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Radiation Monitoring System in Clinical Imaging

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To my parents.

Resumo

A prestação de cuidados de saúde está muito apoiada em técnicas de diagnóstico radiológico nas suas variadas formas, desde a radiografia convencional aos métodos mais sofisticados de aquisição de imagem como a radiologia digital, a tomografia computorizada, mamografia digital, entre outras. Estas práticas são realizadas em instituições de dimensão e apetrechamento técnico variado desde os grandes hospitais centrais a pequenos centros de radiologia. Comum a todos eles, está a utilização de radiações ionizantes que, a par das suas inegáveis qualidades e contributo para a saúde e bem-estar das populações, tem igualmente potencial de, sendo desadequadamente utilizadas, produzirem efeitos indesejáveis.

A proteção radiológica tem vindo a desenvolver normas e regras que nos orientam para doses de radiação adequadas aos diversos procedimentos de forma a maximizar o seu benefício através da obtenção de informação adequada e necessária com o mínimo de risco associado. A aplicação destes níveis de referência deve ter em conta as características dos pacientes, que variam com a sua idade, peso, género e outros fatores.

Dado que em geral, em cada instituição, é necessário tratar mais de uma centena de exames diariamente, é fundamental ter meios que potenciem a informação recolhida com um processamento automático e que seja apresentada em formato adequado permitindo a sua análise em tempo útil.

O presente trabalho teve como objetivo o desenvolvimento de um sistema informático que permite, na *web*, analisar estatisticamente vários parâmetros da imagem, entre os quais, a dose de radiação, a tensão elétrica, tempo de exposição e força de compressão (no caso das mamografias) aplicados e também a comparação dos valores obtidos com as diretivas europeias. Adicionalmente, o sistema também permite o *upload* de dados num perfil de utilizador acessível com *password*, para que seja possível a visualização de dados próprios.

Como caso de estudo, recolheram-se de um hospital público português, dados de tomografias computorizadas, radiografias e mamografias efetuadas num mês.

No geral, os resultados não diferem muito das referências europeias à exceção do DLP (*Dose Length Product*) nos exames de tomografia computorizada cujos valores estão drasticamente acima das orientações sugeridas. Também são relatadas algumas radiografias cujos valores da tensão elétrica e de tempo de exposição estão ligeiramente acima das referências europeias. Nas mamografias existem dois casos específicos cuja dose de radiação atribuída está desajustada tendo em conta a espessura da mama da paciente. Por outro lado, também se observam valores de tempo de exposição relativamente superiores à *guideline* europeia.

Palavras-chave: Radiação ionizante; Monitorização de Dose; Exposição radiológica médica; Efeitos prejudiciais; Guidelines

Abstract

The health care service delivery is, today, being supported by radiological diagnose techniques in the most various ways, from the conventional x-ray to the more sophisticated image acquisition methods, such as digital radiology, computed tomography and mammography. These techniques are performed in institutions with varied technical equipment from the central hospitals to the small radiology centers. Common to them all, is the use of ionizing radiation which, along with its undeniable qualities and contribution to health and population welfare, has also the potential to produce undesirable effects when inappropriately used.

The radiological protection has been developing standards and rules that guide us to appropriate radiation doses on the various procedures in order to maximize their benefit by obtaining adequate and necessary diagnostic information with minimal associated risk. The application of these references and guidelines should consider the patient's characteristics such as weight, height, gender and other factors. Generally, in each institution it is necessary to process hundreds of exams daily being crucial to have the proper means to automatically process the retrieved data and present it, on a suitable format, allowing quick analysis.

The present project had as main goal, the development of an informatic web-based system that permits statistical analysis of various imaging parameters such as radiation dose, exposure time, voltage and compression force (in mammographies), and the comparison of the obtained values with the European guidelines. Additionally, the system allows the upload of data in a user profile accessible by a keyword to make possible the analysis of own data.

As a case-study, data from computed radiographies, computed tomographies and mammographies examinations were collected from a Portuguese public hospital and over a period of one month.

Generally, the results don't diverge from the reference levels, except for the DLP (Dose Length Product) in computed tomographies, whose values are drastically above the guidelines. Are also reported some computed radiographies whose voltage and exposure time values are slightly above the European references. In mammographies, there are two specific cases in which the assigned radiation dose is inadequate taking into account the patient's breast thickness. On the other hand, is observed exposure time values relatively greater than the European guideline.

Keywords: Ionizing radiation; Dose Monitoring; Medical radiological exposures; Undesirable effects; Guidelines

Resumo Alargado

A prestação de cuidados de saúde está muito apoiada em técnicas de diagnóstico radiológico nas suas variadas formas, desde a radiografia convencional aos métodos mais sofisticados de aquisição de imagem como a radiologia digital, a tomografia computorizada, mamografia digital, entre outras. Estas práticas são realizadas em instituições de dimensão e apetrechamento técnico variado desde os grandes hospitais centrais a pequenos centros de radiologia. Comum a todos eles, está a utilização de radiações ionizantes que, a par das suas inegáveis qualidades e contributo para a saúde e bem-estar das populações, tem igualmente potencial de, sendo desadequadamente utilizadas, produzirem efeitos indesejáveis.

A proteção radiológica tem vindo a desenvolver normas e regras que nos orientam para doses de radiação adequadas aos diversos procedimentos de forma a maximizar o seu benefício através da obtenção de informação adequada e necessária com o mínimo de risco associado. A aplicação destes níveis de referência deve ter em conta as características dos pacientes, que variam com a sua idade, peso, género e outros fatores.

A informação relativa à dose de radiação aplicada nos exames encontra-se disponível nos repositórios de imagem médica, também denominados por PACS (*Picture Archiving and Communication System*) que utilizam um protocolo comum a todas as marcas designado por DICOM (*Digital Imaging and Communications in Medicine*). Segundo esta norma, os ficheiros armazenados contêm não só as imagens, mas também outras informações relativas ao exame e à forma como foi adquirido como seja a identificação do paciente, a data da sua realização, a modalidade, a dose aplicada, o tempo de exposição, instituição, equipamento usado, entre outros.

Recentemente, fruto das grandes preocupações com as doses de radiação ministradas nos procedimentos de diagnóstico radiológico, os vários fabricantes, pressionados pela opinião pública e pelo mercado, desenvolveram formas dos equipamentos disponibilizarem um conjunto de informações necessárias à avaliação das doses e que se apresenta sob a forma de um DR (*Dose Report*). No entanto, este formato não é ainda aplicado pela maior parte dos equipamentos radiológicos, pelo que a recolha de informação carece de soluções que sejam abrangentes e inclusivas dos tipos de tecnologia em uso. Dado que em geral, em cada instituição, é necessário tratar mais de uma centena de exames diariamente é fundamental ter meios que potenciem a informação recolhida com um processamento automático e que seja apresentada em formato adequado permitindo a sua análise em tempo útil. Assim, sem uma aplicação informática como a que será apresentada no presente trabalho, quer o DR quer a informação sobre dose recolhida de outras formas, não cumpre o objetivo para a qual foi criada, desaproveitando todo o trabalho produzido a montante e deixando as instituições sem forma de dar melhor resposta a um conjunto de obrigações de carácter humanitário e legal.

A legislação já existente sobre estas matérias vem claramente reforçada nas preocupações com a dose disponibilizada nos procedimentos de diagnóstico pela nova diretiva europeia, publicada em Dezembro de 2013. Nesta legislação encontra-se expressa a obrigatoriedade dos responsáveis de cada Instituição garantir a boa utilização dos equipamentos produtores de radiação ionizante, bem como a salvaguarda da segurança radiológica de pacientes e trabalhadores. Também os processos de certificação de qualidade exigem a criação de registos e controlo de doses de radiação sendo necessária a demonstração da sua evidência.

Para tentar dar resposta a todos estes requisitos, foi desenvolvido um sistema informático disponível em http://rmsci.fc.ul.pt/, cujo principal objetivo é monitorizar para além das doses de radiação, outros parâmetros igualmente importantes e com elevado contributo na obtenção de uma imagem de qualidade. São eles: tensão elétrica, tempo de exposição e a força de compressão. Para isso, foram recolhidos exames de tomografias computorizadas, radiografias computorizadas e mamografias efetuados num mês num hospital público português. Adicionalmente, são também prestadas análises estatísticas dos dados como a média aritmética e o percentil 90. Estes parâmetros estatísticos permitem ter uma ideia da tendência central dos dados e abaixo de que valor está a maioria dos exames, respetivamente.

São disponibilizados diversos filtros sequenciais para uma análise mas detalhada dos dados: para os exames de tomografia computorizada, os dados podem ser divididos em $CTDI_w$ (*weighted CT Dose Index*) e DLP (*Dose Length Product*). Para cada um destes tipos de dose, os dados são filtrados por parte do corpo e posteriormente por modelo de equipamento. Para os exames de radiografia, a análise pode ser feita à dose de radiação (DAP – *Dose Area Product*), ao tempo de exposição e à tensão elétrica. Para cada um destes parâmetros os dados podem ser filtrados por parte do corpo, projeção dos raios x e modelo do equipamento. Nos exames de mamografia, os parâmetros disponíveis são a dose de radiação (*Organ Dose*), o tempo de exposição e a força de compressão. Para a dose de radiação, os dados poderão ser filtrados de acordo com a espessura da mama e com o modelo do equipamento em que foi realizado o exame. Já o tempo de exposição e a força de compressão apenas podem ser filtrados por modelo do equipamento.

Adicionalmente, o sistema também permite também fazer o *upload* de dados num perfil de utilizador acessível através de uma *password*, para que seja possível a visualização de dados próprios à parte dos disponíveis.

De uma forma geral, os resultados não diferem muito das referências europeias com exceção do DLP nos exames de tomografia computorizada cujos valores estão drasticamente acima das *guidelines*. Também são relatadas algumas radiografias cujos valores da tensão elétrica e de tempo de exposição estão ligeiramente acima das referências europeias. Nas mamografias existem dois casos específicos cuja dose de radiação atribuída está desajustada tendo em conta a espessura da mama da paciente. Por outro lado, também se observam valores de tempo exposição relativamente superiores à *guideline* europeia.

Estas diferenças podem ou não ser valorizadas dependendo de vários fatores: parâmetro adequado à composição corporal do paciente e obtenção de uma imagem de qualidade. Noutras palavras, a dose de radiação de um determinado exame pode estar substancialmente acima da referência europeia, mas ser a dose adequada para a obtenção de uma imagem com elevada qualidade e que permita um correto diagnóstico, tendo em conta a fisionomia do paciente.

Dado que, as *guidelines* europeias disponibilizam níveis de referência para indivíduos com uma estatura standard e que os dados disponibilizados não continham atributos relacionados com o peso do paciente, não foi então possível fazer qualquer estimativa acerca da dose correta que deveria ter sido administrada. A qualidade das imagens obtida não foi alvo de estudo, mas seria interessante fazê-lo num trabalho futuro.

A proteção radiológica é assim, uma matéria muito subjetiva devido à elevada diversidade de pacientes. No entanto, é indispensável o estabelecimento de níveis de referência a fim de proteger o paciente dos efeitos da radiação em exposições pontuais e cumulativas e também para otimizar os procedimentos.

Uma das grandes lacunas deste trabalho foi precisamente os dados terem pouca qualidade devido ao facto de muitos parâmetros úteis não estarem preenchidos ou terem sido omitidos. Este fator não permitiu retirar conclusões mais aprofundadas, mas foi possível ter uma ideia geral do cumprimento das *guidelines*.

Futuramente, seria interessante aplicar um sistema deste género em todo o sistema nacional de saúde consciencializando os profissionais de saúde da necessidade de procedimentos individualizados corretos e otimizados.

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List of Acronyms

ACR – American College of Radiology

ACR DIR - American College of Radiology Dose Index Registry

AJAX - Asynchronous JavaScript and XML

ALARA – As Low As Reasonable Achievable

AP – Antero-Posterior

API - Application Programming Interface

ASCII - American Standard Code for Information Interchange

BESAK – Breast Entrance Skin Air Kerma

CR – Computed Radiography

CT – Computerized Tomography

CTDI – CT Dose Index

$CTDI_{vol}$ – CT Dose Index volume

$CTDI_{w}$ - CT Dose Index weighted

DAP – Dose Area Product

DBMS - Database Management System

DICOM – Digital Imaging and Communications in Medicine

DICOM-SR - Digital Imaging and Communications in Medicine Structured Report

DIR – Dose Index Registry

DLP – Dose Length Product

DNA - Deoxyribonucleic acid

DR - Digital Radiography

DRL – Dose Reference Level

EMR – Electronic Medical Record

ER – Entity-Relationship

ESAK – Entrance Surface Air Kerma

ESD – Entrance Surface Dose

EURATOM - European Atomic Energy Community

HIS – Hospital Information System

HL7 – Health Level Seven International

HRCT – High Resolution Computed Tomography

HTML – Hyper Text Markup Language

HTTP - Hypertext Transfer Protocol

HTTPS - Hypertext Transfer Protocol Secure

IADP - Image And Fluoroscopy Area Dose Product

ICRP - International Commission on Radiological Protection

ICRP 103 – International Commission on Radiological Protection Publication 103

IHE – Integrating the Healthcare Enterprise

IOD - Information Object Definitions

JPEG – Joint Photographic Experts Group

JS - JavaScript

JSON - JavaScript Object Notation

KAP – Kerma Area Product

LAT - Lateral

MG – Mammography

MGD – Mean Glandular Dose

MPPS - Modality Performed Procedure Step

MySQL – My Structured Query Language

NEMA – National Electrical Manufacturers Association

OCR – Optical Character Recognition

PA – Postero-Anterior

PACS – Picture Archiving and Communication System

PC – Personal Computer

PK – Primary Key

PMMA - Polymethylmethacrylate

QA – Quality Assurance

RDSR – Radiation Dose Structured Report

REM – Radiation Exposure Monitoring

RIS – Radiology Information System

RMSCI - Radiation Monitoring System in Clinical Imaging

SaaS – Software as a Service

SOP - Service-Object Pairs

SSDE – Size-Specific Dose Estimates

SSL - Secure Sockets Layer

TLS - Transport Layer Security

URI – Uniform Resource Identifiers

URL - Uniform Resource Locator

WADO - Web Access to DICOM Persistent Objects

XA - X-Ray Angiography

XML – Extensible Markup Language

Chapter 1

Introduction

This section provides the context and the motivation for the work as well as the inherent problem. The purpose and the objectives of the project will also be described as well as the methodology applied and the contributions. The overview provides the structure of the document to facilitate the navigation on it.

1.1 Context and Motivation

In the current days, prescribing an imaging examination has become common. It is a non-invasive technique to diagnose diseases or to discard them as it is not painful or plaguy for the patient. However, there are some imaging modalities that make use of ionizing radiation that may be harmful to human health when not controlled or monitored. Examples of such modalities are Computed Radiography (CR), Computed Tomography (CT) and Mammography (MG), that with an inadequate radiation dose, a high number of examinations performed, an exaggerated cumulative radiation administered over the time to a specific patient or an examination performed incorrectly could increase the risks of developing dangerous diseases such as cancer. It is crucial to alert the doctors about the prescription of these exams, the technicians that perform them and the radiologists that diagnose as well as the society in general to be aware of these matters and to take measures on radiological protection.

On the other hand, with the increasing number of examinations performed and the consequently generation of enormous volumes of data, storage problems arise. It is greatly important to develop software to permit the continuously entry of new data without compromising efficiency as well as to provide tools to manipulate, analyze, track and draw conclusions about the examination in general and the patient's clinical condition in particular.

1.2 Problem

As mentioned above, the non-monitoring and non-storing of the radiation dose information can lead to obliviousness about the ionizing radiation administered so far, the value of those doses, if they are adequate to the case or not and the risks that a patient has of developing carcinogenic diseases such as solid tumors or hematologic diseases. If the exposition is controlled and accompanied the risks are minimum. There are also cases when imaging examinations are prescribed without being necessary or there is another imaging modality that does not make use of ionizing radiation and is sufficient for what is intended.

The current reality is that the radiation dose administered to the patients in medical exposures is not well monitored. There are already several applications on the market, that will be discussed in the section "Related Work", with the purpose to provide tools to manipulate and monitor the radiation dose administered in medical exposures. The underlying problem consists of the fact that not all the health institutions possess these applications for the various reasons: it is not mandatory; it is expensive or just because it is not profitable.

The existing national legislation on these matters clearly reinforces the concerns about the dose available in diagnostic procedures by the new European Directive, published in December 2013. This legislation expresses the obligation of those responsible for each institution to ensure the proper use of the ionizing radiation producer equipment and the radiological safety of patients and workers. Also, the quality certification processes require the creation of records and control of radiation doses requiring the demonstration of its evidence. However, the absence of rigid criteria in radiation dose adequacy is still a fault.

1.3 Objectives

To contribute to the radiological protection and to better alert the great importance of this topic, it was initially thought and projected the development of a web-based platform with the following main objectives:

Objective 1: Real-time data collection of the examinations that have been performed so far;

Objective 2: Application of filters to allow the navigation within data;

Objective 3: Statistical analysis of the data with the use of the average and 90th Percentile;

Objective 4: Compare the administered radiation doses with the European Guidelines;

Objective 5: Allow manually upload of data by any user.

These objectives were established together with the Portuguese public hospital that offered conditions and resources to develop the project. However, to obey the first objective is necessary to have free access to their web service that is managed by Sectra and who did not allow it. To bypass this situation, it was

collected data from one month corresponding to CT, CR and MG examinations and, instead of having new data continuously being analyzed, the analysis was done only with this subset.

1.4 Methodology

To achieve the purposed objectives, the work was divided in three phases.

The first one consisted in the comprehension of the national needs for monitoring the radiation dose in medical exposures, and to establish objectives for this work. It can be divided in two sub-phases:

1. Comprehension of the national needs on monitoring the radiation dose in medical exposures:
    - The radiation dose is not well monitored and not all the health institutions that perform medical imaging possesses equipment to track the dose at various levels;
    - Due to the adverse effects that the radiation may have in health when is improperly used, it is greatly important to take measures on radiation monitoring.
2. Establishment of the objectives described above (see section 1.3).

The second phase of the work is related with the collection of data that was provided by the Portuguese public hospital.

The third and last phase concerns the development of the monitoring system and it is based on the following technical aspects:

- **System:**
    - MySQL (My Structured Query Language) database-backed site with dynamically generated content;
    - PHP-based RESTful (Representational State Transfer) web service to allow exchange of data;
    - HTML (Dynamic Hyper Text Markup Language) front-end that involve the users in data analysis and uploading their own data;
    - Highcharts (JavaScript charting library) to display the results;
    - AJAX (Asynchronous JavaScript and XML) that permits constant asynchronously calls to the web service without having to reload the webpage.

1.5 Contributions

The main contributions for this work were:

1. Development of the Radiation Monitoring System in Clinical Imaging (RMSCI), available at http://rmsci.fc.ul.pt/;

2. A case-study analysis of the dosimetry and other relevant parameters of radiological examinations (CT, MG and CR) performed over a month in a Portuguese public hospital;
3. Presentation of a Poster in the 5th Edition of Bioinformatics Open Days (Florencio, Couto, Matela, & Afonso, 2016).

1.6 Overview

The present work has six chapters divided into subsections. In the first chapter is given a brief introduction about the purpose of the work, referring the context and motivation, the inherent problem, objectives, methodology and the contributions. In chapter two is presented the main ground information to better understand the basic concepts studied as well as some legislation about the topic. In chapter three is presented some of the systems already available on the market with the same purpose of the one that was developed for this project. Chapter four is related with the system itself and how it was designed and developed. The fifth chapter is reserved for the results obtained and respective discussion. Lastly, chapter six has the main conclusions of the work and some perspectives on future studies in this area.

Chapter 2

Medical Imaging and Dosimetry

The diagnose and the monitoring of diseases remains a challenge. For this reason, there was more scientific investigation on this area and nowadays, the medical imaging became a simple, safe, comfortable and painless way to observe the internal structures of the human body without needing a surgery or any other invasive techniques. It also assists in the early diagnosis and, consequently in the best treatment for a specific clinical condition. All these advantages lead to an increase in the number of examinations and a growth of digital imaging technologies. With this increase in the number of examinations the following was verified:

1. The patients are exposed to higher amount of radiation that may have serious health implications;
2. The information in paper and the capacity of film-based systems are no longer supported and become impracticable;
3. To store the information computationally and to diffuse it is required computer information standards;
4. With the inherent risks of medical exposures, emerged new opportunities on radiation dose monitoring.

As referenced in point one, the dosimetry is one of the crucial and most worrying parameters in medical imaging that must be treated with special attention. Ionizing radiation has sufficient energy to displace an electron from its orbit around a nucleus and the most important consequence of this displacement on human tissue is the damage that can be caused on deoxyribonucleic acid (DNA) directly or indirectly. The adverse effects of this damage may be distinguished in two types (Strom, 2003):

- Stochastic effects:
    - The risk of an effect occurring increases linearly as the dose increases without a threshold for those effects.
    - Occur due to the ionizing radiation effect of symmetrical translocations taking place during cell division.

- Examples: cancer, hereditary defects (Down Syndrome).

- Deterministic effects:
  - Occur once a threshold of exposure has been exceeded. The severity increases as the radiation dose increases.
  - Because of the existence of a threshold, defense mechanisms can be applied to reduce the likelihood of the effects occurring.
  - Caused by significant cell damage or death.
  - Examples: skin erythema, cataract, sterility, radiation sickness, teratogenesis.

According to the literature (Cook et al., 2011) there are some variables that have direct implication in the dosimetry applied as well as how the image is produced. The most important ones are: kilovolt peak and milliampere-seconds.

The kilovolt peak represents the maximum voltage applied across the x-ray tube and determines the energy of x-ray beam. With a higher kilovolt peak, the energy photons will penetrate the patient and contribute to the image. The opposite leads to an absorption in the patient before reaching the detector. Being the dose proportional to the kilovolt peak squared, small changes in kilovolt peak can result in dose perturbations.

The milliampere-seconds represents the tube current-time product and determine the number of photons produced over a scanning time. Knowing that the dose varies linearly with the tube current, it can be concluded that with fewer milliampere-seconds the dose will decrease but the noise will enhance because few photons reach the detector.

Thus, to obtain a good image with the lowest possible radiation dose, there must be an equilibrium between these two variables.

The way the dose is measured depends on the modality and will be explained in the subsections below. However, and according to the International Dosimetry Code of Practice in Diagnostic Radiology (IAEA, 2014), there are general quantities used for regulatory purposes and thus related to stochastic and deterministic effects:

- Organ and tissue dose (SI Unit is Gray), D_T, simply referred as organ dose that represents the mean absorbed dose in a specific tissue or organ. It is equal to the ratio of the energy imparted, $\overline{\varepsilon_T}$, to the tissue or organ mass, m_T:

$$D_T = \frac{\overline{\varepsilon_T}}{m_T} \tag{2.1}$$

- Equivalent dose (SI Unit is the Sievert), H_T, to an organ or tissue translated in the product of a radiation weighting factor, w_R, with radiation R and organ dose D_T:

$$H_T = w_R D_T \tag{2.2}$$

- Effective dose, E, that represents the sum over all organs and tissues of the body of the product of the equivalent dose to the tissue weighting factor and is measured in Sieverts (Sv).

$$E = \sum_{T} w_T H_T \tag{2.3}$$

Focusing now on points two, three and four, the efficient storage of information is a problem to address. The recent growth in imaging technology encouraged the development of solutions like Picture Archiving and Communication Systems (PACS) that provides economical storage, fast retrieval of images of the different modalities and access at multiple sites. In Figure 2.1 it is explained how a PACS works and their different components (Choplin, Boehme, & Maynard, 1992): image acquisition device (an electronic gateway to the system), data management system (a specialized computer system that controls the flow of information on the network), image storage devices (both short and long term archives), transmission network (which serves local or wide areas), display stations (which include a computer, text monitor, image monitors and a user interface) and devices to produce hard-copy images (multiformat or laser camera).

The image management system must interact with other management systems which include the Hospital Information System (HIS) and the Radiology Information System (RIS). The reason of this interaction is to maintain the integrity of the data across multiple platforms and to optimize the performance. In general, RIS is responsible for managing medical imagery and associated data being specifically useful for tracking radiology imaging orders and billing information and HIS leads with all the administrative needs of hospitals such as medical, administrative, financial and other legal issues.
To increase the performance of these information systems it is necessary to maintain a unique and neutral flow of information. Integrating the Healthcare Enterprise (IHE) is an initiative by healthcare professionals to improve the way computer systems share and transmit information (IHE International, 2016). Digital Imaging and Communications in Medicine (DICOM) and Health Level Seven (HL7) are two of the standards used to address specific clinical needs. A joint DICOM/HL7 working group contributed to the development of the HL7 Reference Information Model, propose extensions to the

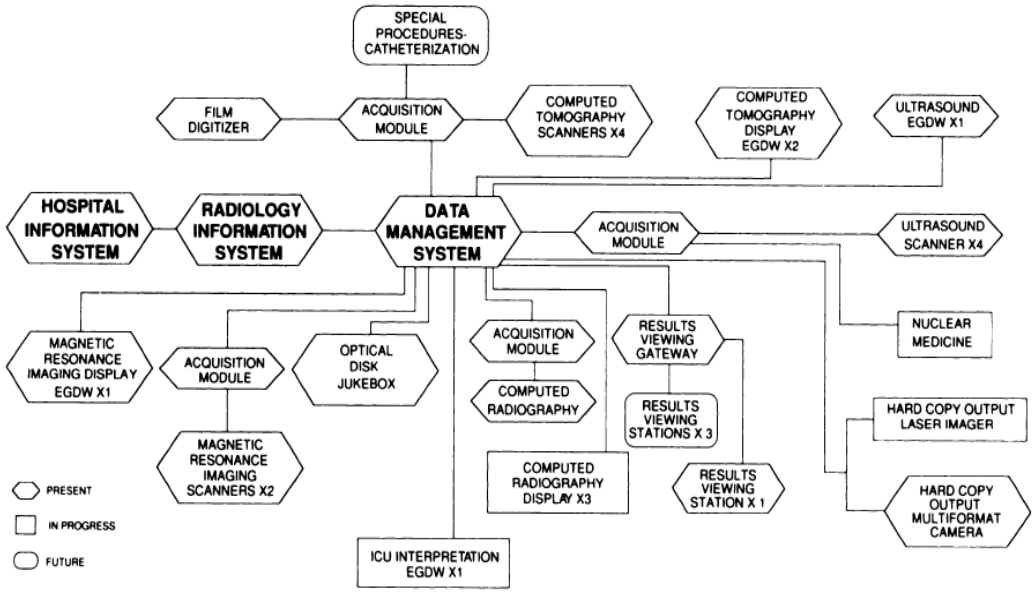

Figure 2.1: Example of a PACS-RIS-HIS network.
The figure demonstrates the interaction between the different information and management systems. Retrieved from: Picture Archiving and Communication Systems: An Overview. 127-129 (of Choplin et al., 1992).

DICOM and HL7 standards when appropriated and developed information linkages between the DICOM and HL7 standards.

2.1 Imaging Modalities

When the subject is imaging modalities, the first thing that must be clarified is that there are several imaging modalities available with many purposes and with different forms to obtain the medical images. Some modalities use ionizing radiation to produce an image and others do not (e.g. ultrasonography, magnetic resonance). These last ones are not a preoccupation because the procedure to acquire the image (in this case, ultra sounds and magnetic fields) does not threaten human health. The same is not verified with the modalities that uses ionizing radiation. These must be equated in the sense that is necessary to evaluate the risks versus benefits of that exposure. In general, if a health professional prescribes an examination is because it is useful in a specific clinical condition and provides benefits to the patient. However, there are some factors that must be taking into account and one of them is the patient age (Shaw et al., 2010). As represented in Figure 2.2, the risks exceed the benefits when the patients are younger due to its increased sensitivity to radiation and consequently incremented lifetime cancer risk. The opposite is true in the elderly.

Thus, and as published in the literature (Lin, 2010), "*it is imperative that all imaging tests, particularly those with potential patient harm, be performed only when indicated. Although the absolute radiation risk of any individual medical imaging study is small, these risks could be clinically relevant when compared with benefits that are very low or not established. For example, the benefit of whole-body CT screening in asymptomatic individuals has not been defined. The radiation risk of these studies (and possible follow-up studies generated by the initial screening) may be clinically relevant if compared with the uncertain benefit, particularly if taking into account the additional risks of false-positive results and overdiagnosis."*

Also U.S Food and Drug Administration (U.S. Food & Drug Administration, 2016) reinforce the idea that the patient factors are important to consider the balance of benefits and risks. Other factors that must be considered are: the additional care in imaging pregnant patients and the benefit of possible disease detection against the risks of an imaging screening study on healthy and asymptomatic patients.

To conclude, it is important to underline that radiation protection is a matter of ethical and moral issues that must be well equated according to the type of patient.

The imaging modalities studied in this work were chosen based on the following criteria:

- Uses ionizing radiation to produce a medical image;
- Is commonly prescribed;
- Has European references for guidance.

CR, CT and MG complies all these criteria and the following subsections are dedicated to them.

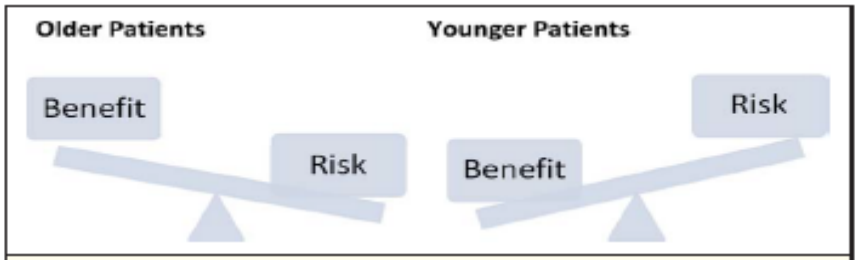

Figure 2.2: The Potencial Relationship Between the Benefit of Cardiac Imaging and Harm Associated With Medical Imaging Radiation In Younger and Older Patients.
As a patient ages, the relative harm associated with medical Imaging radiation decreases due to the decreased lifetime cancer risk and is lowest in the elderly. The benefit is proposed to increase with the prevalence of coronary artery disease and is greatest for middle-aged to elderly patients. Radiation-induced cancer risks are higher in younger patients and, as such, the risk may exceed any benefit. When testing is limited to appropriate patients and indicators, the benefit exceeds the harm. Retrieved from: Imaging Modalities and Radiation: Benefit Has Its Risks…550-552 (of Shaw et al., 2010)

2.1.1 Computed Radiography

In general, radiography is an imaging technique that consists of using electromagnetic radiation to view the internal structure of an object such as the human body. To create the image, it is used an x-ray generator which produces a beam of x-rays that pass through the object. Some of the energy is absorbed by it depending on its density and composition and the remaining one collides with a photographic film producing the x-ray image (Figure 2.3).

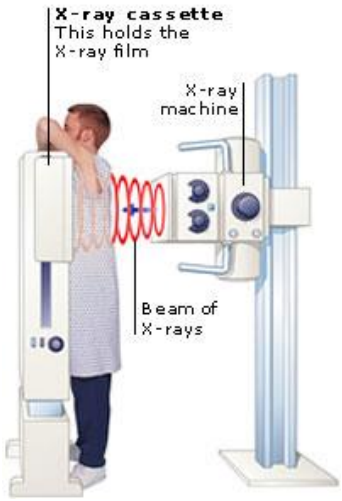

Figure 2.3: Obtainment of an x-ray image.
Procedure to obtain an x-ray image. Downloaded on 08-05-2016 from http://www.aviva.co.uk/health-insurance/home-of-health/medical-centre/medical-encyclopedia/entry/test-chest-x-ray/

Depending on the direction of the x-ray beam relatively to the patient position, the projection is different. The most common ones are: Antero-Posterior (AP), Postero-Anterior (PA) and Lateral (LAT).

Computed Radiography has grown during the past decade as an alternative method to replace the conventional film/screen combination for digital image acquisition. It uses a reusable imaging plate in

place of the film. Its large dynamic range, reduced repeat rates, reduced doses, digital image storage and image manipulation are some of the advantages. The higher costs and the reduced spatial resolutions are the disadvantages (Patel, 2005).

Regarding dosimetry, the quantity that best measure the radiation dose administered to the patient is the **Dose Area Product (DAP)** also called as **Kerma Area Product (KAP)** (Seltzer et al., 2011). It is used to assess the radiation risk from diagnostic X-ray examinations and represents the absorbed dose multiplied by the area irradiated. Expressed in gray-centimeters squared, Gy.cm2, represents not only the dose within the radiation field but also the area of tissue irradiated. *g* indicates the fraction of energy that is lost in radiative processes in the material.

$$DAP = KAP \times (1 - g) \tag{2.4}$$

Entrance Surface Dose (ESD) or Entrance Surface Air Kerma (ESAK) are other parameters to measure the absorbed dose to air on the central axis of the x-ray beam at the point where it enters the patient or phantom, including backscattered radiation (Wall et al., 2008). The calculation is performed with the following formula:

$$ESD\ (mGy) = \frac{mGy}{mAs} \times (kVp)^2 \times (\frac{FDD}{FSD})^2 \times BSF \tag{2.5}$$

Both ESD and DAP can be used as the practical dose quantity for single radiographs. For more complex examinations consisting of higher number of radiographs, the total DAP accumulated over the complete examination is the preferred quantity (Wall et al., 2008).

Beyond radiation dose, there are other variables that indirectly increase the radiation dose absorbed such as the exposure time and the voltage, the last one already evidenced above. Limiting or minimizing the exposure time reduces the dose from the radiation source.

2.1.2 Computed Tomography

Computed Tomography uses different combinations of many x-ray images taken from different angles to produce cross-sectional images of specific areas of a scanned object (Figure 2.4). All data is processed by a computer to produce a series of image slices representing three-dimensional view of the target organ or body region.

Compared with plain-film radiography, CT involves much higher doses of radiation resulting in a relevant increase in radiation exposure but has a benefit to risk ratios (Brenner & Hall, 2007).

CT Dose Index (CTDI) is a specification of the amount of radiation in CT examinations and it is measured in a cylindrical acrylic phantom placed at the scanner isocenter (Shope, Gagne, & Johnson, 1981). **CT Dose Index volume ($CTDI_{vol}$)** is easily accessible to the radiologist because it has in consideration the volume irradiated and is also the metric used by the American College of Radiology (ACR) for CT practice accreditation. $CTDI_{vol}$ does not change with the patient size and scan length that's

why it does not quantify how much radiation a patient receives but simply indicates the intensity of that radiation:

$$CTDI_{vol} = \frac{CTDI_w}{CT\ pich\ factor} \tag{2.6}$$

CT Dose Index weighted ($CTDI_w$) represents the weighted sum of CT dose index measured in the center and periphery of a 16 cm diameter or a 32 cm diameter standard polymethylmethacrylate (PMMA) CT dosimetry phantom, $C_{K,PMMA,w}$ (Wall et al., 2008):

$$CTDI_w = C_{K,PMMA,w} \tag{2.7}$$

Both $CTDI_w$ and $CTDI_{vol}$ are measured in milligrays (mGy). The amount of radiation incident on the patient, known as Dose Length Product (DLP), is the product of the $CTDI_{vol}$ by the scan length and is measured in milligray-centimeters (mGy.cm) (Huda & Mettler, 2011):

$$DLP = CTDI_{vol} \times L \tag{2.8}$$

The total amount of radiation administered in all the examination is the sum of the DLP of all images.

