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Medical Informatics

Master Thesis

Analysis of New Concepts and Definitions in

DICOM Second Generation Radiotherapy Objects

Based on an Experimental Implementation

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Abstract

This thesis examines the new major concepts for communicating radiotherapy-related data with DICOM, introduced in Supplement 147.

As the existing DICOM information objects, used to transfer radiotherapy-related information, are mostly overloaded and static, new concepts to describe this data are developed at the moment in Supplement 147. These concepts facilitate a more convenient representation of new treatment devices and treatment techniques in DICOM and solve other issues with first-generation DICOM RT objects.

Hence Supplement 147 is replacing the entire working concept strategy for a complete domain, and the supplement itself is extensive in comparison to other supplements, an overview whether all these concepts work together just by examining them on a drawing board is hardly possible. Therefore, this thesis investigates the information separation into different Information Object Definitions (IODs), the new radiation prescription object and the new concept to enable abstract access to volumetric objects, which are considered to be the major conceptual changes.

A conversion of first-generation objects into second-generation environment is performed as a first step of this thesis in order to test the new separation of information because no system that supports second-generation objects is available, yet. Next, the new prescription object *RT Physician Intent* is examined in more detail by means of wishes of clinical experts for radiation prescription, which are reflected in the *Standard Prescription Proposal* of the *Radiation Oncology Safety Stakeholder Group (ROSSG)*. Then the abstract access to volumetric objects, called *Conceptual Volumes*, is investigated by simulating different radiation prescription scenarios, that are a result of a discussion with clinical experts.

During the investigation in this work little inconsistencies in the concepts respectively the definitions are detected and communicated to *DICOM Working Group 7*, which are solved and published in later drafts of the Supplement. Furthermore, this work shows that the mentioned concepts provide more flexible and more adaptive data structures to facilitate a more convenient adaption for future enhancements and developments in treatment devices and treatment techniques. Additionally, it is noticed during this evaluation that the first-generation conversion, a feature that is explicitly out of scope of Supplement 147, is a feature which is most likely desired from clinical and vendor's perspective. Hence corresponding "Transition Guidelines" will be provided by *DICOM Working Group 7* as soon as Supplement 147 is finished.

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Contents

Nomenclature

AAPM	American Association of Physicists in Medicine
ASTRO	American Society for Therapeutic Radiation Oncology
CBCT	Cone Beam Computed Tomograpy
CID	Context Group Identifier
CSV	Comma-Separated Value
CT	Computer Tomography
CTV	Clinical Target Volume
DCMR	DICOM Content Mapping Resource
DICOM	Digital Imaging and Communication in Medicine
DNA	Desoxyribonucleic Acid
DRR	Digital Reconstructed Radiograph
DT	Defined Terms
DVH	Dose Volume Histogramm
EBRT	External Beam Radiotherapy
EI	Experimental Implementation
EPID	Electronic Portal Imaging Device
EV	Enumerated Value
FSU	Functional Sub Unit
GTV	Gross Target Volume
GUI	Graphical User Interface
Gy	Gray
ICRU	International Comission on Radiation Units and Measurements
IGRT	Image Guided Radiation Therapy
IHE	Integrating the Healthcare Enterprise
IMRT	Intensity Modulated Radiation Therapy
IOD	Information Object Definition
ITV	Internal Target Volume
LET	Linear Energy Transfer
LINAC	Linear Accelerator
MeV	Mega Electronvolt

$MITA$	Medical Imaging & Technology Alliance
MLC	Multileaf Collimator
MR	Magnetic Resonance Imaging
MU	Monitor Unit
MV	Megavolt
$NEMA$	National Electrical Manufacturers Association
$NTCP$	Normal Tissue Complication Probability
OAR	Organ at Risk
$PPMS$	Patient Position Modification System
$PPVS$	Patient Position Verification System
PRV	Planning Organ at Risk Volume
PTV	Planning Target Volume
QA	Quality Assurance
$R\&V$	Record & Verify
ROI	Region of Interest
$RSNA$	Radiological Society of North America
$RTOG$	Radiotherapy Oncology Group
$SBRT$	Stereotactic Body Radiotherapy
SOP	Service Object Pair
Sv	Sievert
TID	Template Identifier
TMS	Treatment Management System
TPS	Treatment Planning System
UID	Unique Identifier
VM	Value Multiplicity
WG	Working Group

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1 Introduction

Motivation

The first definition of DICOM Information Objects (IODs - s. 2.2.2) applicable to the domain of radiation oncology were introduced in 1997 and designed to act as containers for radiotherapy-related data [24][25]. Because of the development and improvements in radiation therapy practice (2.1.3 and 2.1.5) and the DICOM standard itself (e.g., workflow management [27]) Supplement 147 is being defined at the moment to address the needs for a new generation of IODs and processes required for use in radiation therapy [28].

Reason for initiation of Supplement 147 are some defects in the current radiation prescription. Because of some considerations during this prescription redefinition, the result is a new definition of all radiotherapy-related DICOM objects within Supplement 147. This supplement tries to provide more flexible and adaptive data structures and concepts to avoid problems that occurred with the mostly overloaded and static first-generation radiotherapy objects.

Compared to other supplements Supplement 147 is very extensive (more than 250 pages). Therefore, it is hardly possible to overview whether the content of all these concepts work together just by examining them theoretically. But it is desirable to have a reliable draft without mistakes, that are easily overlooked, like inconsistent references, missing, wrong and/or differently spelled attributes, before starting the *Public Comment Project Phase* (2.2.5).

Aim of This Work

This thesis elaborates the first time practical examination of Supplement 147 in an *Experimental Implementation (EI)*. The focus of this work is the examination of the information separation into different IODs (s. 3.1), the examination of the new radiation prescription object (s. 3.2) and the investigation of the new concept to enable abstract access to volumetric objects (s. 3.3).

The aim of this work is to inspect these concepts and search for inconsistencies and unconsidered aspects to communicate them to the *DICOM Working Group 7* in order to enter the Supplement's development process. Another subject is the creation respectively

adaption of data structures in the underlying framework (s. 3.4) to facilitate the usage of second-generation objects in future.

Research Approach

To examine the data separation, this thesis investigates whether it is possible to model a radiation plan with second-generation objects. As there are no treatment planning systems available that support second-generation objects yet, first-generation objects are converted, instead, to provide this information. Multiple data sets with different treatment setups are converted to establish an extensive investigation as complete as possible.

Although this feature is explicitly out of scope of Supplement 147, it is noticed during this evaluation that this first-generation conversion is most likely desired from clinical and vendor's perspective. As a consequence this first-generation object conversion is examined by this thesis to provide hints, which information is required additionally and how it can be provided for a translation device.

The investigation of the new object for radiation prescriptions is performed by means of wishes of clinical experts. These wishes are reflected in the *Standard Prescription Proposal* of the *Radiation Oncology Safety Stakeholder Group (ROSSG)* [72], a group consisting of clinical users and specialists. Corresponding prescription objects are created to reflect this information. It is examined if any information exists that cannot be mapped and that indicates an unconsidered aspect.

Associated with the investigation of the new prescription object the abstract access to volumetric objects is examined. This investigation is done by simulating different prescription scenarios (3.3), which are the result of a discussion with clinical experts. The new abstract volumetric object concept is assumed to be correct if the simulated scenarios can be performed with objects that use such an abstract volumetric object.

2 Materials and Methodology

At first major concerns of radiation treatment planning are presented (s. 2.1). Next the DICOM standard (s. 2.2), its radiotherapy objects (s. 2.2.4) and the investigated Supplement 147 (s. 2.3) are described. Following a brief introduction to existing DICOM libraries (s. 2.4) and the presentation of some important organizations (s. 2.5) of the radiology oncology domain is made. The last section of this chapter deals with the introduction of the framework used in this work (s. 2.6).

2.1 Radiotherapy

Radiotherapy uses different kinds of ionizing radiation. The radiation sources are divided into two main groups depending on the position of the source. The *teletherapy* (also known as *external beam radiotherapy*) uses distant radiation sources (*tele-*: greek prefix for distant), *brachytherapy* (also known as *internal radiotherapy*, *sealed source radiotherapy*, *curie-therapy* or *endocurietherapy*) uses radioactive sources in direct contact with the tissue (*brachys*: greek word meaning short distance) [49].

As this thesis mainly deals with the investigation of Supplement 147 in respect to *external beam radiotherapy (EBRT)*, this section focuses on the description of teletherapy relevant information. Nevertheless, brachytherapy represents an effective treatment option for e.g., cervical, prostate, breast or skin cancer [9, 6, 29, 70].

2.1.1 Physical Basics

2.1.1.1 Radiation

"Radiation is a process in which energetic particles or energetic waves travel trough a vacuum or matter-containing media that are not required for their propagation" [86]. Commonly radiation is differentiated by two energy levels and their way of interaction with matter into *ionizing radiation* and *non-ionizing radiation* [69]. *Ionization* is the process of removing one or more electron(s) from an atom or a molecule which results in a positive charged atom or molecule that is called *ion*. If *ionizing radiation* is related with transportation of matter (e.g., α- /β-particles, electrons, protons or heavy particles) it is called *corpuscular radiation*, otherwise it is called *photon radiation* or *electromagnetic radiation* (e.g., X-ray or gamma-ray photons) [69].

In *conventional radiotherapy* mainly *ultra-hard X-ray bremsstrahlung* is used [69]. *X-ray bremsstrahlung* is generated by a high-energetic process in which charged particles are accelerated and electrons are suddenly decelerated. This leads to high-energetic transitions in the atomic electron shell that result in a characteristic X-ray radiation depending on the acceleration voltage. Typically *ultra-hard X-ray bremsstrahlung* with energies between 6 and 15 MeV is used for radiation therapy [69]. The energy of x MeV refers to the fact that electrons are accelerated with a voltage of x MV. This unit is more convenient than a declaration of $W = 1,6 \cdot 10^{-19} \cdot x$ J for the energy of an electron.

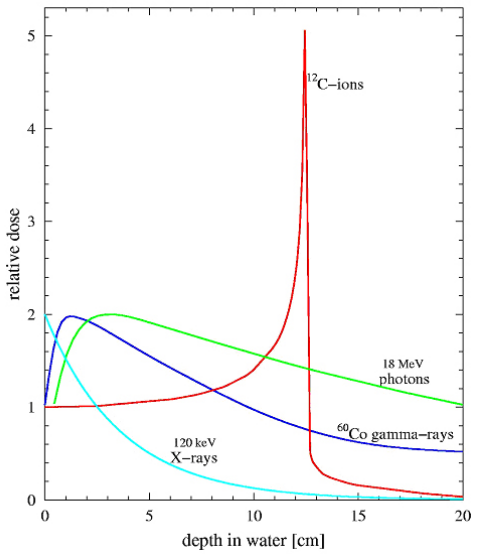


Figure 2.1: Depth Dose Characteristic of Different Radiation Types [37]

Besides the *conventional radiotherapy* the *particle therapy* has to be mentioned as a type of *external beam radiotherapy*. This type uses neutrons, protons or heavy ions (^{4}He, ^{12}C, ^{20}Ne) for radiation. In contrast to the dose absorption by the tissue (typical exponential decay with increasing thickness) of the previously described X-ray, protons and heavy ions increase their dose while particles penetrate the tissue and the particle loses energy continuously (fig. 2.1) [50]. Near the end of the particle's range the *Bragg peak* can be found (highest dose). Beyond the *Bragg peak*, the dose drops to zero (for protons) or almost zero (for heavy ions). The depth of penetration of a particle beam is defined by its final energy of the acceleration process by means of a cyclotron or synchrotron [50].

Thus, by variation of beam energy and deflection of the beam by electromagnets in transverse direction, an entire target volume can be covered, providing an irradiation exactly following the shape of the tumor.

2.1.1.2 Rays and Radiation Field

As soon as particles leave a radiation source they create a *radiation field*. The terms *radiation* and *radiation field* describe transportation phenomenon of matter. In contrast to this the term *ray* is used to describe the geometrical pathway of radiation. The power of all types of radiation follows an inverse-square law of power with regard to distance from its source [14].

Radiation fields consist of discrete particles. Thus, on contact with matter random interaction between particle and absorber can be observed and not a continuous energy transfer as expected by classic physics . The measurement dependent *bias* can be estimated with typical stochastic methods. To reduce variations either the number of particles has to be reduced or the detector volume has to be increased. A measure for the (microscopic) interaction probability is the *cross section* σ. It can be applied per electron (σ_e) or per atom (σ_a) [14]. The corresponding macroscopic measure is the *absorption coefficient* µ. It describes the interaction probability of indirect ionizing radiation like photons or neutrons.

2.1.1.3 Energy Dose and Equivalent Dose

Because of its dangerous ionizing impact we need a measure for (radioactive) radiation that records all changes in molecule bindings (s. 2.1.2). This can be achieved by the following approximation [11]:

$$Energydose: \; D \;=\; \frac{energy\,\Delta E}{mass\,\Delta M} \qquad [\frac{J}{kg} = Gray(Gy)] \tag{2.1}$$

The energy transfer from radiation beam to matter, and its energy dose, is dependent on the kind of interaction, the atomic number of the matter and the radiation energy. The following kinds of interactions can be observed for electronic-magnetic waves [69]:

- Photoelectric effect
- Compton scattering
- Pair production

For charged particles (electrons):

- Bremsstrahlung
- Coulomb interaction → Ionization

Thus, for the energy dose it has to be specified what kind of matter it refers to. The equivalent dose considers different ionization of different kinds of radiation and is defined as follows:

$$Equivalent\,dose \quad = \quad w_R \cdot D \qquad [Sievert\,(Sv)] \tag{2.2}$$

w_r is the radiation weighting factor. It represents different ionizations by the same dose. For example photons and electrons have a w_r of $1\frac{Sv}{Gy}$, α-particles a w_r of $20\frac{Sv}{Gy}$.

2.1.2 Biological Basics

Ionized radiation transfers this energy during absorption in biological matter by ionization and excitation. These energy transfer occurs along the pathway of the charged particles. Radiation can be divided by the density of its ionization. The *Linear Energy Transfer (LET)* was introduced to describe this fact [69]:

$$LET \quad = \quad \frac{locally\,absorbed\,energy}{distance} \qquad [\frac{keV}{\mu m}] \tag{2.3}$$

This *LET* is differentiated into *loose (low-LET)* and *dense ionizing radiation (high-LET)*. The distance of ionization loci is farther for *loose ionization radiation* than for *dense ionized radiation*.

The DNA is the most sensitive part of a human cell. *Ionized radiation* can impact DNA either directly or indirectly by forming free radicals, an anatomic or molecular species with unpaired electrons on an otherwise open shell configuration (= very reactive), which impact on the DNA (fig. 2.2). Direct impact is normally generated by *high-LET radiation* (e.g., α-particles or neutrons) [69].

Depending on the resulting damages of an *ionized radiation* in a cell, the cell repair mechanisms, which are cell specific, can fix them or not. For example one Gray of photon radiation causes approximately 3000 base defects, 1000 single and 40 double strand breaks (DSB) [14]. If the damages cannot be repaired the cell dies. The repair of *high-LET radiation* damages last longer than damages produced by *low-LET radiation*. Furthermore, the dose and the time of influence of the radiation is important for the

range of DNA damage. The sensibility for radiation increases with the DNA content of a cell, which is related to its cell division rate. There are also some conditions that influence the impact of radiation like caffeine, which increases the sensibility [84], or cysteine, which weakens the impact [68].

An important fact is that the repair mechanisms of tumor cells are normally not as good as the repair mechanisms of normal cells (fig 2.3 on the following page). This fact is used with the treatment modification of *fractionation* (s. 2.1.2.2).

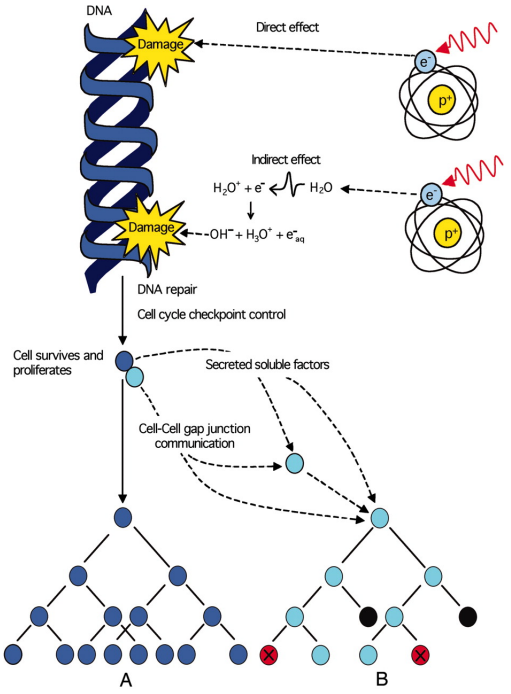


Figure 2.2: Direct and Indirect DNA Damage Caused by Radiation [55]

2.1.2.1 Normal Tissue Tolerance Doses

Besides the tumor volume also normal tissue is radiated during *external beam radiotherapy* and therefore, it is injured as well. Thus, for radiation oncologists it is necessary to know about the likelihood of side effects of a treatment. This *Normal Tissue Complication Probability (NTCP)* is based on published data on normal tissue complications and clinical experiments of radiation oncologists. Rubin and Cassarett introduced the concepts of $TD_{5/5}$ and $TD_{50/5}$ in 1972 [73, 74, 76, 75]. These concepts represent the *NTCP* at 5% and 50% within 5 years after radiation. Rubin and Cassarett published $TD_{5/5}$ and $TD_{50/5}$ for a number of normal tissues and organs.

In 1991 Emami et al. [31] assembled and published *normal tissue tolerance doses* for a number of normal tissues and organs in terms of $TD_{5/5}$ and $TD_{50/5}$. These tolerance data are defined for uniformly radiated $\frac{1}{3}$, $\frac{2}{3}$ and $\frac{3}{3}$ partial volumes of normal tissues and organs. Furthermore, these values base on conventional fractionation (s. 2.1.2.2) schedules of 1.8 to 2 Gy per fraction by 5 fractions per week. Various other researchers have reported tolerance dose for individual organs, but the data are scattered in the literature and the number of dose values of the tolerance values for the same organ are reported by different scientists, which leads to the problem of choosing the “right” value for routine clinical practice.

2.1.2.2 Fractionation

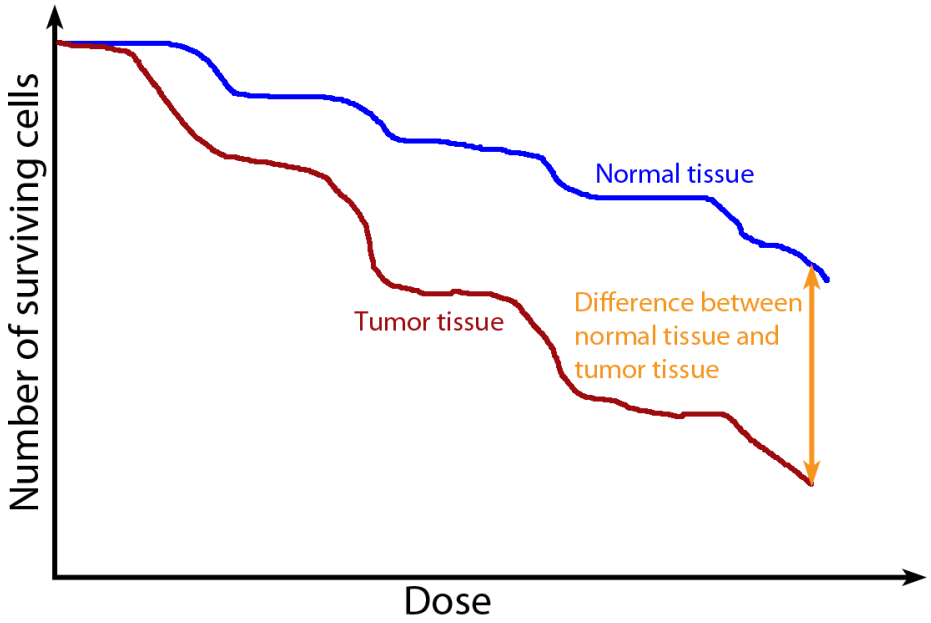


Figure 2.3: Fractionation Uses Different Healing Capabilities Between Normal and Tumor Tissue

Source: Based on illustration in lecture notes [14]

Fractionation uses the fact of different reparability of radiation damages in tumor cells and healthy cells (s. 2.1.2). The total dose to deliver is separated into small single doses (1,8 - 2,5 Gy). This reduces the number of killed normal tissue cells at the same dose for the tumor tissue. Thus, the maximum tolerated dose of normal tissue (s. 2.1.2.1) can be increased (up to 80 Gy).

The biological impact of different fractionation can be calculated by the *linear-quadratic formula* (*LQ formula*, [32])

$$E = n \cdot (\alpha \cdot d + \beta \cdot d^2) \tag{2.4}$$

with E: effect, n: number of fractions, d: dose, α and β: tissue constants. The relation $\frac{\alpha}{\beta}$ can be calculated by dose-effect curves. With the help of the *LQ formula* it is possible

to calculate the (theoretical) total dose for a particular effect when changing the dose of a single fraction.

Unfortunately, the *LQ formula* has some limitations and cannot describe some phenomena [71]. This is the reason why this formula is critically judged, but there are no other alternatives that describe the observed context in a better way.

2.1.3 Treatment Delivery Devices (TDD)

Since the introduction of first-generation DICOM RT objects (s. 2.2.4) treatment delivery devices have evolved and new device types were developed. As second-generation DICOM RT objects (s. 2.3) are designed to represent all the features of these devices, this section gives a brief overview of different treatment devices used in *external beam radiotherapy (EBRT).* This shall give an idea of the device specific information which needs to be described by the second-generation RT objects.

The first kind of devices to bring up are the isotope radiation devices. They consist of a radioactive source (^{60}Co, ^{137}Cs) in a shielded box (material with heavy nuclei, commonly lead). This source is moved over a hole so the radiation can pass out and can be directed to the patient. One main disadvantage of these devices is that the decay in the radioactive sources result in an increasing time to deliver a prescribed radiation dose as time goes by (will double after 5 years) [10]. Therefore, the radiation sources have to be changed every 5 to 10 years. As a variation of this basic principle the *Gamma Knife®* has to be mentioned. It is described more detailed in the following (s. 2.1.3.1). The second kind of radiation devices are *linear accelerators (LINAC).* Their principle and some device variations will be presented in subsection 2.1.3.2. The last kind of treatment delivery devices are cyclotrons and synchrotrons. They are used to accelerate particles (protons, α-particles, ^{12}C, ^{20}Ne). Therefore, huge accelerators and gantry system (s. 2.1.3.2) are needed. The particles are not accelerated linearly, but on a circle. They pass the acceleration ring several times until they reach the desired energy. Since the treatment with particles is relatively new, there are only 41 treatment facilities worldwide at the moment (June 2012, [3]).

2.1.3.1 Gamma Knife®

The Gamma Knife® is the treatment device that was used first for stereotactic radiotherapy and was introduced in 1951 by the neurosurgeon Lars Leksell [48]. *Stereotactic surgery* or *stereotaxy* is a minimally invasive method which uses a (external) three-dimensional coordinate system to locate small targets inside the brain (respectively the body) and performs some action on them.

The Gamma Knife® was developed by Lars Leksell and Björn Larsson in 1968 and consists of 201 radioactive Cobalt-60 (^{60}Co) sources which are arranged hemispherical. A gamma ray, which is produced by the Gamma Knife®, has an average energy of 1.25 MeV [34].

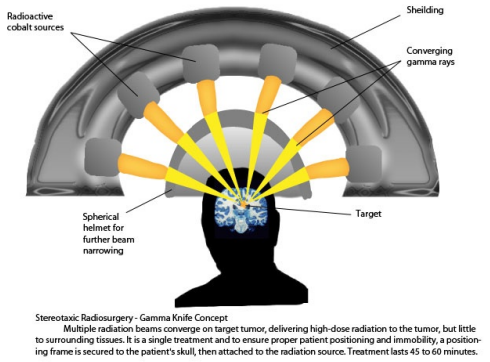


Figure 2.4: Concept of Gamma Knife® Stereotactic Radiosurgery [4]

A first prefocus of the radiation in done by an inner collimator which is enhanced by an additional collimator-helmet (fig. 2.4).

This helmet allows to screw in 201 collimator channels with diameters of 4mm, 8mm, 12mm or 16mm. The patient's head is placed in the treatment device with the helmet at a predefined position for treatment. The position is calculated in an earlier treatment planning. More than 237 Gamma Knife® units (2007) are installed worldwide [52].

