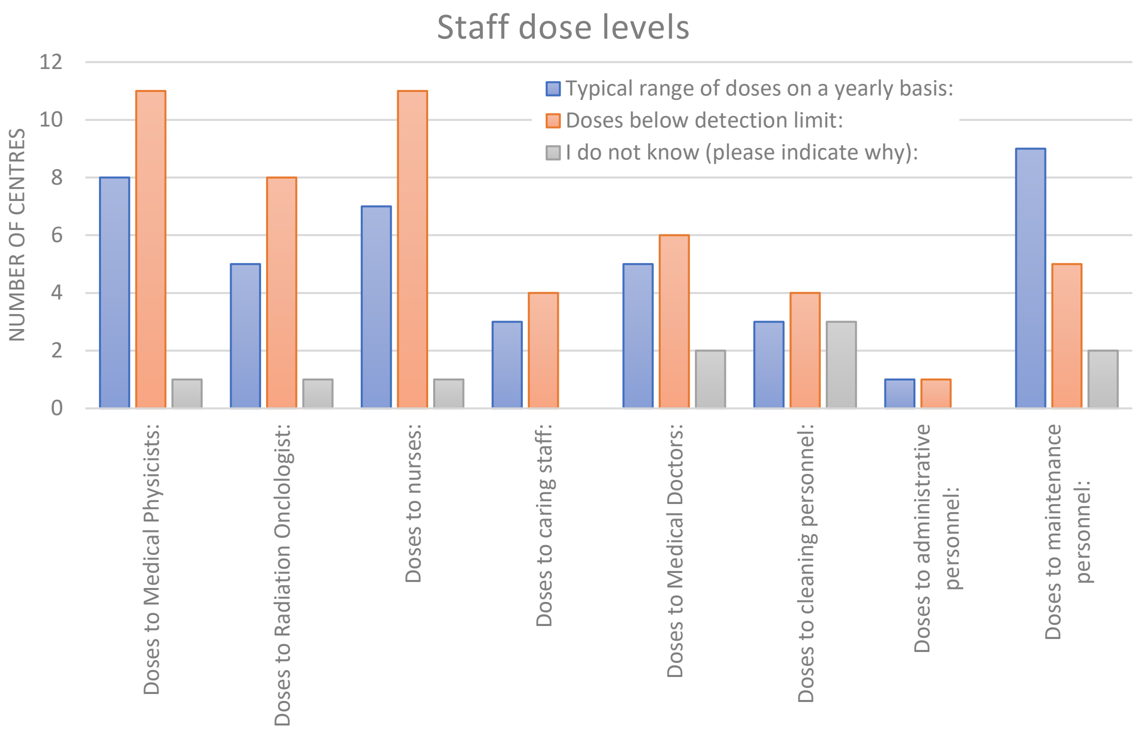


Figure 4. Dose levels measured in different types of personnel with 3 different categories: measurable dose, dose below limit or not known.

