MEDIRAD

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Deliverable D2.2

Implementation and testing of the RDF repository

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Abbreviations

API	Application Programming Interface
BFO	Basic Formal Ontology
CID	(DICOM) Context Group Identifier
CT	Computed Tomography
CTDI	Computed Tomography Dose Index
DCM	DICOM Content Mapping resource
DICOM	Digital Imaging and Communications in Medicine
FHIR	Fast Healthcare Interoperability Resources
FMA	Foundational Model of Anatomy
IOD	Information Object Definition
IRDBB	Image and Radiation Dose BioBank
IRI	Internationalized Resource Identifier
LOINC	Logical Observation Identifiers Names and Codes
NCBO	National Center of Biomedical Ontology
NM	Nuclear Medicine
OBO	Open Biological and Biomedical Ontology
OWL	Ontology Web Language
PACS	Picture Archiving and Communication System
PET	Positron Emission Tomography
RDF	Resource Description Framework
SNOMED	Systematized Nomenclature of Medicine
SPARQL	Simple Protocol And RDF Query Language
SPECT	Single Photon Emission Computed Tomography
SOP	(DICOM) Service Object Pair
SQL	Structured Query Language
SR	(DICOM) Structured Reporting
TID	(DICOM) Template Identifier
UML	Unified Modeling Language
W3C	World Wide Web Consortium
WADO	(DICOM) Web Access to DICOM Objects
XML	eXtensible Markup Language
XSD	XML Schema Definition

Technical terms glossary

Basic Formal Ontology (BFO)	The Basic Formal Ontology is an upper level ontology (or foundational ontology). It provides a set of basic classes and relations that can be used in any application domain. It provides a basic modeling framework that facilitates the consistent modeling of entities in complex pluridisciplinary applications. BFO is used by all the ontologies of the Open Biological and Biomedical Ontology (OBO) Foundry.
DICOM Context Group Identifier (CGI)	DICOM Context Groups specify Value Set restrictions for the use of codes in the DICOM standard. DICOM Context Groups are referred to using Context Group Identifiers.
DICOM Content Mapping resource (DCM)	DICOM uses as much as possible existing terminology resources (such as SNOMED CT, LOINC, UCUM). However, DICOM manages its own terminology resource called DICOM Content Mapping resource.
Fast Healthcare Interoperability Resources (FHIR)	Fast Healthcare Interoperability Resources refer to a set of data models defined by HL7 for the representation and exchange of medical data. Open source implementations of FHIR-compatible databases exist to manage medical data based on FHIR. Such an implementation is used to manage and store non-DICOM data in the IRDBB system.
Foundational Model of Anatomy (FMA)	The Foundational Model of Anatomy is a reference ontology addressing the domain of normal human anatomy. MEDIRAD uses an extract of FMA for representing all information pertaining to anatomy.
Information Object Definition (IOD)	In DICOM, an Information Object Definition is an information object that can be exchanged between DICOM Application Entities.
Image and Radiation Dose BioBank (IRDBB)	The Image and Radiation Dose BioBank is a resource for managing image and dose data in an integrated way. IRDBB supports both DICOM data and non-DICOM data. The IRDBB software supports importation, internal management and query/retrieval of MEDIRAD research data.
Open Biological and Biomedical Ontology (OBO)	The Open Biological and Biomedical Ontology (OBO) Foundry is a collective of ontology developers that are committed to collaboration and adherence to shared principles. The mission of the OBO Foundry is to develop a family of interoperable ontologies that are both logically well-formed and scientifically accurate.
Ontology Web Language (OWL)	The Ontology Web Language is one of the main standard languages developed by the World Wide Web Consortium (W3C) for representing ontologies. It is based on Description Logics (DL), a term that denotes a family of knowledge representation languages.
Resource Description Framework (RDF)	The Resource Description Framework (RDF) is a family of W3C specifications used as a general method for conceptual description or modeling of information that is implemented in web resources, using a variety of syntaxes. In practice, RDF is a directed, labeled graph data format for representing information in the Web, that is also used in knowledge

	management applications. [adapted from Wikipedia]
Simple Protocol And RDF Query Language (SPARQL)	The SPARQL specification defines the syntax and semantics of the SPARQL query language for RDF. SPARQL contains capabilities for querying required and optional graph patterns along with their conjunctions and disjunctions. SPARQL also supports extensible value testing and constraining queries by source RDF graph. The results of SPARQL queries can be results sets or RDF graphs. [adapted from Wikipedia]
DICOM Service Object Pair (SOP)	A DICOM Service Object Pair is a specification of a service in the DICOM standard. It associates an object class (i.e. an Information Object Definition) to a set of services that can be applied to this object.
DICOM Structured Reporting (SR)	DICOM Structured Reporting is a specification of a class of objects in the DICOM standard, based on a hierarchical organization of observations (called SR tree). DICOM SR is used for representing a broad range of documents such as reports of imaging procedures, procedure logs, reports of Computed Assisted Detection (CAD) analyzes, and radiation dose structured reports.
DICOM Template Identifier (TID)	A DICOM SR Template specifies the structure of a sub-graph of a DICOM SR tree. It is represented as a table describing the characteristics of each node (called content item) of the SR sub-graph, such as: nesting level, type of node (e.g. CODE, TEXT, PNAME, etc), type of relation with parent node, multiplicity (e.g. unique or multiple), requirement type (i.e. mandatory or optional), restrictions on content (for CODE nodes). DICOM SR Templates are referred to by means of DICOM Template Identifiers, e.g. to specify their use in a particular Structured Report IOD.
Unified Modeling Language (UML)	Unified Modeling Language is a general-purpose, developmental, modeling language in the field of software engineering, that is intended to provide a standard way to visualize the design of a system. Various kinds of models can be represented in UML, including Class Diagrams, Sequence Diagrams, Use Case Diagrams etc. [adapted from Wikipedia]
DICOM Web Access to DICOM Objects (WADO) or DICOMweb	DICOM Web Access to DICOM Objects (also called DICOMweb) is a term applied to the family of RESTful DICOM services defined for sending, retrieving and querying for medical images and related information. DICOMweb provide a light-weight mobile device and web browser friendly mechanism for accessing images, which can be implemented by developers who have minimal familiarity with the DICOM standard and which uses consumer application friendly mechanisms like http, JSON and media types (like "image/jpeg") to the maximum extent possible.The standard is formally defined in DICOM PS3.18 Web Services. [adapted from Wikipedia]
eXtensible Markup Language (XML)	The Extensible Markup Language (XML) is a markup language of the W3C that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable. It is a textual data format with strong support via Unicode for different human languages. Although the design of XML focuses on documents, the language is widely used for the

	representation of arbitrary data structures such as those used in web services. Several schema systems exist to aid in the definition of XML-based languages, while programmers have developed many application programming interfaces (APIs) to aid the processing of XML data. [adapted from Wikipedia]
XML Schema Definition (XSD)	XSD (XML Schema Definition) is a recommendation of the W3C, that specifies how to formally describe the elements in an Extensible Markup Language (XML) document. It can be used by programmers to verify each piece of item content in a document. They can check if it adheres to the description of the element it is placed in. Like all XML schema languages, XSD can be used to express a set of rules to which an XML document must conform in order to be considered "valid" according to that schema. [adapted from Wikipedia]

1. Introduction

This Deliverable describes the development of the RDF repository (also called Metadata repository) that constitutes the semantic repository of the *Image and Radiation Dose BioBank* (IRDBB).

It recalls the motivation for developing this component, and describes the methodology for its development and integration into the IRDBB system. The work described in this Deliverable is based on the needs expressed by the MEDIRAD partners in their answers to the questionnaire sent on October 5th, 2017 (User needs concerning the IRDBB repository [1]).

The work was done primarily by INSERM, in close collaboration with two MEDIRAD partners (b<>com and ITMI), who co-develop with INSERM the IRDBB system.

2. Content

2.1 Introduction

2.1.1 Motivation for the RDF repository

2.1.1.1 Context

The context of this work is the design of an integrated repository of dosimetric and image data (called *Image and Radiation Dose Biobank* or IRDBB). This system will support the storage and sharing of image and radiation dose data that are produced and used in the Clinical research studies involved in the MEDIRAD project.

This repository will be composed of two main components:

1) a *DICOM data repository* suitable for managing radiological images and Radiation Dose Structured Reports, and
2) a *RDF repository*, supporting the semantic (i.e. ontology-based) descriptions of both DICOM and non-DICOM data, and facilitating the querying of the IRDBB repository.

The main advantage expected from the use of a semantic repository is the ability to query the RDF database, using queries expressed in the SPARQL query language. The latter provides a similar functionality as SQL (the query language for relational databases), but with enhanced possibilities resulting from the use of domain knowledge embedded in the ontology. For example, queries can use as search criteria the entities and relationships appearing in the actual content of DICOM CT Radiation Dose Structured Reports.

2.1.1.2 Metadata repository

Functionally, the metadata repository must store in structured form any information that may be involved in users' queries, aiming at:

- selecting particular DICOM documents (images, doses calculated by the image acquisition system) involved in a Clinical research study carried out in MEDIRAD
- selecting specific dose information about images managed in the MEDIRAD Clinical research studies, as well as provenance data associated to them (e.g. how such doses were estimated).

This involves several kinds of data.

1. Essential data about images and how they were acquired (main aspects of acquisition protocol, especially those impacting dose and / or useful for dose calculation); the list of images to be supported is provided in Table 1
2. Relation of those images with MEDIRAD Clinical research studies
3. Essential data items about dosimetric data estimated by the image acquisition device, encoded as DICOM Radiation Dose Structured Reports (the Root Templates of corresponding DICOM IODs are listed in Table 2)
4. Non-DICOM documents describing dosimetric data calculated in the context of MEDIRAD Clinical research studies, such as organ doses and associated provenance data, documenting how this dosimetric data were obtained (descriptions of the main processing steps and associated input and output data)
5. Relation of those dosimetric data with MEDIRAD Clinical research studies.

