



Report on the Pilot Survey on Obtaining Occupational Exposure Data in Interventional Cardiology

Working Group on Interventional Cardiology (WGIC)

*Information System on Occupational Exposure in Medicine, Industry and
Research (ISEMIR)*

Working material

Limited distribution

Reproduced by the IAEA

June 2013

*The material in this document has been supplied by the WGIC and has not been edited by the IAEA.
The views expressed remain the responsibility of the WGIC. In particular, the IAEA cannot be held
responsible for any material reproduced in this document.*

CONTENTS

EXECUTIVE SUMMARY	3
1. INTRODUCTION	5
2. METHOD	5
3. RESULTS	6
3.1. Number of responses	6
3.2. Number of procedures per year	6
3.3. Monitoring periods and numbers of dosimeters worn	7
3.4. Quality of the dose data reported	7
3.5. Estimates of dose metrics – occupational doses per procedure	7
3.6. Filtering the raw data to improve its quality	9
3.7. Using the dose metric to benchmark IC facilities	10
3.8. Using the dose metric to identify potential areas for action	10
4. DISCUSSION	11
4.1. Obtaining occupational exposure data from IC facilities	11
4.2. Facility-specific dose data	11
4.3. Monitoring periods and numbers of dosimeters worn	12
4.4. Quality of reported dose data	12
4.5. Quality of reported workload data	13
4.6. Estimates of dose metrics – occupational doses per procedure	13
4.7. The next step – the ISEMIR international database	14
5. CONCLUSION	14
APPENDIX I. DETAILED RESULTS OF THE IC PILOT SURVEY	16
I.1. Responses to the survey	16
I.2. Numbers of facilities, personnel and procedures in IC	16
I.3. Monitoring periods and numbers of dosimeters worn	19
I.4. Quality of the dose data reported	20
I.5. Estimates of dose metrics – physicians	23
I.6. Estimates of dose metrics – non-physician personnel	24
I.7. Over apron dose to under apron dose ratios	25
I.8. Filtering the raw data to improve its quality	26
I.9. Benchmarking the performance of qualified interventional cardiologists in IC facilities	31
APPENDIX II. MEMBERS OF THE ISEMIR WORKING GROUP ON INTERVENTIONAL CARDIOLOGY (WGIC)	32
REFERENCES	33

EXECUTIVE SUMMARY

As part of the Information System on Occupational Exposure in Medicine, Industry and Research (ISEMIR) project, the Working Group on occupational exposures and radiation protection of staff in interventional cardiology (WGIC) was formed in 2009 to undertake activities focussed on improving the implementation of occupational radiation protection in interventional cardiology (IC).

In 2009 the WGIC conducted a world-wide survey to gain insight into the practice of occupational radiation protection in IC around the world. Conclusions from the 2009 survey included that there was room for significant improvement in the practice of occupational radiation protection throughout the world, and that obtaining reliable data from radiation protection regulatory bodies on occupational exposures in IC was difficult.

This resulted in a pilot survey in 2010-11 to test the feasibility of obtaining IC occupational dose data directly from IC facilities and to test whether the reported data could be used to derive a dose metric for occupational exposure in IC that could, in a later situation, be used to assess the effectiveness of actions to improve the optimization of occupational radiation protection in a given IC facility.

About 100 selected IC facilities from around the world were contacted and responses were received from 26 IC facilities, with about 850 individuals including interventional cardiologists (347), electrophysiologists (49), nurses (210) and technicians (126).

The majority of responding IC facilities had monthly occupational exposure monitoring periods. For IC physicians, two dosimeters were worn in 27% of facilities, one under apron dosimeter in 50% of facilities, and one over apron dosimeter in 19% of facilities. For non-physician personnel, the respective percentages were: 15%, 38%, and 23%. Numbers and positions of dosimeters worn were not reported for physicians in 4% of IC facilities and for non-physician personnel in 23% of facilities.

Many of the reported dose data were of poor quality. Reported “zero doses” for physicians per monitoring period were common (55% for under apron dosimeters and 33% for over apron dosimeters), and there were missing data (16%). About 10% of physicians with over apron dosimeters reported zero doses for all their monitoring periods in the year and, similarly, about one-quarter of physicians with under apron dosimeters reported zero doses for the entire year. Compliance with being monitored continues to be an issue with many IC personnel.

Dose metrics (occupational dose per procedure) were derived from the survey data, including reported zero doses. For physicians, the mean occupational effective dose per procedure was about 10 μSv for interventional cardiologists and about 3 μSv for electrophysiologists. The dose metric for trainee interventional cardiologists appeared to be higher than for qualified interventional cardiologists. Both nurses and technicians had a mean occupational effective dose per procedure of a little less than 1 μSv .

Three types of quality factor were derived to assess each individual’s reported monitoring period dose data, based on: the compliance of an individual in being monitored; the percentage of reported “zero doses”; and the consistency of reported doses. By assigning a threshold value to a quality factor, suspect data were able to be excluded from the analysis. The application of such filtering increased the value of the dose metric relative to that derived from the raw data, primarily due to the removal of varying numbers of zero doses. The filtering was most successful for dose metrics based on over apron dosimeters, highlighting the limited usefulness of under apron dosimeters when the dose being detected is close to the limits of detectability.

The average dose metric of effective dose per procedure was derived for each IC facility for their qualified interventional cardiologists. Using the raw data, the facility-averaged dose metric (occupational effective dose per procedure) for qualified interventional cardiologists ranged from 0.9 to 75.8 μSv per procedure, with a mean and median of 9.6 and 3.9 μSv per procedure. Even if the variation due to procedure complexity is considered, this would seem to indicate a wide variation in occupational radiation protection practice between the different IC facilities and, further, points to how a larger set of data with more participating facilities and personnel could provide a very useful benchmarking tool as an aid to improving the optimization of occupational radiation protection.

The two WGIC surveys have set the stage for the development of the ISEMIR international database. The purpose of the ISEMIR database will be to provide an active tool for assessing the level of, and hence guiding, implementation of the radiation protection principle of optimization of protection at a given IC facility. Once fully developed and populated, the database will support three broad types of analyses – occupational doses per procedure as a function of personnel and facility attributes (i.e. the circumstances of the occupational exposure); benchmarking of facilities and individuals; and trends with time.

The second WGIC survey has shown that it is feasible to obtain data on occupational exposure in IC directly from IC facilities and to use this data to derive dose metrics for occupational exposure in IC. Because the participation rate was about 25%, it does emphasize that, if the proposed ISEMIR international database is to be successful, there needs to be a clear incentive for participation – in particular it needs to be demonstrable that the database would be a tool for each IC facility to use as an interactive means for improving occupational radiation protection in their facility. With regard to the dose metrics, this survey has shown that the quality of data needs to be improved – in particular, better compliance in wearing dosimeters is needed.

1. INTRODUCTION

The Information System on Occupational Exposure in Medicine, Industry and Research, known as the ISEMIR project, was launched by the IAEA in early 2009 to help to improve occupational radiation protection practice in targeted areas of medicine, research and industry where non-trivial occupational exposures occur. As part of ISEMIR, a working group on occupational exposure and radiation protection of staff in interventional cardiology (WGIC) was established in February 2009. In the same year the WGIC conducted a world-wide survey of occupational radiation protection in interventional cardiology (IC) to gain insight into the practice of occupational radiation protection in IC around the world. This survey was reported in 2010 [1].

There were several conclusions from the 2009 survey. In particular, there was room for significant improvement in the practice of occupational radiation protection throughout the world, and obtaining reliable data on occupational exposures in IC from radiation protection regulatory bodies was difficult. Many regulatory bodies have limited access to such data and, further, the limited data that were available were not detailed enough to facilitate analysis of occupational exposure within IC facilities. Detailed information on occupational doses in a given IC facility and the circumstances under which the doses were incurred needs to be known if the next step of implementing actions to improve the optimization of occupational radiation protection is to take place.

On the basis of these conclusions, it was proposed that alternative strategies for the collection of reliable IC occupational dose data needed to be considered. This resulted in a pilot survey in 2010-11 to test the feasibility of obtaining IC occupational dose data directly from IC facilities and to test whether the reported data could be used to derive dose metrics for occupational exposure in IC.

This report presents and discusses the results of this pilot survey.

2. METHOD

Over the period 2010-11 a multinational pilot survey collected data at the hospital or facility level, on individual personnel doses and workloads. Excel data sheets were designed and sent to IC facilities to facilitate the collection of IC occupational dose data. For each individual, the information collected included their role (interventional cardiologist, electrophysiologist, nurse, technician, or other), their status (staff or trainee), the number of procedures per year, their annual occupational dose data, and their occupational dose data per monitoring period. The dose quantities requested were $H_p(10)$ measured over the apron, $H_p(10)$ measured under the apron, lens dose and hand dose, as appropriate to a given IC facility.

Initial contact with selected IC facilities was made by the members of the WGIC, primarily by email, explaining the purpose of the pilot survey and inviting participation. Many of the contacted IC facilities had previously participated in the 2009 survey. Approximately 100 IC facilities around the world were contacted in this manner, resulting in responses from 26 IC facilities and about 850 IC personnel including interventional cardiologists, electrophysiologists, nurses and technicians.

The data were used to derive estimates of occupational dose per IC procedure – namely, over apron $H_p(10)$ per procedure, under apron $H_p(10)$ per procedure, occupational effective dose per procedure, lens dose per procedure, and hand dose per procedure. Changes in these dose metrics could then be used to assess the effectiveness of any subsequent actions to improve occupational radiation protection.

3. RESULTS

The purpose of the pilot survey was to test the feasibility of first obtaining occupational dose data directly from IC facilities and, second, of deriving dose metrics for occupational exposure in IC that could, in a later situation, be used to assess the effectiveness of actions to improve the optimization of occupational radiation protection in a given IC facility.

To that end, the scope of the pilot survey was quite limited, with contact being made with only selected IC facilities. The values that are reported below are valid in their context, but do not purport to be necessarily representative of the worldwide practice of IC.

The summarized results of the pilot survey are presented here, with detailed results given in Appendix I. Tables and figures in the body of this report are referred to as Table 1, Figure 1, etc., and tables and figures in the Appendix to this report are referred to as Table I.1, Figure I.1, etc. Note that the term “technician” is used in many tables and figures to mean technicians, technologists, radiographers and similar occupations; and the abbreviation EP means electrophysiology. While the abbreviation IC means interventional cardiology, in the interest of brevity, it is intended to include both interventional cardiology and electrophysiology. Hence the terms “IC facility” “IC personnel” and “IC” physicians are wider in scope than just specifically “interventional cardiology”. When referring to a particular cardiology subspecialty, the terms interventional cardiologist and electrophysiologist are used.

3.1. Number of responses

- There were 26 responses from IC facilities, from 16 countries.
- Data for individual IC personnel were obtained from:
 - 347 interventional cardiologists, 49 electrophysiologists, and 18 “other” physicians;
 - 210 nurses, 126 technicians, and 102 persons that were either a nurse or technician.

See Tables I.1 – I.3 and Figures I.1 and I.2 in Appendix I for more details.

3.2. Number of procedures per year

- Statistics on the reported number of procedures per year performed by personnel in a given IC facility are summarized in Table 1. See Tables I.4 and I.5 and Figures I.3 and I.4 in Appendix I for more details.

TABLE 1. NUMBER OF PROCEDURES PERFORMED BY IC PERSONNEL PER YEAR IN A GIVEN FACILITY¹

	No. of responses	Mean	Minimum	Median	Maximum
Interventional cardiologists	258	248	1	177	1394
Electrophysiologists	45	189	43	182	496
Interventional cardiologists, qualified	149	321	10	277	1394
Interventional cardiologists, trainee	43	181	1	162	674
Nurses	47	317	2	250	667
Technicians	41	448	73	484	1025

¹ Some personnel may work in other facilities as well, but this is not relevant to this survey as it is the dose-workload relationship in a given facility that is of importance for a given person.