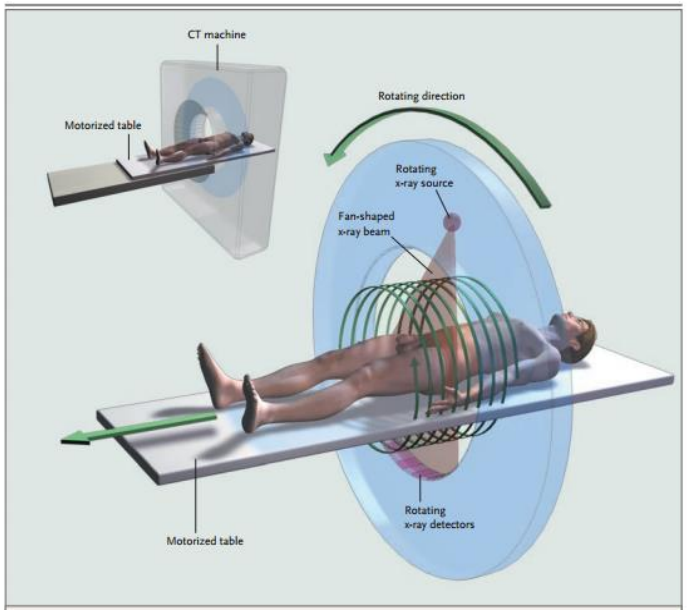

Figure 2.4: The Basis of CT.
A motorized table moves the patient through the CT imaging system. At the same time, a source of x-rays rotates within the circular opening, and a set of x-ray detectors rotates in synchrony on the far side of the patient. The x-ray source produces a narrow, fan-shaped beam, with widths ranging from 1 to 20 mm. In axial CT, which is commonly used for head scans, the table is stationary during a rotation, after which it is moved along for the next slice. In helical CT, which is commonly used for body scans, the table moves continuously as the x-ray source and detectors rotate, producing a spiral or helical scan. The illustration shows a single row of detectors, but current machines typically have multiple rows of detectors operating side by side, so that many slices (currently up to 64) can be imaged simultaneously, reducing the overall scanning time. All the data are processed by computer to produce a series of image slices representing a three-dimensional view of the target organ or body region. Retrieved from: Computed Tomography – An Increasing Source of Radiation Exposure. 2277- 2284 (of Brenner & Hall, 2007)

2.1.3 Mammography

Mammography is a breast cancer preventive exam that gained momentum in women between the ages of 50 and 64 years. This examination uses low x-rays doses and consists of compressing the breast with the policy to take two views of each breast: a mediolateral oblique (MLO) and a craniocaudal view (CC) (Figure 2.5).

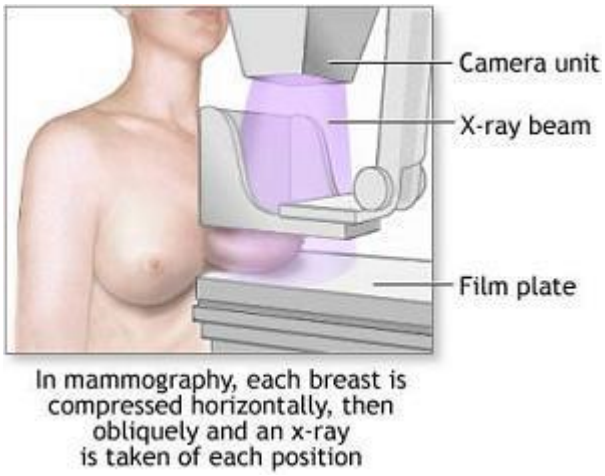

Figure 2.5: Basis of mammography.
Procedure to obtain a mammography image. Downloaded on 08-05-2016 from https://www.verywell.com/why-not-annual-ultrasounds-instead-of-mammograms-430185

Until some years ago, mammography was typically performed with screen-film cassettes. Now, it is undergoing transition to digital detectors, known as digital mammography. There are two types of mammogram studies that must be distinguished: screening and diagnostic mammograms. The first ones are performed on asymptomatic patients and consist only on four standard x-ray images. The diagnostic mammograms are reserved for patients with breast symptoms or abnormal findings.

The architecture of the breast tissue is variable, mammograms have a noisy, unstructured appearance and cancer is not usually revealed directly. Its presence must be inferred from other ambiguous signs (Taylor, Champness, & Johnston, 2005).

Since it was discovered that the glandular tissues are more radiosensitive than the adipose tissues, the estimation of **Mean Glandular Dose (MGD)** also named as Organ Dose, has become an area of concern and interest (Faulkner, Law, & Robson, 1995). The estimation was achieved through the Breast Entrance Skin Air Kerma (BESAK) measurement with the help of conversion factors by computer simulation (Dance, Skinner, Young, Beckett, & Kotre, 2000):

$$MGD = K_f \times g \times c \times s \tag{2.9}$$

K_f is the BESAK, g represents the conversion factor, c is the glandularity correction factor and s represents the spectrum correction factor (Dong et al., 2002).

The conversion factors are dependent upon the compressed breast thickness, the quality of the mammographic beam and the glandularity of the breast (Dance, 1990).

Because theoretically the breast is the only tissue irradiated, mean glandular dose is the more adequate measure to estimate the radiation dose absorbed.

2.2 Legislation and Guidelines on Medical Dosimetry

The International Commission on Radiological Protection (ICRP) define as a medical exposure the exposures that cover the following criteria:

- The exposure of individuals for diagnostic, interventional, and therapeutic purposes, including exposure of the embryo/fetus or infant during medical exposure of patients who are pregnant or breast-feeding;
- Exposures (other than occupational) incurred knowingly and willingly by individuals such as family and close friends helping either in hospital or at home in the support and comfort of patients undergoing diagnosis or treatment;
- Exposures incurred by volunteers as part of a programme of biomedical research that provides no direct benefit to the volunteers.

Based on this definition, the same commission also defends that radiation exposures of patients in medicine require an approach that differs from the radiological protection in other planned exposure situations. The exposure is intentional and for the direct benefit of the patient. Also the medical use of radiation should be justified, as if any other planned exposure situation (ICRP, 2007). Besides that, there is a greatly reinforcement by this International Commission that is difficult to set diagnostic reference levels in virtue of the existence of other factors that influence image quality. Nevertheless, if the observed doses are consistently far below the diagnostic reference level, there should be a local review of the quality of the images obtained.

The European Atomic Energy Community (EURATOM) 2013/59 Directive (Council of the European Union, 2013) available in Appendix A, responsible Member States to justify the prescription of a particular examination, to optimize the procedure keeping the doses for volumes and non-target tissues As Low As Reasonable Achievable (ALARA), ensure responsibilities, specify the protocols for each procedure, check if the training and recognition requirements are met for the practitioner, monitor if the equipment is used under strict surveillance, verify the existence of special protection during pregnancy and breastfeeding, take reasonable measures to minimize the probability and magnitude of accidental or unintended exposures of individuals subject to medical exposures and ensure that the distribution of individual dose estimates from medical exposure for radiognostic and interventional radiology purposes is determined. Furthermore, also advices the use of the recommended European Diagnostic Reference Levels (DRL) when available. These DRLs represent the dose level for typical examinations for groups of standard-sized patients or phantoms to optimize the procedures. Some countries have their own reference levels and also these ones are useful as guidelines.

As such and for this work, the European Guidelines on Quality Criteria For Diagnostic Radiographic Images (European Commission, 1996) was a guidance for the exposure time and voltage reference levels on CR examinations and is represented in Appendix C (Table 2.1). The DAP reference levels were

obtained through the Radiation Protection Nº 180 (Appendix E) of the European Commission (European Union, 2014) (Table 2.2).

For CT examinations, the guidelines available (Table 2.3) refers to $CTDI_w$ and DLP and were extracted from the European Guidelines on Quality Criteria for Computed Tomography (European Comission, 1999) available in Appendix B. In Table 2.3, routine head examinations include the brain and skull base encompassing cranium and petrous bone, orbits, sella and hypophysis, salivary glands (parotid and submandibular), pharynx and larynx body parts. Vertebral trauma is related with vertebral and paravertebral structures. The reference levels for routine chest also include examinations to the spinal cord and mediastinal vessels. Routine abdomen covers the general abdomen, kidneys, pancreas, adrenal glands, lumbar spine and discal herniation.

Both guidelines for CR and CT are specific for each body part. The projection type in CR examinations, is a major factor in radiation dose being also differentiated.

Lastly, for MG exams the parameters analyzed and compared were the organ dose (Table 2.4), exposure time and compression force. The references were retrieved from the European Guidelines for quality assurance in breast cancer screening and diagnosis provided in Appendix D (Perry et al., 2006). As seen in Table 2.4, the organ dose reference levels depend on the breast thickness. In the cases where the breast thickness is not tabulated, the estimation was made by interpolation considering an existence of linearity among values.

Table 2.1: Summary of the voltage and exposure time DRLs in CR.
DRLs for the voltage and exposure times in CR images. Retrieved from: European Guidelines on Quality Criteria for Diagnostic Radiographic Images. (of European Commission, 1996)

Body Part and Projection	Voltage Reference Levels (kV)	Exposure Time Reference Levels (ms)
Chest PA	125	< 20
Chest LAT	125	< 40
Skull PA	70-85	< 100
Skull LAT	70-85	< 100
Lumbar Spine AP	75-90	< 400
Lumbar Spine PA	75-90	< 400
Lumbar Spine LAT	80-95	< 1000
Lumbo-Sacral Joint LAT	80-100	< 1000
Pelvis AP	75-90	< 400

Table 2.2: DAP DRLs according to the Radiation Protection Nº180.
DRLs for DAP values in CR images. Retrieved from: RADIATION PROTECTION N ° 180 Diagnostic Reference Levels in Thirty-six European Countries. (of European Commission, 2014).

Anatomical region	Projections	Most common value	Range	Max/min	Countries with the most common DRL	Countries with higher DRL	Countries with lower DRL
Head, skull, cranium	AP or PA	650	600-1000	1,7	CH, DE, LU	AT, PL	BE, SI
	LAT	600	500-1000	2	BE, DE, LU, SI	AT, PL	CH
Dental	Panoramic	120	120-200	1,7	FI	FR	-
Chest, thorax	PA	160	120-1000	8,3	DE, IE, LU	AT, BE, BG, CZ, FR, PL	CH, SI, UK
	LAT	600	250-1000	4	CH, LU	AT, CZ, FR, PL	BE, DE, SI
Thoracic spine	AP	1300	970-2200	2,3	DE, LU, SI	FR, PL	IE
	LAT	1700	1200-3200	2,7	DE, LU	FR, IE, NO, PL	SI
Abdomen	AP or PA	3000	2000-8000	4	AT, FI, DE, LU, NL, UK	BE, CZ, FR, NO, PL	IE, SI
Lumbar spine	AP	2300	1500-10000	6,7	DE	BE, BG,CH, CZ, FR, LU, PL	IE, SI, UK
	LAT	4200	2750-8000	2,9	DE, CH	BE, FR, PL	AT, IE, SI, UK
	LSJ	3000	2400-3000	1,3	SI, UK	-	IE
Pelvis	AP	3000	1500-7000	4,7	AT, DE, FI, UK	BE, BG, CZ, FR, LU, PL, SE	CH, DK, IE, NO, SI

Table 2.3: Proposed reference dose values for routine CT examinations.
$CTDI_w$ and DLP DRLs for CT examinations. Retrieved from: European Guidelines on Quality Criteria for Computed Tomography European Guidelines on Quality Criteria. 1-71. (of European Comission, 1999)

Examination	Reference dose value	
	$CTDI_w$ (mGy)	DLP (mGy cm)
Routine head[a]	60	1050
Face and sinuses[a]	35	360
Vertebral trauma[b]	70	460
Routine chest[b]	30	650
HRCT of lung[b]	35	280
Routine abdomen[b]	35	780
Liver and spleen[b]	35	900
Routine pelvis[b]	35	570
Osseous pelvis[b]	25	520

Legend:
HRCT – High Resolution Computed Tomography
a – Data related to head phantom (PMMA 16 cm)
b – Data related to body phantom (32 cm)

Table 2.4: Organ Dose reference levels according to the breast thickness.
Organ Dose DRLs to predetermined breast thicknesses. Retrieved from: for quality assurance in breast cancer screening and diagnosis (of Perry et al., 2006)

Thickness of PMMA	Equivalent breast thickness	Maximum average glandular dose to equivalent breasts	
		acceptable level	achievable level
[cm]	[cm]	[mGy]	[mGy]
2.0	2.1	< 1.0	< 0.6
3.0	3.2	< 1.5	< 1.0
4.0	4.5	< 2.0	< 1.6
4.5	5.3	< 2.5	< 2.0
5.0	6.0	< 3.0	< 2.4
6.0	7.5	< 4.5	< 3.6
7.0	9.0	< 6.5	< 5.1

The maximum automatically applied compression force to the breast must be between 130 and 200 N what is equivalent to 13-20 kg. The acceptable exposure time is below 2 seconds and the achievable is below 1.5 seconds. In this case, the guideline used was the acceptable exposure time due to the interest in radiological protection and not in achieving the best image quality.

2.3 Digital Imaging and Communications in Medicine (DICOM)

DICOM exists to create and maintain national standards for communication of biomedical information that use digital images and associated data. It was developed by the DICOM Standards Committee, whose members are also partly members of the National Electrical Manufacturers Association (NEMA) who holds the copyright to this standard (DICOM, 2014). Is used in several modalities like radiology, cardiology, oncology, dentistry, surgery, neurology, breast imaging, radiotherapy, ophthalmology, pathology, veterinary and pneumology.

DICOM Standard is based on the following principles (NEMA, 2016a):

- global applicability and localization in the sense that is a world-wide standard that can be used in every locale;
- continuous maintenance in accordance with the procedures of the DICOM Standards Committee;
- each instance of information objects such as images, is identified by a globally unique object identifier which persist with the instance across all exchanges (e.g Patient ID);
- conformance stated in terms of Service-Object Pairs (SOP) that represents Services operating on types of Information Objects;
- consistency of the Information Model which consists in information objects that possesses entities representing the Patient, Study, Series, Equipment, Frame of Reference and the specific instance data type.

To achieve these principles there must be primarily, a general communication model that allows the flow of information. According to Figure 2.6, DICOM's general communication model has both online (network) and offline components (media storage interchange) and the transport mechanisms can be (NEMA, 2016a):

1. **Upper Layer Service** – independence from networking support;
2. **HTTP Service** – use of common hypertext for transport of DICOM Services;
3. **Basic File Service** – access to Storage Media independently from media storage formats and file structures.

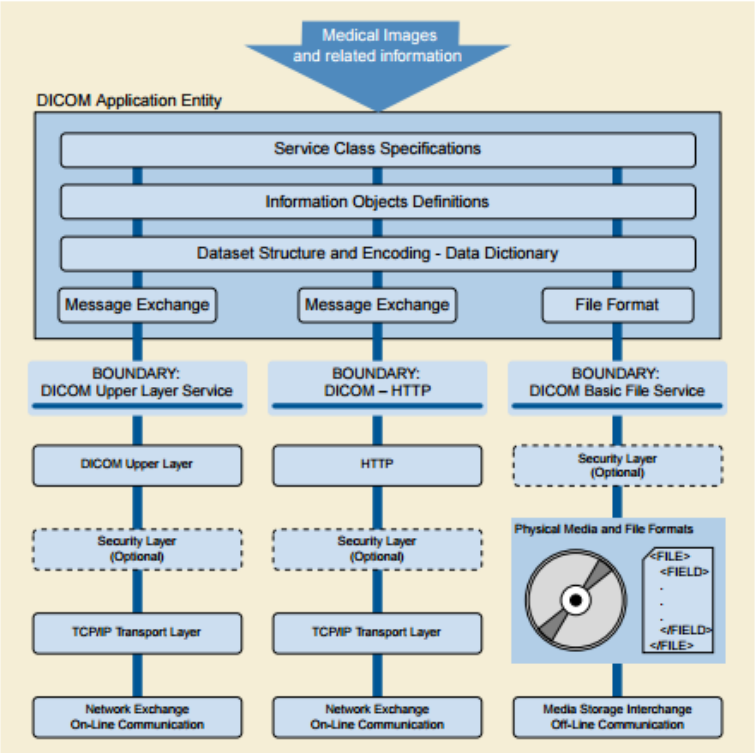

Figure 2.6: DICOM's general communication model.
DICOM's transport mechanisms available. Retrieved from: DICOM PS3.1 2015c - Introduction and Overview. 1-34. (of NEMA, 2016a)

The standard is divided in 16 parts mentioned below (parts 9 and 13 have been withdrawn):

- PS 3.1: Introduction and Overview
- PS 3.2: Conformance
- PS 3.3: Information Object Definitions
- PS 3.4: Service Class Specifications
- PS 3.5: Data Structure and Encoding
- PS 3.6: Data Dictionary
- PS 3.7: Message Exchange
- PS 3.8: Network Communication Support for Message Exchange
- PS 3.10: Media Storage and File Format for Data Interchange
- PS 3.11: Media Storage Application Profiles
- PS 3.12: Media Formats and Physical Media for Data Interchange
- PS 3.14: Grayscale Standard Display Function
- PS 3.15: Security and System Management Profiles
- PS 3.16: Content Mapping Resource
- PS 3.17: Explanatory Information
- PS 3.18 Web Access to DICOM Persistent Objects (WADO)

In PS 3.3 (NEMA, 2016b) it is described the usability of Information Object Definitions (IOD). Generally, this part specifies the attributes that characterize an image, such as type of the object, the patient data, adopted procedures and technical information. There are attributes specifically for each modality and device. Private attributes are also available only for the manufacturers to save proprietary data that cannot be used by other manufacturers.

To transfer information, both workstations must support the same service and objects. When this condition is verified the stations are called SOP Class described in PS 3.4.

For the present work, PS3.3 was a guide for the comprehension of the meaning of the images attributes. Table 2.5 represents the extracted common attributes for the three modalities and Table 2.6 describes the specific attributes retrieved for each modality. Both tables reference the attribute's name, the keyword, the tag (uniquely identifies the attribute) and the respective description.

To conclude, DICOM holds a series of advantages and disadvantages. Some of the advantages are (Mustra, Delac, & Grgic, 2008; NEMA, n.d.): physicians have better access to images allowing them to make a faster diagnosis; patients acquire more effective care; a unique standard helps in avoiding problems that occur if a patient moves from one hospital to another; it takes up less space for digital storage and digital data is easier to transmit; different workgroups are responsible to work on a small part of the standard and DICOM defines all the attributes that should be included in each modality (can be required or optional). Disadvantages also exists: possibility for entering too many optional fields which leads to inconsistency due to blank fields or incorrect data; display an image on a device made from a different manufacturer can result in an overexposed or underexposed image (different amplitude ranges).

Table 2.5: DICOM attributes extracted independently of the modality.
Represents the common DICOM attributes extracted (with the respective keyword, tag and description) for the three modalities.

Attribute Name	Keyword	Tag	Attribute Description
Patient ID	Patient ID	(0010,0020)	Primary identifier for the patient.
Patient's Sex	PatientSex	(0010,0040)	Sex of the named patient. Enumerated Values: M male F female O other
Patient's Age	PatientAge	(0010,1010)	Age of the patient.
Pregnancy Status	PregnancyStatus	(0010,21C0)	Describes pregnancy state of patient. Enumerated Values: 0001 not pregnant 0002 possibly pregnant 0003 definitely pregnant 0004 unknown
Study Instance UID	StudyInstanceIUD	(0020,000D)	Unique identifier for the Study
Content Date	ContentDate	(0008,0023)	The date the image pixel data creation started
Modality	Modality	(0008,0060)	Type of equipment that originally acquired the data used to create the images associated with this Modality Performed Procedure Step
Operators' Name	OperatorsName	(0008,1070)	Name(s) of the operator(s) who supporting this Series.
Manufacturer	Manufacturer	(0008,0070)	Manufacturer of the equipment that produced the sources.
Manufacturer's Model Name	ManufacturerModel Name	(0008,1090)	Manufacturer's model name of the equipment that produced the sources.
Study Description	StudyDescription	(0008,1030)	Institution-generated description or classification of the Study (component) performed.
Body Part Examined	BodyPartExamined	(0018,0015)	Text description of the part of the body examined.
KVP	KVP	(0018,0060)	Peak kilo voltage output of the x-ray generator used.
Exposure Time	ExposureTime	(0018,1150)	Time of x-ray exposure or fluoroscopy in msec.

Table 2.6: DICOM Attributes extracted depending on the modality.
Presents the DICOM attributes (with the respective keyword, tag and description) retrieved for each modality.

Attribute Name	Keyword	Tag	Attribute Description	Modality
Spiral Pitch Factor	SpiralPitchFactor	(0018,9311)	Ratio of the Table Feed per Rotation (0018,9310) to the Total Collimation Width (0018,9307).	CT
$CTDI_{vol}$	$CTDI_{vol}$	(0018,9345)	Computed Tomography Dose Index ($CTDI_{vol}$), in mGy according to IEC 60601-2-44, Ed.2.1 (Clause 29.1.103.4), The Volume $CTDI_{vol}$. It describes the average dose for this image for the selected CT conditions of operation.	CT
Slice Thickness	SliceThickness	(0018,0050)	Nominal slice thickness, in mm.	CT
Series Description	SeriesDescription	(0008,103E)	Description of the Series	CR
Relative X-Ray Exposure	RelativeXRayExposure	(0018,1405)	Relative x-ray exposure on the plate. Meaning of values is implementation specific. May be used to adjust the dynamic range of the plate digitizer (scanner).	CR/MG
Exposure Index	ExposureIndex	(0018,1411)	Measure of the detector response to radiation in the relevant image region of an image acquired with a digital x-ray imaging system as defined in IEC 62494-1.	CR
Image And Fluoroscopy Area Dose Product	ImageAndFluoroscopyAreaDoseProduct	(0018,115E)	Total area-dose-product to which the patient was exposed, accumulated over the complete Performed Procedure Step and measured in dGy*cm*cm, including fluoroscopy. Equivalent to DAP.	CR
Focal Spots	FocalSpots	(0018,1190)	Size of the focal spot in mm. For devices with variable focal spot or multiple focal spots, small dimension followed by large dimension.	CR
View Position	ViewPosition	(0018,5101)	Radiographic view associated with Patient Position (0018,5100).	CR

Attribute Name	Keyword	Tag	Attribute Description	Modality
			For humans: Defined Terms: AP Anterior/Posterior PA Posterior/Anterior LL Left Lateral RL Right Lateral RLD Right Lateral Decubitus LLD Left Lateral Decubitus RLO Right Lateral Oblique LLO Left Lateral Oblique	
Organ Dose	OrganDose	(0040,0316)	Average organ dose value measured in dGy during the acquisition of this image.	MG
Entrance Dose In mGy	EntranceDoseInmGy	(0040,8302)	Average entrance dose value measured in mGy at the surface of the patient during this Performed Procedure Step.	MG
Entrance Dose	EntranceDose	(0040,0302)	Average entrance dose value measured in dGy at the surface of the patient during this Performed Procedure Step.	MG
Body Part Thickness	BodyPartThickness	(0018,11A0)	The average thickness in mm of the body part examined when compressed, if compression has been applied during exposure.	MG
Compression Force	CompressionForce	(0018,11A2)	The compression force applied to the body part during exposure, measured in Newtons	MG

Chapter 3

Related Work

This section surveys previous work in collecting, tracking and analyzing ionizing radiation in medical exposures. Currently, there are many applications available on the market with this purpose. In general, they are distinguished by the modalities covered, methods to retrieve, process and analyze data from existing systems and for being open-source or closed-source. Some of them will be presented in the subsections below. It should be noted that the in-depth information available for each application is different. The majority of the applications are designed by companies and, for competitive reasons, becomes disadvantageous to disclose how the application was built in its totality. For that reason, the applications with more detailed information are described first and separately and the remaining ones are mentioned in the subsection "Other Software".

At the end of this chapter, Table 3.1 compares all the following products with the one developed in this work considering the most important features.

3.1 Radimetrics™ Enterprise Platform

On June 2012, Radimetrics, INC. applied to a patent application publication (Couch & Couch, 2012) consisting of estimate patient radiation exposure during CT scans. Their main concern was the impossibility of measuring radiation exposures in live patients directly, as part of a CT exam which leads to a non-tracking of the patient's cumulative dose over many procedures. However, estimates were proposed with the use of phantoms corresponding to the individual when matching a given set of parameters related to the imaging scan. If there were more than two matches, the estimates of radiation dose are interpolated with Shepard's method (Gordon & Wixom, 1978). If not, simulations may be performed with Monte Carlo simulation (Mooney, 1997). Additionally, embodiments also included a SaaS (Software as a Service) or cloud provider to perform these estimates and to store all the obtained information.

Radimetrics™ Enterprise Platform, a Bayer product, comes up on 2014, result of an initial product named radimetrics eXposureTM released on 2009. It is a closed-source multiple modality, (CT's, x-ray, mammography and interventional imaging) vendor-neutral and web-based platform with the following major objectives: dose reporting and tracking, protocol management and benchmarking. Besides offering a radiation dose management it also provides a contrast dose management (Bayer, 2014).

All the exam data are extracted from RIS/PACS and become available in the fully DICOM/HL7, RadLex integration (ontological system that provides unified vocabulary for the radiologists) and IHE support platform allowing data-driven. Here the technicians, radiologists and physicians can access to the patient cumulative radiation history, elaborate speech dose reports, simulate future scenarios with interactive interfaces, receive alerts based on customized DRLs and ALARA principle and identify outliers. The DRLs can be relative to DLP, SSDE (Size-Specific Dose Estimates) or ICRP 103 or can be set based on a percentile (Bayer, 2015).

Although, nowadays, the imaging scanners provide estimates of the radiation dose administered to the patient, when this information is not disclosed, Radimetrics™ Enterprise Platform estimates the radiation dose based on the embodiments presented in their patent. Figure 3.1 represents an overview of the platform functioning.

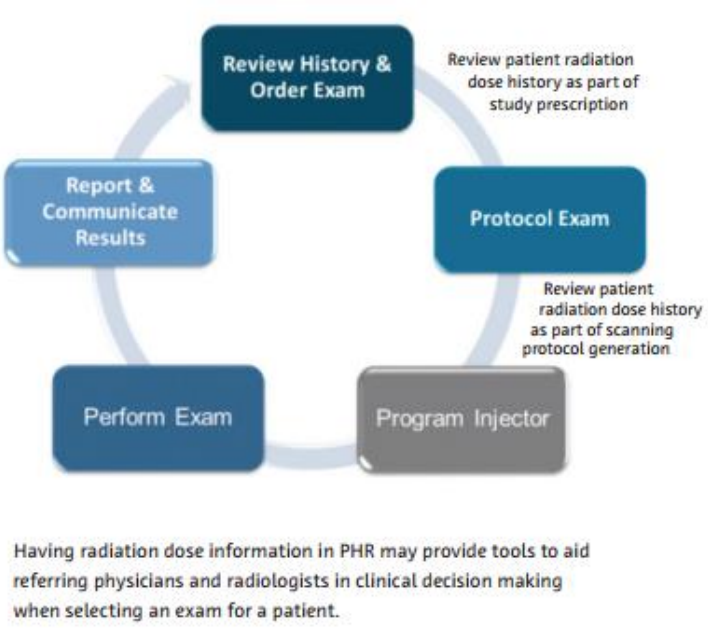

Figure 3.1: Radimetrics™ Enterprise Platform functioning.
Radimetric's dataflow. Retrieved from: The Joint Commission Standards for Diagnostic Imaging - Is Your Radiology Department Ready? (of Bayer, 2015).

3.2 Sectra DoseTrack™

According to Sectra's website (Sectra, 2016), Sectra DoseTrack™ is a web-based platform that allows the connection to multiple modalities to ensure a complete radiation monitoring solution. It supports both IHE and DICOM protocols, EMR, RIS and PACS and helps the health institutions ensuring that the radiation is kept ALARA. It is also possible to set dose reference levels when the radiation exceeds

given thresholds or the system can be configured to use local or international DRLs. Other tools such as sending automatic reports by e-mail and exporting data to Excel are available to the user. The reports are sent to ACR, where the dose values are stored in the Dose Index Registry allowing comparison with regional and national values. Sectra DoseTrack™ calculates the effective organ dose according to the patient's physiognomy and the high-risk patients can be redirected to other type of examinations to minimize their risk. When accessing to the patient's reports, physicians can avoid unnecessary examinations and provide the most appropriate imaging procedure. When an outlier exists, the system provides tools to investigate the reason for that deviation. The patient history is also stored and alerts can be delivered on the number of examinations. The product provides a multi-level analysis: department, modality and staff levels. Updating reports frequently, calibrating the imaging scanners regularly, and measuring the impact of dose reduction in a specific practice or department are some of the many features available (Sectra, 2013). Dave Jordan, a Physicist at University Hospitals Case Medical Center, adds "The interface on this system gives you a lot of options. It doesn't force you to look at certain default datasets or graphs. You pick the subset of patients, procedures, dates, or any other combination of parameters, and you get whatever it is you were looking for immediately." (Lew, 2014). Sectra DoseTrack™ is a SaaS and all the updates are provided remotely and immediately. It can be accessing from any web browser from a secure location and it is closed-source.

3.3 RADIANCE

For RADIANCE, a RadioGraphics article is available with all the detailed procedures used to develop the application and the following information is based on that article (Cook et al., 2011). RADIANCE is an automated free and open-source software to extract, store and monitor radiation dose for CT examinations. In general, it ensures a IHE REM (Radiation Exposure Monitoring) profile, allows querying PACS for CT dose sheets using DICOM query-retrieve operations, examining dose data at various levels and identifying outliers.
Requires an access to the World Wide Web and MySQL (My Structured Query Language) servers to run. The software was implemented using PHP but the pipeline is a Windows batch file that limits the usage on other machines. The Windows PC (Personal Computer) must be configured to receive dose sheets from a scanner or from a PACS and these dose sheets are searched on the RADIANCE inbox which are posteriorly processed with Optical Character Recognition (OCR) and stored in database. To query DICOM sheets an additional software is needed depending on the place we want to retrieve from.

The algorithm, represented in Figure 3.2, starts with a DICOM CT dose sheet as input. Secondly, the pixel-based information of the dose sheet is converted into American Standard Code for Information Interchange (ASCII) text (with OCR) to extract the relevant parameters of the image and the DICOM header is translated into Extensible Markup Language (XML). It is produced a Joint Photographic Experts Group (JPEG) copy of the original DICOM for validation.

To store all the parsed data is used a MySQL relational database residing behind a firewall with a password that protects confidential information. The study date, examination code and description, scanner manufacturer and model, institution name, patient identification number and patient date of birth are retrieved from the image header and the data extracted from the dose sheet is vendor specific. RADIANCE can process Siemens, GE, Toshiba, Philips and NeuroLogica dose sheets. The dose related parameters are kilovoltage, x-ray tube milliamperes, reference milliamperes, $CTDI_{vol}$ and DLP. After these data is validated the effective dose is estimated by multiplying DLP by the tissue factor.

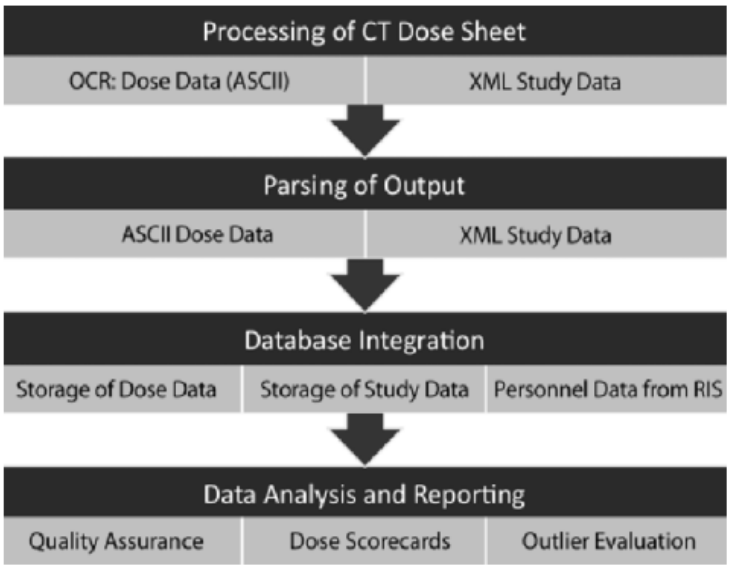

Figure 3.2: RADIANCE algorithm.
Represents the Radiance dataflow. Retrieved from: Informatics in Radiology: RADIANCE: An Automated, Enterprise-wide Solution for Archiving and Reporting CT Radiation Dose Estimates. 1833-1846. (of Cook et al., 2011).

A Radiation Dose Structured Report (RDSR) Java based is generated and can be automatically transmitted to American College of Radiology Dose Index Registry (ACR DIR). It is also possible to import RDSRs into the database delivered by other scanner models. For the front-end it was built a Highcharts (JavaScript (JS) charting library) dashboard that summarizes all the relevant information like dose estimates, cumulative dose until now and cumulative lifetime dose estimates and allows an interactive analysis. Effective dose DRLs can be set and data can be displayed grouped by patient, scanner, personnel, departmental section or examination type. For instance, and particularly on personnel views, it is possible to analyze dose estimates for referring physicians, performing technologists and reporting radiologists.

Some RADIANCE faults are:

1. Supports only CT exams;
2. OCR process only compatible with Windows PCs;
3. Incorrect dose estimates when dose sheets include series from more than one body part;
    - RADIANCE expects dose sheets to refer only to one body part.

3.4 DoseMonitor®

DoseMonitor® is a PACS-based, vendor-neutral and multi-modality (CT, x-ray angiography (XA), digital radiography (DR), MG) automated tool that provides healthcare facilities throughout the hospital or health system according to DoseMonitor® website (DoseMonitor®, 2016). With enterprise – level data acquisition, it allows to aggregate, interpret, compare, track and report ionizing radiation data on a patient, study, physician, technologist or device. Identify outlier devices and procedures as well as technicians who may need training, to better adhere to protocols, improve quality and better manage consistency.

DoseMonitor® uses a single server that includes the DIR functionality and allows benchmarking facilities against other providers and a user-friendly web-browser interface that makes easier to access from a PC and even from mobile devices (Figure 3.3). It requires Microsoft Windows Server 2008 and MS-SQL 2008 Standard.