CT Image IOD
Enhanced CT Image IOD
PET Image IOD
Enhanced PET Image IOD
NM Image IOD

Table 1. List of DICOM Image IODs

Template ID	Root template
TID 10011	CT Radiation Dose SR IOD Templates
TID 10021	Radiopharmaceutical Radiation Dose
TID 10030	Patient Radiation Dose
TID 10001	*Projection X-Ray Radiation Dose (not analyzed yet)*

Table 2. List of DICOM Dose SR IOD Root templates

2.1.2 Main aspects of the design

The design of the RDF repository took into account the IRDBB architecture, defined in collaboration with b<>com and ITMI, and described in [2].

2.1.2.1 Integration into the IRDBB architecture

2.1.2.1.1 IRDBB architecture

Figure 1 details the proposed architecture of the IRDBB system. The metadata repository will consist in a RDF database implemented in a RDF Triple store. This RDF database will contain data that are instances of the classes of the ontology as well as relationships connecting these instances.

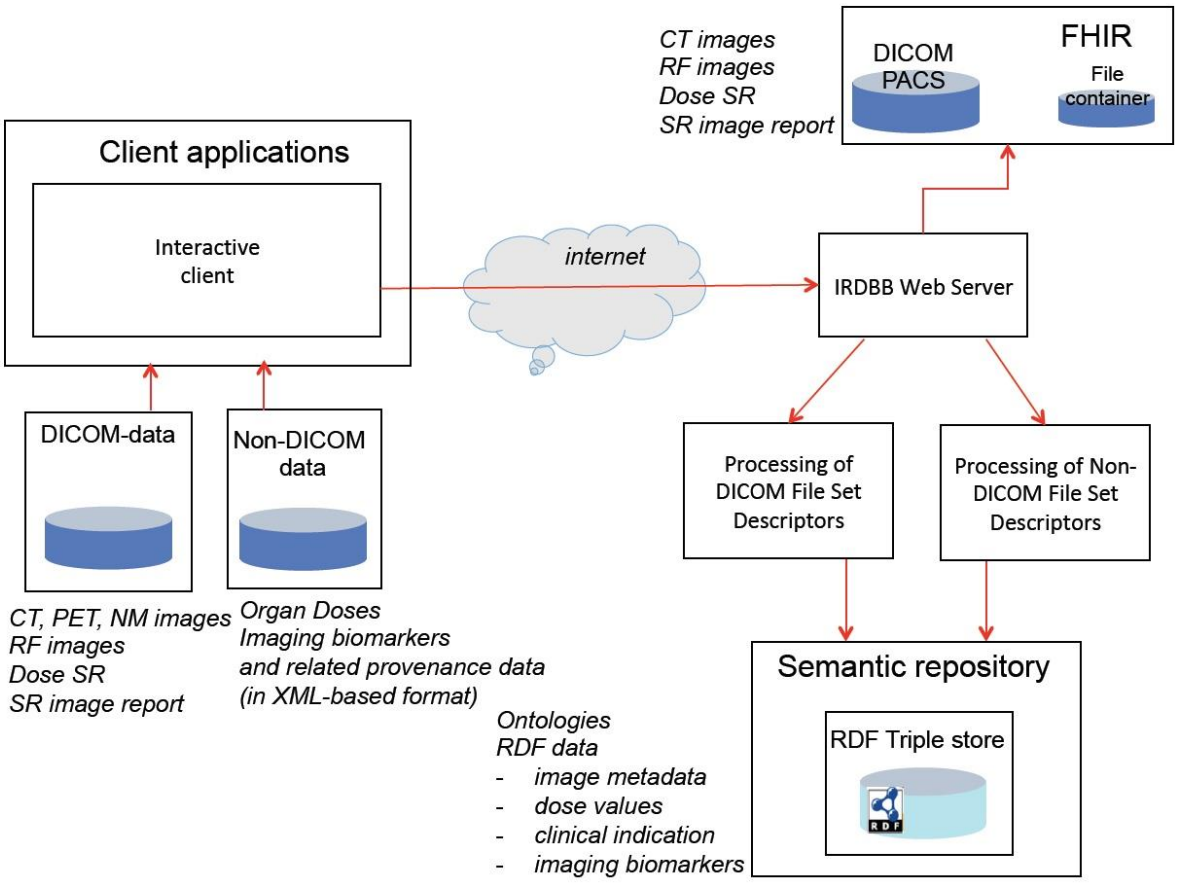


Figure 1. Proposed architecture of the IRDBB system

The IRDBB system is represented in the right part of Figure 1. It is composed of two main components: a *PACS*, managing the DICOM data, and the *Metadata repository*, supporting the semantic database, hosted on a RDF Triple store. Both are fed through a Web server (IRDBB Web Server) in interaction with the client applications, which function is to import or query and retrieve the image and dosimetric data.

2.1.2.1.2 Importation of DICOM and non-DICOM documents

As explained in [2], data will be imported into IRDBB in *File sets*. Each File set pertains to one patient, and to his/her participation in one Clinical research study. Two kinds of File sets are distinguished:

- *DICOM File sets*, that are composed of DICOM files only
- *Non-DICOM File sets*, that are composed of:
    - non-DICOM files (files that will be stored in the IRDBB system but their detailed content will not be stored in the Metadata repository)
    - and of one XML Description file (containing the detailed data to be stored into the Metadata repository).

Management of DICOM File sets: The importation software will import DICOM files into the DICOM repository and will automatically create an XML description file (called *DICOM File set Descriptor*). As explained in [2] "this XML Description File is used to inform the Metadata repository which DICOM files have been uploaded to the PACS and to which Clinical research study they should be associated. This XML Description file will contain: 1) the essential reference links with the Clinical research study and between DICOM entities; 2) the essential DICOM data items and metadata items". This content will be translated into RDF and stored in the RDF repository.

Management of Non-DICOM File sets: The importation software will import non-DICOM files into the file manager of the Metadata repository. It will import the XML description file (called *Non-DICOM File set Descriptor*) into the Metadata repository. This content will be translated into RDF and stored in the RDF repository.

2.1.2.2 Main aspects of the development

The development of the RDF repository involves three main aspects:

1. The design of the ontology
2. The design of the RDF software, called *Semantic Translator* (to populate the RDF repository)
3. The deployment on the STARDOG Triple store and integration

These three aspects were addressed in sequence, because the development of the Semantic Translator consists in populating the RDF database with instances of the classes of the ontology and relating these instances by means of object properties of the ontology; similarly, deployment of the RDF database on the STARDOG Triple store can be done only once the Semantic Translator is available. However, these three tasks are now managed in parallel, since the ontology is still evolving, based on refined understanding of the MEDIRAD users' needs in the context of the various Clinical research studies which data are planned to be managed in the IRDBB system.

2.2 Main achievements

2.2.1 Design of the ontology

The design of the ontology corresponds to the specification of the semantics of the information to be managed in the RDF repository.

Therefore, it is based on a needs analysis, i.e. an analysis of what information needs to be supported in the IRDBB system and what queries MEDIRAD users will express in the future operation of the

system. This design must take into account existing ontologies, so that not to reinvent the wheel, on the one hand, and to maximize the chances that the IRDBB system will be able to interoperate and be federated with similar data repositories (if needed), on the other hand.

2.2.1.1 Method

2.2.1.1.1 Definition of the scope of the ontology

The scope of this ontology was defined from the answers received to the questionnaire sent to the MEDIRAD partners on October 5th, 2017 [1]. Basically, these answers highlighted the importance of the various DICOM Radiation Dose Structured Reports, and suggested that most of the data items that they contain should be represented in the semantic repository. So, the early versions of the ontology primarily rely on the specification of the contents of the existing DICOM Dose report Information Object Definitions (IODs). It was assumed that most of entities to be used in the IRDBB semantic repository actually appear in the DICOM Dose reports, which justifies to start with these terms.

The first aspect of the work was a preliminary identification of the relevant entities from the relevant templates specified in DICOM Part 16. These templates have a hierarchical structure described in Annex 1. The list of the Root templates corresponding to the three main DICOM Dose Reports that we have considered is given in Table 2.

This analysis led to the design of a UML class diagram, showing both the main involved entities and the basic relationships connecting them. The latter are important because they will help specifying:

- essential properties to be modeled in the axioms associated to each class of the ontology
- relationships that will ultimately connect the instances in the IRDBB semantic repository.

Besides the templates, it was also necessary to consider in detail the DICOM Content Mapping Resource (DCMR) Context Groups that are referred in the templates, because they list the actual coded values that will be found in the actual DICOM reports SOP instances to be managed in the IRDBB repository. For example, the list of Radiosensitive Organs is provided in CID 10044.

2.2.1.1.2 Alignment with, and reuse of existing ontologies

The second aspect of the work consisted in searching in the ontology literature and in the existing ontology repositories (NCBO[1] Bioportal, Ontobee repository[2]) what ontological resources could be reused.

As a general strategy, it was decided to use the Basic Formal Ontology [3] (BFO2[3]) as a foundational ontology, and to rely as much as possible on the ontologies available from the Open Biomedical Ontologies (OBO) foundry. The list of the ontologies to be reused is provided in Table 3.

[1] National Center of Biomedical Ontology : https://bioportal.bioontology.org/

[2] OntoBee : http://www.ontobee.org/

[3] BFO2: https://github.com/BFO-ontology/BFO2

Acronym	Name	Entirety or extract
BFO2	Basic Formal Ontology	entirety
OBI	Ontology of Biomedical Investigations	extract
IAO	Ontology of Information Artefacts	extract
FMA	Foundational Model of Anatomy	extract
UO	Ontology of Units (of Measurements)	extract
PATO	Ontology of qualities (phenotypic traits)	extract
SNMI	Ontology of radiopharmaceuticals (SNMI)	extract
CheBI	Ontology of radionuclide (CheBI)	extract

Table 3. List of reused ontologies

Concretely, this led to associating to each important entity of the previous class diagram either a corresponding term from an existing ontology, or a term that provides a superclass of this entity, which will be given an identifier (IRI) in the MEDIRAD ontology.

