Assessing Occupational Exposure to Radiation in Nuclear Medicine Laboratories in Newfoundland and Labrador's Hospitals

by

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Abstract

Among the health care workers, nuclear medicine staff are the highest in terms of exposure to ionizing radiation [1][2]. In response to this and as a compliance with the international and national standards, clinical sites have developed detailed procedures to minimize and monitor the occupational exposure. Our study aims to assess the feasibility of using available radiation dose data in the clinical settings in NL for research purposes, and to assess the occupational radiation dose to nuclear medicine staff in Newfoundland and Labrador's hospitals for the period of 2007 to 2018. Furthermore, our goal is to investigate the general trend of these doses and the effect of technology change on occupational radiation dose. Our study found that the average annual whole body and extremities doses were well below the 50 mSv for whole body dose limit and the 500 mSv for extremities limit which are set by the Canadian Nuclear Safety Commission (CNSC). The average annual whole-body doses in the Health Science's Centre and St. Clare's Hospital were below the worldwide average annual dose of 1.9 mSv that was reported by The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)[3]. Overall data showed that 78% of the high value measurements were readings for experienced participants and 22% of the high value readings were for new staff or less experienced participants. Technology changes, such as installing a new imaging machine in HSC shows an impact on the occupational radiation dose trend. Our currently available data is not enough to

detect the correlation between the dose variations and (i) the number of procedures, (ii) number of staff, or (iii) type of radiopharmaceuticals. This is establishing the need to enhance the quality of the occupational radiation dose records.

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Chapter 1

Introduction and Basic Background

1.1 Introduction

One of the hazards that health care professionals working in the nuclear medicine department face, is the possible ongoing exposure to ionizing radiation. Multiple standards have been developed in this area, not only to limit occupational exposure but also to mitigate the interplay between professional exposure to ionizing radiation and health incidences [4] [5] [6]. Maintaining a low level of occupational radiation exposure has been the core concern of governments across the globe. Canada considers 50mSv to be the annual whole body dose limit and 500 mSv to be the annual extremities dose limit for Nuclear Medicine workers. [6]. These national limits are supported by other international standards including the International Atomic Energy Agency (IAEA)[5], the International Commission on Radiological Protection (ICRP)[7], and the International Labor Organization (ILO)[8] whose principles are to offer protection to radiation workers and public. Researchers in nuclear medicine field have studied different aspects of the occupational exposure to radiation. Some of whom have tracked the evolution in the use of the radiopharmaceuticals and tried to estimate the

occupational doses historically since the very beginning of their introductions before 1960s up until recent times [9] [10]. Other researchers have investigated suggested techniques to minimize the occupational radiation dose [11] [12] [13]. A few other researchers have dedicated their work to assessing annual radiation doses to ensure that radiation doses of nuclear medicine workers are well controlled and within the permitted limits[2][1][14][15]. Findings of these studies are explained in the literature review section.

The hospitals in the Province of Newfoundland and Labrador are recording the radiation doses of nuclear medicine workers both at the whole body level and at the extremities level only on paper records.The current study is about creating a database using the existing paper record data of the documented radiation exposure to Health Care Professionals working in nuclear medicine departments in hospital setting in Newfoundland and Labrador since 2010 to 2018, and assessing how well these hospitals are adhering to Canadian guidelines through the changes in technology over time. Before presenting the literature review, methodology, we present in what follows the basic background information regarding the isotopes and exposure to the isotopes radiation.

1.2 Basic Information on Radioactivity, Radionuclides, and Radiopharmaceuticals

1.2.1 Isotopes

An atom is made up of three types of particles which are known as subatomic particles. These subatomic particles are called (i) protons, (ii) neutrons and (iii) electrons. Protons and electrons are charged particles in which the electron carries a negative

charge while the proton carries a positive charge and neutrons carry no charge. In a neutral atom, the number of protons and electrons is always the same. The Atomic Number (Z) represents the number of protons. The collective number of neutrons (N) and protons (Z) in an atom is known as Atomic Mass number (A=N+Z) which lies in the nucleus of an atom. Where the number of protons and electrons remain the same in all the atoms of an element, the number of neutrons may vary, creating different types of atoms of the same element which are called isotopes. Hence, isotopes of an element are atoms which have the same atomic numbers but different mass numbers. For example, I-131 and I-123 are different isotopes of Iodine where both have the same atomic number 53, but differ in the atomic mass 131 for the former and 123 for the latter, as their number of neutrons are different.[16]

1.2.2 Stability and Decay

Among these different isotopes of the same element, some are stable, while others are unstable in nature and they emits ionizing radiation and go through decay to achieve stability. The isotopes emitting this radiation are referred to as radionuclides.[16]

Alpha-particle emission is the type of emission which involve the emission of particles consisting of two protons and two neutrons (making up one alpha particle), leading to reduction in proton and neutron number. Emission of electrons (beta particle) is also common in radionuclides which is known as Beta-particle emission. In another phenomenon, the protons may capture the electrons from the innermost shells forming a neutron and a neutrino, this phenomenon is called as Electron capture, in which the number of neutrons increases by one and the number of protons decreases by one. The type of emission in which the number of protons, and neutrons remain unchanged is known as gamma rays emission and the transition is called an isomeric transition. In a case where there is a measurable delay in the emission of the gamma-

ray photon by a radio-nucleus, given that the decay process is an isomeric transition, this intermediate excited state of the specific isotope is referred to as metastable. In radionuclides where there are a relative excess of protons, protons convert into neutrons and positron emission takes place. [16]

1.2.3 Radionuclide Production

Radioisotopes can be prepared synthetically by particulate bombardment or fission causing an unstable change in proton to neutron ratio in the nucleus. The following equation represents the formation of a radioisotope by bombarding with neutrons and causing the emission of radiation, more specifically gamma radiation from Molybdenum. [16]

$$ {}^{A}_{Z}X + n(neutron) \longrightarrow {}^{A+1}_{Z}X + Y, \tag{1.1} $$

$$ {}^{98}_{42}Mo + n(neutron) \longrightarrow {}^{99}_{42}Mo + Y, \tag{1.2} $$

Nuclear fission of Uranium-235 produces fission isotopes including Iodine (131I), Xenon (133Xe), Strontium (90Sr), Molybdenum (99Mo), Cesium (137Cs), and others. Isotopes can also be produced via cyclotron, which usually consists of electron capture or positron emission. Some examples include Iodine-123, Fluorine-18, Gallium-67, Indium-11, and Thallium-201 [16].

1.2.4 Radioactive Decay

The amount of disintegration taking place per second in a radioactive atom is known as its 'activity'. The old SI unit of radioactivity is Curie ($3.7*10^{10}$ disintegration per second). However, the new and convenient SI unit is Becquerel (Bq), which is

one disintegration per second. The activity of a radio-isotope per unit mass of that element is referred to as its specific activity. A longer half-life will mean lower specific activity. Half-life of a radioactive isotope is the time required by a radionuclide to reduce to half of its original activity. The physical half-life (Tp) is equal to $0.693/\lambda$, whereλ is the decay constant which differs for different radioactive isotopes. The following formula can be used to calculate the activity (A) of a certain isotope at a giving time (t). [16]

$$A = Aoe^{\frac{-0.693}{Tp}(t)}, \tag{1.3}$$

Where Ao is the initial activity at time 0, Tp is physical half-life, and t is given time.

Biological half-life is the time it takes for a living organism to get rid of half of the chemical compound i.e. to eradicate it out of its system. While the term effective half-life is used for pharmaceutical procedures as it incorporates both physical and biological half-life of a radioactive chemical and the following formula can be used for its calculation;

$$Te = \frac{Tp \times Tb}{Tp + Tb}, \tag{1.4}$$

Where Te is effective half-life, Tp is physical half-life and Tb is Biological half-life. [16]

1.2.5 Generator Systems

The radionuclides used in nuclear medicine are usually generated as short-lived isotopes emitting gamma rays as they decay. Some common isotopes are generated via on-site generators. These include Technetium-99m, Indium-113m, Krypton-81m, Rubidium-82, Strontium-87m, and Gallium-68 etc. Generators have a parent element

attached to a column which keeps decaying and then produces daughter radioactive elements. A common parent element is Molybdenum-99 which is attached to an alumina column. It has a 67 hour half-life and produces 99mTc which has a half-life of only 6 hours and can be removed easily from the column. Dry as well as wet 99Mo-99mTc generator systems are available. Where the former uses a saline reservoir and a vacuum vial that draws saline across the column, and the latter involves a specific amount of saline in a vial which is placed on the generator entry port and drawn across by a vacuum vial. [16]

When the parent isotope has a slightly greater half-life than the daughter isotope, the equilibrium obtained is called transient equilibrium. This is applicable in 99Mo-99mTc generator systems which is used in most hospitals. In one half-life i.e. 6 hours, the quantity of generated 99mTc reaches about half the theoretical maximum. This indicates that 24 hours (4 half-lives) the amount of 99mTc again reaches to 95% in the generator (as per theoretical maximum). [16].

1.2.6 Radionuclides and Radiopharmaceuticals for Imaging

There are certain qualities of a radionuclide which makes it feasible to be used in nuclear medicine. These qualities are that the radionuclides should have minimum particulate emission; its emitted photon energy should range from 50-511keV; its Tp should be more than the time required to prepare injection while Te should be more than the examination time needed; its chemical form and reactivity should be suitable for human use and it should be none toxic; it should be stable or at least near-to-stable. Some of the most commonly used radionuclides are given below [16].

Technetium-99m

Technetium-99m is used in more than 80% of imaging procedures in USA. With no particle emission and a 6 hours half-life, it emits photon with energy of 140keV and exhibits only 10% internal conversion. It is obtained from a Molybdenum-99 parent generator. It exists in the valence states from -1 to +7. When eluted from the alumina column, it is found in heptavalent state. It could be administered in the form of pertechnetate which binds loosely to protein and leaves the plasma of the cell to be released in the extracellular matrix. It rapidly concentrates in the salivary glands, choroid plexus, thyroid gland, gastric mucosa, and functioning breast tissue and crosses the placenta during pregnancy. It is excreted out of the body via both gastrointestinal and renal secretions.[16]

Table 1.1: Imaging Radiopharmaceuticals and its' Historical Uses. Adapted From (Mettler et.al, 2012; Drozdovitch et.al, 2015)

Radionuclide	Radiopharmaceuticals	Uses (procedure)	history (first used)
Technetium-99m	Diphosphonate	Bone	-
	Diisopropyliminodiacetic Acid	Biliary	Mid 1980s
	DMSA (dimercaptosuccinic acid)	Renal cortical	Mid 1970s
	DTPA	Renal, brain, lung	1970s,1960s
	ECD(ethyl cysteinate dimmer)	Brain perfusion	Early1990s
	Glucoheptonate	Brain,renal dynamic	1970s,1970s
	Hexamethylpropyleneamine oxine	Brain perfusion	Mid 1980s
	Labelled red cells	GI bleeding, cardiac	1960s,1970s
	MAA (macroaggregated albumen)	Lung perfusion	Mid1960s
	MAG3(mercaptoacetyltriglycine)	Renal	Early 1990s
	Mebrofenin	Biliary	Mid 1970s
	Pertechnetate	Thyroid scan	Mid 1960s
	Sestamibi	Myocardial, thyroid	Mid1980s, -
	Sulphur colloid	Liver, bone marrow	Mid1960s, mid1960s
	Teboroxime	Myocardial perfusion	-
	Tetrofosmin	Myocardial perfusion	Early 1990s

Table 1.2: Iimaging Radiopharmaceuticals and its' Historical Uses. Adapted From (Mettler et.al, 2012; Drozdovitch et.al, 2015)

Radionuclide	Radiopharmaceuticals	Uses (procedure)	history (first used)
Iodine-123	Sodium	Thyroid scan	Early 1970s
		Thyroid uptake	Mid 1970s
Iodine-131	sodium	Thyroid	Early 1960s

Iodine-123 and Iodine-131

Both isotopes of iodine, I-123 (13.2 h) and I-131 (8.06 d), are used for imaging in clinical applications, and usually administered in the form of iodide. I-123 emits 28keV (92%) and 159keV (84%) photon energy and decays to form Tellurium-123. It is commonly produced by cyclotron bombardment of Antimony-121 (Sb-121), or by bombarding I-127. I-131 is not considered suitable for imaging purposes, due to the fact that it has a long half-life, and the beta-particle emission involved in its decay. However, it is cheaper than alternatives. Iodine concentrates in salivary glands, thyroid, and gastric mucosa, its oral administration leads to its absorption by gastrointestinal tract and it can be found in extracellular fluid. It mainly gets secreted by urinary route. [16]

Xenon-133

Xenon-133 is used commonly for pulmonary ventilation studies because it is an inert gas. It is insoluble in water and soluble in fat and oil which is considered as a drawback for its usage. It has a Tp of 5.3 days while Tb is 30 seconds. Its main radiation consists of gamma photon with an energy of 81keV and also emits a 374keV beta particle [16]

Table 1.3: Imaging Radiopharmaceuticals and its' Historical Uses. Adapted From (Mettler et.al, 2012; Drozdovitch et.al, 2015)

Radionuclide	Radiopharmaceuticals	Uses (procedure)	history (first used)
Xenon-127 or 133	Gas	Lung ventilation	Mid 1960s
Gallium-67	citrate	tumor	Mid 1970s

Gallium-67

Produced by different cyclotron reactions, the physical half-life of Gallium-67 is 78.3 h. It emits gamma photons in a wide energy range including 90, 190, 290, and 390 keV. It readily attaches to the plasma proteins when administered via injection. In the first 24 hours, elimination takes place through urine and afterwards the body gets rid of Ga-67 through intestinal excretions. However, only one-third gets secreted and the remaining gallium resides in the body for a far longer period of time. It accumulates in the bowl can creates confusion in future diagnosis as it my mask disease. [16]

Indium-111

Two Isotopes of indium have been found to be of interest including In-111 and In-113m. The former has a physical half-life of 67 h and can be produced by a cyclotron. Its main photons emitted are 173keV (89%) and 247keV (94%). In-113m has a physical half-life of 1.7 hours and photon energy of 392keV. Indium-113m can be produced through Sn-113 generator. Indium-111 is used for intracranial cisternography, to label platelets, white cells, monoclonal antibodies, and peptides. with the use of Indium-111, activities can be seen in liver and spleen and also in bone marrow [16].

Thallium-201

Thallium-201 is produced in cyclotron protons bombardment with thallium metal target, having a Tp of 73.1 hours. Its production is expensive. Thallium-201 is

Table 1.4: Imaging Radiopharmaceuticals and its' Historical Uses. Adapted From (Mettler et.al, 2012; Drozdovitch et.al, 2015)

Radionuclide	Radiopharmaceuticals	Uses (procedure)	history (first used)
Indium-111	DTPA	CSf flow	Early 1980s
-	Oxine labeled white cells	Infection	-
-	pentetreotide	Tumors	Early 1990s

Table 1.5: Imaging Radiopharmaceuticals and its' Historical Uses. Adapted From (Mettler et.al, 2012; Drozdovitch et.al, 2015)

Radionuclide	Radiopharmaceuticals	Uses (procedure)	history (first used)
Thallium-201	chloride	Myocardial perfusion	Early 1970s
Fluorine-18	FDG (flurodeoxyglucose)	Tumor, cardiac ,brain	Mid1980s, early1990s,mid1980s
	Sodium	Bone	Mid 1960s

administered in a chloride form and has a Tb of 30sec-3min. It mostly spreads into skeletal and cardiac muscles. Any presence of Thallium-202 contamination can hinder the imaging [16]

Fluorine-18

Fluorine-18 fluorodeoxyglucose (18F-FDG) are the most commonly used positron emitting particles in clinical imaging practices. It takes part in glucose metabolism but can stay for longer time period in the cells. It can be detected and give information regarding the normal and abnormal cells of the body. this process is mainly used in tumour detection. Excretion mostly occurs through renal system. Pregnancy and breast feedings should be taken into account when it is administered to women as it may present in breastmilk [16].

1.2.7 Adverse Reactions

There are no immunological reactions to simple radiopharmaceuticals preparations. on the other hand there may be inflammatory responses as some compounds are toxic. Mild reaction might occur, but generally they are as safe as any other drug. The incidence rate of adverse reactions in USA is 2.3/100,000 administrations. These include rash, itching, dizziness, nausea, chills, flushing, hives, and vomiting [16].

1.3 International standards and Canadian regulations

There are more than 800,000 nuclear industry workers in the world and also there are more than two million workers in the health care industry who are also exposed to radiation [17]. In Canada alone, there are about 40,000 workers in the nuclear industry [17]. All organizations and licensees are subjected to a number of regulations and rules which are set by the Canadian Nuclear Safety Commission (CNSC) and comply with the international standards in order to make working in contact with radiation sources, safe and well controlled [6]

Nuclear energy involving radioactive elements is being used in different areas of life today. Where it has some great benefits, the prolonged exposure of living organisms to ionizing radiation can be harmful and even dangerous. Hence, the need to make a plan for the occupational radiation protection is inevitable. The term occupational exposure refers to the exposure of a worker, which is received by or committed to the worker during a specific period of time while he/she works. Basic Safety Standards (BSS) includes the exposure limits, which should not be exceeded over a period of time. All the companies using the natural or synthetic nuclear energy resources should follow the guidelines provided in BSS. There are two types of situations when a program regarding the protection against nuclear radiation is being designed. These can be termed as practices and interventions, where the former involves the actions and tasks that involve the use of nuclear energy, while the latter deals with those actions which are taken to limit its exposure to the public and workers [5].

According to the United Nations Scientific Committee, there is an annual average effective dose of 2.4mSv received globally from all the natural radiation which include cosmic rays, radon, etc [17]. On the other hand, most of the man-made radiation

exposure is associated with medical procedures. The Linear No-Threshold Model (LNT) is "the risk model used to set the radiation dose limits for the workers and the members of the public" [6]. The Canadian Nuclear Safety Commission is the organization that determines the radiation dose limits to workers and public in Canada. The CNSC follows the recommendations of the International Commission on Radiological Protection, and the standards of the International Atomic Energy Agency [6]. These standards and regulations regarding the occupational radiation protection include: dose limits for workers, monitoring doses, radiation protection programs and so many other aspects which can be illustrated in details at the following sections.

Definitions

According to CNSC, the absorbed dose is "The energy deposited by ionizing radiation to a suitably small volume of matter divided by the mass of that volume. The unit of measurement is the gray (Gy)".[18]

According to CNSC, the effective dose is "A measure of dose designed to reflect the amount of radiation detriment. The effective dose is obtained by multiplying the equivalent dose of each tissue or organ by an appropriate tissue weighting factor and summing the products. The unit of measurement is the sievert (Sv)" [18]. This represents the whole-body dose.

According to CNSC, the equivalent dose is "A measure of the dose to a tissue or organ designed to reflect the amount of harm caused to the tissue or organ. The equivalent dose is obtained by multiplying the absorbed dose by a radiation weighting factor to allow for the biological effectiveness of the various types of radiation in causing harm to tissue. The unit of measurement is the sievert (Sv)" [18]. In our study this is represented by the extremities dose.

Radiation Protection Program

The Canadian Radiation Protection Regulations stipulated that a radiation protection program must be established and implemented by the licensee. Taking social and economic factors into account, the exposure amount of radiation must be as low as reasonably achievable [6].This can be done by:

- Having good management control over work practices. [6]
- providing training to qualify staff. [6]
- be ready for any unexpected incident. [6]

Furthermore the quantity of the substance being used in the licensed procedures should be established and reported, this can be achieved by [6]:

- Measuring its amount directly by using specific monitoring tools. [6]
- In a case where monitoring the quantity, utilizing resources that outweighs the usefulness of the monitoring, the quantities should be estimated. [6]

1.3.1 Dosimetry Services

Requirement to use Licenced dosimetry service

Dosimetry services measure and monitor the radiation doses to which the people or the employees working around nuclear energy are exposed. Every licensee should have a licenced dosimetry service as having this service makes it possible to estimate the occupational exposure to radiation for workers. This requirement must be followed in any situation where it is reasonably possible for the workers to receive a dose higher than 5mSv over a one-year dosimetry period [6].

Radiation Dose Limit

BSS defines dose limit as “the value of the effective dose or equivalent dose to individuals from controlled practices that shall not be exceeded" [5]. There are certain basic limits, which are defined by BSS and should not be exceeded in order to ensure the occupational protection of the workers. These are further explained in the Canadian context in the upcoming sections.

Effective Dose Limits

The licensee should make sure that the effective doses of radiation received by the workers or any member of the public is not exceeding the stipulated limits. Following are the regulated effective doses limits [6]:

- General workers working in a nuclear energy environment in a one-year dosimetry period have an effective dose limit of 50mSv and in a five-year dosimetry period have an effective dose limit of 100mSv. [6]
- Specifically, a pregnant nuclear energy worker working in a nuclear energy environment has an effective dose limit of 4mSv. [6]
- However, a person who is not a nuclear energy worker has an annual effective dose limit of 1mSv. [6]

Equivalent Dose Limits

The doses of radiation received by the organs and tissues of the persons working in a nuclear energy environment should be monitored and maintained. Thus, it should not exceed the set dose limits[6]. The main equivalent doses limits are given below:

- In a one-year dosimetry period the equivalent dose limit in reference to eyes, for a nuclear energy worker is 150mSv while for any other member of public (one calendar year) is 15mSv. [6]

• In a one-year dosimetry period the equivalent dose limit in reference to skin, for a nuclear energy worker is 500mSv while for any other member of the public (one calendar year) is 50mSv.[6]

• In a one-year dosimetry period the equivalent dose limit in reference to hands and feet, for a nuclear energy worker is 500mSv while for any other member of the public (one calendar year) is 50mSv. [6]

Dose Assessment and Monitoring

It is very important to keep a proper check on the dose limits via proper monitoring and measurements. Monitoring does not simply imply to the measurements of doses, instead it involves the proper analysis and assessment of data collected through measurements. Monitoring has many other benefits; it provides the data for research purposes, indicating level of exposure at a particular workplace. It motivates the workers as they are being taken good care of, and helps maintain a healthy work environment. It is basically a technique, which is used for ensuring the radiological protection [5]

Monitoring Program

A good monitoring program is made to achieve several purposes. All of these should be aimed to attain in the planning of a good monitoring program. It confirms the good engineering and working practices of the particular work place. It gives information regarding the conditions of workplace and how it has been affecting the exposure to nuclear energy. It provides the exposure data and ensures that it is within the limits provided in the guidelines. It helps the operational systems to evolve and get better after every assessment. [5]

It is important that the objectives of the monitoring are clear and well defined as

the design of the program is based on successfully achieving those objectives. The design of the monitoring program is prepared in such a way that it meets the quality assurance requirements. The results are recorded and further assessed based on goals of the program. Separate monitoring programs should be created for the purpose of dose assessment and control operations. It is imperative to keep the records of the monitoring program, as that will help the management to devise strategies for the improvement of control procedures. These aspects should be reviewed on a regular basis to ensure that the monitoring efforts are being conducted effectively. Three types of monitoring are conducted, these include routine monitoring, task related monitoring and special monitoring. [5]

Routine monitoring is done on the on-going operations, in order to assess the working conditions of the workplace to make sure that it meets the regulatory standards. Task based monitoring is conducted on a specific operation providing data for the particular operation in order to take immediate decisions regarding that particular operation. However, special monitoring is for investigational reasons. It provides detailed information to solve the problems which impede successful exposure control. All three of the mentioned monitoring types can be applied on two levels: individual monitoring and workplace monitoring, where the latter deals with the measurements made to assess the whole workplace environment while the former deals with the monitoring of individual exposure, which is measured by the equipment worn by workers. Workplace monitoring involves the assessment of external radiation, surface contamination and air contamination. These can be taken as the sub-divisions of workplace monitoring.[5]

Individual Monitoring

According to BSS, workers who are exposed to radiation in a controlled area and receives considerable occupational exposure should be subjected to individual monitoring where feasible [5]. However, in situations where individual monitoring is not feasible, occupational monitoring is conducted based on the workplace monitoring results and on the position and the duration of exposure of the worker. Like workplace monitoring, individual monitoring can also be divided into further sub-divisions; monitoring for external exposure, internal exposure and skin contamination. [5]

Performing individual monitoring can easily assess the external exposure to ionizing radiation using dosimeter. The dosimeter should include the necessary capability to measure external exposure of all the radiations being emitted at the particular workplace. Furthermore, the International Atomic Energy Agency requires staff to wear an extra dosimeter (e.g. extremities) in the situation where staff is exposed to non-uniform radiation field. On the other hand, internal exposure is assessed in cases when there is an intake of radioactive material. [5]

Exceeding Dose Limits

In a case where the effective dose limits or equivalent dose limits of tissues or organs is found to be exceeding the regulated limits, there are certain responsibilities for a licensee which are given as follows [6]:

- The commission should be immediately notified of the exceeding dose. [6]
- The person should not be asked to take part in any task, which will add to his/her radiation dose. [6]
- A thorough investigation should be done to measure the exceeding amount of the dose and to analyze as to how it exceeded the limited figure. [6]
- A report should be prepared based on the investigation and analysis done on

the incident and should be presented to the Commission within a period of 21 days. [6]

Chapter 2

Literature Review

2.1 Literature Review Findings

Recent studies have observed and documented the historical evolution of using the radiopharmaceuticals in nuclear medicine imaging since the 1950s. These studies have showed constancy in the use of most radiopharmaceuticals from sometime between the mid-1970s and late 1990s up to the present [10]. For example, by the beginning of 2000s, about half of the thyroid scan procedures were performed with 123I-sodium iodide [10]. This percentage has stabilized at 56 percent by 2010. For the thyroid uptake procedures, it was reported that the use of 131I- sodium iodide and 123I-sodium iodide was about 45 percent and 55 percent of the total performed procedures respectively from the mid-1990s until 2010 [10]. For about 15 diagnostic nuclear medicine procedures investigated in Drozdovitch et.al studies, all procedures have showed constancy in the use of radiopharmaceuticals for at least the past 15 years. More information of the most common radioisotopes historical use is presented in the first section of this paper.