3.3. Monitoring periods and numbers of dosimeters worn

- 60% (15 out of 26) of responding IC facilities had monthly monitoring periods, 20% (5 out of 26) had three-monthly monitoring periods and 15% (4 out of 26) had two-monthly monitoring periods. Two IC facilities did not provide monitoring period data.
- Numbers of dosimeters worn were:
 - Two dosimeters (over apron and under apron) were worn by physicians in 27% (7 out of 26) of IC facilities and by non-physician personnel in 15% (4 out of 26) of facilities;
 - One over apron dosimeter was worn by physicians in 19% (5 out of 26) of IC facilities and by non-physician personnel in 23% (6 out of 26) of facilities;
 - One under apron dosimeter was worn by physicians in 50% (13 out of 26) of IC facilities and by non-physician personnel in 38% (10 out of 26) of facilities;
 - Numbers of dosimeters worn were not known for physicians in one IC facility and for non-physician personnel in 6 facilities.
 - Extremity dosimeters were worn by physicians in 19% (5 out of 26) of IC facilities and lens dosimeters in only one facility.

See Tables I.6 and I.7 in Appendix I for more details.

3.4. Quality of the dose data reported

- From a total of 2026 monitoring periods reported, 84% (1691 out of 2026) had a numerical value (zero or greater). For the remaining 16%, no dose data were provided.
- From a total of 1648 monitoring periods reported with an under apron dosimeter, 92% (1509 out of 1648) had a numerical value (zero or greater). 55% (824 out of 1648) were reported with a zero value.
- From a total of 888 monitoring periods reported with an over apron dosimeter, 70% (625 out of 888) had a numerical value (zero or greater). 33% (206 out of 888) were reported with a zero value.
- Averaged per physician:
 - 82% of monitoring periods in the year had a reported numerical value (zero or greater); but 6% of physicians (16 out of 251) had no monitoring periods with a reported numerical value (zero or greater).
 - 77% of reported over apron doses in the year were not zero; but 11% of physicians (10 out of 95) had all monitoring periods with a reported value equal to zero.
 - 53% of reported under apron doses in the year were not zero; but 23% of physicians (48 out of 207) had all monitoring periods with a reported value equal to zero.

See Table I.8 – I.11 and Figures I.5 and I.6 in Appendix I for more details.

3.5. Estimates of dose metrics – occupational doses per procedure

Reported zero doses were included in the estimation of dose metrics.

- Over apron dose¹ per procedure ($\mu\text{Sv/procedure}$):
 - All interventional cardiologists (135): mean = 39.7 ± 13.8 ; range 0 - 700; median = 24.4;
 - All electrophysiologists (27): mean = 34.7 ± 11.7 ; range 0 - 102; median = 28.6;

¹ Over apron dose means the reported $H_p(10)$ from a dosimeter placed above the protective apron, normally at collar level.

- Qualified interventional cardiologists (94): mean = 30.3 ± 5.9 ; range 0 - 150; median = 26.8;
 - Trainee interventional cardiologists (41): mean = 61.1 ± 43.1 ; range 0 - 700; median = 21.1;
 - Nurses (20): mean = 9.9 ± 5.5 ; range 0 - 32; median = 1.5;
 - Technicians (31): mean = 7.2 ± 2.1 ; range 0 - 25; median = 7.0.
- Under apron dose² per procedure ($\mu\text{Sv/procedure}$):
- All interventional cardiologists (113): mean = 11.4 ± 5.6 ; range 0 - 230; median = 2.6;
 - All electrophysiologists (20): mean = 1.1 ± 0.7 ; range 0 - 6; median = 0.3;
 - Qualified interventional cardiologists (92): mean = 10.8 ± 5.1 ; range 0 - 159; median = 2.8;
 - Trainee interventional cardiologists (21): mean = 61.1 ± 43.1 ; range 0 - 700; median = 21.1;
 - Nurses (36): mean = 0.3 ± 0.2 ; range 0 - 4; median = 0.1;
 - Technicians (13): mean = 0.6 ± 0.3 ; range 0 - 1.5; median = 0.2.
- Occupational effective dose³ per procedure ($\mu\text{Sv/procedure}$):
- All interventional cardiologists (255): mean = 10.6 ± 4.5 ; range 0 - 419; median = 2.3;
 - All electrophysiologists (45): mean = 3.0 ± 1.0 ; range 0 - 18; median = 2.0;
 - Qualified interventional cardiologists (148): mean = 12.5 ± 5.2 ; range 0 - 261; median = 3.1;
 - Trainee interventional cardiologists (41): mean = 16.3 ± 20.5 ; range 0 - 419; median = 2.7;
 - Nurses(46): mean = 0.7 ± 0.4 ; range 0 - 7; median = 0.2;
 - Technicians (41): mean = 0.7 ± 0.2 ; range 0 - 3; median = 0.5.
- Lens dose⁴ per procedure ($\mu\text{Sv/procedure}$):
- All interventional cardiologists (201): mean = 31.7 ± 9.9 ; range 0 - 700; median = 16.1;
 - All electrophysiologists (37): mean = 44.8 ± 36.5 ; range 0 - 680; median = 19.2;
 - Qualified interventional cardiologists (94): mean = 30.3 ± 5.8 ; range 0 - 149; median = 25.9;
 - Trainee interventional cardiologists (41): mean = 61.1 ± 43.1 ; range 0 - 700; median = 21.1;
 - Nurses (20): mean = 9.9 ± 5.5 ; range 0 - 32; median = 1.5;
 - Technicians (31): mean = 7.2 ± 2.1 ; range 0 - 25; median = 7.0.
 - Note that over apron doses do not, and lens dose may not, account for the possibility that protective eyewear was being used.
- Hand dose per procedure ($\mu\text{Sv/procedure}$):
- All interventional cardiologists (17): mean = 199.5 ± 114.5 ; range 6 - 724; median = 56.9.

See Tables I.12 – I.20 in Appendix I for more details.

² Under apron dose means the reported $H_p(10)$ from a dosimeter placed under the protective apron, normally at chest or waist level.

³ Effective dose has been calculated from the reported dosimeter values using the algorithm: If 2 dosimeters, $ED = 0.075OA + 1.64UA$; if one dosimeter, $ED = 0.075OA$ or $ED = 1.64UA$, depending on which dosimeter was worn, where ED = effective dose, OA = reported $H_p(10)$ from a dosimeter placed over the protective apron, and UA = reported $H_p(10)$ from a dosimeter placed under the protective apron.

⁴ Lens dose means the reported value from a dosimeter specifically placed to measure lens dose or the reported over apron dose.

3.6. Filtering the raw data to improve its quality

Seven quality factors, as presented in Table 2, were used to assess and filter the raw dose data.

TABLE 2. QUALITY FACTORS USED TO ASSESS THE RAW REPORTED DOSE DATA AND THE DERIVED DOSE DATA

Quality Factor	Based on:
QF1	Percentage of monitoring periods with a reported numerical value, including zero and “less than minimum detectable or reported dose” ¹ .
QF2	Percentage of <u>reported</u> over apron numerical values that were NOT zero.
QF3	Percentage of <u>reported</u> under apron numerical values that were NOT zero.
QF4	Coefficient of variation of <u>reported</u> over apron values.
QF5	Coefficient of variation of <u>reported</u> under apron values.
QF6	Percentage of <u>calculated</u> effective dose values that were NOT "zero".
QF7	Coefficient of variation of <u>calculated</u> effective dose values.

¹ Over apron results were used if available, otherwise under apron or deep dose results were used.

As can be seen from Table 2, the quality factors fall into 3 groups – the first, QF1, assesses the compliance of an individual in being monitored, with the caveat that it is possible for the dosimeter to be routinely returned but having never been used for its intended purpose in the cardiac investigation suite; the second group, QF2, QF3, QF6, assesses the percentage of reported “zero doses” for an individual; and the third group, QF4, QF5, QF7, assesses consistency of reported doses for an individual. By assigning a threshold value to a quality factor, suspect data can be excluded from the analysis. The influence of such filtering on deriving estimates of the dose metrics for qualified interventional cardiologists is presented in detail in Appendix I, summarized here and illustrated in Table 3 and Figure 1.

- The application of any filter reduced the number of data in the analysis;
- The application of any filter increased the value of the dose metric relative to that derived from the raw data, primarily due to the removal of varying numbers of “zero doses”;
- Having data for all monitoring periods (QF1 = 100) was clearly important in obtaining a robust estimate for the dose metric;
- The presence or not of “zero doses” (QF2, 3, 6) impacted on the value of the dose metric;
- The use of the coefficient of variation quality factor (QF4, 5, 7) as a filter affected the dose metric in a similar manner to that of excluding zero doses.

TABLE 3. INFLUENCE ON THE ESTIMATES OF THE EFFECTIVE DOSE METRIC (OCCUPATIONAL EFFECTIVE DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS TO FILTER THE RAW DATA (SEE TABLE 2)

Quality filter applied	Effective dose per procedure (µSv/proc)		Number of data
	Mean	2 x standard error	
No filter – raw data	14.8	6.3	117
QF1 > 75	17.9	7.6	95
QF1 = 100	20.8	9.1	78
QF6 > 50	15.6	6.9	104
QF6 > 75	16.7	7.8	91
QF6 = 100	21.9	10.8	64
QF7 < 150	17.9	8.2	86
QF7 < 100	15.4	7.3	62
QF7 < 50	18.6	11.5	32
QF1 = 100 & QF6 = 100	27.2	13.5	50
QF1 = 100 & QF7 < 100	18.9	9.0	49
QF1 = 100 & QF6 = 100 & QF7 < 100	21.6	11.1	39

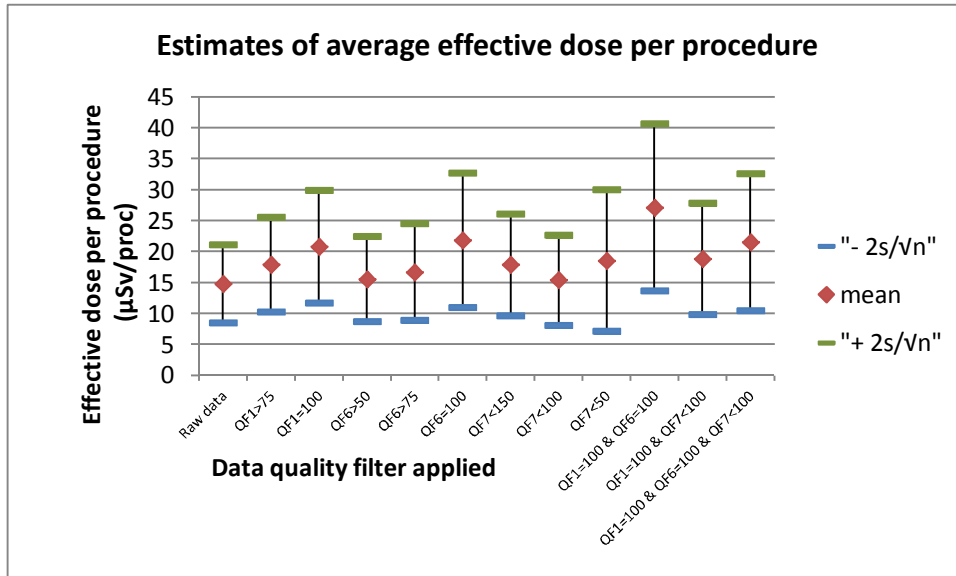


FIG. 1. Estimates of occupational effective dose per procedure (mean \pm 2 x standard error) for qualified interventional cardiologists as a function of the data quality filter applied.

See Tables I.23 – I.31 and Figures I.7 – I.12 in Appendix I for more details.

3.7. Using the dose metric to benchmark IC facilities

Although the number of IC facilities was small and the number of participating IC personnel in each facility relatively small, the average dose metric of effective dose per procedure was derived for each IC facility for the largest occupational group in the survey – namely qualified interventional cardiologists. The detailed results are given in Appendix I (Table I.32). Using the raw data, the facility-averaged dose metric (occupational effective dose per procedure) for qualified interventional cardiologists ranged from 0.9 to 75.8 μ Sv per procedure, with a mean and median of 9.6 and 3.9 μ Sv per procedure. This would seem to be indicative of the wide variation in radiation protection practice between the different IC facilities and, further, points to how a larger set of data with more participating facilities and personnel could provide a very useful benchmarking tool as an aid to improving the optimization of occupational radiation protection.