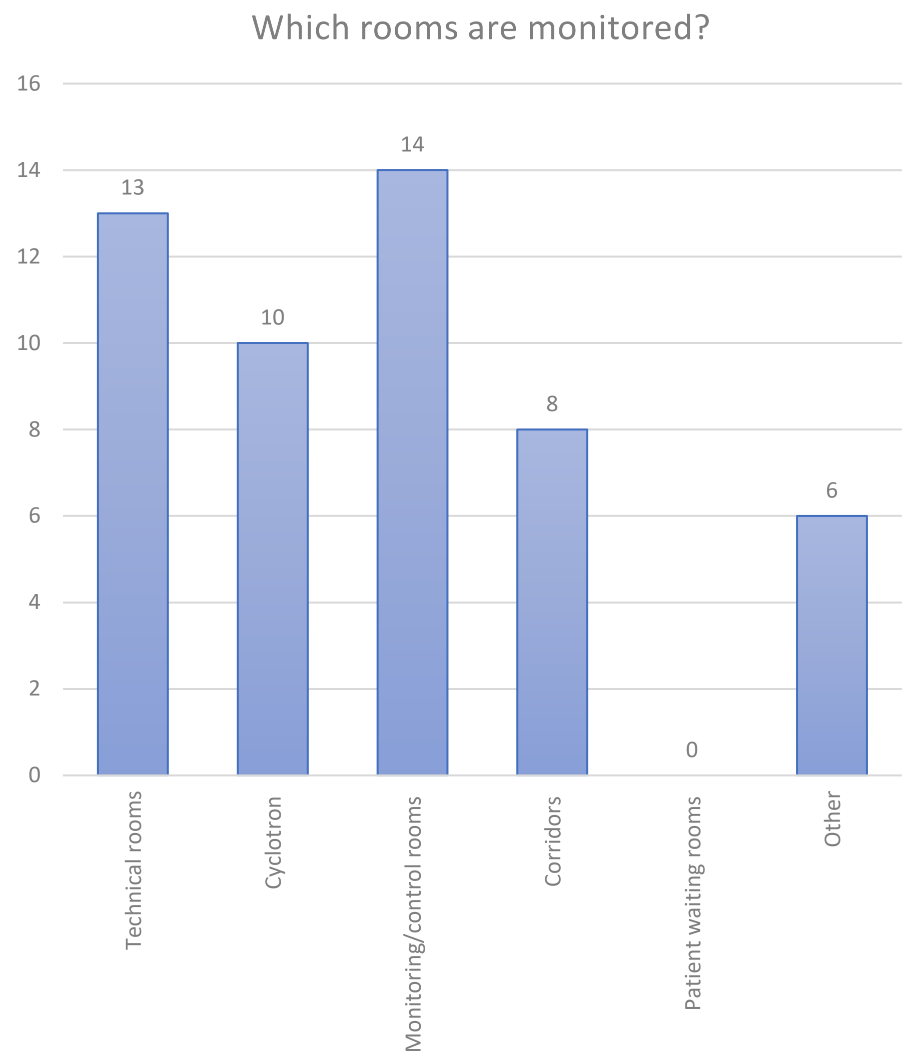


4) Which types of ambient dose monitoring systems are used?
   a) Fixed monitors
      i) Type and manufacturer:
         In table 2 an overview of responses to this question is shown providing information on the 17 centers and types of fixed ambient monitors used plus its manufacturer. In 3 centers no response is given, while only for one center it is clear this is because no fixed detectors are placed in their facility.
         Few centers use passive detector systems to monitor the ambient doses. For example, Skandion Clinic combines IPLUS and Neutrak to measure ambient doses in various locations while an active detector (FHT 6020) is used at the end of the beamline which also serves as a beam cutter when doses increase above certain fixed thresholds. Furthermore, the use of TLDs to monitor ambient doses has been reported from GPTC and MedAustron.
         When taking a closer look into the active detectors used in the PT centers, in many cases Berthold (indicated in green) systems are used as reported by 5 centers of various types. In MedAustron various types are used for neutrons (LB111, LB112 and LB6411-Pb) as well as gammas (LB6360-H10, LB6500-H10) while in Cyclotron Center Bronowice they use 2 types LB6411-Pb and LB6360 to monitor neutrons and gammas respectively. In other centers the specific type was not specified.
         On the other hand, 2 centers use Wendi's (indicated in red), from Thermo Fisher Scientic, which in one center is combined with Geiger Muller tubes. Finally in 3 centers Ludlum systems (indicated in blue) are used, as is the case in Essen (WPE), UZ Leuven (Particle) and Paris (Institut Curie).
      ii) More information on calibration, detection limits etc. showed that in most centers neutrons are considered when monitoring ambient doses in PT centers (2 did not answer while 15 answered positively to this question). The radiation quality of the calibration of these detectors was reported and revealed Cs-137 was mostly used (8 out of 14 reported) for calibration of gamma doses while for neutrons the use of Am-Be has been reported in almost half of the cases (6 out of 14 centers reported).
      iii) Rooms monitored and sharing of dose records
         Figure 5 shows which rooms are monitored by fixed ambient detectors which reveals that in almost all cases (13/14 reported) technical rooms and monitoring/ treatment control rooms are monitored. Cyclotron/accelerator vault and corridor monitoring is reported in fewer centers but still in more than half of the centers these areas are monitored. More specifically in 9 and 8 centers (out of 14 reported) monitors are placed close to cyclotron and corridor respectively. None of the centers reported to monitor the doses in patient waiting rooms.
         The following 6 centers inserted 'other' rooms were monitored:
         - MedAustron: Perimeter of Radiation Area, Air filters, Water filters, Ion sources, Loading Dock
         - WPE: treatment rooms
         - The Skandion Clinic: Treatment control rooms, Research area
         - IMPT Nice: treatment rooms/effluent (ventilation)
         - UPTD: treatment rooms

         Interestingly, some centers have reported monitoring the doses in treatment rooms, which is the case in all 6 centers.
         Finally, we asked whether the room maps can be shared (indicated where fixed monitors are placed in the facility) as well as dose records. Only 3 centers indicated they are willing to share room maps, and in the end no room maps have been shared. We also asked if dose records were available from fixed monitors, and responses showed more than half of the centers has records available (10 out of 17). Still no centers answered positively ('YES') to the question to share these

records while 8 centers mentioned they are 'MAYBE' willing to share them. It may be that the reluctance to share data from personal dosimetry may originate in other requirements on the handling of personal data after the implementation of GDPR.

Figure 5. The rooms/areas where fixed monitors are placed to monitor the ambient doses in PT centers.



b) Transportable monitors

(1) Type and manufacturer

Table 3 shows an overview of transportable monitors and the diversity of systems used. In many centers, systems are similar to the fixed ambient monitors described earlier.

Possible uses of the monitors include:

- Performing measurements for research
- Measuring activation/possible contamination and release in immobilization devices
- Commissioning of building by verifying the secondary radiation doses at the start of clinical operations.
- Periodic inspections
- Personnel exposure estimates
- Allowing access for unmonitored people when dose is <500nSv/h
- Monitor rooms that are not monitored with fixed detectors
- Replacement of fixed monitor (e.g., when broken or during maintenance)

Table 2. Overview of fixed ambient monitors and manufacturers of these monitors, listed for all 17 PT centers.