Occupational radiation exposure in nuclear medicine procedures for the period

from1950s to mid-1970s in the United States have also been studied and documented [9]. Drozdovitch et.al have studied the occupational radiation exposure to nuclear medicine personnel for the period from 1950s to mid-1970s [9]. The study found that estimated radiation exposure per procedure varied from less than 10^{-5}mSv for thyroid scan using 131I-sodium iodide to $4*10^{-4}$mSv for brain scan using 203Hg-chlormerodin. After introducing the 99mTc as a new radioisotope in medical imaging in more recent procedures, the occupational radiation exposure per procedure has notably increased to range from $8*10^{-4}$mSv for thyroid scans using 99mTc-pertechnitate to $2.5*10^{-3}$mSv for brain scan using 99mTc-pretechnitate [9].

Minimizing the occupational exposure has been an interest for many researchers as a way to control the occupational radiation doses. Those researchers have investigated some suggested techniques, or the effects of using new technology on the occupational doses. Duvall et.al have conducted a study to determine if the change in stress myocardial perfusion protocol and using a new camera technology could reduce the occupational radiation exposure to ionizing radiation [13]. The study has compared the occupational radiation exposure before and after the installation of the high-efficiency SPECT camera system with a change in the stress myocardial perfusion protocol. The investigators found that the combination of the two investigated techniques have significantly reduced the occupational exposure with approximately 40 percent in the monthly measured radiation doses among all staff members [13]. The revolution in using new radiopharmaceuticals has also played an important role in reducing the occupational radiation doses [12]. For example, using Rb-82 PET for myocardial perfusions examinations when compared with 99mTc SPECT showed significant reduction in the occupational whole body effective dose with 0.4μSv per examination for Rb-82 PET while it was 1.7μSv for 99mTc SPECT examination [12]. The same comparison has been conducted in another study and the findings showed

that the radiation doses during Rb-82 PET are lower than those measured for 99mTc SPECT with reported estimated doses of 0.45 ± 0.25μSv per examination using Rb-82 while for 99mTc SPECT, the estimated measured dose calculated was 1.075 ± 0.320μSv per examination [19]. It was also revealed that the automated dispensing and injecting system is associated with significant reduction ranging from 12 – 67 percent in the occupational radiation doses [11].

The occupational radiation doses to nuclear medicine staff in many countries around the world have been investigated. These studies have studied the average annual doses for either the whole body or a specific part of the body, and evaluated the result based on the compliance with international or local regulations.

Massood et, al. in their study "Assessment of the occupational radiation exposure doses to workers at INMOL (institute of nuclear medicine and oncology) in Pakistan (2007 – 2011)" reported an annual average whole body doses to nuclear medicine workers in Pakistan as 1.11mSv in 2007, 1.91mSv in 2008, 1.36mSv in 2009, 0.71mSv in 2010, and 0.51mSv in 2011. As a comparison, the study reported average annual doses of 1.4mSv, 0.75mSv, and 1.96mSv for nuclear medicine workers in China (1986 – 2000), Australia (1990 - 1994), and Canada (1990 – 1994) respectively. The study concludes that the nuclear medicine workers average annual doses in Pakistan are within the regulated limits, and are comparable to those of other countries [1]. In other Pakistani's study, it was reported that nuclear medicine workers in Punjab are exposed to an annual average radiation of 0.3 to 0.97 mSv for the period from 2003 to 2012 [14].

In Saudi Arabia, the average annual radiation dose to nuclear medicine workers at King Abdulaziz University's Hospital has been reported to be 1.56 mSv [20]. At King Faisal Specialized Hospital, the average annual dose for the period from 1985 – 1999 has been reported to be varying from 0.5mSv to 1.2mSv whereas the annual average

dose for the measureable readings has been reported to be ranging from 1 mSv to 2.6 mSv [2].

In Kuwait, the average annual radiation dose to nuclear medicine workers has been documented to be 1.06± 0.03mSv in 2008, and 1.01 ± 0.03mSv in 2009 for nuclear medicine physicians, and it was reported to be 1.07±0.01mSv in 2008, and 1.00±0.01mSv in 2009 for nuclear medicine technologists [21]. The study also reported that the nuclear medicine and diagnostic radiology technologist whole body dose and skin dose in 2008 were significantly higher than those of 2009. The conclusion of the study indicated that the occupational radiation doses of workers during the period 2008 – 2009 in Kuwait is well below the limits of the international commission on radiological protection. In 2015, the annual occupational dose in Kuwait Cancer Control Center was 2.4 mSv and 1.8mSv for whole body and extremity respectively [22]

In Poland, Piwowarska-Bilska et.al conducted a study that aimed to estimate the radiation exposure of department of nuclear medicine during 17 years period (1991 – 2007), and to investigate the possible relationship between the doses of personnel and the number of examinations conducted at the department of interest [23]. The main findings of this study was reported as follows; 1) nurses are the most exposed group with average annual dose ranged from 2 – 9.5mSv followed by technicians 0.8 – 3.7mSv, then radiopharmacy technicians 0.7 – 3.7mSv, 2) even the experienced workers should be sometimes supervised by radiation protection officer and be subject to training on radiation protection rules, and 3) weak correlation between the monitored employee annual and the number of procedures performed with r=0.67, whereas no linear correlation was detected between the exposed employees annual doses and the number of procedures [23].

In Portugal, Martins et.al aimed to analyze and discuss the annual effective dose

received by individuals working in nuclear medicine department for the period 1999 – 2003 [24]. The study analyzed data for seven groups of workers; administrative, auxiliary, medical doctors, nuclear medicine technicians, nurses, pharmacist, and physicians. The measured effective doses were reported for each group to be as follows; 1) for administrative, the effective dose ranged from 1.04mSv in 2000 to 2.13mSv in 2001. 2) For auxiliary staff, the effective dose ranged from 1.27mSv in 1999 to 1.98mSv in 2003. 3) For medical doctors, the dose ranged from 1.54mSv in 2000 to 2.13mSv in 1999. 4) For nuclear medicine technicians, the dose ranged from 2.45mSv in 2000 to 3.45mSv in 2003. 5) For nurses, the effective doses ranged from 2.73mSv in 2001 to 3.23mSv in 2002. 6) For pharmacists, the dose ranged from 0.43mSv in 2000 to 5.52mSv in 1999. 7) And for physicians, the defective dose ranged from 0.81mSv in 1999 to 1.49mSv in 2002. As of these measurements authors conclude the study with doubt on the actual type of work performed by the administrative staff claiming that they might be involved in in other tasks or have access to restricted areas. Furthermore, the study claimed that medical doctors, nuclear medicine technicians, and nurses are the most exposed groups to radiation [24].

Annual radiation doses to hands measured by finger dosimeters were also assessed in some studies and the findings were evaluated based on the permitted limits. According to Kaljevic et.al in their study "Hand Dose Evaluation of Occupationally Exposed Staff in Nuclear Medicine", the average annual doses to hands was reported as follows; for nurses, the average annual radiation dose was 34 ± 22mSv in 2010, 58 ± 80mSv in 2011, 36 ± 45mSv in 2012, 30 ± 40mSv in 2013, and 100 ± 218mSv in 2014. For nuclear medicine technologists the annual average doses reported to be 28 ± 22mSv in 2010, 85 ± 80mSv in 2011, 14 ± 8.4mSv in 2012, 22 ± 25mSv in 2013, and 12 ± 6mSv in 2014. The study concluded that the estimate doses are within the regulated limits of 500mSv and the large standard deviation indicates that further

optimizations are required for working procedures [25].

Similarly, Tandon et.al has conducted a study to measure the finger dose received during different procedures in 54 different institutions in India [26]. Authors reported that most of the procedures in the 54 facilities were performed using 99mTc, activity used was 1 – 6GBq daily per facility and 300 – 2300GBq annually. There were about three to four workers in every facility. The main findings were; in the 54 institutions, the annual equivalent dose to the hand per GBq of activity at injection phase were ranged from 0.005mSv/GBq to 0.999mSv/GBq, while at the scintigraphy and elution phases, the equivalent dose were ranged from 0.004mSv/GBq to 0.950mSv/GBq, and from 0.002mSv/GBq to 0.354mSv/GBq respectively. The study main conclusion was that the doses measured were well within the limits, however more optimization required for the procedures investigated. [26]

In Serbia, Antic et.al conducted a study to assess the radiation exposure to whole body and extremities of nuclear medicine staff working in PET/CT practice [11]. The study included two Serbian nuclear medicine centers. Using thermoluminescence and electronic personal dosimeters, the whole body effective doses per procedure were ranged from 4.2μSv – 7μSv and from 5μSv – 6μSv for the two centers, while the whole body doses per unit of activity were ranged from 17 – 19μSv/GBq and 21 – 26μSv/GBq, in the two centers. The study also reported the hand doses per procedure in one of the centers to be ranged from 34μSv - 126μSv. The study conclusion was that "Although the individual doses are within the recommended regulatory limits, the increase in the workload would result in in higher staff doses". [11]

In USA, recent study has collected data from nine large U.S. medical institutions. the result of this study reported that between 1992 and 2015, the average annual personal dose per technologist ranged from 0.06 mSv to 11.1 mSv. [15]

The review of the literature regarding the occupational radiation doses, demonstrates that the annual occupational doses vary between facilities and from country to another. Even though all studies concluded that the occupational doses are within the permitted level, these findings raise more questions than it gives answers to the issue. For instance, does the number of staff, number of procedures, and type of procedure play role in the variation of the occupational radiation doses? If so, how could those factors explain the variation in occupational doses? Answering these questions will help us understand the variation's behaviour of the occupational doses across different facilities, and therefore better equips us with ability to control radiation doses.

The indicated conclusion gives the impression that the occupational radiation dose is "well controlled". However, when we further critically investigated the studies' findings, we found that variation in occupational radiation doses was left unexplained.This limitation was demonstrated as follows, when we looked at the data presented in many articles described previously, we found clear trends and dramatic changes in the measured doses that could help to explain the variation if investigated. For example, in Piwoworska et.al study, the data presented showed a trend of increasing of the radiation doses for three groups of the workers; nurses, radio-pharmacy technicians, and nuclear medicine technicians' in three consecutive years from 1993 to 1996, which was left unexplained [23]. The data from the same study showed dramatic drop in the measured doses in 1993 for all of the groups included in the study [23]. Furthermore, the same limitation was observed in other studies such as the one conducted in Pakistan in 2013 where the data showed clear decreasing trend in the average annual radiation doses from 2008 – 2011, and dramatic increasing of the doses in 2008, and again the authors settle for saying doses are below the regulated limits [1].

In the Indian study, we notice that the occupational doses varied in the 54 institutions. However, that variation does not follow any reasonable pattern. For example,

the calculated radiation dose per activity in the institution number 23 during the injection phase was 0.045mSv/GBq when using activity of 1546GBq, while in the institution number 24, the reported average dose per activity was almost the same 0.046mSv/GBq but by using half of the activity used in the other institution 861GBq [26].

As we can see in all the research done in various countries, the purpose is to assess the occupational radiation with an intent to safeguard the health care workers health interest. In our current study, we are looking at the plight of the nuclear departments healthcare workers in the hospital settings in Newfoundland and Labrador. Our objectives are to: [1] assess the feasibility of using available radiation dose data in the clinical settings in NL for research purposes, [2] Assess the occupational radiation doses in nuclear medicine departments in three facilities in Newfoundland, [3] investigate the change in radiation dose over time, and [4] assess the effect of technology, number of staff and number of procedures on the variation of occupational doses.

Chapter 3

Methodology

Data for the current study were collected from three sites in Newfoundland and Labrador: the Health Science Center, and St. Clare's Mercy Hospital in St. John's, and Western Memorial Regional Hospital in Corner Brook. Anonymized records of measured quarterly doses at the three locations for the period from 2007 to 2018 were obtained. We obtained the paper records of the exposure doses of the nuclear medicine department's staff in these three facilities. The collected sheets did not present the names of workers as required by the Health Research Ethics Board (HREB). Instead, each participants' names were replaced by a code that could not expose their identity, yet make it easy to refer back at any phase of the research. The de-identified and coded records for nuclear medicine department staff, had the information on the current quarter whole body and extremity doses, the cumulative dose for the current year, and the life aggregate dose, which means the sum of all measured doses since the worker joined the service. For example, the second quarter sheet of 2011 contains the dose measured for the second quarter of 2011, the sum of the first and second quarter doses equal the collective year dose, and the sum of every single measured dose since the worker started his/her service up until the second quarter of 2011 equals

the life dose. Some quarter sheets were not available either were missing or were not recorded such as the extremity doses of the first 3 years in Corner Brook's facility as they started measuring extremity doses in late 2010 and started regular reporting from middle 2012.

The National Dosimetry Services (NDS) was the dosimetry service provider for the three facilities. Eastern Health recently replaced the dosimetry service provider NDS with Landauer Dosimetry Services starting from the third quarter of 2017. The main difference between the two providers as it relates to this study is that the minimum detectable dose in NDS was 0.1 mSv, whereas the LDS service provider are able to detect doses as minimum as 0.01 mSv. NDS refered to doses below 0.1mSv with the symbol " - ", whereas the LDS used the letter "m" to refer to any dose below 0.01mSv. During the analysis phase, we replaced these notations for NDS and LDS respectively with the values 0.05 mSv and 0.005 which are the average values between 0.0 - 0.1 and 0.00 - 0.01.

Quarterly measurements for whole body and extremities doses were extracted from the past records and entered into an Excel Sheets. There were 34, 10, and 12 participants (Physicians and Radiology Technologist) in the Health Science Center, Saint Clare's Mercy Hospital, and Western Memorial Regional Hospital respectively. For any missing measurements, we calculated the values by using the collective year (the sum of four quarters in the same year) or life dose measurements. Dosimeter readings related to students, residents or trainers were excluded from this study.

At some points we noticed that some participants are exposed to a dose that is higher than most of everybody else is exposed to. we were not sure if that was normal or due to an incident. To avoid any effect of that high dose on the quarter average, we decided to determine a high level cut off and treat any dose greater than that limit as high dose or (outlier), and examine whether that high doses have an effect

on the general trend or not.In this study, any whole body dose reading that exceeds 1.5mSv was considered a high level dose and analyzed separately as 97% of whole body measurements are below or equal to 1.5mSv. The same criterion was applied to the extremities readings but the limit is 7.5 mSv instead as 98% of extremities measurements are below 7.5mSv.

The analysis in the study presents the average quarterly dose and the average annual dose of all healthcare workers in these departments, first when the doses below the detectable limit such as 0.05mSv or 0.005mSv and above the high level cut off are included and we call it "All Included". Second, when doses above the high level cut off ($>$ 1.5 mSv) are excluded and we call it "High Values Excluded". Third, when the doses below the detectable limit ($<$0.1 mSv,for NDS and $<$0.01 mSv for LDS) and High Values are excluded, and we call it "Measureable Readings". For a given quarter, The sum of measurements of workers for whom the doses are available divided by the number of workers contributing to the sum, represents the quarter average. For a given year, the sum of the four quarters measurements of workers for whom the four doses are available divided by the number of workers contributing to the sum, represents the annual average. The trends in the annual and quarterly average dose were also presented using the line graphs and smoothed 4 quarterly moving averages graphs to describe and analyse the data.

In the Health Science Centre, a total of 701 whole body quarter dose measurements during the period from the first quarter of 2007 to the third quarter of 2018 were collected. Among these doses, there were 200 measurements below detectable limits. Moreover, there were 10 measurements above the high level cut off that was set for this study.With regard to extremities, a total of 598 quarterly dose measurements were collected. Among these doses, there were 156 measurements below the detectable limits and there were 16 measurements above the high level cut off which was set for

this study.

In the St. Clare's Mercy Hospital, a total of 247 whole body quarterly dose measurements during the period from the first quarter of 2007- the first quarter of 2017 were collected. Among these doses there were 127 measurements below the detectable limits and there was only 1 measurement above the high level cut off for this study. With regard to extremities, a total of 247 extremities' quarter dose measurements were collected. Among these doses, there were 114 measurements below the detectable limits.

In the Western Memorial Regional Hospital, a total of 112 whole body quarter dose measurements during the period, from the third quarter of 2009 to the second quarter of 2018 were collected. Among these doses, there were 6 measurements below the detectable limits. Moreover, there were 2 measurements above the high level cut off that was set for this study. A total of 76 extremities' quarter dose measurements were obtained. Among these doses, there were 30 measurements below the detectable limits and 12 high level measurements.

In the analysis of the high values, we looked at each measurement and examine the effect of being new staff or less experienced in the event of being exposed to high dose. We set four criteria for participants to be considered as new staff. First, when the quarter dose and the life dose are the same; second, when the life dose is greater than the quarter dose by the value of the previous quarter only; third, if the participant was away for more than two quarters; fourth, when the participant has just moved to new location regardless of any previous experience. If a participant met one of the criteria, he/she was considered a new staff or less experienced staff.

Chapter 4

Result and Analysis

4.1 Health Sciences Centre (HSC)

4.1.1 Whole Body Dose: (Including doses below detectable limit <0.1 mSv and high values >1.5 mSv)

A total of 701 whole body quarterly dose measurements for 34 employee were collected from the quarterly's dose reported by NDS and LDS during the period from the first quarter of 2007 to the third quarter of 2018. The average of the 701 recorded measurements was 0.35 mSv with a minimum dose of 0.005 mSv, and a maximum dose of 3.45 mSv. Among these doses, there were 200 measurements below detectable limits 0.1 (NDS), 0.01 mSv (LDS). Moreover, there were 10 measurements above the high level cut off that was set for this study which is 1.5 mSv.A.1

The quarterly average doses were also calculated and are listed in table A.1, Figure 4.1 where the whole body average quarter doses ranged from 0.19 mSv to 0.55 mSv. The standard deviation ranged from 0.18 mSv to 0.84 mSv.

The annual exposure whole body doses ranged from 0.95 mSv to 1.77 mSv in 2009.

The standard deviations ranged from 0.70 to 1.72. Table A.2, Figure 4.2

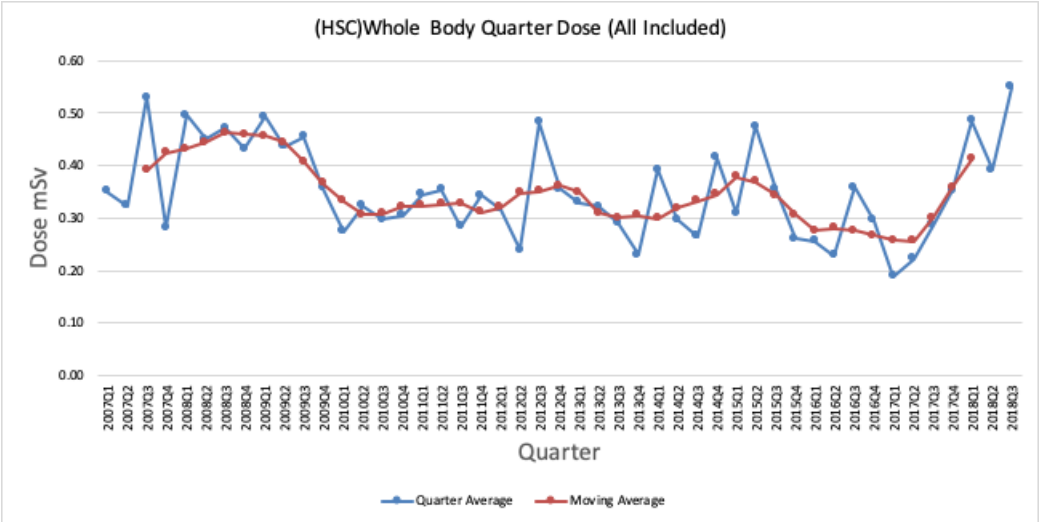

Figure 4.1: Represents the quarterly average and the moving average trend for the whole body quarter average dose including all measurements.

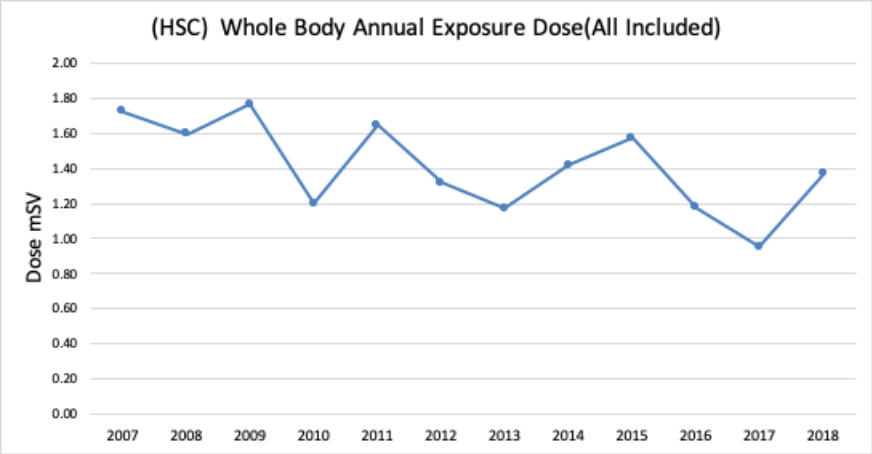

Figure 4.2: Represents the annual trend for the whole body annual average dose including all measurements.

4.1.2 Whole Body Dose: (Excluding the high level values>1.5 mSv)

To remove any overestimation due to rare events of the whole body average doses, those 10 measurements that met the exclusion criteria were removed. The average of the remaining 691 dose measurements is 0.32 mSv with a minimum dose of 0.005 and a maximum dose of 1.5 mSv.