3.8. Using the dose metric to identify potential areas for action

In a similar way, the dose metric for a given group of persons can be used to identify areas that could be improved or, on the other hand, that represent good practice. To illustrate, the qualified interventional cardiologists in the survey were divided into two groups – those who performed fewer than 150 procedures in the reported year and those who performed 150 or more procedures in the year. The estimates of mean effective dose per procedure were 37.0 ± 21.5 and 6.8 ± 1.9 μ Sv per procedure for the lower workload group and higher workload group, respectively, indicating that some particular attention probably needs to be given those interventional cardiologists who perform fewer procedures. These results are presented in Figure 2.

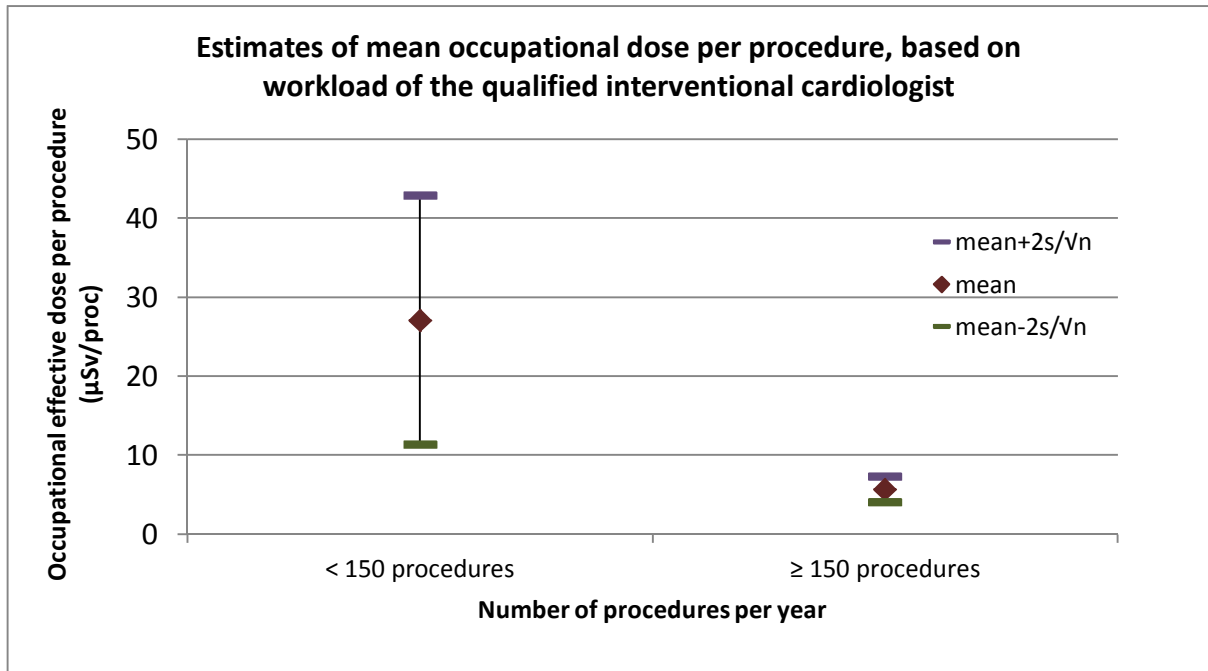


FIG. 2. Example of statistical analysis, comparing the performance of qualified interventional cardiologists with a lower workload with those having a higher workload, thus identifying an area needing attention.

4. DISCUSSION

4.1. Obtaining occupational exposure data from IC facilities

One of the reasons for the pilot survey was to ascertain whether it was realistic to obtain occupational exposure data for IC personnel directly from the IC facilities where they worked. Of those IC facilities initially contacted, about one-quarter provided actual occupational exposure data for their facility. On the one hand this would indicate that data can be obtained directly from facilities – a significant proportion were willing to participate in a pilot survey, with no particular added value for doing so. But on the other it emphasizes that, if the proposed ISEMIR international database (see section 4.7) is to be successful, there needs to be a clear incentive for participation – in particular it needs to be demonstrable that the database would be a tool for each IC facility to use as an interactive means for improving occupational radiation protection for their workers.

4.2. Facility-specific dose data

IC is characterized in many countries throughout the world by personnel who work in more than one IC facility. This can cause substantial problems in determining compliance with occupational dose limits. For this pilot survey, annual occupational doses were not reported – it was not known whether the participating personnel worked elsewhere and, further, this information was not necessary for the purposes of this survey.

The goal of the pilot survey is to assess whether IC facility-specific data could be used to improve the practice of occupational radiation protection in that facility. If, for example, an interventional cardiologist worked in two IC facilities, then the circumstances of his or her occupational exposure are likely to be quite different in each facility – the types of X ray equipment used and their performance characteristics, the protective tools available, the types of procedures being performed, and the room layout, to name a few factors, are likely to be different. Therefore, for the example interventional cardiologist, optimization of occupational protection would need to take place independently in each of the facilities, by looking at the factors relevant to that facility. In the ISEMIR international database (see section 4.7), the example interventional cardiologist would “appear” in the database in two places, assuming both of the IC facilities were participating.

4.3. Monitoring periods and numbers of dosimeters worn

The majority of participating IC facilities had a monthly monitoring period. In one of these cases there were actually only 11 “months” in the year, with January being combined with February. Similarly, some of the “two-monthly” or “three-monthly” monitoring periods were not uniform – holiday seasons typically were the reason why the cycles were not always evenly spaced. Such irregularities in monitoring periods need to be able to be accommodated in the design of the data entry for the ISEMIR international database (see section 4.7).

Two dosimeters were worn in a minority of the participating IC facilities. The International Commission on Radiological Protection have for some time recommended that two dosimeters be worn in IC [2, 3], but the responses from the survey show that the single under apron dosimeter remains the most common form of monitoring. This tension between legal requirements in many countries and what is best practice does have implications for the quality of the occupational dose data as will be discussed further, below.

4.4. Quality of reported dose data

The interpretation of the monitoring period dose data, as initially provided, was not always straight forward. In many instances (16% of reported monitoring periods) there were gaps or blanks in the data and it was unclear whether these were due to no dose value being reported because either the person concerned was away and did not use a dosimeter or the dosimeter was lost, or the dosimeter was carried over to the next monitoring cycle, or for some other reason.

Another problem area is the minimum detectable dose or the minimum reported dose. Each dosimetry provider has their own minimum detectable dose and, in addition, there are various ways of reporting the minimum dose. These include reporting it as “less than the minimum dose” or assigning a zero dose, or assigning the minimum detectable dose, or assigning some fraction of the minimum detectable dose, such as one-half or one-fifth.

For a viable ISEMIR international database (section 4.7), it is crucial that the reported occupational dose data for any given IC facility are entered into the database in a consistent manner. The database data entry screens need to provide clear guidance on what is required.

The percentage of reported zero doses was quite significant – for physicians with dose data per monitoring period, 55% for the under apron dosimeters and 33% for the over apron dosimeters. Further, for the 108 physicians who used over apron dosimeters, 17 had a reported annual dose of zero, and of these 11 were for physicians who performed more than 100 procedures in the year. A reported zero dose for a dosimeter can be due to very good radiation protection practice but, unfortunately, it can also be due to the dosimeter not being

worn in the investigation suite. The over apron results, at least, point to the latter interpretation, with poor compliance in being monitored being a real issue that could undermine the usefulness of the ISEMIR international database (section 4.7). Perhaps the future availability of the ISEMIR international database will provide an additional incentive for on-going compliance in wearing dosimeters.

Zero doses for under apron dosimeters are a more likely eventuality, especially if good radiation protection practice is being followed. Therefore from a dose metric perspective, and for determining whether dosimeters are being worn, under apron dosimeters are not as useful as over apron dosimeters – for under apron dosimeters, the magnitude of the reported dose will always be smaller and nearer the minimum detectable dose, making the signal to noise ratio poor. As mentioned above, while legal requirements in some countries may necessitate the use of under apron dosimeters, the more prevalent use of over apron dosimeters or double dosimetry would help the implementation of the ISEMIR international database.

4.5. Quality of reported workload data

The IC facilities also provided estimates of the annual number of procedures performed by each of the IC personnel. The nature of the numbers reported indicated that in some cases the values reported were rounded estimates (such as 300 or 350), while in other cases there had clearly been efforts to more accurately assess the number. However in any case, it is recognized that not all procedures are equal. Some of the procedures may have been only diagnostic in nature, while others were interventional. Two facilities gave additional data on both numbers and types of procedures, giving an average of 2.8 diagnostic procedures per interventional procedure (range 0 to 6) for the 23 interventional cardiologists in the two facilities. In some facilities a diagnostic procedure that then continued to become an interventional procedure may have been counted as a single procedure while in other facilities it may have been counted as two. Of course, not all procedures are of equal complexity. Complexity affects patient doses and therefore affects staff doses. All of these considerations affect the robustness of using the naïve “number of procedures” as the denominator of the dose metric. In developing the ISEMIR international database (section 4.7), more detailed information on the type of workload will be sought.

Further, an interventional cardiologist may have performed 300 procedures, but his or her role may not have always been that of the primary operator. Again, additional information on the person’s role in a procedure and the technique being used (femoral versus radial artery entry for interventional cardiology; thoracic (pacemaker) versus femoral access for electrophysiology) would increase the potential usefulness of derived dose metrics in the ISEMIR international database.

4.6. Estimates of dose metrics – occupational doses per procedure

This was the second main purpose of the pilot survey – to test the feasibility of deriving dose metrics in IC, where the dose metrics would be used to assess the impact of various actions to improve the optimization of occupational radiation protection.

Dose metrics were derived for over apron doses, under apron doses, effective doses, lens doses and hand doses per procedure. One would expect *a priori* that the estimate for a given metric (i.e. mean \pm 2 x the standard error) would be relatively large, given the large number of factors that can affect the occupational dose a person receives during a given procedure. This was certainly borne out in the results presented in this report.

As one includes or excludes the conditions that affect occupational exposure, one would expect the estimate for a given metric to converge to a representative value (for those conditions), and for the standard error to become narrower as the attributes become more selective. The dose metric for a given “profile” of circumstances then becomes a tool for investigating performance of occupational radiation protection practice.

Many of the reported data were of poor quality. The results of using derived quality factors to filter the raw data in an attempt to improve the data have been presented in the results section, and show a fairly mixed outcome. A further indicator of whether the use of quality factors for filtering the data was useful was to consider the effect on the coefficient of correlation between the annual dose and the annual workload. For the over apron doses for qualified interventional cardiologists, the application of various quality factor filters improved the value of the correlation coefficient from 0.75 (for the raw data) to as high as 0.88. For the under apron doses and effective doses, there was no correlation between doses and workload, and the application of filters made no improvement. This latter result again illustrates the limitations of under apron doses (and hence derived effective doses) in the role of dose metrics due to their low signal to noise ratios.

For this pilot survey, a simplistic approach was taken for calculating effective dose. The algorithm reported by Clerinx et al [4] for two dosimeters, effective dose = 0.075 * over apron dose + 1.64 * under apron dose, was used where data for two dosimeters were given. Where only an over apron dosimeter value was reported, the algorithm was simplified to effective dose = 0.075 * over apron dose; where only an under apron dosimeter value was reported, the algorithm was simplified to effective dose = 1.64 * under apron dose. It is recognized that this introduces a systematic underestimate for both the single dosimeter situations. Data were available from four IC facilities that enabled calculation of over apron dose to under apron dose ratios. The data presented in Appendix I (see Section I.7) point to there being a difference between the mean ratios for interventional cardiologists and for electrophysiologists. More robust algorithms for calculating effective dose, depending on whether under apron, over apron or both dosimeters are being worn, need to be decided upon for use in the ISEMIR international database.

Although not an aim of this pilot survey, it is worth commenting that the derived dose metrics for the lens of the eye for the various professional roles, as presented in Section 3.5, coupled with the annual workloads reported in Section 3.2 would indicate the possibility of exceeding the annual dose limit of 20 mSv for the lens of the eye. From the reported data, approximately 8% (22 out of 268) of the interventional cardiologists and electrophysiologists would have exceeded the dose limit, based on over-apron and lens dosimeters and without making any allowance for whether protective eyewear may have been worn. Such results would further emphasize the clear need for optimization of occupational radiation protection in interventional cardiology.