2.1.3.2 C-Arm LINAC

The first patient treatment by a linear accelerator (LINAC) was performed in 1953 at Hammersmith Hospital [16]. But the push forward of this technology for radiosurgery was made in the mid 1980's by Betti [15] and Colombo [23].

A linear accelerator normally consists of a stationary part, with a micro-wave transmitter and an electron source, and a movable part (gantry) that contains the accelerating wave guide and the bending system (fig. 2.5). Because of the need of high energy for the required bremsstrahlung and isolation issues towards the environment ($\rightarrow$ earth potential) multi-stage acceleration with minor voltage created by microwaves is used instead of a one time acceleration with high voltage. These microwaves commonly have a wave length of 10 cm (S-Band accelerator [85]).

One kind of accelerators are *traveling wave accelerators* that consists of 2.5 cm wide *cavity resonators* that are arranged in a way to form a guide tube with many segments which are divided by apertures ($\rightarrow$ collimation). In case of resonance a charge distribution is established that changes in time with the microwave frequency.

By injection of microwaves into the guide tube segments are generated with pure positive charge on the one hand and segments with pure negative charge on the other hand. As a

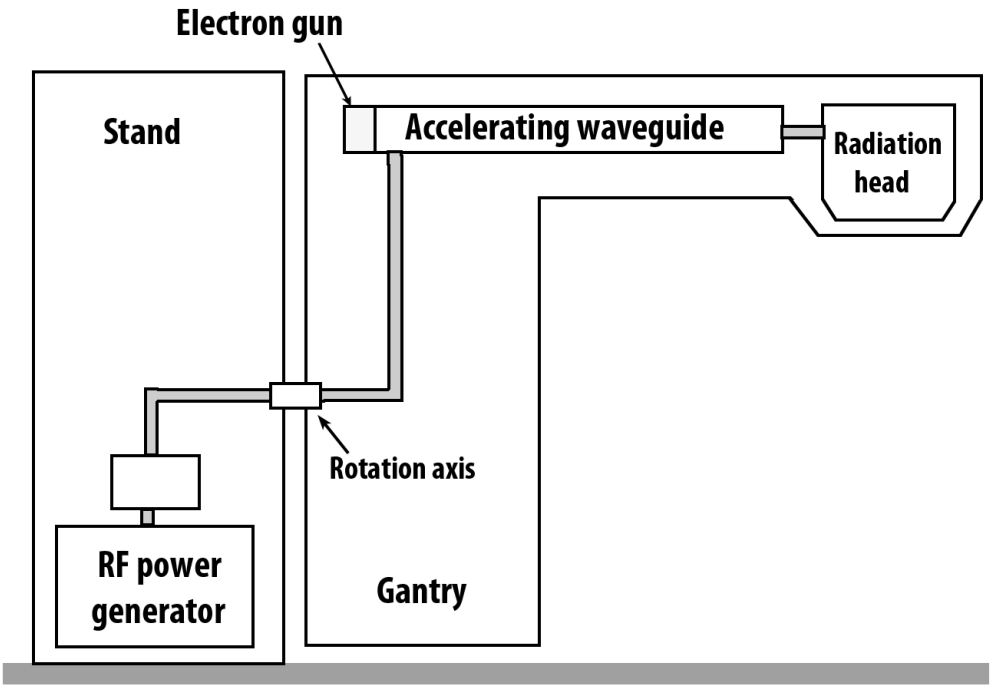


Figure 2.5: Schematic Construction of a Linear Accelerator (LINAC)

consequence these segments create "poles" in which no acceleration can occur. These poles are located at the zero-crossings of the electromagnetic component of the microwave. Between these poles further segments are generated which create a negative electronic field component that accelerates electrons which move in the direction of the microwaves and are in these "acceleration segments".

As the acceleration of electrons is typically performed in horizontal direction (fig. 2.5), the electrons must be bent through a suitable angle [50]. "This is done by a beam transport system, which consists of an achromatic focusing and bending magnet, as well as steering and focusing coils"[50]. The advantage of the 270° beam redirection over the 90° beam redirection is a much smaller focal spot (approx. 2-3 mm diameter [50]). In comparison to the focal spot created by a ^{60}Co-source it is 10 times smaller [50].

Following the redirection a therapeutic beam field is created (fig. 2.6 on the next page). To create photons the accelerated electrons are directed onto a *target* (tungsten) which decelerates the electrons and produces *ultra-hard X-ray bremsstrahlung*.

Because of inhomogeneity of the generated field, which is caused by scattering during the deceleration at the target, a *flattening filter* (lead, tungsten, uranium, steel or aluminum)

is placed into the beam path. The disadvantage of the homogenization is an absorption of 98% of the beam energy by the filter. Therefore, the primary intensity of the beam has to be increased intensively in comparison with the electron mode. As a consequence it is very important to check the position of the target and the used beam mode. If the LINAC operates in photon mode and the target is not in the beam path, major injuries are caused to the patient (e.g., as described in an article of the New York Times [17]).

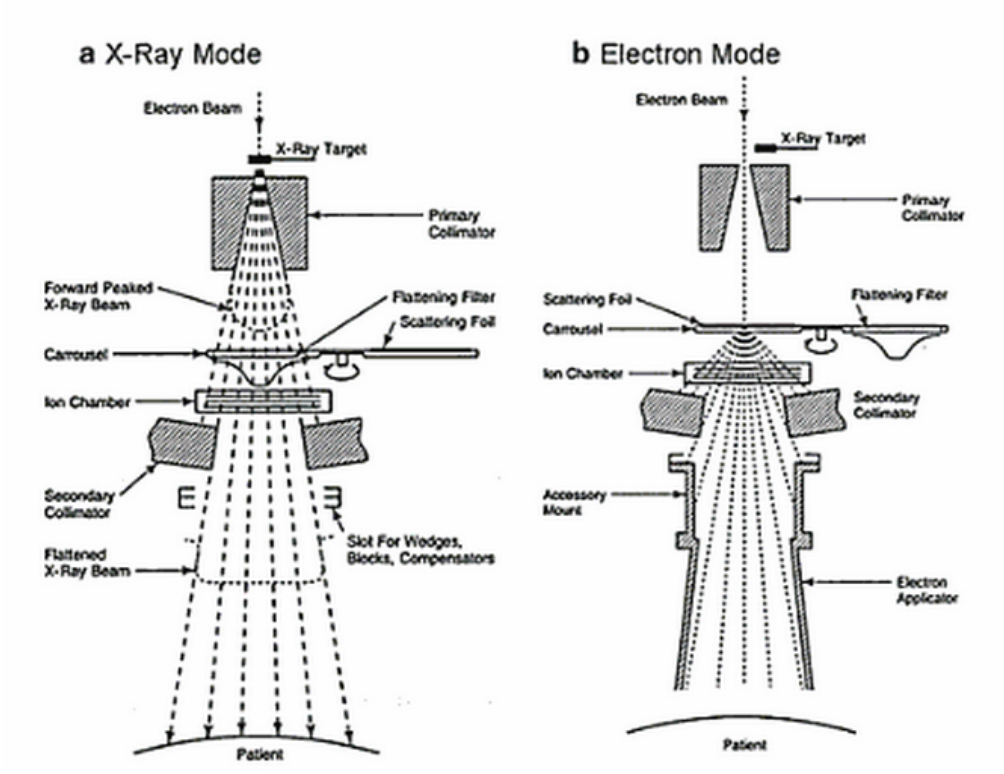


Figure 2.6: LINAC System to Create a Radiation Field [50]

Ongoing the X-ray beam passes a *monitor ionization chamber* which is used to monitor the field symmetry, dose rate and the integrated dose per *monitor unit (MU)*. A *monitor unit* is a measure to connect the number of ionization recorded in the ionization chamber of the LINAC's head with a dose delivered at a specific depth in a water phantom under reference conditions. MUs are used to standardize treatment machines within a single radiotherapy center.

After passing of this *monitor chamber* the beam can be further collimated by two independent movable jaw pairs (lead or tungsten). These jaws can form rectangular fields

with sizes from zero to 40x40 cm at a distance of 100 cm [50]. Furthermore, additional beam modification, as explained in 2.1.4, can be applied.

2.1.3.3 Tomotherapy

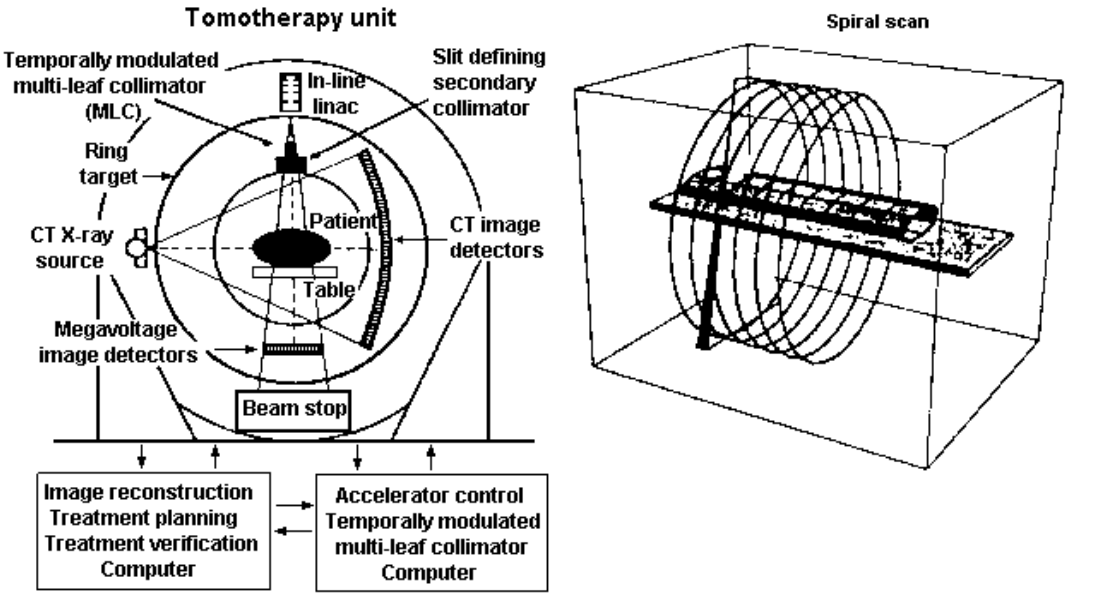


Figure 2.7: Schematic View of the Tomotherapy Concept [54]

Tomotherapy, also known as *Helical Tomotherapy*, is a concept for the delivery of dynamic conformal radiotherapy. It was developed at the University of Wisconsin-Madison by Thomas Rockwell Mackie, Ph.D. and Paul Reckwerdt [51]. This treatment is a new form of computer tomography (CT) guided *Intensity Modulated Radiation Therapy (IMRT)*. During the rotation of the gantry the treatment table is moved continuously forward. Thus, a spiral-shaped movement around the patient is established.

The system contains a small mega-volt X-ray source (X-band accelerator [85]), an opposite high-energy detector ($\rightarrow$ control of appreciated beam) and an X-ray tube with opposing detector, which are shifted by 90° towards the radiation device (fig. 2.7). Hence, simultaneous real time imaging and treatment is enabled.

Indications for tomotherapy are commonly lung cancer, head and neck tumors, breast cancer and prostate cancer [46].

2.1.3.4 CyberKnife®

Figure 2.8: Components of a *CyberKnife®* Treatment Device [56]

This treatment delivery device is a frameless robotic system for radiosurgery [5]. It was developed by John Adler at the Stanford University and first patients were treated in 1994 [2]. The system consists of a small linear accelerator (6 MV, X-Band) that is mounted on a 6-axis industrial robotic arm, a treatment couch that is mounted on a second robotic arm, two X-ray sources, whose rays are arranged perpendicular to each other and two corresponding detector panels (fig. 2.8). Thus, a tracking of the accelerator during movements of organs leads to inaccuracy, these movements are analyzed to extract movement patterns which result in a prediction for the position of the organ, and the accelerator can be positioned accordingly. The accuracy of target localization is less than 2 mm [43, 89]. Furthermore, the beam can be extended by applicators (s. 2.1.4.5) to field sizes of 5 - 60 mm.

The *CyberKnife®* is used for intracranial lesions as well as for extra-cranial treatment, e.g., lung cancer, lung, liver and prostate cancer [83].

2.1.3.5 Vero®

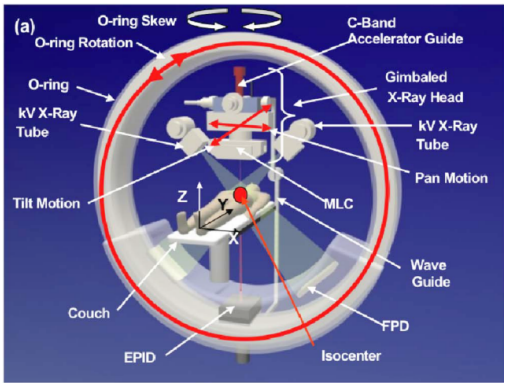


Figure 2.9: Schematic Overview of the *Vero®* System [45]

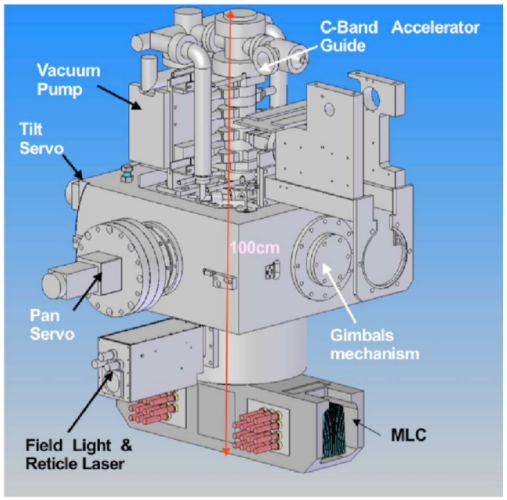


Figure 2.10: Gimbaled X-ray Head [45]

Vero® is a treatment delivery device for *Stereotactic Body Radiotherapy (SBRT)*. It consists of a gimbaled X-ray head (fig. 2.10), two (orthogonal) kilo-volt X-ray tubes and two flat panel detectors that are mounted on an O-ring (fig. 2.9). This O-ring can rotate ±185° around the patient and can be skewed ±60° around its vertical axis. Furthermore, an *electronic portal imaging device (EPID)* is included in the ring and a 6D-movable couch as well as an infrared (IR) tracker are placed outside of the O-ring.

In the gimbaled X-ray head a C-band accelerator guide (s. [85]), a multi-leaf collimator (s. 2.1.4.6) and the gimbals mechanism are arranged. "Pan and tilt motions of the gimbals offer active compensation for mechanical distortion of the O-ring" [45] and quick beam motion to compensate movements of the target around the isocenter. By this beam positioning a predicted accuracy of ±0.1 mm can be attained [45]. The O-ring facilitates a planar port selection and the ring skew provides a non-coplanar beam angle selection and a yaw angle correction in the setup [45]. Because of the dual imaging systems planar images, cone-beam CT (CBCT) and real-time fluoroscope monitoring are enabled.

2.1.3.6 ViewRay™

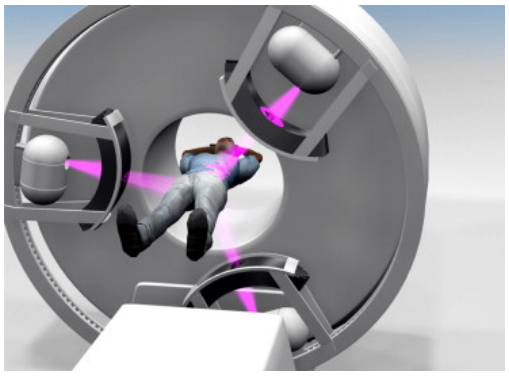


Figure 2.11: Conceptual Image of *ViewRay™* Device [12]

This device makes use of three ^{60}Co-teletherapy heads with multi-leaf collimator for IMRT in combination with magnetic resonance imaging (MRI) guidance (fig. 2.11). Furthermore, it has the capability for continuous imaging during the treatment even while the beam is on.

As this MRI-LINAC hybrid system combination is new, it is an area of research and development [47].

2.1.4 Beam Modifications / Fluence Modification

2.1.4.1 Wedge

Wedges are beam modifying devices to homogenize the dose distribution. They tilt the dose distribution in a defined depth towards a desired angle over the beam. This is achieved by a progressive decrease in intensity across the beam (from the thin edge to the thick edge of the filter). This results in an isodose distribution with a planned asymmetry. The tilt degree depends on the slope of the wedge filter [80]. Wedges are generally used for relatively superficial tumors [80].

The following wedge types exist:

- *Static wedge*: Fixed design
- *Motorized wedge* (also known as *dynamic wedge*): Wedge (with a fixed design) is moved into the beam field for part of the time to create the wedge beam profile
- *Virtual wedge* (also known as *dynamic enhanced wedge*): Are created by computer-controlled movement of one of the collimator jaws while concurrently adjusting the dose rate and the jaw's moving speed during the irradiation

2.1.4.2 Block

Blocks are beam modifiers that are used to shield parts of the patient to protect critical organs, avoid unnecessary irradiation of the surrounding normal tissue near a tumor and/or match adjoining fields [80]. In kilo-voltage radiation placing sheets of lead directly on the surface is sufficient, however, for mega-voltage radiation thicker blocks are required. Because of their weight they are placed in the tray of the treatment device (fig. 2.6 on page 12).

Blocks can be *positive*, which means that the central area is blocked, or *negative*, which represents a peripheral area blocking. A *diverging block* follows the geometric divergence of the beam to achieve a minimization of the block transmission penumbra.

2.1.4.3 Bolus

A *bolus* is a tissue equivalent material which is used to reduce the depth of the maximum dose (D_{max}). For kilo-voltage radiation a *bolus* can be used to adjust the skin surface contours. In mega-voltage radiation they are primarily used to bring up the buildup zone near the skin of treated superficial tumors. Their thickness depends on the energy of the radiation (e.g.: ^{60}Co: 2-3 mm; 6 MV: 7-8 mm; 10 MV: 12-14 mm; 25 MV: 18-20 mm). Commonly used materials are cotton soaked with water or paraffin wax. Furthermore, there are some commercial material available that use different materials to establish better pliability or better conformity of the thickness [80].

2.1.4.4 Compensator

Compensators are used to even out skin surface contours while preserving the buildup effect. Furthermore, they can be used to compensate tissue heterogeneity [30] or to compensate irregularities arising due to reduced scatter near the field edges and horns in the beam profile [80]. The used materials are either polystyrene, which is filled with zinc granules [80] or other radiation absorbing material (e.g., leaded paraffin). *Compensators* can be designed to absorb more radiation than the (normal) tissue. Besides, it is possible to form *compensators* in a way that they compensate the absorption of inner organs.

2.1.4.5 Applicator

Applicators are used to form the radiation beam. Primarily *applicators* are used for treatment with electrons. An *applicator* consists of an electron scattering chamber with an electron emission channel as a primary collimator. The emission channel can be changed and determines the shape of the electron beam. They are mounted to the tube

head and placed "directly" (commonly 5 cm away from patient's body [80]) on the tumor to irradiate the lesion with a collimated beam and keep the radiation away from the normal tissues.

2.1.4.6 Multileaf Collimator (MLC)

Multileaf Collimators (MLC) are used to generate radiation fields of any shape. They consist of a large number of collimating blocks or leaves which can be moved independently in and out of the beam. Usually, tungsten is used as leaf material and the common leaf-thickness is 6 - 7,5 cm.

Initially, MLCs are used for conformal radiotherapy [18] and are adapted to be used for IMRT treatments [21]. The advantage of MLCs is the gain in time because no custom blocks have to be formed and an automatic reshaping is enabled. Furthermore, MLCs can be used as *dynamic wedges* (s. 2.1.4.1) or *electronic compensators* (2D, s. 2.1.4.4). However, it is not possible to perform an "island blocking".

2.1.5 Treatment Techniques of External Beam Radiation Therapy

Radiotherapy aims to create a homogeneous dose distribution conformal to the target volume and simultaneous protection of normal tissue at its best. Besides the treatment delivery device (s. 2.1.3), the patient positioning device, the patient positioning system and the fixation device are important components.

The patient can be positioned *conventionally* with the help of external markers (also called *fiducials*) and a laser visor or by *stereotactic positioning*, where the patient is fixed in a screwed frame to achieve the desired accuracy (head frame). Furthermore, frameless stereotactic positioning is available [35, 38] or can be achieved by *Image Guided Radiation Therapy (IGRT)*. For IGRT two and three-dimensional imaging is realized during a treatment to re-localize the patient and fit the actual geometry to the geometry of the treatment plan. This is necessary because tumors can move between treatments because of different filling of organs or movements while breathing. The available systems use different approaches like 2D-2D matching (including fluoroscopy [39] and digital reconstructed radiographs (DRRs)[88]) or *cone beam computed tomography (CBCT)* [82].

Another characteristic of a treatment technique is, whether the isocenter is located in the target point respectively the tumor *(isocentric treatment*) or not (*non-isocentric treatment*). Furthermore, it can be differentiated between *coplanar* and *non-coplanar* techniques. First mentioned technique arranges all beams in one plane (gantry angle changes between fields and table angle is constant), whereas beams of *non-coplanar* techniques are arranged in different planes (gantry and table angle are changing).

As target volumes are normally irregularly formed the beam shape has to be adapted for different radiation angles to achieve a *conformal* radiation. This can be achieved by the previously mentioned beam modifiers (s. 2.1.4).

2.1.6 Treatment and Treatment Planning

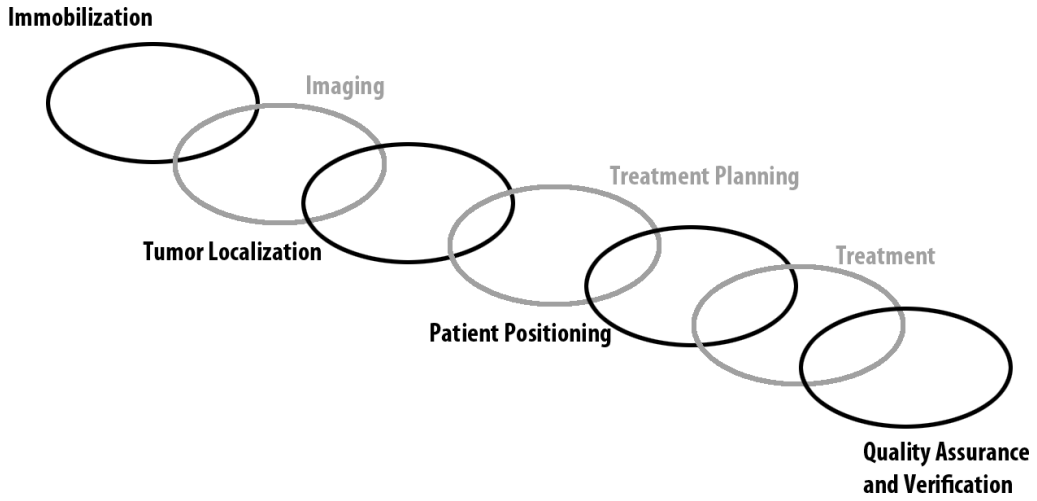


Figure 2.12: Radiotherapy Treatment Chain [14]

Radiotherapy is a complex process consisting of several steps which depend on each other as shown in figure 2.12. Besides the described treatment delivery devices (s. 2.1.3), there are a lot of other systems involved. The *Record & Verify System (R&V),* which is part of a *Treatment Management System (TMS)*, is a software that checks the position of the couch, collimator, gantry and any beam modifiers before a treatment is given. Furthermore, it records what dose was delivered, the treatment status etc.

Another important system is the *Treatment Planning System (TPS)*. It is used to create a treatment plan and contains a contourer, a geometric planner and a dosimetric planner. Moreover, a *Patient Position Verification System (PPVS)*, a *Patient Position Modification System (PPMS)* and a *Quality Assurance System (QA)* are important units. The last mentioned system checks the monitor units (MU) and verifies the delivered dose.

2.1.6.1 Therapy Planning

As mentioned before radiotherapy aims are to irradiate the tumor as conformal as possible, while protecting normal tissue. As a first step relevant anatomic structures have to be defined. This can be done by hand or with the help of (semi-)automatic algorithms (e.g., *Random Walks* [36] or atlas-based segmentation [22]). Next the treatment technique (s. 2.1.5) has to be determined to proceed with the dose calculation. When the generated results are satisfying the treatment plan is created. Otherwise a plan respectively dose optimization has to be performed.