PT centers	Fixed ambient monitors	Manufacturer
MedAustron	LB111, LB112, LB6411-Pb, LB101beta, LB6360-H10, LB6500-H10, Yantar 2L (Seibersdorf Laboratories) TLDs for ambient dose monitoring (Seibersdorf Laboratories)	Berthold Technologies
WPE	M42-30 + 42-30H, M375	Ludlum, additionally glass dosimeter (MPA NRW)
The Skandion Clinic	IPLUS, Neutrak, FHT 6020	Landauer, Themo Scientific
Maastro Proton therapy	No response	No response
Cyclotron Center Bronowice	LB 6360 for gamma, LB 6411 for neutron	Berthold
INFN	Ionization chamber for x and gamma. Rem counter for neutrons	FAG, CENTRONICS, BERTHOLD
QUIRONSALUD	Neutron and Gamma detectors	Berthold
PTC Czech	Geiger counters, neutron detectors	VF Nuclear
IMPT Nice	neutron and gamma detector	Berthold / Novelec
Clínica Universidad de Navarra	Geiger Müller and neutron detectors	Thermo Scientific
Dansk Center for Partikelterapi	None are used	No response
GPTC	building specific TLD's at 4 locations	Mirion
Institut Curie	Gamma and neutrons	Rotem / Ludlum model 42-30H for neutrons and Rotem/Saphymo for gammas
APSS, Trento	No response	No response
HIT	Wendi Wide energy neutron detector	Thermo scientific
UPTD	Geiger Müller tubes, wide energy neutron detectors (Wendi)	Thermo Fisher Scientific
ParTiCLe	M375/9, M375/2, M375+133-2, M375+42-41L	Ludlum

Table 3. Overview of transportable ambient monitors and manufacturers of these monitors as well as their use, listed for all 17 PT centers

PT center	Type of transportable monitor	Manufacturer	Why used?
MedAustron	6105 AD6/E, 6150 AD-b/E, FH40-g-10, ToL/f, 6150 AD-t/E Teletector, LB123 UMO+LB1236-H-10, FHT762 WENDI II, LB123+LB6411-Pb, 6150 AD-k, LB9140, LB101d beta, InSpector1000	Automess, Automess, Thermo Scientific, Berthold Technologies, Automess, Berthold Technologies, Themo Scientific, Berthold Technologies, Automess, Berthold Technologies, Berthold Technologies, Canberra	Measurements
WPE	FH-40G + RadEye-20	Thermo Scientific + RadEye	release of immobilization devices, physics
The Skandion Clinic	451P, LB6411	Fluke Biomedical, Berthold Technologies	Monitoring gamma and neutron doserates on a need basis
Maastro Proton therapy	scinto gamma/x-ray detector	sea	checking activated parts
Cyclotron Center Bronowice	LUDLUM 14C for gamma, betas, NM 2B, WENDI for neutrons	LUDLUM	in case of damaged fixed monitor or to control activation of any elements
INFN	scintillators, geiger-mueller, ionization chamber, proportional counter, rem counter	various	
QUIRONSALUD	neutron and gamma	Berthold	Radioactive waste, check doses outside the maze
PTC Czech	N/A	Not answer	
IMPT Nice	Babyline/FH40/Minialarms/Studsvik digipig/FHT 762/Radeye B20ER/MIP10+SMIG	Nardeux / Wedholm Medical / APVL / Thermo /	photons/ beta / neutrons detection
Clínica Universidad de Navarra	Ionization chamber, scintillation, Geiger Müller, spectrometer	Fluke biomedical, Thermo Scientific, TRF	Measure instant gamma dose rate. Measure possible contaminations. Monitoring air and water activation.
Dansk Center for Partikelterapi	WENDI II, FH40G, RadEye B20-ER, RadEye PRD	Thermo Scientific	commissioning of secondary radiation doses in the building before clinical start, activation measurements, personal exposure estimates
GPTC	FHT 762 Wendi-2 Wide-Energy Neutron Detector	ThermoFisher	survey / monitoring in a mobile setting
Institut Curie	LB 123 Umo With LB6411 (for neutrons) and AT1123 for Gammas	Berthold and APVL	periodic inspection
APSS, Trento	Not answered	Not answer	
HIT	Wendi Wide energy neutron detector	Thermo scientific	after potential activation in the accelerator room/beam transfer lines
UPTD	GM-tube, wide energy neutron detector	Thermo Fisher Scientific	temporary cancelling of access restrictions for unmonitored people in areas with less than 500 nSv/h
ParTiCLe	not applicable	Not answer	

5) Specific radiation protection questions?

a) Are visitors monitored?

In most cases (10/17) the response was ‘YES’. Some (4/17) said it was done only sometimes, while only 2 responded ‘NO’. However, when we asked who is monitored as visitor, we did not get any response and so we cannot know if these visitors are parents accompanying their children or staff (from other institutes or other centers) .

b) Are pregnant women allowed to continue their work?

Most centers (8/17) answered ‘yes’ but performing specific tasks outside treatment areas. 3 centers answered that pregnant women were not able to continue their work. This means that in most cases (11/17) the work close to the treatment area was not allowed for pregnant women. Nevertheless, in 6/17 centers pregnant women are allowed to continue their work.

When asking centers about their specific regulation for pregnant women the following was answered:

- MedAustron: Access to radiation areas is forbidden
- WPE: no access to treatment rooms
- The Skandion Clinic: Doses to the foetus for the remainder of pregnancy not to exceed 1 mSv (according to national law on radiation protection from 2018).
- Maastro Proton therapy: alara
- INFN: national regulation
- QUIRONSALUD: Yes
- IMPT Nice: yes: annual dose limit 1mSv, excluded from the workstation if risk of internal contamination
- Clínica Universidad de Navarra: Yes
- Dansk Center for Partikelterapi: Pregnant physicists should not perform QA tasks that result in significant activation, pregnant radiation therapists should not handle the range shifter after treatment
- GPTC: Our staff is not considered to be radiological worker based on risk analysis - pregnant may not do certain tasks (e.g., administer PET isotopes), but that is not relevant at our proton facility
- Institut Curie: Yes, on the advice of the doctor after a medical visit
- APSS, Trento: pregnant staff cannot enter classified area according to Italian regulation
- UPTD: Many, according to German law, i.e., Strahlenschutzgesetz and Strahlenschutzverordnung
- ParTiCLe: Not in controlled or supervised areas

c) How was commissioning derived?