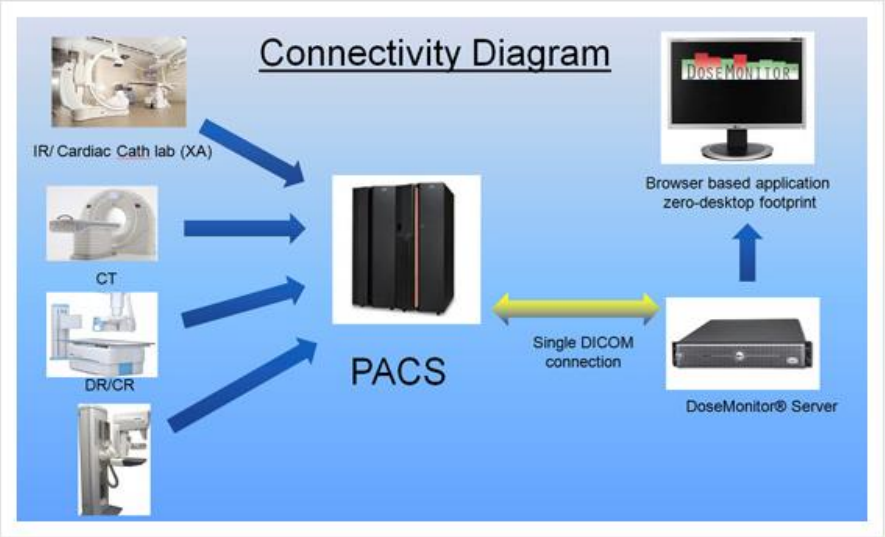

Figure 3.3: DoseMonitor® Implementation.
How the information flows until reaching the Dose Monitor platform. Downloaded on 2016-07-30 from http://www.dosemonitor.com/features/

The historical information across units and departments is accessible in real-time for better-informed decisions. This means that when a patient is submitted to an examination, the physicians and technicians have access to pre-visit real-time and historical data, including historical patient dose profile. Data can be retrieved via DICOM-SR (Structured Reports), OCR, modality performed procedure step (MPPS) and is updated in real-time and customized alerts for any parameter (patient type, dose…) are sent via e-mail or HL7 (Figure 3.4). For reporting, DoseMonitor® offers a flexible reporting with filters by device, facility, technologist, physician, procedure and patient. The data collection and reporting is sent to ACR's dose index registry which means reduced potential for error, no change in workflow and reduced physician and technician time.

It also integrates speech recognition for dictation systems via an application programming interface (API) or HL7.

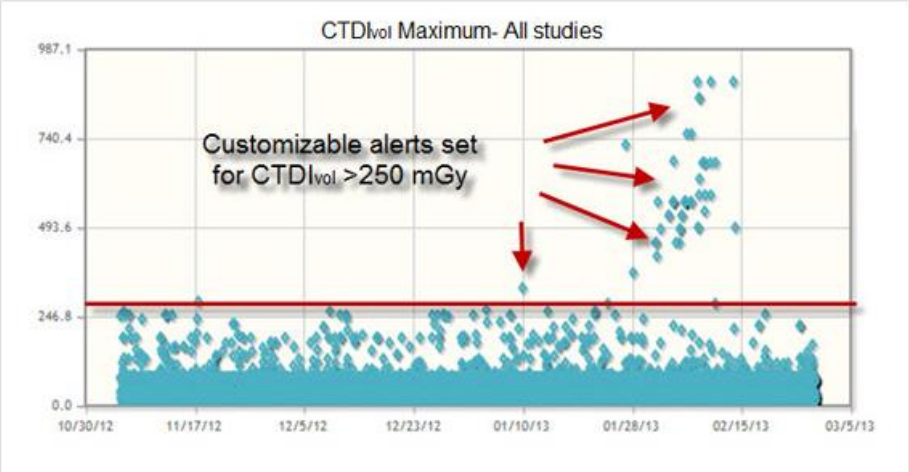

Figure 3.4: Dose Monitor® alerts.
Alerts can be provided based on customizable values. Downloaded on 2016-07-30 from http://www.dosemonitor.com/features/

With DoseMonitor® features, the productivity is high. It is possible to identify patterns and anomalies with summaries and study notifications, compare enterprise data for quality assurance (QA), analysis and modality reporting, access detailed patient and study data, identification of opportunities for staff education and training to improve results as well as identifying outliers.

3.5 Other Software

There are other systems in which the available information is greatly reduced such as Imalogix™, AccuRad™ REM Server provided by Aware and DoseWatch designed by GE Healthcare. Each of them is described below.

According to Imalogix™ website (Imalogix™, n.d.), it is a closed-source product that besides providing dose tracking, it also turns all the imaging data into meaningful information to reduce dose exposures to patients and improve patient care. With normalized data, it is possible to establish thresholds and compare these values internally or against national values and trends. Identifying root-causes for frequent alerts, reducing dose exposures and adjust scanners so that more predictable radiation dose is delivered to the patients are other features available.

Relatively to implementation, Imalogix™ integrates with the scanners with no need for a specific implementation and it takes less than one hour for the installation. It supplies EMR with patient-level dose and enterprise performance information. Reports are done automatically so the radiation doses become measured and stored, simplifying the workflow and also eliminating errors caused by manual entry.

AccuRad™ REM Server is provided by Aware with the purpose of monitoring and storing the radiation doses of CT and fluoroscopy examinations (RF). It is a closed-source, centralized software application that receives the data from PACS and distributes it in a standard format to radiology reporting systems, PACS, and external data registries. Reporting functions through a web-based interface and interactive statistical analyses are also available.

Regarding implementation, it starts with receiving from the imaging scanners the dose data in the form of digital SR compliant with DICOM and IHE. With older scanners OCR is used to extract the image-based textual data and then structure it in compliance with the IHE REM integration profile. Exposure information is calculated in near real-time allowing the clinicians to produce customized reports summarizing exposure estimations by physician, modality, time/date, institution or other queries. Reports can be generated manually or automatically based on predetermined intervals and it also accepts third party reports. For comparison with external results, it is possible to upload the data to the ACR DIR.

Joe Kushi, Aware director of sales strengthens: "AccuRad REM Server simplifies SB 1237 compliance, but also integrates dose data into third-party reporting systems and enables analysis that can help clinicians reduce risks associated with radiological exams. It leverages Aware's expertise in imaging along with critical features of the mature AccuRad ImageShare Server platform, making it the most advanced solution currently available for dose monitoring." (Aware, 2012).

DoseWatch is the dose management solution offered by GE healthcare (GE Helthcare, 2016). It collects and analyses patient radiation dose as well as iodine exposure across multi-facility, multi-modality and multi-vendor imaging environments. The major objective of this product is to provide the right dose to the patient instead of exposing him to enormous or low doses which will lead to another examination and more exposure to ionizing radiation. As well as other features, DoseWatch is an ACR DIR software partner capable of storing cumulative doses and medical history, optimizing performance and enabling compliance with reporting capabilities. It is a closed-source product that supports CT, mammography, interventional and cardiovascular, surgical/mobile c-arms and radiography examinations. It is compatible with DICOM SR & DICOM MPPS protocols, DICOM image header for non-SR/MPPS DICOM CT exams, OCR to extract the relevant information and hybrid connections to maximize data collection. When outliers are present, the system alerts the user that an exam dose exceeded predetermined thresholds. Comparing the doses for all modalities, grouping them by some characteristics like patient age, device, study description are available ways of analyzing the data. The performance can be tested by comparing the doses against national and local DRLs and it can also automatically evaluate the SSDE according to the patient size.

RadLex is used for mapping and standardizing the study description. Inclusion of RIS and data through HL7 integration and automated generation of dose reports in RIS/EMR are also available.

Contrast dose management is a complement to the product that will bring more advantages and additional features such as notifications and alerts on cumulative dose of iodine and clinical context, automatic tracking for GE CT scanners with class 4 integrated injectors and injections details.

Summing up, DoseWatch allows the users to review historical data, optimize protocols, reduce radiation dose, improve image quality and apply ALARA principles.

Table 3.1: Review of each product and comparison with the developed system.
Summary of the features of the described systems and comparison with Radiation Monitoring System in Clinical Imaging.

Features / *Products*	Availability	Modalities Covered	DRLs	ALARA	Alerts	Statistical Analysis	Vendor-neutral	Reports to ACR	DICOM/ HL7	Data extraction	Back-end	Web service	Front-end
Radimetrics™ Enterprise Platform	Closed-source	CT CR MG Interventional Imaging	Yes	Yes	Yes	Yes	Yes	N/A[1]	Yes	RIS/PACS	N/A[1]	N/A[1]	Web-based
Sectra Dosetrack™	Closed-source	Multi-modality	Yes	Yes	Yes	Yes	N/A[1]	Yes	Yes	EMR/RIS/PACS	N/A[1]	N/A[1]	Web-based
RADIANCE	Open-source	CT	Yes	N/A[1]	N/A[1]	Yes	Yes	Yes	Yes	Scanners/PACS	MySQL Relational database	N/A[1]	Highcharts dashboard
DoseMonitor®	Closed-source	CR XA DR MG	Yes	N/A[1]	Yes	Yes	Yes	Yes	Yes	PACS	MS-SQL 2008	Microsoft Windows Server 2008	Web-based and available on mobile devices
Imalogix™	Closed-source	N/A[1]	N/A[1]	N/A[1]	Yes	Yes	N/A[1]	N/A[1]	N/A[1]	EMR	N/A[1]	N/A[1]	N/A[1]
Accurad™ REM Server	Closed-source	CT RF	N/A[1]	N/A[1]	N/A[1]	Yes	N/A[1]	Yes	Yes	PACS	N/A[1]	N/A[1]	Web-based
DoseWatch	Closed-source	CT MG CR Interventional and Cardiovascular, Surgical/Mobile C-arms	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A[1]	N/A[1]	N/A[1]	N/A[1]
RMSCI	Open-source	**CT** **MG** **CR**	Yes	N/A[2]	NA[1]	Yes	Yes	NA[1]	Yes	PACS	MySQL Relational Database	PHP-based	Web-based (Highcharts dashboard)

[1] N/A – Not Available
[2] N/A – Not Applicable

Chapter 4

RMSCI

This section will now describe the work of this thesis namely the Radiation Monitoring System in Clinical Imaging (RMSCI). The subsections include: the architecture, where the mock-up of the work is represented; data retrieval, where it is provided the steps to obtain the data; data processing includes methods to extract meaningful information from the data to generate metadata; data storage that makes use of a Database Management System (DBMS) for storing the metadata after being parsed and extracted; web services that allows the automatic exchange of data through the web and the web interface to allow the user to dynamically visualize and interpret the data.

4.1 Architecture

As mentioned in the introduction (see section 1.3), the major objective of this work was to primarily monitor in real-time the radiation dose administered to patients when submitted to CR, MG and CT examinations. With the existing obstacles described, the concept of the work changed slightly but the system is ready to work the way it was initially planned.

As represented in Figure 4.1, the data was collected from the public hospital's PACS and then processed with a Python script. The main job of this script is to receive files in DICOM format and extract from them the attributes needed to monitor the radiation dose and other relevant parameters. Beyond that, the processed data was organized in the form of SQL INSERTS to immediately insert it in the relational database (back-end). It is greatly important to mention that was not used any type of information that could jeopardize medical confidentiality underlying these matters.

The connection of the back-end with the front-end is made through web services. In this case, was designed a PHP-based RESTful web service that queries the required data from the database and transmit it in JavaScript Object Notation (JSON) format.

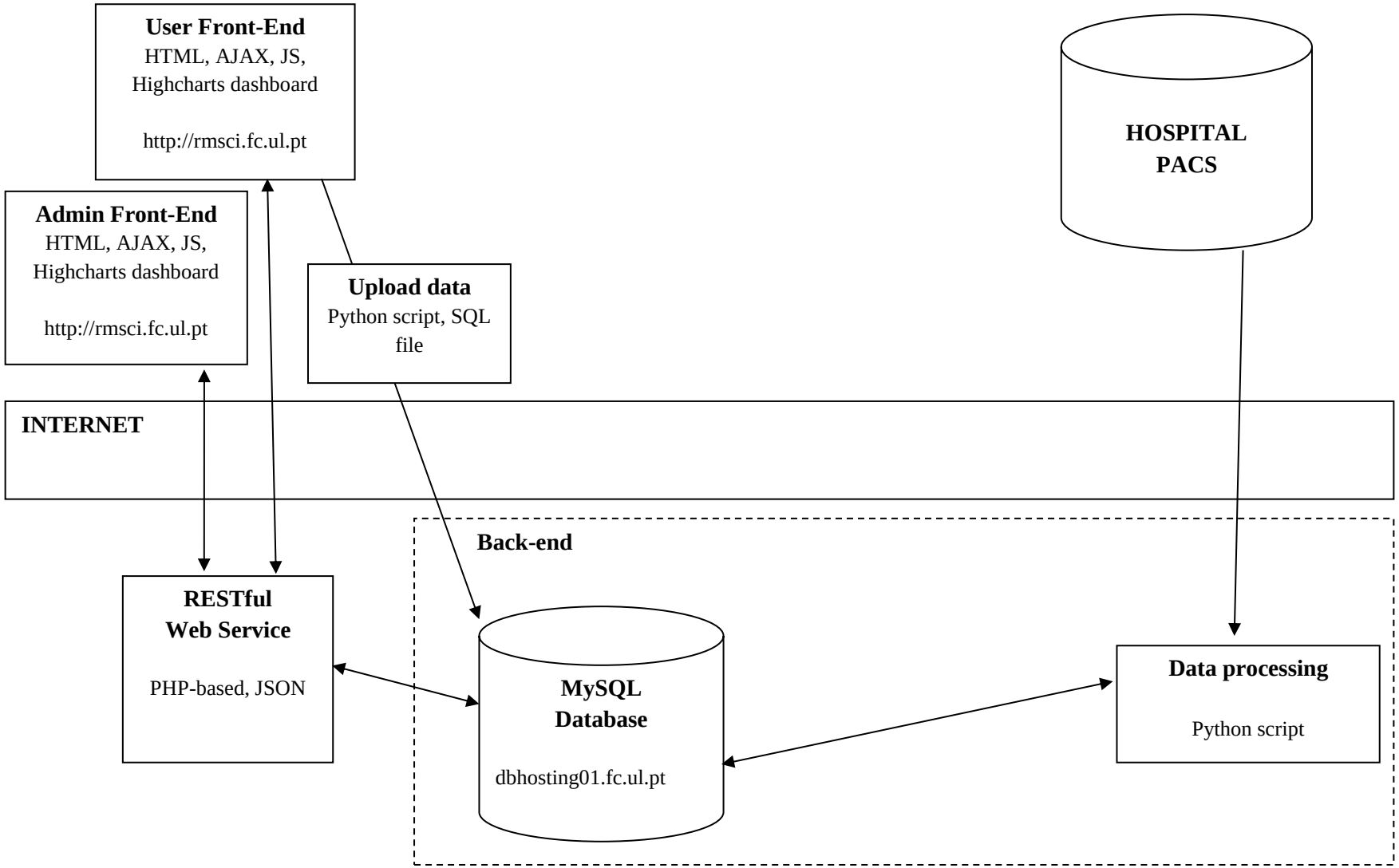

Figure 4.1: Work architecture.
The work has three main components (back-end, web service and front-end) each one of them with their characteristics.

The front-end is a dynamic HTML web application available at http://rmsci.fc.ul.pt/ and the results are visualized and interpreted with the help of a Highcharts dashboard that includes statistical analysis (averages and 90th percentiles) as well as comparisons between radiation doses, voltages, exposure times and compression forces and the European guidelines. The calls to the web service are made asynchronously via AJAX with no interruption of the flow of the JavaScript's interpreter and thus, there is no need to reload the page manually.

To make the flow of information bidirectional and to add more value to the system, it is also possible to upload data to a specific user section accessible by a keyword. For that, the user must run a python script available online for download giving the path for his data. The script will generate a parsed SQL file ready to be uploaded directly into the web application. After the upload, it will be provided a keyword to access the data introduced.

4.2 Data Retrieval

As referred previously, the data used were obtained from a Portuguese public hospital and collected from their PACS to an external disk. In total was collected a sample of 978 exams that is equivalent to data from one month. Of these 978, 178 exams refer to MG exams, 485 to CR examinations and 315 to CT. Of these 315, only 175 provides the radiation dose information ($CTDI_{vol}$). Thus, the rest 140 were discarded for being useless for the intended analysis. Figure 4.2 translates all these numbers in percentages to facilitate the interpretation.

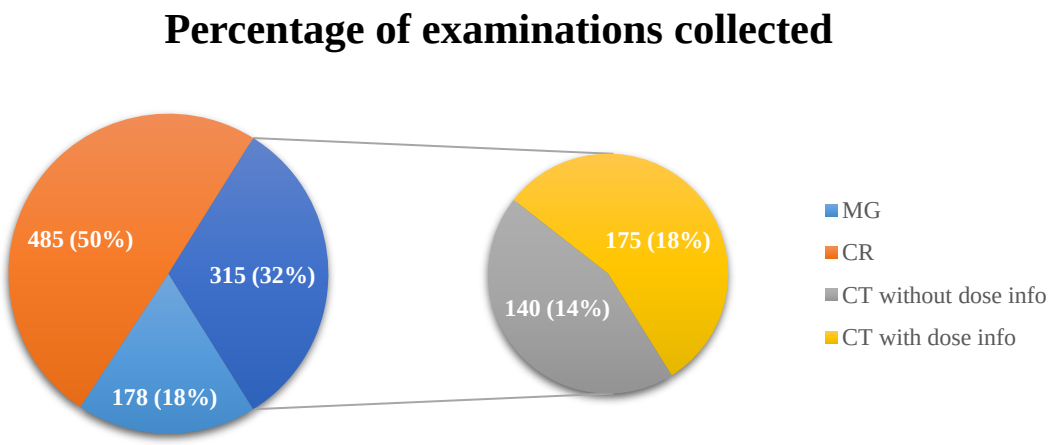

Figure 4.2: Percentage of the examination modalities collected.
The first number represents the quantity of examinations collected and the second one the respective conversion to percentage.

It can be claimed that x-ray exams are the most requested which is not surprising since, in most cases, it is the first-line diagnostic exams. This is due to its low cost, for being a non-invasive procedure, is not plaguy for the patient, makes use of a low radiation dose but mainly because it is possible to analyze all the skeleton, identify injuries or discard suspicions. For more detailed information and according to the patient complaints, other type of examinations might be prescribed such as CT in which the radiation

dose administered is higher. Mammographies are performed only to women within a well-defined range of ages that is why they are fewer than the other exams.

All these statistics are in agreement with the National Health Service data in Portugal where were performed in hospital internment 361.694 CR exams, 203.661 referring to CT examinations and 1.489 MG examinations in 2014 (Administração Central do Sistema de Saúde, 2014). Also in 2016, the National Health Service data in England reported more x-ray procedures than CT and MG examinations (Dixon, 2016).

This number of examinations is reflected in a total of 837 patients, where 350 are males, 474 females and 13 are not defined (Figure 4.3).

It can be concluded that the patients sample is not statistically significant to infer any definitive conclusions because it is not representative of the dimension of the Portuguese population (approximately 10 million people).

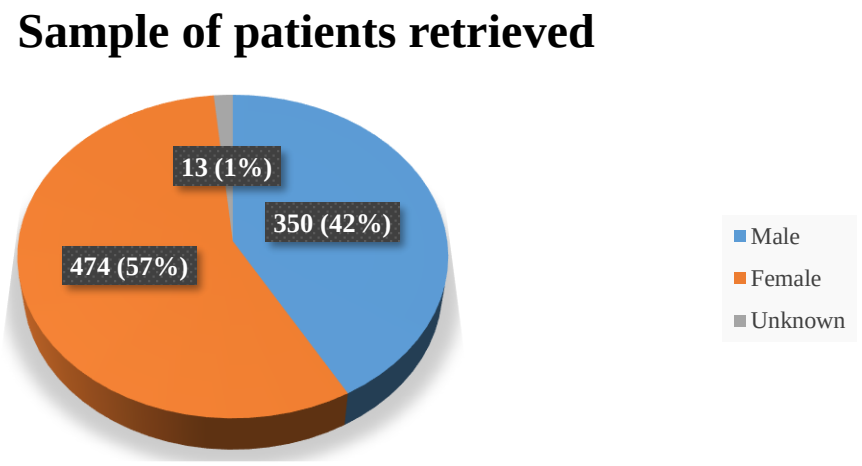

Figure 4.3: Sample of patients retrieved.
The first number represents the quantity of patients and the second one the respective conversion to percentage.

4.3 Data Processing

After the data collection, it is necessary to extract only the relevant information that, in this specific case, is the patient, examination and image data. In Tables 2.5 and 2.6 are specified the DICOM Attributes extracted and manipulated.

For all the modalities, it is common the Patient ID, Sex, Age and Pregnancy status that refers to the patient characteristics. These parameters match the ones that were attributed in the correspondent health institution to facilitate the identification of a specific patient.

Regarding the examination, it was also parsed for the three modalities the Study Instance UID, Content Date, Manufacturer, Manufacturer Model Name, Modality and Operators Name. In this case, what is important is to distinguish the modalities, manufacturers (to assess what brand and model of scanners

are administering more or less dosage) and, eventually the operators. Filter the data by the operator is another interesting analysis that could, in a future work, be performed (in the current data, this attribute is seldom filled).

Concerning the common image attributes, the following can be mentioned: Study Description, Body Part Examined, KVP and Exposure Time. In the image, is relevant to access the body part examined to compare the dose administered with the European guidelines as well as the exposure time and voltage. The study description is additional information that has no impact in the analysis but may be useful for other type of studies.

Specifying the attributes by modality and starting with CT, the variables that are important to extract are: $CTDI_{vol}$ where is stored the dose per slice, the slice thickness that is essential for the DLP calculation and the spiral pitch factor to convert $CTDI_{vol}$ into $CTDI_{w}$.

In CR examinations, the radiation dose is acquired by the Image and Fluoroscopy Area Dose Product (IADP) attribute representing the total area dose product which the patient was exposed to (the same as DAP). The Series Description is a reference for the body part analyzed and for the incidence of the x-rays. When the x-rays projection is not mentioned, this information can be obtained through the view position attribute. The relative x-ray exposure, exposure index and focal spots attributes are also not relevant for the intended analysis but are good indicators of how the image was acquired.

In mammographies, the organ dose DICOM attribute is responsible for storing the radiation dose per examination image. The compression force and the body part thickness are also both important because the European guidelines are based on the breast thickness, in order to calculate a reference level for the organ dose. These guidelines also provide diagnostic reference levels for the compression force applied. Entrance dose is a simple indicator for the dose absorbed by the skin that is not used directly by the system but was also stored due to the fact that is another dose indicator that may be relevant in a future work.

To extract all the attributes mentioned above (see section 2.3), it was used a Python package named *pydicom*[3] which is specific for parsing DICOM files making them easier to read and manipulate. To read all the files in the subdirectories of a folder it was used *os*[4], another Python package.

It is important to mention that the units of the DICOM attributes (NEMA, 2016b) are not in accordance with the dose reference levels and, for that reason, is required a conversion (Table 4.1).

Table 4.1: Conversion of the units of the DICOM keywords.
Represents the DICOM keywords, the respective unit and conversion made.

DICOM Keyword	DICOM Unit	Conversion
ExposureTime	msecs	secs
SliceThickness	mm	cm
FocalSpots	mm	cm
BodyPartThickness	mm	cm
ImageAndFluoroscopyAreaDoseProduct	$dGy*cm^2$	$mGy*cm^2$
OrganDose	dGy	mGy
EntranceDose	dGy	mGy

[3] https://pypi.python.org/pypi/pydicom
[4] https://docs.python.org/2/library/os.html

While the script is parsing all the metadata, it also sends it to a pre-constructed database. This is accomplished with the help of another Python package called *MySQLdb*[5] that is responsible to make the connection to the database based on a host, port, password and database name.

Just to make the display of the program more user-friendly and interact with it in the Windows console, it was used *sys*[6], a fourth Python package that allows the interaction with the program on the command line.

The three scripts that were responsible for all these processing are available online[7] and were coded with the following logic:

- **Script 1 - ToProcess.py**
  - Calls the DICOMProcessing function of the module DICOMProcessing.py and runs the program in the command line.

- **Script 2 - DICOMProcessing.py**
  - Contains one function (DICOMProcessing) that has as input the path for the folder where the files are stored and select only the DICOM files (extension. dcm);
  - Depending on the modality of the images (or DICOM file), is called one of the functions coded in dbInserts.py script:
    - The command *getattr(data, "Modality")*, where data is *dicom.read_file(os.path.join(dirName,filename))*, is responsible for retrieving the modality of the examination. The last command returns all the DICOM keywords of a specific image and the correspondent values.

- **Script 3 - dbInserts.py**
  - Contains seven functions with different tasks.

  - Function “Data”:
    - Receives as input *dicom.read_file(os.path.join(dirName,filename)* and a list of DICOM keywords whose values are desired.
    - Creates and returns a key-value pair dictionary where the key is the DICOM keyword and the value is the correspondent value.

  - Function “IntroducesPatientData”:
    - Receives as input *dicom.read_file(os.path.join(dirName,filename)*
    - Creates and returns a dictionary only related to the patient’s keywords. To do it, calls the function “Data”;
    - Inserts the metadata in Patient Entity.

[5] http://mysql-python.sourceforge.net/MySQLdb.html
[6] https://docs.python.org/2/library/sys.html
[7] https://github.com/ritajflorencio/RMSCI/tree/master/DICOMProcessing

- Function “IntroducesExamData”:
  - Receives as input *dicom.read_file(os.path.join(dirName,filename)*
  - Creates and returns a dictionary only related to the examination’s keywords. To do it, calls the function “Data”;
  - Inserts the metadata in Exam Entity.

- Function “IntroducesImageData”:
  - Receives as input *dicom.read_file(os.path.join(dirName,filename)*
  - Creates and returns a dictionary only related to the image’s keywords. To do it, calls the function “Data”;
  - Inserts the metadata in Image Entity.

- Function “IntroducesCTData”:
  - Receives as input *dicom.read_file(os.path.join(dirName,filename)*
  - Creates and returns a dictionary only related to the CT image’s keywords. To do it, calls the function “Data”;
  - Inserts the metadata in CT Entity.

- Function “IntroducesCRData”:
  - Receives as input *dicom.read_file(os.path.join(dirName,filename)*
  - Creates and returns a dictionary only related to the CR image’s keywords. To do it, calls the function “Data”;
  - Inserts the metadata in CR Entity.

- Function IntroducesMGData:
  - Receives as input *dicom.read_file(os.path.join(dirName,filename)*
  - Creates and returns a dictionary only related to the MG image’s keywords. To do it, calls the function “Data”;
  - Inserts the metadata in MG Entity.

Figure 4.4 represents the interaction between these scripts.

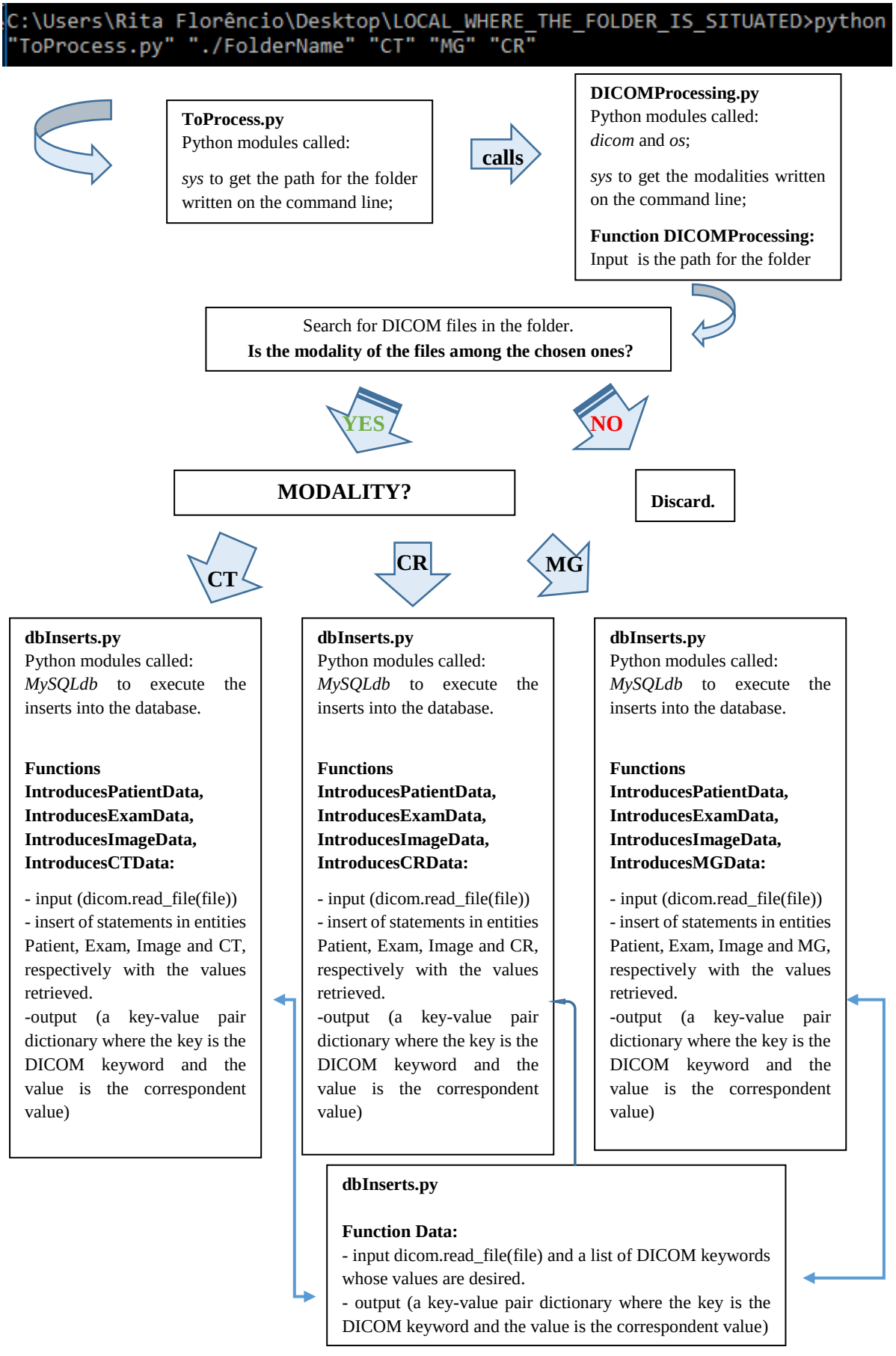

Figure 4.4: Dataflow between python scripts.

4.4 Data Storage

Data storage is one of the most important processes of dealing and organizing data. For the present project, a MySQL database was created that represents an organized way to store data being possible to query, analyze results and draw conclusions. A well-structured database is the key for efficient queries and consequently to obtain faster results.

The Entity-Relationship (ER) database schema is represented in Figure 4.5 and the SQL code to create the database is available online[8].

Before any further explanation about the schema itself, it is important to mention that the data always has an identity. In other words, all the metadata in the database is linked to the e-mail of the person/entity who uploaded it preventing mixes and ensuring unequivocally. This is reflected on the fact that all the entities/tables have a column named "e-mail". To store all the users that have already uploaded DICOM files, it was created an entity "Users" that archives the username, e-mail of the owners and keyword (Primary key (PK) e-mail) to access the user section. Ideally, it should have been assigned an auto increment integer as the primary key that references those e-mails. However, as this thesis is a proof of concept, it was only intended to show the functionality of the system. In the future, all these issues will be enhanced and improved.

The names given to the columns of the entities are slightly different comparatively with the DICOM attributes. The correspondence between them is provided in Table 4.2.
The data types used were: CHAR (characters), INT (integers), FLOAT (float numbers) and DATE (dates).

Considering that we are dealing with patients and exams, a Patient and Exam e are entities obviously needed:

- **Patient entity:**
  - Stores all the metadata belonging to the patients;
  - PK – Patient ID (CHAR) and owner e-mail (CHAR);
  - Other attributes:
    - gender (CHAR);
    - pregnancy (INT);
    - age (INT);
  - The Patient ID is the unique identifier of that patient in the health establishment where it was retrieved from. This helps identifying immediately the person without any further research.

- **Exam entity:**
  - Archives the metadata related to the examination in general;
  - PK – Exam ID (CHAR) and owner e-mail (CHAR);
  - Foreign Keys (FK) - Patient ID (CHAR) and owner e-mail referencing Patient entity;
  - Other attributes:
    - date (DATE);
    - equipment (CHAR);

[8] https://github.com/ritajflorencio/RMSCI/blob/master/RMSCI/tools/tables_rmsci.sql

- equipmentModel (CHAR);
- modality (CHAR);
- operatorsName (CHAR);
- DLP_mGYcm (FLOAT) to store the DLP of CT examinations. For the remaining modalities, this attribute is NULL;
- DAP_mGycm2 (FLOAT) to store the total dose administered in the CR examinations (sum of all IADPs of a specific examination). For the remaining modalities, this attribute is NULL;

- The Exam ID is the unique identifier of that exam in the health establishment where it was retrieved from. This helps identifying immediately the exam without any further research.

Table 4.2: Correspondence between the DICOM keywords and the entity attributes.
Represents the correlation between the DICOM keywords and the names given to the attributes of the entities.

Entity attribute	DICOM Keyword
gender	PatientSex
pregnancy	PregnancyStatus
age	PatientAge
examID	StudyInstanceUID
date	ContentDate
equipment	Manufacturer
equipmentModel/equipmentmodel	ManufacturerModel
modality	Modality
operatorsName	OperatorsName
studyDescription	StudyDescription
bodyPart/bodypart	BodyPartExamined
voltage_kV/voltage	KVP
exposureTime_secs/exposureTime	ExposureTime
seriesDescription/seriesDesc/series	SeriesDescription
relativeExposure	RelativeXRayExposure
exposureIndex	ExposureIndex
IADP_mGycm2/DAP_mGycm2	ImageAndFluoroscopyAreaDoseProduct
focalSpot_cm	FocalSpots
ctdivol_mGy	$CTDI_{vol}$
sliceThick_cm/ slice_thick/	SliceThickness
organDose_mGy	OrganDose
entranceDose_mGy	EntranceDoseInmGy
sliceThickness_cm	BodyPartThickness
cforce_N	CompressionForce
pitch_factor	SpiralPitchFactor

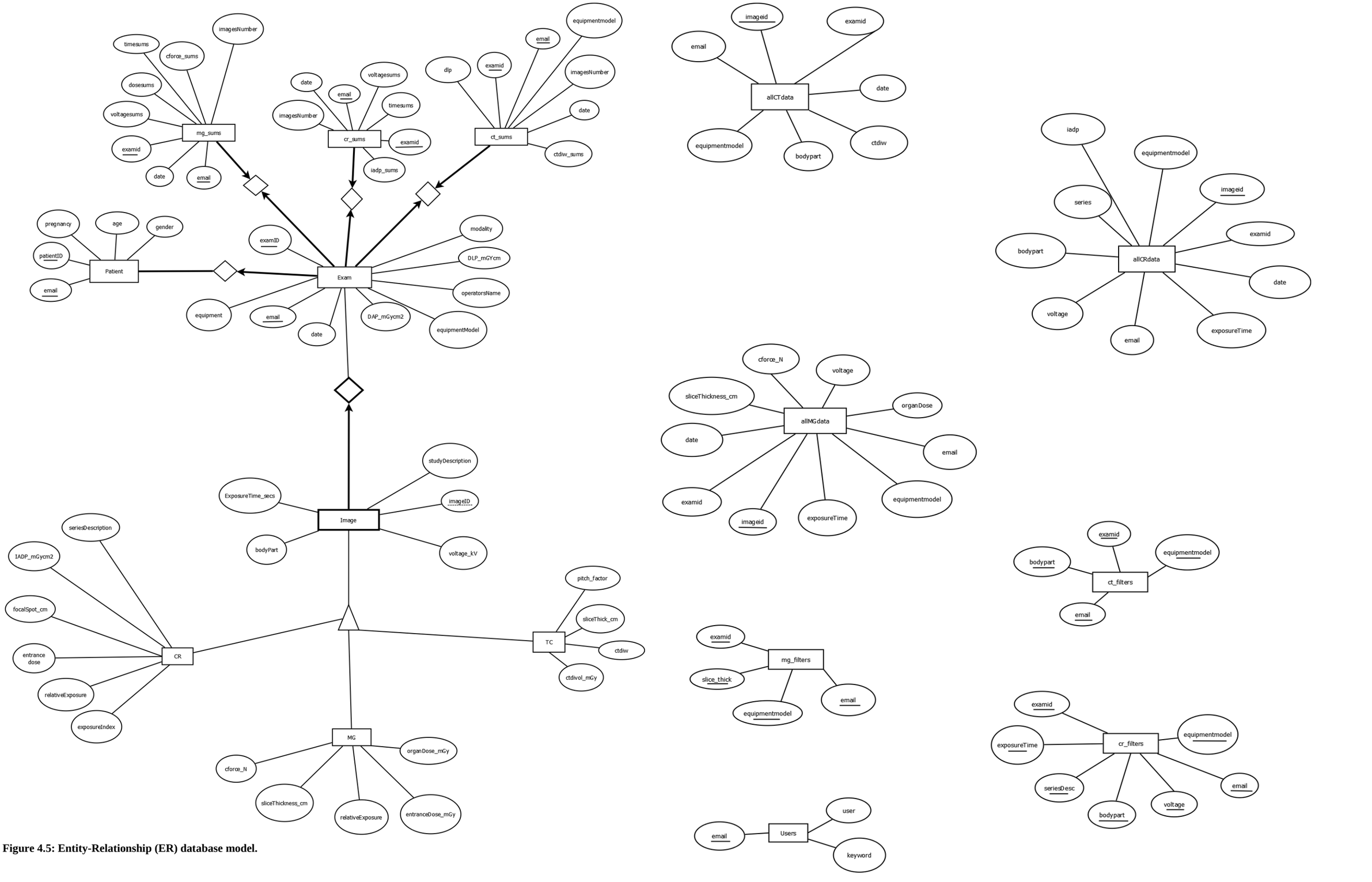

Figure 4.5: Entity-Relationship (ER) database model.