The quarterly average doses ranged from 0.19 mSv to 0.50 mSv. The standard deviations ranged from 0.18 mSv to 0.42 mSv. Table A.3, Figure 4.3

The annual whole body exposure doses ranged from 0.95 mSv to 1.77 mSv. The standard deviations ranged from 0.67 to 1.35. Table A.4, Figure 4.4

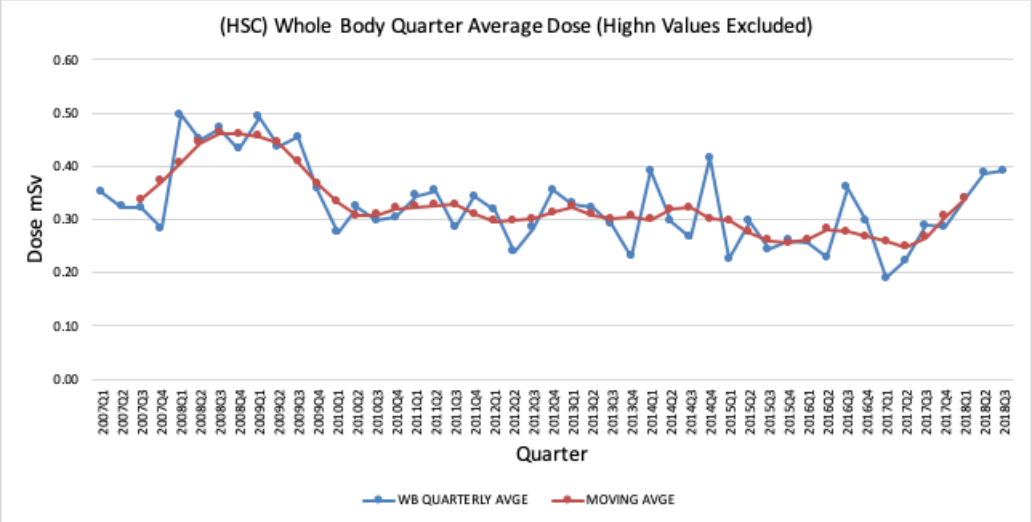

Figure 4.3: Represents the quarterly average and the moving average trend for the whole body quarter average dose after excluding the high dose readings

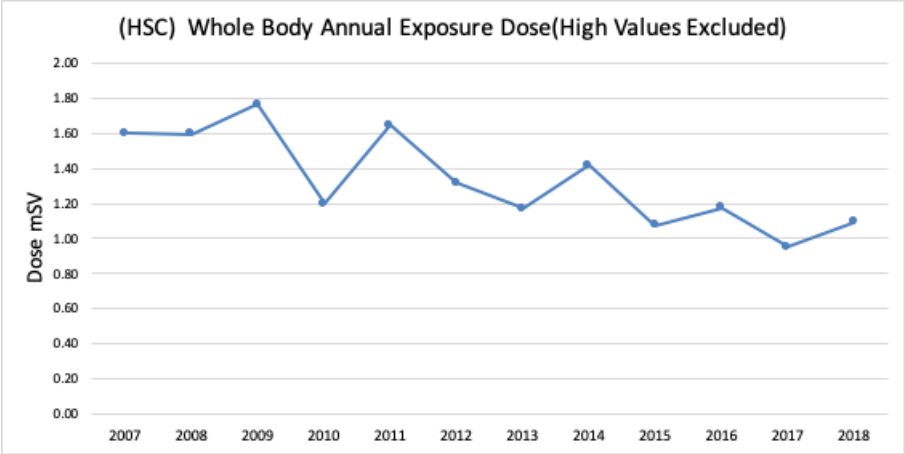

Figure 4.4: Represents the annual trend for the whole body Annual average dose after excluding the high dose readings

4.1.3 Whole Body Dose: (Measureable Readings >= 0.1 mSv (NDS), >=0.01 mSv (LDS), and <1.5 mSv)

To remove both overestimation and underestimation effect of the whole body average doses, those 200 measurements that met the exclusion criteria were removed. The average of the remaining 501 dose measurements is 0.32 mSv with a minimum dose of 0.01 (LDS), and 0.1 mSv (NDS) and a maximum dose of 1.5 mSv.

The quarterly average doses ranged from 0.30 mSv to 0.66 mSv. The standard deviations ranged from 0.14 mSv to 0.43 mSv. Table A.5, Figure 4.5

The annual average whole body doses ranged from 1.15 mSv to 2.46 mSv. The standard deviations ranged from 0.49 to 1.45. Table A.6, Figure 4.6

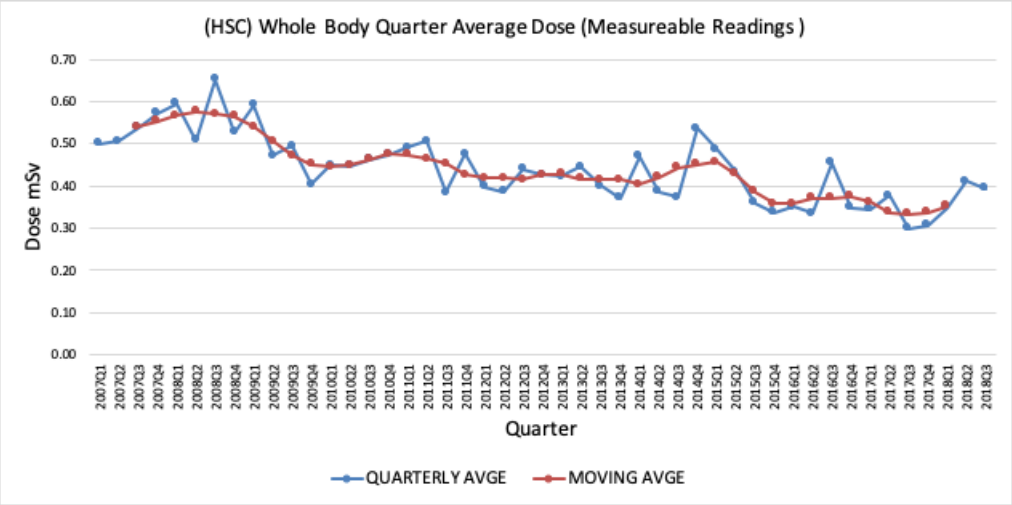

Figure 4.5: Represents the quarterly average and the moving average trend for the whole body quarter average dose after excluding the high dose readings and doses below detectable limit

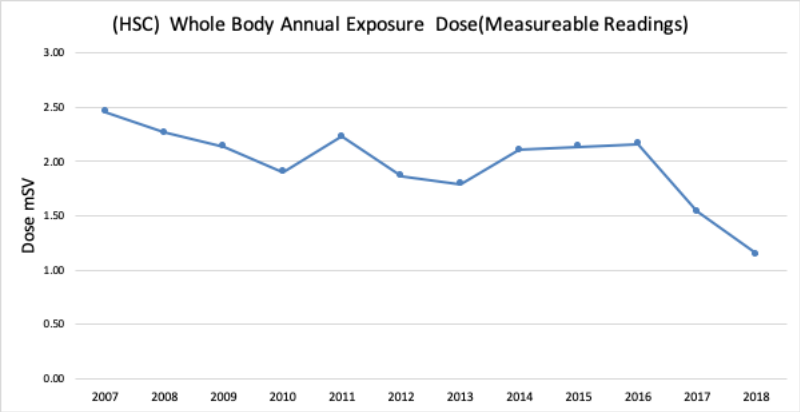

Figure 4.6: Represents the annual trend for the whole body annual average dose after excluding the high dose readings and doses below detectable limit

The Health Science Center Whole Body's figures show that there was an increasing in the whole body quarterly average doses during the period from 2007 to 2008, also during the period from 2017 onward. the department's technical manager and safety officer were able to recall that the way the scan was conducted in past where the technicians would be inside the room where the patient was scanned is actually associated to this increase which was gradually decreased after the technique has

been changed. In 2017, a new technology introduced that is associated with higher energy radiopharmaceutical that might increase the occupational radiation dose. The general trend shows an overall decreasing in the quarterly average doses and the annual average doses.

4.1.4 Extremities Dose: (Including doses below detectable limit <0.1 (NDS), 0.01 mSv (LDS) and high values >7.5 mSv)

A total of 598 extremities' quarter dose measurements were collected from the NDS quarters' dose's reports during the period, the first quarter of 2007- the third quarter of 2018, and used in this study. The average of the 598 recorded measurements was calculated to be 1.5 mSv with a minimum dose of 0.005 mSv, and a maximum dose of 20.13 mSv. Among these doses, there were 156 measurements below the detectable limits 0.1, and 0.01 mSv. Moreover, there were 16 measurements above the high level cut off which was set for this study to be 7.5 mSv.

The quarterly average doses were also calculated and are listed in table A.7,Figure 4.7 and ranged from 0.41 mSv to 6.01 mSv. The standard deviation ranged from 0.47mSv to 5.61 mSv.

The annual extremity exposure doses ranged from 2.30 mSv to 11.34 mSv. The standard deviation ranged from 2.12mSv to 10.70mSv. Table A.8, Figure 4.8

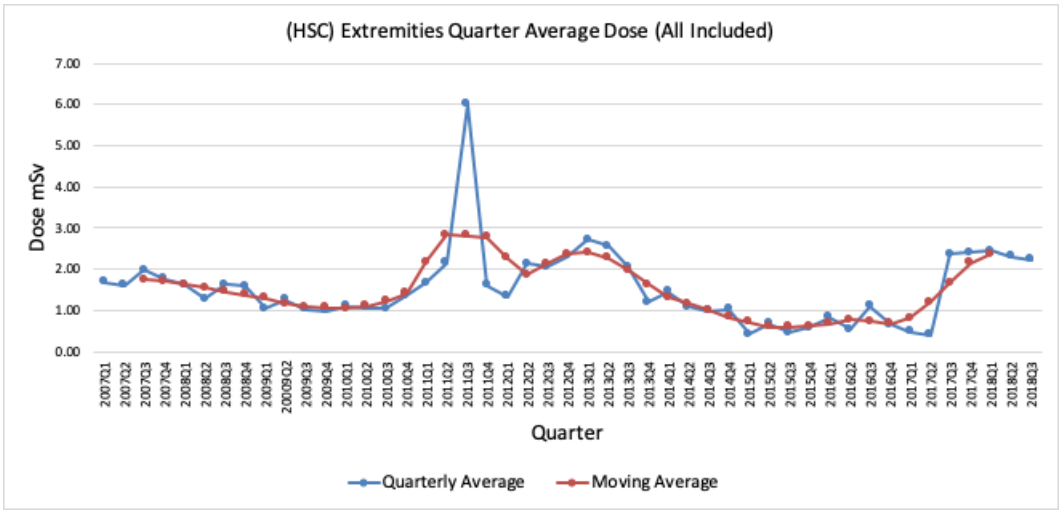

Figure 4.7: Represents the quarterly average and the moving average trend for the extremity quarter average dose including all measurements

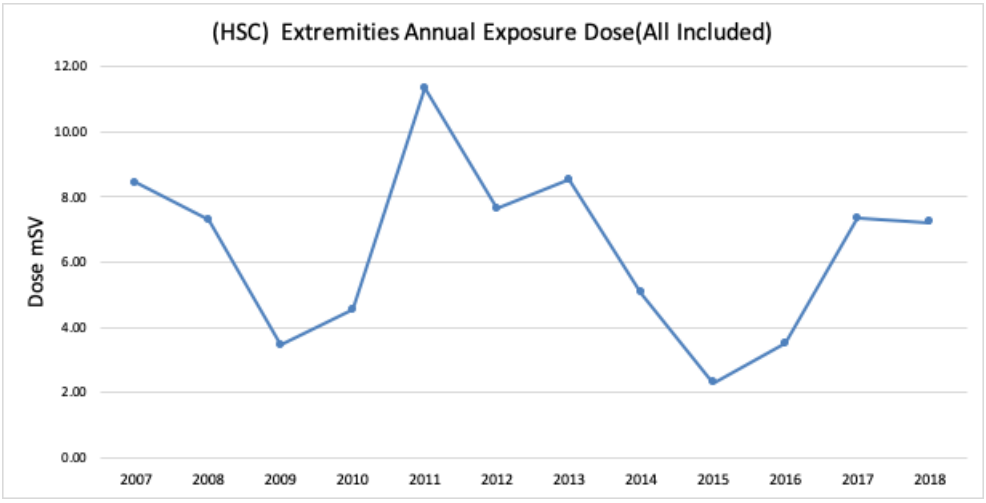

Figure 4.8: Represents the annual trend for the extremity annual average dose including all measurements

4.1.5 Extremities Dose: (Excluding the high level values>7.5 mSv)

To remove any overestimation of the extremity average doses, those 16 measurements that met the exclusion criteria were removed. The average of the remaining 582 dose measurements was 1.26 mSv with a minimum dose of 0.005 and a maximum dose of 7.5 mSv.

The quarterly average doses were also calculated and are listed in table A.9, Figure 4.9. The extremity quarter average doses ranged from 0.41 mSv to 2.31 mSv. The standard deviations ranged from 0.47mSv to 2.6 mSv.

The annual extremity exposure doses ranged from 2.16 mSv to 7.29 mSv. The standard deviations ranged from 1.95 to 10.06. Table A.10, Figure 4.10

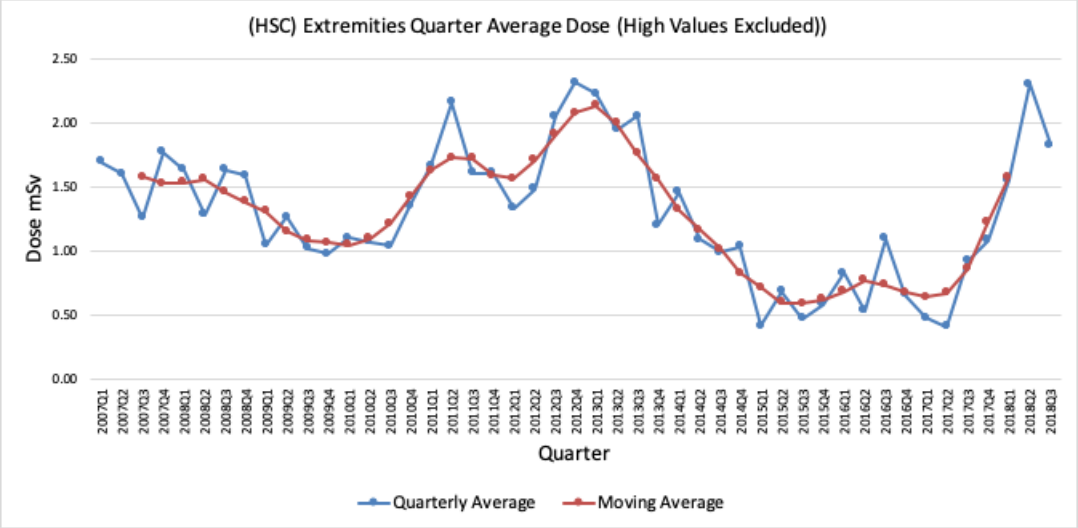

Figure 4.9: Represents the quarterly average and the moving average trend for the extremity quarter average dose after removing the high dose readings

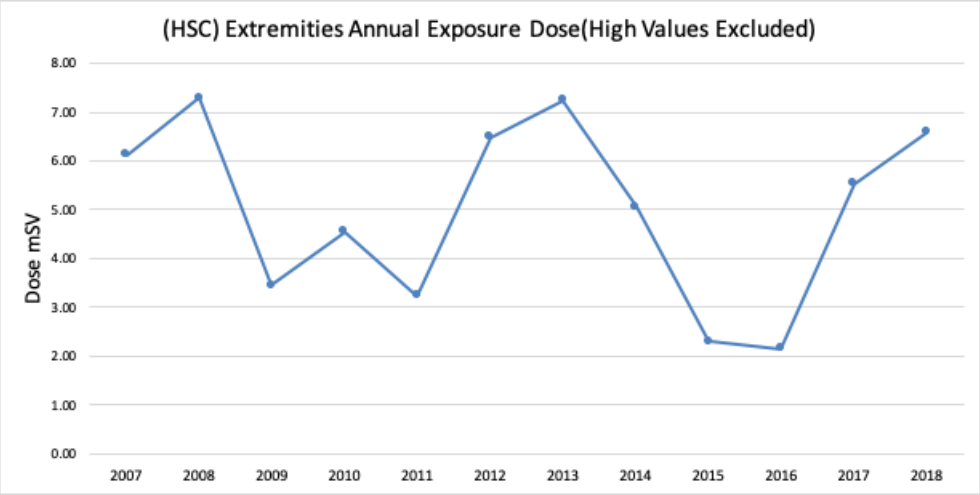

Figure 4.10: Represents the annual trend for the extremity annual average dose after removing the high dose readings

4.1.6 Extremities Dose: (Measureable Readings >= 0.1 mSv (NDS) / >=0.01 mSv (LDS) and < 7.5 mSv)

To remove both overestimation and underestimation effect of the whole body average doses, the 159 measurements that met the exclusion criteria were removed. The average of the remaining 439 dose measurements is 1.7 mSv with a minimum dose of 0.1 mSv and a maximum dose of 7.5 mSv.

The quarterly average doses were also calculated and are listed in table A.11, Figure 4.12, the extremity quarter average doses ranged from 0.6 mSv to 3.85 mSv. The standard deviations ranged from 0.47mSv to 2.7 mSv.

The annual extremity exposure doses ranged from 3.93 mSv to 12.04 mSv in 2007. The standard deviations ranged from 2.50 to 7.16. Table A.12, Figure 4.12

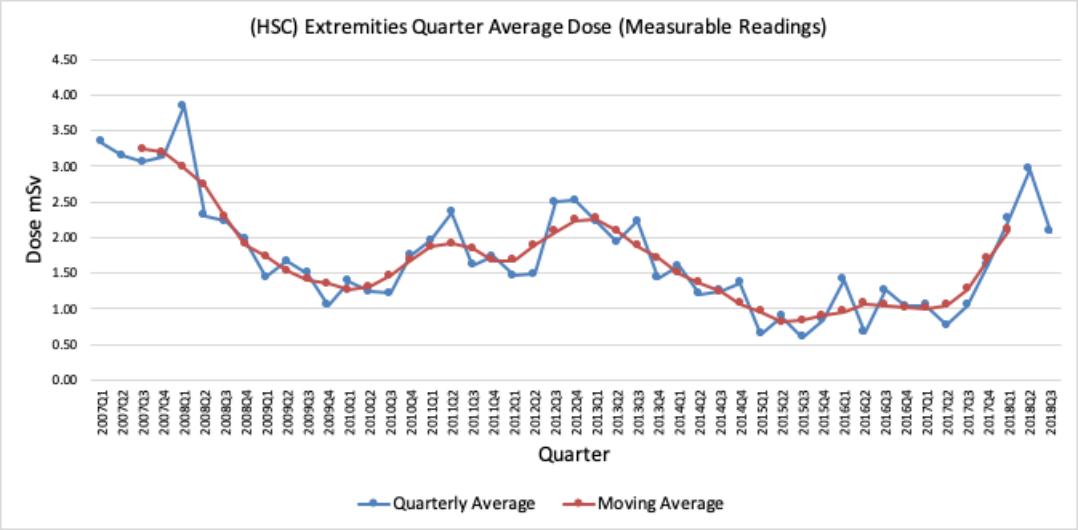

Figure 4.11: Represents the quarterly average and the moving average trend for the extremity quarter average dose after removing the high dose readings and doses below detectable limit

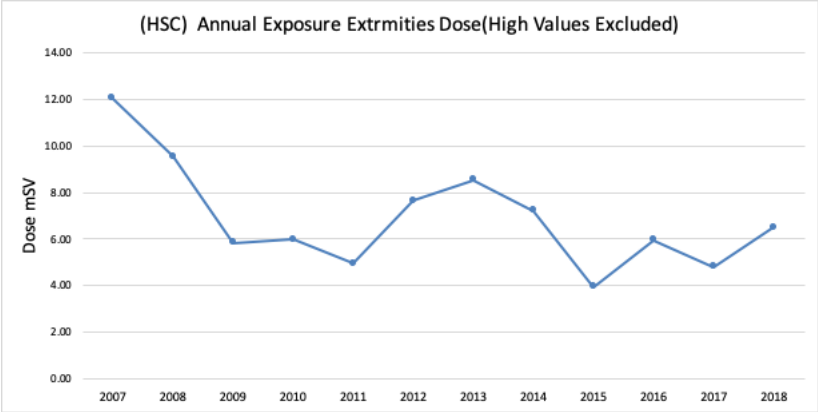

Figure 4.12: Represents the annual trend for the extremity annual average dose after removing the high dose readings and doses below detectable limit

The Health Science Center Extremities' figures showed an interesting observation in the quarterly average doses, especially when all doses are included figure4.7. In the third quarter of 2011 there was a dramatic increase in the quarter average doses. Unfortunately, neither technical manager nor the technicians were able to recall any incident or operational changes that would cause the increase in the occupational doses.The general trend shows decrease in the quarterly average dose.

4.2 St.Clare's Mercy Hospital (SC)

4.2.1 Whole Body Dose: (Including the doses below detectable limit <0.1 mSv and high values >1.5 mSv)

A total of 247 whole body quarter dose measurements were collected from the NDS quarters' dose's reports during the period, the first quarter of 2007 to the first quarter of 2017. The average of the 247 recorded measurements was calculated to be 0.25 mSv with a minimum dose of 0.05 mSv, and a maximum dose of 1.91 mSv. Among these doses there were 127 measurements below the detectable limits 0.1 mSv. There was also 1 measurement above the high level cut off for this study which is 1.5 mSv.

The quarterly average doses were also calculated and are listed in table A.13, Figure 4.13 the whole body average quarter doses ranged from 0.088 mSv to 0.71 mSv. The standard deviations ranged from 0.085 mSv to 0.77 mSv.

The annual whole body exposure doses ranged from 0.47 mSv to 1.54 mSv . The standard deviations ranged from 0.43 to 1.72. Table A.14, Figure 4.14

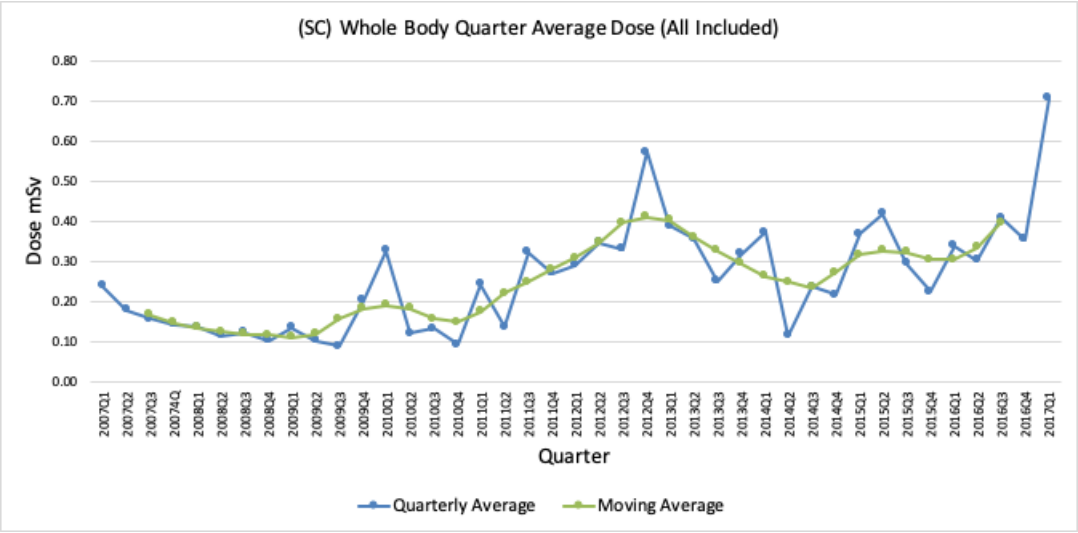

Figure 4.13: Represents the quarterly average and the moving average trend for the whole body quarter average dose including all measurements

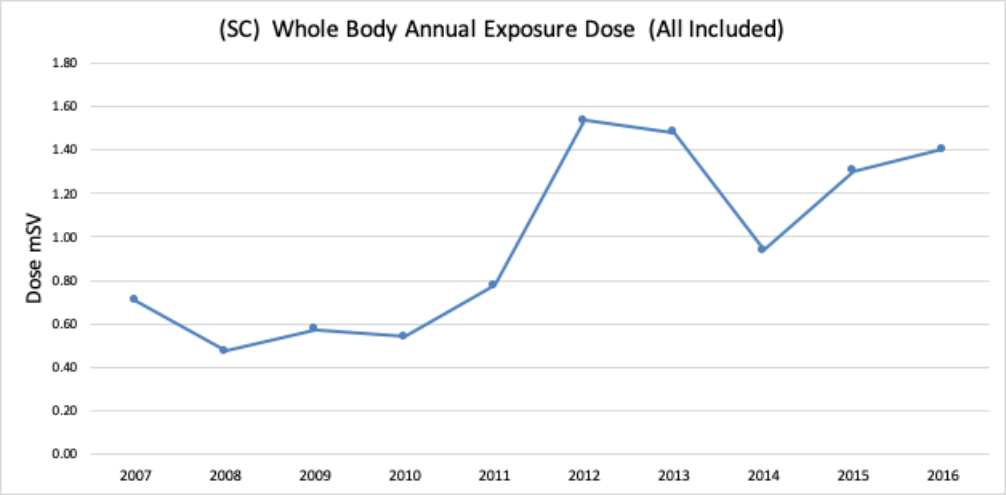

Figure 4.14: Represents the annual trend for the whole body annual average dose including all measurements

4.2.2 Whole Body Dose: (excluding the high level values>1.5 mSv)

To remove any overestimation of the whole body average doses, the measurement that met the exclusion criteria was removed. The average of the remaining 246 dose measurements is 0.32 mSv with a minimum dose of 0.05 and a maximum dose of 1.5 mSv.