As shown in figure 6 in most cases (8/17) commissioning was based on both dosimetric measurements and Monte Carlo simulations. Only in 5 centers the commissioning was based on measurements while no commissioning was based only on Monte Carlo simulations.

d) Are treatment room doors controlled and unlocked following a certain cut-off dose/time following radiation?

The answers to this question revealed that only few centers (3 centers), namely MedAustron, Maastro and Cyclotron Center Bronowice have such control systems at their doors. All other centers 13/17 said there is no such control system at their doors.

e) Would you consider collaboration within SINFONIA project?

Interestingly only 1 center, namely HIT answered ‘NO’ to this question while the other answers revealed that half of the participants answered ‘YES’ and the other half ‘MAYBE’ to collaborate. The interest to collaborate in the SINFONIA project is depicted in figure 7.

More detailed answered were derived from

- Dansk Center for Partikelterapi: Research - high dose rates in FLASH
- Dansk Center for Partikelterapi Radiation protection concern - pregnant patients, pacemaker, implants
- GPTC: Measurements - yearly ambient dose outside the facility

Figure 6. Plot showing how commissioning was derived in PT centers.

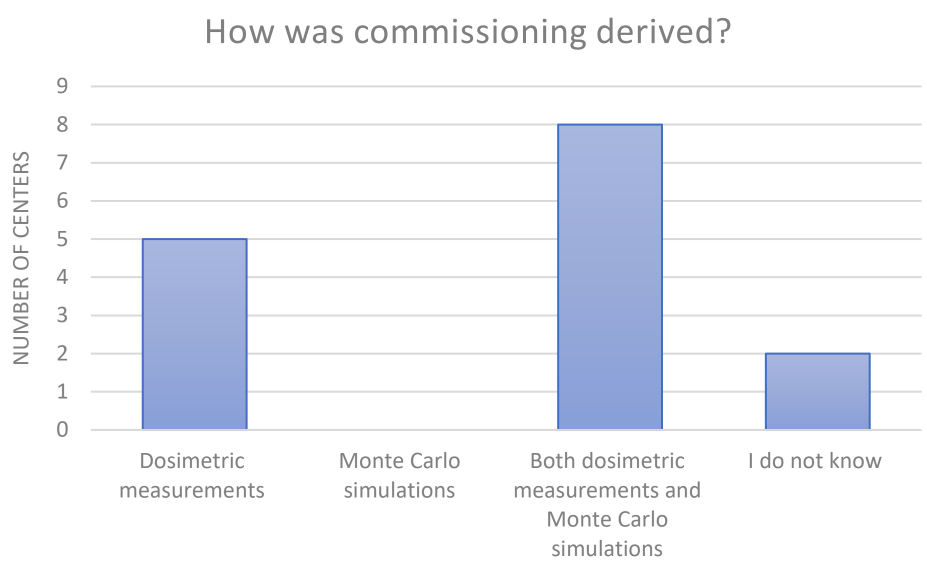
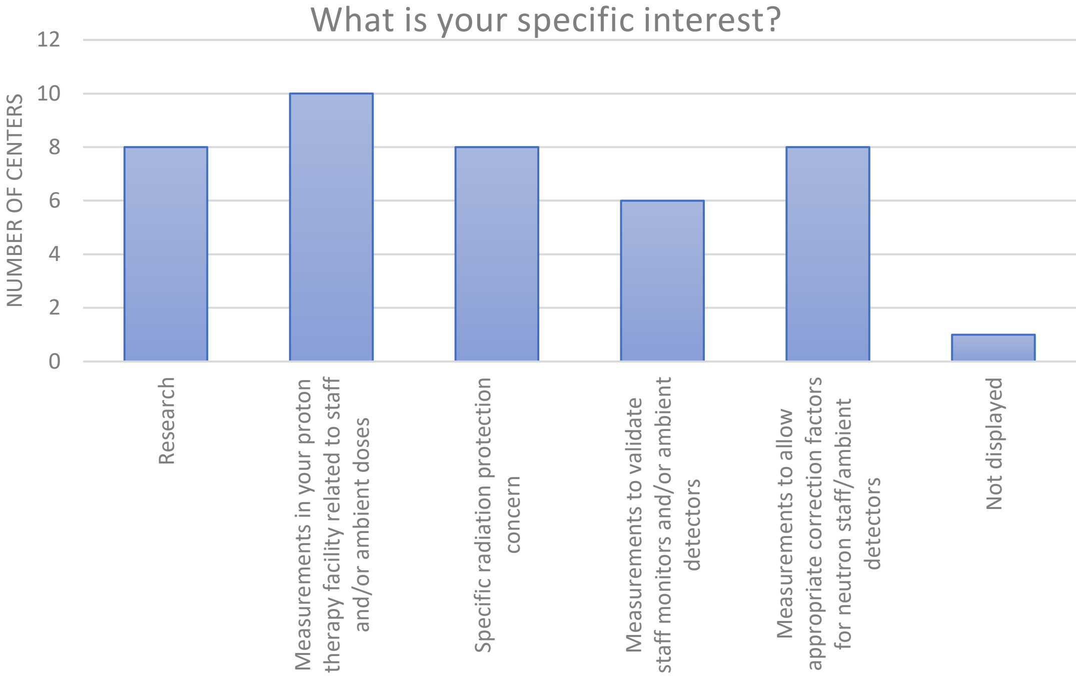


Figure 7. Specific interest to collaborate within the SINFONIA project.