Typically, each exam has more than one image making it necessary to create an image entity:

- **Image entity:**
  - Metadata referring to the images of the examinations;
  - Weak entity of Exam entity;
  - PK – Image ID (auto increment INT) and examID;
  - FK – Exam ID (CHAR) and owner e-mail (CHAR) referencing Exam entity;
  - Other attributes:
    - studyDescription (CHAR);
    - bodyPart (CHAR);
    - voltage_kV (FLOAT);
    - exposureTime_secs (FLOAT).

Each image can belong to different modalities being separated in the respective tables:

- **CR entity:**
  - Stores metadata related to CR images exclusively;
  - Generalization of Image entity;
  - PK – image ID (INT) and exam ID (CHAR);
  - FK - image ID and exam ID referencing Image entity;
  - Other attributes:
    - seriesDescription (CHAR);
    - relativeExposure (FLOAT);
    - exposureIndex (FLOAT);
    - IADP_mGycm2 (FLOAT);
    - focalSpot_cm (FLOAT);
    - owner e-mail (CHAR).

- **CT entity:**
  - Organizes the metadata of CT images;
  - Generalization of Image entity;
  - PK – image ID (INT) and exam ID (CHAR);
  - FK - image ID and exam ID referencing Image entity;
  - Other attributes:
    - ctdivol_mGy (FLOAT);
    - ctdiw (FLOAT);
    - pitch_factor (FLOAT),
    - sliceThick_cm (FLOAT);
    - owner e-mail (CHAR).

- **MG entity:**
  - Metadata related to MG images;
  - Generalization of Image entity;
  - PK - image ID (INT) and exam ID (CHAR);
  - FK - image ID and exam ID referencing Image entity;
  - Other attributes:
    - organDose_mGy (FLOAT);
    - relativeExposure (FLOAT);

- entranceDose_mGy (FLOAT);
- sliceThickness_cm (FLOAT);
- cforce_N (FLOAT);
- owner e-mail (CHAR).

Later it will be explained in detail that the web interface has filters that allows the navigation and exploration of data between different layers. To construct that filters, it was necessary to query the database and these queries must be efficient what does not happen when it is required to join many tables with large amounts of data. To fix this issue were created three tables that group all the information required for the three modalities:

- **CT_filters entity:**
  - Stores the different unique combinations between the exam ID, body part examined, equipment model and owner e-mail of CT examinations;
  - PK:
    - exam ID (CHAR);
    - body part (CHAR);
    - equipment model (CHAR);
    - owner e-mail (CHAR);
- **CR_filters entity:**
  - Stores the different unique combinations between exam ID, body part examined, series description, voltage, exposure time, equipment model and owner e-mail of CR examinations;
  - PK:
    - exam ID (CHAR);
    - bodypart (CHAR);
    - seriesDesc (CHAR);
    - voltage (FLOAT);
    - exposureTime (FLOAT);
    - equipmentmodel (CHAR);
    - data owner e-mail (CHAR).

- **MG_filters entity:**
  - Stores the different unique combinations between exam ID, slice thickness, equipment model and owner e-mail of MG examinations;
  - PK:
    - exam ID (CHAR);
    - slice_thick (FLOAT);
    - equipmentmodel (CHAR);
    - data owner e-mail (CHAR);

To facilitate the statistical calculation such as the averages and the 90th Percentiles, it was initially planned to create three tables, one for each modality, that stores the sum of the radiation doses per exam ID, the number of images and the date of that exam. In the web interface when a region of the chart is zoomed, the statistics are recalculated only for the points in the selected area. However, the zoom is relative to the x (date) and y (radiation dose/exposure time/voltage/breast thickness) axes. The extraction of data between two selected dates is trivial because, independently of the number of images of the exam, they all have the same date. On the other hand, the extraction of data between two selected doses

is more robust due to the fact that only the sums are stored and not all the points individually. Despite these tables are not being used for the initial objective, they were not deleted and are described below:

- **CT_sums entity:**
  - Archives the $CTDI_w$ sums and the DLP per CT exam ID;
  - PK: exam ID (CHAR) and owner e-mail (CHAR) that references the Exam entity;
  - Other attributes:
    - date (DATE);
    - ctdiw_sums (FLOAT);
    - DLP (FLOAT);
    - imagesNumber (INT);
    - equipmentmodel (CHAR).

- **CR_sums entity:**
  - Stores IADP, exposure times and voltages sums per CR exam ID;
  - PK: exam ID (CHAR) and owner e-mail (CHAR) that references the Exam entity;
  - Other attributes:
    - date (DATE);
    - iadp_sums (FLOAT);
    - timesums (FLOAT);
    - voltagesums (FLOAT);
    - imagesNumber (INT).

- **MG_sums entity:**
  - Stores organ doses, exposure times, voltages and compression force sums per MG exam ID.
  - PK: exam ID (CHAR) and e-mail (CHAR) that references Exam entity;
  - Other attributes:
    - date (DATE);
    - dosesums (FLOAT);
    - timesums (FLOAT);
    - voltagesums (FLOAT);
    - cforcesums (FLOAT);
    - imagesNumber (INT).

CT data are in more quantity due to the enormous amount of images required to perform only one exam. To estimate the averages and percentiles is necessary the join of more than two tables which is not very efficient and becomes worse as filters are applied. To work around this situation, was created an entity named allCTdata, only for CT examinations, to store all the $CTDI_w$ values together with the manufacturer model used and the body part examined. MG and CR modalities don't have this problem for now due to the amount of data being substantially smaller but, to maintain the same structure it was created one table for each modality that combines all the required information:

- **allCTdata entity:**
  - Stores $CTDI_w$ values together with the body part examined and manufacturer model per examID;
  - PK: image ID (INT);

- Other attributes:
  - exam ID (CHAR);
  - date (DATE);
  - CTDIw (FLOAT);
  - bodypart (CHAR);
  - equipmentmodel (CHAR);
  - data owner e-mail (CHAR).

- **allCRdata entity:**
  - Stores all CR data together;
  - PK: image ID (INT);
  - Other attributes:
    - exam ID (CHAR);
    - date (DATE);
    - iadp (FLOAT);
    - exposureTime (FLOAT);
    - voltage (FLOAT);
    - bodypart (CHAR);
    - seriesDesc (CHAR);
    - equipmentmodel (CHAR);
    - owner e-mail (CHAR).

- **allMGdata entity:**
  - Stores all MG data together;
  - PK: image ID (INT);
  - Other attributes:
    - exam ID (CHAR);
    - date (DATE);
    - organDose (FLOAT);
    - sliceThickness_cm (FLOAT);
    - cforce_N (FLOAT);
    - voltage (FLOAT);
    - exposureTime (FLOAT);
    - equipmentmodel (CHAR);
    - owner e-mail (CHAR).

When new files are uploaded, the processed metadata is inserted in the main tables: patient, exam, image, CT, MG, CR and users. The remaining entities are populated automatically with the aid of triggers:

- **"after_Exam" Trigger:**
  - When a new exam is inserted in the exam entity, the "after_exam" trigger inserts a row on ct_sums, cr_sums and mg_sums depending on the modality (CT, CR and MG respectively) with the exam ID, date, equipment model and the e-mail.
  - The remaining fields are set to NULL that will change as the image entity is populated.

- **“after_ct” Trigger:**
  - After inserting a row in CT entity, ctdiw_sums and dlp attributes (in ct_sums entity) are updated and it is inserted a row in allCTdata and ct_filters.

- **“after_cr” Trigger:**
  - After inserting a row in CR entity, iadp_sums (in cr_sums entity) attribute is updated and it is inserted a row in allCRdata and cr_filters.

- **“after_image” Trigger:**
  - After inserting a row in image entity, voltagesums and timesums attributes are updated in cr_sums and mg_sums entities.

- **“after_mg” Trigger:**
  - After inserting a row in MG entity, dosesums and cforcesums (in mg_sums entity) attributes are updated and it is inserted a row in allMGdata and mg_filters.

- **“after_cr_sums” Trigger:**
  - The DAP value on exam entity is updated at the same time the images of that exam are being inserted.
  - Updates DAP value on exam table when an update is done on iadp_sums in cr_sums entity.

- **“after_ct_sums” Trigger:**
  - The DLP value on exam entity is updated at the same time the images of that exam are being inserted.
  - Updates DLP value on exam table when an update is done on DLP in ct_sums entity.

Furthermore, to maintain the database integrity it was taken measures for preventing SQL injection that will be explained later in the web interface subsection.

4.5 Web Services

Web services are an essential part of the exchange of data through electronic devices using machine readable file formats such as XML and JSON. In practice, web services transmit the data between the database and the front-end bidirectionally.

For this work, was implemented a PHP-based RESTful web service and the data-interchange format used was JSON. In the REST architectural style, data is considered a resource and is accessed using Uniform Resource Identifiers (URI’s), represented by links on the Web. Thus, it represents a client/server architecture and is designed to use specific protocols like Hypertext Transfer Protocol (HTTP). The primary or most-commonly-used HTTP methods are POST, GET, PUT and DELETE corresponding to create, read, update, and delete operations, respectively.

For now, the web service only permits GET requests (Table 4.3). POST requests are not executed directly on the web service but are achieved otherwise with the upload of data in the web interface.

DELETE and PUT requests are not suitable according to the purpose of the work where is not intended and allowed to change or delete data. In the cases when the user uploads incorrect data, the solution is to create a new user and upload in that section the correct data.

The PHP scripts with the code to generate the several JSON's are available online[9]. The main script uses the "*spliti*" and "*sizeof*" PHP functions to determine how much parameters (separated by slashes) the URI has. Depending on that number and on the given parameters for each field, a specific function is called to generate the JSON with the intended data.

All the JSON's contain objects whose x value always represents the date (in UNIX timestamp) of when the examination was performed. The y variable depends on the URI parameter assigned. It can be a radiation dose, an exposure time, voltage or a compression force values.

Generally, the calls to the respective functions are performed depending on five different URI sizes and a common attribute required for all the functions is the keyword to access private data ("public" for the collected data).

In the cases where the URI parameters are four, its format is similar to the first one in Table 4.3. These URIs return all the data corresponding to a particular modality and a selected parameter in JSON format and it is with it that the web interface will build the dashboard. When the modality is CR the following parameter can be IADP (to obtain the IADP values of all examinations), TIME (to obtain the distinct exposure times for each examination) or VOLTAGE (to obtain the distinct voltages for each examination) and the JSON has the format below:

```
[{"x":1345503600000,"y": IADP, exposure time or voltage
values,"bodyPart":"CHEST","seriesDescription":"Chest
lat","equipmentModel":"digital DIAGNOST"}]
```

Note: when the y value is an exposure time or a voltage, it is only retrieved the different voltages and exposures times per exam ID avoiding overrepresentation of the same value.

If the modality is CT, the $CTDI_w$ and DLP are the parameters available representing the average of the $CTDI_w$ values for each examination and the DLP of the total examination, respectively. The JSON format is represented below:

```
[{"x":1437001200000,"y": DLP or CTDIw
average,"bodyPart":"CHEST","equipmentModel":"GEMINI TF TOF 16"}]
```

Note: "bodyPart" represents the distinct concatenated body parts examined per examination.

For MG examinations, the important parameters to exchange between services are the organ dose for each examination, distinct exposure times and compression forces:

Example of the JSON format if the parameter is the organ dose:

```
[{"x":1426723200000,"y":
0.8928,"sliceThickness_cm":"5.3","equipmentModel":"Mammomat Inspiration"}]
```

[9] https://github.com/ritajflorencio/RMSCI/tree/master/RMSCI/tools

Example of the JSON format for compression forces and exposure times:

```
[{"x":1445209200000,"y":compression force or exposure time,"equipmentModel":"Mammomat Inspiration"}]
```

Note: For each examination are shown the distinct exposure times and compression forces.

If the number of path parameters is nine, the URI is equivalent to the second one in Table 4.3. These JSONs are responsible for the exchange of statistical numbers (averages and 90th Percentiles) calculated according to the selected range of x and y values. In this case, the statistics are made according to the first parameter assigned.

Towards ten path parameters, the suitable URI is the third one represented in Table 4.3. The statistics are performed according to one more parameter (par1) that can be a body part (in CR and CT examinations), a breast thickness (if Organ Dose chosen in MG examinations) or an equipment model (if voltage or compression force chosen in MG examinations).

In the cases where the path parameters are eleven, the applied URI is the fourth one in Table 4.3. Here we have a third parameter (par2) that enters in the statistical calculations: series description for CR examinations, equipment model for CT and MG Organ Doses.

Lastly, when the URI parameters are twelve, it means that a fourth and last parameter must be considered in the calculations. This type of URI (last one of Table 4.3) is only applied to CR examinations because it is the only modality with an additional layer of filters.

Table 4.3: Requests to the web service.
URLs that are responsible for the requests to the web service and the description of their parameters.

URL	Method	Function	Result
http://rmsci.fc.ul.pt/tools/webservice.php/key/modality/par ➢ key – keyword to access the data ("public" for the collected data); ➢ modality – CR, CT or MG; ➢ par (parameter): For CT – $CTDI_w$ or DLP; For MG – Organ Dose, TIME (exposure time) or COMPFORCE (compression force); For CR – DAP, TIME or VOLTAGE.	GET	Retrieve	Gets the metadata according to the modality and parameter chosen.
http://rmsci.fc.ul.pt/tools/webservice.php/key/modality/par/stats/xmin/xmax/ymin/ymax ➢ key – keyword to access the data ("public" for the collected data); ➢ modality – CR, CT or MG; ➢ par: For CT – $CTDI_w$ or DLP; For MG – Organ Dose, TIME or COMPFORCE; For CR – DAP, TIME or VOLTAGE. ➢ stats (statistics) – AVG (average) or PER (90^{th} Percentile); ➢ xmin and xmax – minimum and maximum dates selected; ➢ ymin and ymax – minimum and maximum y values selected.	GET	Retrieve	Gets the average or the 90^{th} percentile of a selected zoom according to the modality and parameter chosen.
http://rmsci.fc.ul.pt/tools/webservice.php/key/modality/par/par1/stats/xmin/xmax/ymin/ymax ➢ key – keyword to access the data ("public" for the collected data); ➢ modality – CR, CT or MG; ➢ par: For CT – $CTDI_w$ or DLP; For MG – Organ Dose, TIME or COMPFORCE; For CR – DAP, TIME or VOLTAGE.	GET	Retrieve	Gets the average or the 90^{th} percentile of a selected zoom according to the modality, par and par1 chosen.

URL	Method	Function	Result
➢ par1 (parameter 1): For CT – body part examined; For MG: If par is Organ Dose: breast thickness; If par is TIME or COMPFORCE – equipment model; For CR – body part examined; ➢ stats – AVG or PER; ➢ xmin and xmax – minimum and maximum dates selected; ➢ ymin and ymax – minimum and maximum y values selected.			
http://rmsci.fc.ul.pt/tools/webservice.php/key/modality/par/par1/par2/stats/xmin/xmax/ymin/ymax ➢ key – keyword to access the data ("public" for the collected data); ➢ modality – CR, CT or MG; ➢ par: For CT – CTD_w or DLP; For MG – Organ Dose; For CR – DAP, TIME or VOLTAGE. ➢ par1: For CT – body part examined; For MG – breast thickness; For CR – body part examined; ➢ par2 (parameter 2): For CT – equipment model; For MG – equipment model; For CR – series description; ➢ stats – AVG or PER; ➢ xmin and xmax – minimum and maximum dates selected; ➢ ymin and ymax – minimum and maximum y values selected.	GET	Retrieve	Gets the average or the 90th percentile of a selected zoom according to the modality, par, par1 and par2 chosen.

URL	Method	Function	Result
http://rmsci.fc.ul.pt/tools/webservice.php/key/modality/par/par1/par2/par3/stats/xmin/xmax/ymin/ymax ➢ key – keyword to access the data ("public" for the collected data); ➢ modality – CR; ➢ par : For CR – DAP, TIME or VOLTAGE. ➢ par1: For CR – body part examined; ➢ par 2: For CR – series description; ➢ par3 (parameter 3): For CR – equipment model; ➢ stats – AVG or PER; ➢ xmin and xmax – minimum and maximum dates selected; ➢ ymin and ymax – minimum and maximum y values selected.	GET	Retrieve	Gets the average or the 90th percentile of a selected zoom of CR according to par, par1, par2 and par 3 chosen.

For the first URI, the JSON obtained is no more than objects defined into classes that have a specific structure. These classes are also available in the GitHub repository[10].

[10] https://github.com/ritajflorencio/RMSCI/blob/master/RMSCI/tools/classes.php

4.6 Web Interface

A web interface is a graphical front-end accessible via a web browser. The Radiation Monitoring System in Clinical Imaging was tested on Google Chrome, Microsoft Edge, Mozilla Firefox and Safari. For the remaining browsers, the functioning is not fully assured.

The protocol used was HTTP which is not so safe as HTTPS (Hypertext Transfer Protocol Secure). HTTPS sends and receives data in encrypted form with aid of SSL (Secure Sockets Layer)/TLS (Transport Layer Security) protocols (digital certificates), not allowing the visualization of the content by third parties and ensuring confidentiality, integrity and authentication.

The designed web interface is divided in six menus: Home, About, Upload Data, Team, Contacts and Login/Forgot your key? and the most relevant are described below.

The code of the web interface is available online[11] and was organized in the following scripts:

1. **index.php**
   - HTML code for the static part of the homepage;
   - JavaScript functions to make the connection to the web service and obtain the collected data;
   - AJAX function to ping the web service every five seconds;
   - JavaScript functions to process the submit forms via AJAX;

2. **login.php**
   - HTML code for the static part of the user section;
   - JavaScript functions to do the connection to the web service and obtain the user data;
   - AJAX function to ping the web service every five seconds;
   - JavaScript functions to process the submit forms via AJAX;

3. **upload.php**
   - deals with all the restrictions needed to securely upload data to the database.

4. **upload.js**
   - transmits messages in the web interface according to the obtained results of upload.php.

5. **getPass.php**
   - leads with the keyword recovery.
6. **check.php**
   - responsible for checking if a keyword is valid.

7. **ajax-dd3ck.php**
   - all the dependencies between filters and selected options is processed with this script.

[11] https://github.com/ritajflorencio/RMSCI/tree/master/RMSCI

8. **modalities.php**
   - retrieves the modalities stored for a specific user section to field the first filter.

9. **download.php**
   - to download the python script required for uploading data.

10. **config.php**
    - makes the connection with the database.

Figure 4.6 represents all the interactions between these ten scripts.

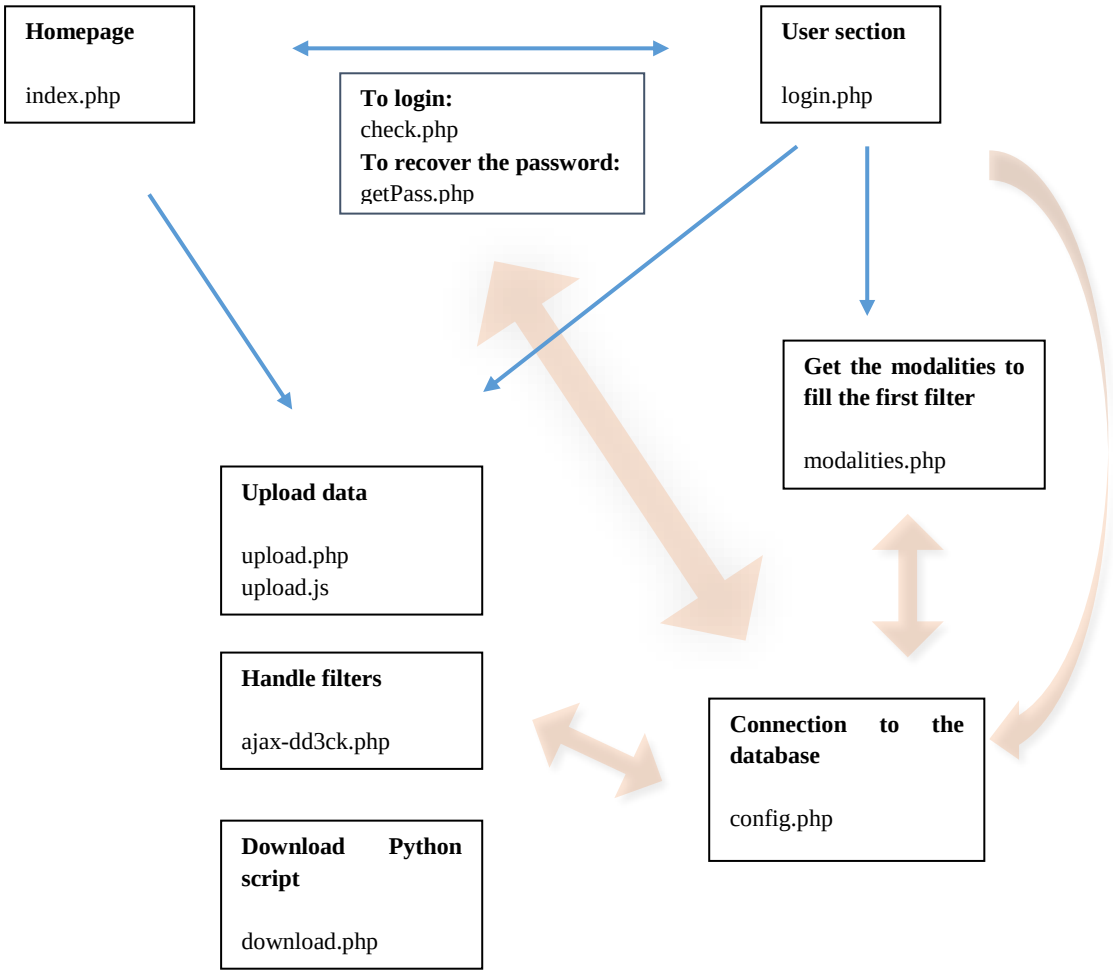

Figure 4.6: Interaction between the scripts responsible for the development of RMSCI.

4.6.1 Home

In the Home menu is presented a Highcharts dashboard with all the processed data prepared to be filtered between different layers. Below the chart, exists two checkboxes that controls the visibility of the statistics. The blue, yellow and green points correspond to CR, CT and MG examinations, respectively. Depending on the second filter applied, each point in the dashboard has a different meaning (Table 4.4). On the subsequent filters, the data will be restricted but the point's definition is maintained.

Figures 4.7 and 4.8 represents the main interface without any statistics or only with one of them, respectively.

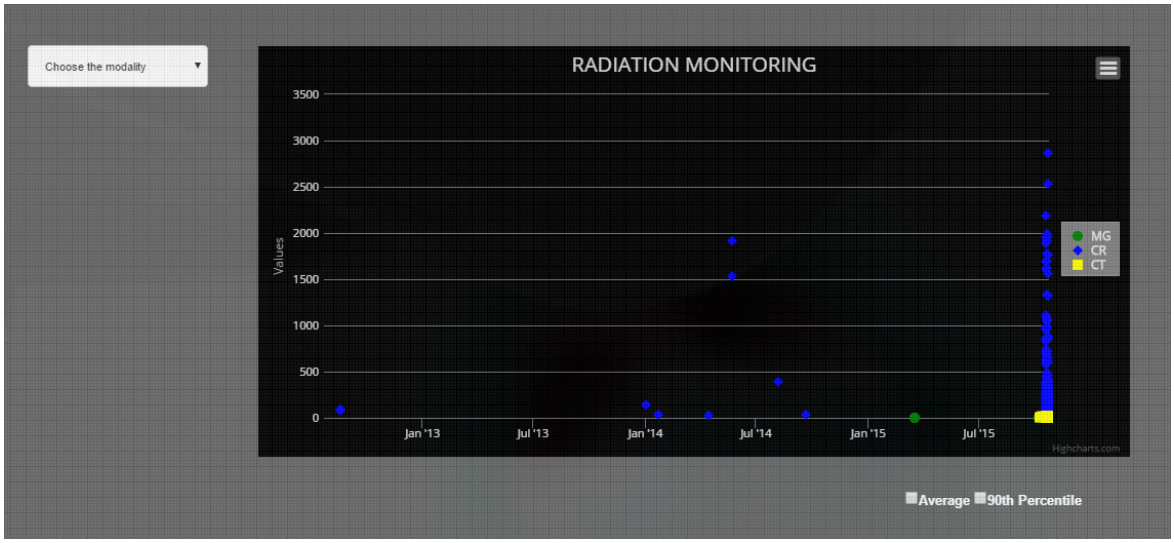

Figure 4.7: Main interface without any statistics.

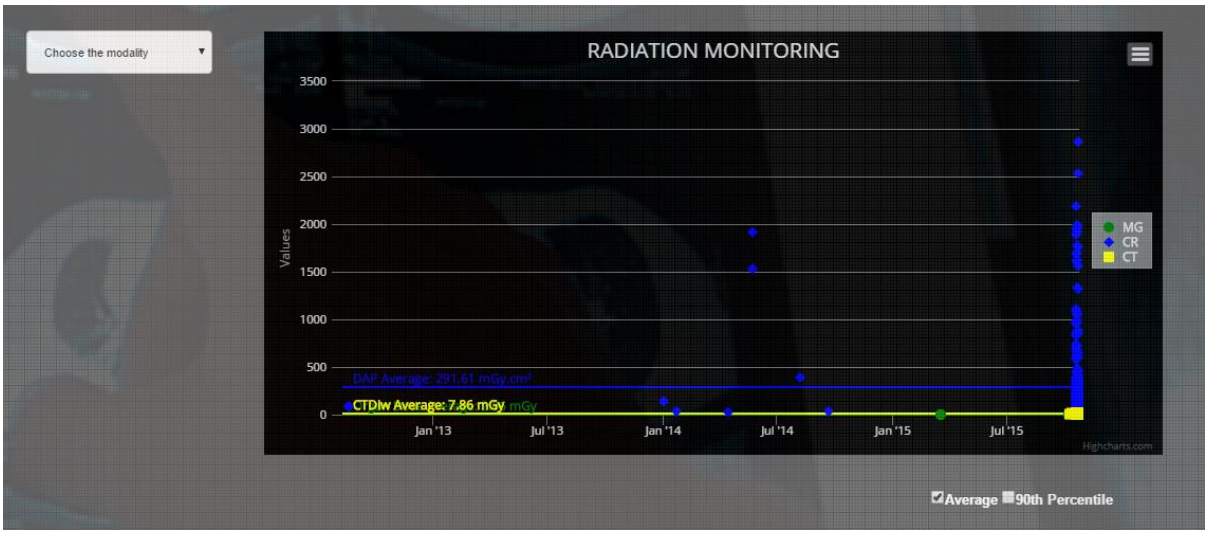

Figure 4.8: Main interface with only the averages.

Table 4.4: Meanings of the dashboard points depending on the parameter chosen.

Modality	Parameter	Point meaning	Observations
CR	Radiation Dose (DAP)	IADP value per CR image	
	Exposure Time	Distinct exposure time values per examination	Only the distinct values are represented but the statistics are made with all the data in the database
	Voltage	Distinct voltage values per examination	Only the distinct values are represented but the statistics are made with all the data in the database
CT	$CTDI_w$	$CTDI_w$ average per examination	Only the averages are represented but the statistics are made with all the data in the database
	DLP	DLP value per examination	
MG	Organ Dose	Organ Dose values per image	
	Exposure Time	Distinct exposure time values per examination	Only the distinct values are represented but the statistics are made with all the data in the database
	Compression Force	Distinct compression force values per examination	Only the distinct values are represented but the statistics are made with all the data in the database

Walking through CR examinations, it is observed that many filters are available. When CR is selected, a new box emerges with various parameters to be analyzed (DAP, Exposure Time, Voltage) as represented in Figure 4.9. Choosing the radiation dose, all the DAP values for each examination shows up with the respective statistics. Additionally, a second box appears regarding the body part. Selecting the body part, it will only be represented the DAP values of the examinations performed to the selected body part. The view position options can posteriorly be chosen to obtain the European Guidelines applied for each case. For example, if the body part chosen was the abdomen, and the view position PA, it means that the visible points correspond to DAP values of abdomen PA examinations. In this case,

the European guidelines recommend to maintain the DAP between 2000 and 8000 mGy.cm^2 as illustrated in Figure 4.10.

The equipment model is the last filter available that permits the differentiation of the scanners where the CR examinations were performed.

The same logic is applied to the other two modalities. The unique differences that can be distinguished are the number of filters available and at what level the European Guidelines are represented. For CT examinations, the guidelines are represented when a body part is selected. For MG examinations, when the organ dose is the chosen parameter, the reference levels emerge as soon as a breast thickness is selected. In the cases where the exposure time or the compression force are selected, the European Guideline appears together with all the points due to the absence of additional dependent factors.

Lastly and like explained above, for CR examinations, the guidelines depend on the view position of the procedure.

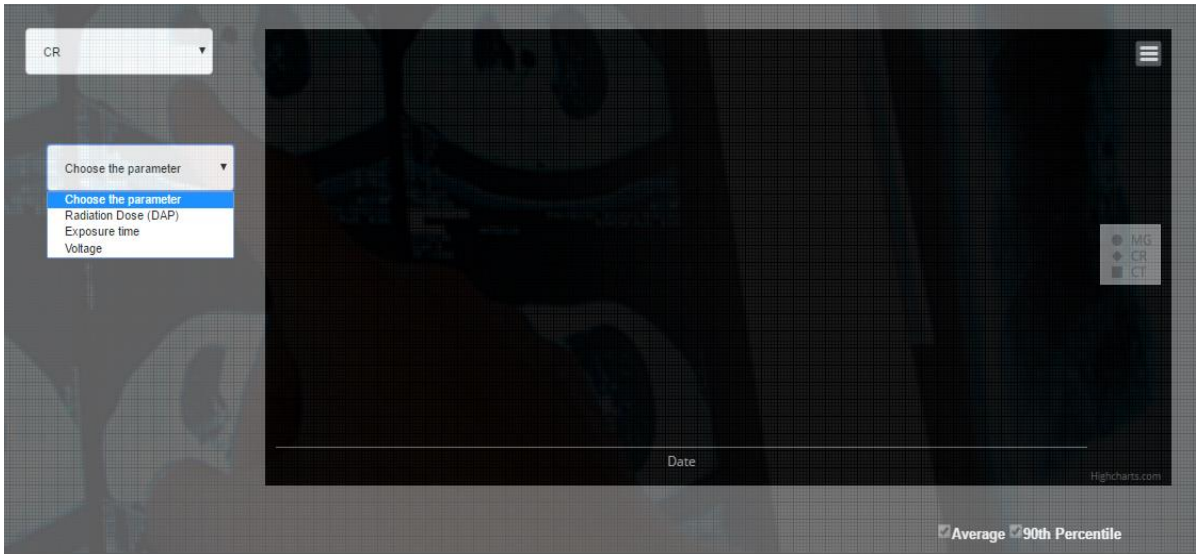

Figure 4.9: CR parameter options.

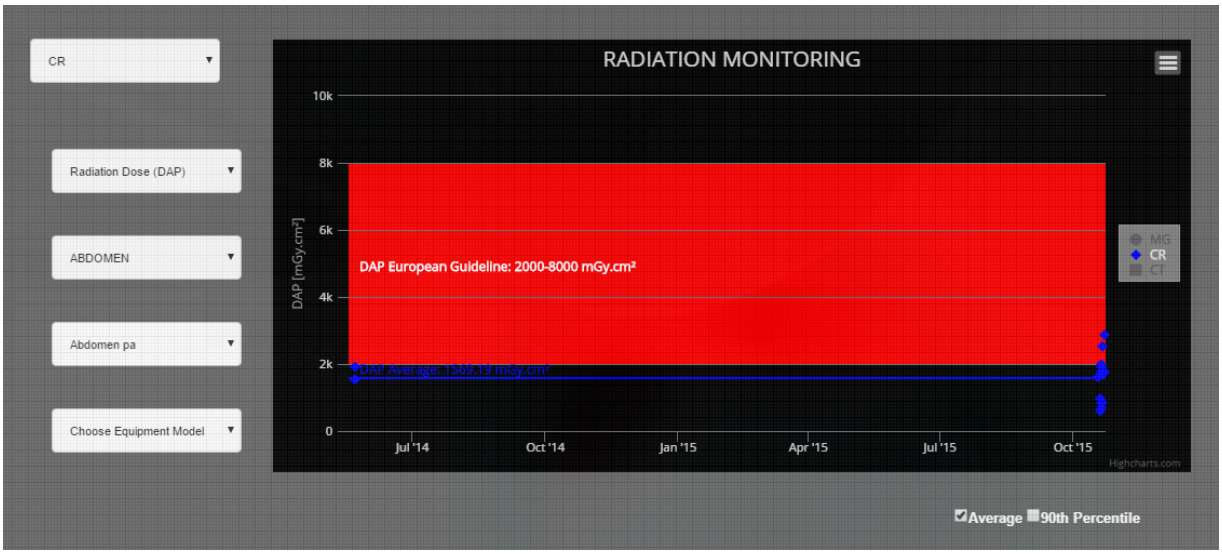

Figure 4.10: European Guideline for Abdomen pa in CR examinations.