When multiple terms need to be extracted from the same ontological source, this extraction needs to be automated. Based on our experience, we have used the OntoFox[4] software that allows to tune and to achieve such extraction. This software allows to specify precisely what items should be extracted (e.g. parent classes, subclasses, associated axioms and annotation properties). It produces an OWL file that constitutes a module of the ontology (to be imported by the application ontology).

2.2.1.1.3 Modeling of entities

As a general modeling approach, we rely on the "realism-based" principle, consisting in focusing attention on the entities that exist in reality, rather than abstractions, as recommended in the OBO foundry community[5]. This consists is making very clear distinctions between, e.g. irradiated entities (e.g. a physical person), the radiation exposure processes (e.g. a CT examination, injection of a radiopharmaceutical), and information about such entities (e.g. a DICOM dose structured report, a CT Dose Index $_{vol}$ or Dose x Length Product value). Concerning the record of quantitative values, we introduced distinctions between measurement values (that result from some measurement or estimation process), device settings (i.e. elements of an acquisition protocol consisting on setting some parameter to a value) and device characteristics (i.e. elements of specification of a device component, e.g. nominal collimation width). This approach leads to ignoring many entities in DICOM templates that do not have any counterpart in reality, but are only containers of information, e.g. Observer Context, CT Irradiation Event Data, CT Dose Check Details, Radiopharmaceutical Administration Patient Characteristics, etc.

As far as DICOM terminology is concerned, we reused many context groups that are referred to in the DICOM templates involved in the various radiation dose structured reports (DICOM Part 16 Content Mapping Resource). Some terms come from SNOMED and LOINC, but most of them come from the DCM terminology resource. Related information about each term (i.e. code value, coding scheme designator, code meaning, definition) was carefully included into OntoMEDIRAD as annotation data. As for the terms from the DCM terminology resource, a software (*DCM Term Extractor*) was developed so that to automatically retrieve the IRI and annotations from the DCM.owl resource, available from the NCBO Bioportal ontology repository.

4 OntoFox: http://ontofox.hegroup.org/

5 Open Biological and Biomedical Ontology (OBO) Foundry: http://www.obofoundry.org/

2.2.1.2 Result

The OntoMEDIRAD ontology is organized as a set of files represented in OWL, the Web Ontology Language. At this stage of development, the ontology is essentially a taxonomy of classes, related by the subClassOf object property. The detailed definitions are provided mainly for those terms that were retrieved from existing ontological resources. For the other entities, definitions will be added in the future updates of the ontology, as well as formal axioms, when relevant.

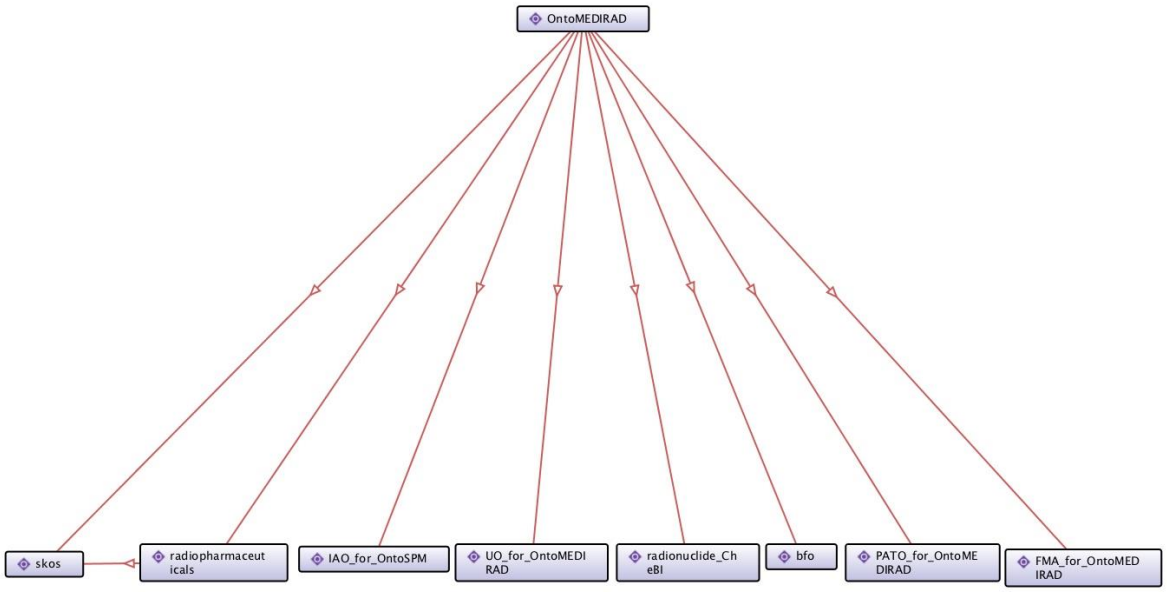


Figure 2. Ontologies imported by OntoMEDIRAD

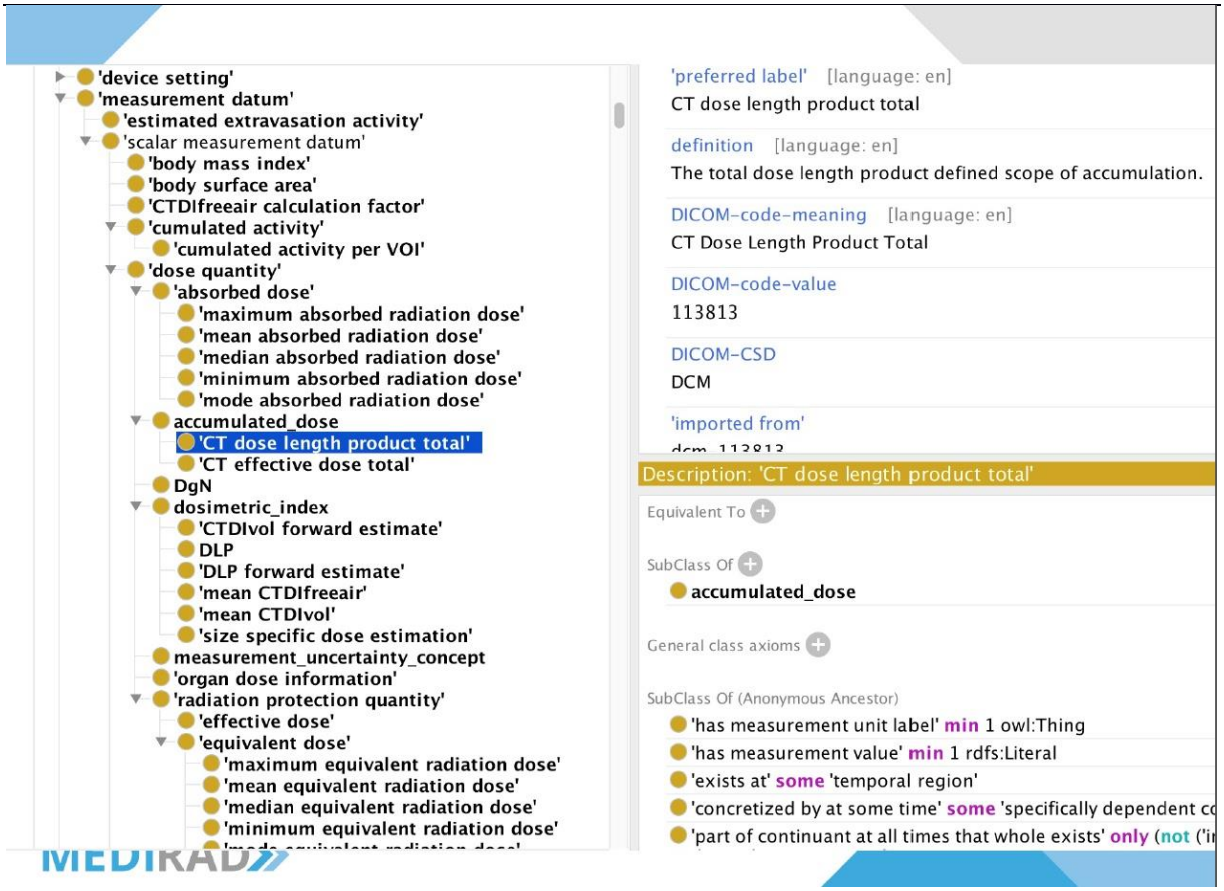


Figure 3. Extract of the OntoMEDIRAD taxonomy of classes

At the date of writing of this Deliverable, the current version of the OntoMEDIRAD ontology is version 1.1 (released on March 30th, 2018); it is available for download from the EIBIR Document Sharing Platform.

2.2.2 Design of the Semantic Translator

As explained above, the function of this software is to create the RDF data that will populate the RDF repository. The data to be translated into RDF has two origins:

- XML DICOM File set descriptors and non-DICOM File set descriptors
- Actual content the DICOM Structured report trees (called *content items*).

The first version of the Semantic Translator processes XML DICOM File set descriptors referring to DICOM Radiation Dose Structured Reports. It focuses primarily on the content of the CT Radiation Dose Structured Report.

2.2.2.1 Method

The software, developed in Java, parses the SR content tree, thanks to a software library developed by David Clunie (PixelMed), also editor of the DICOM standard.

This allows parsing the various content items and relations involved in the relevant SR templates specified in DICOM Part 16. Recognition of each content item may lead to the creation of one or more RDF instances of the ontology's classes, and to the creation of one or more RDF assertions that connect these instances to some data item (e.g. numerical value, or character string) or to some other RDF instances, using a data property or an object property (respectively) from the OntoMEDIRAD ontology. The program creates in-memory representations of the ontology and of the

RDF instance graph, using the Jena API. RDF data are created by applying rules that translate into RDF the relevant DICOM information items.

All these assertions of the RDF instance graph are then serialized into a RDF data file. Then the software pushes the RDF file to a STARDOG server by using the STARDOG API.