5. Conclusions

This survey revealed that radiation protection practices in line with national recommendations are in place at all sites. In addition, doses to staff working in proton therapy centers are very low (<1 mSv/year) and therefore risk related effects of radiation to this staff population are not expected.

What is reassuring is that neutrons are considered for personnel monitoring. In case of personnel monitoring systems, the use of track detectors was reported by almost half of the centers and the use of TLD combinations to detect neutrons was described for another 2 centers. As such, staff monitoring considered neutrons in more than half of the centers. Interestingly, this did not result in significant differences between centers, as doses were very low and close to the detection limits. Again, this reveals that the risks to staff working in proton therapy centers are very low. We also believe that the most important personnel groups are monitored involving the people working very close to the treatment rooms (medical physicists and nurses) as well as to the accelerator (maintenance personnel).

Even though we were not able to retrieve dose reports from ambient monitors, we noticed that almost all centers have fixed monitoring systems on site. In almost all cases, the ambient monitor system(s) were able to monitor both neutrons and gammas. Still, it is not clear from the survey how the response is of these detectors in the specific locations and whether corrections were applied for the local neutron spectra. As several different types of detectors were used for neutron monitoring (Berthold, WENDI-2, Ludlum), all having a characteristic response to neutron/gamma energy and angle, it may be interesting to verify this in more depth and make sure appropriate correction factors are applied (see section 6 on ‘future steps’).

In the centers with fixed monitors, a number of rooms are monitored and important locations such as technical rooms (can be close to the treatment room/cyclotron) and accelerator are part of the monitored areas. Moreover, the use of transportable detectors for activation of materials is considered in many centers as an important radiation protection concern. Furthermore, these detectors are important for many other applications, which involved radiation protection concerns. This is usually for situations such as for granting non-monitored people access to specific areas of the facility, monitoring non controlled rooms as well as for commissioning of the PT facility.

Overall, the outcome of the survey is not increasing the concern of risk for staff working in proton therapy. On the contrary, the results demonstrate that the current classification may be too strict, as doses were never exceeding 1 mSv/year. This could suggest it is possible to sample staff monitoring, which will requires only few people to be monitored. A similar approach is already done in some countries for staff working in External Beam RadioTheray (EBRT), which perhaps could be also applied for personnel working in PT centers. This can be achieved by following a dialogue with the national radiation protection authority, but it may be a bit controversial as the concern of secondary neutrons and activation during PT treatments has always triggered attention towards radiation protection of staff and patients.

Also, for pregnant women our data suggest that the risk of being exposed during their work is very low. Still in some centers pregnant women are not allowed to retain their duties. Nevertheless, to keep ALARA principles these people may be allowed to work in daily clinical practice but for example avoid performing some clinical and QA tasks, as is the case already in some centers.

This survey also showed that for many centers the commissioning was done through both measurements and Monte Carlo (MC) and none of the commissioning procedures of the facilities were based purely on MC simulations. A limitation of MC calculations is that they depend on the level of detail the facility is modelled as well as on the code used and how neutrons are modelled within the code. Therefore, MC calculations always need to be validated with measurements, which is done in most centers.

6. Future steps within SINFONIA

As mentioned in the previous section, the survey revealed that the current practice in PT centers to monitor staff is rather satisfying and there are no major radiation protection concerns. Besides the fact that there is little concern about doses measured in PT centers, there is a lot of interest of the participants to collaborate within SINFONIA. The exact reason to collaborate however remained rather vague as the response to this question was quite broad and not very specific.

We also noted that there is a diversity of detector systems as well as various locations in which staff and ambient doses are monitored. This implies that detector systems will be exposed to varying energy and angular distributions of neutrons and gammas, for which, depending on their angular and energy response, corrections may need to be applied. Correcting for the detector response is not done in many PT centers and definitely not the use of local correction factors, which require an in-depth knowledge of the radiation field in certain location of the center and detector response.

As mentioned in the introduction of this report, a key step in this goal to improve accuracy of the dose assessment, is to have an in-depth knowledge on the detector response. Not only the angular and energy response of detector systems is important, it is also essential to know the dose-rate dependency of these detectors. A recent publication showed that commercial rem counters may underestimate H*(10) quantities by a factor of 2 to more than 10 when measuring ambient doses in Mevion S250i Hyperscan synchrocyclotron which is delivered in pulses with a pulse width of 10 µs at 750 Hz frequency (Zorloni, Bosmans et al. 2022). The discrepancies were mostly because of dead time losses and depended on the rem-counter model and neutron dose per pulse (DPP). In this study a DPP of 200nSv/pulse was measured which is too high for commercial rem counter while LUPIN (Long interval, Ultra-wide dynamic range, pile-up free, Neutron rem-counter) is able to accurately assess the doses within 20% (Zorloni, Bosmans et al. 2022). In the studied Mevion systems it is well known that the neutron dose is higher than in other systems, such as IBA, and therefore the issue of underestimating the dose might be even more relevant compared to other systems.