The quarterly average doses were also calculated and are listed in table2.15 and Figure 4.15, the whole body average quarter doses ranged from 0.088 mSv to 0.71 mSv. The standard deviations ranged from 0.059 mSv to 0.55 mSv.

The annual whole body exposure doses ranged from 0.47 mSv to 1.48 mSv. The standard deviations ranged from 0.43 to 1.81 . Table 2.16, Figure 4.16

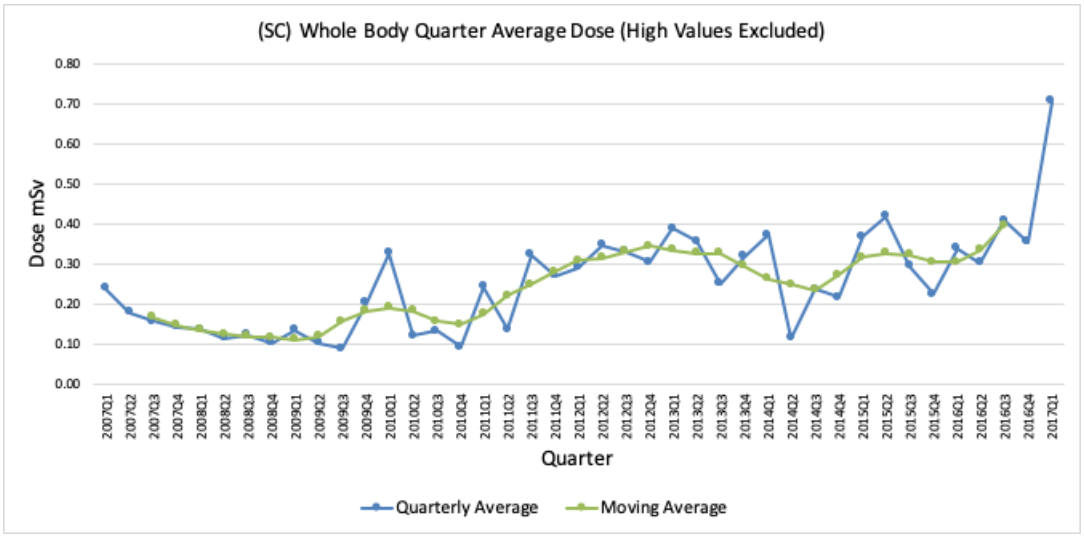

Figure 4.15: Represents the quarterly average and the moving average trend for the whole body quarter average dose after removing the high dose readings

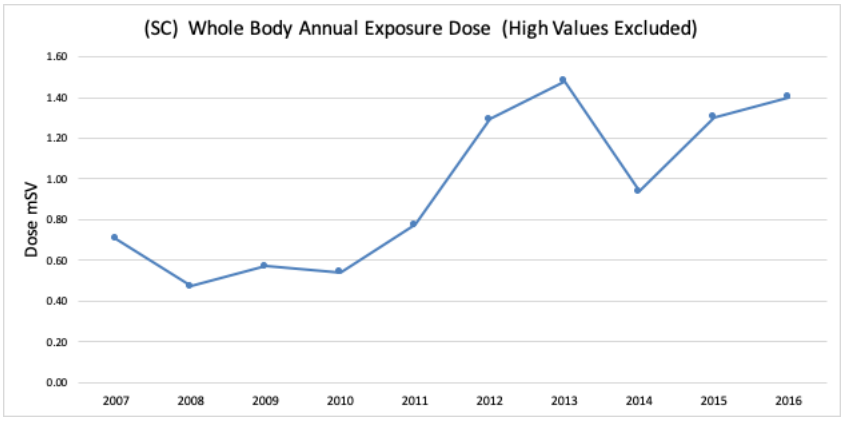

Figure 4.16: Represents the annual trend for the whole body annual average dose after removing the high dose readings

4.2.3 Whole Body Dose: (Measureable Readings >= 0.1 mSv and < 1.5 mSv)

To remove both overestimation and underestimation effect of the whole body average doses, the 128 measurements that met the exclusion criteria were removed. The average of the remaining 119 dose measurements is 0.44 mSv with a minimum dose of 0.11 mSv and a maximum dose of 1.46 mSv.

The quarterly average doses ranged from 0.17 mSv to 0.77 mSv. The standard deviations ranged from 0.00 mSv to 0.63 mSv. Table A.17, Figur 4.17

The annual whole body exposure doses ranged from 1.28 mSv to 2.93 mSv. The standard deviations ranged from 0.14mSv to 2.02mSv. Table A.18, Figure 4.18

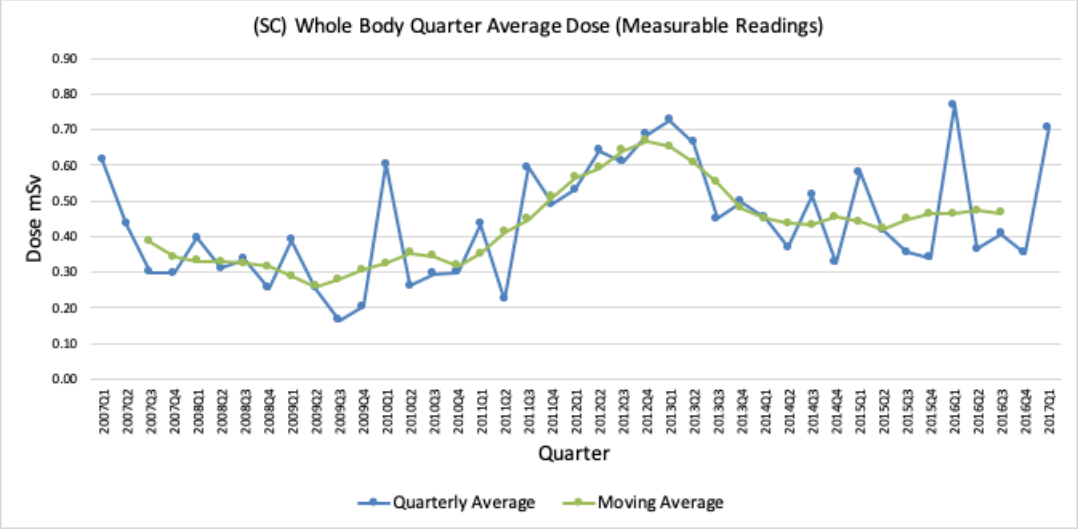

Figure 4.17: Represents the quarterly average and the moving average trend for the whole body quarter average dose after excluding the high dose readings and doses below detectable limit

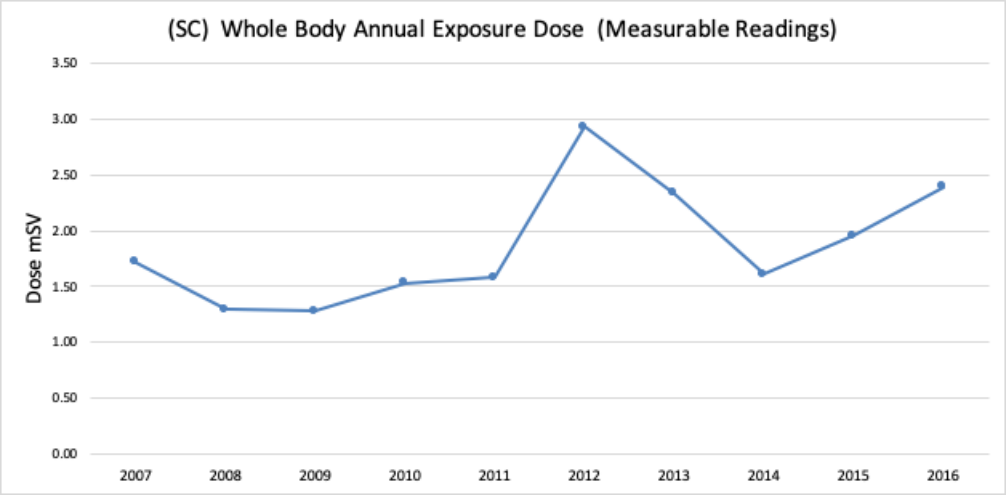

Figure 4.18: Represents the annual trend for the whole body annual average dose after excluding the high dose readings and doses below detectable limit

The St. Clare's Mercy Hospital's Whole Body's figures show that there was a slight increase in the whole body quarterly average doses during the period from 2011 to 2013. We were not able to detect the reason behind that increase as the available data is not enough to provide explanation. The general trend shows an overall increasing in the quarterly average doses and the annual average doses.

4.2.4 Extremities Dose: (Including doses below detectable limit <0.1 mSv and high values)

A total of 247 extremities' quarter dose measurements were collected from the NDS quarters' dose's reports during the period, the first quarter of 2007 to the first quarter of 2017. The average of the 247 recorded measurements was calculated to be 0.21 mSv with a minimum dose of 0.05 mSv, and a maximum dose of 6.47 mSv. Among these doses, there were 114 measurements below the detectable limits 0.1 mSv.

The quarterly average doses were calculated and are listed in table A.19 and Figure 4.19, the extremity quarter average doses ranged from 0.05 mSv to 1.14 mSv. The

standard deviations ranged from 0.00 mSv to 2.53 mSv.

The annual extremity exposure doses ranged from 0.24 mSv to 2.53 mSv. The standard deviations ranged from 0.03 to 3.18. Table A.20, Figure 4.20

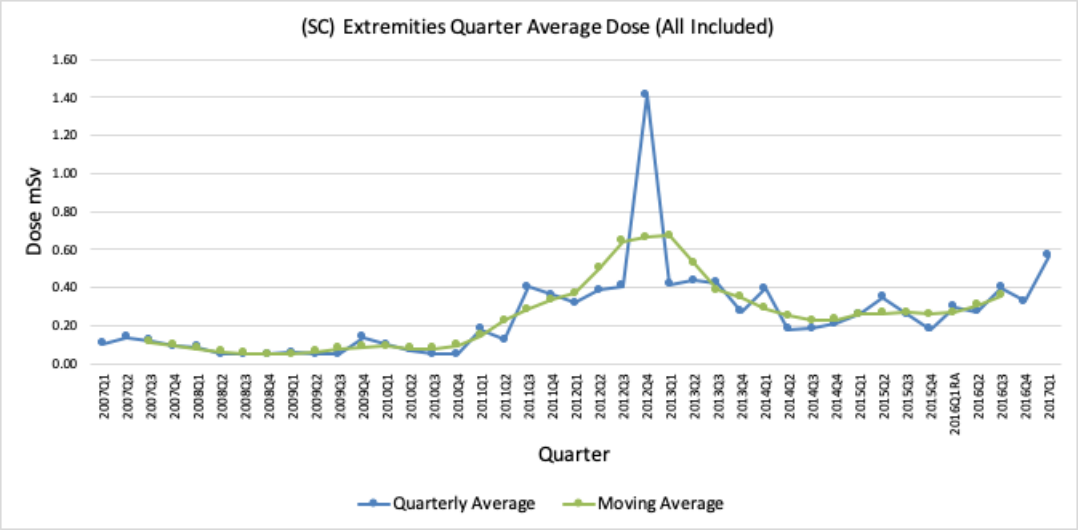

Figure 4.19: Represents the quarterly average and the moving average trend for the extremity quarter average dose including all measurements

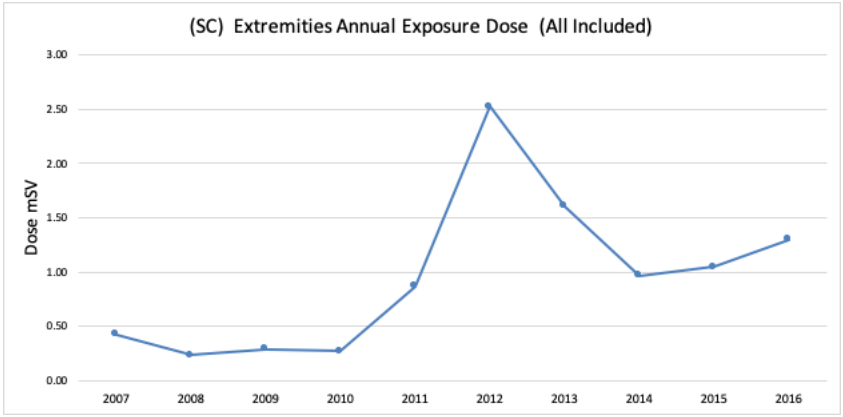

Figure 4.20: Represents the annual trend for the extremity annual average dose including all measurements

4.2.5 Extremities Dose: (Measureable Readings between >= 0.1 mSv and <7.5 mSv)

To remove both overestimation and underestimation effect of the whole body average doses, the 114 measurements that met the exclusion criteria were removed. The average of the remaining 133 dose measurements is 0.40 mSv with a minimum dose of 0.1 mSv and a maximum dose of 6.47 mSv

The quarterly average doses were also calculated and are listed in table A.21 and Figure 4.21, the extremity quarter average doses ranged from 0.11 mSv to 1.7 mSv. The standard deviations ranged from 0.03 mSv to 2.73 mSv.

The annual extremity exposure doses ranged from 0.29 mSv to 3.60 mSv. The standard deviations ranged from 0.03 to 3.50. Table A.22, Figure 4.22

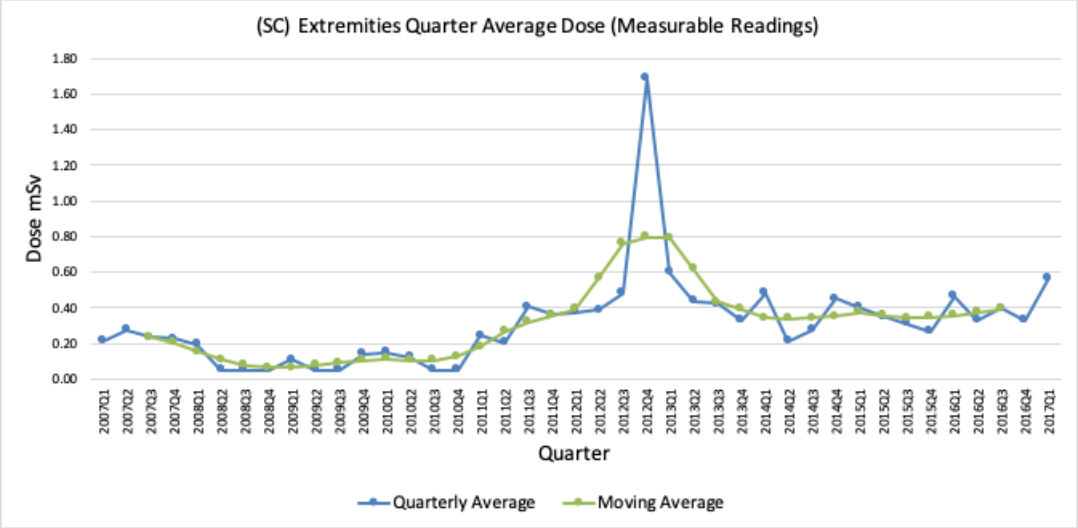

Figure 4.21: Represents the quarterly average and the moving average trend for the extremity quarter average dose after removing the doses below detectable limit

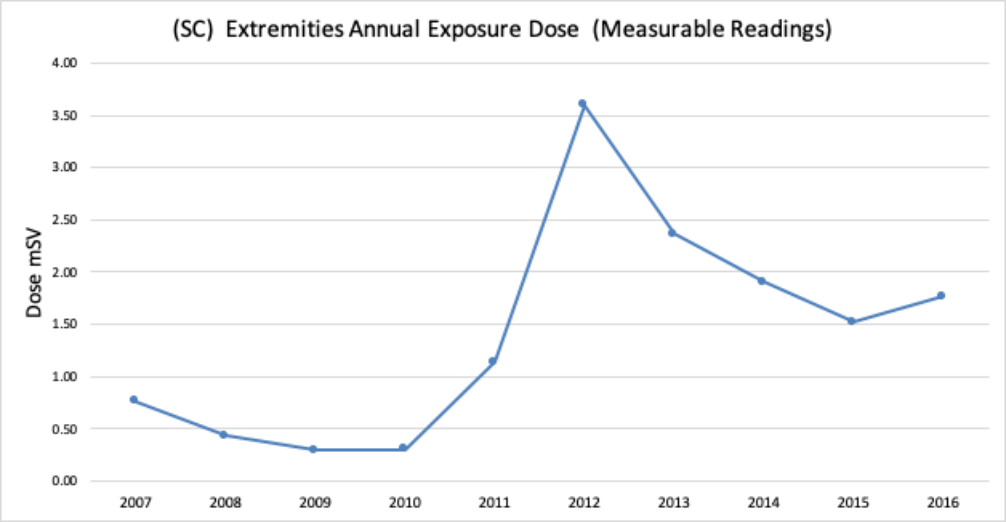

Figure 4.22: Represents the annual trend for the extremity annual average dose after removing the doses below detectable limit

The St. Clare's Mercy Hospital's extremities' figures show dramatic increase in the the fourth quarter of 2012. similar to the observation in the whole body doses, we were not able to detect the reason behind that observation. The general trend shows increase in the quarterly and annually average doses.

4.3 Western Memorial Regional Hospital (WMH)

4.3.1 Whole Body Dose: (including doses below detectable limit < 0.1 mSv and high values > 1.5 mSv)

A total of 112 whole body quarter dose measurements for 12 employees were collected from the NDS quarters' dose's reports during the period, from the third quarter of 2009 to the second quarter of 2018. The average of the 112 recorded measurements was 0.61 mSv with a minimum dose of 0.05 mSv, and a maximum dose of 1.66 mSv. Among these doses, there were 6 measurements below the detectable limits which is 0.1 mSv. Moreover, there were 2 measurements above the high level cut off that was

set for this study which is 1.5 mSv.

The quarterly average doses were also calculated and are listed in table A.23 and Figure 4.23 where the whole body average doses per quarter ranged from 0.20 mSv to 1.12 mSv. The standard deviations ranged from 0.03 mSv to 0.63 mSv.

The annual whole body exposure doses ranged from 1.36 mSv to 3.79 mSv . The standard deviations ranged from 0.04 to 1 mSv. Table A.24, Figure 4.24

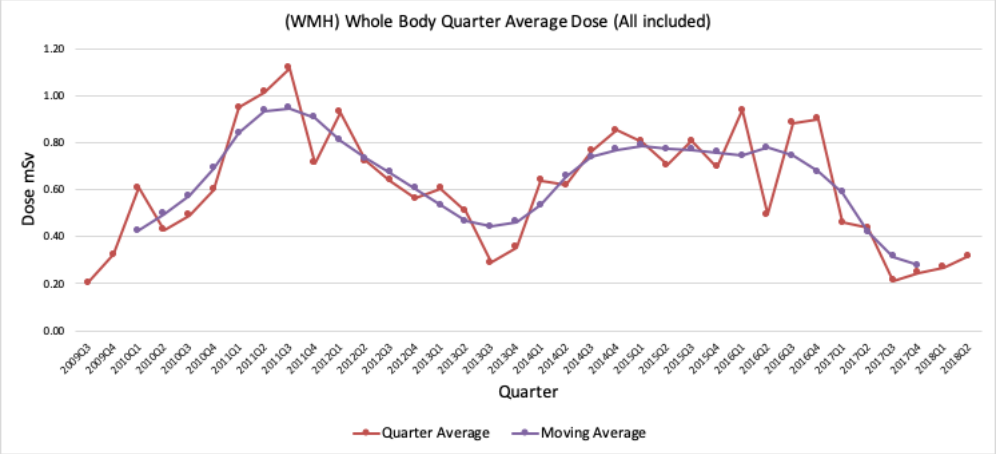

Figure 4.23: Represents the quarterly average and the moving average trend for the whole body quarter average dose including all measurements

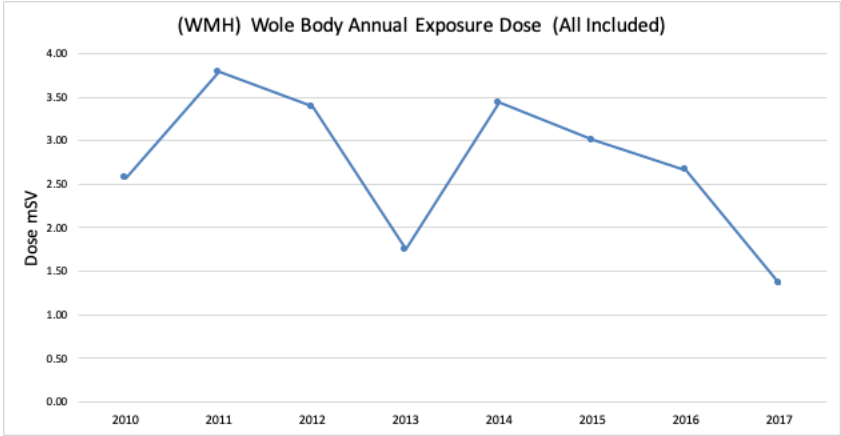

Figure 4.24: Represents the annual trend for the whole body annual average dose including all measurements

4.3.2 Whole Body Dose: (excluding the high-level values >1.5 mSv)

To remove any overestimation due to rare events of the whole body average doses, those 2 measurements that met the exclusion criteria was removed. The average of the remaining 110 dose measurements is 0.59 mSv with a minimum dose of 0.05 and a maximum dose of 1.33 mSv.

The quarterly average doses were also calculated and are listed in table A.25 and Figure 4.25 where the whole body average doses per quarter ranged from 0.20 mSv to 1.12 mSv. The standard deviations ranged from 0.03 mSv to 0.47 mSv.