2.2.2.2 Result

The current version of the software supports most of the content of the DICOM CT Radiation Dose Structured Report, especially what concerns the cumulated doses (considering the related scope of accumulation) and the individual irradiation events (corresponding to the different image acquisitions) with the corresponding dose indices and major protocol settings.

Information items about the patient contained in the DICOM metadata are also supported, and translated in RDF. Other DICOM metadata are not yet supported.

As for anatomical target regions, it takes into account the translation between the anatomical terms used in DICOM and the corresponding terms of the FMA ontology (including management of laterality).

2.2.3 Deployment on the STARDOG Triple store, integration and testing

Preliminary software integration was achieved early April 2018, aiming at testing the importation and semantic querying of the content of DICOM CT Radiation Dose Structured Reports, including:

- Interactive creation of a DICOM File set (drag and drop of DICOM CT Radiation Dose Structured Reports) (b<>com software)
- Automatic creation of the corresponding DICOM File set descriptor (b<>com software)
- Automatic importation of DICOM files into the DCM4CHE PACS (b<>com software)
- Creation of the RDF data file corresponding to this DICOM File set descriptor (INSERM software)
- Importation of this RDF data file into a MEDIRAD database supported by STARDOG Triple store (INSERM software)
- Querying of RDF data by means of SPARQL queries (selected interactively by a user and sent by a b<>com software).

2.2.3.1 Method

2.2.3.1.1 Deployment on STARDOG

STARDOG[6] is a powerful platform (RDF Triple store) to store and search semantic data. A community version can be downloaded free of charge (but with a mandatory registration).

Semantic data are stored on the STARDOG server.

The initial deployment is based on a single MEDIRAD database. This database contains:

- the OWL files of the OntoMEDIRAD ontology
- the RDF files that were produced by the Semantic Translator (translation into RDF of the content of DICOM File set descriptors)

[6] https://www.stardog.com/

2.2.3.1.2 Integration and testing

The whole configuration relies on a set of RESTful Services packaged in Docker[7] containers and communicating through http.

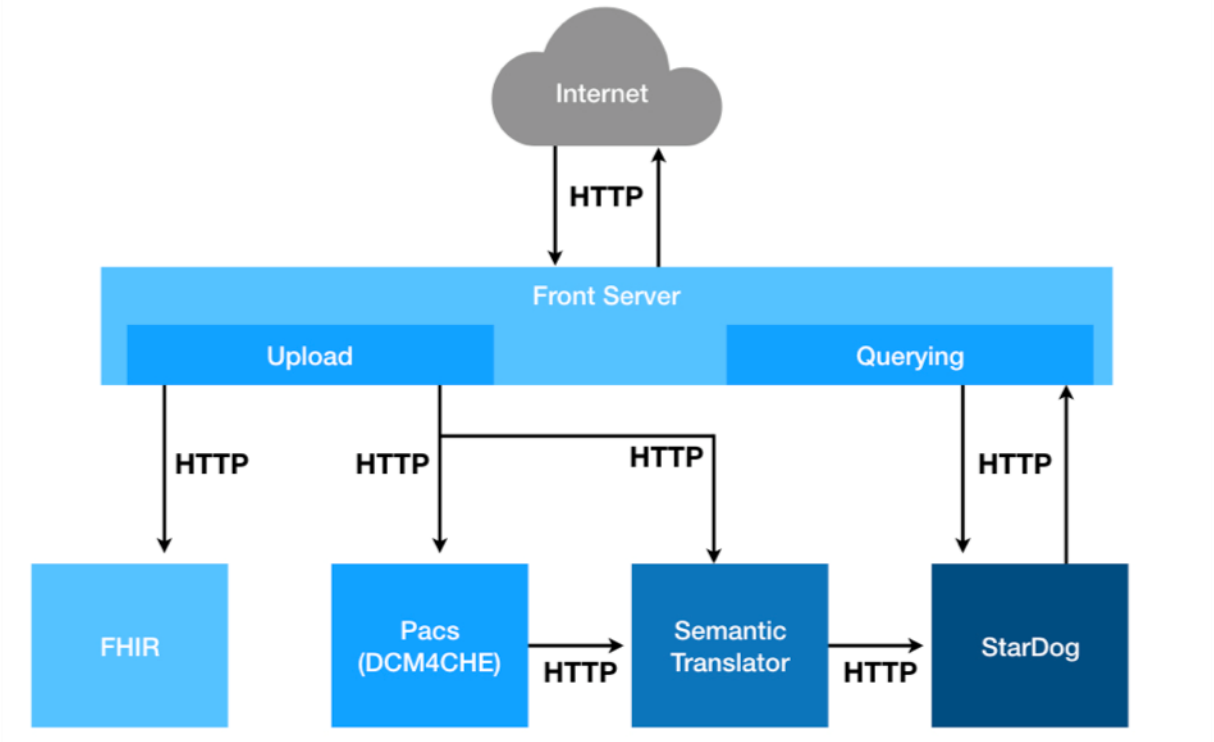


Figure 4. Architecture for preliminary integration (April-May 2018)

2.2.3.2 Result

All components are integrated, according to the architecture shown on Fig.4. FHIR will store non-DICOM Files.

A full demonstration is shown on this video: https://www.youtube.com/watch?v=maptn3dIjYw (the Semantic Translator it is not visible on the video since it has no User Interface).

Once dragged and dropped on the Front Server (Fig. 5), DICOM files are analyzed and transmitted to the PACS; a DICOM File set descriptor is created then pushed to the Semantic Translator, that creates the semantic graph, which is then pushed to the STARDOG server in a few seconds.

The user can then select a query from a set of predefined queries, represented in SPARQL. Three demonstration queries were proposed:

- QUERY #1: list of CT radiation SR, cumulated doses and scope of accumulation
- QUERY #2: list of reports, irradiation events, and related dose indices
- QUERY #3: list of CT acquisitions, target regions and basic CT parameters

Fig 6. Shows the results returned following QUERY #2.