To represent all the data in a chart was required a connection between the web service and the front-end. This connection was achieved with a specific JavaScript function (jQuery Library) named jQuery.ajax() that gets the data through a given Uniform Resource Locator (URL). Then, constructs the JSON's depending on the filters applied and posteriorly presents the objects in form of points in the Highcharts dashboard. Another JavaScript function pings the web service and displays continuously new data that have been uploaded without needing to manually refresh the webpage. Instead of loading constantly all the data every time a ping is performed, the function walks through the JSON and only loads it if a new change is detected.

Apart from visualizing the accessible data, the upload of private data will add value to the system allowing a specific user to analyze your data (in a section only accessible by a keyword) regardless the one available on the homepage. This feature also allows a direct and better interaction between the user and the system. Thus, the same Home menu allows the uploading only of SQL parsed files (the upload is faster due to the data being inserted directly in the database without the need for any type of connection to a server by the user) in the form represented in Figure 4.11.

This form has some particularities that must be explained in detail:

1. **The files accepted are only files with extension .sql:**
   - If the user uploads other type of files, the system returns an error (Figure 4.12).

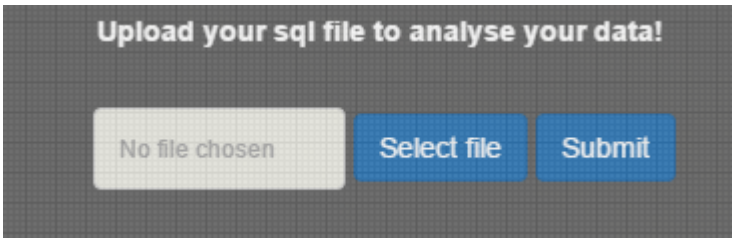

Figure 4.11: Tool to upload data.

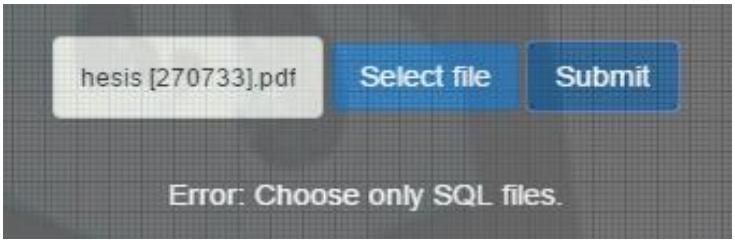

Figure 4.12: Error returned if the uploaded file is not a SQL file.

2. **SQL Injection prevented:**
   - If the file contains DROP, DELETE, UPDATE or CREATE statements, the system returns an error (Figure 4.13).

Figure 4.13: Example of a SQL injection prevention.

3. **In the homepage, it is not permitted to upload new data to a user section with an already registered e-mail;**
   - This task must be done in the user section (Figure 4.14).

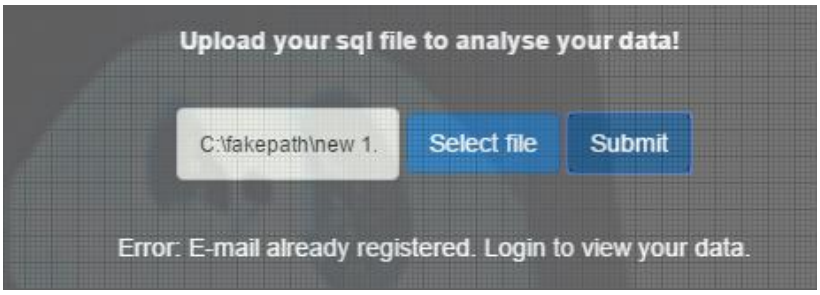

Figure 4.14: Upload error.

When none of these conditions is verified, the system returns a random keyword to access the uploaded data (Figure 4.15). The submission is done via ajax directly in the web browser using PHP and JQuery.

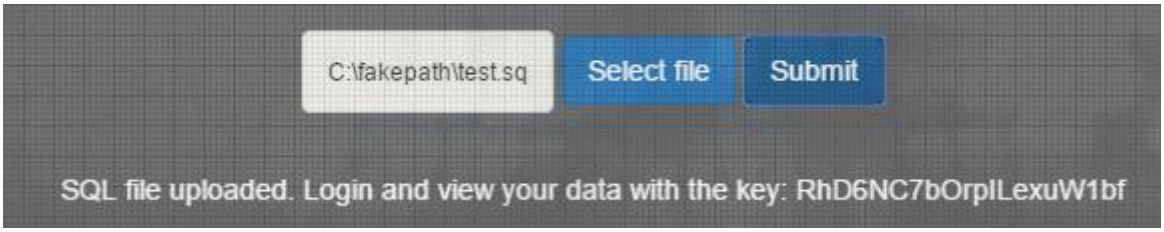

Figure 4.15: Example of successful upload.

4.6.2 Upload data

"Upload Data" section is responsible for teaching step-by-step, how to upload data directly in the web interface using the form represented in Figure 4.11.

To do it is necessary:

1. Download Python if it is not installed;
2. Download the Python script available in my site;
    - The script code is provided online[12] for consultation and has a structure similar to the one used to process the collected data (described in subsection 4.3);
    - The main difference is related to the fact that, in this case, the statements are written in a file and not immediately sent to the database.
3. Run the script pressing F5 and follow the instructions (Figure 4.16);
4. Upload the SQL file generated by the script (Figure 4.17).

For more detailed information, it is available a video[13] that explains all the procedures to adopt.

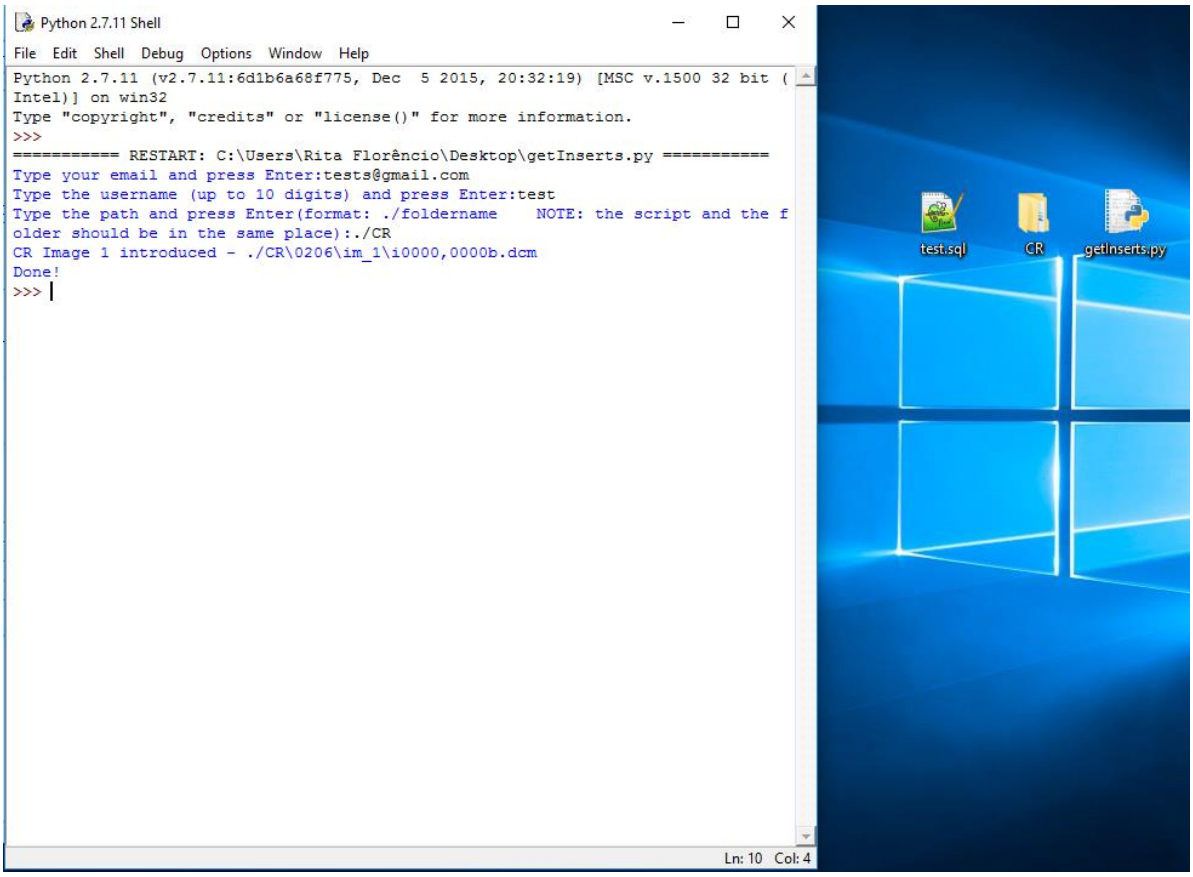

Figure 4.16: Interaction with the program to obtain the SQL file parsed.

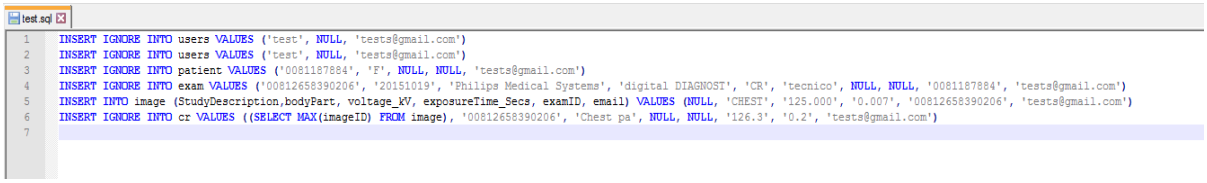

Figure 4.17: Example of the content of a SQL file ready to be uploaded.

[12] https://github.com/ritajflorencio/RMSCI/blob/master/RMSCI/getInserts.py
[13] https://www.youtube.com/watch?time_continue=132&v=BSYxV1dCiko

4.6.3 Login/Forgot your key?

There are two ways to login in a user section:

- type the keyword returned when the data was uploaded (Figure 4.18).
- Access through the URL of the user section (e.g. http://rmsci.fc.ul.pt/login.php?key=nkbPRI5UTG47A14lmJjc)

When the typed key is not registered in the database, the form informs to type a valid key (Figure 4.19).

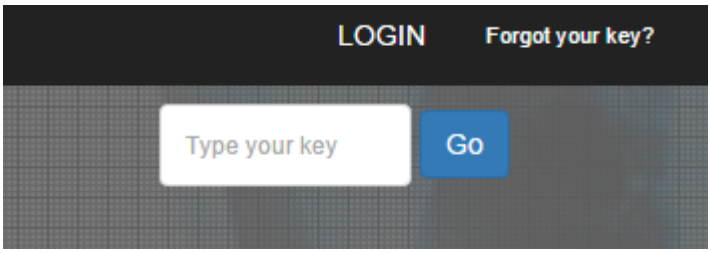

Figure 4.18: Form for login.

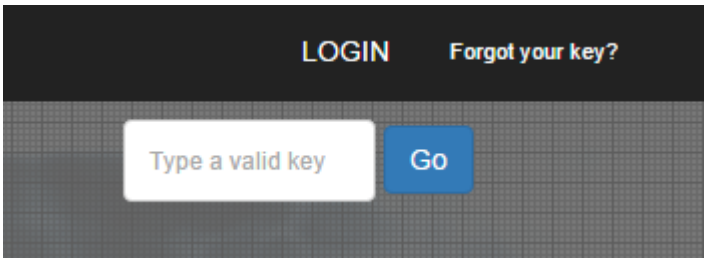

Figure 4.19: Alert to type a valid key.

In a successful authentication, the name of the user logged is displayed on the top right corner as well as the data uploaded with the respective statistics (Figure 4.20). The submission form is always available if the user wants to upload more data for that section. To avoid security issues, there are some security measures explained below:

1. **In a user section, it is not possible to upload data with a different e-mail from the one registered with the current username;**
   - First time e-mails are uploaded in the homepage.
2. **Data duplicates are not supported;**
   - Even when there is new data mixed with duplicate ones, the whole file is not inserted in the database;
   - Introduce bias in the statistics calculations.
3. **The username must be exactly the same as the first submission;**
4. **SQL Injection prevention.**

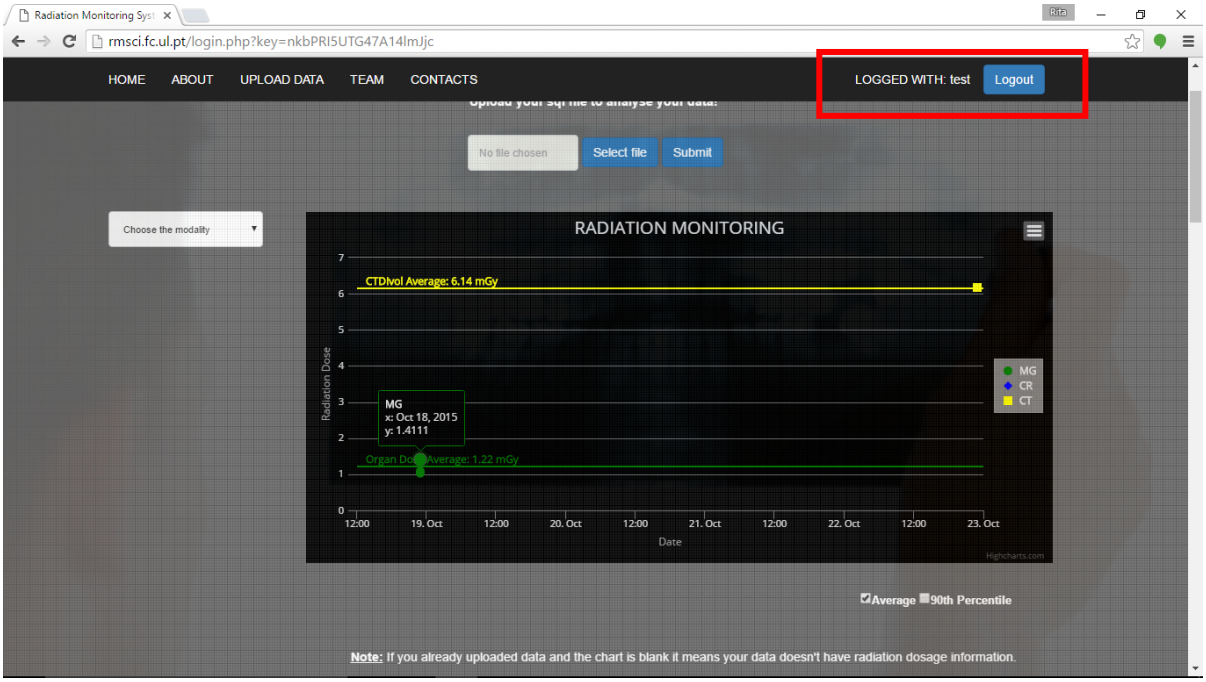

Figure 4.20: Example of a user section.

It may happen that the uploaded data does not have the variables needed to draw the chart. In these cases, the chart becomes blank until new data is inserted with the required information.

The keyword must be stored by the user for future accesses but in forgetfulness cases, is available a form to recover the keyword associated to a specific e-mail (Figure 4.21).

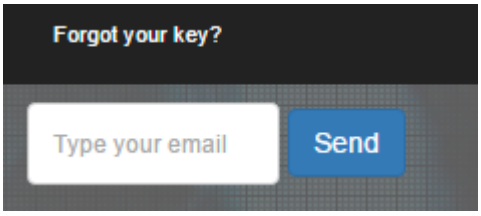

Figure 4.21: Form to recover the keyword.

In case of success, a message is returned as the one represented in Figure 4.22 and the e-mail received has the structure presented in Figure 4.23.

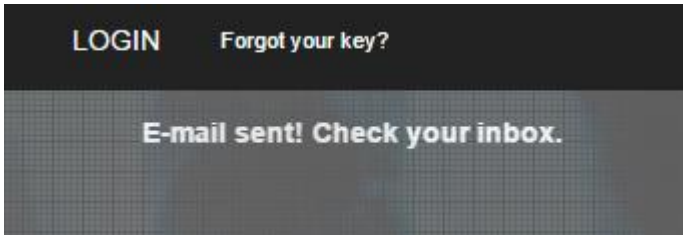

Figure 4.22: Successful keyword recovery.

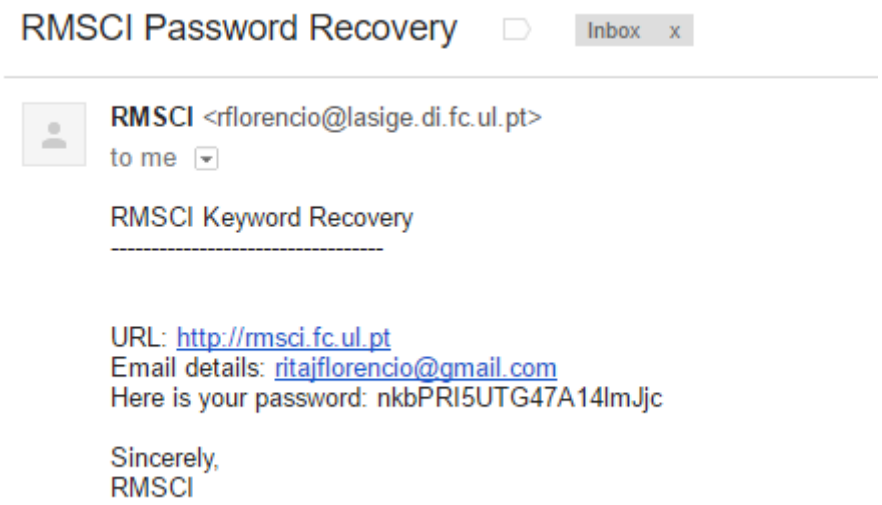

Figure 4.23: E-mail sent with the keyword to access the user section.

If the typed e-mail is valid but for some reason the message was not sent, an error message is returned (Figure 4.24).

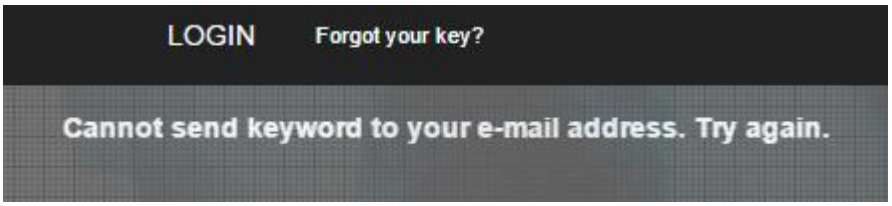

Figure 4.24: Error in sending the e-mail for password recovery.

Chapter 5

Results and Discussion

Before analyzing the results, it is important to underline that the radiation dose European Guidelines used in this project were calculated according to a standard-sized adult patient (70 kg bodyweight or 5 cm compressed breast thickness). With this in mind, is expected some radiation doses to exceed or to be substantially below these guidelines due to the different body compositions. For CR and CT examinations, the collected data do not provide the patient weight being not possible to estimate a dose reference for each patient. On the other hand, in MG examinations, the DICOM files provide the breast thickness which permitted the estimation of the DRL by linear interpolation.

In addition to the radiation dose, other image parameters were also monitored such as the voltage (for CR), exposure time (for CR and MG) and compression force (for MG). Knowing that the applied voltage depends directly on the dose administered (see Chapter 2), it can be concluded that even the voltage must have a specific DRL for each body composition.

The exposure time reference level provided by the European guidelines was also measured in standard conditions. Because it is not mentioned how these values vary in MG examinations and what are their dependencies, it was applied the standard guideline for all examinations.

According to (de Groot, Branderhorst, Broeders, den Heeten, & Grimbergen, 2012), a fixed target compression (180N) is applied consistently in practice without a different force in MLO and CC views and the radiographers are instructed to stop if the patient verbalizes severe pain. In the European protocol for the quality control of the physical and technical aspects of mammography screening, is given a range of 130-200N for the compression force maybe to cover any type of breast without compromising image quality and hurting the patient.

Beyond the guidelines, a statistical analysis is also relevant to study tendencies. The average is one of the parameters available as well as the 90th Percentile. The average shows the central tendency of a certain variable and the 90th Percentile represents the value for which 90% of the data points are smaller. It's a good variable to have an idea of the most frequent values.

In this chapter, it will only be discussed the cases where the values exceed the DRLs due to its high importance. The remaining results are available for consultation in Appendix F.

When a modality is selected as well as the parameter, the dashboard displays the average and the 90th Percentile of those values. These statistics do not have any representative meaning only a general idea of a trend (Figure 5.1).

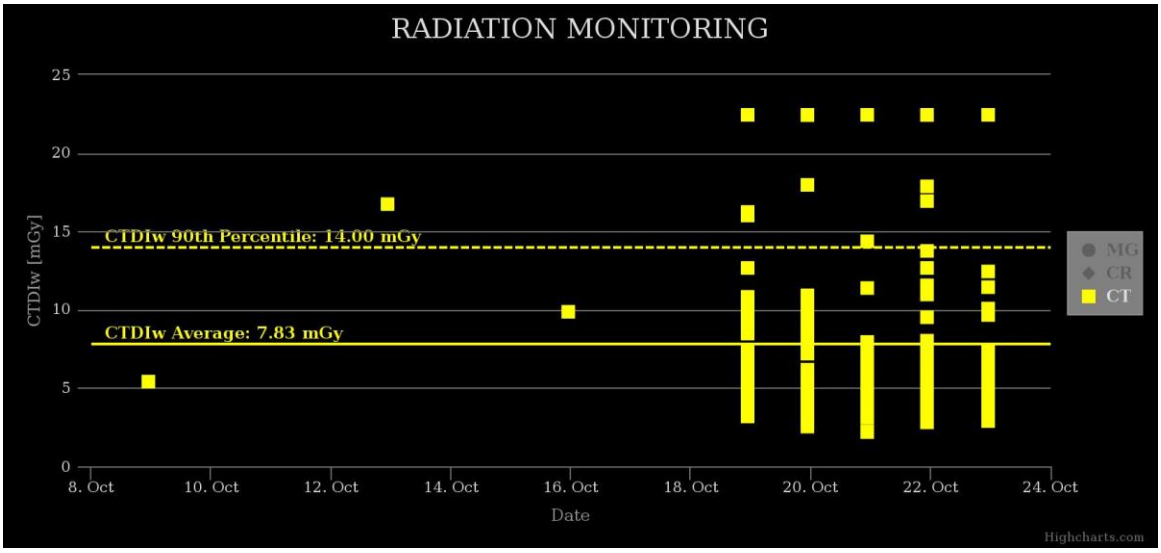

Figure 5.1: $CTDI_w$ general statistics.

Starting with the CT results, and particularizing for body parts, none of the $CTDI_w$ doses are above the European Guidelines (F.1.1). On the other hand, the obtained DLP values were worrisome. The general statistics reached were 1293.35 mGy.cm for the average and 3123.45 mGy.cm for the 90th Percentile (Figure 5.2). Comparing the mean value with the mean DLP values obtained in a study of eight hospitals in different countries (Table 5.1), it can be concluded that this result is substantially higher. All the examinations performed to a specific body part have the DLP values above the European Guidelines as well as the 90th Percentile being so a cause of concern (Figure 5.3 and Figure 5.4), except for the shoulder exams that do not have a guideline specified yet. Figure 5.5 indicates the percentage of CT specific body part examinations that are above or below the European Guidelines. What is immediately observed is that only CT chest examinations have more exams with DLP below the reference levels and

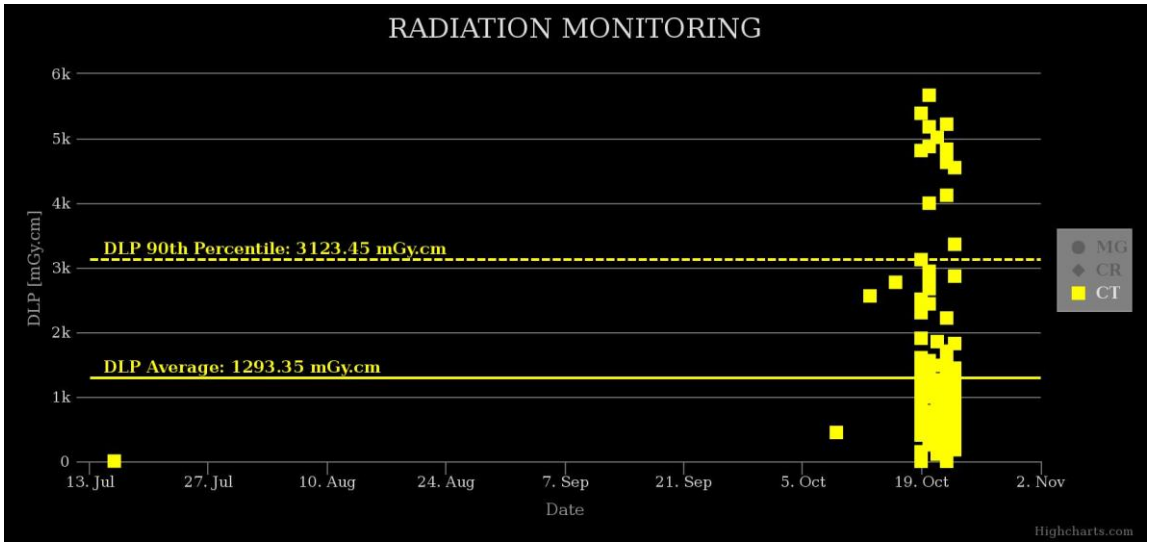

Figure 5.2: DLP general statistics.

the pelvis examinations are equilibrated. Head exams have the highest percentage of DLP values not according to the guidelines and chest examinations the smallest percentage.

Table 5.1: $CTDI_w$ (mGy) and DLP (mGy.cm) averages per hospital.
Retrieved from: Assessment and evaluation of patient doses in adult common CT examinations towards establishing national diagnostic reference levels. 245-252. (of Sadri, Khosravi, & Setayeshi, 2013)

Dose quantities	CT Examination	Average $CTDI_w$(mGy) and DLP(mGy.cm) values per hospital								
		E Hospital (GE)	A Hospital (Hitachi)	B Hospital	C Hospital	G CT Center	A Hospital (Siemens)	F CT Center	D Hospital	EC Guide-lines [9,10]
$CTDI_w$	Base	116.2	80.4	15.4	59.1	78.7	-	52	101	60
	Cerebrum	23.2	32.1	15.4	38.2	34.4	-	23	42	60
	Sinus	27.9	24.1	30.8	69.2	46.7	-	13	39	35
	Chest	12.5	-	10.7	9.3	11.2	10.67	7.3	7.2	30
	Abdomen-pelvis	12.5	-	10.7	13.2	21.5	15.09	10.6	6.99	35
DLP	Head	488	530	169.2	552	572	-	400	792	1050
	Sinus	213	289.3	230.8	449.8	935.1	-	105	371	360
	Chest	186.8	-	155.1	250.3	244.9	313	171	253	650
	Abdomen-pelvis	315.3	-	244.5	509.9	774.5	660	494	375	1350

The obtained DLP averages for abdomen, neck, spine, chest, head, pelvis and shoulder were 1091.39, 1184.84, 1623.95, 416.56, 4109.51, 886.99 and 409.41 mGy.cm, respectively. The corresponding 90th Percentile values are: 1905.74, 1569.69, 3123.45, 695.11, 5390.42, 1354.02 and 409.41 mGy.cm.

Chest CT examinations are the only ones whose DLP values are not so disparate comparing with the European guideline and with the averages obtained in the study referenced above (Table 5.1). The examinations to the remaining body parts reveal that there is a wide variation of values far above the guidelines. These variations can be mainly due to different applied exposures parameters (voltage, tube current and exposure time) consequence of the different physiognomies and body compositions. Other explanations such as incorrect exam performance and incorrect adjust of parameters can be also attributed. Also in oncological hospitals, the examinations have a longer duration so that is possible the search of metastasis.

Specifically, in head CT examinations, there are two manufacturer models in use, SOMATOM Scope and SOMATOM Definition AS, and only one examination was performed in the last referred equipment with a DLP value above the guideline which is not sufficient to differentiate their procedure protocols and radiation dose optimization.

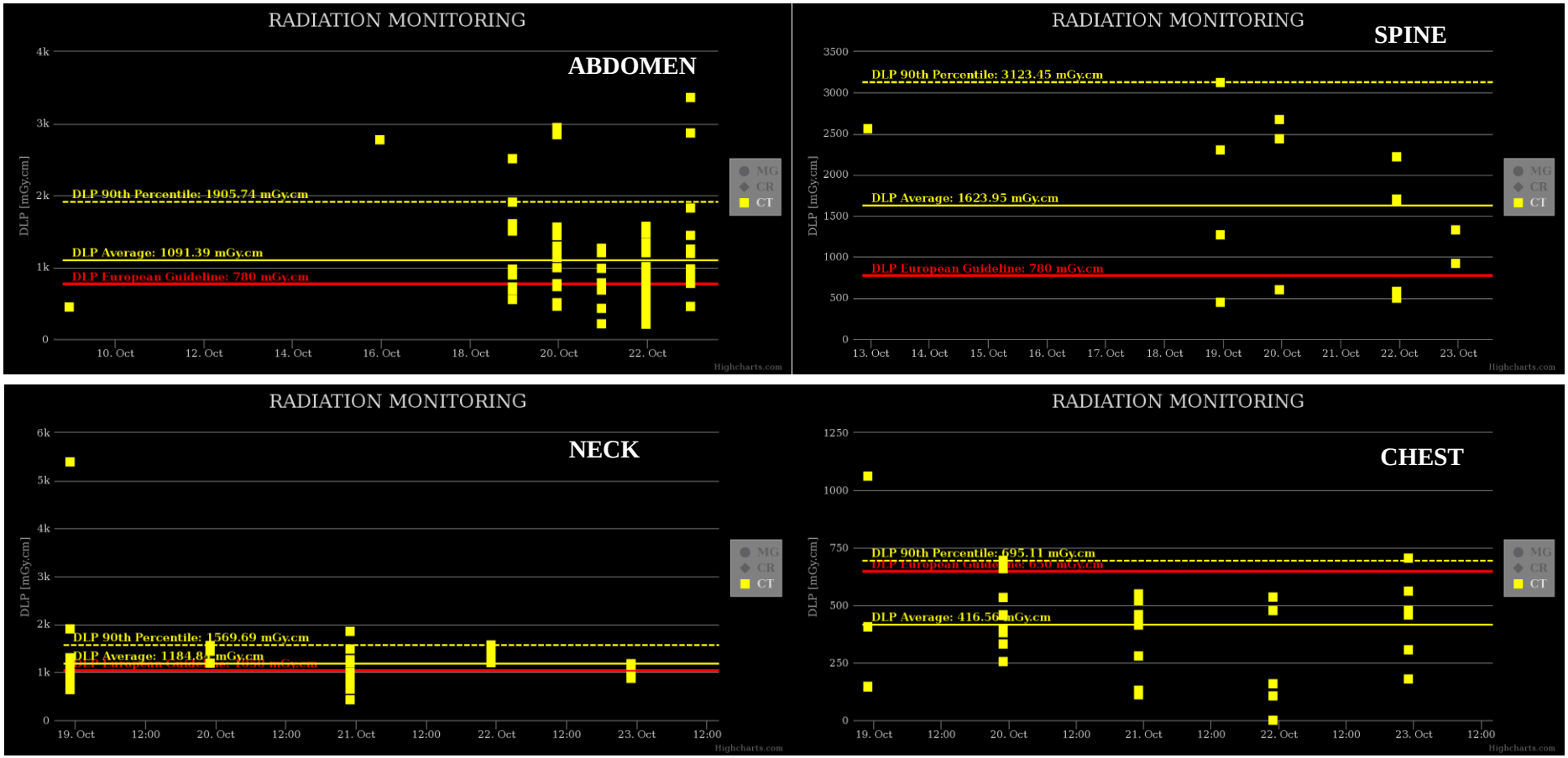

Figure 5.3: DLP values for each body part and with the respective guidelines and statistics.

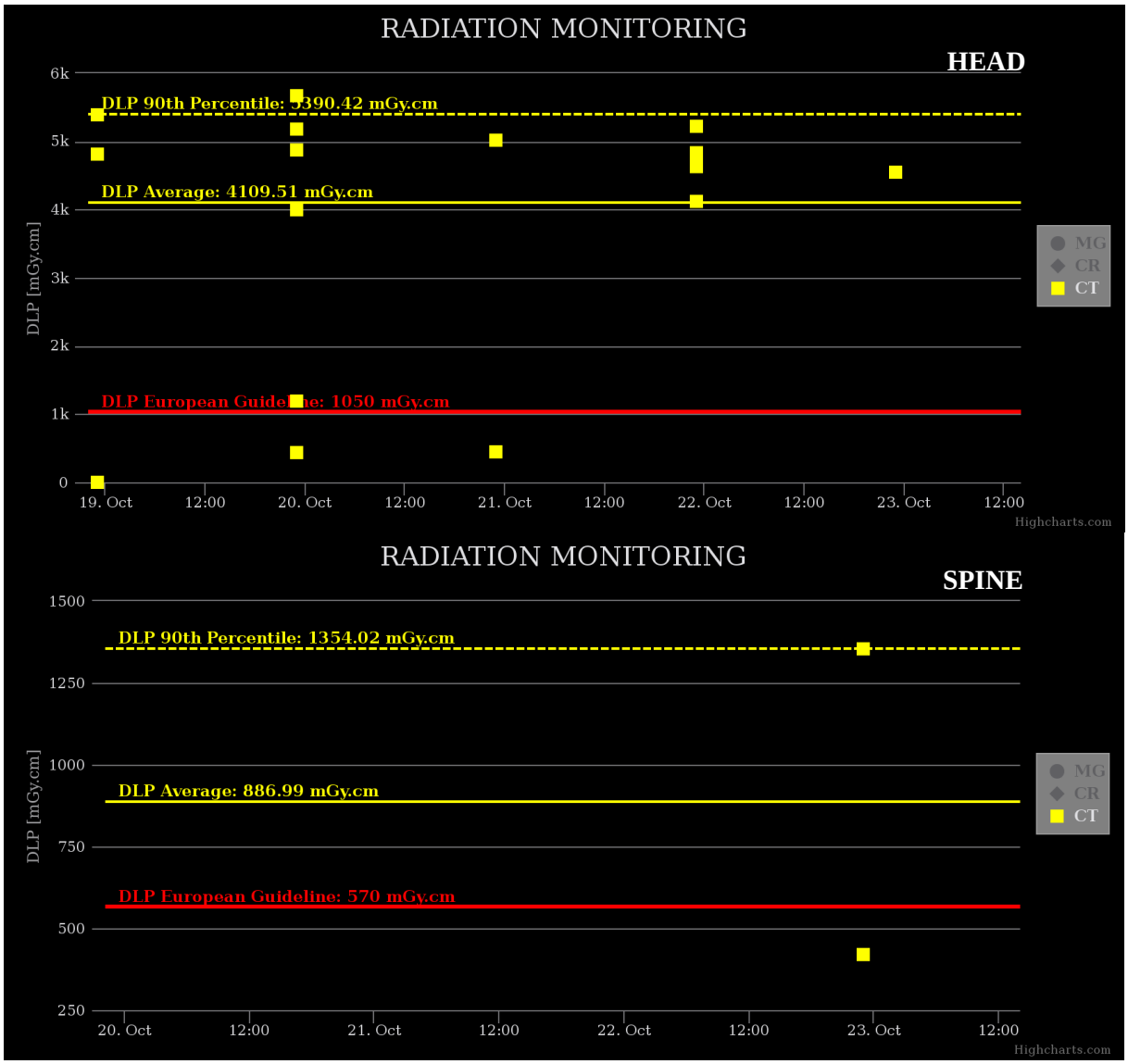

Figure 5.4: DLP values for each body part and with the respective guidelines and statistics (cont.).