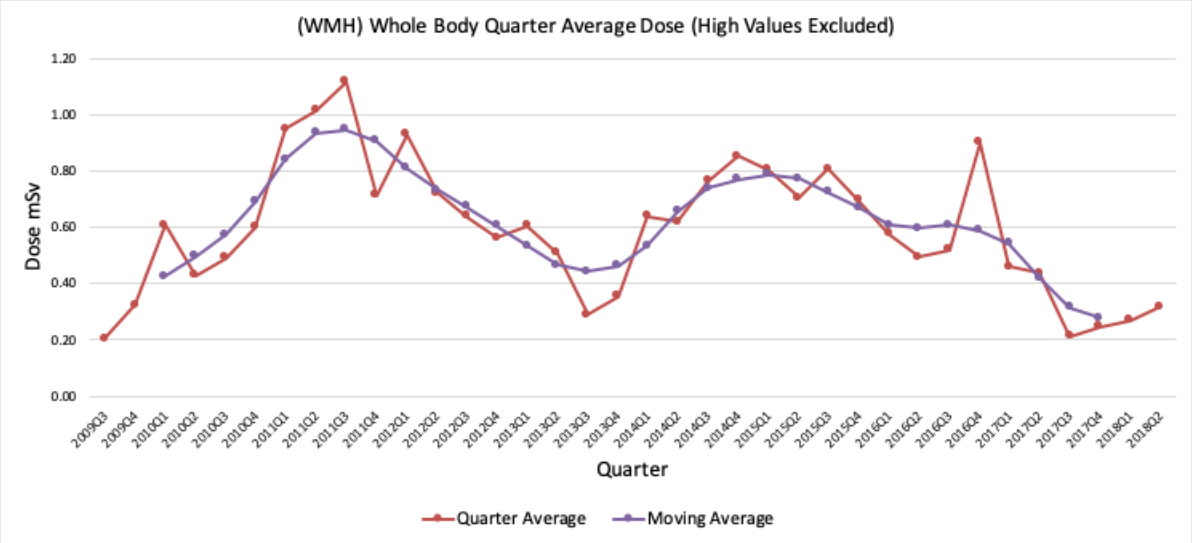

Figure 4.25: Represents the quarterly average and the moving average trend for the whole body quarter average dose after excluding the high dose readings

4.3.3 Whole Body Dose: (Measureable Readings >= 0.1 mSv and <1.5 mSv)

To remove both overestimation and underestimation effect of the whole body average doses, those 6 measurements that met the exclusion criteria were removed. The

average of the remaining 104 dose measurements is 0.63 mSv with a minimum dose of 0.1 mSv and a maximum dose of 1.33 mSv.

The quarterly average doses were also calculated and are listed in table A.26 and Figure 4.26, where the whole body average doses per quarter ranged from 0.20 mSv to 1.12 mSv. The standard deviations ranged from 0.03 mSv to 0.47 mSv.

The annual whole body exposure doses ranged from 1.75 mSv to 3.79 mSv. The standard deviations ranged from 0.04 to 1 mSv. Table A.27, Figure 4.27

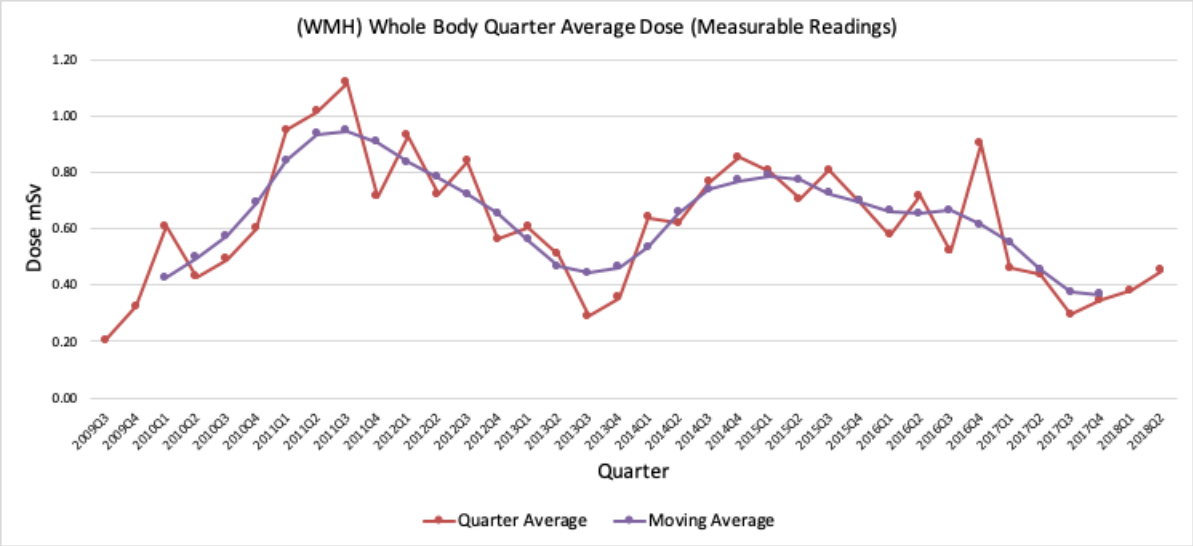

Figure 4.26: Represents the quarterly average and the moving average trend for the whole body quarter average dose after removing the high dose readings and doses below detectable limit

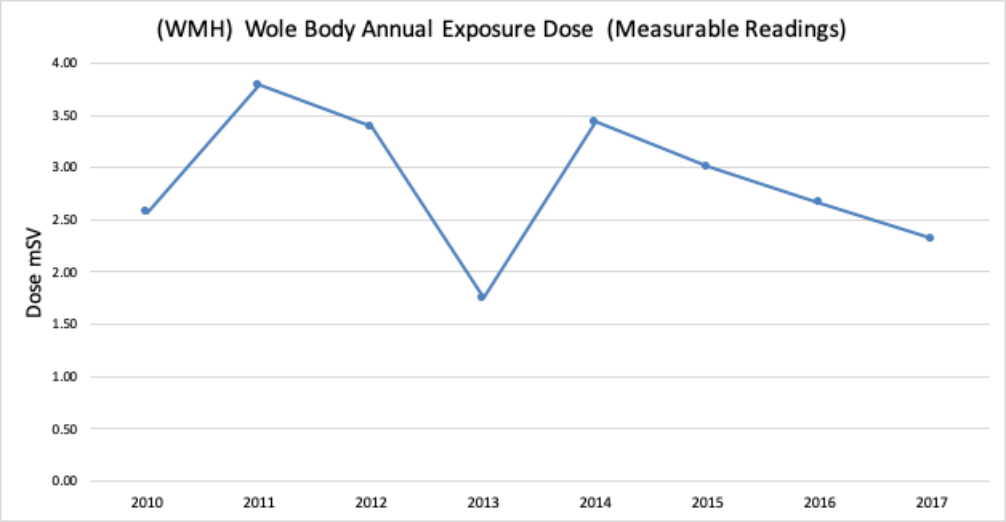

Figure 4.27: Represents the annual trend for the whole body annual average dose after removing the high dose readings and doses below detectable limit

The Western Memorial Regional Hospital whole body figures show that the quarterly average dose has slightly decreased during the period from 2011 to 2014. The available data is not enough to explain why would that happen. The general trend shows that the annually and quarterly whole body doses slightly increased over time.

4.3.4 Extremities Dose: (Including doses below detectable limit $<$ 0.1 mSv and high values)

A total of 76 extremities' quarter dose measurements were collected from the NDS quarters' dose's reports during the period, from the second quarter of 2012 to the second quarter of 2018. The average of the 76 recorded measurements was calculated to be 5.32 mSv with a minimum dose of 0.05 mSv, and a maximum dose of 62.9 mSv. Among these doses, there were 30 measurements below the detectable limits 0.1 mSv and 12 high level measurements which is 1.5 mSv.

The quarterly average doses were calculated and are listed in table A.28 and Figure 4.28, where the extremity quarter average doses ranged from 0.05 mSv to 22.05 mSv.

The standard deviations ranged from 0.00mSv to 35.41 mSv.

The annual extremity exposure doses ranged from 2.95 mSv to 22.38 mSv. The standard deviations ranged from 2.40 to 25.56 mSv. Table A.29, Figure 4.29

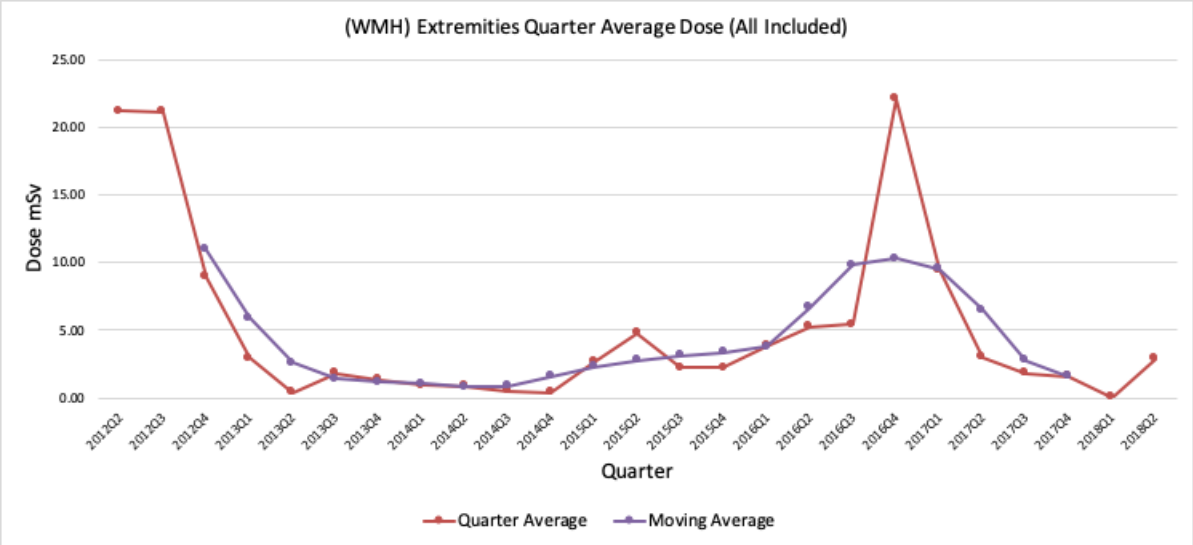

Figure 4.28: Represents the quarterly average and the moving average trend for the extremity quarter average dose including all measurements.

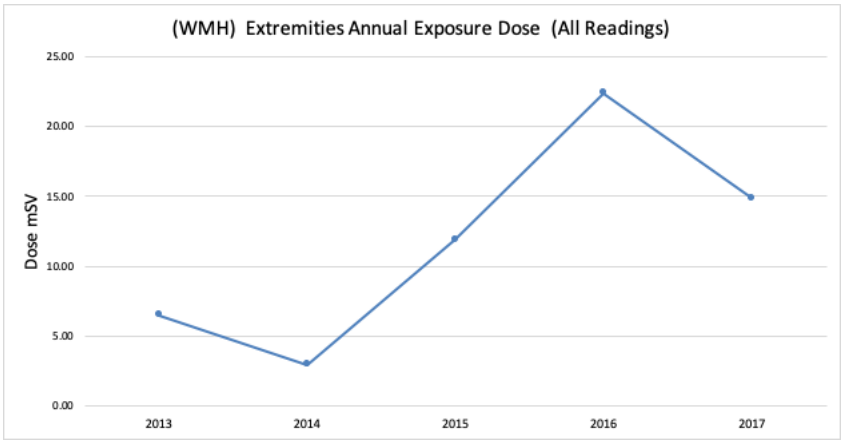

Figure 4.29: Represents the annual trend for the extremity annual average dose including all measurements.

4.3.5 Extremities Dose: (Excluding the high level values)

To remove any overestimation of the extremity average doses, the 12 measurements that met the exclusion criteria was removed. The average of the remaining 64 dose measurements is 1.56 mSv with a minimum dose of 0.05 and a maximum dose of 6.40 mSv.

The quarterly average doses were calculated and are listed in table A.30 and Figure 4.30, where the extremity quarterly average doses ranged from 0.05 mSv to 3.83 mSv. The standard deviations ranged from 0.00mSv to 3.82 mSv.

The annual extremity exposure doses ranged from 0.73 mSv to 10.45 mSv . The standard deviations ranged from 0.74 to 2.40. Table A.31, Figure 4.31

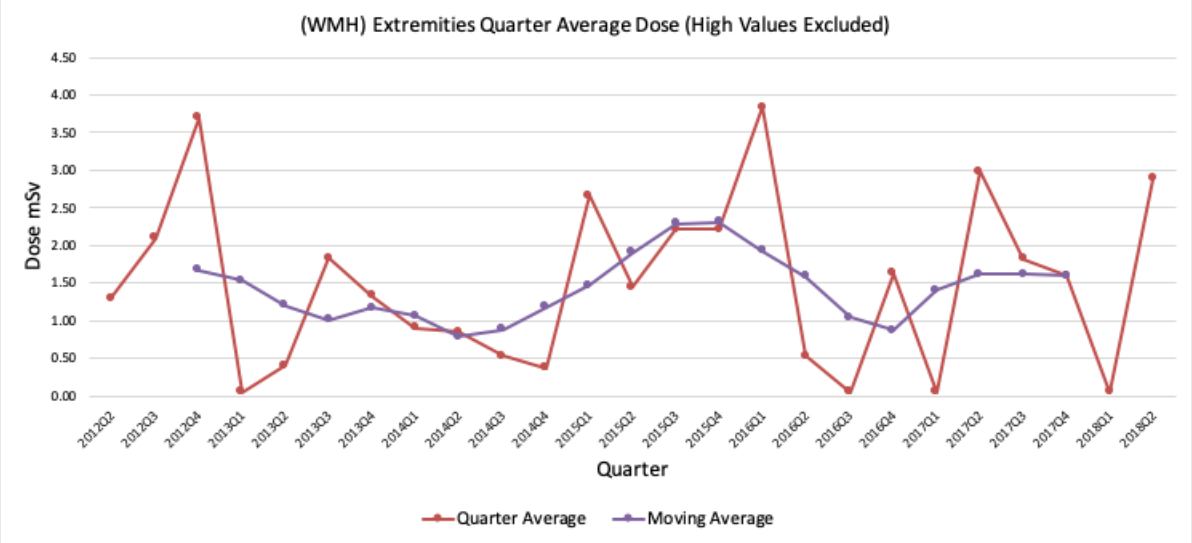

Figure 4.30: Represents the quarterly average and the moving average trend for the extremity quarter average dose after removing the high dose readings

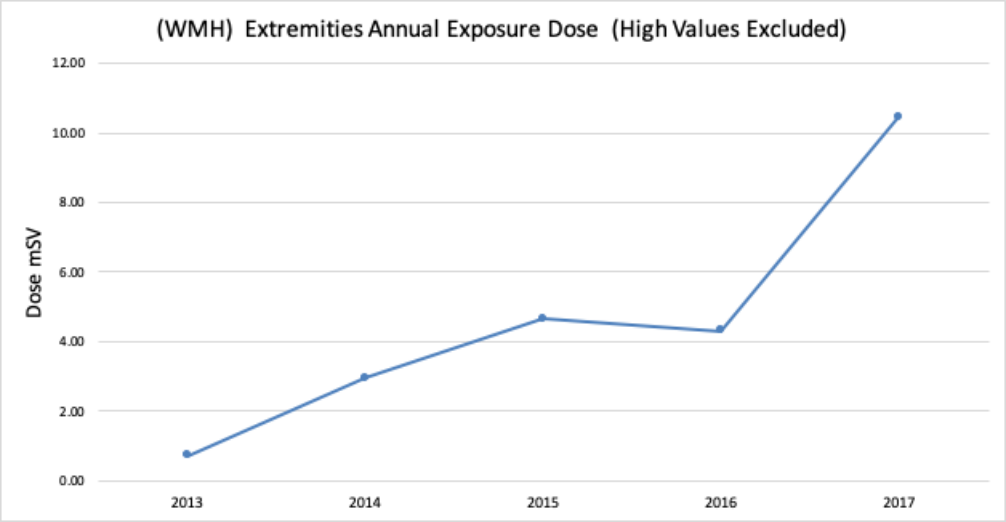

Figure 4.31: Represents the annual trend for the extremity annual average dose after removing the high dose readings

4.3.6 Extremities Dose: (Measureable Readings $>= 0.1$ mSv and < 7.5 mSv)

To remove both overestimation and underestimation effect of the Extremity's average doses, the 30 measurements that met the exclusion criteria were removed. The average of the remaining 34 dose measurements is 2.90 mSv with a minimum dose of 1 mSv and a maximum dose of 6.4 mSv

The quarterly average doses were also calculated and are listed in table A.32 and Figure 4.32, where the extremity quarter average doses ranged from 0.05 mSv to 5.4 mSv. The standard deviations ranged from 0.0 mSv to 3.82 mSv.

The annual extremity exposure doses ranged from 1.25 mSv to 10.45 mSv. Table A.33, Figure 4.33

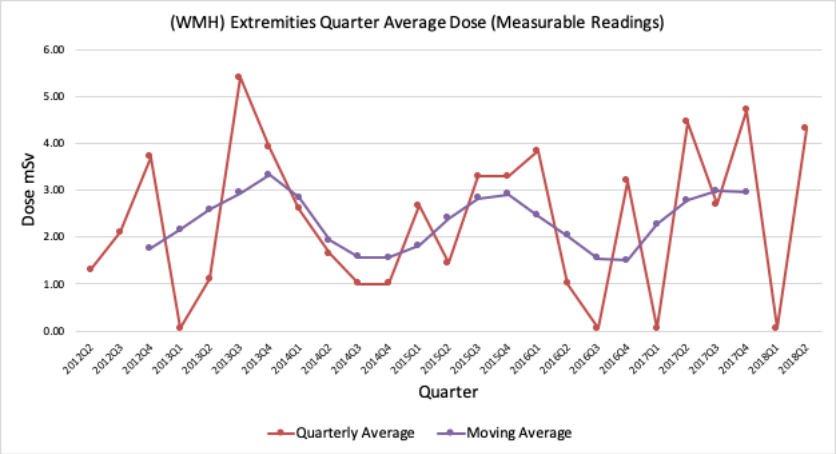

Figure 4.32: Represents the quarterly average and the moving average trend for the extremity quarter average dose after removing the high dose readings and doses below detectable limit

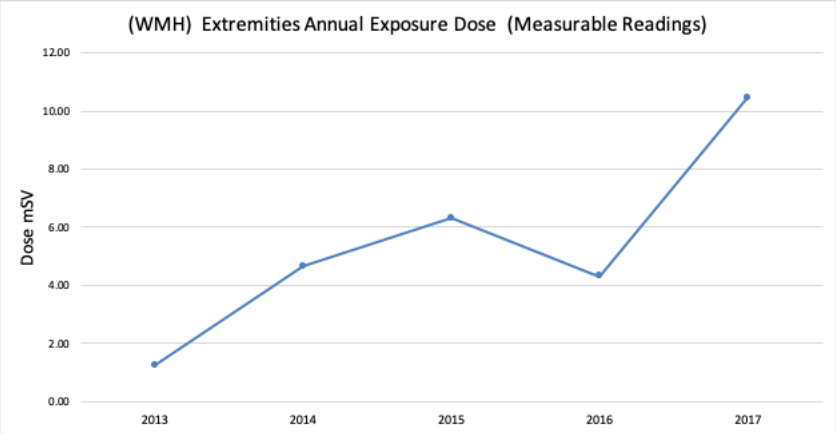

Figure 4.33: Represents the annual trend for the extremity annual average dose after removing the high dose readings and doses below detectable limit

The Western Memorial Regional Hospital Extremities' figures show that there are two dramatic increase at two different period of times from 2012 to 2013 and from 2016 to 2017 when all readings is Included.In the other two levels, figures show that there is not any significant variation over time. Due to limitation in the available data, it is not possible to detect the reason behind the variation.

4.4 Moving Average Comparison Between the Three levels analysis

Separating the analysis into three levels was conducted to avoid any overestimation or underestimation on the calculated average doses. However, the analysis showed that the trend was not considerably affected when we only removed the high values, or when we removed both the high values and the doses below detectable limits. The effect was noticeable on the overall trend line. The line was leveled down when we removed the high values and leveled up when we removed the doses below the detectable limits. See figures 4.34 4.35 4.36 4.37 4.38 4.39.

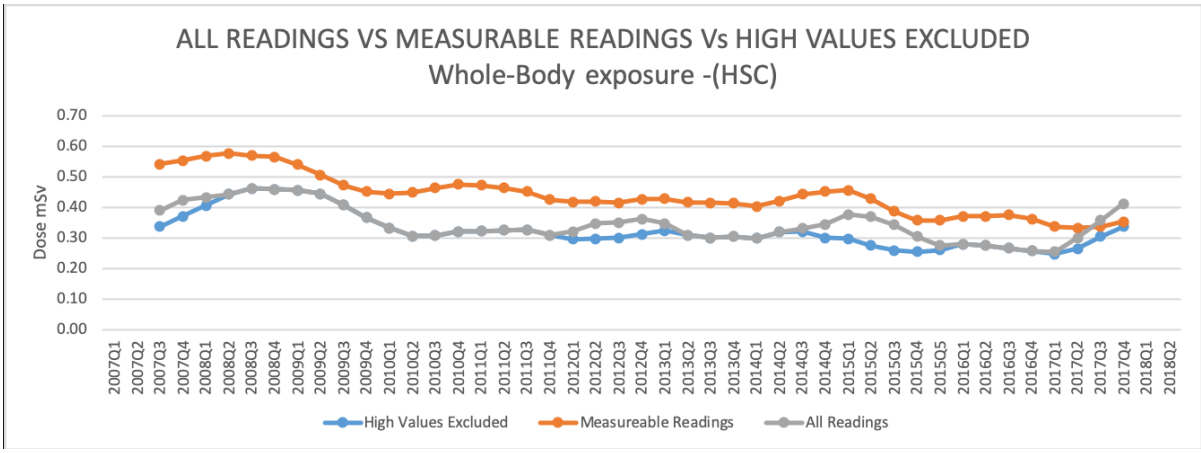

Figure 4.34: Represents the Health Sciences Center's quarterly moving average trend for the whole body at the three levels.

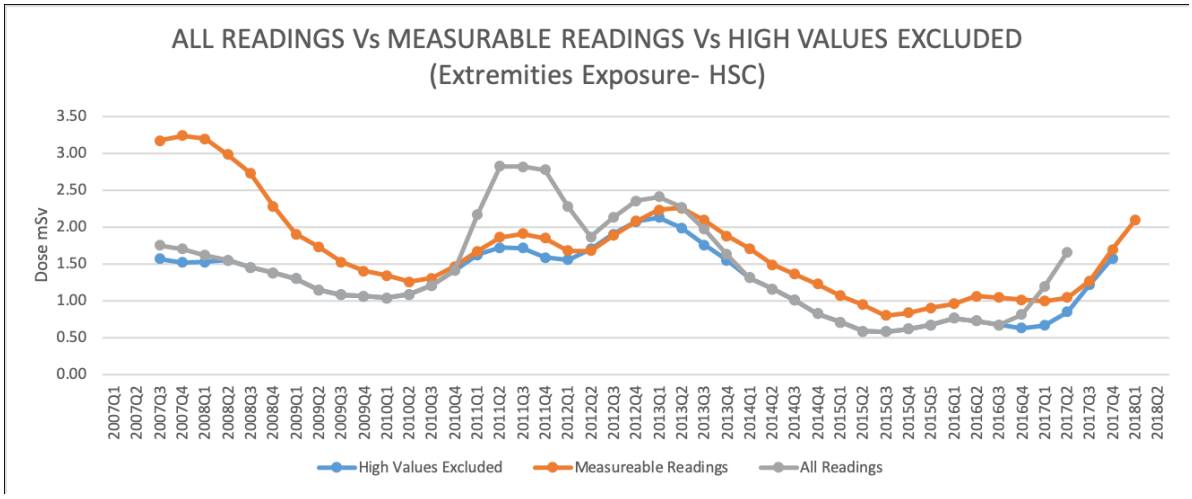

Figure 4.35: Represents the Health Sciences Center's quarterly moving average trend for the extremities dose at the three levels.