Besides the detector response, it is important to have a priori knowledge on the proton therapy delivery system, including details of the time structure of the beam. Therefore, one of the next steps we will take within SINFONIA will be to closer investigate the systems in Europe with a high pulse frequency for which dose rate, energy and angular distributions may have the highest influence. We will therefore approach the participants from the survey to find the centers who are interested to host measurements. We will also explore the possibility to test our detector systems in FLASH proton therapy and gather information about which centers have the possibilities to perform FLASH treatments. This will involve even higher dose rates with even more challenges related to accurate measurement of stray radiation doses. An intercomparison of different detector systems could be considered within SINFONIA. We envisage testing detector systems through collaborations (LUPIN – CERN, Ludlum UZ Leuven) or within our institutes (SCK CEN/SKANDION) such as WENDI-2, Berthold but also passive systems (track detectors, Bubble detectors, TLDs, OSLDs) could be explored. Such an intercomparison of various detectors will allow to investigate the accuracy of detector systems available and used for monitoring ambient and personnel doses. We believe this step is important to make sure the deviations are acceptable, definitely when high dose rates are being used. These data will allow to validate current neutron dose measurements and simulations performed for clinical operations which will be a reassurance that the performed measurements and calculations are still valid.

7. Annexes

Annex 1: Online Survey

SINFONIA - Staff dosimetry in Proton Therapy

Dear colleague,

This survey aims to document current staff doses and dosimetry practices in Proton Therapy (PT) and report on the applied regulations for occupational exposures in PT centers. Moreover, this questionnaire invites PT centers to collaborate within the SINFONIA project. SINFONIA project is a four-year research project funded by EURATOM research and training program 2019-2020. It aims at developing tools for comprehensive risk appraisal for detrimental effects of radiation exposure on patients, workers, carers and comforters, the public and the environment.

The survey is conducted by the Belgian nuclear research center, SCK CEN, and targets radiation protection officers or other employees responsible for occupational exposures in their center.

Results of this questionnaire will be kept confidential and will be used to map staff doses and risks within PT. Moreover, we will compare occupational dosimetry practices and assess radiation protection concerns. We will not share data with third parties.

Clicking on the 'next' button indicates that:

You have read the above information

You voluntarily agree to participate

You are at least 18 years of age

There are 75 questions in this survey.

Name of the proton therapy center: *

Please write your answer here:

Name of the person providing the data: *

Please write your answer here:

E-mail of the person providing the data: *

Please check the format of your answer.

Please write your answer here:

Profession of the person providing the data:

*

Check all that apply

Please choose **all** that apply:

Medical physicist

Radiation oncologist

Radiation protection expert

Radiation technologist

Other:

Which personal dosimeter types are used to monitor staff?

(add specific type in text box)

*

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Thermoluminescence detectors (TLDs):

Radiophotoluminescent detectors (RPLDs):

Optically stimulated luminescence detectors

(OSLDs):

Track detectors:

Bubble detectors:

Direct Ion Storage (DIS):

Electronic detectors:

Film dosimeters:

Other dosimeters:

<u>TLD dosimeter information:</u>

Only answer this question if the following conditions are met:

Answer was at question '5 [E1]' (Which personal dosimeter types are used to monitor staff? (add specific type in text box))

<u>TLD calibration information</u>

Dosimetric quantity:

Only answer this question if the following conditions are met:

((E1_SQ001.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Hp(10)

Hp(0.07)

Hp(3)

Other:

Calibration radiation quality:

Only answer this question if the following conditions are met:

((E1_SQ001.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Other:

Specific corrections applied:

Only answer this question if the following conditions are met:

((E1_SQ001.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Neutron energy

Neutron angular distribution

I do not know

Other:

RPL dosimeter information:

Only answer this question if the following conditions are met:

Answer was at question '5 [E1]' (Which personal dosimeter types are used to monitor staff? (add specific type in text box))

RPL calibration information

Dosimetric quantity:

Only answer this question if the following conditions are met:

((E1_SQ002.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Hp(10)

Hp(0.07)

Hp(3)

Other:

Calibration radiation quality:

Only answer this question if the following conditions are met:

((E1_SQ002.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Other:

Specific corrections applied:

Only answer this question if the following conditions are met:

((E1_SQ002.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Neutron energy

Neutron angular distribution

I do not know

Other:

OSL dosimeter information:

Only answer this question if the following conditions are met:

Answer was at question '5 [E1]' (Which personal dosimeter types are used to monitor staff? (add specific type in text box))

OSL calibration information

Dosimetric quantity:

Only answer this question if the following conditions are met:

((E1_SQ010.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Hp(10)

Hp(0.07)

Hp(3)

Other:

Calibration radiation quality:

Only answer this question if the following conditions are met:

((E1_SQ010.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Other:

Specific corrections applied:

Only answer this question if the following conditions are met:

((E1_SQ010.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Neutron energy

Neutron angular distribution

I do not know

Other:

Track detector information:

Only answer this question if the following conditions are met:

Answer was at question '5 [E1]' (Which personal dosimeter types are used to monitor staff? (add specific type in text box))

Track detector calibration information

Dosimetric quantity:

Only answer this question if the following conditions are met:

((E1_SQ003.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Hp(10)

Hp(0.07)

Hp(3)

Other:

Calibration radiation quality:

Only answer this question if the following conditions are met:

((E1_SQ003.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Other:

Specific corrections applied:

Only answer this question if the following conditions are met:

((E1_SQ003.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Neutron energy

Neutron angular distribution

I do not know

Other:

Bubble detector information:

Only answer this question if the following conditions are met:

Answer was at question '5 [E1]' (Which personal dosimeter types are used to monitor staff? (add specific type in text box))

Bubble detector calibration information

Dosimetric quantity:

Only answer this question if the following conditions are met:

((E1_SQ004.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Hp(10)

Hp(0.07)