[7] https://www.docker.com/

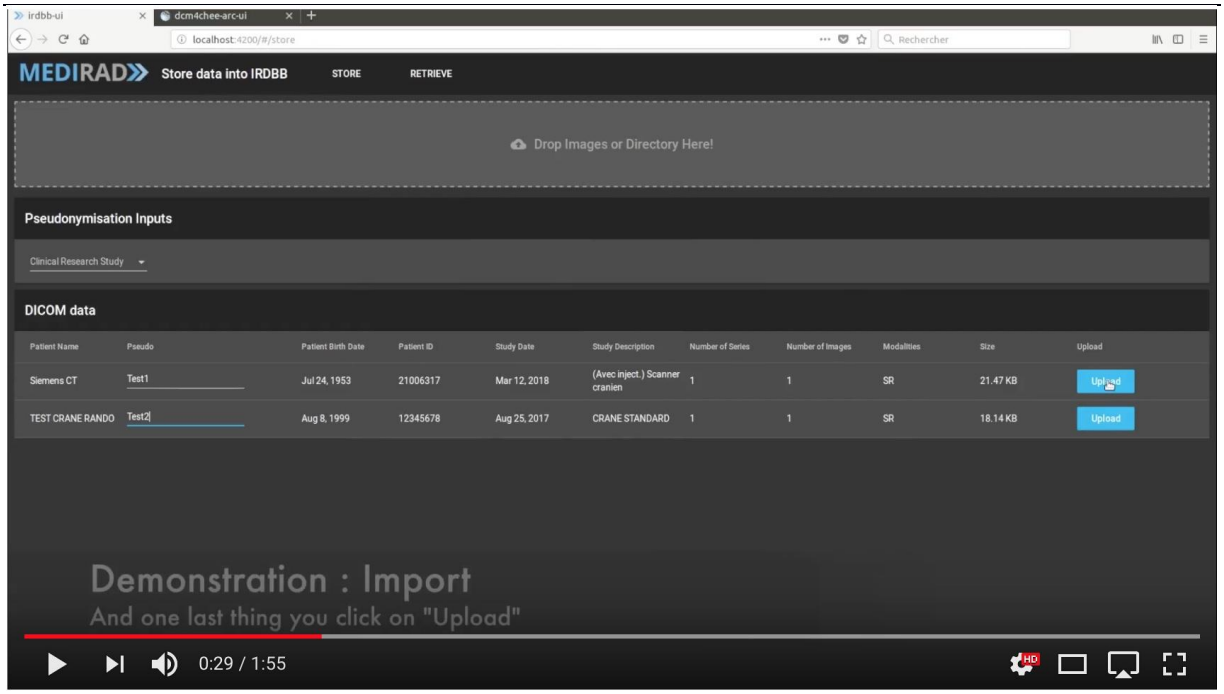


Figure 5. IRDBB Demonstration video: selected DICOM SRs to be imported

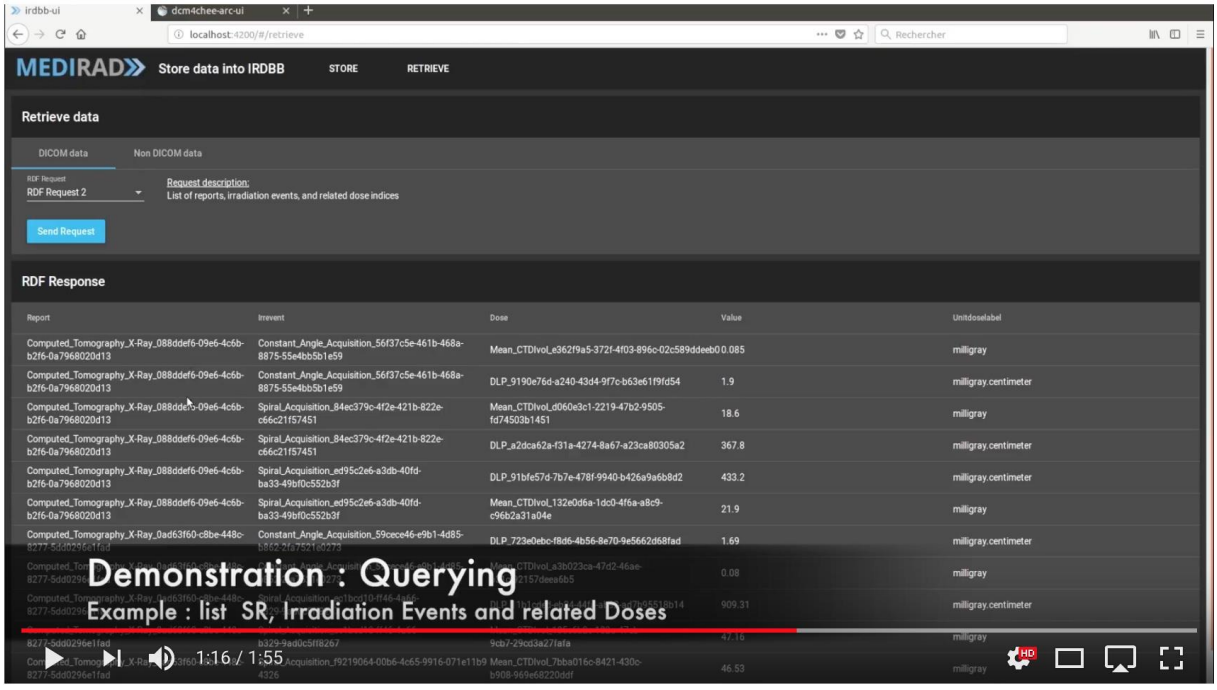


Figure 6. IRDBB Demonstration video: result of SPARQL query

2.3 Next steps

2.3.1 Further extension of the ontology

The major extensions will be related to additional needs that will arise from the analysis of the workflows of the different MEDIRAD Clinical research studies which data are planned to be managed in the IRDBB system, namely:

1. Subtask 2.1.2: Development of a novel method to estimate patient organ dose from chest CT (UoC)
2. Subtask 2.3.2.1: Estimation of patient organ doses from chest CT used in multi-modality systems (UGENT)
3. Subtask 2.3.2.2: Estimation of patient organ doses from two commonly used PET and SPECT tracers (INSERM)
4. Task 3.2: Biokinetic modelling and treatment planning – I-131 ablation of thyroïd (RMH/ICR)
5. Task 3.3: Dosimetry calculation - I-131 ablation of thyroïd (INSERM)
6. Subtask 5.3.1: Doses for cohort members from extension of follow-up (ISGlobal)
7. Subtask 5.3.2: Estimation of doses for sujects in the case-control study (ISGlobal)

A preliminary analysis of the workflow pertaining to WP3 (Tasks 3.2 and 3.3) was completed, in collaboration with our INSERM partners in Toulouse. This analysis allowed to specify a first version of the XML schemas (.XSD files) to be used to populate the XML DICOM File set descriptors and Non-DICOM File set descriptors pertaining to the corresponding research data (Annex 2 and 3).

It is assumed that the needs arising from Subtask 2.1.2, 2.3.2.1 and 2.3.2.2 are properly addressed in this specification. A prototype implementation is in progress to demonstrate the remote importation of both DICOM and non-DICOM images from the University of Crete, addressing the needs of Subtask 2.1.2. This achievement corresponds to Milestone MS17 Implementation of the RDF module of the central repository. The draft specification of the Non-DICOM File set descriptors pertaining to the corresponding research data (contours of at-risk organs, 3D maps of absorbed doses) in provided as Annex 4.

Version 1.2 of the OntoMEDIRAD ontology takes into account a part of these needs.

The next steps will consist in interacting closely with all the project partners (of WP2, WP3 and WP5) in charge of these subtasks, in order to agree on the information to be managed, through the specification of the XML schemas (.XSD file) to be used to populate the XML DICOM and Non-DICOM File set descriptors pertaining to their specific research data.

Besides, a discussion has started with UMC-Mainz to explore how the structured reports considered in Subtask 2.4.3 should be described in the RDF repository. Indeed, it is clearly envisaged that the reports can be stored as DICOM or Non-DICOM files in the IRDBB system, but their level of semantic description in the RDF repository remains to be defined.

2.3.2 Further development of the Semantic Translator

The next steps of the development of the Semantic Translator are the following:

In the next month:

- Management of data properties providing a http handle (WADO-RS reference) to DICOM instances available in the IRDBB PACS
- Extension of the software to manage DICOM image metadata (for CT, PET and SPECT DICOM images), especially the various protocol settings.

In the following 6 months:

- Extension of the software to manage Non-DICOM File set descriptors.

2.3.3 Refined deployment on STARDOG

Other modalities of deployment on STARDOG are being explored so that to optimize the capabilities and efficiency of semantic querying, e.g.:

- Use of additional separate databases for the each MEDIRAD Clinical research study
- Use of *Named graphs* corresponding to each individual RDF graph produced by the Semantic Translator
- Use of rule-based semantic post-processing, in order to enrich the RDF graphs.

2.3.4 Deployment in server mode

A prototype deployment in server mode (hosted in ITMI facilities at Geneva) is planned, so that to implement the MS17 milestone (testing of on-line importation of dosimetric data by UoC).

3. Conclusion

As presented at the MEDIRAD Plenary Meeting held in Rome on 12-13 April 2018, the development on the IRDBB system is on good way. The development of the RDF repository is delicate because highly dependent on the choices of the MEDIRAD users and on the Clinical research projects which data will eventually be managed in the IRDBB system.

The initial plan was to rely on existing standards to communicate image and dose data (i.e. DICOM), so that to relax as much as possible the previous constraint. However, it turns out that most Clinical research studies in MEDIRAD actually do not use existing standards to communicate; e.g., neither the Radiopharmaceutical Radiation Dose SR, nor the DICOM Patient Radiation Dose SR seem to be used.

Consequently, it is of key importance that the MEDIRAD partners who plan to use the IRDBB system to manage their research data collaborate actively with those involved in the IRDBB development (i.e. INSERM, b<>com and ITMI), so that:

1. to specify in detail what information has to be managed, and so that
2. they can produce the XML File set descriptors that are needed to document the meaning and provenance of research data files.

In this respect, the M12-M18 time period is critical because it is a period in which development resources still exist to further develop and test the IRDBB system, which will be much harder after M24 (Fig. 7).

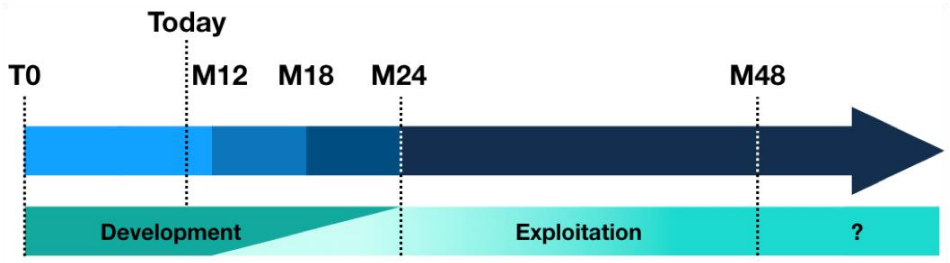


Figure 7. Scheduling of development and exploitation of the IRDBB system

4. References

[1] Questionnaire “User needs concerning the IRDBB repository”, MEDIRAD Report, October 5th, 2017

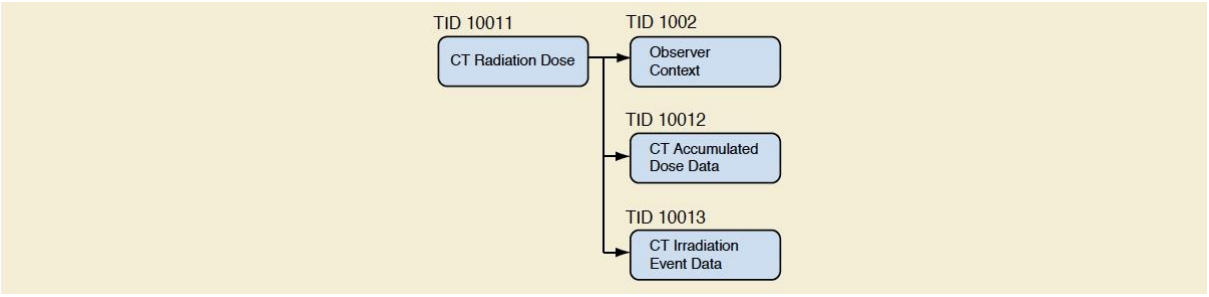
[2] E. Guiffard, b<>com, Specification of DICOM import and central repository communication protocol 28/09/2017

[3] B. Smith, Basic Formal Ontology 2.0: Specification and user's guide, 26/6/2015

ANNEX 1

This annex provides the hierarchical structure of the templates of the three IODs considered in this version of the ontology, as well as a basic text describing each of them (copied from the DICOM standard Part 16)

CT Radiation Dose SR IOD Templates



TID 10011 CT Radiation Dose

This Template defines a container (the root) with subsidiary Content Items, each of which corresponds to a single CT X-Ray irradiation event entry. There is a defined recording observer (the system or person responsible for recording the log, generally the system).

Accumulated values shall be kept for a whole Study or at least a part of a Study, if the Study is divided in the workflow of the examination, or a performed procedure step. Multiple CT Radiation Dose objects may be created for one Study.

TID 10012 CT Accumulated Dose Data

This general Template provides detailed information on CT X-Ray dose value accumulations over several irradiation events from the same equipment and over the scope of accumulation specified for the report (typically a Study or a Performed Procedure Step).

TID 10013 CT Irradiation Event Data

This Template conveys the dose and equipment parameters of a single irradiation event.