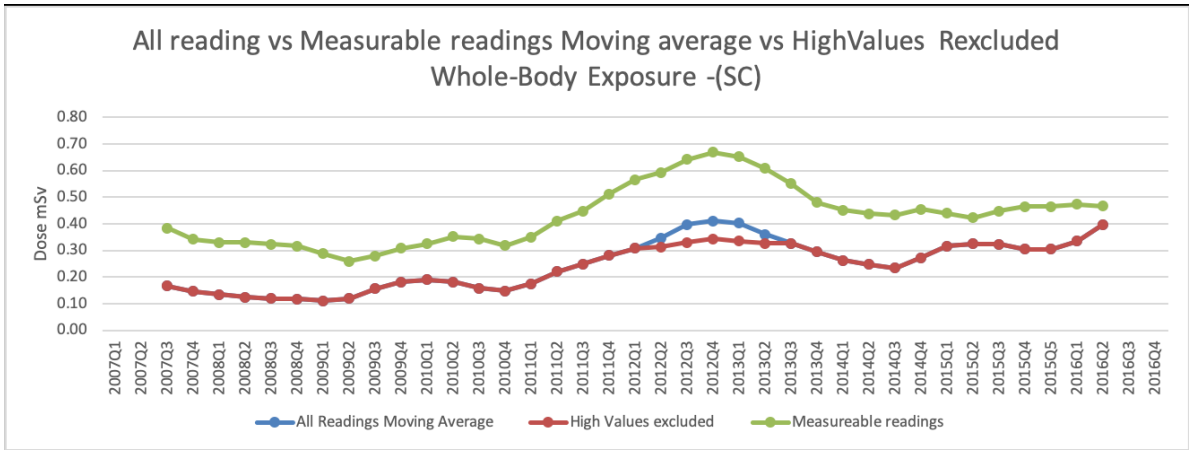

Figure 4.36: Represents the St.Clare's Hospital's quarterly moving average trend for the whole body dose at the three levels.

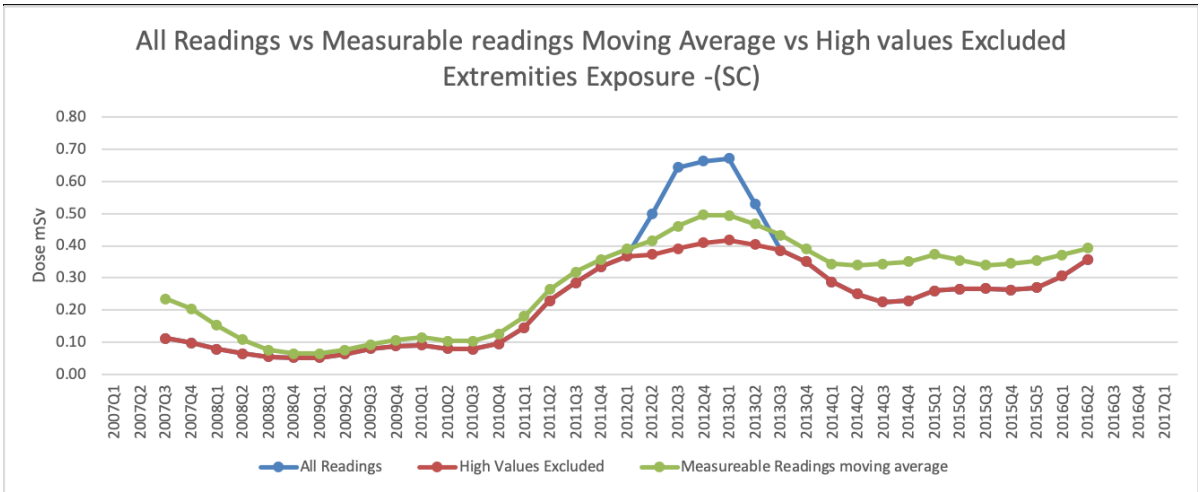

Figure 4.37: Represents the St.Clare's Hospital's quarterly moving average trend for the extremities dose at the three levels.

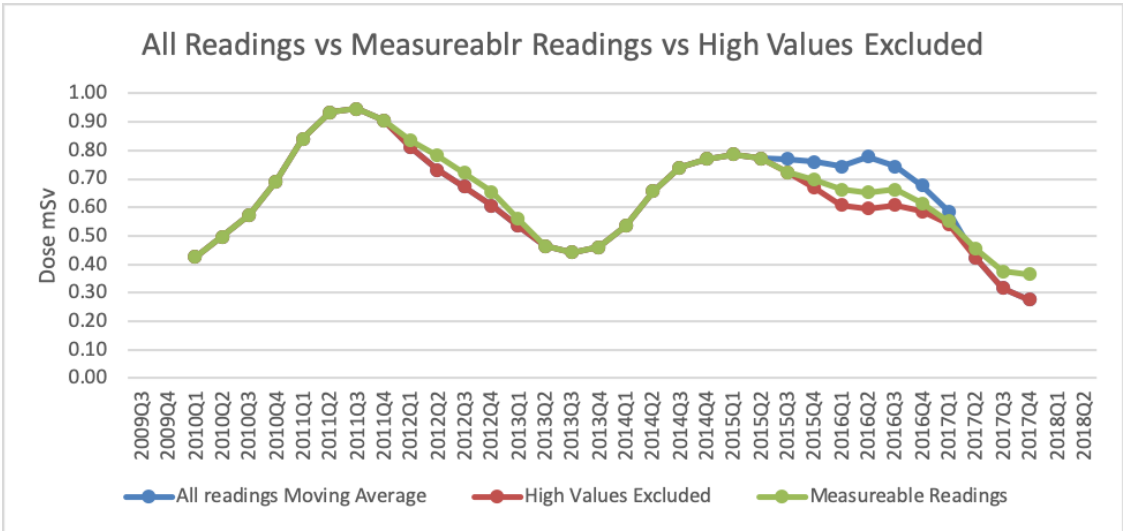

Figure 4.38: Represents the Western Memorial Regional Hospital's quarterly moving average trend for the whole body dose at the three levels.

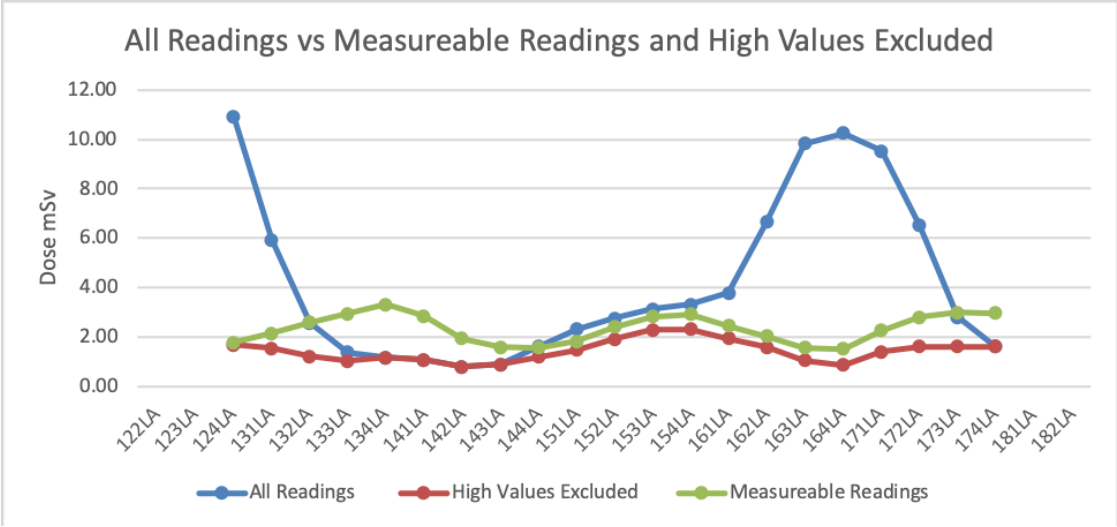

Figure 4.39: Represents the Western Memorial Regional Hospital's quarterly moving average trend for the extremities dose at the three levels.

Chapter 5

Discussion

The analysis at the three levels, including all readings, after removing high values, and after removing readings below detectable limits in the three facilities, reveals that the average annual whole body and extremities doses are well below the 50 mSv whole body dose limit and the 500 mSv extremities dose limt which are set by the CNSC and IAEA. There were differences between the levels at the same facility in the average annual whole body dose compared to the worldwide average annual dose of 1.9 mSv, which was reported by UNSCEAR [3]. The ten years annual averages whole body dose in the Health Science's Centre (0.95 mSv - 1.77 mSv) and St.Clare's Hospital (0.47 mSv - 1.48 mSv) was below the worldwide average annual dose in two levels (including all readings and when excluding the high values). However, the average annual whole body dose at the third level (excluding both the high values and values below detectable limits) was higher than the worldwide average annual dose. In the Western Memorial Regional Hospital, the average annual whole body dose in some years was higher than the worldwide reported average annual dose in the three levels. the staff in Western Memorial Hospital tended to be exposed to higher doses than those in Health Science's Centre and St.Clare's Hospital.

The annual average dose in the three facilities in ten years is comparable to that reported in Pakistan in several years (0.51 mSv - 1.91) [1], (0.3 mSv - 0.97 mSv) [14]. It is also comparable to that in Saudi Arabia (0.5 mSv - 2.6 mSv) [2] [20] and Kuwait (1.01 mSv - 2.4 mSv) [21] [22]. The annual exposure is lower than that reported in Poland (2 mSv - 9.5 mSv) [23], Portugal (2.45 mSv - 3.45 mSv) [24], and the USA (0.06 mSv - 11.1 mSv) [15]. The annual extremities dose in the three facilities is lower than that reported in the Serbian study (14 mSV - 85 mSv) [25], and is comparable to what was reported in Kuwait (1.8 mSv) [22].

The Health Sciences Centre's charts shows an increase in the quarterly average dose at the beginning, 2007, 2008, and at the end, in 2017 and 2018. The increase of the quarter average dose in 2007 and 2008 is associated with the imaging procedures that were followed in the past where the nuclear medicine technologist would be inside the room where the patient was scanned. However, that was gradually changed by installing a new camera that allows the technologist to perform the scan from a different room than the one where the patient is scanned. The increase in 2017 and 2018 is associated with the use of PET (Positron Emission tomography) technology that involves using radiopharmaceuticals with higher energy than the radiopharmaceuticals used in the SPECT (Single Photon Emision Tomography).

Unlike the Health Science Center, we were not able to explain the variation in the occupational radiation doses in both St. Clare's Mercy Hospital and Western Memorial Regional Hospital due to unavailability of the data that would help to explain the reason behind the variation.

The current available Data is feasible to detect and illustrate the trend and variation of the occupational radiation doses. However, it is extremely limited to go further and investigate the reasons behind any remarkable observation. Furthermore, the three facilities did not have a digital data base, and now they can use our excel

sheet to continue monitor the trends in the future.

At the high values analysis, among 1973 measurements from the three locations, we found 41 high measurements. The Health Sciences Centre data had 26 high measurements, of which 10 were whole body measurements, and 16 were extremities measurements. Based on our new staff criteria, there were 6 high measurements for new staff. St. Clare's data contains only one whole body high measurement, which was for an experienced participant. Western Memorial Hospital's data involved 14 high measurements, of which 2 were whole body measurements, both of which were for experienced participants, and 12 extremities measurements, two of which were new staff. The overall data showed that 78% of the high value measurements were readings for experienced participants and 22% of the high value readings for new staff or less experienced participants. This suggests that the perception about the effect of someone's experience level, which suggests that the lower experienced staff are slower and therefore are more likely to be exposed to higher doses, requires reconsideration as the majority of the high values in this study are associated with experienced staff Table 5.1.

Table 5.1: High Values Analysis

PARTICIPANT	FACILITY	WB/EXT	Q DOSE	QUARTER	LIFE DOSE	NEW
1	HS	WB	2.41	2007/3	32.75	N
2	HS	WB	3.45	2012/3	3.57	Y
3	HS	WB	1.76	2015/2	92.22	N
4	HS	WB	1.59	2015/1	3.69	y
4	HS	WB	1.69	2015/2	5.38	y
4	HS	WB	2.13	2015/3	7.51	N
5	HS	WB	1.62	2017/4	1.62	y
5	HS	WB	1.92	2018/1	3.54	Y
5	HS	EXTR	10.9	2018/1	10.9	Y
6	HS	WB	1.77	2018/1	14.95	N
6	HS	EXTR	13.08	2017/3	47	N
6	HS	EXTR	20.13	2017/4	67	N
6	HS	EXTR	8.3	2018/1	75	N
7	HS	WB	3.35	2018/3	3.35	Y
8	HS	EXTR	9.2	2007/3	27.85	N
9	HS	EXTR	9.92	2011/3	390	N
10	HS	EXTR	14.74	2011/3	60	N
10	HS	EXTR	9.02	2017/3	129	N
10	HS	EXTR	8.78	2018/3	152	N
11	HS	EXTR	10.19	2011/3	75	N
11	HS	EXTR	8.67	2012/2	86	N
12	HS	EXTR	8.21	2017/3	94	N
12	HS	EXTR	8.45	2017/4	102	N
15	HS	EXTR	11.19	2011/3	105	N
16	HS	EXTR	8.18	2013/1	83	N
16	HS	EXTR	9.32	2013/2	93	N
17	SC	WB	1.91	2012/4	57.83	N
18	WMH	WB	1.66	2016/1	14.22	N
18	WMH	EXTR	46.3	2012/3	46.3	Y
19	WMH	WB	1.61	2016/3	11.12	N
20	WMH	EXTR	35.1	2012/2	200	N
20	WMH	EXTR	34	2012/3	234	N
20	WMH	EXTR	19.3	2012/4	253	N
20	WMH	EXTR	8.7	2013/1	262	N
20	WMH	EXTR	10.6	2017/1	294	N
21	WMH	EXTR	27.1	2012/3	131.3	N
22	WMH	EXTR	62.9	2016/4	157.64	N
22	WMH	EXTR	17.7	2017/1	175.34	N
23	WMH	EXTR	11.5	2015/2	16.1	Y
23	WMH	EXTR	14.7	2016/2	47.5	N
23	WMH	EXTR	16.5	2016/3	64	N

Chapter 6

Conclusions and Recommendations

The occupational radiation dose received by the workers in the Nuclear Medicine department in Newfoundland and Labrador's hospitals from the first quarter of 2007 to the third quarter of 2018 were analyzed in this study. The overall results reveal that the occupational doses are well controlled and have not exceeded the allowed limits.

The annual average dose in the three facilities in ten years is comparable to that reported in Pakistan, Saudi Arabia, and Kuwait. The annual exposure is lower than that reported in Poland, Portugal, and the USA. The annual extremities dose in the three facilities is lower than that reported in the Serbian study, and is comparable to what was reported in Kuwait.

The trend was explained in the Health Sciences facility as the staff were able to recall the difference in practices in the past. However, in the other two facilities, the change in dose trends was not able to be explained as we could not link the change in the trends to any change in the practices or technology. Therefore, we suggest that, besides collecting the dose reading every quarter, a practices review should be done once a year to explain the trend change through the current year and to anticipate

the trend for the following year.

The dose variation behavior is difficult to be explained, as there are so many factors that play significant roles in that variation, including but not limited to, the number of procedures, individual skills, level of experience, individual jobs roles, and types of radiopharmaceuticals. The effect of the change in any of these factors would not be detectable as the radiation dose assessment is usually done for the staff as a cohort, while the factors mentioned earlier affect the radiation doses at the individual level. Therefore, we suggest that the occupational radiation dose assessment should be done only on the individual level. For every single staff member, the quarterly dose, number of procedures, type of procedure, level of experience, should be recorded for research purposes. Then, they should be followed for about 8 consecutive quarters. This way, the change in the number of procedures for example done by one individual could give more certain explanation of variation in the same individual dose as the other factors such as skills, experience level, and job's role are controlled for. Factors will be examined in all the staff to check the effect consistency. For example, number of procedures effect on one individual dose's trend should be similar to that on the other staff members with controlling for the other factors.

For future work, we recommend following a group of nuclear medicine staff radiation doses individually to investigate the behavior of the radiation dose variation, as it will help us to control its prolonged health effects.

Appendix A

Analysis Tables

Table A.1: Descriptive Statistics (HSC) - whole body average dose(All Included)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2007Q1	9	0.05	1.01	0.3500	0.33967
2007Q2	10	0.05	1.12	0.3230	0.36151
2007Q3	10	0.05	2.41	0.5300	0.72775
2007Q4	9	0.05	0.79	0.2822	0.30466
2008Q1	11	0.05	1.10	0.4964	0.42259
2008Q2	8	0.05	0.78	0.4500	0.28455
2008Q3	10	0.05	1.26	0.4710	0.42223
2008Q4	10	0.05	0.79	0.4320	0.28205
2009Q1	11	0.05	0.98	0.4927	0.33666
2009Q2	12	0.05	0.92	0.4358	0.29709
2009Q3	11	0.05	0.94	0.4545	0.31851
2009Q4	15	0.05	0.67	0.3567	0.21672
2010Q1	16	0.05	0.64	0.2744	0.23506

Continuation of Table A.1					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2010Q2	16	0.05	1.02	0.3231	0.28408
2010Q3	15	0.05	1.02	0.2973	0.29647
2010Q4	15	0.05	1.18	0.3040	0.31710
2011Q1	15	0.05	1.36	0.3440	0.34612
2011Q2	15	0.05	1.30	0.3533	0.35991
2011Q3	10	0.05	0.70	0.2840	0.21072
2011Q4	16	0.05	1.39	0.3425	0.34784
2012Q1	13	0.05	0.93	0.3177	0.26010
2012Q2	16	0.05	0.84	0.2394	0.24090
2012Q3	16	0.05	3.45	0.4819	0.83944
2012Q4	16	0.05	0.88	0.3556	0.25797
2013Q1	16	0.05	0.71	0.3294	0.24258
2013Q2	16	0.05	0.96	0.3219	0.31027
2013Q3	16	0.05	1.18	0.2906	0.33654
2013Q4	16	0.05	0.81	0.2306	0.24480
2014Q1	16	0.05	1.49	0.3913	0.37220
2014Q2	15	0.05	1.11	0.2967	0.31270
2014Q3	15	0.05	0.83	0.2653	0.24459
2014Q4	16	0.05	1.36	0.4150	0.42286
2015Q1	16	0.05	1.59	0.3100	0.42510
2015Q2	16	0.05	1.76	0.4750	0.60855
2015Q3	17	0.05	2.13	0.3541	0.51641
2015Q4	15	0.05	0.99	0.2607	0.26553

Continuation of Table A.1					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2016Q1	16	0.05	0.83	0.2563	0.25168
2016Q2	16	0.05	0.63	0.2281	0.21299
2016Q3	17	0.05	1.24	0.3588	0.37496
2016Q4	17	0.05	0.87	0.2959	0.27566
2017Q1	17	0.05	0.54	0.1888	0.17624
2017Q2	17	0.05	0.63	0.2229	0.20438
2017Q3	23	0.005	1.130	0.28717	0.305855
2017Q4	22	0.005	1.620	0.35250	0.376316
2018Q1	22	0.010	1.950	0.48545	0.528346
2018Q2	20	0.005	1.500	0.39125	0.411384
2018Q3	19	0.020	3.350	0.54895	0.771304
End of Table					

Table A.2: Descriptive Statistics (HSC) - whole-body exposure per year (All Included)

year	N	Minimum	Maximum	Mean	Std. Deviation
2007	8	0.2	3.93	1.7225	1.2973021
2008	7	0.2	3.13	1.5957143	1.1419991
2009	10	0.2	3.04	1.767	1.064112
2010	14	0.2	3.8	1.2007143	1.0827704
2011	10	0.2	4.75	1.645	1.3429259
2012	13	0.2	3.18	1.3192308	0.8988832
2013	16	0.2	3.61	1.1725	1.0284649
2014	13	0.2	4.79	1.4192308	1.329326
2015	13	0.2	5.62	1.5753846	1.7166179
2016	15	0.2	3.23	1.1746667	1.0757513
2017	16	0.11	2.42	0.953125	0.6712249
2018	17	0.06	3.89	1.3685294	1.2390719

Table A.3: Descriptive Statistics (HSC) - whole body average (high values removed)

Quarter	N	Range	Minimum	Maximum	Mean	Std. Deviation
2007Q1	9	0.96	0.05	1.01	0.3500	0.33967
2007Q2	10	1.07	0.05	1.12	0.3230	0.36151
2007Q3	9	0.96	0.05	1.01	0.3211	0.32394
2007Q4	9	0.74	0.05	0.79	0.2822	0.30466
2008Q1	11	1.05	0.05	1.10	0.4964	0.42259
2008Q2	8	0.73	0.05	0.78	0.4500	0.28455
2008Q3	10	1.21	0.05	1.26	0.4710	0.42223
2008Q4	10	0.74	0.05	0.79	0.4320	0.28205
2009Q1	11	0.93	0.05	0.98	0.4927	0.33666
2009Q2	12	0.87	0.05	0.92	0.4358	0.29709
2009Q3	11	0.89	0.05	0.94	0.4545	0.31851
2009Q4	15	0.62	0.05	0.67	0.3567	0.21672
2010Q1	16	0.59	0.05	0.64	0.2744	0.23506
2010Q2	16	0.97	0.05	1.02	0.3231	0.28408
2010Q3	15	0.97	0.05	1.02	0.2973	0.29647
2010Q4	15	1.13	0.05	1.18	0.3040	0.31710
2011Q1	15	1.31	0.05	1.36	0.3440	0.34612
2011Q2	15	1.25	0.05	1.30	0.3533	0.35991
2011Q3	10	0.65	0.05	0.70	0.2840	0.21072
2011Q4	16	1.34	0.05	1.39	0.3425	0.34784
2012Q1	13	0.88	0.05	0.93	0.3177	0.26010
2012Q2	16	0.79	0.05	0.84	0.2394	0.24090

Continuation of Table A.3						
Quarter	N	Range	Minimum	Maximum	Mean	Std. Deviation
2012Q3	15	0.97	0.05	1.02	0.2840	0.28943
2012Q4	16	0.83	0.05	0.88	0.3556	0.25797
2013Q1	16	0.66	0.05	0.71	0.3294	0.24258
2013Q2	16	0.91	0.05	0.96	0.3219	0.31027
2013Q3	16	1.13	0.05	1.18	0.2906	0.33654
2013Q4	16	0.76	0.05	0.81	0.2306	0.24480
2014Q1	16	1.44	0.05	1.49	0.3913	0.37220
2014Q2	15	1.06	0.05	1.11	0.2967	0.31270
2014Q3	15	0.78	0.05	0.83	0.2653	0.24459
2014Q4	16	1.31	0.05	1.36	0.4150	0.42286
2015Q1	15	0.75	0.05	0.80	0.2247	0.26227
2015Q2	14	1.20	0.05	1.25	0.2964	0.39038
2015Q3	16	0.81	0.05	0.86	0.2431	0.24711
2015Q4	15	0.94	0.05	0.99	0.2607	0.26553
2016Q1	16	0.78	0.05	0.83	0.2563	0.25168
2016Q2	16	0.58	0.05	0.63	0.2281	0.21299
2016Q3	17	1.19	0.05	1.24	0.3588	0.37496
2016Q4	17	0.82	0.05	0.87	0.2959	0.27566
2017Q1	17	0.49	0.05	0.54	0.1888	0.17624
2017Q2	17	0.58	0.05	0.63	0.2229	0.20438
2017Q3	23	1.12	0.005	1.13	0.2891	0.30411
2017Q4	21	0.93	0.005	0.93	0.2857	0.26090
2018Q1	20	0.92	0.005	0.92	0.3390	0.30806

Continuation of Table A.3						
Quarter	N	Range	Minimum	Maximum	Mean	Std. Deviation
2018Q2	20	1.50	0.005	1.50	0.3863	0.41596
2018Q3	19	3.35	0.005	1.25	0.3910	0.38036
End of Table						

Table A.4: Descriptive Statistics (HSC) - whole body exposure per year (High -Values excluded)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2007	7	0.2	3.93	1.602857143	1.352734444
2008	7	0.2	3.13	1.595714286	1.141999083
2009	10	0.2	3.04	1.767	1.064112045
2010	14	0.2	3.8	1.200714286	1.082770409
2011	10	0.2	4.75	1.645	1.34292591
2012	13	0.2	3.18	1.319230769	0.89888321
2013	16	0.2	3.61	1.1725	1.028464875
2014	13	0.2	4.79	1.419230769	1.329326029
2015	11	0.2	3.5	1.074545455	1.187353053
2016	15	0.2	3.23	1.174666667	1.075751343
2017	16	0.11	2.42	0.953125	0.671224937
2018	15	0.06	3.67	1.093	1.016695979