Hp(3)

Other:

Calibration radiation quality:

Only answer this question if the following conditions are met:

((E1_SQ004.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Other:

Specific corrections applied:

Only answer this question if the following conditions are met:

((E1_SQ004.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Neutron energy

Neutron angular distribution

I do not know

Other:

Direct Ion Storage (DIS) dosimeter information:

Only answer this question if the following conditions are met:

Answer was at question '5 [E1]' (Which personal dosimeter types are used to monitor staff? (add specific type in text box))

Direct Ion Storage (DIS) calibration information

Dosimetric quantity:

Only answer this question if the following conditions are met:

((E1_SQ005.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Hp(10)

Hp(0.07)

Hp(3)

Other:

Calibration radiation quality:

Only answer this question if the following conditions are met:

((E1_SQ005.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Other:

Specific corrections applied:

Only answer this question if the following conditions are met:

((E1_SQ005.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Neutron energy

Neutron angular distribution

I do not know

Other:

Electronic dosimeters information:

Only answer this question if the following conditions are met:

Answer was at question '5 [E1]' (Which personal dosimeter types are used to monitor staff? (add specific type in text box))

Electronic dosimeter calibration information

Dosimetric quantity:

Only answer this question if the following conditions are met:

((E1_SQ006.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Hp(10)

Hp(0.07)

Hp(3)

Other:

Calibration radiation quality:

Only answer this question if the following conditions are met:

((E1_SQ006.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Other:

Specific corrections applied:

Only answer this question if the following conditions are met:

((E1_SQ006.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Neutron energy

Neutron angular distribution

I do not know

Other:

Film dosimeter information:

Only answer this question if the following conditions are met:

Answer was at question '5 [E1]' (Which personal dosimeter types are used to monitor staff? (add specific type in text box))

Film dosimeter calibration information

Dosimetric quantity:

Only answer this question if the following conditions are met:

((E1_SQ009.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Hp(10)

Hp(0.07)

Hp(3)

Other:

Calibration radiation quality:

Only answer this question if the following conditions are met:

((E1_SQ009.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Other:

Specific corrections applied:

Only answer this question if the following conditions are met:

((E1_SQ009.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Neutron energy

Neutron angular distribution

I do not know

Other:

Other dosimeter information:

Only answer this question if the following conditions are met:

Answer was at question '5 [E1]' (Which personal dosimeter types are used to monitor staff? (add specific type in text box))

Other dosimeter calibration information

Dosimetric quantity:

Only answer this question if the following conditions are met:

((E1_SQ007.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Hp(10)

Hp(0.07)

Hp(3)

Other:

Calibration radiation quality:

Only answer this question if the following conditions are met:

((E1_SQ007.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Other:

Specific corrections applied:

Only answer this question if the following conditions are met:

((E1_SQ007.NAOK == "Y"))

Check all that apply

Please choose **all** that apply:

Neutron energy

Neutron angular distribution

I do not know

Other:

Which type of personnel is wearing a dosimeter? *

Check all that apply

Please choose **all** that apply:

Medical Physicist

Nurses

Caring staff

Medical Doctors from outside of PT center (e.g. anesthetists)

Cleaning personnel

Maintenance personnel

Radiation Oncologists

Administrative personnel

Other:

Doses to Medical Physicists: *

Only answer this question if the following conditions are met:

Answer was at question '42 [E2]' (Which type of personnel is wearing a dosimeter?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Typical range of doses on a yearly basis:

Doses below detection limit:

I do not know (please indicate why):

Doses to Radiation Onclologist:

Only answer this question if the following conditions are met:

Answer was at question '42 [E2]' (Which type of personnel is wearing a dosimeter?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Typical range of doses on a yearly basis:

Doses below detection limit:

I do not know (please indicate why):

Doses to nurses:

Only answer this question if the following conditions are met:

Answer was at question '42 [E2]' (Which type of personnel is wearing a dosimeter?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Typical range of doses on a yearly basis:

Doses below detection limit:

I do not know (please indicate why):

Doses to caring staff:

Only answer this question if the following conditions are met:

Answer was at question '42 [E2]' (Which type of personnel is wearing a dosimeter?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Typical range of doses on a yearly basis:

Doses below detection limit:

I do not know (please indicate why):

Doses to Medical Doctors:

Only answer this question if the following conditions are met:

Answer was at question '42 [E2]' (Which type of personnel is wearing a dosimeter?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Typical range of doses on a yearly basis:

Doses below detection limit:

I do not know (please indicate why):

Doses to cleaning personnel:

Only answer this question if the following conditions are met:

Answer was at question '42 [E2]' (Which type of personnel is wearing a dosimeter?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Typical range of doses on a yearly basis:

Doses below detection limit:

I do not know (please indicate why):

Doses to administrative personnel:

Only answer this question if the following conditions are met:

Answer was at question '42 [E2]' (Which type of personnel is wearing a dosimeter?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Typical range of doses on a yearly basis:

Doses below detection limit:

I do not know (please indicate why):

Doses to maintenance personnel:

Only answer this question if the following conditions are met:

Answer was at question '42 [E2]' (Which type of personnel is wearing a dosimeter?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Typical range of doses on a yearly basis:

Doses below detection limit:

I do not know (please indicate why):

When dose is below detection limit, specify detection limit:

Only answer this question if the following conditions are met:

-------- Scenario 1 --------

Answer was at question '43 [G1]' (Doses to Medical Physicists:)

-------- or Scenario 2 --------

Answer was at question '44 [G4]' (Doses to Radiation Onclologist:)