Volume Definition

ICRU[1] report 50 and 62 define several levels of target volume definition [19, 20]:

- *Gross Tumor Volume (GTV)*: "The is the gross palpable or visible/demonstrable extent and location of the malignant growth"
- *Clinical Target Volume (CTV)*: "The CTV is a tissue volume that contains a GTV and/or subclinical microscopic malignant disease, which has to be eliminated. This volume thus has to be treated adequately."
- *Internal Target Volume (ITV)*: "The ITV is defined as the sum of CTV and Internal Margin (IM). The IM is defined so as to take into account variations in size, shape, and position of the CTV in relation to anatomical reference points (e.g., filling of stomach, bladder, movements due to respiration, etc.)."
- *Planning Target Volume (PTV)*: "The PTV is a geometrical concept, and it is defined to select appropriate beam size and beam arrangements, taking into consideration the net effect off all possible geometrical variations and inaccuracies in order to ensure that the prescribed dose is actually absorbed in the CTV."
- *Treated Volume*: "Is the volume enclosed by an isodose surface, selected and specified by the radiation oncologist as being appropriate to achieve the purpose of treatment (e.g., tumor eradication, palliation)"
- *Irradiated Volume*: "Is that volume which receives a dose that is considered significant in relation to normal tissue tolerance"

The ideal case is that PTV is equal to Treated Volume.

[1] International Commission on Radiation Units and Measurements

Besides target volumes ICRU report 50 [19] respectively 62 [20] defines the terms:

- *Organ at Risk* (OR respectively OAR): "ORs (critical normal structures) are normal tissues whose radiation sensitivity may significantly influence treatment planning and / or prescribed dose"
  - Further classification for purpose of evaluation of volume-fractionation-response according to functional models based on *Functional Sub Unit (FSU)* [44, 87, 67]:
    - *serial*: Organ structure for which damage to any segment of the organ damages the entire organ
    - *parallel*: Organ structure for which damages to any segment of the organ damages only that segment
    - *serial-parallel*
- *Planning Organ at Risk Volume (PRV)*: "The PRV is a geometrical concept, and it is defined in the same way as the PTV for the CTV, taking into consideration the net effect off all possible geometrical variations (movements and changes in shape) of the OR as well as set-up uncertainties when considering radiation effects on the OR"

Plan Optimization

The following parameters can be optimized in a treatment planning:

- Beam type
- Beam energy
- Gantry and table angle
- Beam shape
- Coordinate of treatment and target position
- Number of beams, fractions
- Weighting of fields
- Intensity modulation of radiation fields

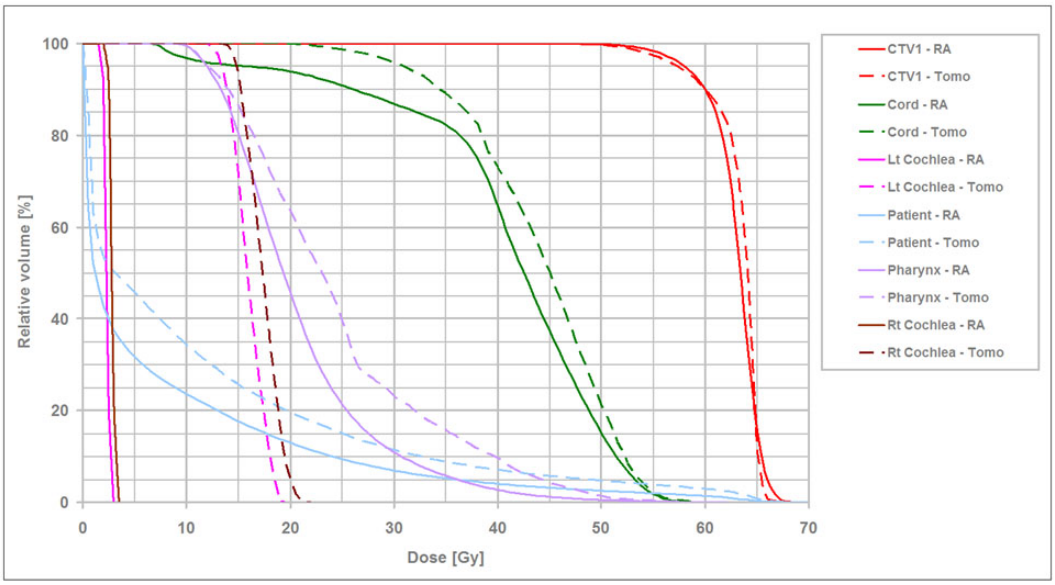


Figure 2.13: Dose Volume Histogram (DVH) [77]

Sometimes this optimization problem is hard to solve analytically. The physician has the choice between *manual optimization* (trial and error), *semi-automatic procedures* (e.g., knowledge-based systems) or *automatic procedures* (e.g., inverse planning). The decision whether a plan is acceptable or not can be based on a *dose volume histogram* (DVH, fig. 2.13), which summarizes the dose distribution in a two-dimensional format. Thus a quick overview is given, whether the maximum dose for critical structures is not exceeded and the prescribed dose for the target volume is achieved. A quantitative optimization can be done with the help of *physical constraints* (→ penalty function) or *biological models* (e.g., TCP and NTCP, s. 2.1.2.1).

As mentioned before an analytical optimization is not possible all the time. Nevertheless, it is possible by specifying specific boundary conditions to get an approximated solution.

2.2 DICOM Standard

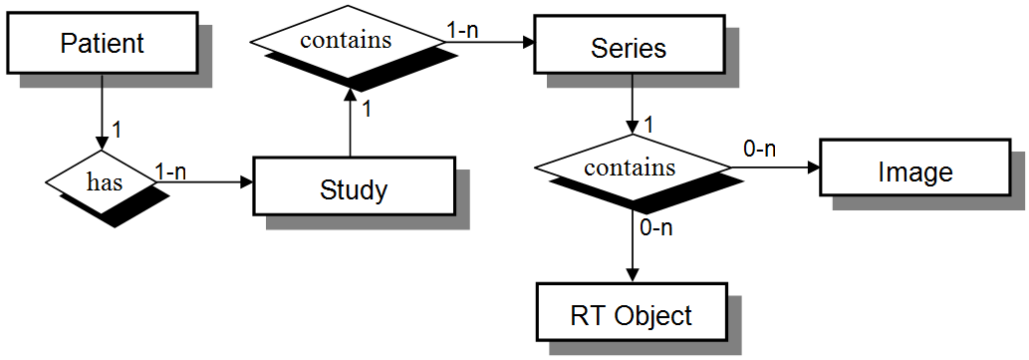


Figure 2.14: Simplified DICOM Model of the Real World

2.2.1 General

Digital Imaging and Communications in Medicine (DICOM) is an open standard for information exchange in medicine that was introduced in 1993 [57]. It specifies how medical images and their related information (e.g., segmentations or radiation treatment plans) shall be provided in an object oriented manner "to ensure interoperability of systems used to produce, store, display, process, send, retrieve, query or print" this information as well as "to manage the related workflows" [58, 57].

DICOM is a standard that consists of several parts, which are documented in separate documents (18 parts, state: Oct. 2012) [60]. The advantage of this approach is that single parts can be developed independently and the overall structure is not influenced. To meet the perpetually changing requirements and technologies in medicine, hardware and software, the DICOM standard is continually extended by 28 *Working Groups* (WG, state: Oct 2012) [64]. Each group is responsible for a special sub-part of the standard (e.g WG-06: Base Standard or WG-07: Radiotherapy). The existing (first-generation) objects for radiotherapy are introduced in more detail in 2.2.4. Latest specifications are published by the NEMA (National Electrical Manufactures Association) [60].

To represent the basic dependency structure of the DICOM *Information Object Definitions (IOD*, s. 2.2.2), the *DICOM Model of the Real World* was introduced. Figure 2.14 shows the typical hierarchical structure used in DICOM applications: A patient has one or more hospital stays (*Study*). Each stay contains one or more *Series*, which are modality specific and might contain several images. The *Frame of Reference* defines the coordinate system for one or more series.

As mentioned before, DICOM IODs define certain properties (*Characteristics*) and operations (*Service Class*), that are applied to them, in *Information Object Definitions (IOD, s. 2.2.2)*. Information objects are connected to their services by *Service Object Pairs (SOP)*. Each *SOP Class*, which is the definition of such a connection, and each *SOP Instance*, which represents a concrete object of that class, get unambiguous *Unique Identifier (UID)*. Class UIDs are defined by the NEMA and Instance UIDs have to be unique worldwide. Therefore, producers of hardware or software get a root-number assigned by one of the registration authorities (e.g., ANSI, DIN CERT). This root-number is extended by the producer to generate unique UIDs for their devices respectively installations.

A DICOM file is a list of attributes containing the object's information. For image objects one can divide the DICOM file into two parts. The first part contains all attributes describing an image. The second part contains the (compressed or uncompressed) image data itself. It is possible to define own producer-specific objects, modules or attributes with the help of *private tags* (s. 2.2.3). If these *private tags* are published, e.g., in a *DICOM Conformance Statement*, which should be present for every DICOM conform device to describe its capabilities, interconnectivity between different manufacturers can be established.

2.2.2 Information Object Definition (IOD)

The third part of the DICOM standard specifies all objects by *Information Object Definitions (IODs)*. An IOD is divided into several modules that are used to group the attributes of an information object. Hence, modules are used by different object types, each object has to define whether the module is *mandatory* (M), *conditional required* (C) or *user optional* (U).

Every module consists of attributes. An attribute is unambiguously defined by a hexadecimal number that is divided into two four-digit hexadecimal numbers (tag) to establish a better readability. The first hexadecimal number describes the belonging to a group and the second number specifies the element. Each attribute has one of the types: *1* (mandatory), *2* (mandatory, but can be empty) or *3* (optional). If a *'C'* is appended to the type, it means that the attribute has to be defined under special conditions, which are specified in the *Attribute Description*. Furthermore, attributes are characterized by their *Value Representation (VR)*, which describes the element's data type, and their *Multiplicity* (*VM)*, which describes the number of allowed items of this attribute.

Another important thing to take note of is the inclusion of attributes in different modules. Thus, attribute description and type definition are context specific. Elements are written to the DICOM header according to their ascending order ($\rightarrow$ *tags*). Some elements are repeated in so called *sequences*. These are constructs, which summarize multiple

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
	Clinical Trial Subject	C.7.1.3	U
Study	General Study	C.7.2.1	M
	Patient Study	C.7.2.2	U
	Clinical Trial Study	C.7.2.3	U
Series	RT Series	C.8.8.1	M
	Clinical Trial Series	C.7.3.2	U
Equipment	General Equipment	C.7.5.1	M
Structure Set	Structure Set	C.8.8.5	M
	ROI Contour	C.8.8.6	M
	RT Observation	C.8.8.8	M
	Approval	C.8.8.16	U
	SOP Common	C.12.1	M

Table 2.1: Object Definition of RT Structure Set [60]

attributes in a kind of block. Sequence items are identified by a '>' in the DICOM standard. Sequence can be nested which is indicated by multiple '>' (e.g., '>>').

As *DICOM Attribute Macros* are extensively used in Supplement 147 (s. 2.3), and this thesis tries to integrate a concept to represent *DICOM Macros* in the underlying framework (s. 3.4.3), their usage in the DICOM standard is explained at this point. *DICOM Macros* represent a set of "same DICOM Attributes [that] are used in multiple tables or multiple places in one Module" [62]. *Macros* are included as a reference in these tables. The *Attribute Macro* content shall be included at the place of the *Macro* reference. Furthermore, *Macros* can be used inside of a Sequence, which is indicated by one or more '>'. As "there may be specializations of the description of attributes in the *Attribute Macro*[,] this spezialiation is described in the *Description* column of the *Module*" [62].

The last important thing regarding DICOM information objects and this work are the *DICOM Content Mapping Resources (DCMR)*, which are defined in part 16 of the DICOM standard. They define *Templates* and *Context Groups* that are used in the standard. *Templates* are patterns that describe the *Content Items*, *Value Types*, *Relationship Types* and *Value Sets* used in other *Content Item constructs* like a Protocol Context or a Structured Report (similar to a Module of an Information Object Definition) [61]. A *Context Group* is a "set of coded concepts forming a set appropriate to use in a particular context" [61]. *Templates* and *Context Groups* are identified by a TID respectively CID.

2.2.3 Private Data Element Tags

As mentioned before it may be required to communicate implementer-specific information. This information is encapsulated in *Private Data Elements* [63]. These elements have the same structure as standard elements (s. 2.2.2). But the group number has to be odd to indicate a private group. *Private Data Elements* shall not be used instead of *Standard Data Elements* when *Standard Elements* exist. To enable multiple implementers to define *Private Elements* with the same group number, *Private Elements* shall be assigned to a *Private Data Element Tag* (sometimes called Private Creator Code). Therefore, "the implementer shall insert an identification code in the first (unassigned) element in the series to reserve a block of private elements. *Private Creator Data Element* (gggg, 0010), is a data element that identifies the implementer reserving element (gggg, 1000-10FF), *Private Creator Data Element* (gggg, 0011) identifies the implementer reserving elements (gggg, 1100-11FF), and so on, until *Private Creator Data Element* (gggg, 00FF) identifies the implementer reserving elements (gggg, FF00 -FFFF)"[63]. Thus, the total number of blocks that can be reserved and can later be used within one group is 0xFF - 0x10 = 240.

2.2.4 DICOM RT - A Extension for Radiotherapy

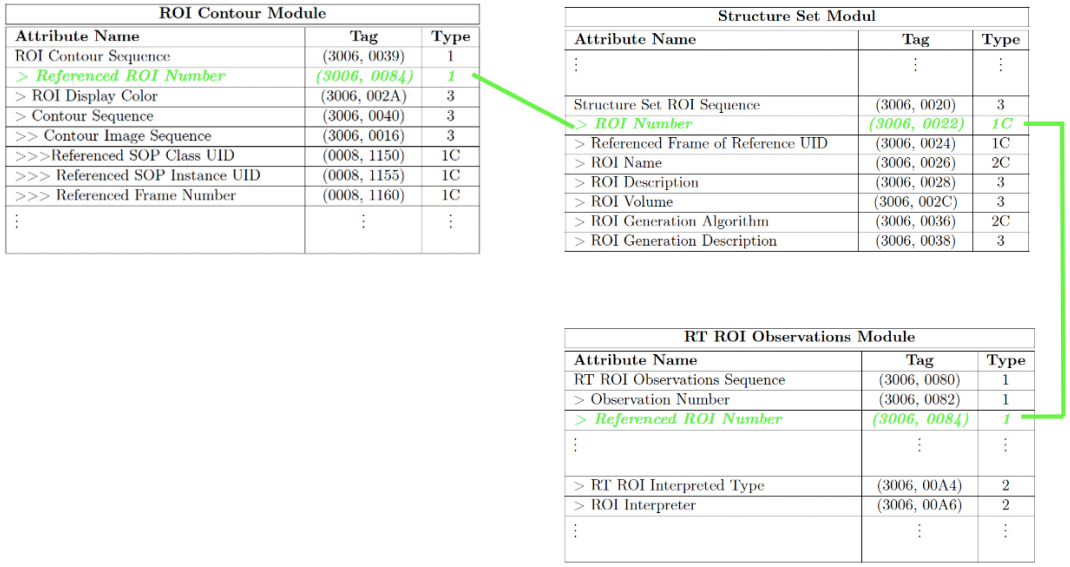
DICOM RT is the extension of the DICOM standard with objects and elements for radiotherapy. First efforts to introduce a common exchange standard in radiotherapy were undertaken in 1982 by the *American Association of Physics in Medicine* (s. 2.5.3) in their Report No. 10 [13]. Emerging from this report the *Radiotherapy Oncology Group (RTOG)* developed the RTOG standard, which was published in the same year and already contained a lot of RT relevant information.

Hence, this standard was principally used in North American countries, the International Electronical Commission (IEC) had started an initiative in the late 1980's to develop a communication standard for radiotherapy [66]. During the RSNA (Radiological Society of North America) meeting of 1994 an ad-hoc Working Group, that later became *Working Group 7 (Radiotherapy Objects)*, was formed [1]. Their task was to extend the established DICOM standard for needs of radiotherapy. Since then the following objects are defined and entered the latest standard (state: Oct. 2012):

- RT Image
  - "Describes normally 2D image data and consists of parts describing the image (e.g. device, referenced RT Plan, exposure sequence)" [24].
- RT Structure Set
  - "Addresses the requirements for transfer of patient structures and related data defined on CT scanners, virtual simulation workstations, treatment planning

systems and similar devices" [60]. A more detailed description can be found in 2.2.4.1

- RT Dose
  - "Describes the dose distribution. Can be transmitted as a 2D respectively 3D grid similar to a normal image (dose date = *Pixel Data* attribute) or as isodose curves and points similar to the concept of used in *RT Structure Sets*" [24].
- RT Plan
  - "Transfer of treatment plans generated by manual entry, [...], treatment planning system before or during a course of treatment. Such a plan may contain fractionation information, and define external beams and/or brachytherapy application setups" [60]. A more detailed description can be found in 2.2.4.2
- RT Beams Treatment Record
  - "Transfer of treatment session reports generated by a treatment verification system during a course of external beam treatment, with optional cumulative summary information" [25].
- RT Brachy Treatment Record
  - "Transfer of treatment session reports generated by a treatment verification system during a course of Brachytherapy treatment, with optional cumulative summary information" [25].
- RT Treatment Summary Record
  - "Transfer cumulative summary information, normally generated at the completion of a course of treatment" [25].
- RT Ion Plan
  - "Transfer of treatment plans generated by manual entry, a virtual simulation system, or a treatment planning system before or during a course of Ion therapy treatment. Such plans may contain fractionation information, and define Ion beams" [26].
- RT Ion Beams Treatment Record
  - "Transfer of treatment session reports generated by a treatment verification system during a course of Ion beam treatment, with optional cumulative summary information" [26].



ROI Contour Module		
Attribute Name	**Tag**	**Type**
ROI Contour Sequence	(3006, 0039)	1
> Referenced ROI Number	*(3006, 0084)*	*1*
> ROI Display Color	(3006, 002A)	3
> Contour Sequence	(3006, 0040)	3
>> Contour Image Sequence	(3006, 0016)	3
>>>Referenced SOP Class UID	(0008, 1150)	1C
>>> Referenced SOP Instance UID	(0008, 1155)	1C
>>> Referenced Frame Number	(0008, 1160)	1C
⋮	⋮	⋮

Structure Set Modul		
Attribute Name	**Tag**	**Type**
⋮	⋮	⋮
Structure Set ROI Sequence	(3006, 0020)	3
> ROI Number	*(3006, 0022)*	*1C*
> Referenced Frame of Reference UID	(3006, 0024)	1C
> ROI Name	(3006, 0026)	2C
> ROI Description	(3006, 0028)	3
> ROI Volume	(3006, 002C)	3
> ROI Generation Algorithm	(3006, 0036)	2C
> ROI Generation Description	(3006, 0038)	3

RT ROI Observations Module		
Attribute Name	**Tag**	**Type**
RT ROI Observations Sequence	(3006, 0080)	1
> Observation Number	(3006, 0082)	1
> Referenced ROI Number	*(3006, 0084)*	*1*
⋮	⋮	⋮
> RT ROI Interpreted Type	(3006, 00A4)	2
> ROI Interpreter	(3006, 00A6)	2
⋮	⋮	⋮

Figure 2.15: Connection Between Modules of RT Structure Set [81]

2.2.4.1 RT Structure Set

RT Structure Set IODs are designed to contain information of segmented anatomical structures of a patient. The *Regions of Interest (ROI)* are defined in the *Structure Set Module*. Besides general structure information (e.g., name and description), information of referenced images, series or studies are contained. Furthermore, coordinate transformations can be specified if the referenced images are not in the same coordinate system (→ *Frame of Reference*). Each *ROI* must have a unique reference number (*ROI Number*) to connect it to its contour data that are defined in the *ROI Contour Module*, respectively its interpretation, which is defined in the *RT ROI Observation Module*. The described connection is illustrated in figure 2.15.

As an alternative to specify contours the *Segmentation IOD* is mentioned at this point as it gets a more important role in the second-generation environment. *Segmentations* are multi-frame images and are a binary or fractional classification of pixels in one or more referenced images. If a *Frame of Reference*, the identification of a specific coordinate reference, is specified in the referenced images, the *Segmentation* instance shall have the same *Frame of Reference* but does not have to have the same spatial sampling or extent as the referenced images. In case of *Frame of Reference* absence, the "*Segmentation* instance shall have the same spatial sampling and extent as the referenced image" [60].

2.2.4.2 RT Plan

The *RT Plan* object was introduced to encapsulate the geometric data needed in a course of *external beam radiotherapy* respectively *brachytherapy*. A major difference to other DICOM objects is that this objects contains dynamic components. A *RT Plan* contains elements to describe the prescription of doses and tolerance doses, the patient positioning, tolerance tables, fractionation information and description of the treatment technique(s).

2.2.5 Extending the Standard - DICOM Supplements

As defined in the DICOM "Procedures" document [59], the development of a Supplement shall be performed in the phases:

1. Requirements Definition (optional)
2. Early Draft
3. Public Comment Draft
4. Intermediate Draft
5. Trial-Use Draft (optional)
6. Letter-Ballot Text and
7. Final Text

During the first phase, a detailed proposal of the project's scope, subgroup resources and time-frame for completion is prepared.

In the *Early Draft* phase, the initial drafts of the standard respectively supplement are prepared. It is finished when the subgroup prepares a *Public Comment Draft* of the proposed standard respectively supplement and the *Public Common Draft* is approved by the *Base Standards Working Group* (s. 2.2.1).

At the beginning of the *Public Comment Draft* phase, which shall be at least 45 days, "the proposed standard is submitted to a group of interested parties outside the Committee and to other interested subgroups that report to the Committee" [59]. These interested parties (worldwide) shall be identified by the originating subgroup.

In case of the *Intermediate Draft* all received comments are reviewed and a revised draft of the proposed standard is prepared. Appropriate recommendations shall be communicated to the *Base Standard Working Group* whether "the proposed standard should go trough the *Trial-Use Draft* phase or move directly to the *Letter-Ballot* phase" [59]. The final decision is made by *Working Group 6*.

The aim of the *Trial-Use Draft* is "to provide a stable draft of the proposed standard to encourage prototype implementations. It shall be used when it is believed that

implementation experience is needed before the content of the proposed standard can be finalized and submitted" [59]. The changes in this phase have to be well documented and are maintained by the corresponding subgroup.

The following *Letter-Ballot* of the Committee's member shall have a 49-day time limit. Subsequent to this the *Base Standard Working Group* considers all comments from the letter ballot and "may prepare a final proposed standard and explanations how each comment was solved [or] may decide to submit the proposed standard to the subgroup that developed the standard for further action" [59].

When there are "no technical differences that directly and materially affect the use of the standard between the *Letter-Ballot Text* and the *Final Text*, [...], the standard is approved" [59]. In case of minor technical differences all members of the Committee are informed by the secretariat regarding the nature of the change and each member gets a 30-day opportunity to change its vote. At the end of this period the votes are recounted and determined whether to approve or reject the standard.

2.3 Supplement 147

The previously mentioned DICOM RT objects (s. 2.2.4) worked well for many years. But it becomes obvious that these first-generation objects are mostly overloaded and very static. Another problem is that the definitions of these objects base on conventional C-Arm LINAC concepts (s. 2.1.3.2) and do not contain all features of new technologies and treatment techniques. Therefore, Supplement 147 is developed to address these needs for more flexible and adaptive structures.

Figure 2.16 gives an overview of the new introduced IODs and their relationships.

In the following the essential new concepts and some of the new IODs are presented.

2.3.1 Separation of Concerns - IOD Separation

To solve the issue with the overloaded first-generation RT objects, Supplement 147 introduces different IODs for different representations of data. This leads to much smaller IODs. Associated with this it is noteworthy that separate IODs for specific treatment modalities are introduced with the concept of *RT Radiation IODs* (s. 2.3.1.3). This allows to apply more specific conditions to the presence respectively absence of attributes within those IODs and a more convenient introduction of new technologies.

In the following the new objects representing a treatment plan are presented a bit more detailed.