Table A.5: Descriptive Statistics (HSC) - whole body exposure per quarter (Measureable readings)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2007Q1	6	0.11	1.01	0.5000	0.32187
2007Q2	6	0.13	1.12	0.5050	0.36861
2007Q3	5	0.30	1.01	0.5380	0.27851
2007Q4	4	0.38	0.79	0.5725	0.21282
2008Q1	9	0.10	1.10	0.5956	0.40293
2008Q2	7	0.13	0.78	0.5071	0.25296
2008Q3	7	0.11	1.26	0.6514	0.37525
2008Q4	8	0.24	0.79	0.5275	0.22397
2009Q1	9	0.14	0.98	0.5911	0.28598
2009Q2	11	0.10	0.92	0.4709	0.28434
2009Q3	10	0.10	0.94	0.4950	0.30449
2009Q4	13	0.10	0.67	0.4038	0.19160
2010Q1	9	0.14	0.64	0.4489	0.15902
2010Q2	11	0.12	1.02	0.4473	0.25846
2010Q3	9	0.10	1.02	0.4622	0.27811
2010Q4	9	0.24	1.18	0.4733	0.30875
2011Q1	10	0.11	1.36	0.4910	0.33811
2011Q2	10	0.10	1.30	0.5050	0.35331
2011Q3	7	0.20	0.70	0.3843	0.16582
2011Q4	11	0.10	1.39	0.4755	0.34535
2012Q1	10	0.11	0.93	0.3980	0.24321
2012Q2	9	0.12	0.84	0.3867	0.23027

Continuation of Table A.5					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2012Q3	9	0.13	1.02	0.4400	0.27955
2012Q4	13	0.14	0.88	0.4262	0.23333
2013Q1	12	0.12	0.71	0.4225	0.20592
2013Q2	11	0.10	0.96	0.4455	0.30108
2013Q3	11	0.11	1.18	0.4000	0.35746
2013Q4	9	0.11	0.81	0.3711	0.24822
2014Q1	13	0.13	1.49	0.4700	0.37059
2014Q2	11	0.11	1.11	0.3864	0.32203
2014Q3	10	0.11	0.83	0.3730	0.23329
2014Q4	12	0.14	1.36	0.5367	0.42337
2015Q1	6	0.16	0.80	0.4867	0.23517
2015Q2	9	0.12	1.25	0.4333	0.43428
2015Q3	10	0.10	0.86	0.3590	0.24897
2015Q4	11	0.10	0.99	0.3373	0.27295
2016Q1	11	0.11	0.83	0.3500	0.25314
2016Q2	10	0.10	0.63	0.3350	0.20436
2016Q3	13	0.12	1.24	0.4538	0.38196
2016Q4	14	0.10	0.87	0.3486	0.27674
2017Q1	8	0.12	0.54	0.3450	0.13544
2017Q2	9	0.10	0.63	0.3767	0.16447
2017Q3	22	0.010	1.130	0.30000	0.306656
2017Q4	20	0.010	0.930	0.30650	0.251758
2018Q1	20	0.010	0.920	0.34800	0.298180

Continuation of Table A.5					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2018Q2	19	0.010	1.500	0.41158	0.412206
2018Q3	18	0.020	1.250	0.39333	0.377811
End of Table					

Table A.6: Descriptive Statistics (HSC) - whole body exposure per year (Measureable Readings)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2007	4	1.28	3.93	2.455	1.12179915
2008	4	1	3.13	2.265	0.909743554
2009	8	0.84	3.04	2.135	0.824274573
2010	8	0.9	3.8	1.90125	0.926366751
2011	7	1.16	4.75	2.231428571	1.168865954
2012	7	1.08	3.18	1.868571429	0.713989462
2013	9	0.64	3.61	1.791111111	0.97834611
2014	8	0.83	4.79	2.10625	1.269228534
2015	4	0.73	3.5	2.1375	1.449445296
2016	6	0.76	3.23	2.163333333	1.093812903
2017	7	0.98	2.42	1.542857143	0.486987826
2018	14	0.06	3.67	1.145	1.03416819

Table A.7: Descriptive Statistics (HSC) - extremities exposure per Quarter (all readings included)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2007Q1	12	0.050	5.590	1.69333	2.195190
2007Q2	12	0.050	6.030	1.60167	2.163771
2007Q3	11	0.050	9.200	1.97636	3.084290
2007Q4	9	0.050	6.470	1.76556	2.110119
2008Q1	12	0.050	7.410	1.63250	2.370098
2008Q2	11	0.050	4.180	1.27818	1.538063
2008Q3	11	0.050	4.780	1.63091	1.774370
2008Q4	10	0.050	4.290	1.58400	1.618217
2009Q1	14	0.050	2.860	1.04500	0.973580
20009Q2	12	0.050	3.370	1.26000	1.264365
2009Q3	9	0.050	3.110	1.01556	1.049430
2009Q4	14	0.050	2.580	0.97643	0.795010
2010Q1	14	0.050	3.700	1.09929	1.115233
2010Q2	14	0.050	4.180	1.07000	1.378433
2010Q3	13	0.050	2.950	1.03692	1.095996
2010Q4	13	0.050	3.820	1.34846	1.536608
2011Q1	13	0.050	5.800	1.66308	1.706978
2011Q2	12	0.050	5.230	2.15583	1.886712
2011Q3	9	0.160	14.740	6.00778	5.605260
2011Q4	13	0.050	3.790	1.60231	1.445586
2012Q1	11	0.050	3.490	1.33273	1.096805
2012Q2	11	0.130	8.670	2.13364	2.846515

Continuation of Table A.7					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2012Q3	11	0.050	6.860	2.04818	2.601180
2012Q4	12	0.050	4.290	2.31167	1.365136
2013Q1	12	0.100	8.180	2.71917	2.580192
2013Q2	12	0.120	9.320	2.55500	2.936973
2013Q3	12	0.050	7.150	2.04917	2.168235
2013Q4	12	0.050	4.800	1.20000	1.503916
2014Q1	11	0.050	4.810	1.45818	1.731813
2014Q2	10	0.050	3.400	1.08500	1.199410
2014Q3	9	0.050	3.320	0.98667	1.095639
2014Q4	12	0.050	2.280	1.03000	0.822347
2015Q1	13	0.050	1.460	0.41231	0.494674
2015Q2	12	0.050	2.540	0.68083	0.830591
2015Q3	13	0.050	1.460	0.46769	0.474379
2015Q4	12	0.050	2.240	0.58333	0.660844
2016Q1	14	0.050	5.380	0.82214	1.405726
2016Q2	14	0.050	3.340	0.52929	0.869106
2016Q3	14	0.050	7.500	1.09214	2.036230
2016Q4	13	0.050	2.200	0.65692	0.796831
2017Q1	14	0.050	2.330	0.47786	0.711458
2017Q2	14	0.050	2.200	0.40643	0.608347
2017Q3	19	0.005	13.080	2.36895	3.667583
2017Q4	20	0.005	20.130	2.40200	4.654131
2018Q1	18	0.005	10.900	2.44639	3.216279

Continuation of Table A.7					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2018Q2	18	0.005	7.350	2.30111	2.393554
2018Q3	17	0.005	8.780	2.23059	2.367771
End of Table					

Table A.8: Descriptive Statistics (HSC) - extremities exposure per year (all readings included)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2007	9	0.200	26.940	8.43222	9.742805
2008	8	0.250	15.470	7.28500	5.048216
2009	9	0.200	9.370	3.45667	3.518686
2010	13	0.200	12.400	4.54385	4.730209
2011	9	0.310	28.880	11.33556	10.695132
2012	11	0.280	19.190	7.64636	7.025323
2013	12	0.320	22.950	8.52333	8.011958
2014	8	0.200	11.850	5.05875	4.552197
2015	10	0.200	6.560	2.29600	2.115111
2016	12	0.260	18.290	3.50667	5.012703
2017	13	0.445	35.140	7.33692	10.196071
2018	16	0.015	20.640	7.22406	7.012295

Table A.9: Descriptive Statistics (HSC) - extremities exposure per quarter (High Values Excluded)

Quarter	Range	N	Minimum	Maximum	Mean	Std. Deviation
2007Q1	12	5.54	0.05	5.59	1.6933	2.19519
2007Q2	12	5.98	0.05	6.03	1.6017	2.16377
2007Q3	10	6.00	0.05	6.05	1.2540	2.04748
2007Q4	9	6.42	0.05	6.47	1.7656	2.11012
2008Q1	12	7.36	0.05	7.41	1.6325	2.37010
2008Q2	11	4.13	0.05	4.18	1.2782	1.53806
2008Q3	11	4.73	0.05	4.78	1.6309	1.77437
2008Q4	10	4.24	0.05	4.29	1.5840	1.61822
2009Q1	14	2.81	0.05	2.86	1.0450	0.97358
2009Q2	12	3.32	0.05	3.37	1.2600	1.26436
2009Q3	9	3.06	0.05	3.11	1.0156	1.04943
2009Q4	14	2.53	0.05	2.58	0.9764	0.79501
2010Q1	14	3.65	0.05	3.70	1.0993	1.11523
2010Q2	14	4.13	0.05	4.18	1.0700	1.37843
2010Q3	13	2.90	0.05	2.95	1.0369	1.09600
2010Q4	13	3.77	0.05	3.82	1.3485	1.53661
2011Q1	13	5.75	0.05	5.80	1.6631	1.70698
2011Q2	12	5.18	0.05	5.23	2.1558	1.88671
2011Q3	5	5.25	0.16	5.41	1.6060	2.15463
2011Q4	13	3.74	0.05	3.79	1.6023	1.44559
2012Q1	11	3.44	0.05	3.49	1.3327	1.09681
2012Q2	10	5.08	0.13	5.21	1.4800	1.94451

Continuation of Table A.9						
Quarter	Range	N	Minimum	Maximum	Mean	Std. Deviation
2012Q3	11	6.81	0.05	6.86	2.0482	2.60118
2012Q4	12	4.24	0.05	4.29	2.3117	1.36514
2013Q1	11	6.07	0.10	6.17	2.2227	2.01741
2013Q2	11	6.36	0.12	6.48	1.9400	2.12033
2013Q3	12	7.10	0.05	7.15	2.0492	2.16824
2013Q4	12	4.75	0.05	4.80	1.2000	1.50392
2014Q1	11	4.76	0.05	4.81	1.4582	1.73181
2014Q2	10	3.35	0.05	3.40	1.0850	1.19941
2014Q3	9	3.27	0.05	3.32	0.9867	1.09564
2014Q4	12	2.23	0.05	2.28	1.0300	0.82235
2015Q1	13	1.41	0.05	1.46	0.4123	0.49467
2015Q2	12	2.49	0.05	2.54	0.6808	0.83059
2015Q3	13	1.41	0.05	1.46	0.4677	0.47438
2015Q4	12	2.19	0.05	2.24	0.5833	0.66084
2016Q1	14	5.33	0.05	5.38	0.8221	1.40573
2016Q2	14	3.29	0.05	3.34	0.5293	0.86911
2016Q3	14	7.45	0.05	7.50	1.0921	2.03623
2016Q4	13	2.15	0.05	2.20	0.6569	0.79683
2017Q1	14	2.28	0.05	2.33	0.4779	0.71146
2017Q2	14	2.15	0.05	2.20	0.4064	0.60835
2017Q3	16	3.13	0.01	3.13	0.9188	1.01294
2017Q4	18	4.70	0.01	4.70	1.0811	1.31265
2018Q1	16	5.32	0.01	5.32	1.5522	1.95506

Continuation of Table A.9						
Quarter	Range	N	Minimum	Maximum	Mean	Std. Deviation
2018Q2	18	7.35	0.01	7.35	2.3011	2.39355
2018Q3	16	4.80	0.01	4.80	1.8213	1.71514
End of Table						

Table A.10: Descriptive Statistics (HSC) - Extremities exposure per year (high values excluded))

Year	N	Minimum	Maximum	Mean	Std. Deviation
2007	8	0.2	18.81	6.11875	7.309709
2008	8	0.25	15.47	7.285	5.048216
2009	9	0.2	9.37	3.456667	3.518686
2010	13	0.2	12.4	4.543846	4.730209
2011	5	0.31	11.37	3.23	4.590599
2012	10	0.28	18.42	6.492	6.209049
2013	11	0.32	22.95	7.237273	6.984158
2014	8	0.2	11.85	5.05875	4.552197
2015	10	0.2	6.56	2.296	2.115111
2016	11	0.26	5.96	2.162727	1.948954
2017	11	0.445	35.14	5.529091	10.06243
2018	15	0.015	20.64	6.581667	6.753533

Table A.11: Descriptive Statistics (HSC) - extremities exposure per quarter (Measureable Readings)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2007Q1	6	0.540	5.590	3.33667	2.029824
2007Q2	6	0.440	6.030	3.15333	2.126449
2007Q3	4	0.570	6.050	3.06000	2.308333
2007Q4	5	1.820	6.470	3.13800	1.899360
2008Q1	5	2.200	7.410	3.84800	2.220286
2008Q2	6	0.100	4.180	2.30167	1.402076
2008Q3	8	0.520	4.780	2.22375	1.739228
2008Q4	8	0.270	4.290	1.96750	1.589463
2009Q1	10	0.620	2.860	1.44300	0.867820
2009Q2	9	0.130	3.370	1.66333	1.210806
2009Q3	6	0.550	3.110	1.49833	0.960738
2009Q4	13	0.110	2.580	1.04769	0.779542
2010Q1	11	0.120	3.700	1.38545	1.093841
2010Q2	12	0.110	4.180	1.24000	1.422974
2010Q3	11	0.130	2.950	1.21636	1.100557
2010Q4	10	0.140	3.820	1.73800	1.554869
2011Q1	11	0.130	5.800	1.95636	1.697500
2011Q2	11	0.150	5.230	2.34727	1.852534
2011Q3	5	0.160	5.410	1.60600	2.154630
2011Q4	12	0.240	3.790	1.73167	1.429118
2012Q1	10	0.250	3.490	1.46100	1.065619
2012Q2	10	0.130	5.210	1.48000	1.944508

Continuation of Table A.11					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2012Q3	9	0.200	6.860	2.49222	2.690292
2012Q4	11	0.240	4.290	2.51727	1.221451
2013Q1	11	0.100	6.170	2.22273	2.017415
2013Q2	11	0.120	6.480	1.94000	2.120335
2013Q3	11	0.220	7.150	2.23091	2.176090
2013Q4	10	0.180	4.800	1.43000	1.552968
2014Q1	10	0.210	4.810	1.59900	1.757855
2014Q2	9	0.120	3.400	1.20000	1.212281
2014Q3	7	0.220	3.320	1.25429	1.106599
2014Q4	9	0.240	2.280	1.35667	0.670559
2015Q1	8	0.140	1.460	0.63875	0.516843
2015Q2	9	0.100	2.540	0.89111	0.865801
2015Q3	10	0.110	1.460	0.59300	0.473757
2015Q4	8	0.120	2.240	0.85000	0.665175
2016Q1	8	0.220	5.380	1.40125	1.665991
2016Q2	11	0.100	3.340	0.66000	0.945643
2016Q3	12	0.110	7.500	1.26583	2.160953
2016Q4	8	0.100	2.200	1.03625	0.812965
2017Q1	6	0.140	2.330	1.04833	0.795372
2017Q2	7	0.100	2.200	0.76286	0.710932
2017Q3	14	0.100	3.130	1.04929	1.018381
2017Q4	12	0.120	4.700	1.61917	1.309750
2018Q1	11	0.110	5.320	2.25545	1.998111

Continuation of Table A.11					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2018Q2	14	0.190	7.350	2.95714	2.325128
2018Q3	14	0.120	4.800	2.08071	1.677583
End of Table					

Table A.12: Descriptive Statistics (HSC) - extremities exposure per year (Measurable Readings)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2007	4	6.1	18.81	12.0375	5.590768
2008	5	5.58	15.47	9.536	3.960458
2009	5	2.22	9.37	5.838	2.953764
2010	9	0.86	12.4	5.968889	4.960906
2011	3	1.53	11.37	4.943333	5.569249
2012	8	0.88	18.42	7.6525	6.416167
2013	9	0.9	22.95	8.542222	7.082614
2014	5	1.08	11.85	7.216	4.379547
2015	4	0.71	6.56	3.93	2.502519
2016	5	0.84	18.29	5.956	7.156635
2017	2	1.86	7.76	4.81	4.17193
2018	7	0.56	14.81	6.508571	4.567116

Table A.13: Descriptive Statistics (SC) - whole body exposure per quarter (All Readings)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2007Q1	6	0.05	0.79	0.2383	0.33632
2007Q2	6	0.05	0.50	0.1783	0.22836
2007Q3	7	0.05	0.36	0.1571	0.16567
20074Q	8	0.05	0.38	0.1425	0.15887
2008Q1	8	0.05	0.50	0.1363	0.19127
2008Q2	8	0.05	0.37	0.1150	0.14704
2008Q3	8	0.05	0.39	0.1213	0.15784
2008Q4	8	0.05	0.35	0.1013	0.12850
2009Q1	8	0.05	0.39	0.1350	0.18053
2009Q2	8	0.05	0.40	0.1013	0.14121
2009Q3	6	0.05	0.17	0.0883	0.05947
2009Q4	6	0.11	0.34	0.2017	0.10187
2010Q1	6	0.05	1.16	0.3267	0.46305
2010Q2	6	0.05	0.30	0.1200	0.13663
2010Q3	6	0.05	0.43	0.1317	0.17463
2010Q4	6	0.05	0.30	0.0917	0.12247
2011Q1	6	0.05	0.86	0.2417	0.33315
2011Q2	6	0.05	0.33	0.1367	0.13556
2011Q3	6	0.05	0.85	0.3217	0.35725
2011Q4	6	0.05	0.81	0.2700	0.32210
2012Q1	6	0.05	1.07	0.2900	0.41443
2012Q2	6	0.05	1.16	0.3450	0.45184

Continuation of Table A.13					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2012Q3	6	0.05	1.15	0.3300	0.45161
2012Q4	6	0.05	1.91	0.5717	0.77039
2013Q1	6	0.05	1.45	0.3883	0.56230
2013Q2	6	0.05	1.23	0.3567	0.47822
2013Q3	6	0.05	0.72	0.2500	0.28829
2013Q4	5	0.05	0.65	0.3180	0.28787
2014Q1	5	0.05	1.07	0.3720	0.41027
2014Q2	5	0.05	0.37	0.1140	0.16547
2014Q3	5	0.05	0.55	0.2360	0.28316
2014Q4	5	0.05	0.50	0.2160	0.22744
2015Q1	5	0.05	0.84	0.3680	0.38512
2015Q2	5	0.11	0.92	0.4180	0.39404
2015Q3	5	0.05	0.65	0.2940	0.26463
2015Q4	5	0.05	0.67	0.2240	0.27754
2016Q1	5	0.05	0.78	0.3380	0.42181
2016Q2	5	0.05	0.82	0.3020	0.31886
2016Q3	5	0.28	0.67	0.4080	0.15418
2016Q4	5	0.18	0.79	0.3540	0.24684
2017Q1	5	0.28	1.46	0.7060	0.55424
End of Table					

Table A.14: Descriptive Statistics (SC) - whole body exposure per year (All Readings Included)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2007	6	0.2	1.93	0.706667	0.796082
2008	8	0.2	1.4	0.47375	0.509984
2009	6	0.26	1.28	0.571667	0.43213
2010	5	0.2	1.53	0.542	0.560598
2011	5	0.2	1.7	0.776	0.740459
2012	6	0.2	4.36	1.536667	1.722158
2013	5	0.2	4.05	1.482	1.5719
2014	5	0.26	2.04	0.938	0.825694
2015	5	0.26	2.75	1.304	1.196466
2016	5	0.63	3.04	1.402	1.019201

Table A.15: Descriptive Statistics (SC) - whole body exposure per quarter (highe values execluded)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2007Q1	6	0.05	0.79	0.2383	0.31205
2007Q2	6	0.05	0.50	0.1783	0.20302
2007Q3	7	0.05	0.36	0.1571	0.13997
2007Q4	8	0.05	0.38	0.1425	0.13403
2008Q1	8	0.05	0.50	0.1363	0.16928
2008Q2	8	0.05	0.37	0.1150	0.12456
2008Q3	8	0.05	0.39	0.1213	0.13517
2008Q4	8	0.05	0.35	0.1013	0.10763
2009Q1	8	0.05	0.39	0.1350	0.15739
2009Q2	8	0.05	0.40	0.1013	0.12253
2009Q3	6	0.05	0.17	0.0883	0.05947
2009Q4	6	0.11	0.34	0.2017	0.10187

Continuation of Table A.15					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2010Q1	6	0.05	1.16	0.3267	0.44392
2010Q2	6	0.05	0.30	0.1200	0.11136
2010Q3	6	0.05	0.43	0.1317	0.15263
2010Q4	6	0.05	0.30	0.0917	0.10206
2011Q1	6	0.05	0.86	0.2417	0.31422
2011Q2	6	0.05	0.33	0.1367	0.11147
2011Q3	6	0.05	0.85	0.3217	0.33253
2011Q4	6	0.05	0.81	0.2700	0.29967
2012Q1	6	0.05	1.07	0.2900	0.39573
2012Q2	6	0.05	1.16	0.3450	0.43094
2012Q3	6	0.05	1.15	0.3300	0.43174
2012Q4	5	0.05	0.98	0.3040	0.40556
2013Q1	6	0.05	1.45	0.3883	0.54326
2013Q2	6	0.05	1.23	0.3567	0.45776
2013Q3	6	0.05	0.72	0.2500	0.26525
2013Q4	5	0.05	0.65	0.3180	0.26214
2014Q1	5	0.05	1.07	0.3720	0.39971
2014Q2	5	0.05	0.37	0.1140	0.14311
2014Q3	5	0.05	0.55	0.2360	0.25589
2014Q4	5	0.05	0.50	0.2160	0.20659
2015Q1	5	0.05	0.84	0.3680	0.36286
2015Q2	5	0.11	0.92	0.4180	0.39404
2015Q3	5	0.05	0.65	0.2940	0.25185

Continuation of Table A.15					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2015Q4	5	0.05	0.67	0.2240	0.25996
2016Q1	5	0.05	0.78	0.3380	0.39442
2016Q2	5	0.05	0.82	0.3020	0.30801
2016Q3	5	0.28	0.67	0.4080	0.15418
2016Q4	5	0.18	0.79	0.3540	0.24684
2017Q1	5	0.28	1.46	0.7060	0.55424
End of Table					

Table A.16: Descriptive Statistics (SC) - whole body exposure per year (High Values Excluded)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2007	6	0.2	1.93	0.706667	0.796082
2008	8	0.2	1.4	0.47375	0.509984
2009	6	0.26	1.28	0.571667	0.43213
2010	5	0.2	1.53	0.542	0.560598
2011	5	0.2	1.7	0.776	0.740459
2012	5	0.2	4.36	1.292	1.805082
2013	5	0.2	4.05	1.482	1.5719
2014	5	0.26	2.04	0.938	0.825694
2015	5	0.26	2.75	1.304	1.196466
2016	5	0.63	3.04	1.402	1.019201