4.7. The next step – the ISEMIR international database

The results and experiences of the two WGIC surveys have led to the design and development of the ISEMIR international database. The purpose of the ISEMIR database will not be to assess compliance with occupational dose limits, but rather will be to provide an active tool for assessing the level of, and hence guiding, implementation of the radiation protection principle of optimization of protection at a given IC facility. Once fully developed and populated, the database will support three broad types of analyses – occupational doses per procedure as a function of personnel and facility attributes; benchmarking; and trends with

time. Indicative illustrations of the first two types of analyses have been presented in the results section.

5. CONCLUSION

The initial survey of the WGIC in 2009 on occupational exposure in IC was a general assessment of the current practice of occupational radiation protection in IC worldwide, concluding that there was considerable room for improvement.

This second survey has shown that it is feasible to obtain data on occupational exposure in IC directly from IC facilities. The participation rate was about 25% which indicates that, if the proposed ISEMIR international database is to be successful, there needs to be a clear incentive for participation – in particular it needs to be demonstrable that the database can be used by an IC facility as an interactive tool for improving their occupational radiation protection.

Many of the data from the IC facilities were of poor quality, with significant numbers of reported zero doses or missing data. Compliance with monitoring continues to be an issue with IC personnel. Clarity of instructions to IC facilities re future data submissions to the ISEMIR international database will be crucial.

Dose metrics (occupational dose per procedure) could be derived from the survey data. For physicians, the mean occupational effective dose per procedure was about 10 μSv for interventional cardiologists, and about 3 μSv for electrophysiologists. The dose metric for trainee interventional cardiologists appeared to be higher than for qualified interventional cardiologists. Both nurses and technicians had a mean occupational effective dose per procedure of about 1 μSv .

Derived quality factors, based on analyses of personnel dose data per monitoring period, were used to filter the raw data in an attempt to improve the dose metric estimates. This was most successful for analyses based on over apron dosimeters, highlighting the limited usefulness of under apron dosimeters when the detected dose is close to the limits of detectability.

The two WGIC surveys have set the stage for the ISEMIR international database that will facilitate the calculation of a given dose metric for a selected set of circumstances for occupational exposure. The ISEMIR database will be an active tool for assessing the level of, and hence guiding, implementation of the radiation protection principle of optimization of protection at a given IC facility. Once fully developed and populated, the database will support three broad types of analyses – occupational doses per procedure as a function of personnel and facility attributes; benchmarking; and trends with time.

APPENDIX I. DETAILED RESULTS OF THE IC PILOT SURVEY

The principal findings from the IC pilot survey are given in the results section of the main text. This appendix gives additional data in the form of tables and figures. Not all data were provided for all IC personnel in a given IC facility.

I.1. Responses to the survey

TABLE I.1. DETAILS ON IC FACILITIES PARTICIPATING IN THE SURVEY

Regions	No. of Countries	No. of IC facilities	IC, tot	EP, tot	N, tot	T, tot
Asia-Pacific	4	6	84	18	54	52
Europe	8	13	96	2	95	29
Latin America	3	5	34	4	14	11
North America	1	2	133	25	47	34
Global	16	26	347	49	210	126

Note:

1. “IC, tot” means all interventional cardiologists, regardless of status; “EP, tot” means all electrophysiologists, regardless of status; “N, tot” means all nurses, regardless of status; “T, tot” means all technicians, technologists or radiographers, regardless of status.

I.2. Numbers of facilities, personnel and procedures in IC

TABLE I.2. NUMBERS OF FACILITIES AND PHYSICIANS PARTICIPATING IN THE SURVEY

	IC, s	IC, t	IC, ??	IC, tot	EP, s	EP, t	EP, ??	EP, tot	All Drs
No facilities	25	10	1	26	8	2	1	9	26
No of participating physicians	195	75	77	347	36	2	11	49	414
Physicians per facility, for those facilities with participating physicians of the given type:									
Mean	7.8	7.5	77.0	13.4	4.5	1.0	11.0	5.4	15.9
Minimum	1	1	-	1	1	1	-	2	1
Median	6	4	77	9	2.5	1	11	3	10
Maximum	31	25	-	77	13	1	-	14	88

Note:

1. “IC, s” means consultant or qualified interventional cardiologist; “IC, t” means trainee interventional cardiologist; “IC, ??” means an interventional cardiologist of unspecified status; “IC, tot” means all interventional cardiologists, regardless of status.

2. “EP, s” means consultant or qualified electrophysiologist; “EP, t” means trainee electrophysiologist; “EP, ??” means an electrophysiologist of unspecified status; “EP, tot” means all electrophysiologists, regardless of status.

3. “All Drs” (last column) means all participating physicians from a facility, and includes 18 physicians that were neither interventional cardiologists nor electrophysiologists.

4. It is not known if all the interventional cardiologists and electrophysiologists at any given facility were included in the survey response for that facility. It would appear from some of the responses, at least, that not all physicians from a given facility were included in that facility’s response.

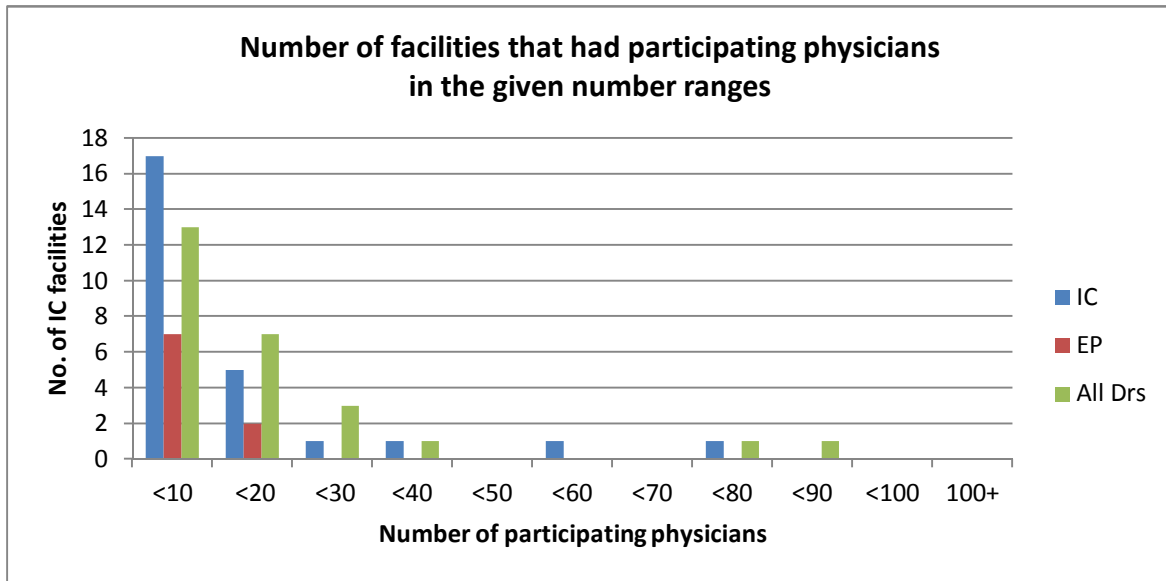


FIG. I.1. Number of facilities as a function of the number of participating physicians.

TABLE I.3. NUMBERS OF FACILITIES AND NON-PHYSICIAN PROFESSIONALS PARTICIPATING IN THE SURVEY

	N, s	N, t	N, ??	N, tot	T, s	T, ??	T, tot	N or T, ??	Total
No. of facilities	17	1	2	19	14	1	15	3	21
No. of participating professionals	179	2	29	210	93	33	126	102	438
Non-physician professionals per facility, for those facilities with participating professionals of the given type:									
Mean	10.5	2	14.5	11.1	6.6	33	8.4	34	20.9
Minimum	2	-	4	2	1	-	1	1	3
Median	7	-	14.5	7	4	-	4	7	9
Maximum	47	-	25	47	34	-	34	94	94

Note.

1. "N, s" means qualified nurse; "N, t" means trainee nurse; "N, ???" means a nurse of unspecified status; "N, tot" means all nurses, regardless of status.
2. "T, s" means qualified technician, technologist or radiographer; "T, ???" means a technician, technologist or radiographer of unspecified status; "T, tot" means all technicians, technologists or radiographers, regardless of status.
3. "N or T, ???" means a non-physician health professional of unknown profession or status.
4. It is not known if all the non-physician health professionals at any given facility were included in the survey response for that facility.

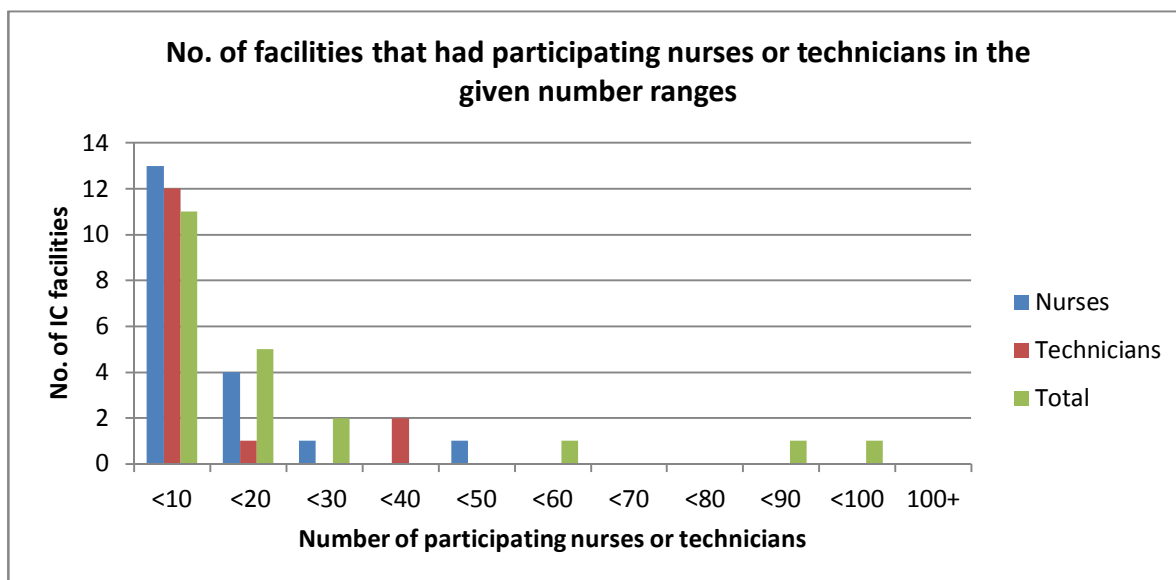


FIG. I.2. Number of facilities as a function of the number of participating nurses and technicians.

TABLE I.4. NUMBER OF PROCEDURES PERFORMED BY PHYSICIANS PER YEAR IN A GIVEN FACILITY¹

	No. of responses	Mean	Minimum	Median	Maximum
Interventional cardiologists	258	248	1	177	1394
Electrophysiologists	45	189	43	182	496
Other physicians	11	340	23	150	1285
Qualified interventional cardiologists	149	321	10	277	1394
Trainee interventional cardiologists	43	181	1	162	674
Qualified electrophysiologists	34	177	43	176	496

¹ Some physicians may work in other facilities as well, but this is not relevant to this survey as it is the dose-workload relationship in a given facility that is of importance for a given physician.