A CT irradiation event is the loading of X-Ray equipment caused by a single continuous actuation of the equipment's irradiation switch, from the start of the loading time of the first pulse until the loading time trailing edge of the final pulse. Any on-off switching of the radiation source during the event shall not be treated as separate events; rather the event includes the time between start and stop of radiation as triggered by the user, e.g., a single sequence of scanning comprised of multiple slices acquired with successive tube rotations and table increments shall be treated as a single irradiation event. Depending on the examination workflow and the anatomical target region the CT irradiation event data may split into multiple instances of this Template for better dose estimation. The irradiation event is the "smallest" information entity to be recorded in the realm of Radiation Dose reporting. Individual Irradiation Events are described by a set of accompanying physical parameters that are sufficient to understand the "quality" of irradiation that is being applied. This set of parameters may be different for the various types of equipment that are able to create irradiation events.

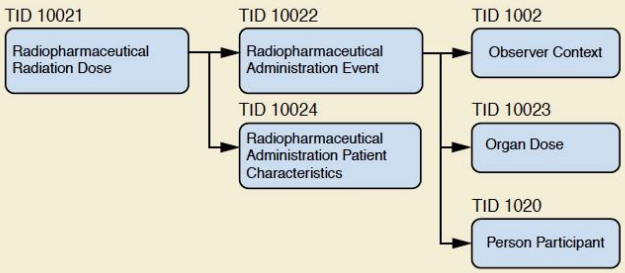
TID 10014 Scanning Length

This Template records details about the scanned region.

TID 10015 CT Dose Check Details

This Template records details related to the use of the NEMA Dose Check Standard (NEMA XR-25-2010).

Radiopharmaceutical Radiation Dose SR IOD Templates



TID 10021 Radiopharmaceutical Radiation Dose

This Template defines a container (the root) with subsidiary Content Items, each of which corresponds to a single Radiopharmaceutical Administration Dose event entry. There is a defined recording observer (the system and/or person responsible for recording the assay of the radiopharmaceutical, and the person administered the radiopharmaceutical). Multiple Radiopharmaceutical Radiation Dose objects may be created for one study.

TID 10022 Radiopharmaceutical Administration Event Data

The Radiopharmaceutical Administration Event conveys the dose and assay and time information of a single radiopharmaceutical event. A Radiopharmaceutical Administration event is one radioactive pharmaceutical administered to a patient.

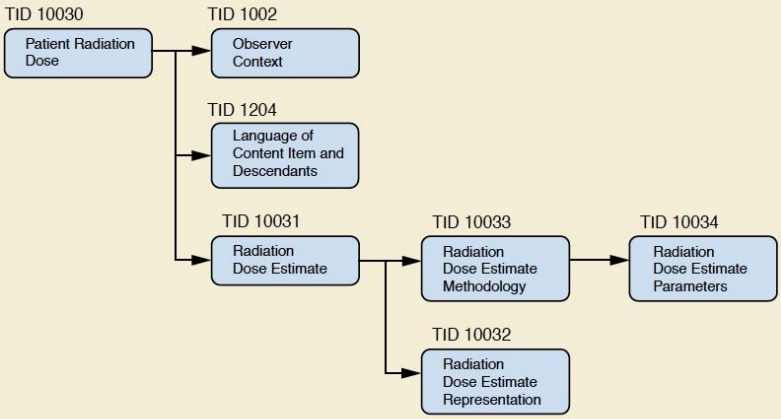
TID 10023 Organ Dose

This Template conveys the information about the dose to a single organ.

TID 10024 Radiopharmaceutical Administration Patient Characteristics

This Template describes the characteristics of the patient that are specific to the current clinical presentation (visit). The characteristics noted may affect the activity received, and how dose is calculated for the patient. Patient Characteristic concepts in this Template, which may replicate attributes in the Patient Study Module, are included here as possible targets of by-reference relationships from other Content Items in the SR tree.

Patient Radiation Dose SR IOD Templates



TID 10030 Patient Radiation Dose

This template defines a container (the root) with subsidiary content items for determining an estimated radiation dose to a patient.

TID 10031 Radiation Dose Estimate

The dose estimate is used to record the results from one analysis method from one or more radiation sources. Organ dose estimates are calculated from one or more irradiation events to a patient. The output from one or more sources of radiation can be used separately or combined to estimate the dose to a patient or individual organs.

TID 10032 Radiation Dose Estimate Representation

Different representations (e.g., images) of the distribution of absorbed energy allow a better understanding of how this energy may affect tissue.

TID 10033 Radiation Dose Estimate Methodology

This template includes the information specific to the organ dose calculation methodology used when estimating dose to individual organs, entire body or a phantom from imaging studies that use ionizing radiation.

TID 10034 Radiation Dose Estimate Parameters

This template includes the parameters that are specific to the Radiation Dose Estimate Method used in the algorithms when estimating dose to individual organs, phantoms, or the entire body from imaging studies that use ionizing radiation.

ANNEX 2

This annex provides a draft XML schema specifying the structure of the DICOM Fileset Descriptor.

```
<?xml version="1.0"?>
<xs:schema
    targetNamespace="https://www.irdbb-medirad.com"
    elementFormDefault="qualified"
    attributeFormDefault="unqualified"
    xmlns:xs="http://www.w3.org/2001/XMLSchema"
    xmlns:irdbb="https://www.irdbb-medirad.com">

    <xs:element name="DicomFileSetDescriptor">
        <xs:complexType>
            <xs:sequence>
                <xs:element name="ReferencedClinicalStudy" type="irdbb:ClinicalStudyType"/>
                <xs:element name="PatientDescriptor" type="irdbb:PatientDescriptorType"/>
                <xs:element name="DICOMStudy" type="irdbb:DICOMStudyType"
maxOccurs="unbounded" />
            </xs:sequence>
        </xs:complexType>
    </xs:element>

    <xs:complexType name="ClinicalStudyType">
        <xs:sequence>
            <xs:element name="ClinicalStudyID" type="xs:string"/>
            <xs:element name="ClinicalStudyTitle" type="xs:string"/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="PatientDescriptorType">
        <xs:sequence>
            <xs:element name="PatientID-00100020" type="xs:string"/>
            <xs:element name="PatientBirthDate-00100030" type="xs:string"/>
            <xs:element name="PatientSex-00100040" type="xs:string"/>
            <xs:element name="PatientAge-00101010" type="xs:string"/>
            <xs:element name="PatientSize-00101020" type="xs:string"/>
            <xs:element name="PatientWeight-00101030" type="xs:string"/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="DICOMStudyDescriptorType">
        <xs:sequence>
            <xs:element name="StudyInstanceUID-0020000d" type="xs:string"/>
            <xs:element name="StudyDate-00080020" type="xs:string"/>
            <xs:element name="StudyTime-00080030" type="xs:string"/>
            <xs:element name="BodyPartExamined-00180015" type="xs:string"/>
            <xs:element name="StudyDescription-00081030" type="xs:string"/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="DICOMSeriesDescriptorType">
        <xs:sequence>
            <xs:element name="SeriesNumber-00200011" type="xs:string"/>
            <xs:element name="SeriesInstanceUID-0020000e" type="xs:string"/>
            <xs:element name="SeriesDate-00080021" type="xs:string"/>
            <xs:element name="SeriesTime-00080031" type="xs:string"/>
            <xs:element name="Modality-00080060" type="xs:string"/>
            <xs:element name="Manufacturer-00080070" type="xs:string"/>
            <xs:element name="ManufacturersModelName-00081090" type="xs:string"/>
            <xs:element name="InstitutionName-00080080" type="xs:string"/>
            <xs:element name="ProtocolName-00181030" type="xs:string"/>
            <xs:element name="SeriesDescription-0008103e" type="xs:string"/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="DICOMStudyType">
        <xs:sequence>
            <xs:element name="DICOMStudyDescriptor" type="irdbb:DICOMStudyDescriptorType"/>
            <xs:element name="DICOMSeries"  type="irdbb:DICOMSeriesType" maxOccurs="unbounded"
/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="DICOMSeriesType">
        <xs:sequence>
            <xs:element name="DICOMSeriesDescriptor" type="irdbb:DICOMSeriesDescriptorType"/>
```

```
            <xs:element name="DICOMSOPInstanceDescriptor"
type="irdbb:DICOMSOPInstanceDescriptorType" maxOccurs="unbounded" />
            <xs:element name="DICOMSOPInstance" type="irdbb:DICOMSOPInstanceType"
maxOccurs="unbounded" />
        </xs:sequence>
    </xs:complexType>


    <xs:complexType name="DICOMSOPInstanceType">
        <xs:sequence>
            <xs:element name="DICOMSOPInstanceUID" type="xs:string"/>
            <xs:element name="DICOMSOPClassUID" type="xs:string"/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="StructuredReportDescriptorType">
        <xs:sequence>
            <xs:element name="ContentTemplateSequence-0040a504"
type="irdbb:DICOMCodeSequenceType" minOccurs="0" />
            <xs:element name="ConceptNameCodeSequence-0040a043"
type="irdbb:DICOMCodeSequenceType" minOccurs="0" />
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="DICOMSOPInstanceDescriptorType">
        <xs:choice>
            <xs:element name="CTImageAcquisitionDescriptor"
type="irdbb:CTImageAcquisitionDescriptorType"/>
            <xs:element name="NMImageAcquisitionDescriptor"
type="irdbb:NMImageAcquisitionDescriptorType"/>
            <xs:element name="PETImageAcquisitionDescriptor"
type="irdbb:PETImageAcquisitionDescriptorType"/>
            <xs:element name="StructuredReportDescriptor"
type="irdbb:StructuredReportDescriptorType"/>
        </xs:choice>
    </xs:complexType>

    <xs:complexType name="CTImageAcquisitionDescriptorType">
        <xs:sequence>
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            <xs:element name="ImageType-00080008" type="xs:string" minOccurs="0" />
            <xs:element name="AcquisitionDate-00080022" type="xs:string" minOccurs="0" />
            <xs:element name="AcquisitionTime-00080032" type="xs:string" minOccurs="0" />
            <xs:element name="AcquisitionType-00189302" type="xs:string" minOccurs="0" />
            <xs:element name="RevolutionTime-00189305" type="xs:string" minOccurs="0" />
            <xs:element name="TotalCollimationWidth-00189307" type="xs:string" minOccurs="0"
/>
            <xs:element name="GantryDetectorTilt-00181120" type="xs:string" minOccurs="0" />
            <xs:element name="TableFeedPerRotation-00189310" type="xs:string" minOccurs="0" />
            <xs:element name="SpiralPitchFactor-00189311" type="xs:string" minOccurs="0" />
            <xs:element name="KVP-00180060" type="xs:string" minOccurs="0" />
            <xs:element name="ExposureTime-00181150" type="xs:string" minOccurs="0" />
            <xs:element name="XRayTubeCurrent-00181151" type="xs:string" minOccurs="0" />
            <xs:element name="ExposureInMicroAs-00181153" type="xs:string" minOccurs="0" />
            <xs:element name="FilterType-00181160" type="xs:string" minOccurs="0" />
            <xs:element name="FocalSpots-00181190" type="xs:string" minOccurs="0" />
            <xs:element name="ExposureModulationType-00189323" type="xs:string" minOccurs="0"
/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="NMImageAcquisitionDescriptorType">
        <xs:sequence>
            <xs:element name="FrameOfReferenceUID-00200052" type="xs:string" minOccurs="0"/>
            <xs:element name="ImageType-00080008" type="xs:string" minOccurs="0" />
            <xs:element name="AcquisitionDate-00080022" type="xs:string" minOccurs="0" />
            <xs:element name="AcquisitionTime-00080032" type="xs:string" minOccurs="0" />
            <xs:element name="EnergyWindowInformationSequence-00540012"
type="irdbb:EnergyWindowType" minOccurs="0" maxOccurs="unbounded"/>
            <xs:element name="RadiopharmaceuticalInformationSequence-00540016"
type="irdbb:RadiopharmaceuticalType" minOccurs="0"/>
            <xs:element name="ReconstructionMethod-00541103" type="xs:string" minOccurs="0"/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="EnergyWindowType">
        <xs:sequence>
            <xs:element name="EnergyWindowName-00540018" type="xs:string"/>
```

```
            <xs:element name="EnergyWindowLowerLimit-00540014" type="xs:string"/>
            <xs:element name="EnergyWindowUpperLimit-00540015" type="xs:string"/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="RadiopharmaceuticalType">
        <xs:sequence>
            <xs:element name="Radiopharmaceutical-00180031" type="xs:string"/>
            <xs:element name="RadiopharmaceuticalCodeSequence-00540304"
type="irdbb:DICOMCodeSequenceType"/>
            <xs:element name="RadionuclideCodeSequence-005400300"
type="irdbb:DICOMCodeSequenceType"/>
            <xs:element name="RadiopharmaceuticalVolume-00181071" type="xs:string"/>
            <xs:element name="RadiopharmaceuticalStartTime-00181072" type="xs:string"/>
            <xs:element name="RadiopharmaceuticalStopTime-00181073" type="xs:string"/>
            <xs:element name="RadionuclideTotalDose-00181074" type="xs:string"/>
            <xs:element name="RadiopharmaceuticalAdministrationEventUID-00083012"
type="xs:string"/>
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    </xs:complexType>

    <xs:complexType name="DICOMCodeSequenceType">
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            <xs:element name="CodeValue-00080100" type="xs:string"/>
            <xs:element name="CodeMeaning-00080104" type="xs:string"/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="PETImageAcquisitionDescriptorType">
        <xs:sequence>
            <xs:element name="FrameOfReferenceUID-00200052" type="xs:string" minOccurs="0" />
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            <xs:element name="AcquisitionTime-00080032" type="xs:string" minOccurs="0" />
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type="irdbb:EnergyWindowType" minOccurs="0" maxOccurs="unbounded"/>
            <xs:element name="RadiopharmaceuticalInformationSequence-00540016"
type="irdbb:RadiopharmaceuticalType" minOccurs="0"/>
            <xs:element name="ReconstructionMethod-00541103" type="xs:string" minOccurs="0"/>
        </xs:sequence>
    </xs:complexType>

</xs:schema>
```