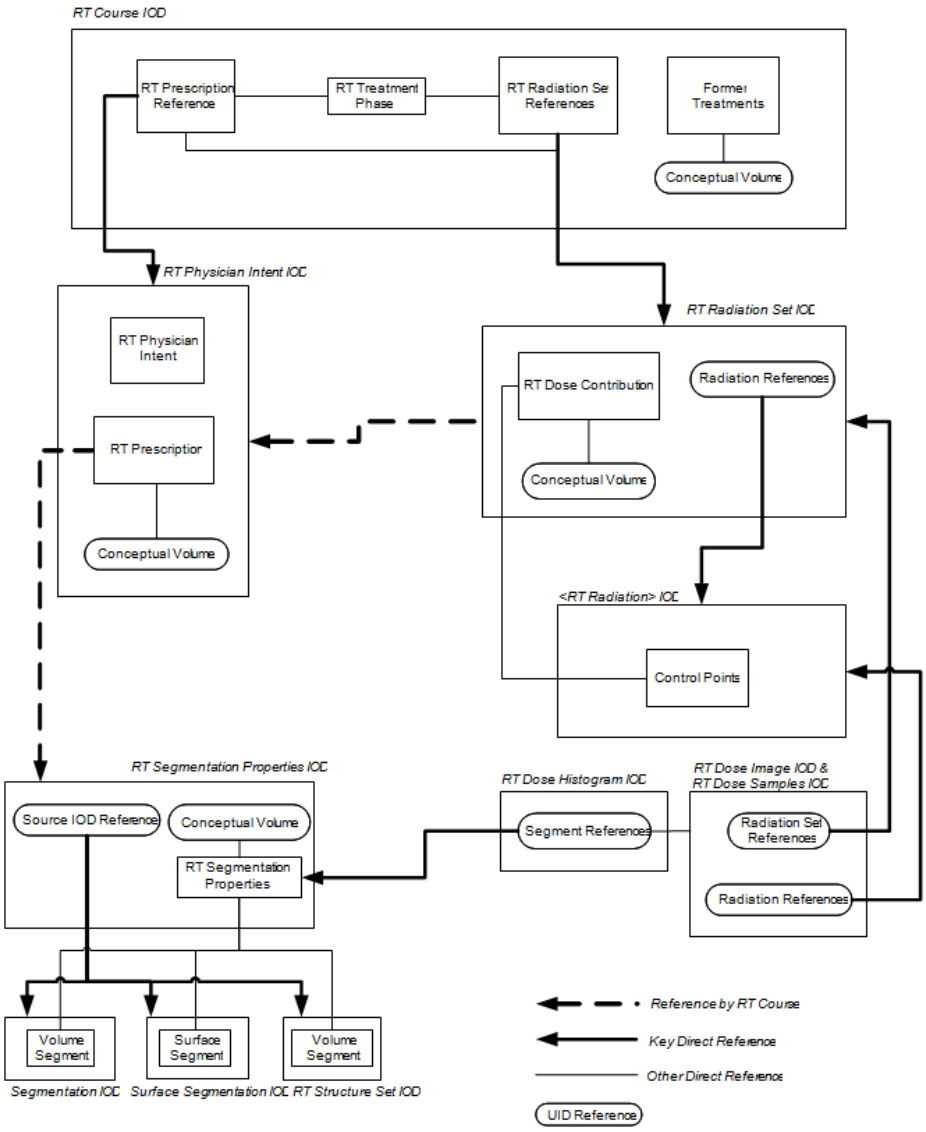


Figure 2.16: Relationships Between Second-Generation Entities [28]

2.3.1.1 RT Physician Intent

The *RT Physician Intent* is the new object that carries the prescription by which a physician describes the therapeutic goal and strategy for a radiotherapeutic treatment. It consists of the *Intent Module* and the *Prescription Module*.

First mentioned module contains mostly descriptive texts to enable formulation "in accordance with the nomenclatures and policies of a certain oncology department" [28]. It is used to define the information about the overall intent of a treatment, like the *Nominal Dose* or the treatment strategy.

Last mentioned module encapsulates the physicists prescriptions that are used to define the intended procedures for the identified target(s) respectively to define constraints for organs at risk. To enable an automatic processing of the prescription data, this information is mostly coded. Additional free text statements can be specified at different levels of this module as well.

2.3.1.2 RT Radiation Set

An *RT Radiation Set* defines a set of beams (*RT Radiation*, s. 2.3.1.3) which is applied to one or multiple fractions. Treatment series respectively treatment phases are described by one or more *RT Radiation Sets*. The relationship between these *RT Radiation Sets* is handled by the new *RT Course IOD* (s. 2.3.1.5).

Time-related relation is described in the *RT Treatment Phase Module* and *RT Radiation Set Reference Module* of the *RT Course IOD*. Relations in respect to changes of a *Radiation Set* in the course of treatment are described in a sequence of the *RT Radiation Set Reference Module* of the *RT Course IOD*. But this sequence can only be used for "small adaptions of the actual *Radiation Set* within the intended series of fractions, keeping the intended treatment technique, beam layout and the planned dose distribution" [28]. Changes beyond this scope are typically handled on the treatment phase level of the *RT Course*.

2.3.1.3 RT Radiation

The *RT Radiation* is the conceptual meta-class representation of a treatment beam. There are already several specific IODs included in Supplement 147, which represent a specific treatment modality:

- *Tomotherapeutic Radiation IOD*: "Representing information required for modeling a treatment using a serial or helical tomotherapeutic photon delivery device." [28], s. 2.1.3.3

- *C-Arm Photon Radiation IOD:* "Representing information required for modeling a treatment using a C-Arm photon delivery device." [28], s. 2.1.3.2
- *C-Arm Electron Radiation IOD*:"Representing information required for modeling a treatment using a C-Arm electron delivery device." [28], s. 2.1.3.2
- *Multiple Fixed Source Radiation IOD*: "Representing information required for modeling a treatment using a multiple fixed source photon delivery device." [28], e.g., Gamma Knife® (s. 2.1.3.1)
- *Robotic Radiation IOD*: "Representing information required for modeling a treatment using a robotic delivery device, such as paths, nodes, and collimation type." [28], e.g., CyberKnife® (s. 2.1.3.4)
- *Multi-axial Radiation IOD*: "Representing information required for modeling a treatment using a C-Arm device having additional degrees of freedom in source positioning." [28], e.g., Vero® (s. 2.1.3.5)

By this separation the introduction of new treatment device concepts shall be facilitated.

2.3.1.4 RT Segmentation Properties

To separate the volumetric definition of a structure from its radiotherapy-relevant metadata the *RT Segmentation Properties IOD* is introduced. It describes the clinical segmentation types (e.g., target volume, organ at risk) and other radiotherapy-specific structure properties, like electron density.

An *RT Segmentation Properties* instance can be used to annotate structure definitions not only defined in an *RT Structure Set* - as in first-generation environment - but also in a *Segmentation* or *Surface Segmentation* (s. 2.2.4.1). The information specified in an *RT Segmentation Properties* instance will overwrite this information in other radiotherapy objects which specify such an information. Furthermore, *Segmentation* instances are the typical referenced object of an *RT Segmentation Properties* object instead of the *RT Stucture Set*.

2.3.1.5 RT Course

The *RT Course IOD* is the new and dynamic top-level entity to describe a given treatment course. It is envisaged that this will typically managed by a *Treatment Management System* (s. 2.1.6) and is typically generated "on-the-fly". All relevant objects are referenced in it and an *RT Course instance* describes information relating to the current approval state of a treatment, treatment phase, and changes because of adaption of the therapy. As this thesis does not investigate the *RT Course IOD* it is referred to Supplement 147 [28] for a more detailed description.

2.3.2 Abstract Access to Volumetric Objects - Conceptual Volume

Another concept is the introduction of an abstract access to volumetric objects, which is called *Conceptual Volume*. This concept is introduced to avoid the direct referencing of structures via a concrete instance and ROI respectively segment, but to keep planning-related meta information separately. A *Conceptual Volume* represents an "abstract spatial entity used in radiotherapy (or elsewhere) to identify the region of a patient" [28]. Generally such a volume has a diagnostic or therapeutic purpose. A *Conceptual Volume* may or may not be defined by a specific segmentation (*Segmentation, Surface Segmentation, RT Structure Set*). Without such a reference of structure definitions a *Conceptual Volume* is used as a pure reference to illustrate a spatial entity. This can be used to prescribe a dosimetric constraint respectively dose for therapy for example. The association of specific structure data can be done afterwards.

2.4 DICOM(-RT) Libraries

As mentioned before (s. 2.2.1) the DICOM standard is very complex and the development of a library to read/write DICOM conform files respectively provide DICOM-conform services "from-scratch" is very tedious. Furthermore, a solution like that would (probably) not support full functionality and result in long-standing development. Therefore, the use of an existing library is to be preferred. There are several toolkits available for different platforms and programming languages. An overview of several toolkits was created as part of another diploma thesis [78, 79]. Thus this thesis is based on a framework that uses the *DICOM Merge Toolkit*, only this toolkit is described a bit more detailed in the following.

2.4.1 DICOM Merge Toolkit

The *DICOM Merge Toolkit*[2] is a commercial DICOM toolkit that supports its usage in the programming languages C/C++, .NET and Java. The toolkit encapsulates the DICOM data dictionary (DICOM standard part 6) with its tags, names, value multiplicities and value representations in a binary dictionary file (*mrgcom3.dct*). Another binary file (*mrgcom3.msg*) is used by the toolkit to encapsulate the *DICOM Service Object Pairs* (s. 2.2.1). The toolkit provides the possibility to define own (private) attributes and services in platform independent ASCII files (*diction.pfl* respectively *info.pfl*). These ASCII files can be converted by corresponding platform-specific executables into their binary representation.

[2] http://www.merge.com/Solutions/Toolkits/Merge-DICOM-Toolkit/Resources.aspx

To use the *Merge DICOM Toolkit* for the *Experimental Implementation* that is done in this work, the toolkit's data dictionary has to be extended with the (private) Supplement's attributes (s. 3.4.1). Therefore, the basic extension process of the *Merge DICOM Toolkit* is explained a bit more detailed in the following.

2.4.1.1 Extension of Data Dictionary

The *Merge DICOM Toolkit* provides a tool to combine two ASCII input files (*mc3dcomb*) that contain attribute definitions. Thus, one can define new attributes in a separate file and merge it with the existing ASCII dictionary file. The resulting file then has to be converted by the previously mentioned utility. Finally, the resulting binary data dictionary is converted by another platform-specific utility called *gendict*. This creates the *Merge source code module* that can be compiled and linked into the application.

Besides the adaption of the data dictionary, the binary message info file can be adapted accordingly. As the message file is used for validation purposes and this work does not use this feature a more detailed description of this process is abandoned.

2.5 Organizations

2.5.1 National Electrical Manufacturers Association (NEMA) / Medical Imaging & Technology Alliance (MITA)

NEMA is the association of electrical equipment and medical imaging manufacturers in the United States [65]. It watches over several standards and incorporates approx. 450 companies [65].

The *Medical Imaging & Technology Alliance (MITA)* is a devision of the NEMA which represents the manufacturers of medical diagnostic imaging equipment, radiotherapy and radiopharmaceutica [53]. Furthermore, it manages the DICOM Standard (s. 2.2).

2.5.2 Integrating the Healthcare Enterprise (IHE)

IHE is an initiative of healthcare professionals and industry that aims to harmonize the data exchange of systems in the healthcare sector. It focuses on the development of open and global *IHE Integration Profiles*, which describe clinical information or workflow scenarios and documents how established standards (e.g., HL7, DICOM) are to be utilized. *IHE* publishes domain-specific *Technical Frameworks*. The first volume of each domain is a documents that specifies *Integration Profiles*, the use cases, the actors involved and

the requirements. Following volume(s) define how to implement transactions that are specified in the *Profiles*.

In *Integration Statements* equipment vendors can publish a list of *IHE Profiles* they fulfill with their product. In annual occurring *Connectathons* equipment vendors can bring their products and test them with other vendors.

2.5.2.1 Radiation Oncology

The *IHE* is organized by clinical and operational domains [41]. Each domain consists of a technical and a planning committee. First mentioned committee's primary task is to develop and document solutions for their domain (→ *Integration Profiles*).

Radiation Oncology is the domain responsible for information sharing, workflow and patient care in radiology oncology and is sponsored by the *ASTRO* (s. 2.5.3). This domain defines the *IHE Radiation Oncology Profiles* and the *Radiation Oncology Technical Framework* (s. 2.5.2.1) [42].

IHE Radiation Oncology Technical Framework (RO TF) In the first volume of the *Radiation Oncology Technical Framework (RO TF)* profiles are specified that aim to reduce the ambiguity in the exchange of DICOM RT objects and establish a basic interoperability (e.g., the *Basic Radiation Therapy Objects Integration Profile (BRTO)*). Besides the description how to implement the corresponding transaction, the second RO TF volume strengthens the requirements on the use of selected DICOM RT type 2 and type 3 attributes (tab. 2.2). An IHE extension of DICOM attributes is indicated with a plus (*+*), a star (***) indicates, that the attribute is not required to be displayed. The letter *R* signals that an element is required and the letter *O* that the element is optional.

The implementations of this work base on these strengthened attribute definitions. Thus, non-IHE-conformal DICOM data are rejected.

2.5.3 American Society for Therapeutic Radiation Oncology (ASTRO) / American Association of Physicists in Medicine (AAPM)

ASTRO is the largest organization in the radiation oncology domain with nearly 10000 members [8]. The organization aims to advance the practice of radiation oncology by providing medical education, health policy analysis, patient information resources and advocacy to its members. Furthermore, *ASTRO* arranges the *ASTRO Annual Meeting*, the largest radiation oncology event in the world, and publishes the weekly newsletter *ASTROgram*, a quarterly magazine *ASTROnews* and the *International Journal of Radiation, Oncology, Biology and Physics* (also called *Red Journal*).

Attribute	Tag	Type	Attribute Note
Structure Set Label	(3006,0002)	R+	
Structure Set Date	(3006,0008)	R+	
Structure Set Time	(3006,0009)	R+	
Referenced Frame of Reference Sequence	(3006,0010)	R+*	This element is required for all 3D RT Structure Sets which are image based. It is to contain a set of references...

Table 2.2: Excerpt of IHE RO Technical Framework Vol. 2, Table A.3-12 [40]

AAPM is a scientific and professional organization of medical physicists. The organization's "goals are the identification and implementation of improvements in patient safety for the medical use of radiation in imaging and radiation therapy" [7]. Furthermore, it publishes scientific and technical information in the discipline of medical physics (e.g., the journal *Medical Physics* or the *AAPM Reports*). Similar to the *ASTRO Annual Meeting* there is a *AAPM Annual Meeting* that is addresses the medical physics community specifically.

2.5.3.1 Radiation Oncology Safety Stakeholder Group (ROSSG)

As a result of a New York Times article about radiation therapy errors (s. [17]) short white papers on safety for IMRT, IGRT, SBRT, HDR and Peer Review were organized first [33]. In the following the *Safety Stakeholder's Initiative* formed and had its first meeting on the *ASTRO Annual Meeting 2010* [33]. The following working groups were established to address the issues of problem identification, reach consensus on solution(s) for them and publish them:

- Error Messages
- QA
- Training
- Nomenclature (This group was abolished in summer 2012)
- Usability

The *Radiation Oncology Safety Stakeholder Group (ROSSG)* meets twice a year (at *AAPM* and A*STRO Annual Meetings*) [72].

Standard Prescription Proposal As this work refers to the *Standard Prescription Proposal* of the *Standard Prescription Subcommittee*, this proposal is introduced at this

point. Within the *Usability Working Group* a *Standard Prescription Subcommittee* is established to solve the "lack of consistency in the way radiation oncology professionals speak to each other" [72]. Therefore, the *Standard Prescription Proposal Usability Guidelines* are developed to define a standard way how to describe a radiation prescription.

2.6 Brainwork - Build Management and Build System

As the implemented applications of this work are based on the Brainlab framework, called *Brainwork*, its underlying build management respectively build system is introduced at this point briefly. It provides several tools to create and build projects in C# and C++. Therefore, XML files are used to configure such a project and define the necessary source files, the desired target (library or executable), language resources etc. Furthermore, an integration into Visual Studio is provided.

The framework consists of several major bundles and packages for different purposes like the domain model, 3D representation, DICOM connectivity and so on. As this work uses the DICOM caches as its data model its concept is introduced a bit more detailed in the following.

2.6.1 Cache Concept

The DICOM connectivity is provided by the DICOM library of the framework, that is based on the *Merge DICOM Toolkit* (s. 2.4.1). It's a wrapper library for the *Merge DICOM Toolkit* with some additional functionality. Common basic functionality for DICOM import and export as well as corresponding conversion routines are provided by the *DicomBase plugin*. Furthermore, DICOM cache classes are offered for convenient access (reading and writing) of (standard conform) DICOM objects.

DICOM cache classes were designed for export purposes and therefore provide a concept to fill DICOM objects with (converted) data without knowing the exact definition and types of the attributes. When a cache object is written to a DICOM object, it can be validated before writing. The used structure of the caches is oriented according to the DICOM standard:

- The class *ObjectDefinition* (and its derived subclasses) is equal to a DICOM IOD
- The class *ModuleDefinition* respectively *ModuleCache* (and its derived subclasses) is equal to a DICOM Module
- The class *SequenceCache* (and its derived subclasses) is equal to a DICOM Sequence
- The class *AttributeDefinition* (and its derived subclasses) is equal to a DICOM Attribute

To define a new cache class, this class has to be derived from one of these base classes. Besides this definition, a registration of the cache class at the *GlobalCacheFactory* is required to be able to use this class. This *GlobalCacheFactory* provides access to special factories (*AttributeCacheFactory, SequenceCacheFactory, ModuleCacheFactory, ObjectCacheFactory*) to create new cache instances. Finally, the data of the objects, modules, sequences can easily be retrieved by access methods according to the attribute name.

Writing of a DICOM object is performed by calling the *fill()* method of the corresponding *ObjectCache*. This method fills a given *Message* item, which is the abstraction object of a DICOM message. The *Message* item provides a save functionality to complete the desired operation. To transfer a DICOM object into a cache object a corresponding file can be read into a *Message* item, which is passed to the *cache()* method of the desired cache object.

This work extends the *DICOM library* with new cache classes for second-generation RT objects (s. 3.4) to create corresponding second-generation objects and to investigate these objects respectively to review some basic new concepts introduced in second-generation environment (s. 3.1 - 3.3).

3 Results

This chapter presents the results of the made investigation of Supplement 147. Statements in this chapter are without any valuation. An appraisal of results is made in the following chapter (s. 4).

First the investigation results of the first-generation RT object separation into different and smaller second-generation RT objects are presented including the findings regarding additional required information for first-generation object conversion (s. 3.1). Next the review results of the *RT Physician Intent's* prescription description capabilities are shown (s. 3.2). Following the findings of the new *Conceptual Volume* concept (s. 3.3). As the last points this chapter describes the structural changes (s. 3.4) that have been made to enable all of the previously mentioned investigations and introduces the two applications that are developed within this work to test the *RT Physician Intent IOD* respectively to test the *Conceptual Volume* concept more convenient (s. 3.5).

3.1 Separation of Concerns

One of the main problems of first-generation RT objects is that they are mostly overloaded with information and contain multiple concepts and that they are very static. As a typical example of this problem the *RT Plan* has to be mentioned. This object can contain information of a radiation plan prescription, fractionation pattern, beam setup, patient setup etc. Furthermore, the first-generation RT objects are based on conventional C-Arm LINAC concepts (s. 2.1.3.2), which makes the representation of all information of new technologies and treatment techniques not possible.

Therefore, Supplement 147 introduces different new IODs for different data representations (s. 2.3.1). This new concept is investigated by a transition of the first-generation objects *RT Structure Set* (s. 2.2.4.1) and *RT Plan* (s. 2.2.4.2) as there are no treatment planning systems available that support second-generation object creation.

Although this feature is explicitly out of scope of Supplement 147, it is noticed during this evaluation that this first-generation conversion is a feature which is most likely desired from clinical and vendor's perspective. As a consequence this first-generation object conversion is examined by this thesis to provide hints, which information is required additionally and how this information can be provided for a translation device.

3.1.1 First-Generation Converter

The idea of the implemented converter for first-generation objects is to have separate converters for each new second-generation object. Because of many common modules it is appropriate to have a common base converter (*DicomRTBase2Converter*) all other converters are derived from. This base converter provides methods to fill the common modules with information. It is derived from the *ExportBaseConverter* of the underlying framework (s. 2.6). As this work operates on cache objects (s. 2.6.1), only the *convert()* method with the *CompositeObjectCache* parameter is implemented and not the *convert()* method with the *ContentItem* parameter (abstract declaration in *ExportBaseConverter*). If the last mentioned method is called an exception is thrown to indicate that this method is not implemented yet.

Another group with additional specific modules are the object definitions for specific *RT Radiations* (s. 2.3.1.3). Therefore, the *DicomRTRadiationBase2Converter* is the abstract base converter for more specific *RT Radiation* converters. For example, the *DicomRT-CArmPhotonRadiationConverter* translates the corresponding radiation information of an *RT Plan instance* (→ *Beam Sequence* items) into *RT C-Arm Photon Radiation* objects (s. 3.1.1.2).

As a first-generation *RT Plan object* is translated into several different second-generation objects (s. 3.1.1.2) that refer to the same *Conceptual Volumes*, for instance, a manager class (*DicomRTBase2Manager*) is introduced to ensure correct referencing between these objects. This manager class is included in the *DicomRTBase2Converter* as a Singleton component to enable all converter instances to operate on the same data base. An important restriction of the manager to take note of is that this is a temporary data base which is not stored when the *DicomRTBase2Manager* is destroyed. However, this is a valuable enhancement for a coming version of the converter.

An overview of the described converter concept is illustrated in figure 3.1.

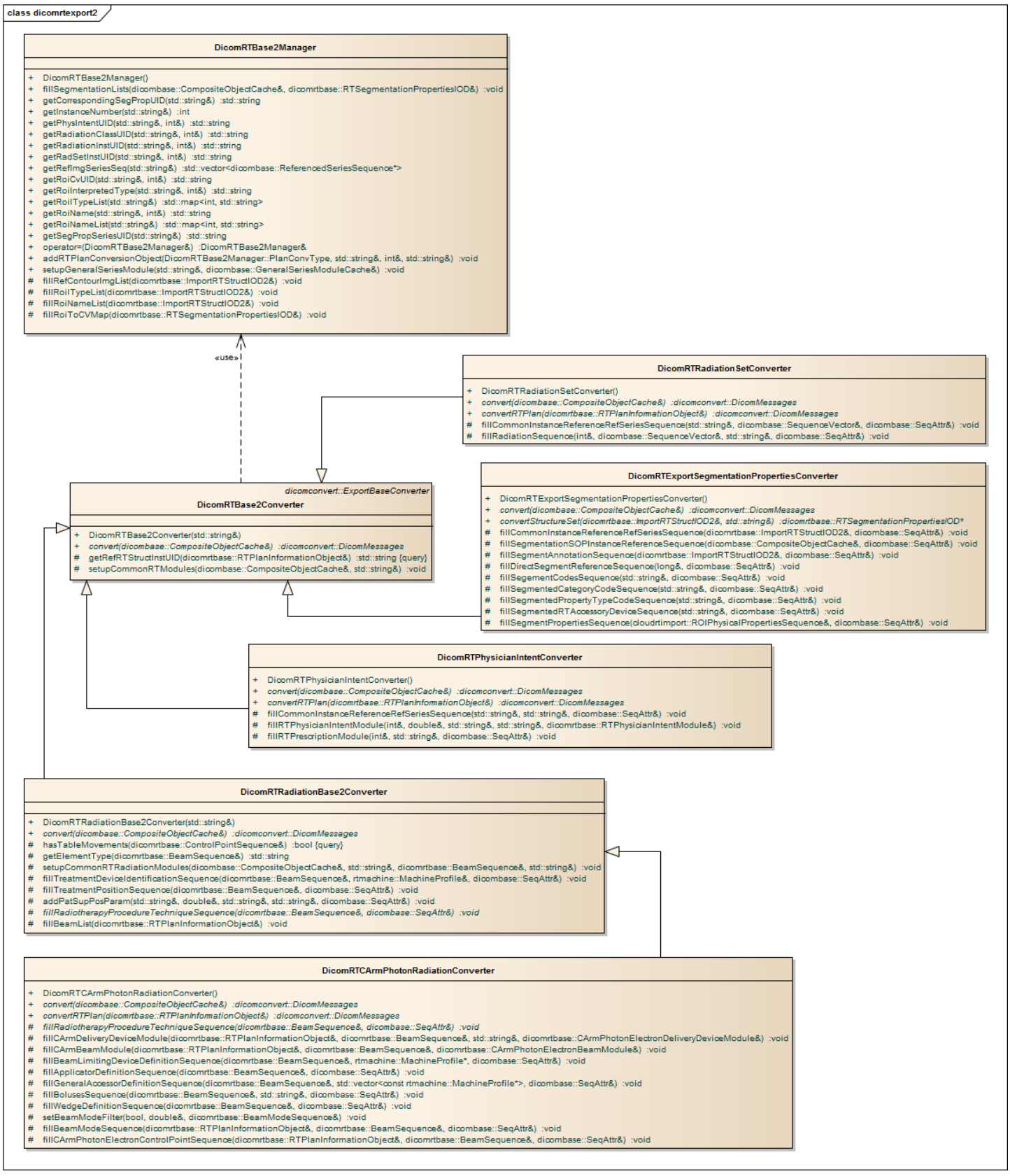


Figure 3.1: Simplified Class Diagram First Generation Converter

3.1.1.1 RT Structure Set

As *RT Structure Set objects* do not contain only structural definitions (e.g., *ROIs*) and properties for these, but also planning-related meta information, it is desirable to separate this information from the structural definition. Therefore, radiotherapy-relevant information of a *RT Structure Set object* is transferred to a *RT Segmentation Properties instance*. Table 3.1 gives an overview how *RT Structure Set's* radiotherapy-related information is assigned by the *DicomRTExportRTSegmentationPropertiesConverter* (s. 3.1.1).