-------- or Scenario 3 --------

Answer was at question '45 [G5]' (Doses to nurses:)

-------- or Scenario 4 --------

Answer was at question '46 [G2]' (Doses to caring staff:)

-------- or Scenario 5 --------

Answer was at question '47 [G3]' (Doses to Medical Doctors:)

-------- or Scenario 6 --------

Answer was at question '48 [G7]' (Doses to cleaning personnel:)

-------- or Scenario 7 --------

Answer was at question '50 [G8]' (Doses to maintenance personnel:)

-------- or Scenario 8 --------

Answer was at question '49 [G6]' (Doses to administrative personnel:)

Please write your answer here:

Fixed ambient monitors

Calibration information of fixed monitors

Calibration radiation quality:

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Other:

Dosimetric quantity:

Check all that apply

Please choose **all** that apply:

H*(10)

Other:

Are neutrons considered?

Choose one of the following answers

Please choose **only one** of the following:

Yes

No

I do not know

Are gammas considered?

Choose one of the following answers

Please choose **only one** of the following:

Yes

No

I do not know

Which rooms are monitored

Check all that apply

Please choose **all** that apply:

Technical rooms

Cyclotron

Monitoring rooms

Corridors

Patient waiting rooms

Other:

Are you willing to share room maps indicating positions of ambient dose monitors?

Check all that apply

Please choose **all** that apply:

Yes

No

Maybe

Upload room maps:

Only answer this question if the following conditions are met:

Answer was at question '58 [L]' (Are you willing to share room maps indicating positions of ambient dose monitors?)

Please upload at most one file

Kindly attach the aforementioned documents along with the survey

Are dose records available?

Check all that apply

Please choose **all** that apply:

Yes

No

Maybe

Are you willing to share dose records?

Only answer this question if the following conditions are met:

-------- Scenario 1 --------

Answer was at question '60 [J]' (Are dose records available?)

-------- or Scenario 2 --------

Answer was at question '60 [J]' (Are dose records available?)

Check all that apply

Please choose **all** that apply:

Yes

No

Maybe

Upload dose records:

Only answer this question if the following conditions are met:

Answer was at question '61 [K]' (Are you willing to share dose records?   )

Please upload at most one file

Kindly attach the aforementioned documents along with the survey

<u>Transportable</u> radiation protection detectors

<u>Calibration information of transportable detectors</u>

Calibration radiation quality:

Check all that apply

Please choose **all** that apply:

Cs-137

Co-60

Cf-252

Dosimetric quantity:

Check all that apply

Please choose **all** that apply:

H*(10)

Are neutrons considered?

Choose one of the following answers

Please choose **only one** of the following:

Yes

No

I do not know

Are gammas considered?

Choose one of the following answers

Please choose **only one** of the following:

Yes

No

I do not know

Are visitors monitored?

Check all that apply

Please choose **all** that apply:

Yes

No

Sometimes

Who is monitored and how?

Only answer this question if the following conditions are met:

Answer was at question '68 [M]' (Are visitors monitored?) *and* Answer was at question '68 [M]' (Are visitors monitored?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Parents or other patient carers that accompany the patient

Visitors

Researchers

Other:

Are pregnant women allowed to continue their work in the PT center?

Choose one of the following answers

Please choose **only one** of the following:

Yes

Yes but performing specific tasks outside treatment area

No

I do not know

Are there specific regulations regarding pregnant staff?

Please write your answer here:

How was commissioning derived?

Check all that apply

Please choose **all** that apply:

Dosimetric measurements

Monte Carlo simulations

Both dosimetric measurements and Monte Carlo simulations

I do not know

Are treatment room doors controled and unlocked following a certain cut-off dose/time following radiation?

Check all that apply

Please choose **all** that apply:

Yes

No

I do not know

Would you consider collaboration within SINFONIA project?

Check all that apply

Please choose **all** that apply:

Yes

No

Maybe

What is your specific interest?

Only answer this question if the following conditions are met:

-------- Scenario 1 --------

Answer was at question '74 [R]' (Would you consider collaboration within SINFONIA project?)

-------- or Scenario 2 --------

Answer was at question '74 [R]' (Would you consider collaboration within SINFONIA project?)

Comment only when you choose an answer.

Please choose all that apply and provide a comment:

Research

Measurements in your proton therapy facility related to staff and/or ambient doses

Specific radiation protection concern

Measurements to validate staff monitors and/or ambient detectors

Measurements to allow appropriate correction factors for neutron staff/ambient detectors

Great job!

Thank you very much to complete the questionnaire. We will provide you with feedback and involve you in the preparation of a report related to the current staff dosimetry practices including your proton therapy center.

20.04.2022 – 00:00

Submit your survey.
Thank you for completing this survey.

Annex 2: Detailed overview of Online Survey results

REFERENCES

Zorloni, G., G. Bosmans, T. Brall, M. Caresana, M. De Saint-Hubert, C. Domingo, C. Ferrante, F. Ferrulli, R. Kopec, J. Leidner, V. Mares, R. Nabha, P. Olko, M. A. Caballero-Pacheco, W. Rühm, M. Silari, L. Stolarczyk, S. Jan, M. Tisi, S. Trinkl, O. Van Hoey and G. Vilches-Freixas (2022). "Joint EURADOS WG9-WG11 rem-counter intercomparison in a Mevion S250i proton therapy facility with Hyperscan pulsed synchrocyclotron." Physics in Medicine & Biology **67**(7): 075005.