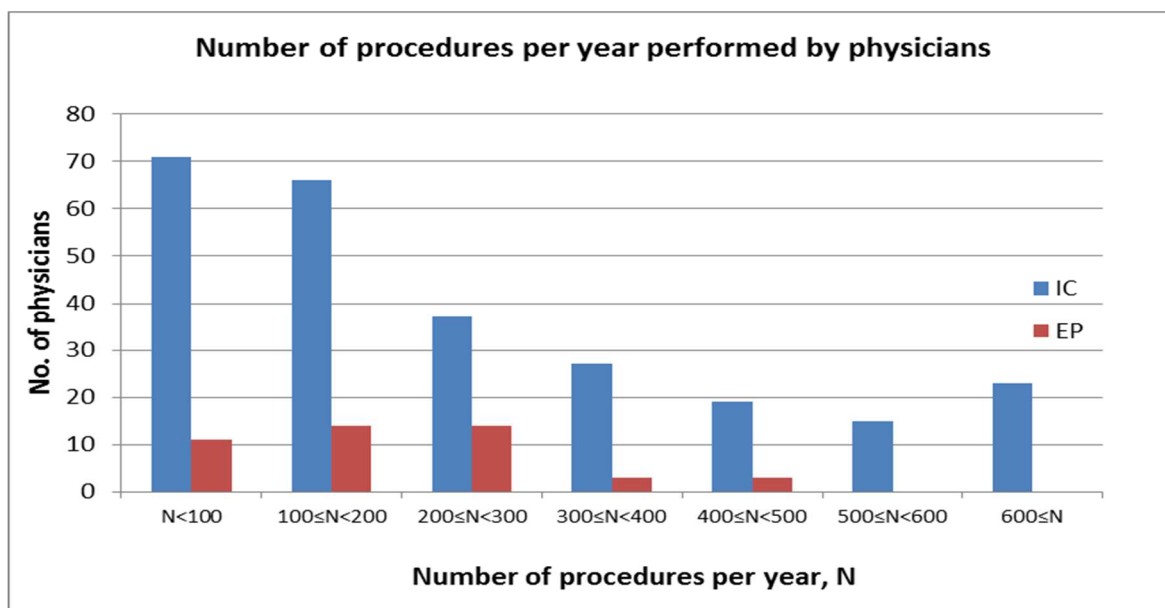


FIG. I.3. Distribution of the reported number of procedures being performed per year by interventional cardiologists and electrophysiologists in a given facility.

TABLE I.5. NUMBER OF PROCEDURES PER YEAR BY NON-PHYSICIAN PERSONNEL IN A GIVEN FACILITY

	No. of responses	Mean	Minimum	Median	Maximum
Nurses	47	317	2	250	667
Technicians	41	448	73	484	1025
Unspecified – nurse or technician	71	482	1	518	1130

Note. The term technician here covers technicians, technologists and radiographers.

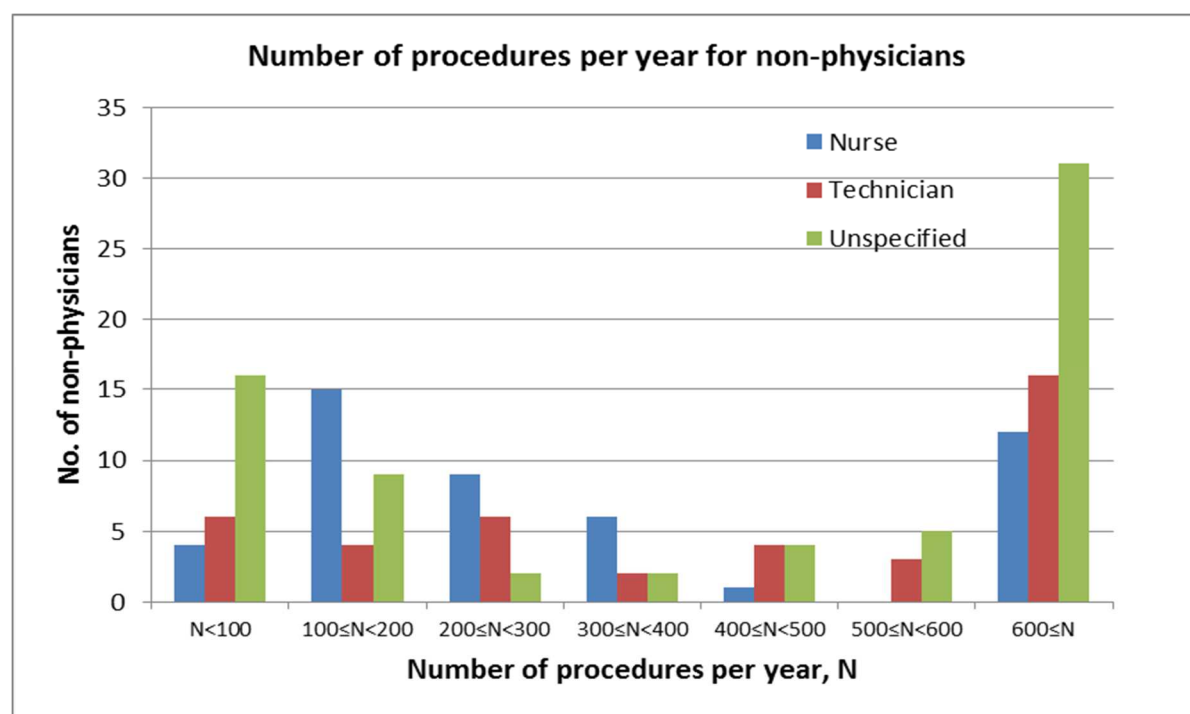


FIG. I.4. Distribution of the reported number of procedures for non-physicians per year in a given facility.

I.3. Monitoring periods and numbers of dosimeters worn

TABLE I.6. NUMBER OF MONITORING PERIODS PER YEAR FOR THE PARTICIPATING IC FACILITIES AND PERSONNEL

Number of monitoring periods per year	Number of IC facilities	Number of participating physicians
4	5	96
6	4	34
11	1	14
12	14	107
Not specified	2	163
Total	26	414

TABLE I.7. NUMBER OF DOSIMETERS WORN AT THE PARTICIPATING IC FACILITIES AND BY THE PERSONNEL

Number of dosimeters worn by physicians	Number of IC facilities	Number of participating physicians
2 dosimeters (over apron and under apron)	7	163
1 dosimeter, over apron	5	108
1 dosimeter, under apron	13	143
Extremity dosimeter	5	25
Lens dosimeter	1	88
Number of dosimeters worn by non-physicians	Number of IC facilities	Number of participating non-physicians
2 dosimeters (over apron and under apron)	4	129
1 dosimeter, over apron	6	140
1 dosimeter, under apron	10	169
Extremity dosimeter	2	22
Lens dosimeter	1	94

I.4. Quality of the dose data reported

TABLE I.8. NUMBER OF MONITORING PERIODS WITH REPORTED DOSES, D, FOR THE PARTICIPATING PHYSICIANS EQUAL TO ZERO, AND GREATER THAN OR EQUAL TO ZERO

Total number of monitoring periods reported	2026
Number of monitoring periods with $D \geq 0$	1691
Percentage of monitoring periods with $D \geq 0$	83.5%
Total number of monitoring periods reported, using an under apron dosimeter	1648
Number of under apron monitoring periods with $D \geq 0$	1509
Percentage of under apron monitoring periods with $D \geq 0$	91.6%
Number of under apron monitoring periods with $D = 0$	824
Percentage of under apron monitoring periods with $D = 0$	54.6%
Total number of monitoring periods reported, using an over apron dosimeter	888
Number of over apron monitoring periods with $D \geq 0$	625
Percentage of over apron monitoring periods with $D \geq 0$	70.4%
Number of over apron monitoring periods with $D = 0$	206
Percentage of over apron monitoring periods with $D = 0$	33.0%

TABLE I.9. QUALITY FACTORS USED TO ASSESS THE RAW REPORTED DOSE DATA AND THE DERIVED DOSE DATA

Quality Factor	Based on:
QF1	Percentage of monitoring periods with a reported numerical value, including zero and "less than minimum detectable or reported dose" ¹ .
QF2	Percentage of <u>reported</u> over apron numerical values that were NOT zero.
QF3	Percentage of <u>reported</u> under apron numerical values that were NOT zero.
QF4	Coefficient of variation of <u>reported</u> over apron values.
QF5	Coefficient of variation of <u>reported</u> under apron values.
QF6	Percentage of <u>calculated effective dose</u> values that were NOT "zero".
QF7	Coefficient of variation of <u>calculated effective dose</u> values.

¹ Over apron results were used if available, otherwise under apron or deep dose results were used.

TABLE I.10. ANALYSIS OF THE QUALITY OF THE REPORTED DOSES, D, PER PARTICIPATING PHYSICIAN FOR THE YEAR

	Mean	Min	Q1	Median	Q3	Max	No. of physicians involved
Percentage of monitoring periods in the year where $D \geq 0$, QF1 per physician	81.7	0	75	100	100	100	251
Percentage of reported over apron doses ¹ that were not zero in the year, QF2 per physician	76.9	0	67	100	100	100	95
Percentage of reported under apron doses ¹ that were not zero in the year, QF3 per physician	53.1	0	8	50	100	100	207
Coefficient of variation of reported over apron doses in the year, QF4 per physician	82.7	0.4	41	72	109	255	79
Coefficient of variation of reported under apron doses in the year, QF5 per physician	123.1	0	53	102	173	346	151

¹ Only reported doses with a numerical value ≥ 0 were considered in the denominator.

TABLE I.11. ANALYSIS OF THE QUALITY OF THE REPORTED DOSES, D, PER PARTICIPATING IC FACILITY FOR THE YEAR

	Mean	Min	Median	Max	No. of IC facilities involved
Percentage of monitoring periods in the year where $D \geq 0$, QF1 per facility	81.9	18	90	100	22
Percentage of reported over apron doses ¹ that were not zero in the year, QF2 per facility	72.0	17	75	100	9
Percentage of reported under apron doses ¹ that were not zero in the year, QF3 per facility	57.9	4	56	100	18
Coefficient of variation of reported over apron doses in the year, QF4 per facility	95.0	37	81	249	9
Coefficient of variation of reported under apron doses in the year, QF5 per facility	127.6	21	104	346	18

¹ Only reported doses with a numerical value ≥ 0 were considered in the denominator.

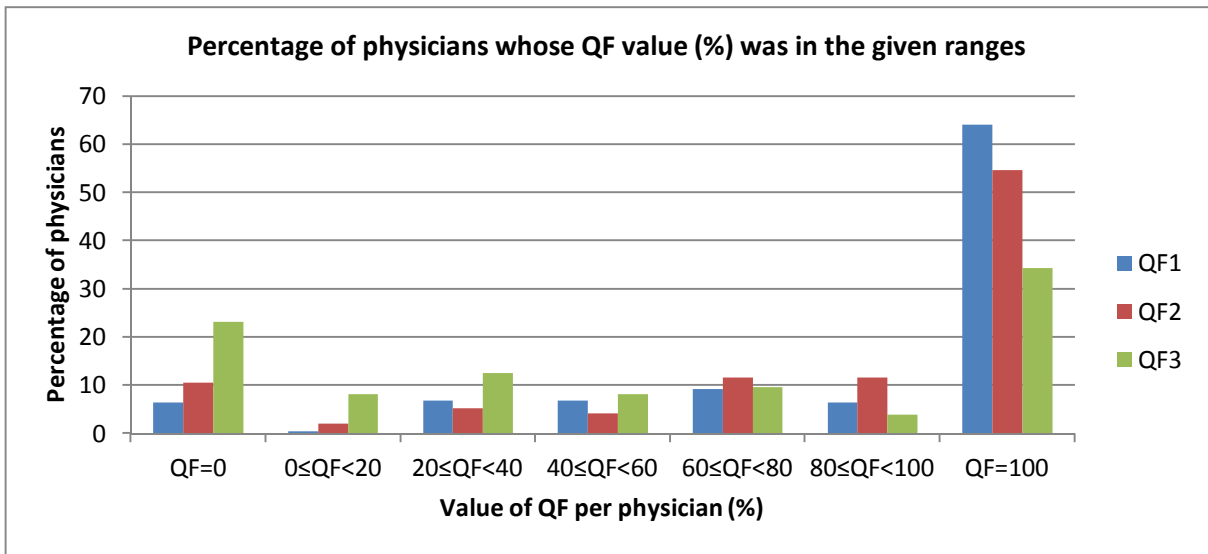


FIG. I.5. Distribution of the values of the Quality Factors (QF1, QF2, QF3) derived for each physician from the monitoring period data for the physicians.