The *Segment Codes Sequence* (30xx,134D), which is used to describe a segment respectively its interpretation more detailed, the *Segmented RT Accessory Device Sequence* (30xx,1349), that is used to describe this segment more detailed if it is an RT accessory, and the *Segment Properties Sequence* (30xx,134B), which is used to associate physical properties with a segment's interpretation, can be filled with information provided by the *RT ROI Interpreted Type* (3006,00A4) in the *RT ROI Observation Sequence* (3006,0080) if present. In case of absence of this sequence the information have to be provided by the user. Table 3.2 shows the underlying transition mapping.

RT Structure Set			RT Segmentation Properties			
Attribute Name	**Tag**	**Type** [1]	**Attribute Name**	**Tag**	**Type**	**Annotation**
Structure Set ROI Sequence	(3006,0020)	3 / R+*	Segment Annotation Sequence	(30xx,1342)	1	
> ROI Name	(3006,0026)	2 / R+	> RT Entity Long Label	(30xx,51E5)	1	If empty label is generated as "ROI xx", with xx = Referenced ROI number
> ROI Description	(3006,0028)	3 / O+*	> RT Entity Description	(30xx,51E4)	3	
			> Direct Segment Reference Sequence	(30xx,1343)	1	A new Conceptual Volume UID is generated for each ROI and all other internal sequences are not filled
> ROI Number	(3006,0022)	1 / R*	>> Referenced ROI Number	(3006,0084)	1C	Referenced Segment Number (0062,000B) → not required
RT ROI Observation Sequence	(3006,0080)	1 / R+*				
> RT ROI Interpreted Type	(3006,00A4)	2 / O+*	> Segment Codes Sequence	(30xx,134D)	1	Details see table 3.2
			> Segmented RT Accessory Device Sequence	(30xx,1349)	1C	Details see table 3.2
> ROI Physical Properties Sequence	(3006,00B0)	3 / O+*	> Segment Properties Sequence	(30xx,134B)	1C	Re-encoding SUP147009, S147150 - S147155
>> ROI Physical Property	(3006,00B2)	1 / R+*				
>> ROI Elemental Composition Sequence	(3006,00B6)	1C	>> Segment Elemental Composition Sequence	(30xx,134C)	1C	

Table 3.1: Transition of *RT Structure Set* into *RT Segmentation Properties*

RT ROI Interpreted Type	**Segmented Category Code**	**Segmented Property Type Code**[2]	**Segmented RT Accessory Device Sequence**[3]
PTV	(S147050, SUP147003, “Target”)	(S147078, SUP147004, “PTV”)	-
CTV	(S147050, SUP147003, “Target”)	(S147072, SUP147004, “CTV”)	-
GTV	(S147050, SUP147003, “Target”)	(S147075, SUP147004, “GTV)	-
TREATED_VOLUME	(S147050, SUP147003, “Target”)	(S147082, SUP147004, “Treated Volume”)	-
IRRAD_VOLUME	(S147050, SUP147003, “Target”)	(S147083, SUP147004, “Irradiated”)	-
AVOIDANCE	(S147050, SUP147003, “Target”)	(S147081, SUP147004, “Avoidance”)	-
EXTERNAL	(S147051, SUP147003, “Anatomical Structure”)	?	-
ORGAN	(S147051, SUP147003, “Anatomical Structure”)	?	-
CONTRAST_AGENT	(S147051, SUP147003, “Anatomical Structure”)	?	-
CAVITY	(S147051, SUP147003, “Anatomical Structure”)	?	-
BOLUS	(S147052, SUP147003, “Extended Anatomical Structure”)	?	(S147460, SUP147031, “Bolus”)
MARKER	(S147053, SUP147003, “Geometrical Information”)	(S147110, SUP147005, “External Marker”)	-
ISOCENTER	(S147053, SUP147003, “Geometrical Information”)	(S147108, SUP147005, “Planning Target Point”)	-
SUPPORT	(S147054, SUP147003, “Fixation or Positioning Device”)	(S147410, SUP147025, “Table”)	(S147410, SUP147025, “Table”)
FIXATION	(S147054, SUP147003, “Fixation or Positioning Device”)	(S147341, SUP147022, “Headframe”)	(S147341, SUP147022, “Headframe”)
BRACHY_CHANNEL	(S147055, SUP147003, Internal Brachytherapy Device”)	(S147133, SUP147007, “Brachytherapy channel”)	(S147133, SUP147007, “Brachytherapy channel”)
BRACHY_ACCESSORY	(S147055, SUP147003, Internal Brachytherapy Device”)	(S147130, SUP147007, “Brachytherapy accessory device”)	(S147130, SUP147007, “Brachytherapy accessory device”)
BRACHY_SRC_APP	(S147055, SUP147003, Internal Brachytherapy Device”)	(S147131, SUP147007, “Brachytherapy source applicator”)	(S147131, SUP147007, “Brachytherapy source applicator”)
BRACHY_CHNL_SHLD	(S147055, SUP147003, Internal Brachytherapy Device”)	(S147132, SUP147007, “Brachytherapy channel shield”)	(S147132, SUP147007, “Brachytherapy channel shield”)
DOSE_REGION	(S147057, SUP147003, Artificial Structure”)	?	-
CONTROL	(S147057, SUP147003, Artificial Structure”)	?	-
REGISTRATION	(S147057, SUP147003, Artificial Structure”)	?	-

Table 3.2: Transition of *RT ROI Interpreted Type* into a *Segment Code*

3.1.1.2 RT Plan

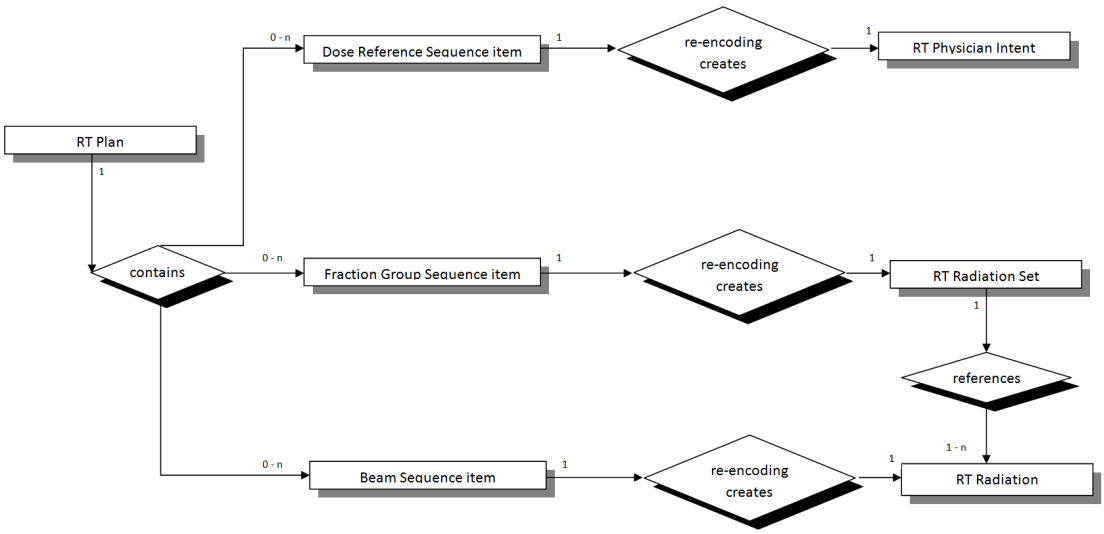


Figure 3.2: Re-encoding of an RT Plan Object

As mentioned before the first-generation object *RT Plan* will not exist in the second-generation environment (s. 2.3). Instead, the information of an *RT Plan instance* is split into the new objects *RT Physician Intent* (s. 2.3.1.1), *RT Radiation Set* (s. 2.3.1.2) and a specific *RT Radiation* (e.g., *C-Arm Photon Radiation* for C-Arm LINACs). Figure 3.2 shows which *RT Plan* sequences provide the information for the new "plan objects" mainly.

The *DicomRTPhysicianIntentConverter* automatically creates *RT Physician Intents*, the new object that carries the prescription by which a physician describes the therapeutic goal and strategy for a radiotherapeutic treatment. Created objects include the *RT Prescription Module*, which encapsulates the physicists prescriptions that are used to define the intended procedures for the identified targets respectively to define constraints for organs at risk, with a minimalist set of values. For each *Dose Reference Sequence* item of type *TARGET* in a first-generation *RT Plan* a new *RT Physician Intent* object is created with the *Target Prescription Dose* (300A,0026) as *RT Physician Intent Nominal Dose* (30xx,0912). All *ORGAN_AT_RISK* items are added in every created *RT Physician Intent* object. Furthermore, the *Conceptual Volume* information is retrieved from the *DicomRTBase2Manager* to fill the *RT Prescription Module* correctly. The *Conceptual Volume Optimization Blocking (30xx,0935)* is set to *NONE* because no information for this attribute is available in current first-generation objects.

Before a *RT Radiation Set* (s. 2.3.1.2), that defines a set of beams, can be created its

referenced *RT Radiations* (s. 2.3.1.3), the representations of treatment beams, have to be produced. For an *RT Plan* the generated *RT Radiations* can be assumed as *C-Arm Photon Radiations* (s. 2.3.1.3), which are treatment beams generated by a C-Arm LINAC (s. 2.1.3.2), as the differentiation is introduced with the second-generation objects. Unfortunately, some information is missing in first-generation objects to set all required attributes of a *C-Arm Photon Radiation* object. The main lack of information is about identifying labels for the treatment device components.

As mentioned before the first-generation conversion is a desired feature. Therefore, the implemented *DicomRTCArmPhotonRadiationConverter* provides the missing information by generation of appropriate dummy labels and with the help of so called "MachineProfiles". A "MachineProfile" is a construct that summarizes treatment device specific properties, e.g., dose rates, jaw properties, motion limits etc., and treatment device configurations (e.g., LINAC x with MLC y) in specific profiles. Furthermore, all *Beam Sequence* items are examined to extract additional information.

These are only some examples that show how to establish the missing information. Within "Transition Guidelines", a document that specifies the recommended procedure for such a first-generation conversion, one of the organizations respectively groups dealing with the domain of radiation oncology (s. 2.5) might specify a more detailed description of such a conversion.

3.1.2 Test Data Sets

To investigate as many different treatment setups as possible, several first-generation *RT Plan instances*, containing different treatment plan characteristics, including corresponding *RT Structure Sets* are converted. The resulting second-generation objects are examined whether they contain all first-generation data and if the referencing between the generated instances is correct. This enables assumptions whether the new concepts work or not. In the following the used plan characteristics are listed:

- Multiple target volumes
- Multiple fractionations
- *Static Wedge*
- *Motorized Wedge*
- *Virtual Wedge*
- *Static Beam* treatment
- *Circular Arc* treatment beam(s)
- *Hybrid Arc* treatment beams(s)

- *Sliding Window IMRT* treatment
- *Step and Shoot IMRT* treatment
- *VMAT* treatment

All the information contained in these test data can be transferred into corresponding second-generation structures. Furthermore, the created *Conceptual Volumes* and *RT Radiations* are referenced correctly in the corresponding second-generation instances that refer to these *Conceptual Volumes* respectively *RT Radiations*.

Example DICOM dump snippets for *Conceptual Volumes* can be found in listing B.2 on page XI (l. 6) and listing B.4 on page XIII (ll.9 - 15) respectively listing B.3 on page XII (l. 6) and listing B.5 on page XIV (ll. 4 - 10) in the appendix. The referencing of *RT Radiations* is shown in listing B.6 on page XV.

3.1.3 Summary

The introduced "separation of concerns" in Supplement 147 provides a more flexible and adaptive way to meet changes in treatment techniques (e.g., *RT Radiations*, s. 2.3.1.3). Furthermore, the split into smaller units makes the impact of changes in an RT object less influential. However, because of the increase of required information in second-generation RT objects, a user interaction seems to be unavoidable at certain points (e.g., *RT Physician Intent*, s. 2.3.1.1). Moreover, this thesis assumes certain default code values (e.g., *Support Device Type* or *Fixation Device Type*), whose choices have to be verified before unconditional usage.

Some extracts of second-generation RT DICOM dumps are attached to this work in appendix B on page XI.

3.2 RT Physician Intent

As mentioned before the first-generation object *RT Plan* won't exist in second-generation environment anymore. One of its new correspondences is the *RT Physician Intent*. As it represents a new concept with high-level descriptions this object shall be investigated a bit more in detail. The *RT Physician Intent IOD* is divided into two parts as introduced in 2.3.1.1. As a result of this division a higher degree of flexibility is available in the prescription process. First the physician can specify the overall intent of the treatment. Later the physicists defines the prescriptions to achieve the treatment goal.

Next it is reviewed whether the *RT Physician Intent IOD* can fulfill all wishes of clinical experts regarding a radiation prescription.

3.2.1 Stressing the Concept with the Standard Prescription Proposal

As the *Standard Prescription Proposal* (s. 2.5.3.1) tries to "define a standard way to describe a radiation prescription [to solve the] lack of consistency in the way in which radiation oncology professionals speak to each other" [72] this *Standard Prescription Proposal* is used to test whether all prescription relevant information can be described by an *RT Physician Intent* object. Furthermore, it can be assumed that the *Standard Prescription Proposal* gains credence in the future for radiation oncology professionals. In the following the obtained information from this document and their representation in an *RT Physician Intent* object are described.

The first and most obvious information to describe in a prescription definition is the definition of a target volume with specification of the desired treatment technique, the beam energy and the fractionation pattern. This information can be specified in the top level sequence of the *RT Prescription Module* of the *RT Physician Intent IOD* (s. 2.3.1.1) - the *RT Prescription Sequence* (30xx,0940).

A refinement of the volume definition are volumes that consist of multiple, spatially divided volumes. As the volume definition is done in a separate sequence inside of the *RT Prescription Sequence* - the *RT Anatomic Prescription Sequence* (30xx,0920) - such a prescription can easily be established by creating *RT Anatomic Prescription Sequence* items accordingly. Hence, second-generation objects use the abstract *Conceptual Volume* (s. 2.3.2) to refer to a volume, more complex volumes can be defined in an *RT Anatomic Prescription Sequence* item ($\rightarrow$ volume combination).

The specification of the desired dose for a target volume respectively (dose) constraints for non-target volumes is enabled by the *Dosimetric Objective Sequence* (30xx,0942) inside the *RT Anatomic Prescription Sequence*. Moreover, this *Dosimetric Objective Sequence* enables a weighting of the constraints.

This layout of the *RT Prescription Module* enables prescriptions with the same fractionation and the application of different dose values to each volume inside a prescription definition as well as different fractionations and dose application for each volume.

Since this work detects a missing possibility to specify the time-dependency between different prescriptions, an additional module was introduced by *DICOM Working Group 7* in a later published draft of Supplement 147 to represent this information. However, the *Treatment Phase Sequence* (30xx,0880) in this module only allows to specify the time gaps day-based. For a more flexible specification, like in the *Standard Prescription Proposal* (e.g., "ASAP" or "Following ..."), the *Prescription Annotation Sequence* (30xx,0978) on *RT Prescription Sequence* level can be used to add a descriptive note (Concepts Codes: *(S147030, DCM, "Radiation Description")* and *(S147037, DCM, "Previous Radiation Note")*) of the intended structure. Nevertheless, it is to question whether a split of

the time-dependency information into different sequences is a good idea or might cause confusion.

The *Prescription Annotation Sequence* turned out to be a very powerful capability of the *RT Physician Intent IOD* to represent prescription relevant information that are not represented by an own attribute (e.g., pre-treatment imaging, patient positioning, etc.). Furthermore, textual notes can be specified on prescription level as well as on anatomic prescription level. This provides the possibility to define further institutional specific information similar to the information for the overall intent in the *RT Intent Module* of the *RT Physician Intent IOD* (s. 2.3.1.1).

Additionally, this thesis remarks that a shift of the information to describe the beam energy and the prescription dose into a separate attribute on a higher level in the *RT Prescription Sequence* might be useful to enable a more convenient access to this information.

3.2.2 Summary

The *RT Physician Intent IOD* provides the capability to encapsulate all necessary information of a radiation prescription that is desired by clinical experts. Furthermore, more flexibility is introduced in the prescription process by splitting this object into two parts.

Prescriptions for multiple target volumes can either be encapsulated in different *RT Physician Intent* objects or in one *RT Physician Intent object* by different *RT Prescription Sequence* items (30xx,0940). The *RT Anatomic Prescription Sequence* (30xx,0920) allows to summarize multiple volumes with the same prescription information in one *RT Prescription Sequence* item.

3.3 Conceptual Volume

As little changes in first-generation objects (e.g., change of contour data) lead to an enormous update process, Supplement 147 tries to meet this problem with the introduction of a concept to access volumetric objects in an abstract way. This abstract volumetric access is called *Conceptual Volume* (s. 2.3.2). Therefore, this concept is examined in more detail in this section by simulating different scenarios that are the result of a discussion with clinical experts. A more detailed description of the used application can be found in 3.5 respectively in A.1 on page I and A.2 on page V in the appendix.

3.3.1 Scenario 1: Structure Definition and Subsequent Prescription

This scenario represents the "classic way" and occurs when a new treatment is planned and the segmentation of structures is performed as the first step. Thus, requirement for this scenario is the existence of segmentation data in an *RT Structure Set* (*Segmentation* and *Surface Segmentation* are not supported by the realized implementation, yet).

3.3.1.1 Creating Conceptual Volumes while Creating RT Segmentation Properties

After selecting the volume definition file, the user decides to use the ROIs or segments in this file as *Conceptual Volumes*. The suggested *Conceptual Volumes* (fig. 3.3) are the result of the conversion by the *DicomRTExportRTSegmentationPropertiesConverter* (s. 3.1.1.1). Now the user is able to specify more information for the suggested volumes (fig. 3.4, 3.5, 3.6) or add respectively delete volumes.

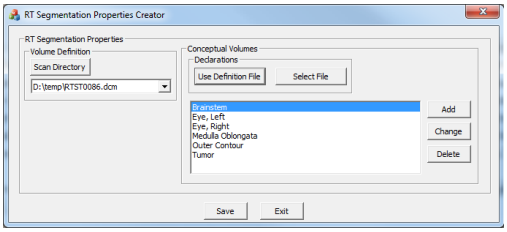


Figure 3.3: Suggested *Conceptual Volumes* for Underlying *RT Structure Set*

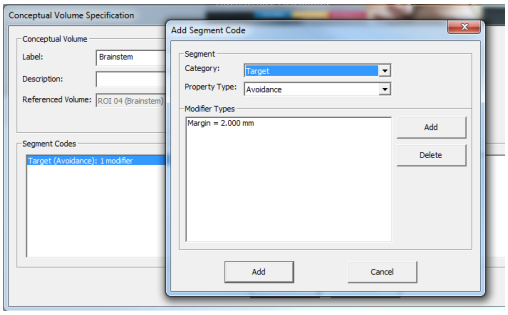


Figure 3.4: Specification of Additional Modifier for a Segment Code

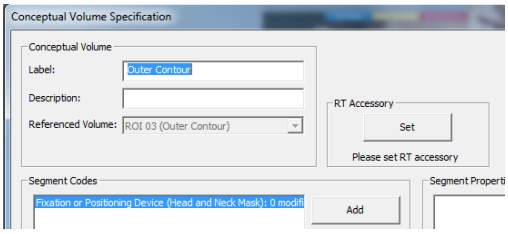


Figure 3.5: Specification of *RT Accessory* Necessary

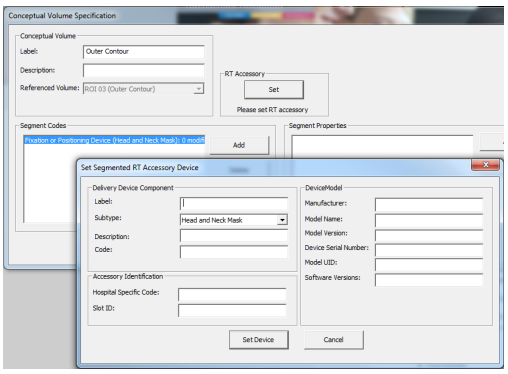


Figure 3.6: Specification of RT Accessory

3.3.1.2 Subsequent Prescription Definition

The "classic prescription scenario" is continued by creating a corresponding *RT Physician Intent* object. Therefore, an existing *Conceptual Volume,* defined in the previously created *RT Segmentation Properties* object (s. 3.3.1.1), is selected in the *Volume Declaration Dialog* (fig. 3.8). When the user confirms the selection the underlying information (volume label, *Conceptual Volume UID* and volume type) are transferred to the volume declaration dialog (fig. 3.9). Now the user has to define the *Optimization Blocking* and can specify the *Radiobiological Structural Type*. If anything else is changed in this dialog after the selection of an existing volume, it means that the current volume declaration creates a new *Conceptual Volume* (→ generate new UID for *Conceptual Volume*).

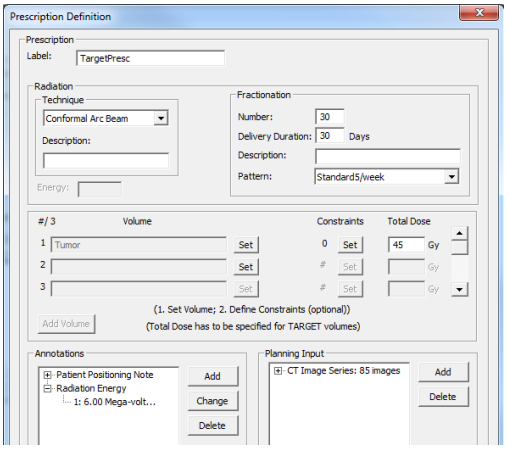


Figure 3.7: Definition of Target Prescription

By repeating this selection process, combining existing *Conceptual Volumes* or defining new *Conceptual Volumes* a comprehensive prescription is created.

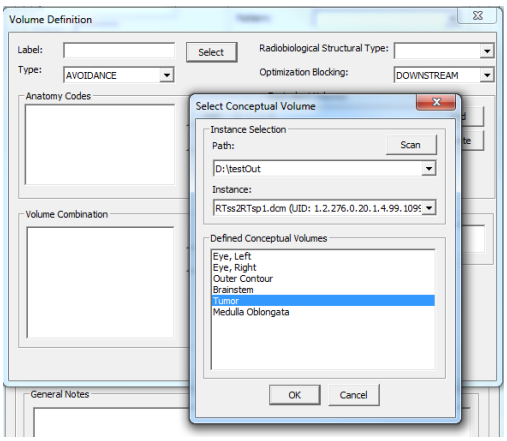


Figure 3.8: Selection of Existing *Conceptual Volume*

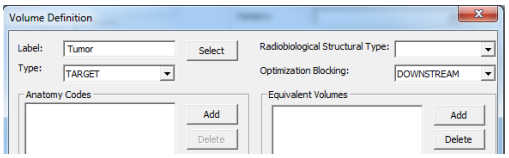


Figure 3.9: Information of Selected Volume is Transferred

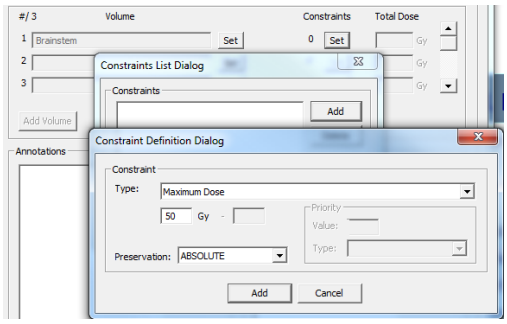


Figure 3.10: Specification of Constraint for Non-target Volume (→ *Conceptual Volume*)

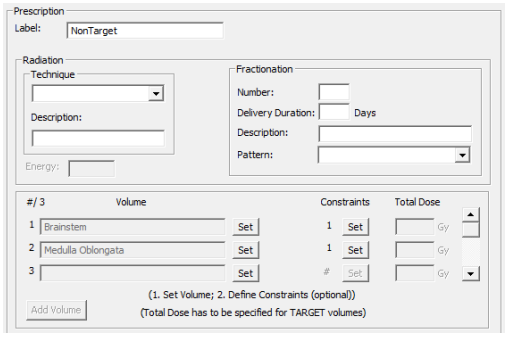


Figure 3.11: Prescription That Contains (All) Non-target Volumes of the *RT Physician Intent*

3.3.2 Scenario 2: Prescription and Subsequent Structure Definition

As mentioned before it is possible in second-generation RT environment to declare *Conceptual Volumes* without defining them at the time of declaration (s. 2.3.2). Therefore, this scenario first creates the prescription (encapsulated in an *RT Physician Intent* object) and just declares the required *Conceptual Volumes*. The volume definition is performed subsequently.