ANNEX 3

This annex provides a draft XML schema specifying the structure of the NonDICOM Fileset Descriptor, taking into account WP3 needs.

```
<?xml version="1.0"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema"
    targetNamespace="https://www.irdbb-medirad.com"
    xmlns="https://www.irdbb-medirad.com"
    elementFormDefault="qualified">
    <xs:element name="NonDicomFileSetDescriptor">
        <xs:complexType>
            <xs:sequence>
                <xs:element name="ClinicalResearchStudy">
                    <xs:complexType>
                        <xs:sequence>
                            <xs:element name="ClinicalResearchStudyID" type="xs:string"/>
                            <xs:element name="ClinicalResearchStudyTitle" type="xs:string"/>
                        </xs:sequence>
                    </xs:complexType>
                </xs:element>
                <xs:element name="PatientId" type="xs:string"/>
                <xs:element name="WP3WorkflowData" maxOccurs="unbounded">
                    <xs:complexType>
                        <xs:sequence>
                            <xs:element name="SPECTCalibration" minOccurs="0">
                                <xs:complexType>
                                    <xs:sequence>
                                        <xs:element name="SPECTCalibrationDataAcquisition"
minOccurs="0">
                                            <xs:complexType>
                                                <xs:sequence>
                                                    <xs:element name="DateTimeProcessStarted"
type="xs:string"/>
                                                    <xs:element name="PerformingInstitution"
type="xs:string"/>
                                                    <xs:element name="PhantomUsed"
type="PhantomType"/>
                                                    <xs:element
name="RadiopharmaceuticalAdministration" type="RadiopharmaceuticalAdministrationType"
minOccurs="0"/>
                                                    <xs:element name="AcquisitionProtocolUsed"
type="AcquisitionProtocolType" minOccurs="0" />
                                                    <xs:element
name="DICOMProjectionDataProduced" type="DICOMDataType" minOccurs="0" maxOccurs="unbounded" />
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                                            </xs:complexType>
                                        </xs:element>
                                        <xs:element name="SPECTCalibrationDataReconstruction"
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                                                    <xs:element name="PerformingInstitution"
type="xs:string"/>
                                                    <xs:element name="DICOMProjectionDataUsed"
type="DICOMDataType"/>
                                                    <xs:element
name="ReconstructionMethodUsed" type="ReconstructionMethodType" minOccurs="0"/>
                                                    <xs:element name="DICOMImageDataProduced"
type="DICOMDataType" minOccurs="0" maxOccurs="unbounded" />
                                                </xs:sequence>
                                            </xs:complexType>
                                        </xs:element>
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                                                <xs:sequence>
                                                    <xs:element name="DateTimeProcessStarted"
type="xs:string"/>
                                                    <xs:element name="PerformingInstitution"
type="xs:string"/>
                                                    <xs:element name="DICOMImageUsed"
type="DICOMDataType"/>
                                                    <xs:element name="SegmentationMethodUsed"
type="SegmentationMethodType" minOccurs="0"/>
```

```
                                                    <xs:element
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                                                </xs:sequence>
                                            </xs:complexType>
                                        </xs:element>
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name="SPECTCalibrationCoefficientCalculation" minOccurs="0" maxOccurs="unbounded">
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                                                <xs:sequence>
                                                    <xs:element name="DateTimeProcessStarted"
type="xs:string"/>
                                                    <xs:element name="PerformingInstitution"
type="xs:string"/>
                                                    <xs:element name="DICOMRTStructureSetUsed"
type="DICOMDataType"/>
                                                    <xs:element name="DICOMImageUsed"
type="DICOMDataType"/>
                                                    <xs:element
name="SPECTCalibrationCoefficientCalculationMethodUsed" type="xs:string" minOccurs="0"/>
                                                    <xs:element name="SensitivityFactorUsed"
type="SensitivityFactorType" minOccurs="0"/>
                                                    <xs:element
name="SPECTCalibrationCoefficientProduced" type="CalibrationCoefficientType" />
                                                </xs:sequence>
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                                        </xs:element>
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                                    <xs:sequence>
                                        <xs:element name="PlanarCalibrationDataAcquisition"
minOccurs="0">
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                                                <xs:sequence>
                                                    <xs:element name="DateTimeProcessStarted"
type="xs:string"/>
                                                    <xs:element name="PerformingInstitution"
type="xs:string"/>
                                                    <xs:element name="PhantomUsed"
type="PhantomType"/>
                                                    <xs:element
name="RadiopharmaceuticalAdministration" type="RadiopharmaceuticalAdministrationType"
minOccurs="0"/>
                                                    <xs:element name="AcquisitionProtocolUsed"
type="AcquisitionProtocolType" minOccurs="0" />
                                                    <xs:element
name="DICOMProjectionDataProduced" type="DICOMDataType" minOccurs="0" maxOccurs="unbounded" />
                                                </xs:sequence>
                                            </xs:complexType>
                                        </xs:element>
                                        <xs:element name="PlanarCalibrationDataSegmentation"
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                                            <xs:complexType>
                                                <xs:sequence>
                                                    <xs:element name="DateTimeProcessStarted"
type="xs:string"/>
                                                    <xs:element name="PerformingInstitution"
type="xs:string"/>
                                                    <xs:element name="DICOMImageUsed"
type="DICOMDataType"/>
                                                    <xs:element name="SegmentationMethodUsed"
type="SegmentationMethodType" minOccurs="0" />
                                                    <xs:element name="ROIDataProduced"
type="NonDICOMDataType" minOccurs="0" maxOccurs="unbounded" />
                                                </xs:sequence>
                                            </xs:complexType>
                                        </xs:element>
                                        <xs:element
name="PlanarCalibrationCoefficientCalculation" minOccurs="0" maxOccurs="unbounded">
                                            <xs:complexType>
                                                <xs:sequence>
                                                    <xs:element name="DateTimeProcessStarted"
type="xs:string"/>
                                                    <xs:element name="PerformingInstitution"
type="xs:string"/>
                                                    <xs:element name="ROIDataUsed"
```

```
type="NonDICOMDataType"/>
                                                    <xs:element name="DICOMImageUsed"
type="DICOMDataType"/>
                                                    <xs:element
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type="xs:string"/>
            <xs:element name="EffectiveDoseUnit" type="xs:string"/>
            <xs:element name="NonDICOMVoxelBasedEffectiveDoseDistribution"
type="NonDICOMDataType" minOccurs="0" />
        </xs:sequence>
    </xs:complexType>
</xs:schema>
```