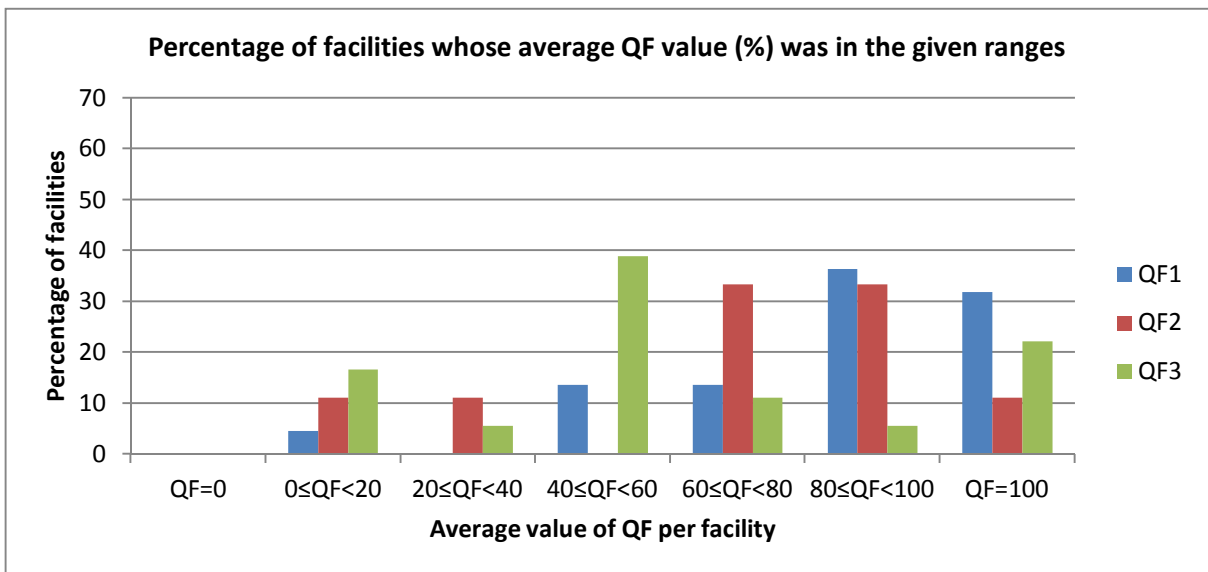


FIG. I.6. Distribution of the average values of the Quality Factors (QF1, QF2, QF3) derived for each IC facility from the monitoring period data for the physicians in that facility.

I.5. Estimates of dose metrics – physicians (for reported doses \geq zero)

TABLE I.12. OVER APRON DOSES PER PROCEDURE FOR PHYSICIANS

	Over apron dose ¹ per procedure (μ Sv/procedure)							No. of physicians
	Mean	SD	Min	Q1	Median	Q3	Max	
All interventional cardiologists	39.7	80.4	0	8.8	24.4	41.4	700	135
All electrophysiologists	34.7	30.3	0	9.4	28.6	57.7	102	27
Qualified interventional cardiologists only	30.3	28.4	0	9.0	26.8	40.8	150	94
Trainee interventional cardiologists only	61.1	138	0	3.5	21.1	41.5	700	41

¹ Over apron dose means the reported $H_p(10)$ from a dosimeter placed above the protective apron, normally at collar level.

TABLE I.13. UNDER APRON DOSES PER PROCEDURE FOR PHYSICIANS

	Under apron dose ¹ per procedure (μ Sv/procedure)							No. of physicians
	Mean	SD	Min	Q1	Median	Q3	Max	
All interventional cardiologists	11.4	29.6	0	0.2	2.6	7.7	230	113
All electrophysiologists	1.1	1.6	0	0	0.3	1.7	5.5	20
Qualified interventional cardiologists only	10.8	24.4	0	0.3	2.8	7.7	159	92
Trainee interventional cardiologists only	13.9	49.9	0	0	0.4	2.9	230	21

¹ Under apron dose means the reported $H_p(10)$ from a dosimeter placed under the protective apron, normally at chest or waist level.

TABLE I.14. EFFECTIVE DOSES PER PROCEDURE FOR PHYSICIANS

	Effective dose ¹ per procedure (μ Sv/procedure)							No. of physicians
	Mean	SD	Min	Q1	Median	Q3	Max	
All interventional cardiologists	10.6	35.8	0	0.1	2.3	5.5	419	255
All electrophysiologists	3.0	3.5	0	0.2	2.0	4.6	17.5	45
Qualified interventional cardiologists only	12.5	31.7	0	1.2	3.1	8.4	261	148
Trainee interventional cardiologists only	16.3	65.6	0	1.0	2.7	4.7	419	41

¹ Effective dose has been calculated from the reported dosimeter values using the algorithm: If 2 dosimeters, $ED = 0.075OA + 1.64UA$; if one dosimeter, $ED = 0.075OA$ or $ED = 1.64UA$, depending on which dosimeter was worn, where ED = effective dose, OA = reported $H_p(10)$ from a dosimeter placed over the protective apron, and UA = reported $H_p(10)$ from a dosimeter placed under the protective apron.

TABLE I.15. LENS DOSES PER PROCEDURE FOR PHYSICIANS

	Lens dose ¹ per procedure (μ Sv/procedure)							No. of physicians
	Mean	SD	Min	Q1	Median	Q3	Max	
All interventional cardiologists	31.7	70.4	0	0	16.1	37.1	700	201
All electrophysiologists	44.8	111	0	1.4	19.2	43.7	680	37
Qualified interventional cardiologists only	30.3	28.3	0	9.1	25.9	40.8	149	94
Trainee interventional cardiologists only	61.1	138	0	3.5	21.1	41.5	700	41

¹ Lens dose means the reported value from a dosimeter specifically placed to measure lens dose or the reported over apron dose.

TABLE I.16. HAND DOSES PER PROCEDURE FOR PHYSICIANS

	Hand dose ¹ per procedure (μ Sv/procedure)							No. of physicians
	Mean	SD	Min	Q1	Median	Q3	Max	
All interventional cardiologists	199.5	236	5.9	50.2	56.9	298	724	17

¹ Hand dose means the reported value from a dosimeter specifically placed to measure hand dose.

I.6. Estimates of dose metrics – non-physician personnel (for reported doses \geq zero)

TABLE I.17. OVER APRON DOSES PER PROCEDURE FOR NON-PHYSICIAN PERSONNEL

	Over apron dose ¹ per procedure (μ Sv/procedure)							No. of persons
	Mean	SD	Min	Q1	Median	Q3	Max	
Nurses ²	9.9	12.2	0	0	1.5	21.6	31.7	20
Technicians ³	7.2	5.8	0	3.1	7.0	10.0	24.6	31

¹ Over apron dose means the reported $H_p(10)$ from a dosimeter placed above the protective apron, normally at collar level.

² If an additional single extreme “outlier” is included, the mean, standard deviation, minimum, 1st quartile, median, 3rd quartile and maximum become 77.3, 309, 0, 0, 1.7, 24.5, 1425, respectively.

³ The term technician here covers technicians, technologists and radiographers.

TABLE I.18. UNDER APRON DOSES PER PROCEDURE FOR NON-PHYSICIAN PERSONNEL

	Under apron dose ¹ per procedure (μ Sv/procedure)							No. of persons
	Mean	SD	Min	Q1	Median	Q3	Max	
Nurses	0.3	0.7	0	0	0.1	0.2	4.0	36
Technicians ²	0.6	0.5	0	0	0.2	0.6	1.5	13

¹ Under apron dose means the reported $H_p(10)$ from a dosimeter placed under the protective apron, normally at chest or waist level.

² The term technician here covers technicians, technologists and radiographers.

TABLE I.19. EFFECTIVE DOSES PER PROCEDURE FOR NON-PHYSICIAN PERSONNEL

	Effective dose ¹ per procedure (μ Sv/procedure)							No. of persons
	Mean	SD	Min	Q1	Median	Q3	Max	
Nurses ²	0.7	1.2	0	0	0.2	0.6	6.6	46
Technicians ³	0.7	0.7	0	0	0.5	0.8	3.0	41

¹ Effective dose has been calculated from the reported dosimeter values using the algorithm: If 2 dosimeters, $ED = 0.075OA + 1.64UA$; if one dosimeter, $ED = 0.075OA$ or $ED = 1.64UA$, depending on which dosimeter was worn, where ED = effective dose, OA = reported $H_p(10)$ from a dosimeter placed over the protective apron, and UA = reported $H_p(10)$ from a dosimeter placed under the protective apron.

² If an additional single extreme “outlier” is included, the mean, standard deviation, minimum, 1st quartile, median, 3rd quartile and maximum become 2.9, 15.5, 0, 0, 0.2, 0.7, 107, respectively.

³ The term technician here covers technicians, technologists and radiographers.

TABLE I.20. LENS DOSES PER PROCEDURE FOR NON-PHYSICIAN PERSONNEL

	Lens dose ¹ per procedure (μ Sv/procedure)							No. of persons
	Mean	SD	Min	Q1	Median	Q3	Max	
Nurses ²	9.9	12.2	0	0	1.5	21.6	31.7	20
Technicians	7.2	5.8	0	3.1	7.0	10.0	24.6	31
Unspecified ³ , IC	5.3	8.3	0	0.2	2.9	5.1	40.0	58
Unspecified ³ EP	0.6	0.6	0	0.1	0.2	0.8	1.9	11

¹ Lens dose means the reported value from a dosimeter specifically placed to measure lens dose or the reported over apron dose. For the persons in this table, all results were based on the over apron dose.

² If an additional single extreme “outlier” is included, the mean, standard deviation, minimum, 1st quartile, median, 3rd quartile and maximum become 77.3, 309, 0, 0, 1.7, 24.5, 1425, respectively.

³ Unspecified means that it was not stated whether the person was a nurse or technician.

I.7. Over apron dose to under apron dose ratios

TABLE I.21. RATIOS OF OVER APRON DOSE TO UNDER APRON DOSE, ANALYSED PER MONITORING PERIOD WHERE THERE WERE REPORTED VALUES FOR BOTH DOSIMETERS AND THE UNDER APRON DOSIMETER WAS NOT ZERO

	Ratio of over apron dose to under apron dose							Number of monitoring periods with data
	Mean	SD	Minimum	Q1	Median	Q3	Maximum	
All Physicians	14.5	19.1	0	2.0	7.5	19.2	129.2	106
Interventional cardiologists	12.7	18.7	0	1.8	6.0	14.9	129.2	90
Electrophysiologists	24.5	18.8	0.05	12.4	19.7	28.1	68.3	16

Note. These data come from only four facilities, and one of those had only one participating physician.

TABLE I.22. RATIOS OF OVER APRON DOSE TO UNDER APRON DOSE, ANALYSED PER PHYSICIAN FOR A YEAR, WHERE THERE WERE REPORTED VALUES FOR BOTH DOSIMETERS AND THE UNDER APRON DOSIMETER WAS NOT ZERO

	Ratio of over apron dose to under apron dose							Number of physicians with data
	Mean	SD	Minimum	Q1	Median	Q3	Maximum	
All Physicians	10.3	13.3	0	1.7	4.7	14.2	56.0	40
Interventional cardiologists	9.7	13.7	0	1.5	2.5	11	56.0	35
Electrophysiologists	14.4	9.4	1.8	9.0	15.2	20.2	26.0	5

Note. These data come from only four facilities, and one of those had only one participating physician.