3.3.2.1 Declaring Conceptual Volumes

During the creation of a new prescription for each volume that receives a prescription a new *Conceptual Volume* is declared, however, without a concrete definition by an underlying *RT Structure Set* or *Segmentation*. This assignment is performed afterwards. The definition of the prescription is, apart from this, equal to the previously mentioned proceeding.

3.3.2.2 Definition of Existing Conceptual Volumes

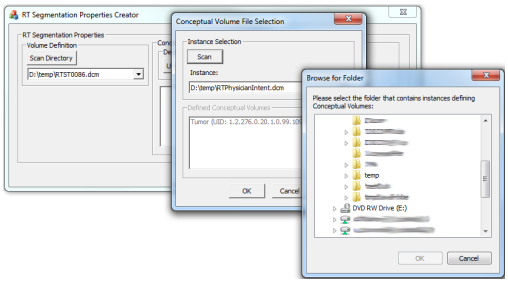


Figure 3.12: Selecting *Conceptual Volume* to Define

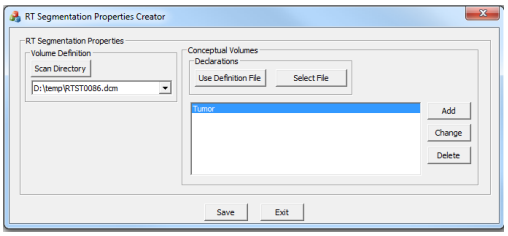


Figure 3.13: Listing of Declared *Conceptual Volumes* in Selected File

Next the declared *Conceptual Volumes* are defined with the help of the *RT Segmentation Properties Creator* (s. 3.5.1). To define a *Conceptual Volume* the user selects the previously created file that contains the corresponding volume(s) (fig. 3.12) in the *CCvSelectionDlg*. After confirmation of that dialog the contained *Conceptual Volumes* are listed in the main dialog (fig 3.13). Now these volumes can be associated with a concrete volume in the underlying *Segmentation* respectively *RT Structure Set* (fig. 3.14). Furthermore, additional information for the volumes can be specified as described before (s. 3.3.1.1).

3.3.3 Scenario 3: Changing Structure Definitions

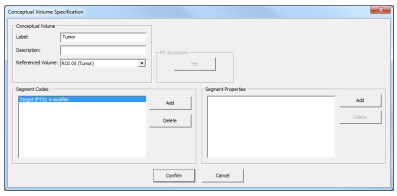


Figure 3.14: Selection of Concrete Volume

As mentioned at the beginning of this section (s. 3.3) changes in the contour data result in an enormous update process for first-generation objects. Reasons for a change in contour data are the reduction of the tumor volume within a course of treatment or a different location respectively shape of an anatomy because of different patient positioning between treatment fractions or because of physiological movements (e.g., breathing or heartbeat).

In second-generation RT environment this problem is solved by *Conceptual Volumes*. As volumes are identified by a *Conceptual Volume UID* instead of a *Instance UID* in conjunction with a *Segment Number / ROI Number*, this update of contour data can easily be done by creating a new *RT Segmentation Properties* object that references the latest segmentation data. This is basically the same process as described in 3.3.2.2.

3.3.4 Summary

The new *Conceptual Volume* concept helps to solve the update issue respectively referencing issue of (anatomical) structures that are used in the radiotherapy treatment process. Furthermore, it provides the possibility to break away from the classic prescription workflow (s. 3.3.1). Hence, further flexibility in the treatment planning process is introduced.

3.4 Adaption of Data Structures

To enable all the previously described investigations some adaption and new definitions in the underlying data structures have to be made. As this work uses the DICOM library of Brainwork 3.6 (s. 2.6) in the made *Experimental Implementation* to examine Supplement 147, new DICOM caches (s. 2.6.1) have to be created for these second-generation objects. Since there are no DICOM standard attribute tags available for the newly introduced attributes and sequences of Supplement 147 yet, these non-standard attributes are defined as private attributes (s. 3.4.1) first. Furthermore, the underlying *DICOM library* has to be adapted as well (s. 3.4.2). Because of enhanced usage of *DICOM Macros* and *DICOM Content Mapping Resources* (s. 2.2.2) in Supplement 147, a new concept to manage *DICOM Content Mapping Resources* is introduced (s. 3.4.4) and different possibilities to integrate a macro concept in the underlying library are considered (s. 3.4.3), but none of this is implemented.

3.4.1 Private Attribute Definition for Experimental Implementation

Since official tags for attributes that are introduced by a supplement are first provided with the approved *Final Text* of a supplement (s. 2.2.5), and Supplement 147 is still being defined at the moment, these new attribute definitions have to be defined as private attributes to be able to use them in this work. In order to compare an output generated by the *Experimental Implementation* of this work with the definitions in Supplement 147 it is preferable that the used attribute tags are similar. Therefore, a proposal of *DICOM WG-07* (s. 2.2.1) to use private attributes shaped in a way similar to the Supplement's definitions is implemented as follows:

For private attributes an odd group number is required (s. 2.2.3). Thus, an obvious suggestion is to use *0x3147* for tags that are introduced in Supplement 147.

The more difficult part is to shape the element tag of the private attributes. For private DICOM attributes the element tag is a combination of a reserved block number (first two element tag digits) and the element number within this block (last two element tag

digits). It is desirable to take the proposed element tag of the Supplement and transfer it directly to the private element tag, e.g., *0x1301* → block number = *0x13*, block element number = *0x01*. Unfortunately, this solution is not possible for elements starting with zero. It is suggested to use "*9x*" for the block (reservation) instead of "*0x*" as there are no new attribute elements "*7xxx*", "*8xxx*" or "*9xxx*" defined in Supplement 147.

In case that the used DICOM library does not allow to assign the private element tag (number of the private attribute block and element number within this block) directly, it is common that these libraries provide a mechanism to reserve a block of tags with a *Private Creator Code* (s. 2.2.3) first, and then assign the attribute to a number in this block. Hence, it is advised to reserve a tag block with an intuitive *Private Creator Code* (e.g., element tag in Supplement = *0x1301* → "DICOM WG-07 Supplement 147 - Block 13") and assign a similar number to this block (e.g., block number *0x13*). The last two digits of an element tag in the Supplement shall be mapped with the block element number (e.g.: element tag in Supplement = *0x1301* → mapped to block element *0x01* in reserved block with the number *0x13*).

3.4.2 Extension of DICOM Library

The underlying DICOM library is the *Merge DICOM Toolkit* (s. 2.4.1). As described in section 3.4.2 it can be extended easily with private attribute tags by specifying them in a text file. As Supplement 147 defines over 350 new tags and it is still in change, it is desirable to transfer the Supplement's new attributes definitions in "Part 6 Addendum" of the document automatically into an input file for *mc3dcomb* (s. 2.4.1.1).

Therefore, a command-line utility (*GenBrainDict*) is implemented in this work that performs this conversion. As input for the attribute definitions a comma-separated value (CSV) file is used. The attribute definitions have to be in the following format:

"(<*tag*>);<*name*>;<*keyword*>;<*value representation*>;<*value multiplicity*>"

E.g.:

```
(30xx,1313);Combined Conceptual Volume Segmentation Reference Sequence;
    CombinedConceptualVolumeSegmentationReferenceSequence;SQ;1
```

To allow a more general usage of the utility the group number, the base *Private Creator Code* string (e.g., "DICOM WG-07 Supplement 147") and the input file must be specified in the call of the tool to generate the desired private attributes ASCII file (e.g.: GenBrainDict.exe -g 3147 -c "DICOM WG-07 Supplement 147" -f Sup147Tags.csv).

Then the generated output is combined with the existing attribute definitions and transferred to the source code module as described in 2.4.1.1. To access the private attributes of Supplement 147 as conveniently as other attributes by cache objects (s. 2.6.1) the information in the resulting source file has to be converted into an additional

private data definition dictionary of Brainwork that is used to register the attributes at the *GlobalCacheFactory* (2.6.1) during the initialization of the *DicomRTPlugin*. As before it is preferable to perform this conversion automatically.

Therefore, another command-line utility (*GenPrvTagDict*) is implemented to transfer the information in the *Merge dictionary source* (*mc3dict.c*) into an appropriate data definition dictionary header and source file that is accessed in the implementations which use these second-generation definitions. Furthermore, the dictionary provides a method to set the *Private Creator Code* (*setPrivateCreatorCodes(dicom::Item& message, dicom::AttrVector itemList)*) in a given message item (s. 2.2.1). This is important because the *Private Creator Codes* used in a DICOM module or sequence have to be register before each item that contains a private attribute tag (s. 2.2.3).

As a consequence new base classes for "private" ModuleCaches and SequenceCaches (*PrivateRTModuleCache* and *PrivateRTSequenceCache*) are introduced. These classes are derived from the existing *ModuleCache* respectively *SequenceCache* (s. 2.6.1) and overwrite the base *fill()* method to enable this automatic registration of the *Private Creator Code* as described before.

Since the DICOM caches are originally designed for export purposes, *SequenceCaches* don't possess functionality to delete or replace certain items. Therefore, two static function templates are introduced in *PrivateRTSequenceCache* to delete a sequence item in a reference cache respectively to replace an item with another item (listing 3.1). The implementation as a template function has to be done to "re-fill" the given reference *PrivateRTSequenceCache* correctly as specific sequence implementations use different "setups" of attributes. This specific setup knowledge is necessary for the *fill()* method to work as desired (s. 2.6.1).

```
1 template<class T>
  static bool replaceItem( dicombase::SeqAttr& refCache, const T& toReplace, T&
      replacement )
3 {
    ...
5 }
```

Listing 3.1: Template Function of PrivateRTSequenceCache to Replace an Item in a Given Cache Instance

Besides the described conversion, the tool provides an option (-txt) to create the registration commands needed for the *init()* method of the *DicomRTPlugin*. The content of the resulting file can simply be copied to this *init()* method to perform the attribute registration at the *GlobalCacheFactory* (s. 2.6.1) and a semi-automatic adaption of the private attribute registration is ensured.

Hence, there are a lot of tools involved in this process of updating the DICOM library all the described steps are taken together in a bash script. The complete workflow is shown in figure 3.15 on the next page.

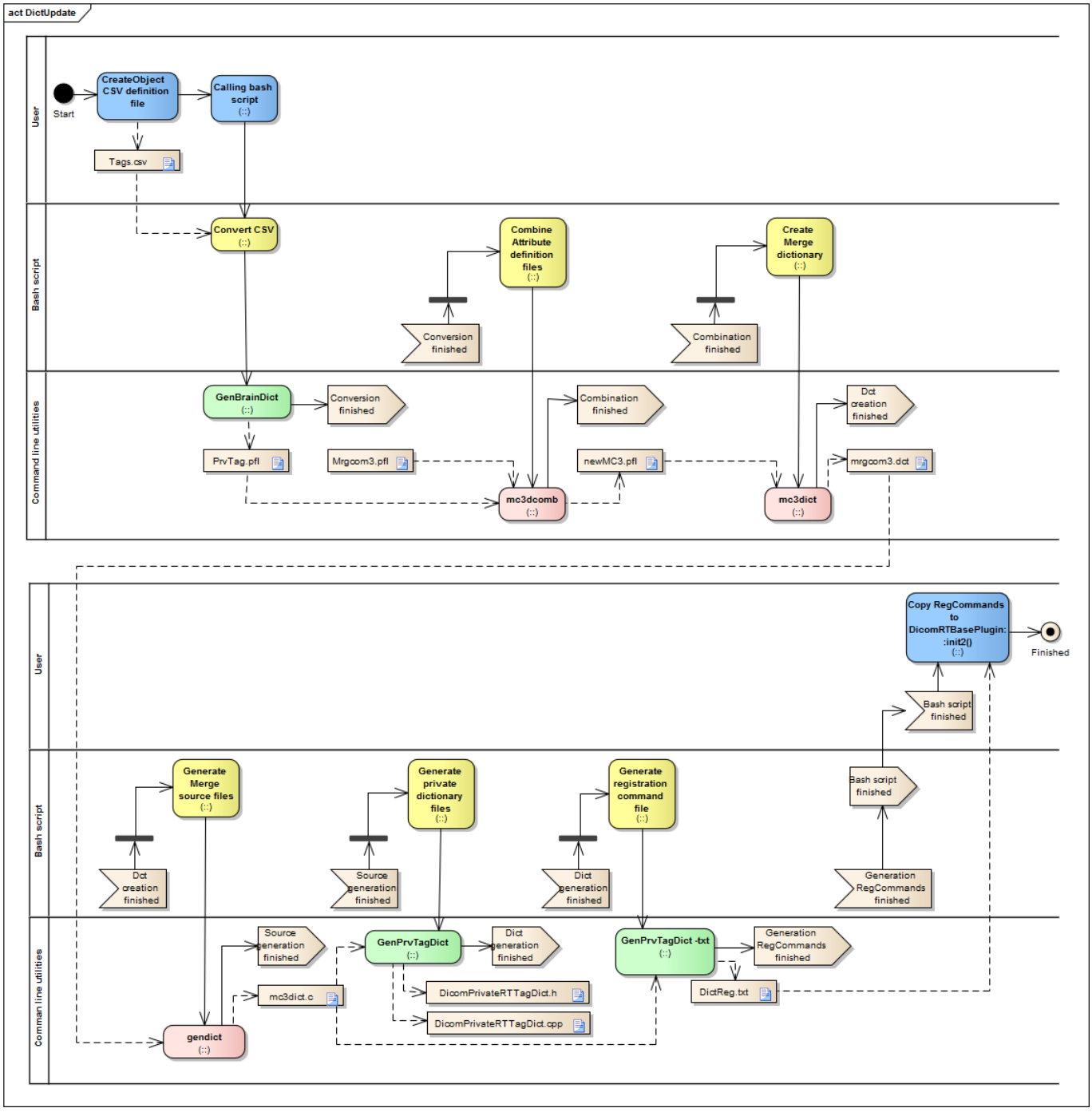


Figure 3.15: Extension of DICOM Library - Blue: User Actions; Yellow: Intermediate Steps; Green: Developed Conversion Tools; Red: Merge DICOM Toolkit Utilities

3.4.2.1 Summary

As mentioned before Supplement 147 defines a lot of new attributes and IODs. It is in the nature of such an ambitious endeavor that some attribute definitions are missing or misspelled in *Part 6 Addendum* of the Supplement draft. Because of the automatization these inconsistencies could be detected very easily. Additionally, it is very simple to integrate new definitions respectively to update definitions of attributes defined by more recent drafts of the Supplement.

3.4.3 Macro Concept

As object-oriented programming (OOP) aims to reuse code of existing objects by inheritance and Supplement 147 defines 33 new macros (s. [28]) that are used in the new Supplement's sequences and modules, it is desirable to encapsulate these macros in own (abstract) classes. Due to the underlying cache concept (s. 2.6.1) these classes have to be derived from *AttributeDefinitionList*.

As DICOM sequences or modules can contain multiple macros (s. 2.2.2) and even macros themselves can consist of other macros (e.g., *Conceptual Volume Reference Macro (C.8.A.1.5)*) the inheritance hierarchy has to be defined virtual, as the implementation is performed in C++. This is necessary to ensure that all parts of the cache class ("normal" module attributes and macro attributes) operate on the same attribute list, which is encapsulated by the common base class *AttributeDefinitionList* (s. 2.6). Without the virtual inheritance different attribute lists would exist, which would cause a loss of information when the cache's *fill()* method is called (s. 2.6.1). The result of the virtual inheritance approach is a very complex inheritance hierarchy (fig. 3.16 on the following page).

Hence, the existing *SequenceCache* and *ModuleCache* (s. 2.6.1) are not derived virtually from its base class *AttributeDefinitionList,* and the introduction of such a virtual inheritance at this point might cause some complications in the rest of the underlying framework, this approach is not implemented.

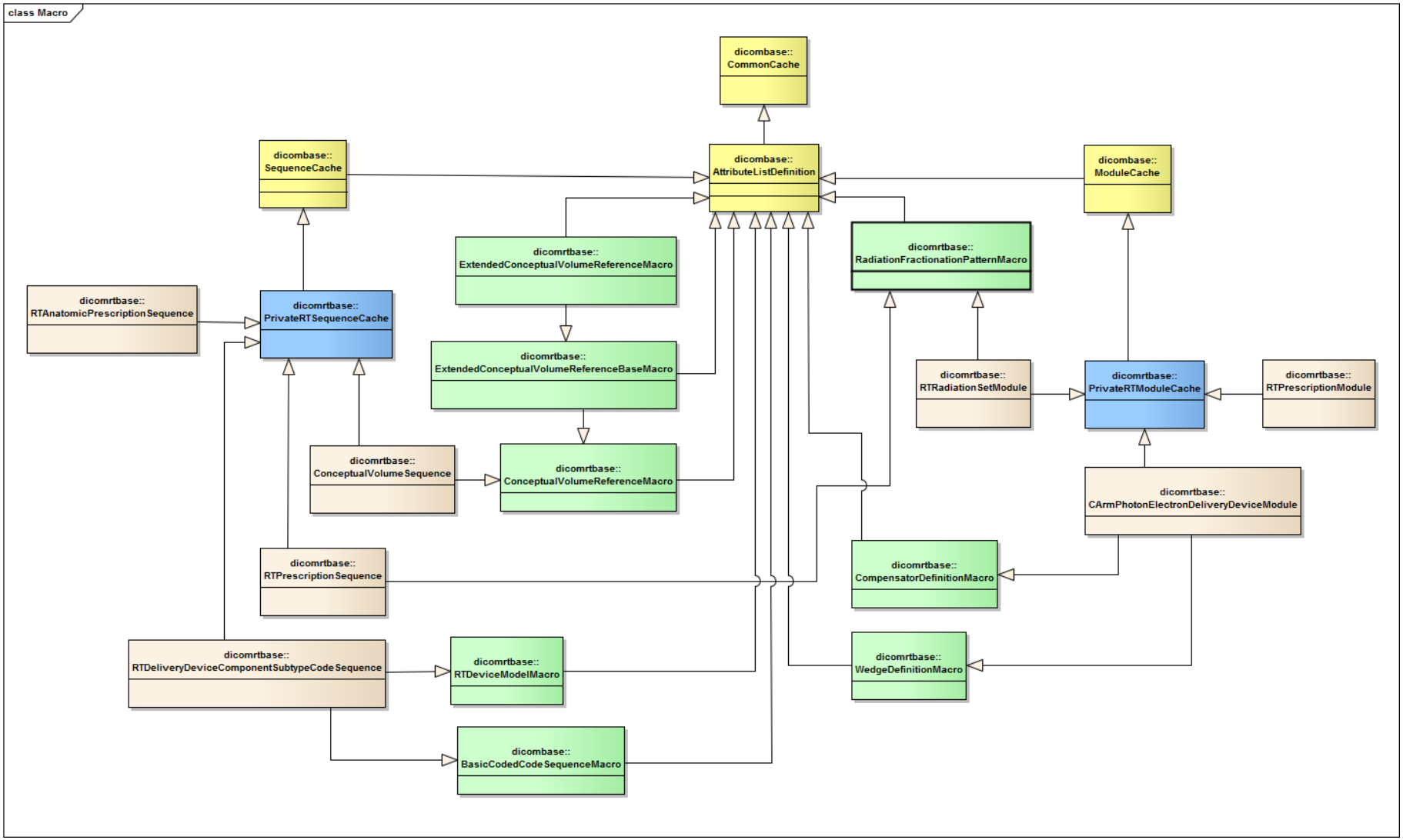


Figure 3.16: Segment of a Virtual Inheritance Hierarchy for DICOM Macros - Green: Macro Class; Yellow: Existing Base Classes in Underlying Framework; Blue: Base Classes for this Implementation (s. 3.4.2)

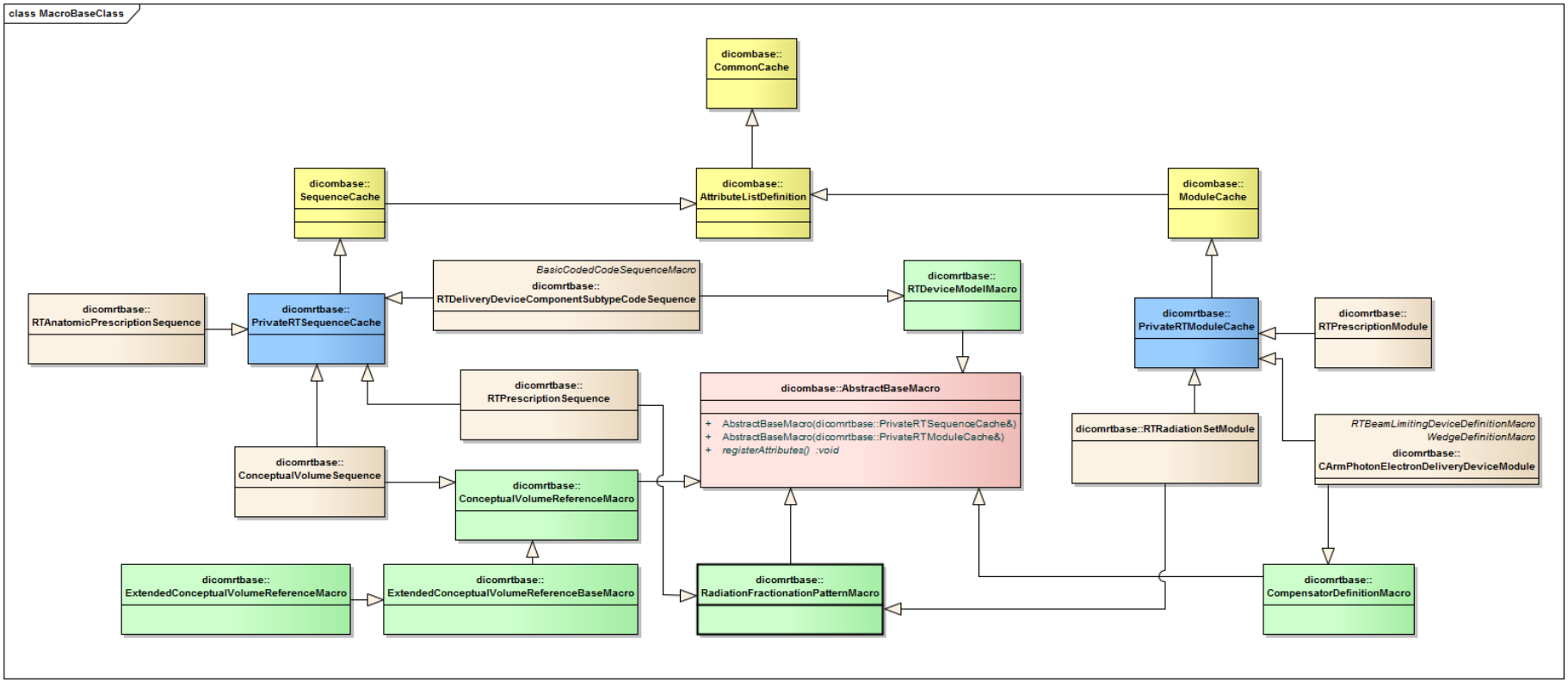


Figure 3.17: Macro Approach with Abstract Base Class (Red) - Green: Macro Classes; Yellow: Existing Base Classes in Underlying Framework; Blue: Base Classes for this Implementation (s. 3.4.2)

Another similar approach is to introduce an abstract base class for all macros containing a *register()* method for the macro attributes in the *AttributeDefinitionList* of the *ModuleCache* respectively *SequenceCache* that contains the macro (fig. 3.17 on the previous page). These *ModuleCaches / SequenceCaches* are derived from the corresponding macro class(es) to inherit their access methods to the macro attributes. In the constructor of the concrete cache class the *register()* method is called. Unfortunately, this approach seems to displace the problem of virtual inheritance to another location. As a consequence this approach is discarded as well.