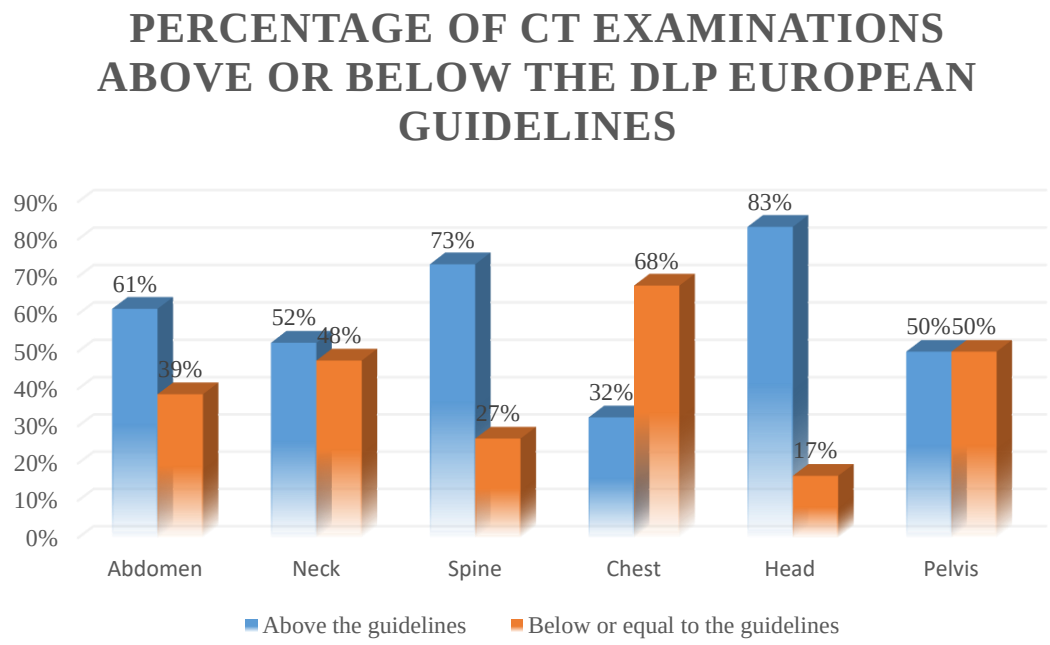

Figure 5.5: Percentage of CT examinations above or below the DLP European Guidelines.

Regarding CR examinations, the variables tracked were DAP, voltage and exposure time. Analyzing firstly the DAP values, it is observed that all of them are within the guideline range or below it (F.2.1). The equipment model used in CR examinations was only one (digital DIAGNOST) which also disallows the comparison of procedures between scanners.

Relatively to the CR exposure time values, all the examinations types represented in F.2.2 are in accordance with the reference levels with only one exception: chest PA exams (Figure 5.6). The 90th Percentile acquired for this specific exam was the same value of the European guideline (0.02 secs) which means that exactly 10% of the chest PA exposure times are above the established threshold. The exposure time have influence in the dose absorbed in the way that the higher the exposure time, the higher the time the patient is being exposed and consequently the higher the dose received. However,

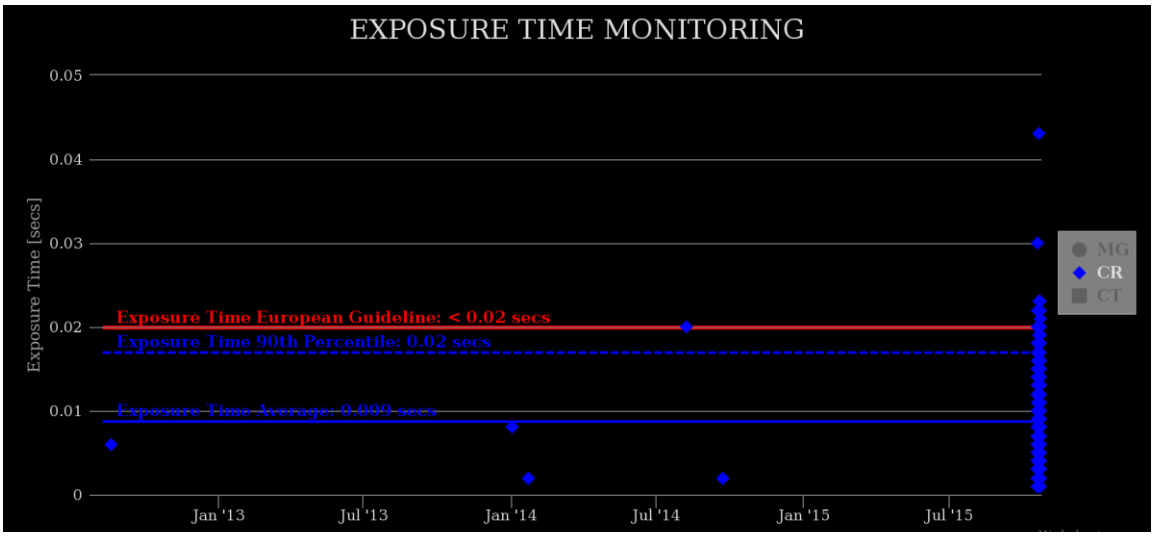

Figure 5.6: Chest PA exposure time values and respective guideline.

the exposure time is generally always kept as short as possible to minimize the motion blur resulting from patient movement.

Relatively to the voltage, the majority of the examinations in Table 2.1 follow the guidelines applied with the exception of one lumbar spine LAT examination which the value applied was 96 kV (Figure 5.7) and all the chest LAT examinations with 133 kV (Figure 5.8). Comparing with the guidelines (80-95 kV and 125kV, respectively) it can be concluded that de difference is not so relevant or harmful. The remaining results are presented in F.2.3.

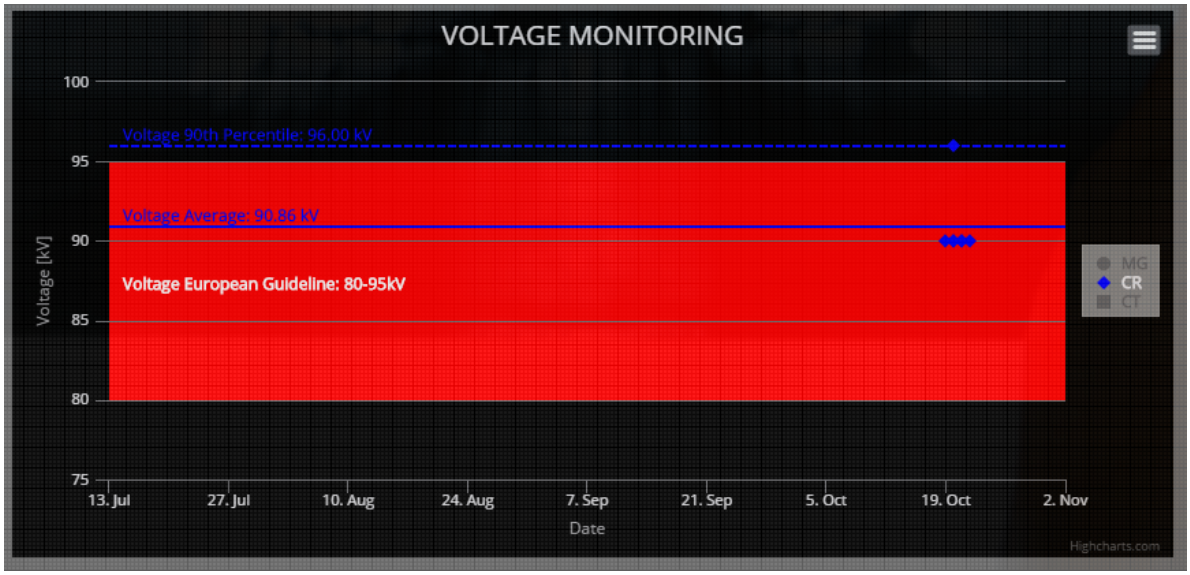

Figure 5.7: CR Lumbar Spine LAT with one voltage value above the guideline.

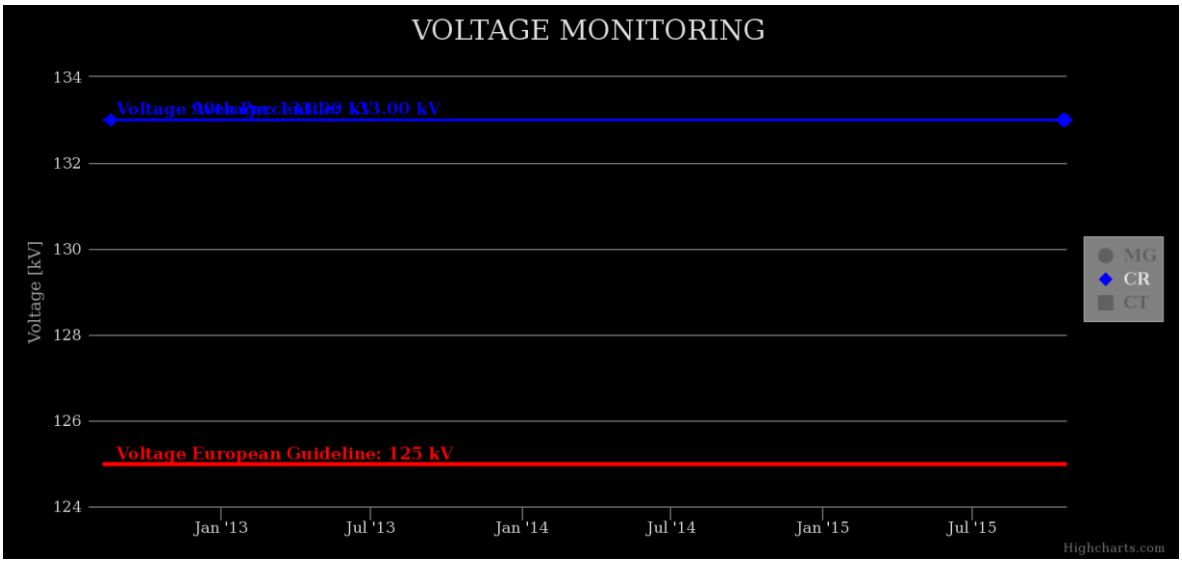

Figure 5.8: Chest LAT with all voltage values above the guideline.

Finalizing with the analysis of the MG examinations and focusing on the organ dose values, it must be mentioned that the only trustworthy guidelines are the ones referenced in Table 2.4 . The breast thicknesses analyzed covers a range between 0.5 and 11.6 cm, and the major examinations were performed to breasts between 5 and 7 cm of thickness. The organ dose values that exceed the thresholds are related to the following breast thicknesses: 0.5, 1.9, 2.5, 3, 3.1, 3.2, 3.4, 4, 4.5, 4.6, 4.7, 4.9, 5.5, 5.7, 5.9 cm. Figures 5.9 and 5.10 presents two examples of this maladjustment (for 3.2 and 4.5 breast thicknesses). In both cases, was found that only one value exceeds the guideline which is not very significant. The remaining thicknesses represented in Table 2.4 which are below the threshold are provided in F.3.1.

The equipment models used were Mammommat Inspiration and DSM and only two examinations were performed in DSM which once again does not permit a useful and meaningful comparison of the organ doses administered by the two scanners.

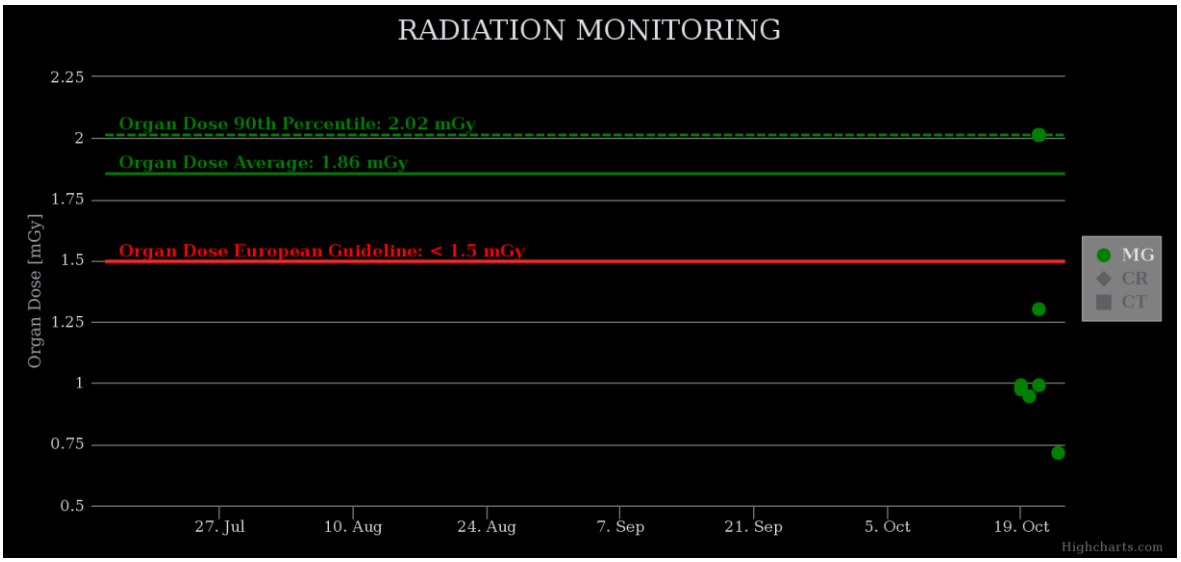

Figure 5.9: Organ Dose DRL for a 3.2 cm of breast thickness.

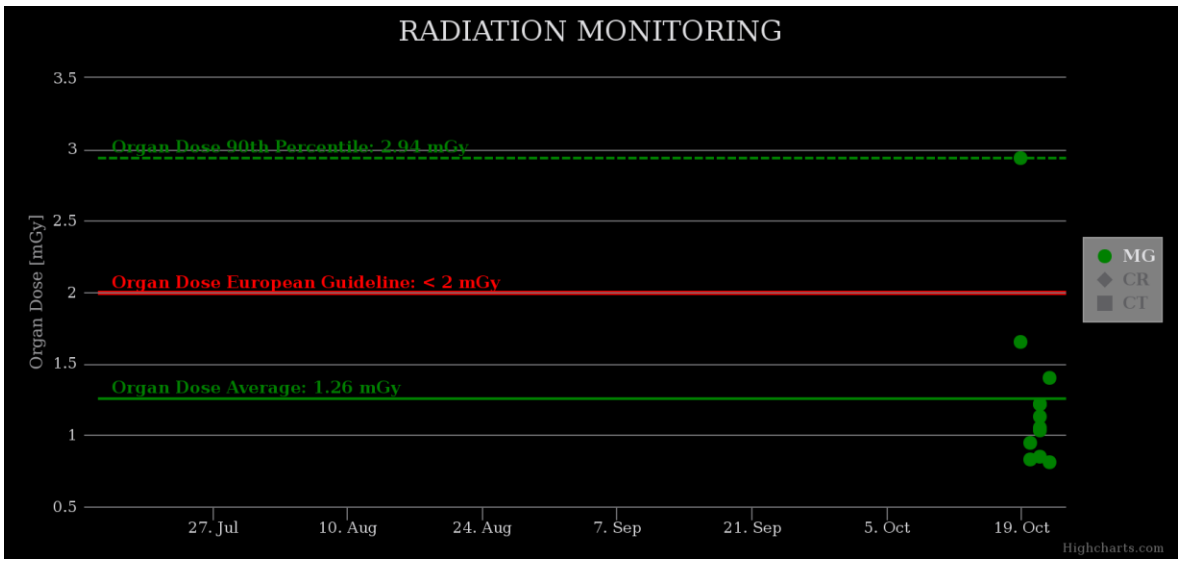

Figure 5.10: Organ Dose DRL for a 4.5 cm of breast thickness.

The exposure time guideline established was above 2 seconds, which was not followed for 6% of the examinations as observed in Figure 5.11 and Figure 5.12.

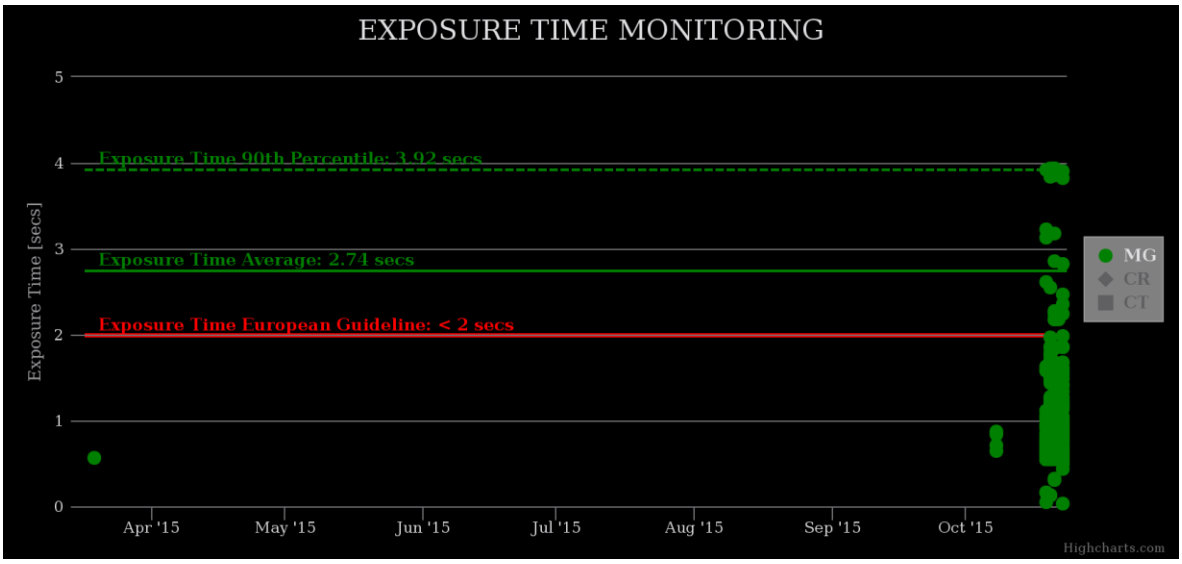

Figure 5.11: MG Exposure time values and respective guideline.

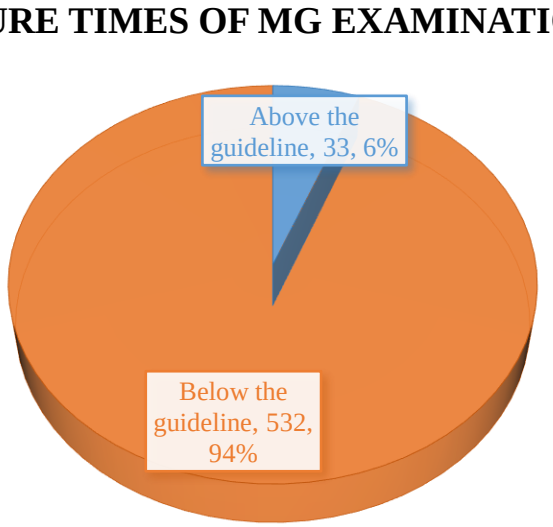

Figure 5.12: Comparison of the MG exposure times to the European Guidelines.

These outliers represent a subject for study due to the high values. The higher the tube current, the lower the exposure time. Therefore, to minimize unsharpness, the maximum tube current should be selected whenever possible.

Relatively to the compression forces values, it is observed that they are situated in the guideline range or below it (F.3.2). There are two zero values represented that must be an error made by the equipment or the operator due to the impossibility to perform a mammography with quality without compressing the breast. The 90th Percentile value tells that the majority of the examinations have a compression force

value below 101.70 N. This reflects on low compression forces that, depending on the breast composition, may lead to a poor or great image quality.

Table 5.2 summarizes all the results of all the examinations that possesses European Guidelines even the ones that have values below these references.

Concluding, generally the guidelines were fulfilled with exception of DLP values which differ a lot from it. To analyze in detail if these values are exaggerated, other variables that characterize the patients such as the age, weight and gender, must be taken into account. Knowing that CT examinations uses a higher radiation dose in comparison with CRs and MGs, it can be concluded that beyond any corporal attribute that possibly justifies these differences, the values obtained are extremely high comparatively to the references.

It is also important to underline that even the values that are according to the guidelines, are not safe from an incorrect dosage. In other words, it may happen that the values that are in accordance to the guidelines, may not be adjusted to the height and patient characteristics. Thus, the protocols must be adjusted to optimize the procedures as much as possible minimizing the inherent risks of a radiation exposure. Also, other variables such as voltage, exposure time and compression force that have a direct involvement not only in radiation exposure but also in the image quality, must be well measured. The health professionals must make use of imaging modalities that do not use ionizing radiation whenever possible or equate the need of the examinations according to the patient's clinical conditions.

Systems like RMSCI must be part of the hospitals and clinics routine for the reasons mentioned above. The obtained results reinforce its relevance.

Regarding system performance, it was not detected any anomalies. In the future, more features may be added to guarantee better informed decisions.

Table 5.2: Summary of all the results of the examinations that possesses European Guidelines.

Modality	Parameter	Body Part/Breast Thickness	Average	90th Percentile	Guidelines accordance	Percentage of non-correspondence to the guidelines (%)
CT	$CTDI_w$ (mGy)	Abdomen	6.88	10.69	Yes	
		Neck	7.19	12.21		
		Spine	9.94	14.00		
		Chest	4.08	5.83		
		Head	21.21	22.44		
		Pelvis	3.80	5.53		
	DLP (mGy.cm)	Abdomen	1091.39	1905.74	No	61
		Neck	1184.84	1569.69		52
		Spine	1623.95	3123.45		73
		Chest	416.56	695.11		32
		Head	4109.51	5390.42		83
		Pelvis	886.99	1354.02		50
CR	DAP ($mGy.cm^2$)	Chest PA	153.26	311.40	Yes	
		Chest LAT	169.54	335.80		
		Skull PA	222.72	296.70		

		Skull LAT	238.92	263.60		
		Thoracic spine AP	769.70	1058.60		
		Thoracic spine LAT	745.28	991.80		
		Abdomen AP	1969.50	1969.50		
		Abdomen PA	1569.19	2865.20		
		Lumbar Spine AP	1003.20	1886.30		
		Lumbar Spine LAT	1292.37	1952.90		
		Pelvis AP	676.26	1689.00		
	Voltage (kV)	Chest PA	125.00	125.00	Yes	
		Chest LAT	133.00	133.00	No	100
		Skull PA	77.00	77.00	Yes	
		Skull LAT	73.00	73.00		
		Lumbar Spine AP	77.67	81.00		
		Lumbar Spine LAT	90.86	96.00	No	20
		Pelvis AP	77.89	81.00	Yes	
	Exposure Time (secs)	Chest PA	0.009	0.02	No	17
		Chest LAT	0.009	0.02	Yes	
		Skull PA	0.02	0.03		
		Skull LAT	0.018	0.03		
		Lumbar Spine AP	0.092	0.16		
		Lumbar Spine LAT	0.041	0.06		
		Pelvis AP	0.013	0.03		
MG	Organ Dose [14](mGy)	3.2 cm	1.86	2.02	No	14
		4.5 cm	1.26	2.94		8
		2.1 cm	0.56	0.56	Yes	
		5.3 cm	1.29	1.76		
		6.0 cm	2.18	2.32		
		7.5 cm	1.98	2.94		
		9.0 cm	1.26	1.26		
	Exposure Time (secs)	All exposure times	2.74	3.92	No	6
	Compression Force (N)	All compression forces	77.00	101.70	Yes	

[14] Represented only the breast thicknesses in Table 2.4

Chapter 6

Conclusions

In this work, the Radiation Monitoring System in Clinical Imaging was developed whose main purpose was to facilitate the monitoring and tracking of the radiation doses and other important variables in medical imaging, by comparing them with the European guidelines. As the name implies, the European guidelines are only a reference for health professionals and is not an obligation by law. Comparatively to the other systems already available on the market, the RMSCI has the advantages of being fully free, the access is achieved through a web browser at any location and allows the upload of private data in a user section.

All the objectives defined in subsection 1.3 were fully achieved with the aid of information technologies (programming languages such as Python, PHP, JavaScript and MySQL), available legislation about the topic and other related work. The system is now available online at http://rmsci.fc.ul.pt/.

One of the main conclusions of the work is that the European Guidelines were in general followed with few exceptions: the DLP values in CT examinations are all greatly above the established guidelines; 100% of the voltage chest LAT CR values and 20% voltage Lumbar spine LAT CR values are above the reference levels; 17% of the chest PA exposure times are above the predefined threshold by the European commission; 14% of the breast thicknesses of 3.2 cm and 8% of 4.5 cm are also above the guidelines and 6% of the MG exposure times are not in accordance with the mentioned references.

The guidelines should depend directly on the physiognomy and patient's characteristics. However, is unaffordable the establishment of thresholds due to the enormous diversity of body compositions. Thus, it is easier to standardize these references and the respective adjustments for each type of patient must be made later. The development of an algorithm that considers the patient's characteristics would be a reliable way to obtain these adjusted values and consequently, moving towards to personalized medicine that is gaining more importance (Alves, 2011; Collins & Varmus, 2015).

Due to the adverse effects of the radiation in human health, these adjustments must be kept as low as reasonable achievable (ALARA) decreasing the risk benefit ratio. In specific conditions (younger patients, pregnant women) the examination must be well equated due to the additional hazards. A platform like the one designed in this project can respond to radiation tracking needs to optimize as much as possible the administered doses, applied voltages, exposure times and compression forces.

Also, the storage and processing of enormous volumes of data is a challenge. Efficient results are only possible to obtain with a correct and organized storing and also with efficient queries. RMSCI has an acceptable performance taking into account the quantity of data stored and processed which is a great advantage.

A limitation of this work is the low quality of the data collected. Several DICOM attributes are not available which did not permit a more in-depth analysis.

Personally, the presented project was a huge challenge because my academic background is Health Sciences and the majority of this project involves advanced computational and programming competences. Although, Master in Bioinformatics and Computational Biology addresses informatics subjects, these subjects presuppose that the basis and the introductory content is already known and well cemented.

On the other hand, professionally this project was an asset for the extension of my knowledge in the computational sciences field and permitted the perception that computing technologies are becoming increasingly useful in the analysis and processing of large-scale data.

6.1 Future work

The present work was a starting point for the development of web applications that ensures radiation dose monitoring. However, a major obstacle was the non-access to data in real-time that would add more value to the project. Another task that was not performed due to the lack of time was the generation of alerts defined by the users. In other words, the user could establish a guideline for a specific modality and parameter and when new data exceeds the predefined threshold, the system would send an alert to the user e-mail or cell phone. This is another work that could be developed in future projects.

Furthermore, more statistical variables could be added to increase the knowledge about the data and to explore it in diverse ways.

Another interesting work that could be performed due to the increasing of investigation in this area, is somehow link this project with the Semantic Web. With the accelerating growth in the biomedicine knowledge (most of it on the Web) and a rapidly rising need for computational methods to enable researchers and physicians to explore that knowledge, new opportunities on knowledge integration (such as ontologies) emerged (Rubin, Mongkolwat, Kleper, Supekar, & Channin, n.d.).

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Appendix A
Council Directive 2013/59 EURATOM of 5 December 2013

Description: Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, and repealing Directives 89/618/EURATOM, 90/641/ EURATOM, 96/29/ EURATOM, 97/43/ EURATOM and 2003/122/ EURATOM.

Filename: CELEX-32013L0059-EN-TXT.pdf

URL: https://ec.europa.eu/energy/sites/ener/files/documents/CELEX-32013L0059-EN-TXT.pdf

Appendix B
European Guidelines On Quality Criteria For Computed Tomography

Description: These guidelines on Quality Criteria for Computed Tomography provide guidance on the definition and introduction of quality criteria for diagnostic images and equipment performance, as well as for dose to the patient.

Filename: CGNA16262ENC_002.pdf

URL:
https://www.google.pt/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwiwibLzwcHPAhXErB4KHQrmCZYQFggoMAE&url=http%3A%2F%2Fbookshop.europa.eu%2Fen%2Feuropean-guidelines-on-quality-criteria-for-computed-tomography-pbCGNA16262%2Fdownloads%2FCG-NA-16-262-EN-C%2FCGNA16262ENC_002.pdf%3Bpgid%3DIq1Ekni0.1lSR0OOK4MycO9B0000KjO9EG1o%3Bsid%3DVE2hFc7BXdGhGZm1Xns_sqzkU56nxskSUp4%3D%3FFileName%3DCGNA16262ENC_002.pdf%26SKU%3DCGNA16262ENC_PDF%26CatalogueNumber%3DCG-NA-16-262-EN-C&usg=AFQjCNEIOvn_nmXCcN67K21sNSfvrVdI5g&bvm=bv.134495766,d.ZGg

Appendix C
European Guidelines On Quality Criteria For Diagnostic Radiographic Images

Description: These guidelines define Diagnostic Requirements for a normal, basic radiograph, specifying anatomical mage criteria and important image details; it indicates Criteria for the Radiation Dose to the Patient and gives an Example for Good Radiographic Technique by which the Diagnostic Requirements and the dose criteria can be achieved.

Filename: EuropeanGuidelineseur16260.pdf

URL: http://www.sprmn.pt/legislacao/ficheiros/EuropeanGuidelineseur16260.pdf

Appendix D
European Guidelines for quality assurance in breast cancer screening and diagnosis

Description: This Publication of the fourth edition of the guidelines by the European Union will ensure that any interested organization, programme or authority in the Member States can obtain the recommended standards and procedures and appoint appropriate persons, organizations and institutions for the implementation of those.

Filename: ND7306954ENC_002.pdf

URL: http://www.euref.org/downloads?download=26:physico-technical-protocol

Appendix E
Radiation Protection Nº 180 – Diagnostic Reference Levels in Thirty-six European Countries

Description: This report provides comprehensive information on 36 European countries regarding frequencies and radiation doses of x-ray and nuclear medicine radiodiagnostic procedures.