I.8. Filtering the raw data to improve its quality

TABLE I.23. INFLUENCE ON THE ESTIMATES OF THE OVER APRON DOSE METRIC (OCCUPATIONAL DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE I.9) TO FILTER THE RAW DATA

Quality filter applied	Over apron dose per procedure ($\mu\text{Sv}/\text{proc}$)		Number of data
	Mean	2 x standard error	
No filter – raw data	22.0	4.9	63
QF1 > 75	27.0	5.6	46
QF1 = 100	28.0	6.3	40
QF2 > 50	23.1	5.2	56
QF2 > 75	22.6	5.4	53
QF2 = 100	26.3	6.8	31
QF4 < 150	28.1	5.2	46
QF4 < 100	28.4	5.7	37
QF4 < 50	33.5	9.3	18
QF1 = 100 & QF2 = 100	30.0	8.5	23
QF1 = 100 & QF4 < 100	32.0	7.1	27
QF1 = 100 & QF2 = 100 & QF4 < 100	30.9	8.7	22

TABLE I.24. INFLUENCE ON THE ESTIMATES OF THE UNDER APRON DOSE METRIC (OCCUPATIONAL DOSE PER PROCEDURE) FOR INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE I.9) TO FILTER THE RAW DATA

Quality filter applied	Under apron dose per procedure ($\mu\text{Sv}/\text{proc}$)		Number of data
	Mean	2 x standard error	
No filter – raw data	10.8	4.8	92
QF1 > 75	11.8	5.3	83
QF1 = 100	13.6	6.2	69
QF3 > 50	13.2	6.2	68
QF3 > 75	15.8	7.8	53
QF3 = 100	18.5	9.4	43
QF5 < 150	14.2	6.9	61
QF5 < 100	13.2	6.4	41
QF5 < 50	15.3	9.8	22
QF1 = 100 & QF3 = 100	21.5	11.0	36
QF1 = 100 & QF5 < 100	14.9	7.4	35
QF1 = 100 & QF3 = 100 & QF5 < 100	16.5	8.7	29

TABLE I.25. INFLUENCE ON THE ESTIMATES OF THE EFFECTIVE DOSE METRIC (OCCUPATIONAL EFFECTIVE DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE I.9) TO FILTER THE RAW DATA

Quality filter applied	Effective dose per procedure ($\mu\text{Sv}/\text{proc}$)		Number of data
	Mean	2 x standard error	
No filter – raw data	14.8	6.3	117
QF1 > 75	17.9	7.6	95
QF1 = 100	20.8	9.1	78
QF6 > 50	15.6	6.9	104
QF6 > 75	16.7	7.8	91
QF6 = 100	21.9	10.8	64
QF7 < 150	17.9	8.2	86
QF7 < 100	15.4	7.3	62
QF7 < 50	18.6	11.5	32
QF1 = 100 & QF6 = 100	27.2	13.5	50
QF1 = 100 & QF7 < 100	18.9	9.0	49
QF1 = 100 & QF6 = 100 & QF7 < 100	21.6	11.1	39

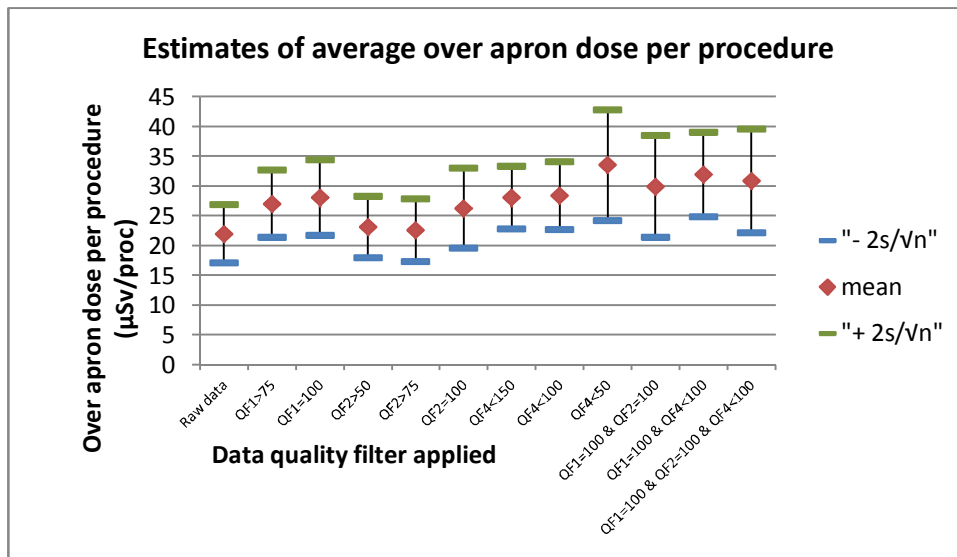


FIG. I.7. Estimates of the average over apron dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied.

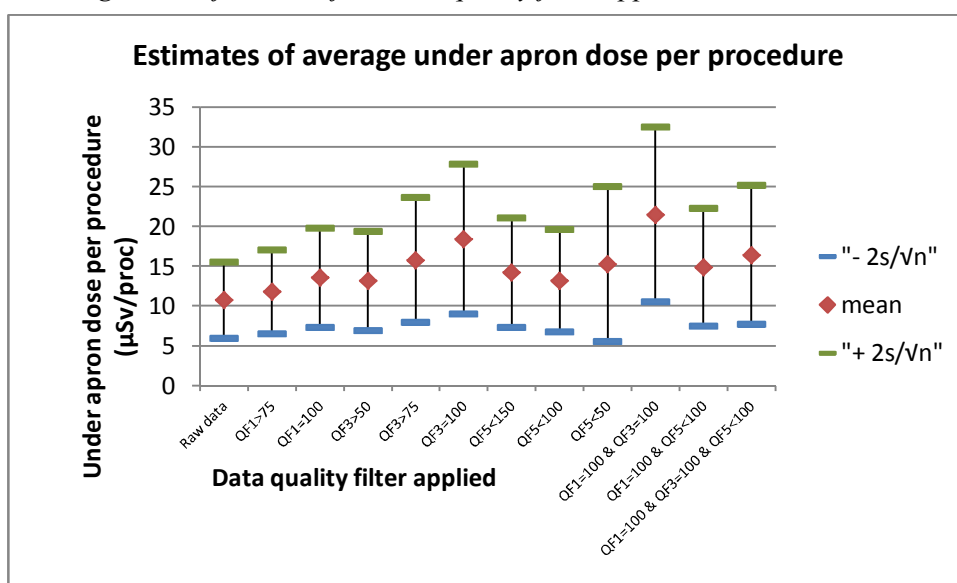


FIG. I.8. Estimates of the average under apron dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied.

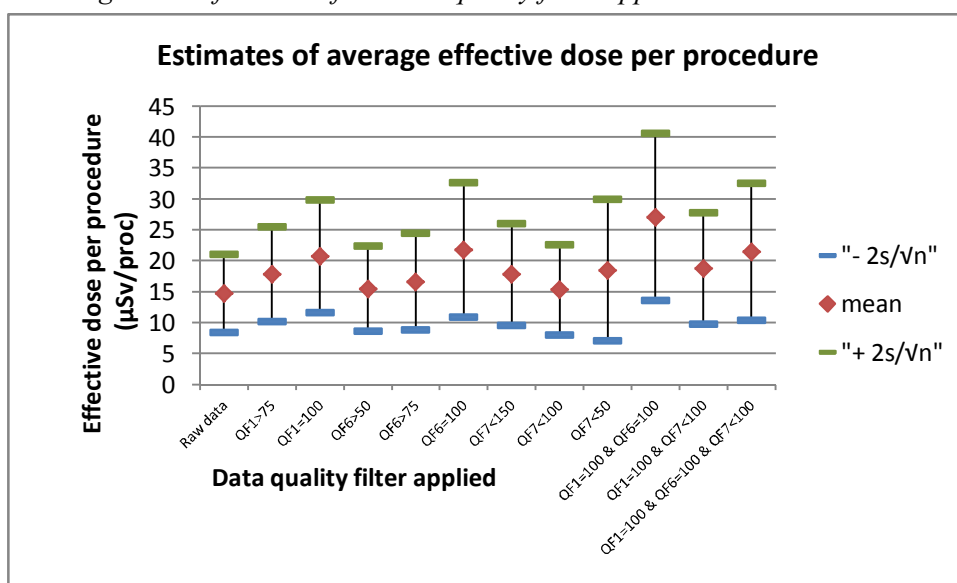


FIG. I.9. Estimates of the average occupational effective dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied.

TABLE I.26. INFLUENCE ON THE ESTIMATES OF THE OVER APRON DOSE METRIC (OCCUPATIONAL DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE I.9) TO FILTER THE RAW DATA, BUT EXCLUDING DATA FOR ANNUAL WORKLOADS OF LESS THAN 50 PROCEDURES

Quality filter applied	Over apron dose per procedure ($\mu\text{Sv}/\text{proc}$)		Number of data
	Mean	2 x standard error	
No filter – raw data	23.2	5.2	57
QF1 > 75	28.2	6.0	42
QF1 = 100	29.0	6.7	37
QF2 > 50	24.3	5.4	51
QF2 > 75	23.5	5.5	49
QF2 = 100	26.7	7.1	29
QF4 < 150	28.8	5.4	43
QF4 < 100	28.8	5.9	35
QF4 < 50	33.5	9.3	18
QF1 = 100 & QF2 = 100	30.8	9.0	21
QF1 = 100 & QF4 < 100	32.8	7.4	25
QF1 = 100 & QF2 = 100 & QF4 < 100	31.9	9.2	20

TABLE I.27. INFLUENCE ON THE ESTIMATES OF THE UNDER APRON DOSE METRIC (OCCUPATIONAL DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE I.9) TO FILTER THE RAW DATA, BUT EXCLUDING DATA FOR ANNUAL WORKLOADS OF LESS THAN 50 PROCEDURES

Quality filter applied	Under apron dose per procedure ($\mu\text{Sv}/\text{proc}$)		Number of data
	Mean	2 x standard error	
No filter – raw data	8.9	3.7	85
QF1 > 75	9.6	4.0	77
QF1 = 100	11.0	4.7	64
QF3 > 50	10.6	4.6	64
QF3 > 75	12.6	5.7	50
QF3 = 100	14.2	6.7	41
QF5 < 150	11.3	5.0	58
QF5 < 100	12.3	6.3	40
QF5 < 50	13.6	9.6	21
QF1 = 100 & QF3 = 100	16.6	7.9	34
QF1 = 100 & QF5 < 100	13.8	7.2	34
QF1 = 100 & QF3 = 100 & QF5 < 100	15.2	8.7	28

TABLE I.28. INFLUENCE ON THE ESTIMATES OF THE EFFECTIVE DOSE METRIC (OCCUPATIONAL DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS FROM THE USE OF QUALITY FACTORS (SEE TABLE I.9) TO FILTER THE RAW DATA, EXCLUDING DATA FOR ANNUAL WORKLOADS OF LESS THAN 50 PROCEDURES

Quality filter applied	Effective dose per procedure ($\mu\text{Sv}/\text{proc}$)		Number of data
	Mean	2 x standard error	
No filter – raw data	12.2	4.8	109
QF1 > 75	14.6	5.7	89
QF1 = 100	16.9	6.8	73
QF6 > 50	12.7	5.1	97
QF6 > 75	13.5	5.8	85
QF6 = 100	17.0	7.9	60
QF7 < 150	14.3	5.9	83
QF7 < 100	14.3	7.0	61
QF7 < 50	16.5	11.0	31
QF1 = 100 & QF6 = 100	21.3	10.0	46
QF1 = 100 & QF7 < 100	17.5	8.7	48
QF1 = 100 & QF6 = 100 & QF7 < 100	19.9	10.8	38

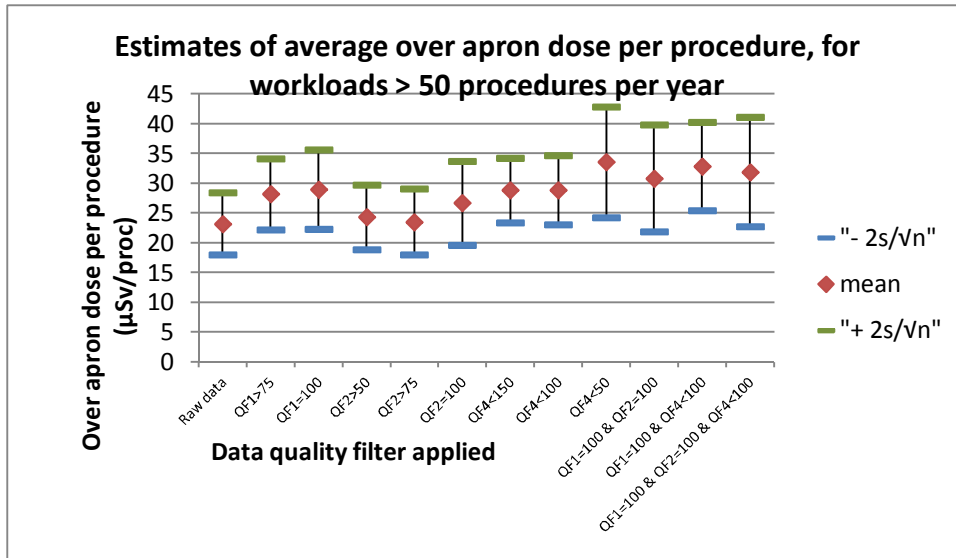


FIG. I.10. Estimates of the average over apron dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied, excluding data for annual workloads of less than 50 procedures.