An implementation of the macro concept as compositions is not appropriate either, because it would destroy the benefit of the convenient usage of access methods to the cache attributes (s. 2.6.1). To obtain the convenient usage of access methods, they have to be defined in the cache classes as well, which leads to a lot code duplicates.

After trying several and different approaches to solve this integration problem, further trials are canceled to spend more time on the actual task - the investigation of some basic concepts of Supplement 147 as described before in this chapter (s. 3.1 - 3.3).

3.4.4 Managing DICOM Content Mapping Resources

Supplement 147 defines over 50 new context groups and templates as described in 2.2.2. Thus, a mechanism to access and manage these information in a way similar to the cache concept for DICOM attributes (s. 2.6.1) would be preferable.

Therefore, an abstract base class for context groups (*Cid*) and one abstract base class for templates (*Tid*) are defined. These classes provide convenient access to items in a concrete implementation by *getItemByMeaning(std::string& codeMeaning)* and *getItemByCodeValue(std::string& codeValue)*. Furthermore, a method to retrieve all items of the context group respectively of the template is provided (*getItems()*) and another method to retrieve the corresponding code meanings (*getItemMeanings()*). To access the information of an item in a context group or a template the abstract classes *CidItem* and *TidItem* are created. They provide methods to gain information about the Code Value (*codeValue()*), Code Meaning (*codeMeaning()*) or the Coding Scheme Designator (*codingSchemeDesignator()*). Furthermore, *TidItem* has methods to get the template type (enumerated value (EV) or defined terms (DT); *getTidType()*), value type (*getValueType()*), the value multiplicity (*getVMin()* and *getVMax()*) and a potential value set constraint context group identifier (*getConstraintCID()*).

Specific implementations of a context group or a template derive from the corresponding base class and set their specific information by calling the constructor of the base class (*Cid*/*Tid*) and by adding the corresponding items to the internal lists.

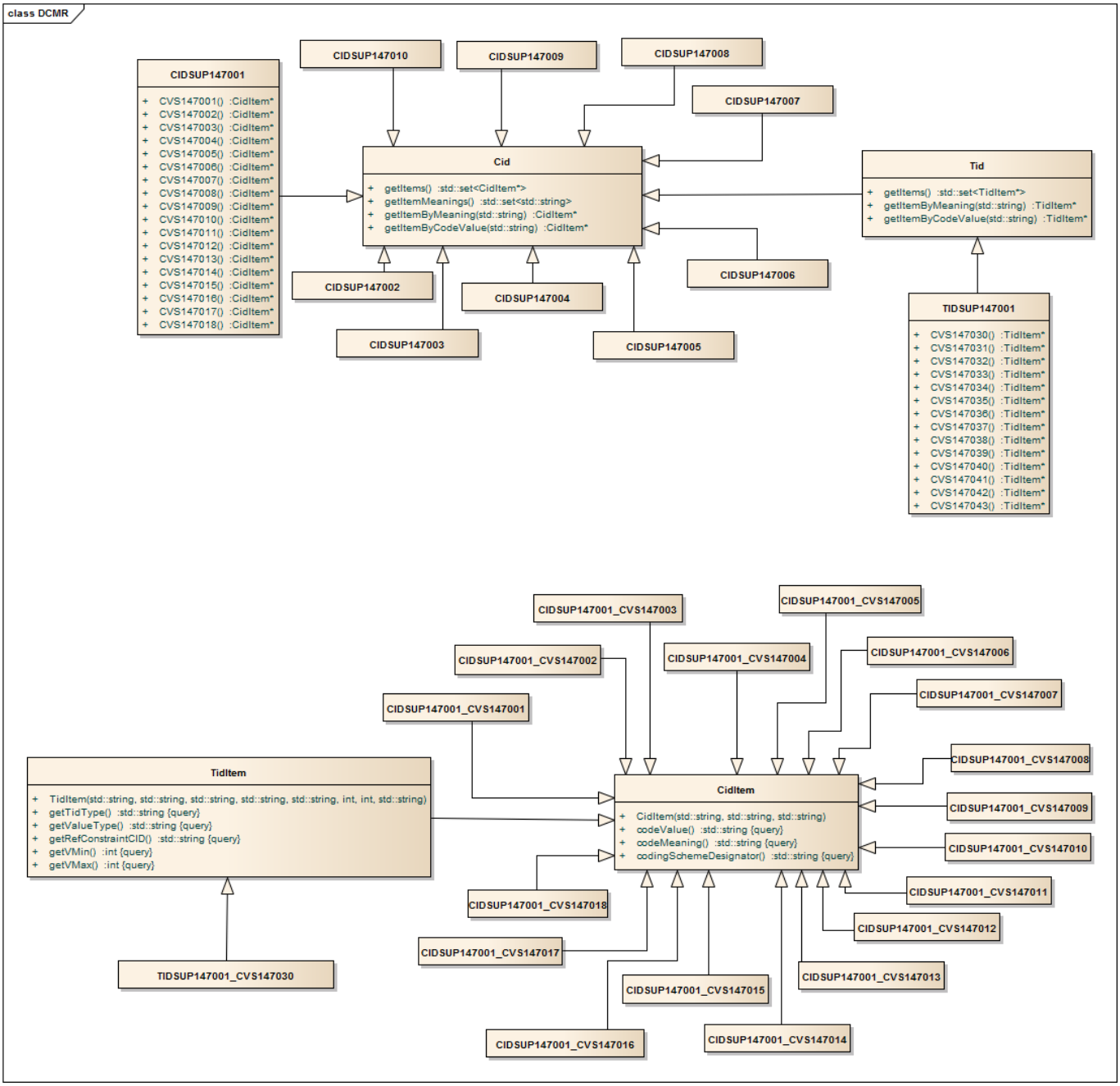


Figure 3.18: Part of UML Class Diagram for Generated DICOM Context Group Classes Respectively DICOM Template Classes that are Managed by the *DCMR-Manager*

Figure 3.18 shows the generated class structure for the context group SUP147001 and one item for template SUP147001.

Since the information in a context group or template does not change, only one instance of each type is enough. As a Singleton provides a pleasant opportunity to ensure such a single instance existence, this design pattern is used for the specific implementations. For convenience, string constants are defined for each context group identifier (e.g., "CIDSUP147001") and template identifier (e.g., "TIDSUP147001") as well as for each item code value (e.g., "CIDSUP147001_CVS147009").

To retrieve information for a specific context group or a specific template a manager class (*DCMRManager*) is implemented. This manager provides methods to get all available context groups and templates (*getAvailableCIDList()* and *getAvailableTIDList()*). Moreover, methods to retrieve a specific context group or template, identified by one of the previously mentioned string contants, are included (*getCID(std::string& id)* or *getTID(std::string& id)*). Hence, this manager does not have to deal with changing information, it is implemented as a Singleton too.

As soon as *DICOM Macros* are integrated into the cache concept (s. 3.4.3), a method to create a *Code Sequence Macro* cache item for context group items and a method to create a *Content Item Macro* cache item for template items would complete the concept to manage *DICOM Content Mapping Resources*.

3.4.4.1 DCMRConverter

Just like the definition of (private) attributes, context group and template definitions in the Supplement 147 (Addendum Part 16) may change between different drafts. Hence, an automatic conversion of definitions for context groups and templates is desirable too. Therefore, another command-line tool (*DCMRConverter*) is implemented. As input serves a comma-separated value file that specifies the context group and template definitions in the following format:

- For context groups:
  - Definition line: "CID;<*ID*>;;;;;"
  - For each item: "<*Designator*>;<*Code Value*>;<*Code Meaning*>;;;;"
- For templates:
  - Definition line: "TID;<*ID*>;;;;;"
  - For each item: "<*Designator*>;<*Code Value*>;<*Code Meaning*>; <TEXT|CODE|NUMERIC>;<*Value Multiplicity*> ;<EV|DT>; [*Constraint CID*]"

– e.g.: TID SUP147001

```
TID;SUP147001;;;;;
DCM;S147030;Radiation Description;TEXT;1;EV;
DCM;S147031;Beam Shaping Means;TEXT;1;EV;
[...]
DCM;S147041;Radiation Type;CODE;1-n;DT;SUP147053
DCM;S147042;Radiation Energy;NUMERIC;1-n;DT;SUP147043
DCM;S147043;Positioning Procedures;CODE;1-n;DT;9242
...
```

Listing 3.2: Excerpt of Definition File for DICOM Context Group and Template Definitions

The *DCMRConverter* generates header and source files that contain the definitions of the context groups and templates as described before (s. 3.4.4). Additionally, the source file and header file of the *DCMRManager* (s. 3.4.4) are generated.

3.5 Test Applications

Within this work two test applications are developed to create *RT Segmentation Properties* respectively *RT Physician Intent* objects which are introduced in the following.

3.5.1 RT Segmentation Properties Creator

The *RT Segmentation Properties Creator* is a simple MFC application to create *RT Segmentation Properties* objects. This application is used to examine the *Conceptual Volume* concept (s. 2.3.2).

3.5.1.1 Structure

The decision to use MFC as the Graphical User Interface (GUI) is made because it is supported by the used build system (s. 2.6) and provides a large and well documented library. Furthermore, no additional frameworks have to be installed. Since the aim of this work is to investigate Supplement 147 a quick solution to create a simple GUI is applied. As data model the DICOM caches (s. 2.6.1) are used. This decision is made as the DICOM caches are the DICOM export data structure of Brainwork (s. 2.6). But it became obvious during the implementation that this approach results in a more complex data handling, which goes beyond the original cache concept (s. 2.6.1). Since this problem was not realized early enough, a change of the data model was not performed as this would have resulted in a loss of valuable time for the investigation task of Supplement

147. However, the introduced controller concept enables a simple replacement of the data model later on.

An instance of the *SegPropCreationManager* is used by the initial dialog of the application (*CSegPropCreatorDlg*) to manage the creation of a new *RT Segmentation Properties* object. This manager as well as the other (sub-)dialogs of the application use special controllers to handle the corresponding information. As mentioned before (s. 2.3) *Conceptual Volumes* may or may not be defined by an underlying segmentation. To manage defined volumes (ROI or segment) the *VolumeDefinitionManager* and to manage existing *Conceptual Volumes* the *ExistingCvDefinitionManager* are introduced. Depending on the dialog and the information that is handled by the dialog, a corresponding controller is passed on to it by the parent dialog. An overview of the *RT Segmentation Properties Creator's* dialogs can be found in the appendix (s. A.1 on page I).

Controller Concept

To enable a simple replacement of GUI and/or data model a controller concept is introduced which is illustrated in figure 3.19. Similar to the previously described converters for first-generation objects (s. 3.1.1), an own controller for each DICOM sequence - that can contain more than one item - within the *RT Segmentation Properties Module* is created. The functionality of these controllers is defined in separate interface classes (red colored classes in figure 3.19). Basically these interfaces define access methods (getter and setter) to attributes within a corresponding sequence item, besides for sequences attributes that can contain more than one item. For these sequence attributes a getter to retrieve the corresponding (sub-)controller is provided. With the help of the returned controller these sequence attributes and their items can be manipulated.

As the introduced controllers shall be able to manage multiple sequence items an extra controller interface (*IMonitorController*) is introduced. It provides three methods that start an operation - *create(), change(), delete()* - and two methods to complete the operation - *confirmOperation()* - respectively to cancel the operation and revert to the controller state before the operation started - *cancelOperation()*.

For controller implementations that combine these two controller concepts an extra controller interface layer is introduced ($\rightarrow$ *IXMonitorController*; green colored classes in fig. 3.19).

The *ICacheDataController* is introduced for controller implementations whose model is based on DICOM caches (s. 2.6.1). This interface provides a method to set the parent sequence cache to operate on.

Besides deriving from a *IXMonitorController* and the *ICacheDataController* the implementing controller classes (thicker border in fig. 3.19) of this work are derived from the *BaseDCMRController*. This controller provides access to the *DCMRManager* as described in 3.4.4.

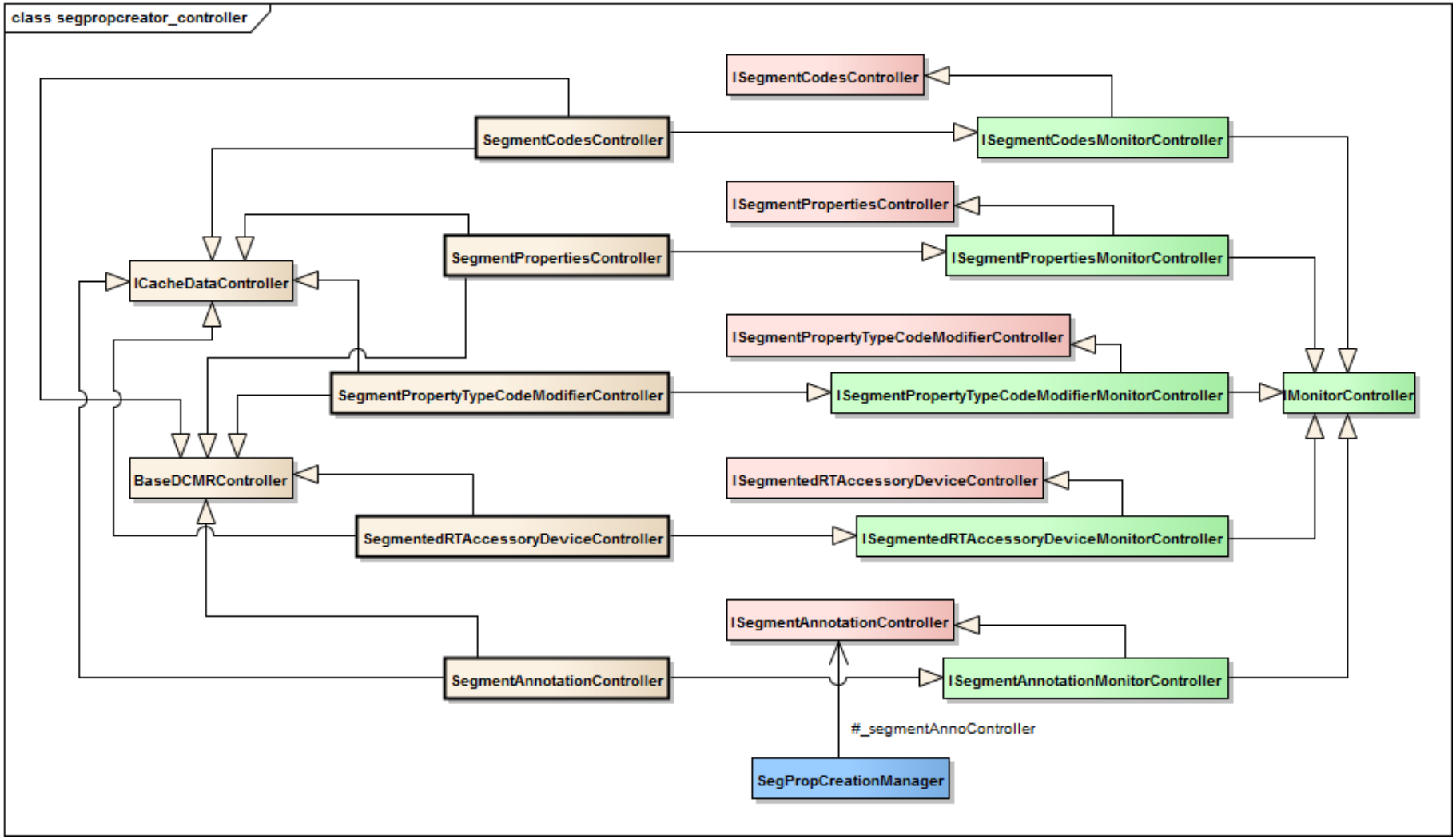


Figure 3.19: Simplified Class Diagram of *RT Segmentation Properties Creator's* Controller Concept - Red: Controller Interfaces; Green: Monitor Controller; Blue: RT Segmentation Properties Creation Manager; Thick Border: Implementing Controller Classes

3.5.2 RT Physician Intent Creator

The *RT Physician Intent Creator* is the second application that is implemented within this work. Besides the investigation of the *Conceptual Volume* concept (s. 3.3), the application is used to examine whether the *RT Physician Intent* can describe all the information that is presented in the *Standard Prescription Proposal* (s. 3.2.1).

3.5.2.1 Structure

Similar to the *RT Segmentation Properties Creator* (s. 3.5.1) it uses the DICOM caches (s. 2.6.1) as data model and the MFC Framework to create the user interface. Furthermore, a controller layer (fig 3.20), like the controller layer in the *RT Segmentation Properties Creator* (s. 3.5.1.1), is introduced to facilitate an easy replacement of the data model as well as the user interface.

Like in the *RT Segmentation Properties Creator* a manager instance (*PhysicianIntentCreationManager*) is used by the initial dialog (*CPhysIntentCreatorDlg*) to manage the object creation. Depending on the (sub-)dialog and the information that are handled in it, the corresponding controller is passed on to it by the parent dialog. Thus, an *RT Physician Intent* object only references second-generation *Conceptual Volumes* one class to manage these volumes is enough (*CvManager*; comparable to *ExistingCvDefinitionManager* of *RT Segmentation Properties Creator*).

An overview of the *RT Physician Intent Creator's* dialogs can be found in the appendix (s. A.2 on page V).

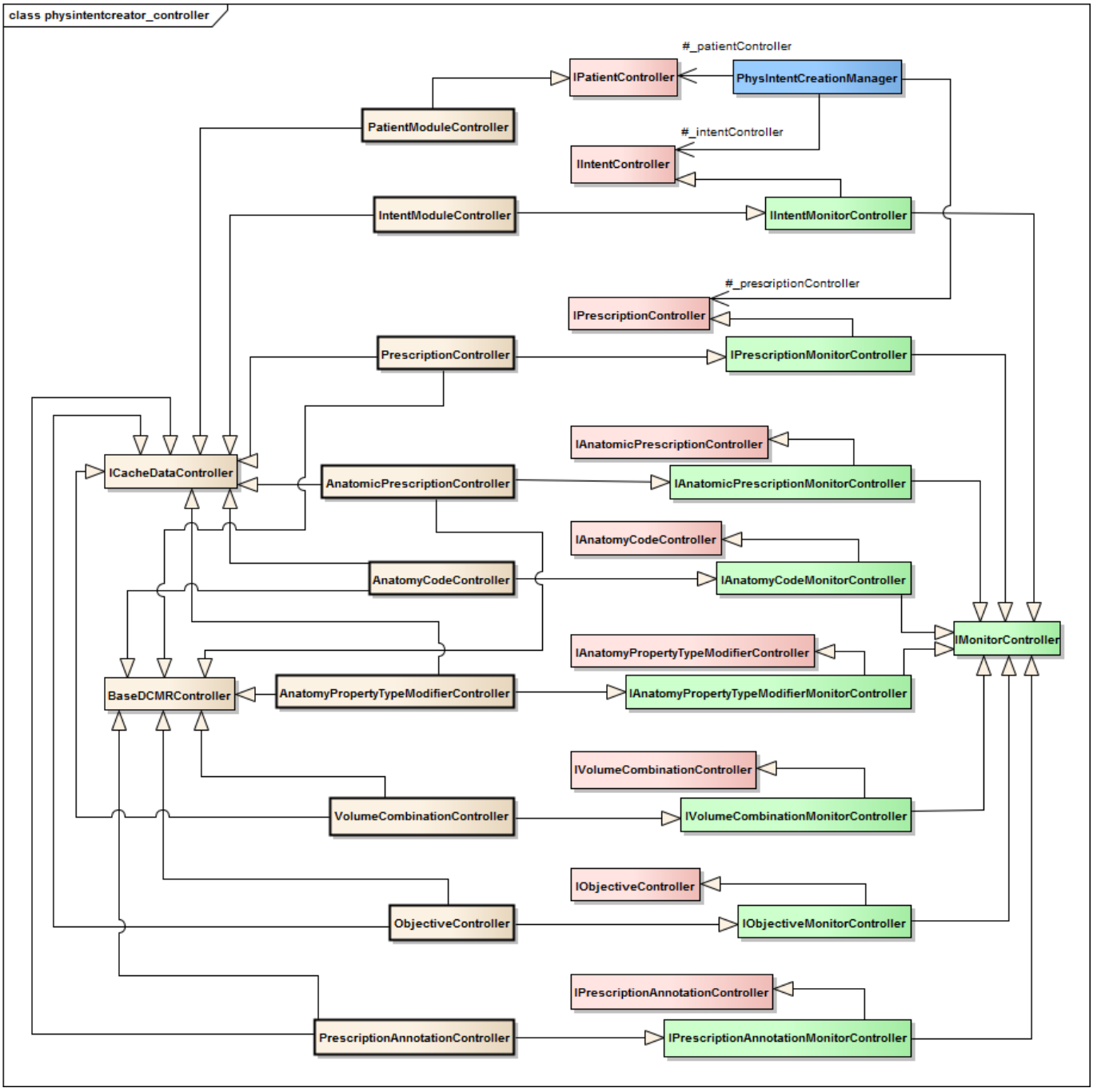


Figure 3.20: Simplified Class Diagram of *RT Physician Intent Creator's* Controller Concept - Red: Controller Interfaces; Green: Monitor Controller; Blue: RT Physician Intent Creation Manager; Thick Border: Implementing Controller Classes

3.6 Recapitulation

This section shall give a brief summary of the main results that were found and implemented in this work.

First it is shown that the introduced separation of radiotherapy-related information into separate IODs (s. 3.1) and the new concept for abstract access to volumetric objects (s. 3.3) results in more flexible structures to facilitate future enhancements and developments in treatment devices and treatment techniques.

During the investigation of the new object for radiotherapy prescriptions (s. 3.2) a missing possibility to represent the time structure between different prescriptions was detected. The introduced solution of *DICOM Working Group 7* for this issue, published in a later draft of Supplement 147, is examined as well. This thesis questions whether the provided solution is sufficient in respect of the *Standard Prescription Proposal*. Furthermore, a relocation of some prescription information in reference to the *Standard Prescription Proposal* of the ROSSG is proposed.

Additional suggestions are made how to transfer first-generation objects into corresponding second-generation objects and what additional information has to be provided. Moreover, some ideas are presented how such information can be supplied.

Besides the investigation of Supplement 147, this thesis started the data structure adaption of the underlying framework for second-generation environment. To facilitate a more convenient update of the underlying DICOM library a few command-line tools are developed (s. 3.4.2). These tools can be used in the future even for further private attribute definitions and integration into the DICOM library. Furthermore, a new concept to manage *DICOM Content Mapping Resources* is integrated into the underlying framework (s. 3.4.4). Moreover, this thesis pointed out a problem with the integration of *DICOM Macros* in the existing cache concept (s. 3.4.3).

Finally, this thesis developed two applications to create the second-generation objects *RT Segmentation Properties* and *RT Physician Intent* more conveniently. Additionally, these applications were used to perform the mentioned examination of the new prescription object and the investigation of the *Conceptual Volume* concept as well.

4 Discussion and Prospect

The objective of this work is the examination of some basic new concepts introduced with Supplement 147, representing radiotherapy-related information, and the creation of corresponding data structures in the underlying Brainlab Framework, called Brainwork (s. 2.6). These concepts address the need for more flexible and adaptive data structures, as first-generation objects are mostly overloaded and static too. Besides this, first-generation radiotherapy objects are based on the conventional C-Arm LINAC concept (s. 2.1.3.2), which results in a missing capability to represent all features of new treatment devices and treatment techniques overall. Furthermore, little changes in the content of first-generation objects, e.g., update of contour data, commonly lead to an enormous update process.

Therefore, this work inspected these concepts and searched for inconsistencies and unconsidered aspects to communicate them to the *DICOM Working Group 7* in order to enter the Supplement's development process. Another aim of this thesis was to create and to adapt the data structures of the underlying framework (s. 3.4) to facilitate the usage of second-generation objects in the future.

First, this thesis investigated whether the new concepts of Supplement 147 lead to more flexible and adaptive data structures. As a result of this a more convenient integration of future developments and enhancements in treatment devices and treatment techniques in the radiation oncology domain shall be facilitated. As there are no treatment planning systems available that support the new DICOM objects in order to create test objects, the decision was made to test the separation of radiotherapy-related information into different IODs by converting existing first-generation treatment plans. However, the chosen plans provided only information for the conventional C-Arm LINAC concept (s. 2.1.3.2), the beam modification by an MLC (s. 2.1.4.6) respectively different kinds of wedges (s. 2.1.4.1) and treatment with static beams, arcs, IMRT and VMAT (s. 3.1.2). Nevertheless, these setups provide a first impression if the introduced separation (s. 2.3.1) results in the desired more adaptive and flexible data structures (s. 3.1). For example, new devices for fluence modification can easily be added as an additional context group, and if applicable as an additional sequence, containing the device-specific configuration parameters, to the corresponding radiation's delivery module. In case that one of the existing specific *RT Radiation* definitions, which has not been examined, contains a problem, it does not influence the basic new separation concept. Further flexibility is provided by the separation of volume definitions, their related radiotherapy-relevant

properties, and the new abstract access to volumetric objects. Therefore, this work concludes that the basic separation concept provides the desired flexibility.