ANNEX 4

This annex provides a draft XML schema specifying the structure of the NonDICOM Fileset Descriptor, taking into account needs from WP2 Subtask 2.1.2 - Development of a novel method to estimate patient organ dose from chest CT.

```
<?xml version="1.0"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema"
    targetNamespace="https://www.irdbb-medirad.com"
    xmlns="https://www.irdbb-medirad.com"
    elementFormDefault="qualified">

    <xs:element name="NonDicomFileSetDescriptor">
        <xs:complexType>
            <xs:sequence>
                <xs:element name="ReferencedClinicalResearchStudy">
                    <xs:complexType>
                        <xs:sequence>
                            <xs:element name="ClinicalResearchStudyID" type="xs:string"/>
                            <xs:element name="ClinicalResearchStudyTitle" type="xs:string"/>
                        </xs:sequence>
                    </xs:complexType>
                </xs:element>
                <xs:element name="PatientId" type="xs:string"/>
                <xs:element name="WP2subtask212WorkflowData" maxOccurs="unbounded">
                    <xs:complexType>
                        <xs:sequence>
                            <xs:element name="CTSegmentation" minOccurs="0">
                                <xs:complexType>
                                    <xs:sequence>
                                        <xs:element name="DateTimeProcessStarted"
type="xs:string"/>
                                        <xs:element name="PerformingInstitution"
type="xs:string"/>
                                        <xs:element name="DICOMImageUsed"
type="DICOMDataType"/>
                                        <xs:element name="SegmentationMethodUsed"
type="SegmentationMethodType" minOccurs="0" />
                                        <xs:element name="VOIDescriptorProduced"
type="VOIDescriptorType" minOccurs="0" maxOccurs="unbounded" />
                                    </xs:sequence>
                                </xs:complexType>
                            </xs:element>
                            <xs:element name="SimpleCTMonteCarloDosimetry" minOccurs="0"
maxOccurs="unbounded">
                                <xs:complexType>
                                    <xs:sequence>
                                        <xs:element name="CalculationOfVoxelMap">
                                            <xs:complexType>
                                                <xs:sequence>
                                                    <xs:element name="DateTimeProcessStarted"
type="xs:string"/>
                                                    <xs:element name="PerformingInstitution"
type="xs:string"/>
                                                    <xs:element name="AttenuatorUsed"
type="AttenuatorType" minOccurs="0" maxOccurs="unbounded" />
                                                    <xs:element name="MonteCarloMethodUsed"
type="MonteCarloMethodType" minOccurs="0" />
                                                    <xs:element name="DICOMCTImageDataUsed"
type="DICOMDataType" minOccurs="0" maxOccurs="unbounded" />
                                                    <xs:element
name="VoxelBasedDistributionOfAbsorbedDoseProduced"
type="VoxelBasedDistributionOfAbsorbedDoseType" minOccurs="0" maxOccurs="unbounded"/>
                                                </xs:sequence>
                                            </xs:complexType>
                                        </xs:element>
                                        <xs:element name="CalculationOfAbsorbedDosesInVOIs">
                                            <xs:complexType>
                                                <xs:sequence>
                                                    <xs:element name="DateTimeProcessStarted"
type="xs:string"/>
                                                    <xs:element name="PerformingInstitution"
type="xs:string"/>
                                                    <xs:element
name="VoxelBasedDistributionOfAbsorbedDoseUsed"
type="VoxelBasedDistributionOfAbsorbedDoseType" minOccurs="0" maxOccurs="unbounded"/>
```

```
                                                    <xs:element name="VOIDescriptorUsed"
type="VOIDescriptorType" minOccurs="0" maxOccurs="unbounded" />
                                                    <xs:element name="AbsorbedDosePerVOI"
type="AbsorbedDosePerVOIType" minOccurs="0" maxOccurs="unbounded" />
                                                        </xs:sequence>
                                                    </xs:complexType>
                                                </xs:element>
                                            </xs:sequence>
                                        </xs:complexType>
                                    </xs:element>
                                </xs:sequence>
                            </xs:complexType>
                        </xs:element>
                    </xs:sequence>
                </xs:complexType>
            </xs:element>

            <xs:complexType name="VOIDescriptorType">
                <xs:sequence>
                    <xs:element name="VOIId" type="xs:string"/>
                    <xs:element name="VOILabel">
                            <xs:simpleType>
                                <xs:restriction base="xs:string">
                                    <xs:enumeration value="bone"/>
                                    <xs:enumeration value="breast"/>
                                    <xs:enumeration value="esophagus"/>
                                    <xs:enumeration value="heart"/>
                                    <xs:enumeration value="lungs"/>
                                    <xs:enumeration value="skin"/>
                                </xs:restriction>
                            </xs:simpleType>
                        </xs:element>
                    <xs:element name="VOIData" type="NonDICOMDataType" minOccurs="0"
maxOccurs="unbounded" />
                </xs:sequence>
            </xs:complexType>

            <xs:complexType name="SegmentationMethodType">
                <xs:sequence>
                    <xs:element name="SegmentationMethod" type="xs:string"/>
                    <xs:element name="SoftwareName" type="xs:string" minOccurs="0"
maxOccurs="unbounded"/>
                    <xs:element name="SegmentationMethodSetting" type="MethodSettingType"
minOccurs="0" maxOccurs="unbounded" />
                </xs:sequence>
            </xs:complexType>

            <xs:complexType name="MonteCarloMethodType">
                <xs:sequence>
                    <xs:element name="MonteCarloMethod" type="xs:string"/>
                    <xs:element name="SoftwareName" type="xs:string" minOccurs="0"
maxOccurs="unbounded"/>
                    <xs:element name="SimulatedImagingDevice" type="xs:string" minOccurs="0"
maxOccurs="unbounded" />
                    <xs:element name="MonteCarloMethodSetting" type="MethodSettingType" minOccurs="0"
maxOccurs="unbounded" />
                </xs:sequence>
            </xs:complexType>

            <xs:complexType name="MethodSettingType">
                <xs:sequence>
                    <xs:element name="MethodSetting" minOccurs="0" type="xs:string"/>
                    <xs:element name="MethodSettingValue" minOccurs="0" type="xs:string"/>
                    <xs:element name="MethodSettingUnit" minOccurs="0" type="xs:string"/>
                </xs:sequence>
            </xs:complexType>


            <xs:complexType name="DICOMDataType">
                <xs:sequence>
                    <xs:element name="DICOMStudyUID" type="xs:string"/>
                    <xs:element name="DICOMSeriesUID" maxOccurs="unbounded" type="xs:string"/>
                </xs:sequence>
            </xs:complexType>


            <xs:complexType name="NonDICOMDataType">
                <xs:sequence>
```

```
            <xs:element name="NonDICOMDataClass">
                <xs:simpleType>
                    <xs:restriction base="xs:string">
                        <xs:enumeration value="VOI"/>
                        <xs:enumeration value="VOI superimposed on images"/>
                        <xs:enumeration value="3D dose map"/>
                    </xs:restriction>
                </xs:simpleType>
            </xs:element>
            <xs:element name="NonDICOMDataFormat">
            <xs:simpleType>
                <xs:restriction base="xs:string">
                    <xs:enumeration value="zipped imageJ contours format"/>
                    <xs:enumeration value="TIFF format embedding imageJ contours"/>
                    <xs:enumeration value="zipped pseudo-DICOM ImpactMC"/>
                </xs:restriction>
            </xs:simpleType>
        </xs:element>
            <xs:element name="NonDICOMDataFileName" type="xs:string" maxOccurs="unbounded" />
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="AttenuatorType">
        <xs:sequence>
            <xs:element name="AttenuatorCategory" type="xs:string"/>
            <xs:element name="EquivalentAttenuatorDescription" type="xs:string"/>
            <xs:element name="EquivalentAttenuatorMaterial" type="xs:string"/>
            <xs:element name="EquivalentAttenuatorThicknessValue" type="xs:string"/>
            <xs:element name="EquivalentAttenuatorThicknessUnit" type="xs:string"/>
            <xs:element name="EquivalentAttenuatorModel" type="xs:string"/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="AbsorbedDosePerVOIType">
        <xs:sequence>
            <xs:element name="AbsorbedDoseCategory">
                <xs:simpleType>
                    <xs:restriction base="xs:string">
                        <xs:enumeration value="mean absorbed radiation dose"/>
                        <xs:enumeration value="maximum absorbed radiation dose"/>
                        <xs:enumeration value="minimum absorbed radiation dose"/>
                        <xs:enumeration value="median absorbed radiation dose"/>
                        <xs:enumeration value="mode absorbed radiation dose"/>
                    </xs:restriction>
                </xs:simpleType>
            </xs:element>
            <xs:element name="AbsorbedDoseValue" type="xs:string"/>
            <xs:element name="AbsorbedDoseUnit" type="xs:string"/>
            <xs:element name="VOI" type="VOIDescriptorType"/>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="VoxelBasedDistributionOfAbsorbedDoseType">
        <xs:sequence>
            <xs:element name="VoxelBasedDistributionOfAbsorbedDoseCategory" type="xs:string"/>
            <xs:element name="AbsorbedDoseUnit" type="xs:string" minOccurs="0"/>
            <xs:element name="NonDICOMVoxelBasedAbsorbedDoseDistribution"
type="NonDICOMDataType" minOccurs="0" />
            <xs:element name="DICOMVoxelBasedAbsorbedDoseDistribution" type="DICOMDataType"
minOccurs="0" />
        </xs:sequence>
    </xs:complexType>
</xs:schema>
```