Table A.17: Descriptive Statistics (SC) - Whole body exposure per quarter (Measurable Readings)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2007Q1	2	0.44	0.79	0.6150	0.24749
2007Q2	2	0.37	0.50	0.4350	0.09192
2007Q3	3	0.22	0.36	0.3000	0.07211
2007Q4	3	0.23	0.38	0.2967	0.07638
2008Q1	2	0.29	0.50	0.3950	0.14849
2008Q2	2	0.25	0.37	0.3100	0.08485
2008Q3	2	0.28	0.39	0.3350	0.07778
2008Q4	2	0.16	0.35	0.2550	0.13435
2009Q1	2	0.39	0.39	0.3900	0.00000
2009Q2	2	0.11	0.40	0.2550	0.20506
2009Q3	2	0.16	0.17	0.1650	0.00707
2009Q4	6	0.11	0.34	0.2017	0.10187
2010Q1	3	0.15	1.16	0.6033	0.51287
2010Q2	2	0.22	0.30	0.2600	0.05657
2010Q3	2	0.16	0.43	0.2950	0.19092
2010Q4	1	0.30	0.30	0.3000	
2011Q1	3	0.21	0.86	0.4333	0.36964
2011Q2	3	0.17	0.33	0.2233	0.09238
2011Q3	3	0.39	0.85	0.5933	0.23459
2011Q4	3	0.28	0.81	0.4900	0.28160
2012Q1	3	0.26	1.07	0.5300	0.46765
2012Q2	3	0.36	1.16	0.6400	0.45078

Continuation of Table A.17					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2012Q3	3	0.23	1.15	0.6100	0.48042
2012Q4	2	0.39	0.98	0.6850	0.41719
2013Q1	3	0.32	1.45	0.7267	0.62804
2013Q2	3	0.35	1.23	0.6633	0.49166
2013Q3	3	0.28	0.72	0.4500	0.23643
2013Q4	3	0.41	0.65	0.4967	0.13317
2014Q1	4	0.22	1.07	0.4525	0.41210
2014Q2	1	0.37	0.37	0.3700	
2014Q3	2	0.48	0.55	0.5150	0.04950
2014Q4	3	0.11	0.50	0.3267	0.19858
2015Q1	3	0.24	0.84	0.5800	0.30790
2015Q2	5	0.11	0.92	0.4180	0.39404
2015Q3	4	0.13	0.65	0.3550	0.24447
2015Q4	3	0.12	0.67	0.3400	0.29103
2016Q1	2	0.76	0.78	0.7700	0.01414
2016Q2	4	0.15	0.82	0.3650	0.31628
2016Q3	5	0.28	0.67	0.4080	0.15418
2016Q4	5	0.18	0.79	0.3540	0.24684
2017Q1	5	0.28	1.46	0.7060	0.55424
End of Table					

Table A.18: Descriptive Statistics (SC) - whole body exposure per year (Measureable Readings)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2007	2	1.51	1.93	1.72	0.296985
2008	2	1.19	1.4	1.295	0.148492
2009	1	1.28	1.28	1.28	
2010	1	1.53	1.53	1.53	
2011	2	1.46	1.7	1.58	0.169706
2012	2	1.5	4.36	2.93	2.022325
2013	3	1.45	4.05	2.336667	1.484093
2014	1	1.61	1.61	1.61	
2015	3	0.66	2.75	1.953333	1.130059
2016	2	1.75	3.04	2.395	0.912168

Table A.19: Descriptive Statistics (SC) - extremities exposure per quarter (All Readings)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2007Q1	6	0.05	0.32	0.1033	0.10801
2007Q2	5	0.05	0.39	0.1400	0.14765
2007Q3	8	0.05	0.35	0.1200	0.11314
2007Q4	8	0.05	0.31	0.0938	0.09288
2008Q1	8	0.05	0.28	0.0863	0.08105
2008Q2	8	0.05	0.05	0.0500	0.00000
2008Q3	8	0.05	0.05	0.0500	0.00000
2008Q4	8	0.05	0.05	0.0500	0.00000
2009Q1	8	0.05	0.11	0.0575	0.02121
2009Q2	8	0.05	0.05	0.0500	0.00000
2009Q3	6	0.05	0.05	0.0500	0.00000
2009Q4	6	0.11	0.18	0.1400	0.03162

Continuation of Table A.19					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2010Q1	6	0.05	0.24	0.1000	0.07376
2010Q2	6	0.05	0.14	0.0733	0.03830
2010Q3	6	0.05	0.05	0.0500	0.00000
2010Q4	6	0.05	0.05	0.0500	0.00000
2011Q1	6	0.05	0.29	0.1800	0.11454
2011Q2	6	0.05	0.40	0.1267	0.13663
2011Q3	6	0.16	0.84	0.4033	0.31053
2011Q4	6	0.11	0.91	0.3617	0.31410
2012Q1	6	0.05	1.11	0.3183	0.40192
2012Q2	6	0.13	1.15	0.3867	0.40535
2012Q3	6	0.05	1.39	0.4083	0.50527
2012Q4	6	0.05	6.47	1.4133	2.52904
2013Q1	6	0.05	1.75	0.4167	0.67057
2013Q2	6	0.17	1.16	0.4383	0.41053
2013Q3	6	0.11	1.00	0.4233	0.38381
2013Q4	5	0.05	0.65	0.2740	0.24825
2014Q1	5	0.05	1.09	0.3960	0.43108
2014Q2	5	0.05	0.46	0.1800	0.16171
2014Q3	5	0.05	0.41	0.1840	0.16577
2014Q4	5	0.05	0.53	0.2100	0.22627
2015Q1	5	0.05	0.60	0.2600	0.24280
2015Q2	5	0.10	0.69	0.3500	0.29334
2015Q3	5	0.05	0.56	0.2600	0.21296

Continuation of Table A.19					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2015Q4	5	0.05	0.45	0.1800	0.17176
2016Q1RA	5	0.05	0.70	0.2980	0.31602
2016Q2	5	0.05	0.67	0.2740	0.23902
2016Q3	5	0.29	0.55	0.3980	0.11009
2016Q4	5	0.15	0.69	0.3280	0.22276
2017Q1	5	0.28	0.95	0.5680	0.31563
End of Table					

Table A.20: Descriptive Statistics (SC) - extremities exposure per year (All Readings)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2007	5	0.2	0.98	0.424	0.343919
2008	8	0.2	0.43	0.23625	0.081053
2009	6	0.26	0.33	0.29	0.031623
2010	6	0.2	0.44	0.273333	0.088919
2011	5	0.42	2.01	0.87	0.650999
2012	6	0.34	7.87	2.526667	3.181507
2013	5	0.46	4.56	1.606	1.768186
2014	5	0.2	2.13	0.97	0.872869
2015	5	0.25	2.12	1.05	0.886256
2016	5	0.56	2.49	1.298	0.814015

Table A.21: Descriptive Statistics (SC) - extremities exposure per quarter (Measureable reading)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2007Q1	2	0.10	0.32	0.2100	0.15556
2007Q2	2	0.16	0.39	0.2750	0.16263
2007Q3	3	0.13	0.35	0.2367	0.11015
2007Q4	2	0.14	0.31	0.2250	0.12021
2008Q1	2	0.11	0.28	0.1950	0.12021
2008Q2	0	-	-	0.05	-
2008Q3	0	-	-	0.05	-
2008Q4	0	-	-	0.05	-
2009Q1	1	0.11	0.11	0.1100	-
2009Q2	0	-	-	0.05	-
2009Q3	0	-	-	0.05	-
2009Q4	6	0.11	0.18	0.1400	0.03162
2010Q1	3	0.10	0.24	0.1500	0.07810
2010Q2	2	0.10	0.14	0.1200	0.02828
2010Q3	0	-	-	0.05	-
2010Q4	0	-	-	0.05	-
2011Q1	4	0.14	0.29	0.2450	0.07047
2011Q2	3	0.10	0.40	0.2033	0.17039
2011Q3	6	0.16	0.84	0.4033	0.31053
2011Q4	6	0.11	0.91	0.3617	0.31410
2012Q1	5	0.11	1.11	0.3720	0.42464
2012Q2	6	0.13	1.15	0.3867	0.40535

Continuation of Table A.21					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2012Q3	5	0.11	1.39	0.4800	0.52972
2012Q4	5	0.10	6.47	1.6860	2.72717
2013Q1	4	0.10	1.75	0.6000	0.78422
2013Q2	6	0.17	1.16	0.4383	0.41053
2013Q3	6	0.11	1.00	0.4233	0.38381
2013Q4	4	0.12	0.65	0.3300	0.24752
2014Q1	4	0.14	1.09	0.4825	0.44485
2014Q2	4	0.10	0.46	0.2125	0.16681
2014Q3	3	0.10	0.41	0.2733	0.15822
2014Q4	2	0.37	0.53	0.4500	0.11314
2015Q1	3	0.18	0.60	0.4000	0.21071
2015Q2	5	0.10	0.69	0.3500	0.29334
2015Q3	4	0.12	0.56	0.3125	0.20516
2015Q4	3	0.10	0.45	0.2667	0.17559
2016Q1	3	0.11	0.70	0.4633	0.31182
2016Q2	4	0.15	0.67	0.3300	0.23509
2016Q3	5	0.29	0.55	0.3980	0.11009
2016Q4	5	0.15	0.69	0.3280	0.22276
2017Q1	5	0.28	0.95	0.5680	0.31563
End of Table					

Table A.22: Descriptive Statistics (SC) - extremities exposure per year (Measureable Readings)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2007	2	0.54	0.98	0.76	0.311127
2008	1	0.43	0.43	0.43	
2009	3	0.27	0.33	0.293333	0.032146
2010	3	0.2	0.44	0.3	0.1249
2011	3	0.62	2.01	1.136667	0.760548
2012	4	0.71	7.87	3.6	3.501533
2013	3	0.57	4.56	2.363333	2.025348
2014	2	1.68	2.13	1.905	0.318198
2015	3	0.55	2.12	1.523333	0.850078
2016	3	1.06	2.49	1.763333	0.715285

Table A.23: Descriptive Statistics (WMH) - whole body exposure per year (All Included)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2009Q3	3	0.11	0.32	0.2033	0.10693
2009Q4	3	0.22	0.49	0.3233	0.14572
2010Q1	3	0.44	0.71	0.6067	0.14572
2010Q2	4	0.21	0.63	0.4275	0.17746
2010Q3	3	0.10	0.73	0.4900	0.34073
2010Q4	3	0.58	0.63	0.6000	0.02646
2011Q1	3	0.64	1.17	0.9500	0.27622
2011Q2	3	0.83	1.27	1.0133	0.22898
2011Q3	3	0.83	1.33	1.1167	0.25794
2011Q4	3	0.48	0.96	0.7133	0.24028
2012Q1	3	0.75	1.07	0.9300	0.16371
2012Q2	4	0.17	1.27	0.7200	0.46769

Continuation of Table A.23					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2012Q3	4	0.05	0.92	0.6400	0.40025
2012Q4	3	0.37	0.77	0.5633	0.20033
2013Q1	3	0.45	0.81	0.6033	0.18583
2013Q2	3	0.34	0.82	0.5067	0.27154
2013Q3	3	0.24	0.33	0.2900	0.04583
2013Q4	3	0.10	0.52	0.3533	0.22301
2014Q1	4	0.11	1.03	0.6375	0.39305
2014Q2	3	0.12	1.04	0.6200	0.46519
2014Q3	3	0.53	1.04	0.7633	0.25775
2014Q4	3	0.74	0.99	0.8533	0.12662
2015Q1	3	0.57	1.01	0.8033	0.22121
2015Q2	3	0.45	1.09	0.7033	0.34020
2015Q3	3	0.53	1.03	0.8067	0.25423
2015Q4	3	0.18	1.04	0.6967	0.45545
2016Q1	3	0.55	1.66	0.9367	0.62692
2016Q2	3	0.05	0.87	0.4933	0.41405
2016Q3	3	0.46	1.61	0.8833	0.63217
2016Q4	3	0.70	1.00	0.9000	0.17321
2017Q1	3	0.22	0.74	0.4600	0.26230
2017Q2	3	0.21	0.63	0.4367	0.21197
2017Q3	3	0.05	0.37	0.2133	0.16010
2017Q4	3	0.05	0.58	0.2467	0.29023
2018Q1	3	0.05	0.57	0.2700	0.26907

Continuation of Table A.23					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2018Q2	3	0.05	0.65	0.3167	0.30551
End of Table					

Table A.24: Descriptive Statistics (WMH) - whole body exposure per year (All Readings)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2010	1	2.57	2.57	2.57	-
2011	3	3.4	4.26	3.793333	0.434665
2012	2	3.25	3.53	3.39	0.19799
2013	3	1.57	2.12	1.753333	0.317543
2014	2	2.78	4.1	3.44	0.933381
2015	3	2.42	4.17	3.01	1.004639
2016	2	2.63	2.69	2.66	0.042426
2017	3	0.7	2.32	1.356667	0.852428

Table A.25: Descriptive Statistics (WMH) - whole body exposure per quarter (High Values Excluded)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2009Q3	3	0.11	0.32	0.2033	0.10693
2009Q4	3	0.22	0.49	0.3233	0.14572
2010Q1	3	0.44	0.71	0.6067	0.14572
2010Q2	4	0.21	0.63	0.4275	0.17746
2010Q3	3	0.10	0.73	0.4900	0.34073
2010Q4	3	0.58	0.63	0.6000	0.02646
2011Q1	3	0.64	1.17	0.9500	0.27622
2011Q2	3	0.83	1.27	1.0133	0.22898
2011Q3	3	0.83	1.33	1.1167	0.25794
2011Q4	3	0.48	0.96	0.7133	0.24028
2012Q1	3	0.75	1.07	0.9300	0.16371
2012Q2	4	0.17	1.27	0.7200	0.46769
2012Q3	4	0.05	0.92	0.6400	0.40025
2012Q4	3	0.37	0.77	0.5633	0.20033
2013Q1	3	0.45	0.81	0.6033	0.18583
2013Q2	3	0.34	0.82	0.5067	0.27154
2013Q3	3	0.24	0.33	0.2900	0.04583
2013Q4	3	0.10	0.52	0.3533	0.22301
2014Q1	4	0.11	1.03	0.6375	0.39305
2014Q2	3	0.12	1.04	0.6200	0.46519
2014Q3	3	0.53	1.04	0.7633	0.25775
2014Q4	3	0.74	0.99	0.8533	0.12662

Continuation of Table A.25					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2015Q1	3	0.57	1.01	0.8033	0.22121
2015Q2	3	0.45	1.09	0.7033	0.34020
2015Q3	3	0.53	1.03	0.8067	0.25423
2015Q4	3	0.18	1.04	0.6967	0.45545
2016Q1	2	0.55	0.60	0.5750	0.03536
2016Q2	3	0.05	0.87	0.4933	0.41405
2016Q3	2	0.46	0.58	0.5200	0.08485
2016Q4	3	0.70	1.00	0.9000	0.17321
2017Q1	3	0.22	0.74	0.4600	0.26230
2017Q2	3	0.21	0.63	0.4367	0.21197
2017Q3	3	0.05	0.37	0.2133	0.16010
2017Q4	3	0.05	0.58	0.2467	0.29023
2018Q1	3	0.05	0.57	0.2700	0.26907
2018Q2	3	0.05	0.65	0.3167	0.30551
End of Table					

Table A.26: Descriptive Statistics (WMH) - whole body exposure per quarter (Measureable Readings)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2009Q3	3	0.11	0.32	0.2033	0.10693
2009Q4	3	0.22	0.49	0.3233	0.14572
2010Q1	3	0.44	0.71	0.6067	0.14572
2010Q2	4	0.21	0.63	0.4275	0.17746
2010Q3	3	0.10	0.73	0.4900	0.34073
2010Q4	3	0.58	0.63	0.6000	0.02646
2011Q1	3	0.64	1.17	0.9500	0.27622
2011Q2	3	0.83	1.27	1.0133	0.22898
2011Q3	3	0.83	1.33	1.1167	0.25794
2011Q4	3	0.48	0.96	0.7133	0.24028
2012Q1	3	0.75	1.07	0.9300	0.16371
2012Q2	4	0.17	1.27	0.7200	0.46769
2012Q3	3	0.74	0.92	0.8367	0.09074
2012Q4	3	0.37	0.77	0.5633	0.20033
2013Q1	3	0.45	0.81	0.6033	0.18583
2013Q2	3	0.34	0.82	0.5067	0.27154
2013Q3	3	0.24	0.33	0.2900	0.04583
2013Q4	3	0.10	0.52	0.3533	0.22301
2014Q1	4	0.11	1.03	0.6375	0.39305
2014Q2	3	0.12	1.04	0.6200	0.46519
2014Q3	3	0.53	1.04	0.7633	0.25775
2014Q4	3	0.74	0.99	0.8533	0.12662

Continuation of Table A.26					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2015Q1	3	0.57	1.01	0.8033	0.22121
2015Q2	3	0.45	1.09	0.7033	0.34020
2015Q3	3	0.53	1.03	0.8067	0.25423
2015Q4	3	0.18	1.04	0.6967	0.45545
2016Q1	2	0.55	0.60	0.5750	0.03536
2016Q2	2	0.56	0.87	0.7150	0.21920
2016Q3	2	0.46	0.58	0.5200	0.08485
2016Q4	3	0.70	1.00	0.9000	0.17321
2017Q1	3	0.22	0.74	0.4600	0.26230
2017Q2	3	0.21	0.63	0.4367	0.21197
2017Q3	2	0.22	0.37	0.2950	0.10607
2017Q4	2	0.11	0.58	0.3450	0.33234
2018Q1	2	0.19	0.57	0.3800	0.26870
2018Q2	2	0.25	0.65	0.4500	0.28284
End of Table					

Table A.27: Descriptive Statistics (WMH) - whole body exposure per year (Measureable Readings)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2010	1	2.57	2.57	2.57	-
2011	3	3.4	4.26	3.793333	0.434665
2012	2	3.25	3.53	3.39	0.19799
2013	3	1.57	2.12	1.753333	0.317543
2014	2	2.78	4.1	3.44	0.933381
2015	3	2.42	4.17	3.01	1.004639
2016	2	2.63	2.69	2.66	0.042426
2017	1	2.32	2.32	2.32	-

Table A.28: Descriptive Statistics (WMH) - extremities exposure per quarter (All Readings Included)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2012Q2	3	1.30	35.10	21.1667	17.66390
2012Q3	4	2.00	46.30	21.1250	22.53492
2012Q4	3	1.00	19.30	8.9000	9.40266
2013Q1	3	0.05	8.70	2.9333	4.99408
2013Q2	3	0.05	1.10	0.4000	0.60622
2013Q3	3	0.05	5.40	1.8333	3.08882
2013Q4	3	0.05	3.90	1.3333	2.22280
2014Q1	3	0.05	2.60	0.9000	1.47224
2014Q2	4	0.05	2.20	0.8500	1.02713
2014Q3	2	0.05	1.00	0.5250	0.67175
2014Q4	3	0.05	1.00	0.3667	0.54848
2015Q1	3	1.70	4.60	2.6667	1.67432
2015Q2	3	1.20	11.50	4.8000	5.80775

Continuation of Table A.28					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2015Q3	3	0.05	5.20	2.2167	2.67036
2015Q4	3	0.05	5.10	2.2167	2.60016
2016Q1	3	1.90	6.40	3.8333	2.31589
2016Q2	3	0.05	14.70	5.2500	8.19771
2016Q3	3	0.05	16.15	5.4167	9.29534
2016Q4	3	0.05	62.90	22.0500	35.41218
2017Q1	3	0.05	17.70	9.4500	8.88102
2017Q2	3	0.05	6.30	2.9833	3.14258
2017Q3	3	0.05	3.10	1.8167	1.58140
2017Q4	3	0.05	4.70	1.6000	2.68468
2018Q1	3	0.05	0.05	0.0500	0.00000
2018Q2	3	0.05	5.00	2.8833	2.55163
End of Table					

Table A.29: Descriptive Statistics (WMH) - extremities exposure per yaer (All Readings Included)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2013	3	0.2	18.05	6.5	10.01636
2014	2	1.25	4.65	2.95	2.404163
2015	3	3	26.4	11.9	12.66531
2016	2	4.3	40.45	22.375	25.56191
2017	2	10.45	19.25	14.85	6.22254

Table A.30: Descriptive Statistics - extremities exposure per quarter (High Values Excluded)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2012Q2	1	1.30	1.30	1.3000	-
2012Q3	2	2.00	2.20	2.1000	0.14142
2012Q4	2	1.00	6.40	3.7000	3.81838
2013Q1	2	0.05	0.05	0.0500	0.00000
2013Q2	3	0.05	1.10	0.4000	0.60622
2013Q3	3	0.05	5.40	1.8333	3.08882
2013Q4	3	0.05	3.90	1.3333	2.22280
2014Q1	3	0.05	2.60	0.9000	1.47224
2014Q2	4	0.05	2.20	0.8500	1.02713
2014Q3	2	0.05	1.00	0.5250	0.67175
2014Q4	3	0.05	1.00	0.3667	0.54848
2015Q1	3	1.70	4.60	2.6667	1.67432
2015Q2	2	1.20	1.70	1.4500	0.35355
2015Q3	3	0.05	5.20	2.2167	2.67036
2015Q4	3	0.05	5.10	2.2167	2.60016
2016Q1	3	1.90	6.40	3.8333	2.31589
2016Q2	2	0.05	1.00	0.5250	0.67175
2016Q3	2	0.05	0.05	0.0500	0.00000
2016Q4	2	0.05	3.20	1.6250	2.22739
2017Q1	2	0.05	0.05	0.0500	0.00000
2017Q2	3	0.05	6.30	2.9833	3.14258
2017Q3	3	0.05	3.10	1.8167	1.58140

Continuation of Table A.30					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2017Q4	3	0.05	4.70	1.6000	2.68468
2018Q1	3	0.05	0.05	0.0500	0.00000
2018Q2	3	0.05	5.00	2.8833	2.55163
End of Table					

Table A.31: Descriptive Statistics (WMH) - extremities exposure per year (High Values Excluded)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2013	2	0.2	1.25	0.725	0.742462
2014	2	1.25	4.65	2.95	2.404163
2015	2	3	6.3	4.65	2.333452
2016	1	4.3	4.3	4.3	-
2017	1	10.45	10.45	10.45	-

Table A.32: Descriptive Statistics (WMH) - extremities exposure per quarter (Measureable Readings)

Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2012Q2	1	1.30	1.30	1.3000	-
2012Q3	2	2.00	2.20	2.1000	0.14142
2012Q4	2	1.00	6.40	3.7000	3.81838
2013Q1	0	-	-	0.05	-
2013Q2	1	1.10	1.10	1.1000	-
2013Q3	1	5.40	5.40	5.4000	-
2013Q4	1	3.90	3.90	3.9000	-
2014Q1	1	2.60	2.60	2.6000	-
2014Q2	2	1.10	2.20	1.6500	0.77782
2014Q3	1	1.00	1.00	1.0000	-
2014Q4	1	1.00	1.00	1.0000	-
2015Q1	3	1.70	4.60	2.6667	1.67432
2015Q2	2	1.20	1.70	1.4500	0.35355
2015Q3	2	1.40	5.20	3.3000	2.68701
2015Q4	2	1.50	5.10	3.3000	2.54558
2016Q1	3	1.90	6.40	3.8333	2.31589
2016Q2	1	1.00	1.00	1.0000	-
2016Q3	0	-	-	0.05	-
2016Q4	1	3.20	3.20	3.2000	-
2017Q1	0	-	-	0.05	-
2017Q2	2	2.60	6.30	4.4500	2.61630
2017Q3	2	2.30	3.10	2.7000	0.56569

Continuation of Table A.32					
Quarter	N	Minimum	Maximum	Mean	Std. Deviation
2017Q4	1	4.70	4.70	4.7000	-
2018Q1	0	-	-	0.05	-
2018Q2	2	3.60	5.00	4.3000	0.98995
End of Table					

Table A.33: Descriptive Statistics (WMH) - extremities exposure per year (Measureabkle Readings)

Year	N	Minimum	Maximum	Mean	Std. Deviation
2013	1	1.25	1.25	1.25	-
2014	1	4.65	4.65	4.65	-
2015	1	6.3	6.3	6.3	-
2016	1	4.3	4.3	4.3	-
2017	1	10.45	10.45	10.45	-

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