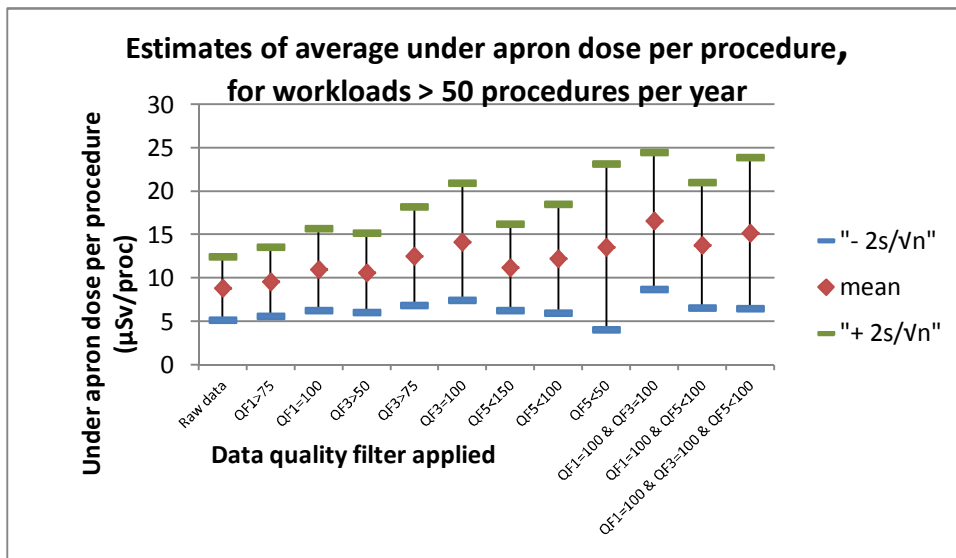


FIG. I.11. Estimates of the average under apron dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied, excluding data for annual workloads of less than 50 procedures.

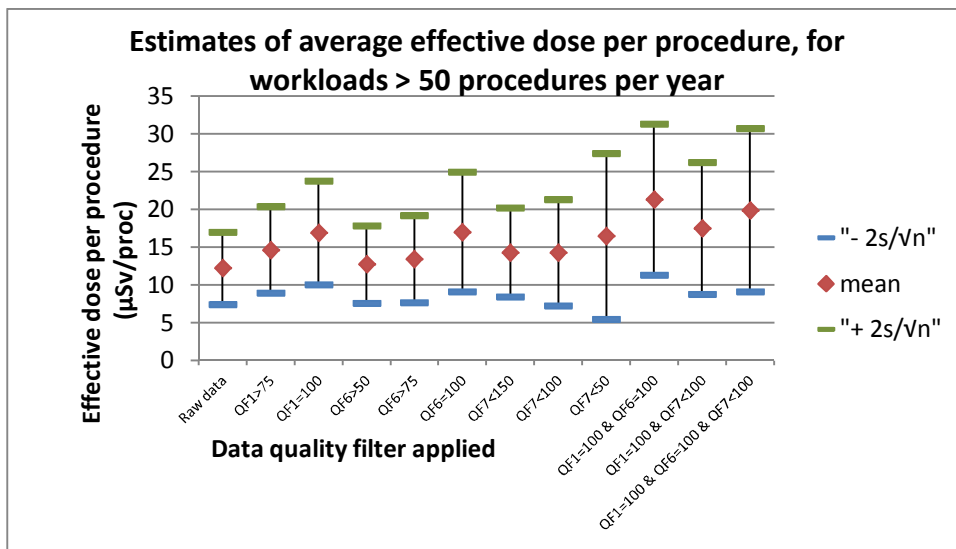


FIG. I.12. Estimates of the average occupational effective dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied, excluding data for annual workloads of less than 50 procedures.

TABLE I.29. INFLUENCE ON THE COEFFICIENT OF CORRELATION BETWEEN THE ANNUAL OVER APRON DOSE AND THE ANNUAL NUMBER OF PROCEDURES FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE I.9) TO FILTER THE RAW DATA

Quality filter applied	All workloads		Only workloads > 50 procedures per year	
	No. of data	Coefficient of correlation ¹ , r	No. of data	Coefficient of correlation ¹ , r
No filter – raw data	63	0.75	57	0.73
QF1 > 75	46	0.81	42	0.80
QF1 = 100	40	0.87	37	0.86
QF2 > 50	55	0.76	50	0.74
QF2 = 100	31	0.71	29	0.69
QF4 < 150	46	0.72	43	0.70
QF4 < 100	37	0.73	35	0.71
QF4 < 50	18	0.83	18	0.83
QF1 = 100 & QF2 = 100	23	0.88	21	0.87
QF1 = 100 & QF4 < 100	27	0.88	25	0.87
QF1 = 100 & QF2 = 100 & QF4 < 100	22	0.88	20	0.87

¹ Pearson product-moment correlation coefficient

TABLE I.30. INFLUENCE ON THE COEFFICIENT OF CORRELATION BETWEEN THE ANNUAL UNDER APRON DOSE AND THE ANNUAL NUMBER OF PROCEDURES FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE I.9) TO FILTER THE RAW DATA

Quality filter applied	All workloads		Only workloads > 50 procedures per year	
	No. of data	Coefficient of correlation ¹ , r	No. of data	Coefficient of correlation ¹ , r
No filter – raw data	92	0.10	85	0.05
QF1 > 75	83	0.08	77	0.03
QF1 = 100	69	0.14	64	0.10
QF3 > 50	58	0.08	55	0.05
QF3 = 100	43	0.02	41	-0.01
QF5 < 150	61	0.09	58	0.06
QF5 < 100	41	0.03	40	0.01
QF5 < 50	22	0.05	21	0.03
QF1 = 100 & QF3 = 100	36	0.01	34	-0.03
QF1 = 100 & QF5 < 100	35	0.01	34	-0.01
QF1 = 100 & QF3 = 100 & QF5 < 100	29	0.03	28	0.01

¹ Pearson product-moment correlation coefficient

TABLE I.31. INFLUENCE ON THE COEFFICIENT OF CORRELATION BETWEEN THE ANNUAL OCCUPATIONAL EFFECTIVE DOSE AND THE ANNUAL NUMBER OF PROCEDURES FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE I.9) TO FILTER THE RAW DATA

Quality filter applied	All workloads		Only workloads > 50 procedures per year	
	No. of data	Coefficient of correlation ¹ , r	No. of data	Coefficient of correlation ¹ , r
No filter – raw data	117	0.11	109	0.06
QF1 > 75	95	0.05	89	0.01
QF1 = 100	78	0.12	73	0.08
QF6 > 50	97	0.12	91	0.08
QF6 = 100	64	0.05	60	0.01
QF7 < 150	86	0.03	83	0.02
QF7 < 100	62	0.00	61	-0.01
QF7 < 50	32	-0.06	31	-0.08
QF1 = 100 & QF6 = 100	50	0.09	46	0.04
QF1 = 100 & QF7 < 100	49	0.04	48	0.03
QF1 = 100 & QF6 = 100 & QF7 < 100	39	0.04	38	0.03

¹ Pearson product-moment correlation coefficient

I.9. Benchmarking the performance of qualified interventional cardiologists in IC facilities

TABLE I.32. MEAN OCCUPATIONAL EFFECTIVE DOSE PER PROCEDURE FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, AVERAGED PER IC FACILITY

IC Facility	Raw data		Filtered data – QF6 > 75 and QF7 < 150	
	No. of physicians	Mean ED per procedure (μSv/procedure)	No. of physicians	Mean ED per procedure (μSv/procedure)
A	5	1.3	2	3.2
B	10	0.9	4	1.9
C	3	4.0	2	6.0
D	9	17.8	3	2.5
E	13	6.8	9	4.8
F	5	10.4	5	10.4
G	14	75.8	13	80.3
H	3	2.1	3	2.1
I	5	9.2	5	9.2
J	6	1.4	6	1.4
K	6	4.2	5	4.3
L	4	3.3	2	6.7
M	4	3.8	0	-
N	4	20.9	4	20.9
O	8	1.5	0	-
P	7	1.0	2	1.2
Q	1	2.4	0	-
R	6	17.2	3	17.7
S	1	2.5	0	-
T	3	5.8	0	-

TABLE I.33. ESTIMATES OF MEAN OCCUPATIONAL EFFECTIVE DOSE PER PROCEDURE FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS DIVIDED INTO TWO GROUPS BASED ON THEIR REPORTED ANNUAL WORKLOAD – THOSE WHO PERFORMED FEWER THAN 150 PROCEDURES IN THE REPORTED YEAR AND THOSE WHO PERFORMED 150 PROCEDURES OR MORE

Reported number of procedures performed	Number of qualified interventional cardiologists	Mean ED per procedure (μSv/procedure)	2 x Standard Error
< 150	44	27.1	15.8
≥ 150	93	5.65	1.6

APPENDIX II. MEMBERS OF THE ISEMIR WORKING GROUP ON INTERVENTIONAL CARDIOLOGY (WGIC)

<p>WGIC Chairperson: Mr Renato Padovani SOC di Fisica Sanitaria Azienda Ospedaliero-Universitaria Santa Maria della Misericordia Piazzale S. Maria della Misericordia, 15 33100 Udine, Italy Email: padovani.renato@aoud.sanita.fvg.it</p>	
<p>WGIC Members:</p>	
<p>Mr Ariel Duran Cardiólogo intervencionista Servicio de Hemodinamia de Adultos 8 de Octubre 2519 bis CP 11600 Montevideo, Uruguay Email: aduran@hc.edu.uy</p>	<p>Mr Donald L. Miller Food and Drug Administration Silver Spring Maryland, USA Email: Donald.Miller@fda.hhs.gov</p>
<p>Mr Sim Kui Hian Sarawak General Hospital Department of Cardiology Jalan Tun Ahmad Zaidi Adruce 63500 Kuching Sarawak, Malaysia Email: sim.kui.hian@health.gov.my</p>	<p>Mr Eliseo Vano Carruana Professor of Medical Physics Radiology Department. Medicine School Complutense University 28040 Madrid, Spain Email: eliseov@med.ucm.es</p>
<p>Consultant to the IAEA:</p>	
<p>Mr Christian Lefaure 2, square Leon Guillot 75015 Paris, France Email: clefaureconsult@free.fr</p>	
<p>IAEA staff:</p>	
<p>Scientific Secretary: Mr John Le Heron Radiation Protection of Patients Unit Division of Radiation, Transport & Waste Safety IAEA, Wagramerstraße 5 1400 Vienna, Austria Email: John.Le.Heron@iaea.org</p>	<p>Ms Hye-Kyung Son Radiation Protection of Patients Unit Division of Radiation, Transport & Waste Safety IAEA, Wagramerstraße 5 1400 Vienna, Austria Email: H.Son@iaea.org</p>

REFERENCES

1. Padovani, R., et al., International project on individual monitoring and radiation exposure levels in interventional cardiology, *Radiat. Prot. Dosimetry* **144**(1-4) (2011), 437-441.
2. International Commission on Radiological Protection. Avoidance of radiation injuries from medical interventional procedures. ICRP Publication 85. *Ann ICRP* 2000; 30(2).
3. International Commission on Radiological Protection. Radiological protection in cardiology. ICRP Publication 120. *Ann ICRP* 2013; 42(1).
4. Clerinx P, Buls N, Bosmans H, de Mey J. Double-dosimetry algorithm for workers in interventional radiology. *Radiat Prot Dosimetry* **129** (2008), 321-7