Filename: RP180 part2.pdf

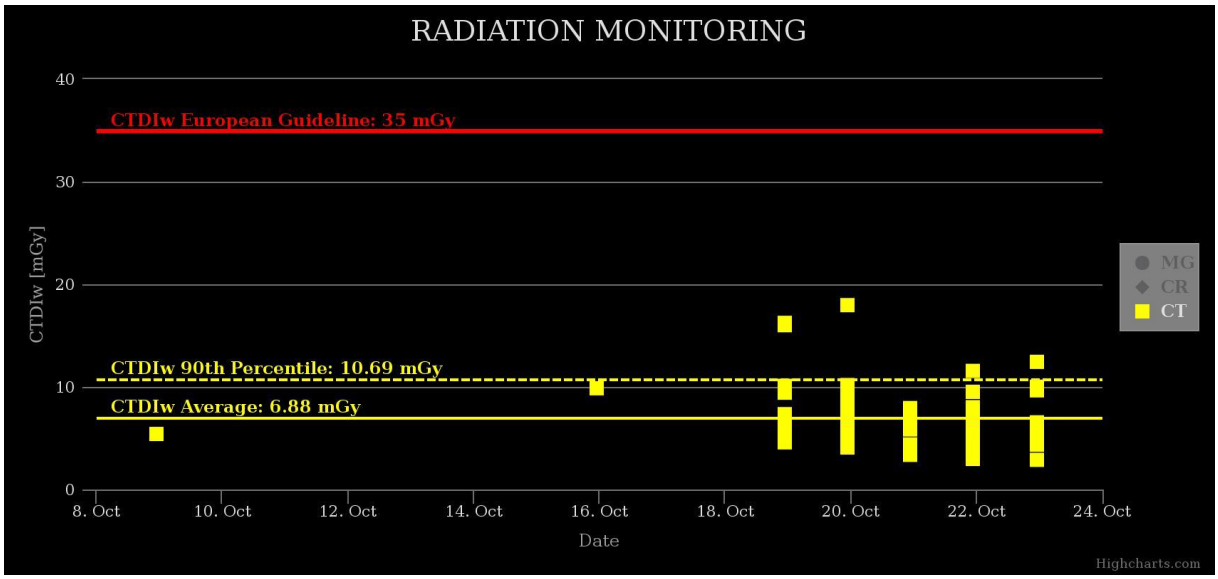
URL: https://ec.europa.eu/energy/sites/ener/files/documents/RP180%20part2.pdf

Appendix F
Results below the European Guidelines

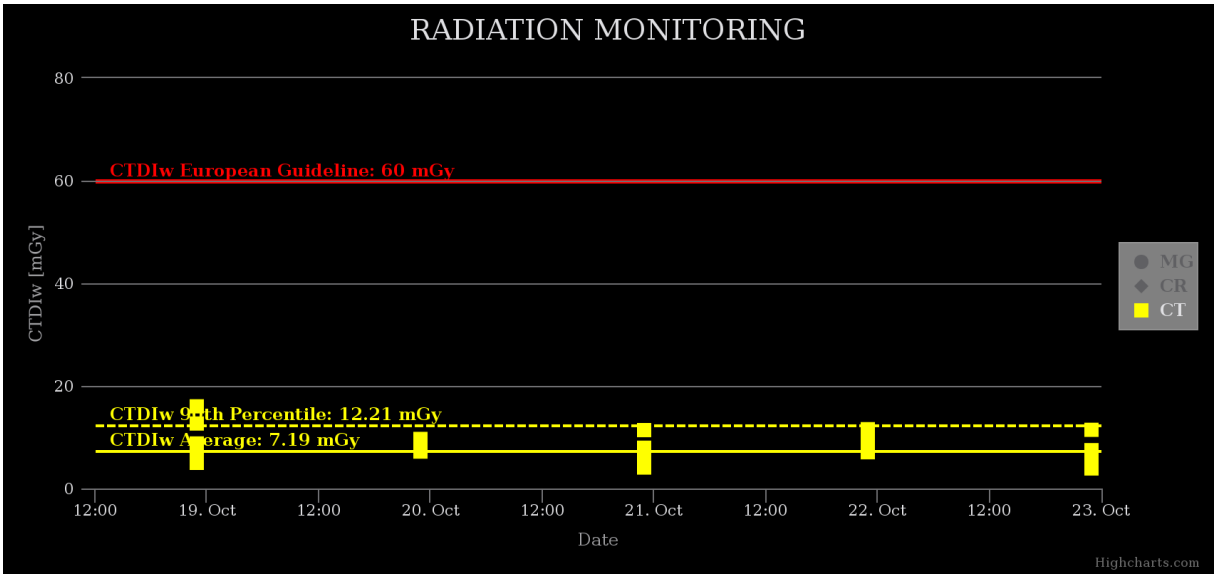
F.1 Computed Tomography

F.1.1 $CTDI_w$

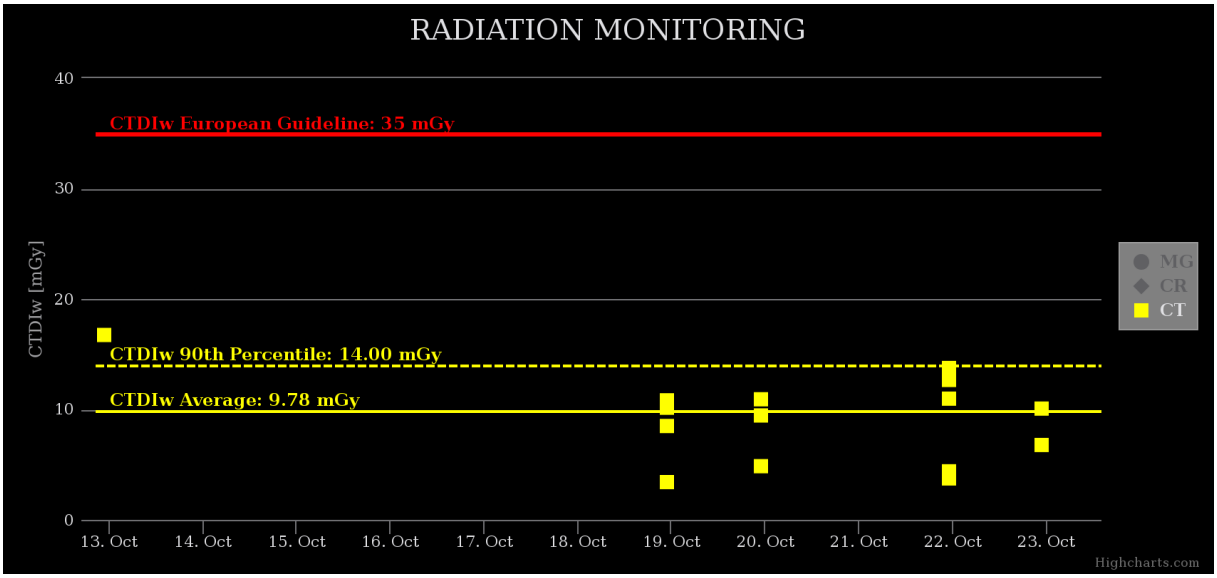
F.1.1.1 Abdomen



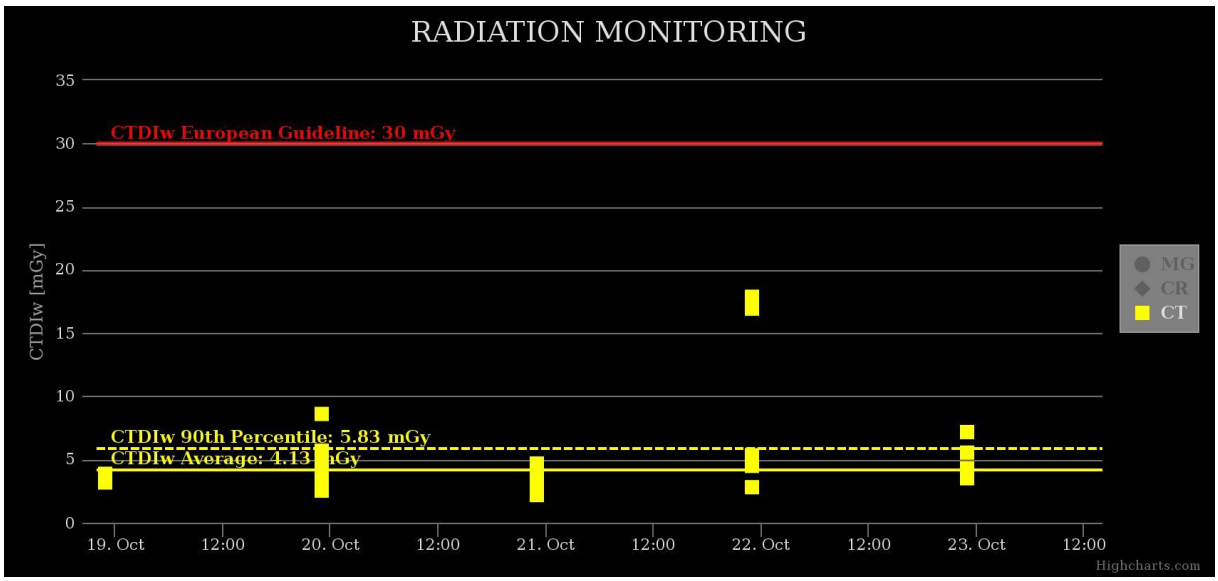
F.1.1.2 Neck



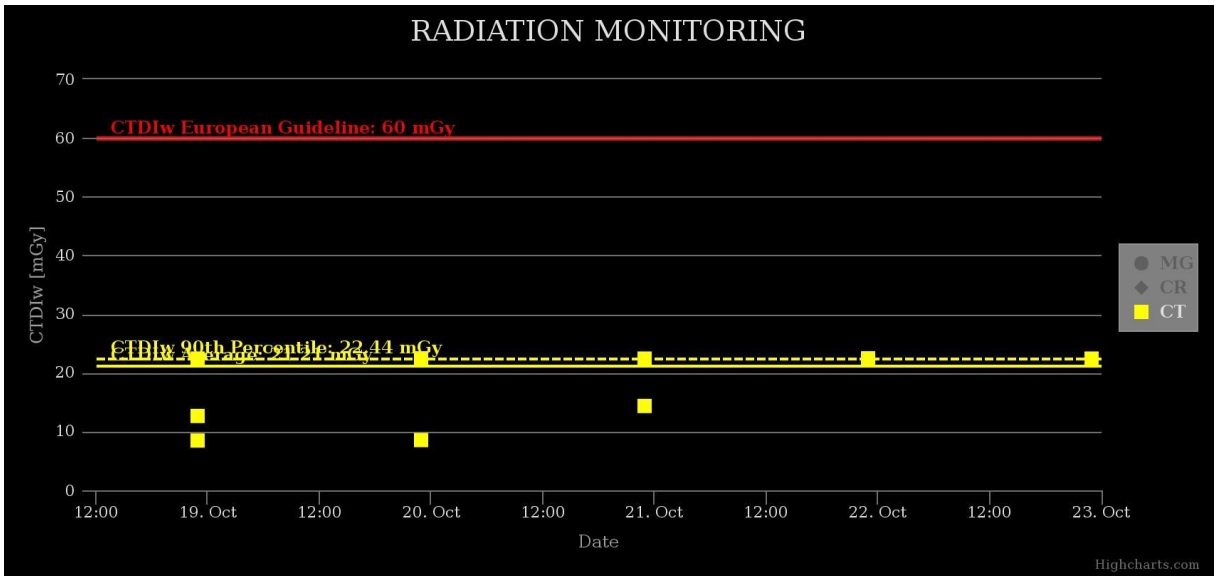
F.1.1.3 Spine



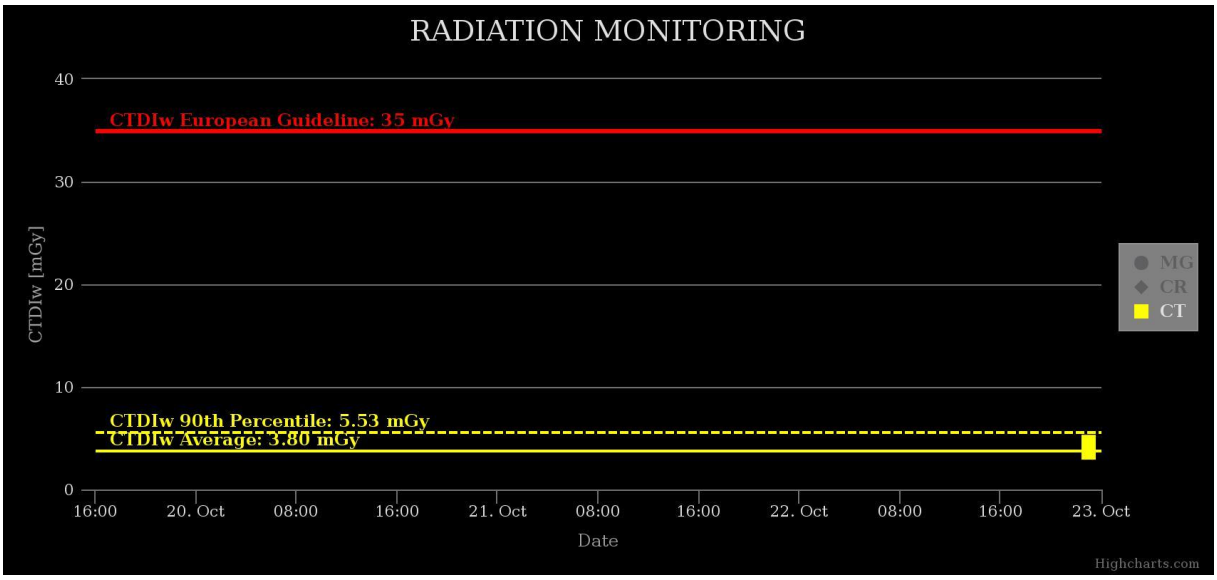
F.1.1.4 Chest



F.1.1.5 Head



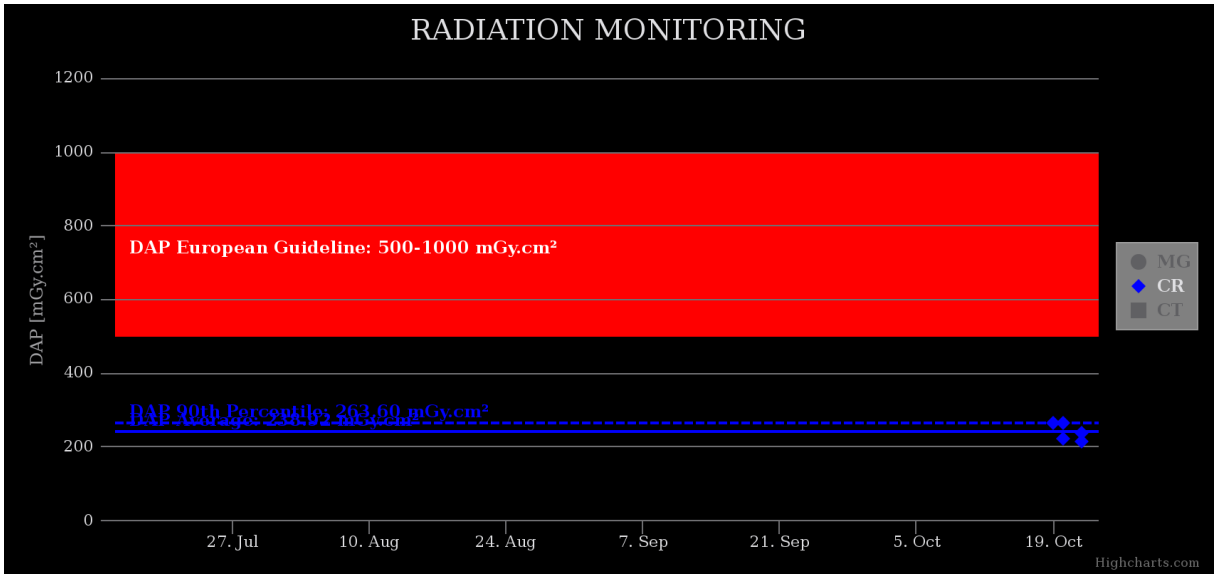
F.1.1.6 Pelvis



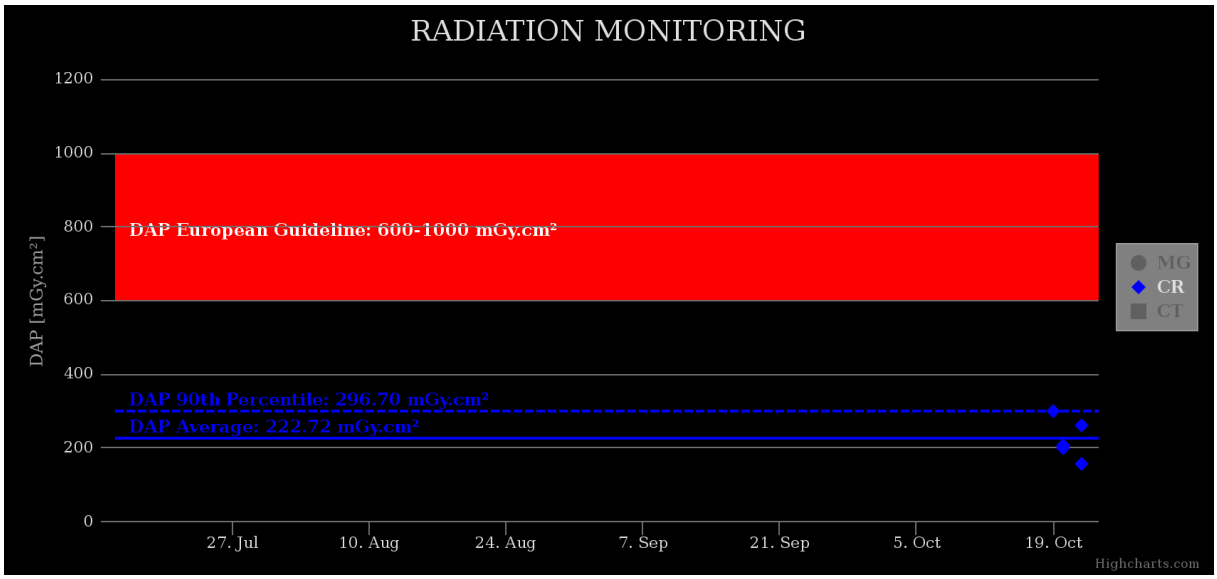
F.2 Computed Radiography

F.2.1 Dose Area Product

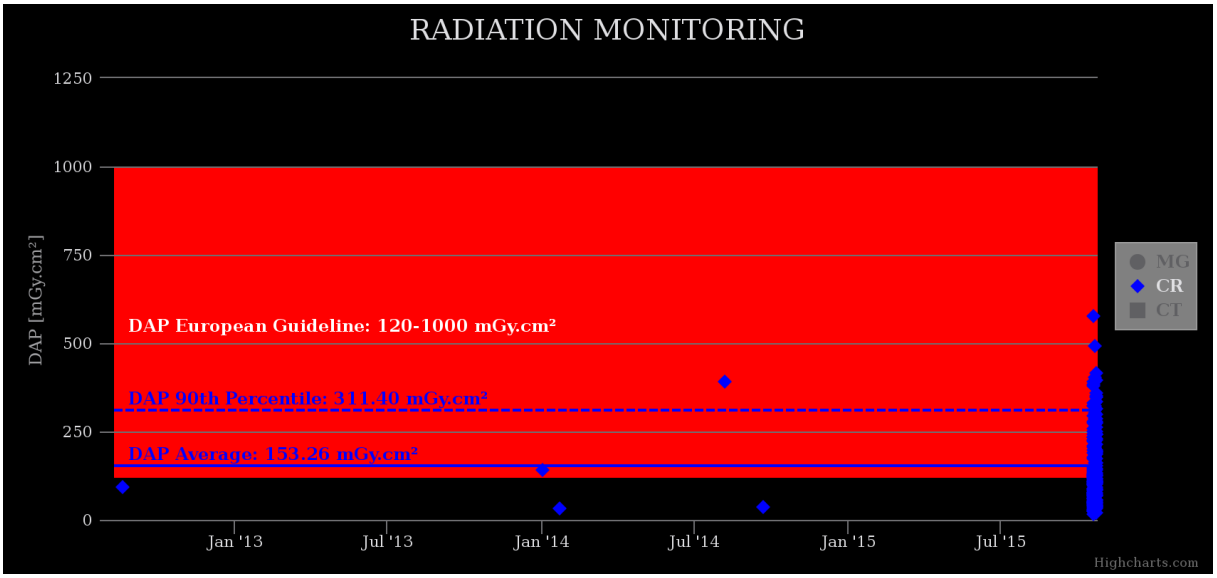
F.2.1.1 Skull LAT



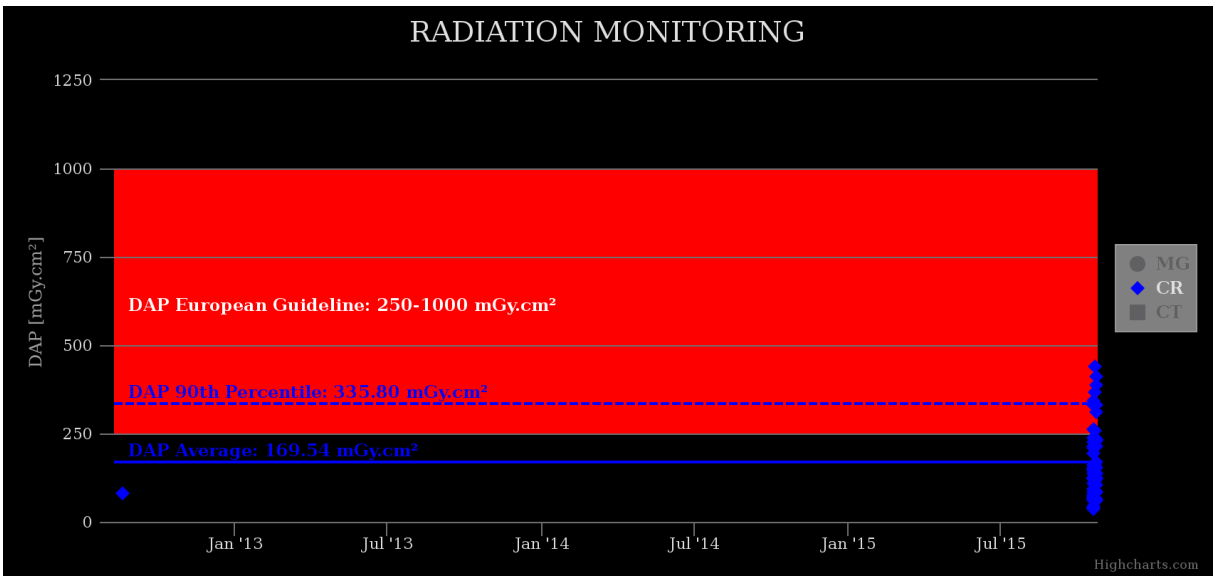
F.2.1.2 Skull PA



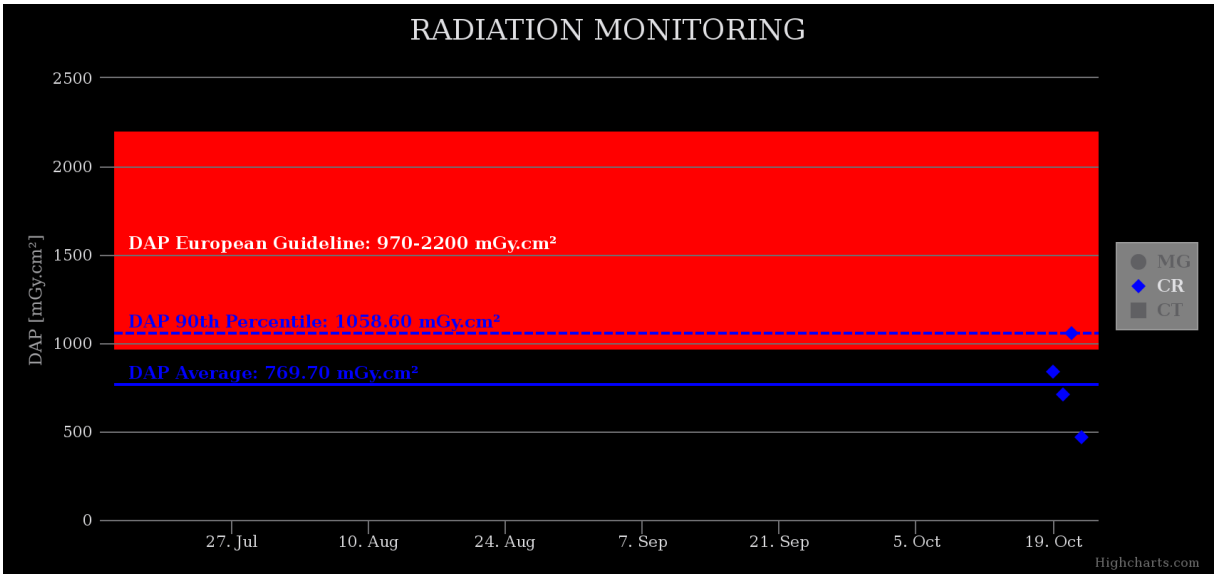
F.2.1.3 Chest PA



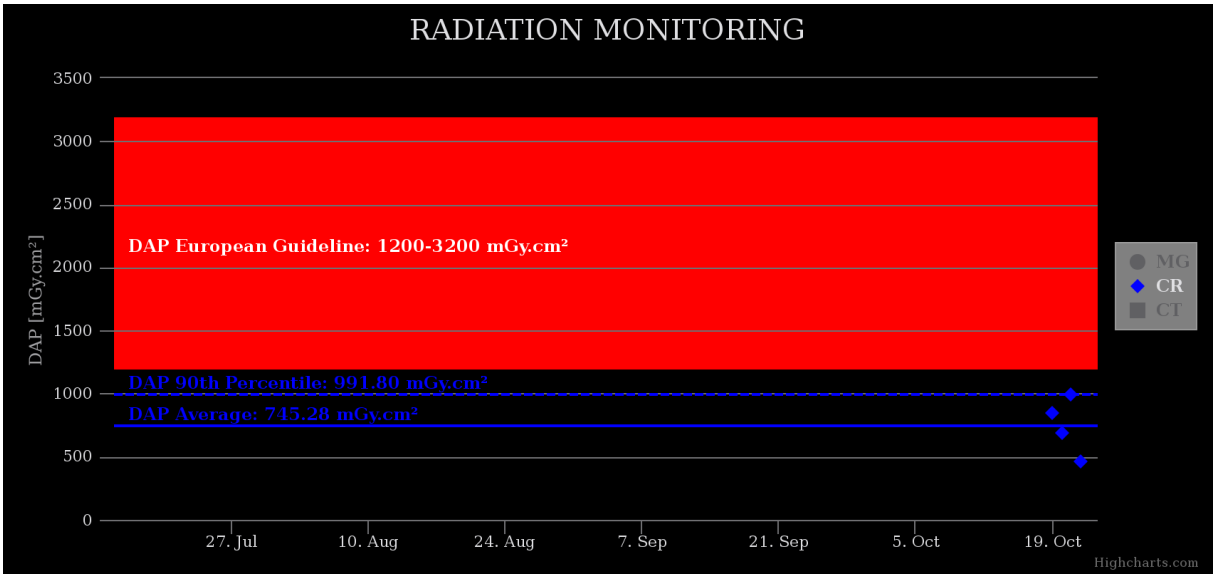
F.2.1.4 Chest LAT



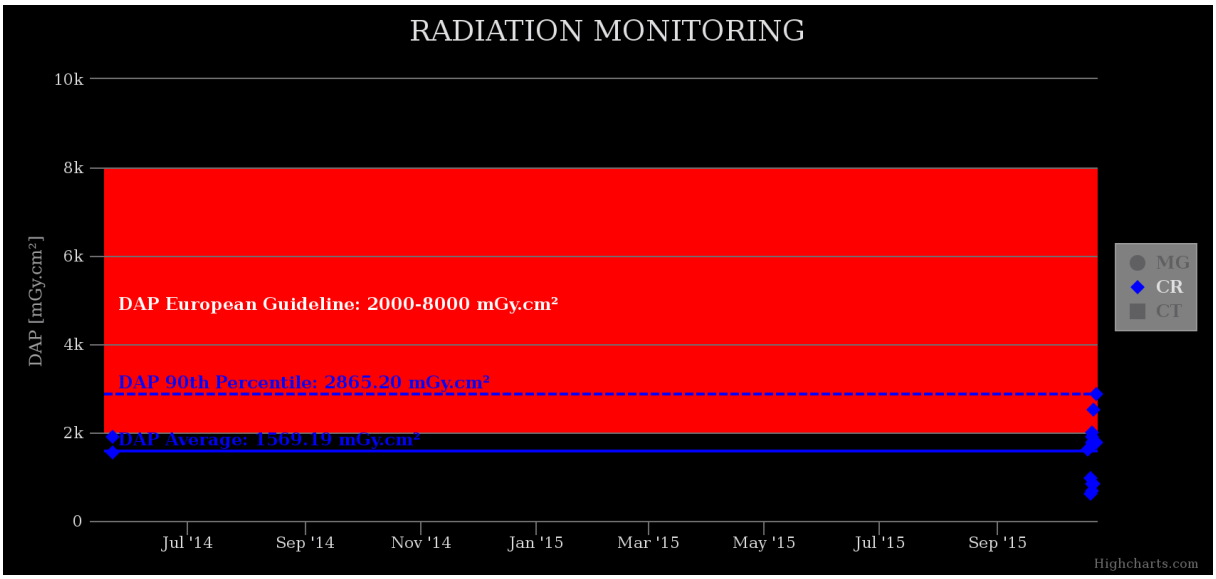
F.2.1.5 Thoracic Spine AP



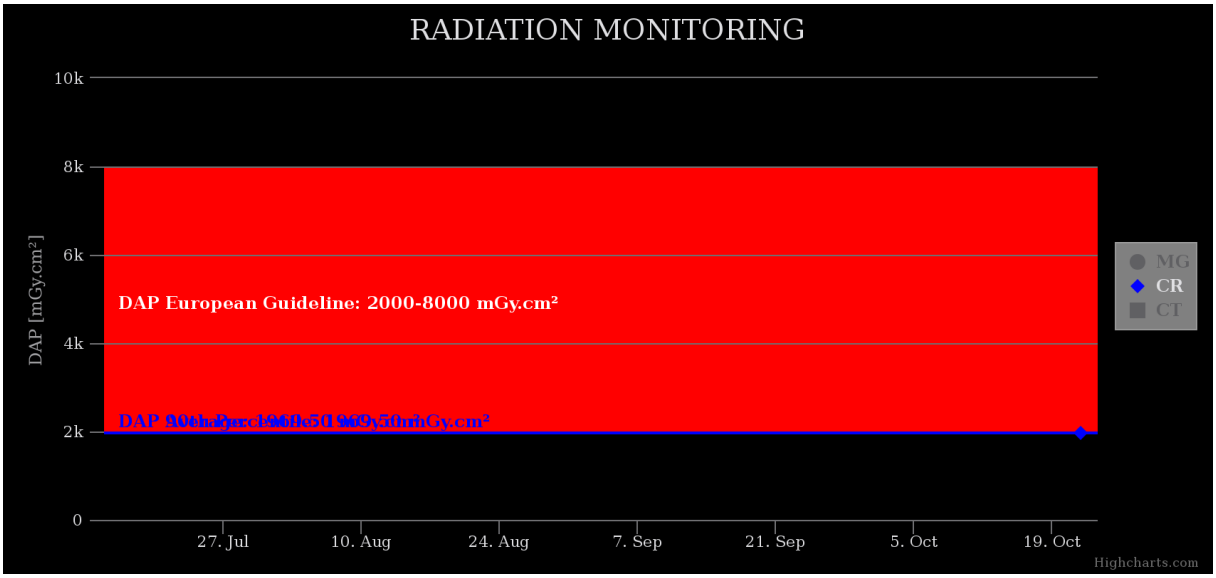
F.2.1.6 Thoracic Spine LAT



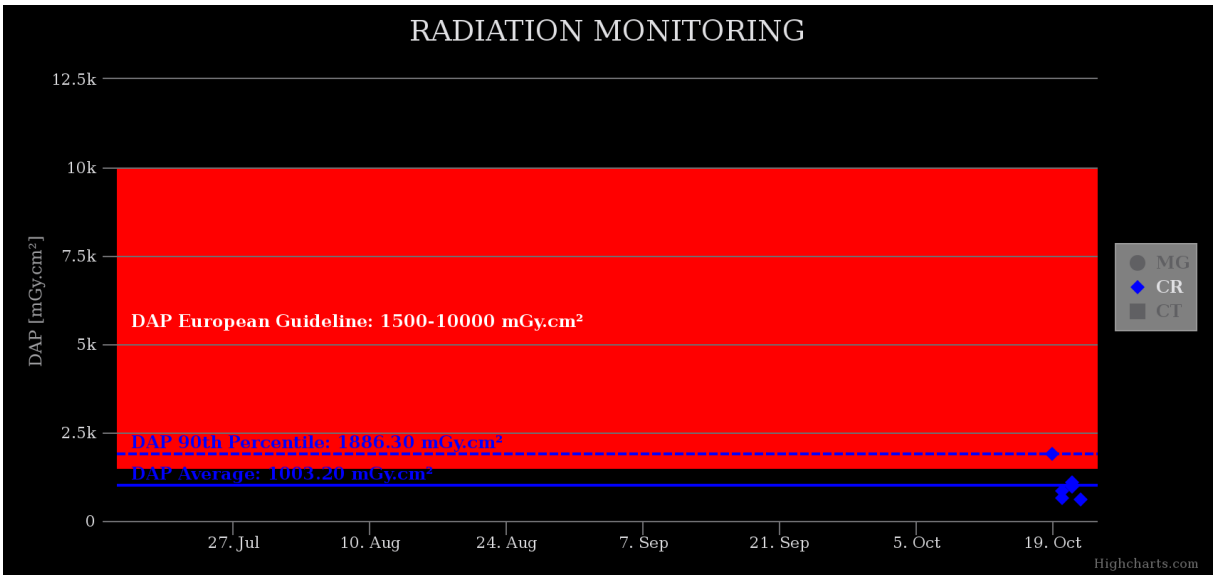
F.2.1.7 Abdomen PA



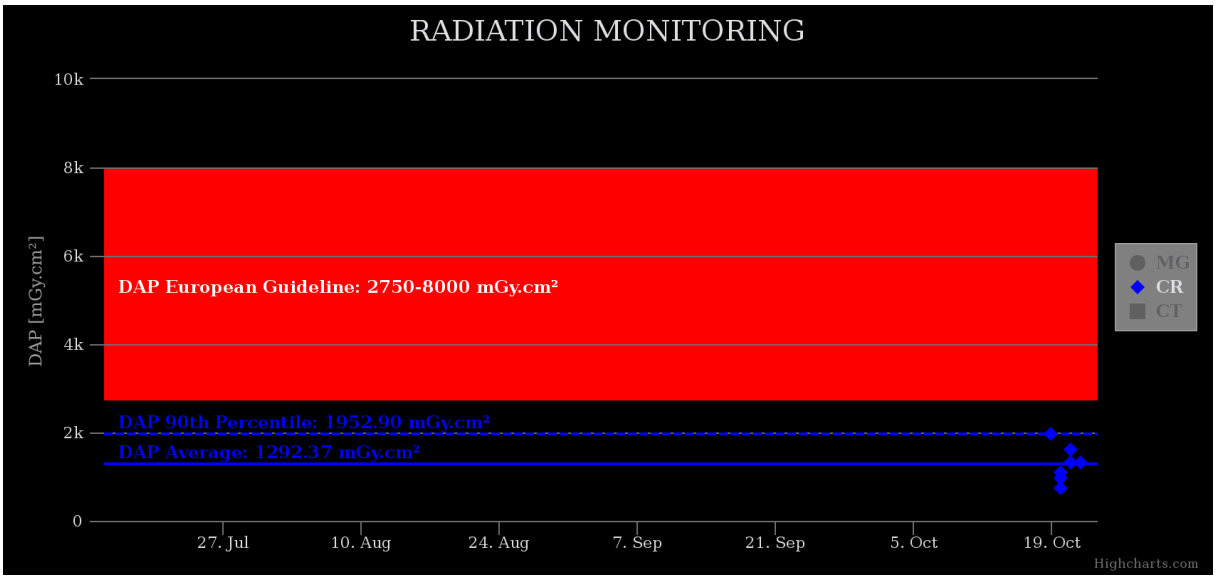
F.2.1.8 Abdomen AP



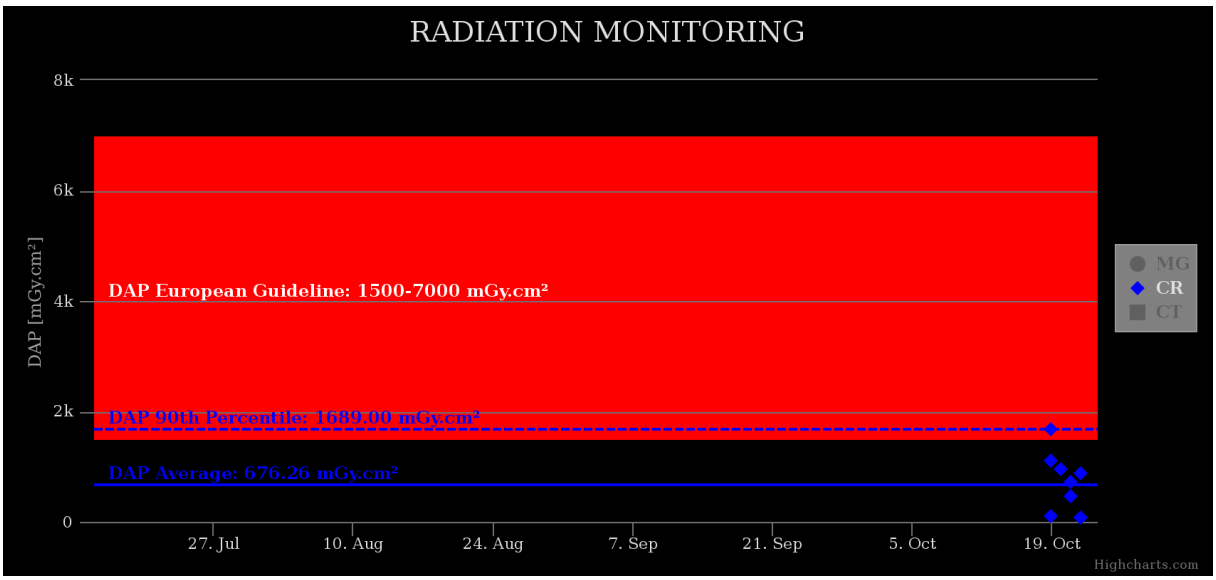
F.2.1.9 Lumbar Spine AP



F.2.1.10 Lumbar Spine LAT

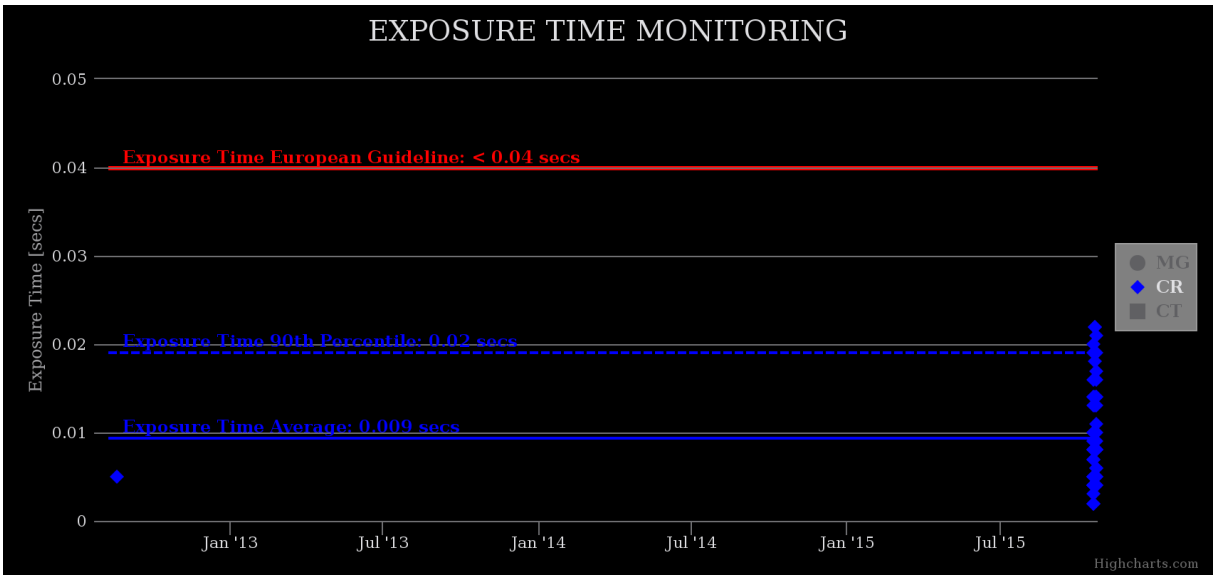


F.2.1.11 Pelvis AP

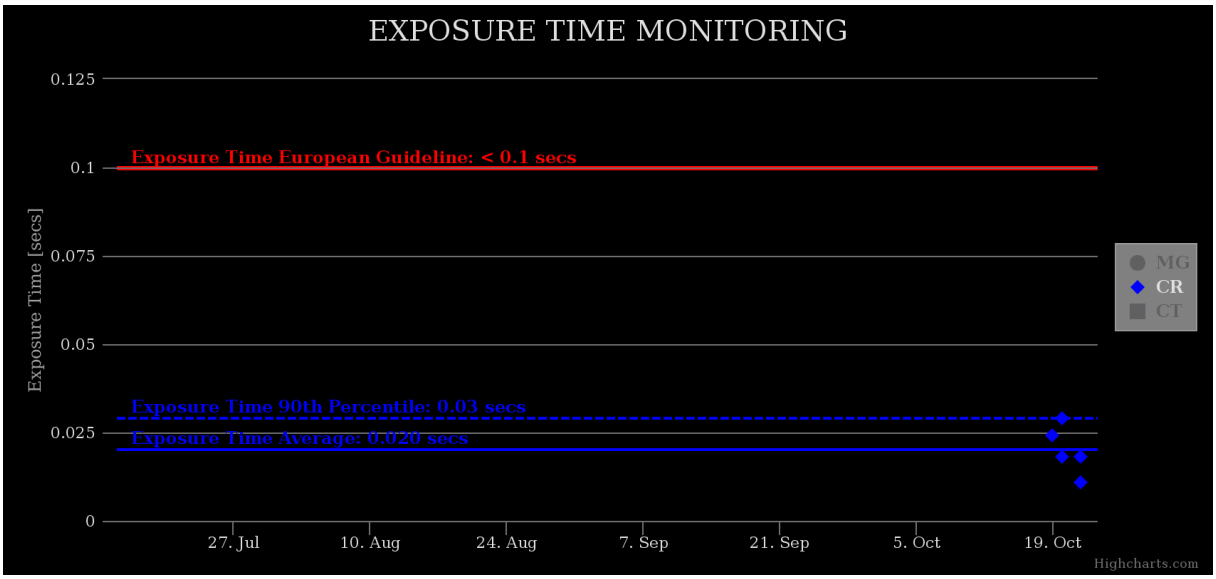


F.2.2 Exposure Time

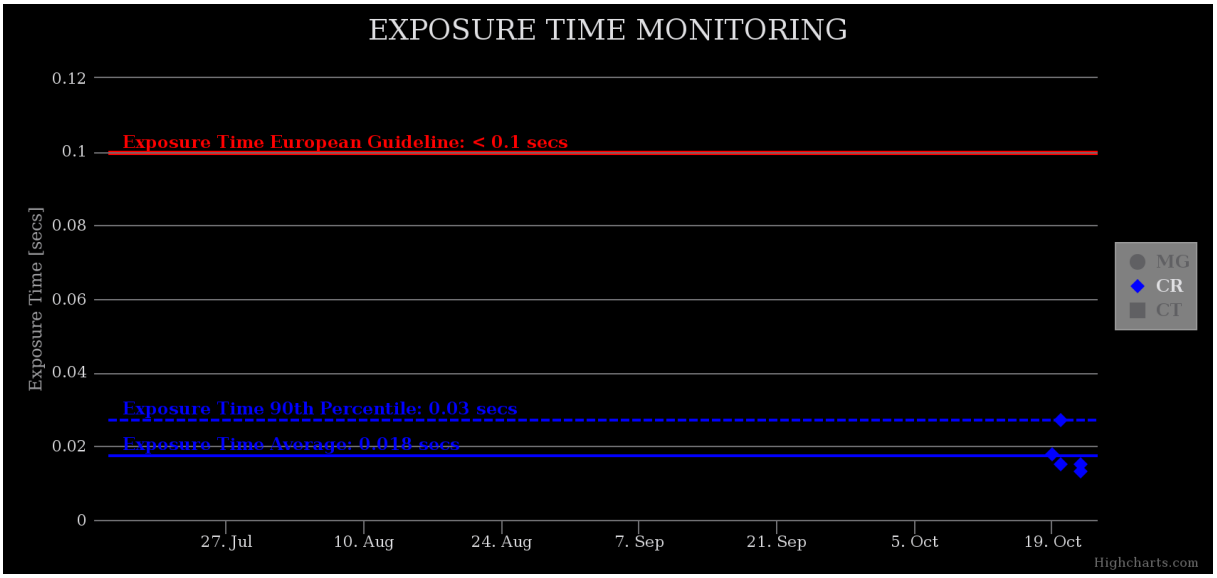
F.2.2.1 Chest LAT



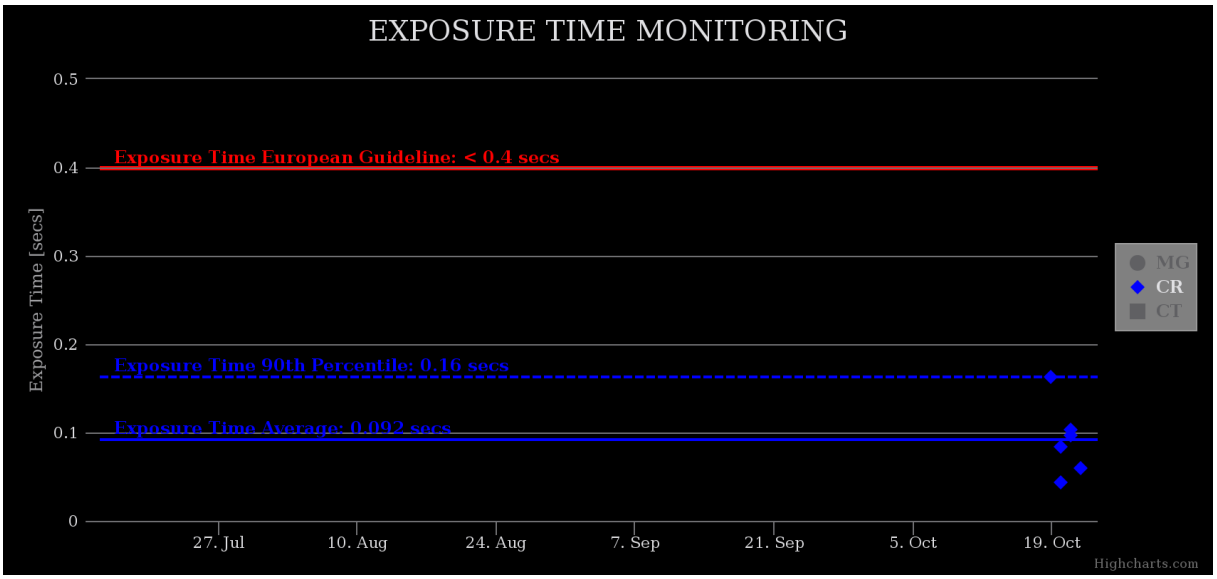
F.2.2.2 Skull PA



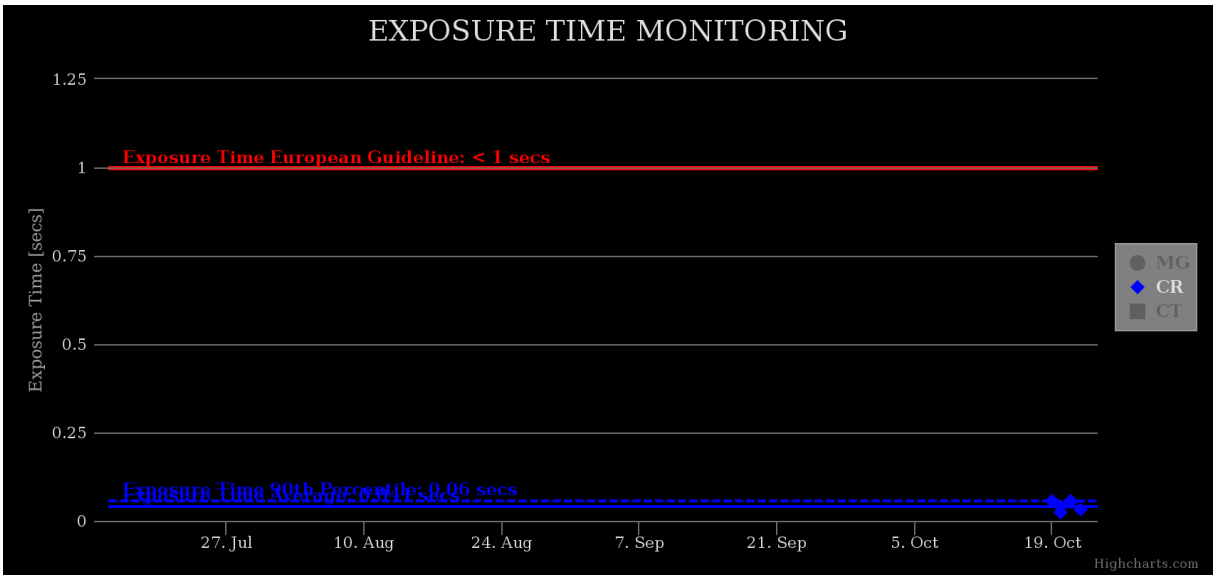
F.2.2.3 Skull LAT



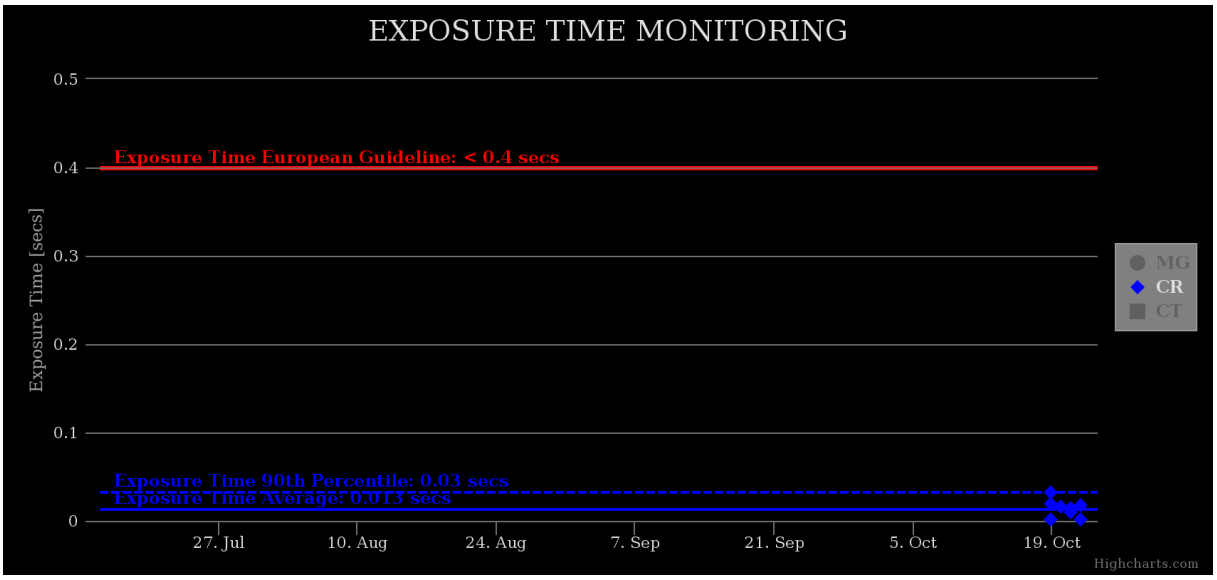
F.2.2.4 Lumbar Spine AP



F.2.2.5 Lumbar Spine LAT

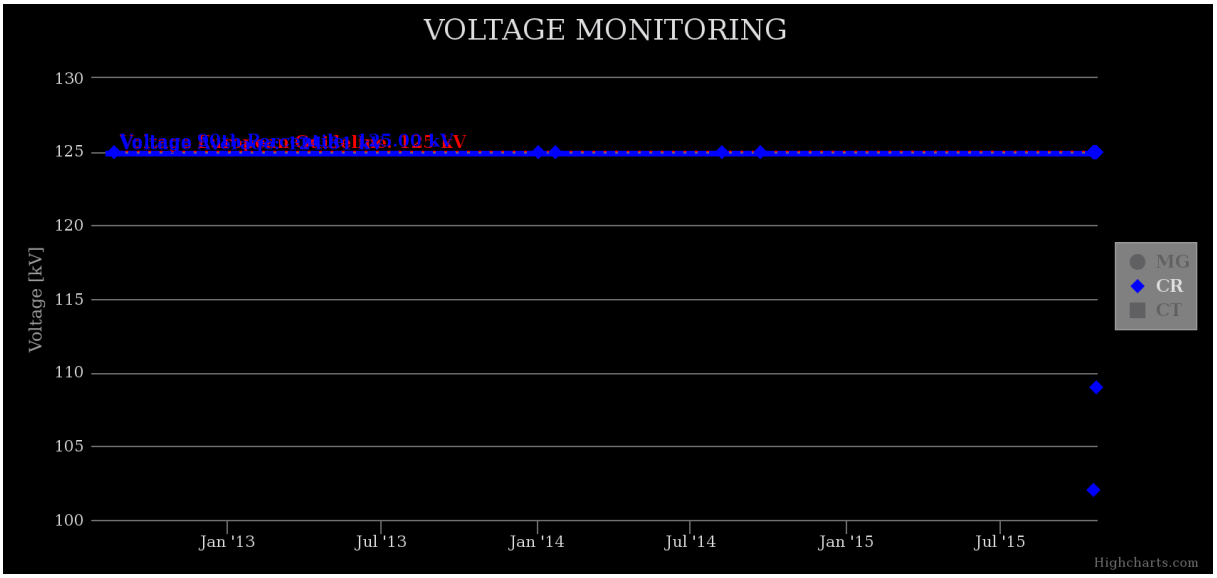


F.2.2.6 Pelvis AP

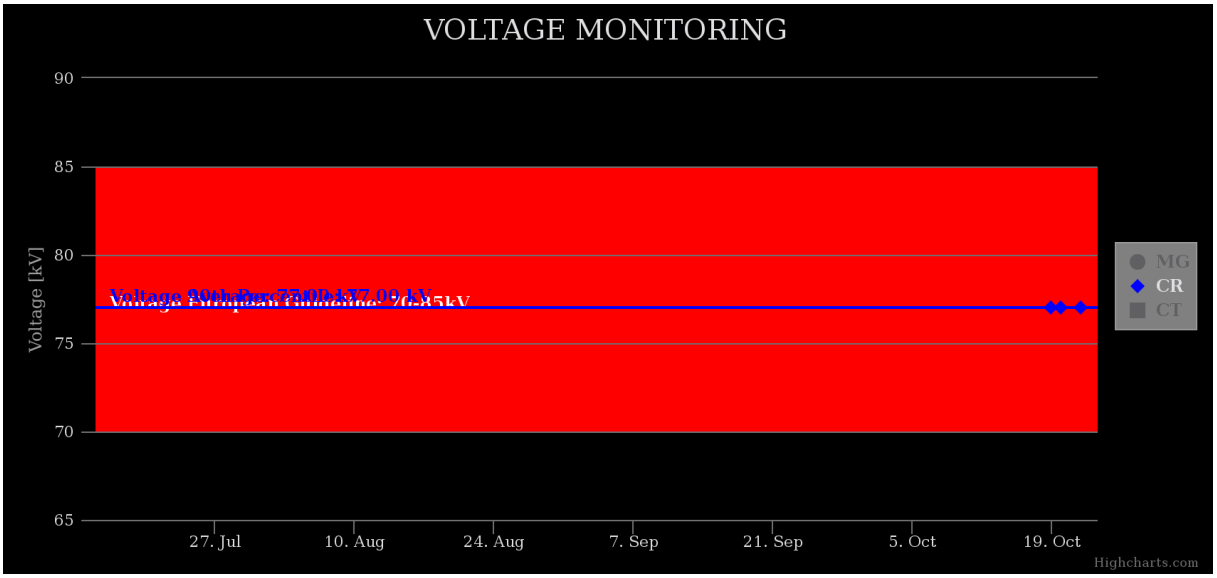


F.2.3 Voltage

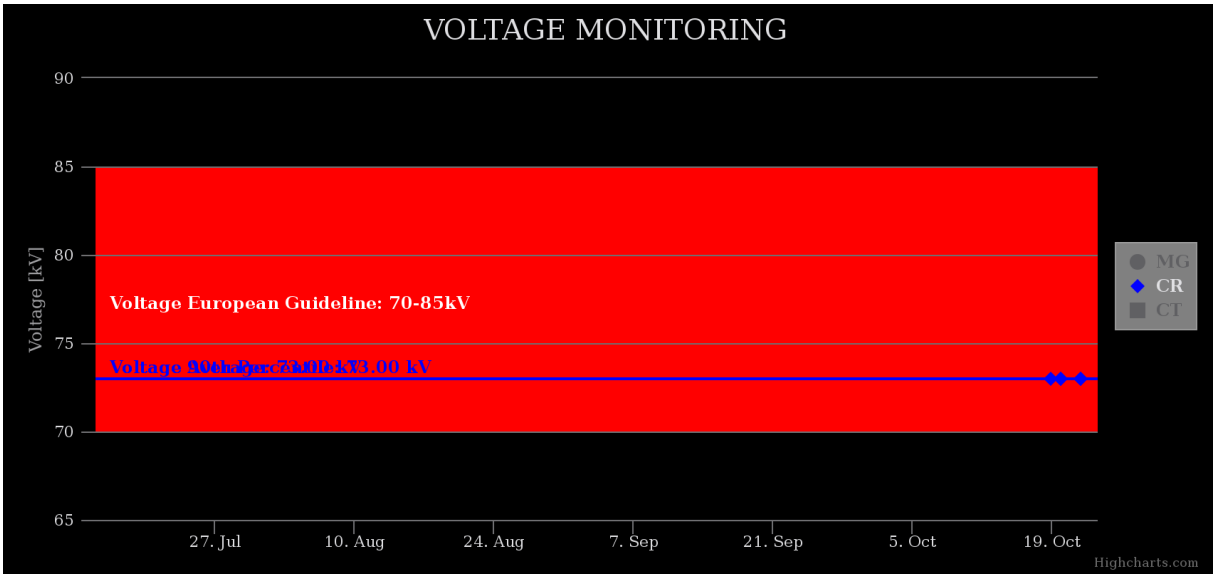
F.2.3.1 Chest PA



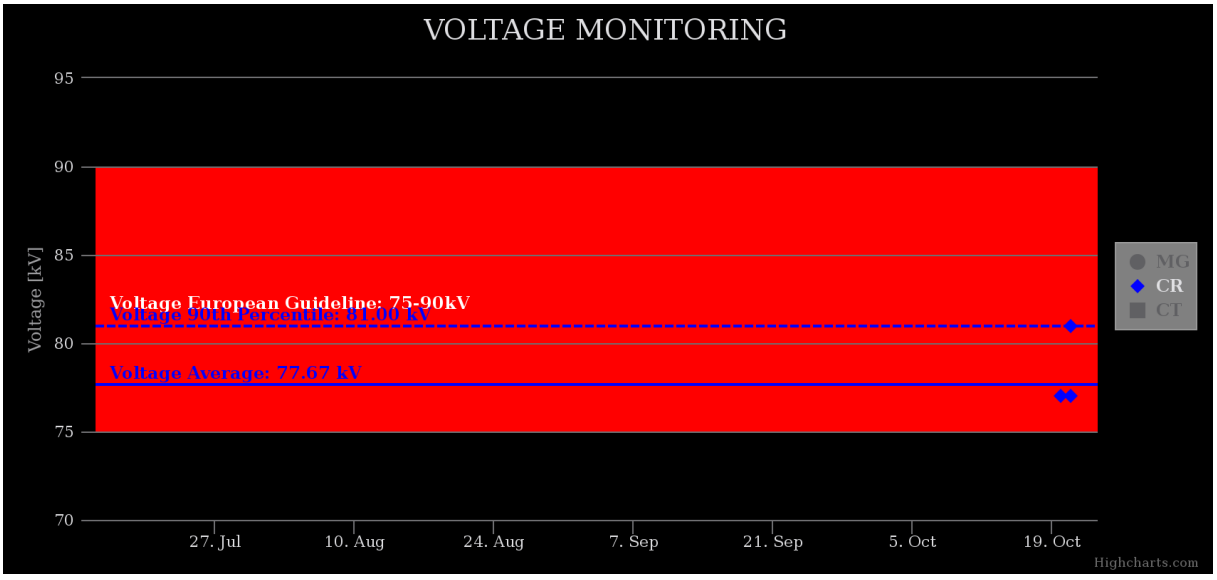
F.2.3.2 Skull PA



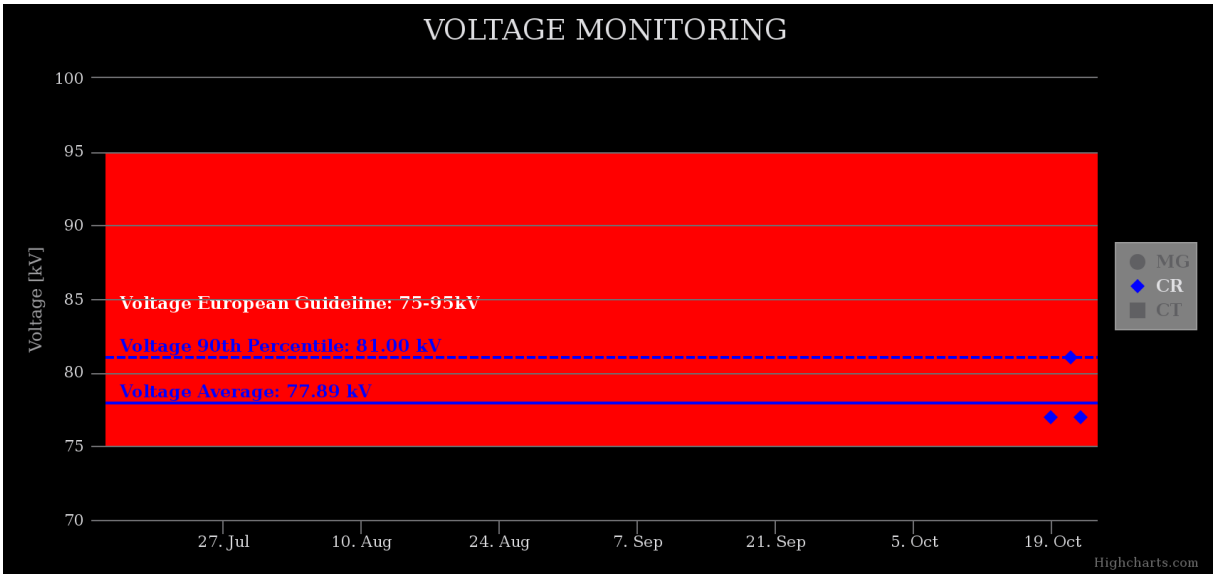
F.2.3.3 Skull LAT



F.2.3.4 Lumbar Spine AP



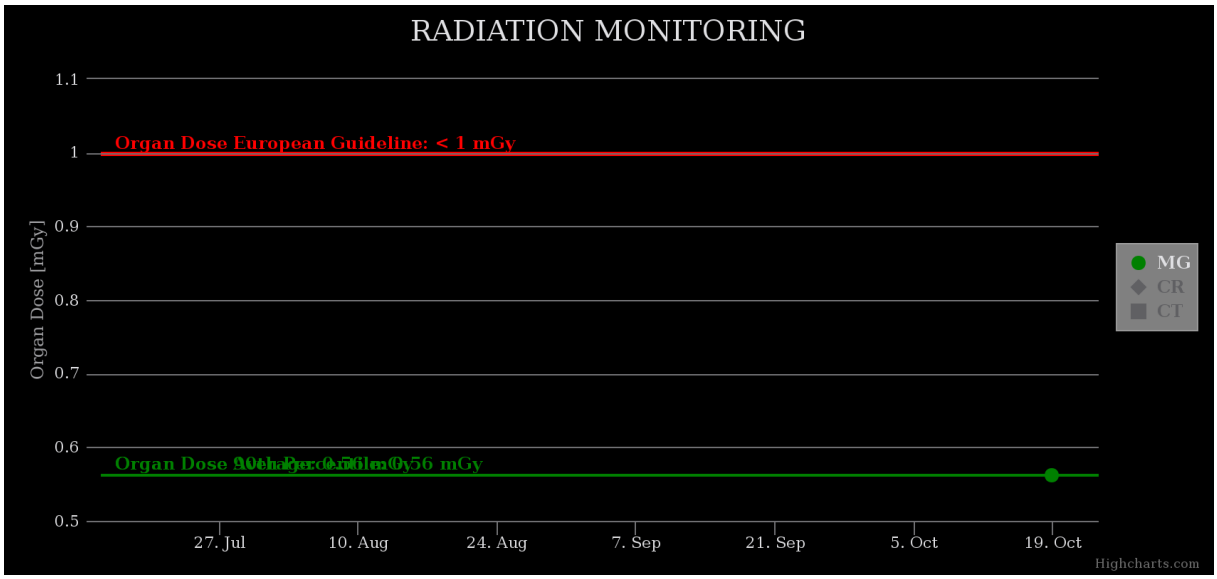
F.2.3.5 Pelvis AP



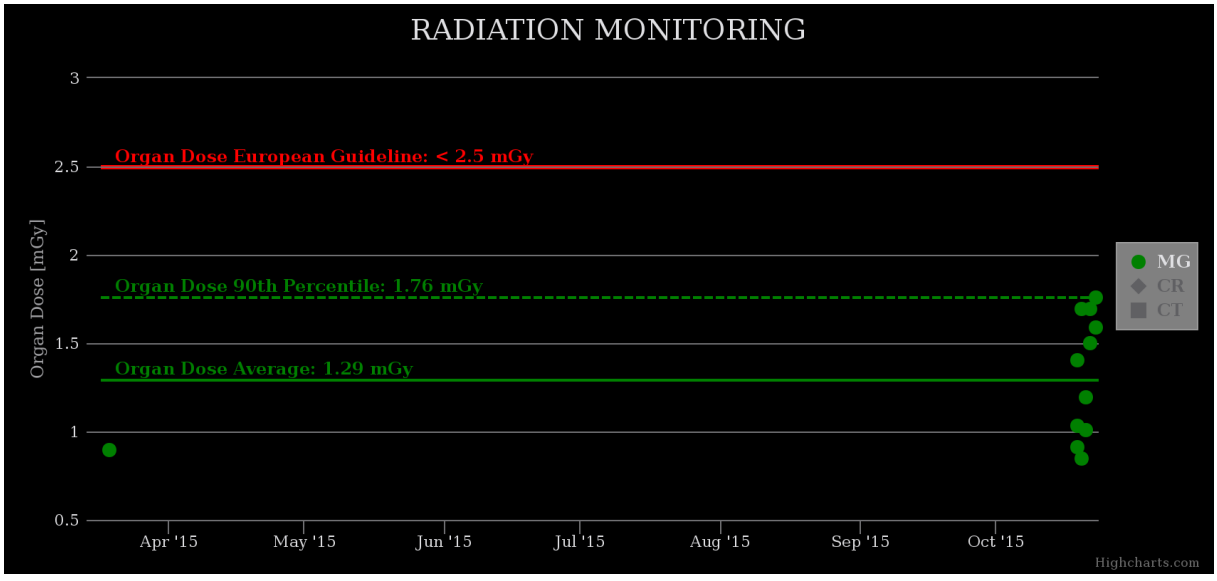
F.3 Mammography

F.3.1 Organ Dose

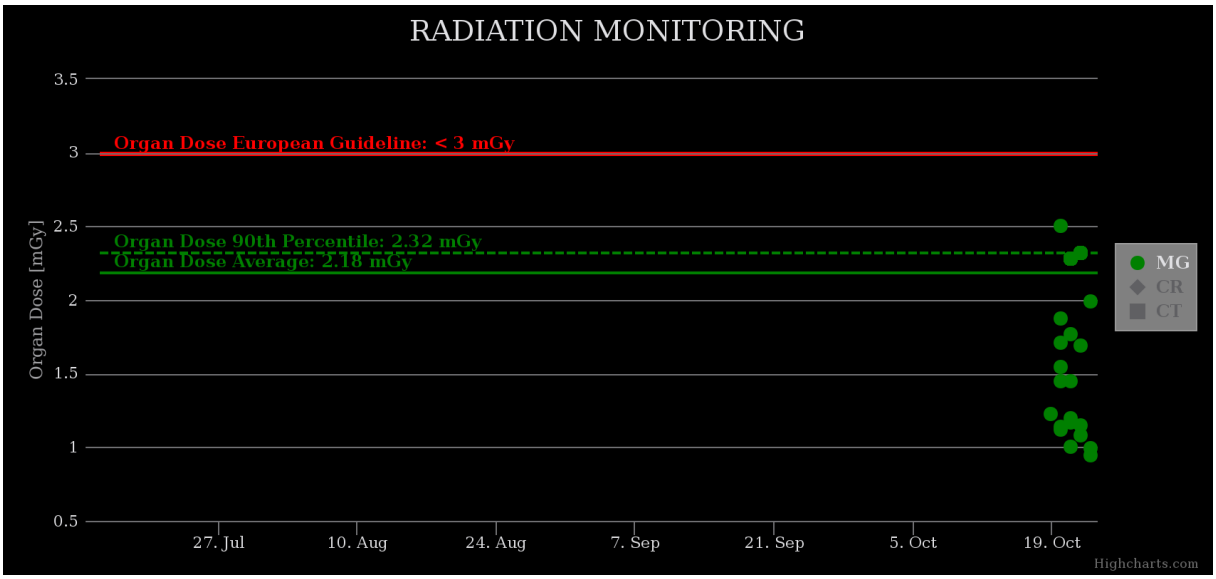
F.3.1.1 2.1 cm



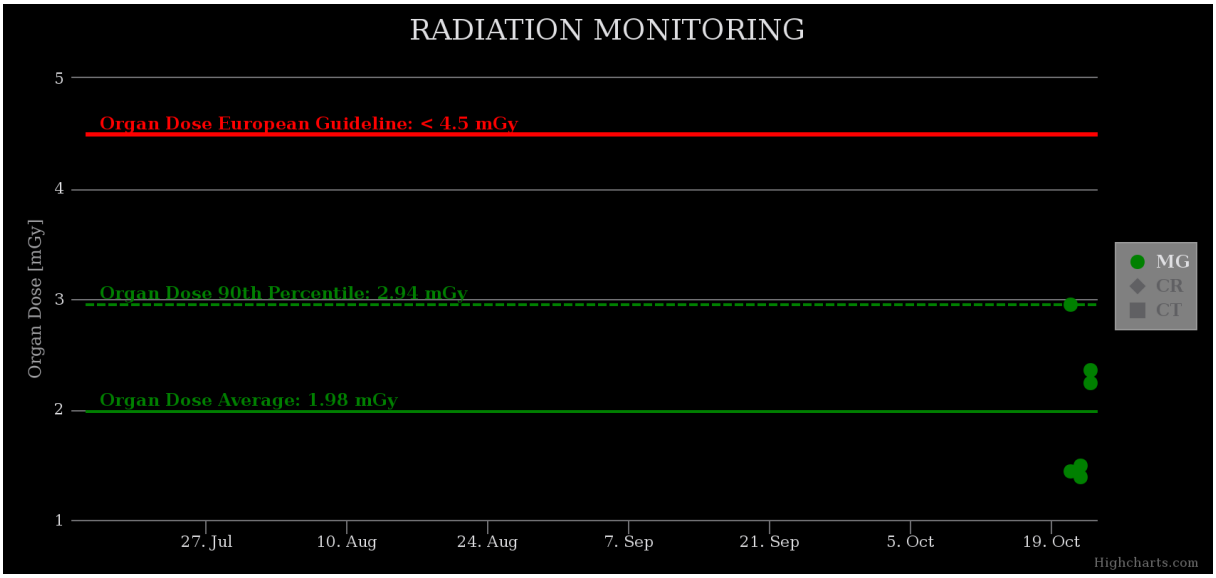
F.3.1.2 5.3 cm



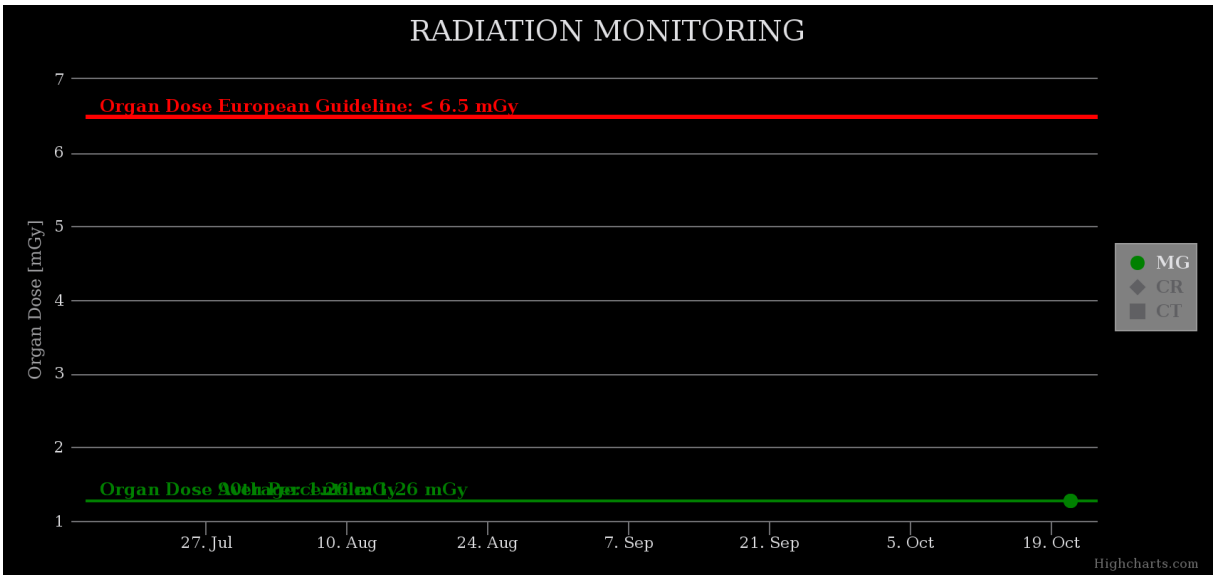
F.3.1.3 6.0 cm



F.3.1.4 7.5 cm



F.3.1.5 9.0 cm



F.3.2 Compression Force