An alternative method to examine this separation concept would have been the development of multiple small applications to create corresponding second-generation objects and perform an investigation similar to the examination of the *Conceptual Volume* concept (s. 3.3). As development of such applications would have consumed quite an amount of time with a very high likelihood of not revealing more relevant results, it was decided to reject this alternative and focus on other aspects within the given time-frame.

Although the first-generation conversion is explicitly out of scope of Supplement 147, it became clear during the investigation, that this feature is most likely desired from clinical and vendor's perspective (s. 3.1). As a consequence this aspect was considered as well during the previous investigation of the second-generation flexibility and adaptiveness. Supplement 147 states that additional information has to be provided for such a conversion [28]. The main lack of such additional information was detected as missing identifying labels for the treatment device components (→ *RT Beam Limiting Device Definition Macro*). Therefore, a translation device needs a database that contains additional information of different used treatment (device) configurations, like the mentioned "Machine Profiles" (s. 3.1.1.2). With the help of this information the translation device can conclude which component was used. In case no or multiple components are found a user interaction is necessary. However, this thesis made some assumptions regarding some default values respectively regarding the proceeding for missing (required) attributes in an *RT Plan* object (s. 3.1.1.2). First hints how to establish a transition in this way were shown within this work (s. 3.1.1). Nevertheless, some official "Transition Guidelines" for the first-generation conversion, published by one of the groups dealing with the radiation oncology domain, are recommended.

Since radiation prescriptions are described in different ways by different radiation oncology professionals, the *Standard Prescription Proposal* of the *Radiation Oncology Safety Stakeholder Group (ROSSG)* [72] was taken as common ground to examine the new prescription object introduced in Supplement 147 (s. 3.2.1). Recommended information that has to be defined in a radiation prescription were extracted from the *Standard Prescription Proposal* (s. 3.2.1) and corresponding second-generation prescription objects were created. To create the new prescription object more conveniently, a small application was developed within this work (s. 3.5.2). During the first investigation of the prescription object a missing possibility to specify the time-dependency between radiations was detected and communicated to *DICOM Working Group 7* (s. 3.2.1). As a consequence of this input provided by this work a new module was introduced by this Working Group in a later published draft of the Supplement. Since this updated draft was published when the investigation of this work was almost finished, this new introduced module was not included in the application to create prescription objects. Therefore, this new concept was reviewed in theory only, if it fulfills the needed requirements. Referring to the *Standard*

Prescription Proposal this thesis pointed out if this provided new concept is enough or should be extended to specify more flexible prescription specification like proposed in the *Standard Prescription Proposal* (s. 3.2). Furthermore, it might be useful to shift the information to describe the beam energy and the prescription dose to a separate attribute on a higher level in the prescription module to enable a more convenient access to this information (s. 3.2.2). Apart from that, this work showed that the new radiotherapy prescriptions object provides the capability to describe all other information, which is mentioned by the *Standard Prescription Proposal* (s. 3.2.1).

To examine the capabilities of the new abstract access to volumetric objects some prescription scenarios were developed in discussion with clinical professionals (s. 3.3). These scenarios contain the different stages of a *Conceptual Volume*. Similar to the previously mentioned first-generation *RT Plan* conversion (s. 3.1.1.2), these prescription scenarios are only a fraction of the scenarios in which *Conceptual Volumes* occur. However, the prescription scenarios show whether the basic concept of the *Conceptual Volume* works. As these scenarios could be described by the new second-generation objects *RT Segmentation Properties* and *RT Physician Intent* it was proved that the *Conceptual Volume* provides the intended and desired abstract access to volumetric objects (s. 3.3.4).

Since Supplement 147 is still being defined at the moment, some concepts and corresponding command-line tools were developed within this thesis (s. 3.4.2 and 3.4.4.1) to enable a convenient update of the underlying DICOM library. This facilitates the introduction and update of attribute definitions and *DICOM Content Mapping Resources (DCMR)* in the underlying framework according to changes between different Supplement drafts. The developed tools provide the capabilities to be used not only for new definitions regarding Supplement 147, but also for other private attribute definitions respectively the introduction and update of other DCMRs. Thus, the transition of the existing DCMR definition, specified in part 16 of the DICOM standard (s. [61]), into the underlying framework is facilitated.

Another framework-related aspect of this work dealt with *DICOM Macros* (s. 2.2.1), because they are extensively used in Supplement 147. As *DICOM Macros* are not only used in *DICOM Sequences*, but also in *DICOM Modules*, this work tried to introduce a new concept to encapsulate *DICOM Macros* conveniently in the underlying framework (s. 3.4.3). Unfortunately, this work couldn't provide a solution for this problem, as there were some difficulties with the existing cache concept (s. 2.6.1) and a proper realization with the used programming language (s. 3.4.3). A more detailed investigation of this issue would have gone beyond the scope of this work. Nevertheless, this thesis strongly recommends to investigate this issue, as the use of *DICOM Macros* in the underlying framework would reduce correlated code duplicates.

At first glance the usage of *DICOM Caches* (s. 2.6.1) as the data model for the implemented converters (s. 3.1.1) and test applications (s. 3.5) seemed obvious as *DICOM*

Caches are the data structure of Brainwork for DICOM export, and the implemented applications should be used to create the new second-generation DICOM objects. As it became obvious that the better attempt for the test applications would have been an additional extension of the library for patient data management in the underlying framework with appropriate second-generation structures, which are used by the test applications instead. At the end of the object creation by a test application the information in these data structures would have been transferred into corresponding *DICOM Caches* to export the information to DICOM objects. Thus, this change of the data model should be implemented as a next step.

In conclusion, this thesis examined some of the major new concepts of Supplement 147 and showed that these concepts result in more flexible and adaptive structures, which were desired by these concepts. Besides smaller inconsistencies, which were communicated to *DICOM Working Group 7* and were mostly corrected by this Working Group in later published drafts of Supplement 147, the missing time-dependencies for radiation prescriptions was detected as an important missing detail in the draft. As a consequence the *RT Treatment Phase Intent Module* was added to the *RT Physician Intent* by *DICOM Working Group 7* in a later published draft of Supplement 147. Furthermore, this work showed that first-generation object conversion is a desired feature. Moreover, this thesis presented some hints how to establish such a conversion and which additional information is required for this. In addition, it was demonstrated how this information can be provided.

Besides corresponding second-generation data structures that were created in the underlying framework by this work, also a new concepts was introduced in this framework to handle *DICOM Content Mapping Resources*. Furthermore, this thesis showed that further investigations regarding the introduction of *DICOM Macros* in this framework are necessary to include this concept in the framework.

Thus, this thesis accomplished its aims by providing information to *DICOM Working Group 7*, which helped to improve the Supplement draft. Additionally the underlying framework was extended with data structures and a new concept to manage specific DICOM content, which form a basis for the second-generation DICOM object usage in this framework. Moreover, this thesis pointed out a difficulty with the usage of the *DICOM Macro* concept and developed some tools to facilitate the mentioned framework extension conveniently in the future.

As this thesis is the first of its type, further works dealing with more detailed investigations of other, more specific aspects of Supplement 147 might follow.

A GUI of Testapplications

In this chapter the dialogs of the developed applications are described.

A.1 RT Segmentation Properties Creator Dialogs

CSegPropCreatorDlg This dialog represents the main dialog. First the user has to select a directory to scan for volume definition files[1](1). Then the user can choose a file that shall be augmented. As the next step a decision has to be made whether to create *Conceptual Volumes* according to the volume file (2) or to select a (second-generation) file that declares *Conceptual Volumes* to define these volumes now (3) or to create new *Conceptual Volumes* manually (4).

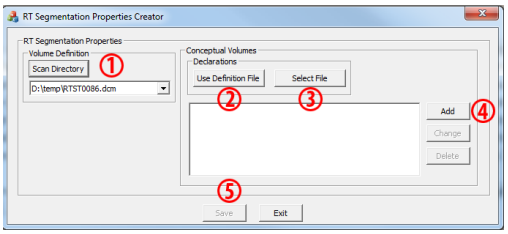


Figure A.1: CSegPropCreatorDlg

After performing the desired changes in the *RT Segmentation Properties* object it can be saved to hard disk (5). The output file is stored in a subfolder named *secondgen* at the location of the volume definition file.

The buttons for the described actions are disabled as long as no volume definition file is selected.

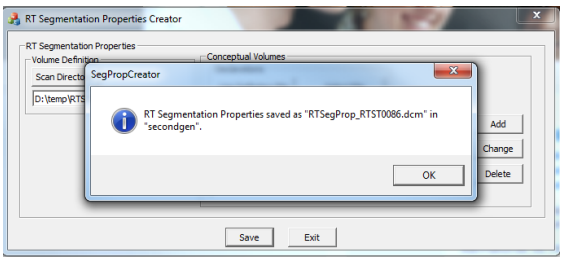


Figure A.2: Confirmation of a Successful *RT Segmentation Properties* Creation

[1] At the moment only support for *RT Structure Sets*

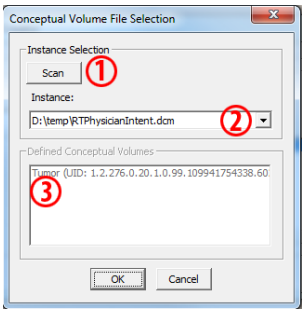


Figure A.3: CCvSelectionDlg

CCvSelectionDlg With the help of this dialog the user can select an instance that defines *Conceptual Volumes*. If no files are known yet, the user can scan a directory for second-generation RT files[2] (1). The found instances are shown in a drop-down list (2) and the user can select the desired instance. As a limitation only files declaring *Conceptual Volumes* are shown. To give an overview of the content of the selected instance, the contained *Conceptual Volumes,* that are declared in the selected file, are shown in the list at the bottom (3). If the user confirms the dialog the corresponding instance is marked in the *ExistingCvDefinitionManager* and can be accessed in other dialogs.

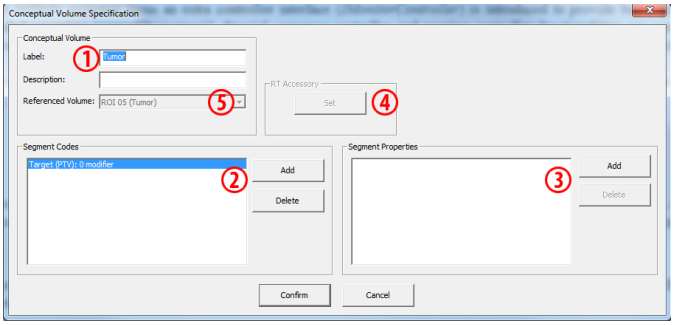


Figure A.4: CCVDefinitionDlg

CCVDefinitionDialog The *CCVDefinitionDialog* is the most extensive dialog of this application. Besides the possibility to specify respectively change the *Conceptual Volume* "base data" (1), it provides options to add or delete *Segment Codes* (2) respectively *Segment Properties* (3) and to set the *RT Accessory* (4) when the current processed *Conceptual Volume* represents an RT accessory according to the definition in Supplement 147.

If the processed *Conceptual Volume* is a result of a pre-conversion of the underlying volume definition file the user cannot change the referenced volume (5).

[2] At the moment only *RT Physician Intents* objects are supported

CAddSegCodeDlg At least one *Segment Code* has to be specified for a *Conceptual Volume*. This can be done with the help of this dialog. According to the selected category (1) corresponding property types (2) are presented to the user. As Supplement 147 does not define property types for all available categories some dummy values are generated for these categories. These dummy values represent examples of property types that are used in an oncology department. These property types have to be defined individually by each institution according to their needs.

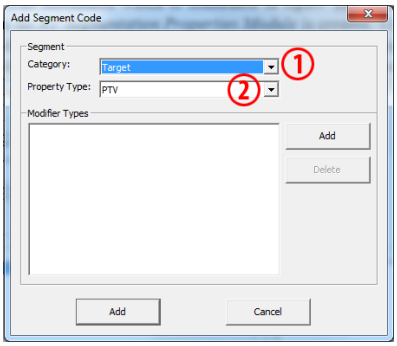


Figure A.5: CAddSegCodesDlg

CAddModTypeDlg If specific modifiers for a segment shall be applied, they can be defined with the help of this dialog (fig. A.6). Each of every modifier type can only be specified once for a segment. When a modifier type is already present in the segment, its value is updated accordingly.

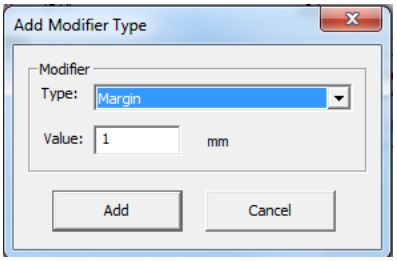


Figure A.6: CAddModTypeDlg

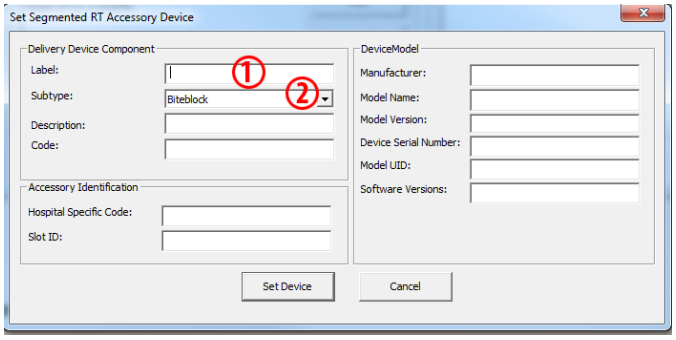


Figure A.7: CRTAccDevDlg

CRTAccDevDlg As defined in Supplement 147, the RT accessory has to be defined for segments with a *Segment Code* of the value (S147054, SUP147003, "Fixation or Positioning Device"), (S147055, SUP147003, "Internal Brachytherapy Device") or (S147057, SUP147003, "Artificial Structure"). Only one RT accessory can be assigned to a segment. The *Delivery Device Component Label* (1) and *Subtype* (2) are required fields in this dialog (fig. A.7). All other text fields allow to specify additional (optional) information to describe the RT accessory more detailed.

When all *Segment Codes,* that imply an RT accessory, are removed from a segment (s. A.1) the set RT accessory is removed as well.

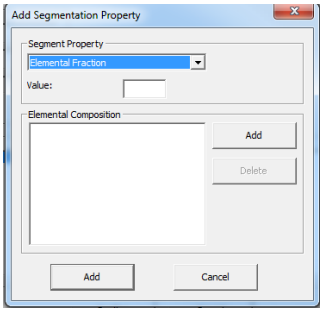


Figure A.8: CAddSegPropDlg

CAddSegPropDlg In case of using certain physical properties for a segment instead of the normal calibration, they can be specified in this dialog (fig. A.1). As mentioned before, no *Segment Property Code* shall appear more than once for a *Segment Code* of a segment. Again a double specification means a replacement of the old value. As a special case of a *Segment Property Code* the code (S147155, SUP147009, "Elemental Fraction") has to be mentioned. For this code the elemental composition has to be defined (s. A.1).

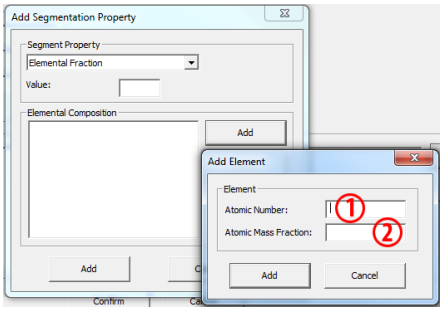


Figure A.9: CAddSegElementDlg

CAddSegElementDlg As said before the elemental composition has to be defined for the *Segment Property Code* (S147155, SUP147009, "Elemental Fraction"). The *Atomic Number* (1) has to be in the range of 1 to 118 and the *Atomic Mass Fraction* (2) in the range of]0;1]. Furthermore, the sum of all elements shall be equal 1.0. But a very liberally tolerance (for floating point precision) of 5% is granted.

A.2 RT Physician Intent Creator Dialogs

CPhysIntentBaseDlg This class is the base class of all dialogs used in the *RT Physician Intent Creator*. It summarizes the common functionality like disabling the display of the help window on F1-key press or calling the *confirm* respectively *cancel* operation of the given monitor controller when a dialog is closed.

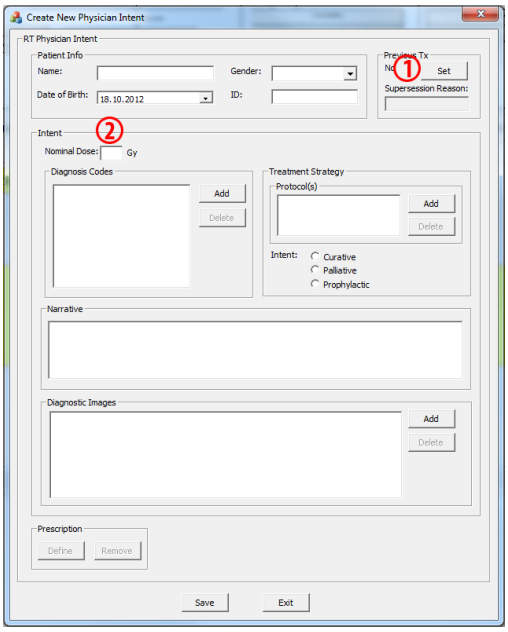


Figure A.10: CPhysIntentCreatorDlg, Prescription Functionality Disabled

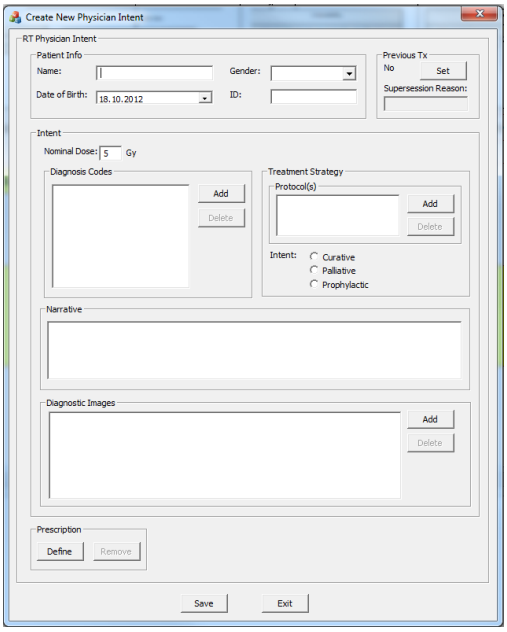


Figure A.11: CPhysIntentCreatorDlg, Prescription Functionality Enabled

CPhysIntentCreatorDlg In this dialog (fig. A.10) the user can specify the information for a treatment intent. The only required field is the *Nominal Dose* (2). As soon as a value is specified the prescription functionality is enabled (fig. A.11). If this *RT Physician Intent object* is replacing an old RT Physician Intent object, the corresponding file can be selected in a file dialog (1). For the case that no *RT Physician Intent* instance is selected an error message is shown. Otherwise the status is changed as illustrated in figure A.12.

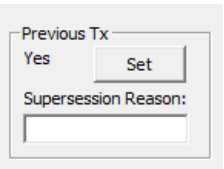


Figure A.12: *RT Physician Intent* is Replaced

Moreover, clinical codes, which are used at prescription state and for other categorization purposes of the diagnosis, can be specified (fig. A.13) as well as clinical protocol codes (fig. A.14).

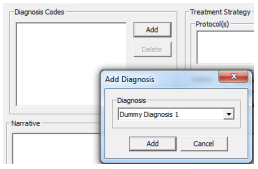


Figure A.13: CDiagnosisDlg

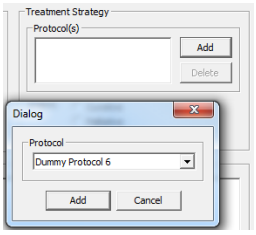


Figure A.14: CProtocolDlg

For both codes no specific context groups are defined by Supplement 147 as it depends on the institution how it uses this information. Therefore, some dummy values are used at the moment in the application.

Diagnostic images are added by a file dialog in which the user can select a directory to scan for image series. The result is presented to the users shown in figure A.15.

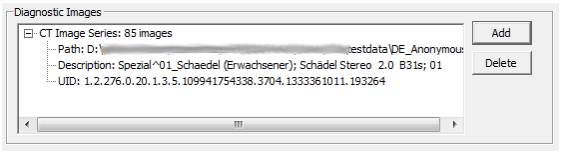


Figure A.15: Presentation of Diagnostic Image Series

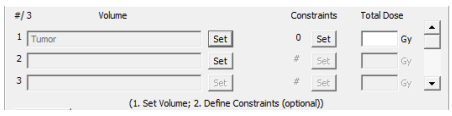


Figure A.16: Volume Declaration Finished

CPrescriptionDlg To give a quick overview of the prescriptions in the *RT Physician Intent* this dialog is introduced. The upper list shows prescriptions that contain at least one volume with the *Prescription Anatomy Role* (30xx,0930) *TARGET*. All other prescriptions are shown in the lower list.

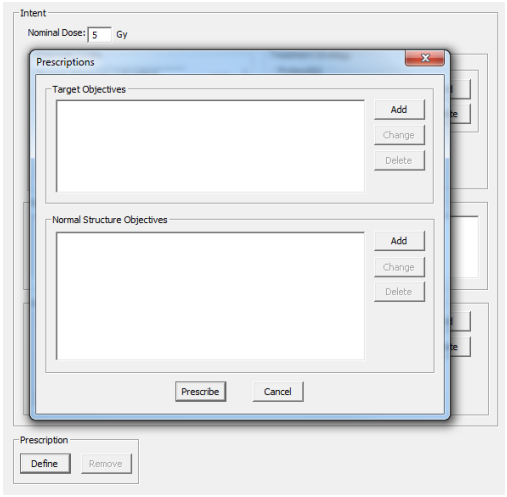


Figure A.17: CPrescriptionDlg

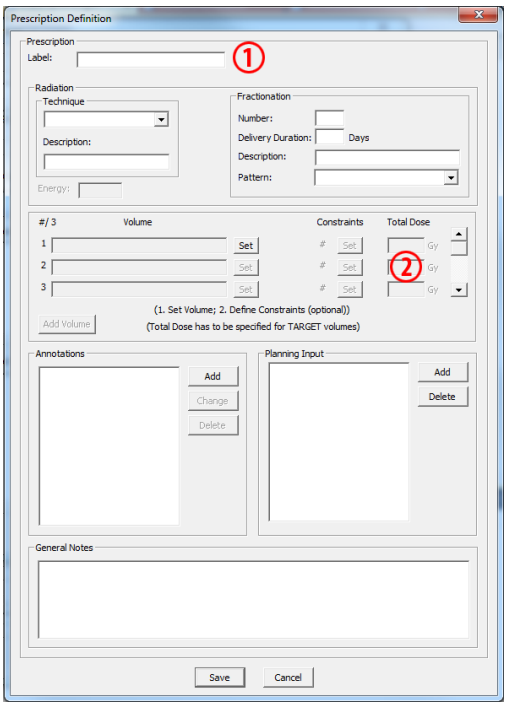


Figure A.18: CPrescriptionDefinitionDlg

CPrescriptionDefinitionDlg With the help of this dialog the user can specify a prescription. The label (1) has to be unique within the *RT Physician Intent* object. Since the declaration of a volume can be more complex (e.g. volume combination) it is outsourced into a separate dialog (fig. A.19). As soon as a volume is declared in that dialog it is displayed in this dialog (fig. A.16) and constraints can be applied to this volume - again in a separate dialog (fig. A.25 and fig. A.26).

For volumes with the *Prescription Anatomy Role* (30xx,0930) *TARGET* the *Total Dose* has to be specified in this dialog (2). It is added by the underlying manager in the *Dosimetric Objective Sequence* (30xx,0942) as (S147009, SUP147001, "Prescription Dose").

According to the *Standard Prescription Proposal* of the ROSSG (s. 2.5.3.1) it is advised to have the possibility to define the beam energy of a prescription in this dialog. This information can be stored as a *Prescription Annotation* item (*DT(S147042, DCM, "Radiation Energy")*). The realization, similar to the made solution for *Total Dose*, is not implemented yet.

Hence, the *Treatment Phase Reference Sequence* (30xx,0870) was introduced in a later

draft of Supplement 147 (Rev. 36) this information is not considered by this application. In a future version of this application corresponding fields should be placed in this dialog to represent the *COURSE/PHASE* concept as described in the *Standard Prescription Proposal*.

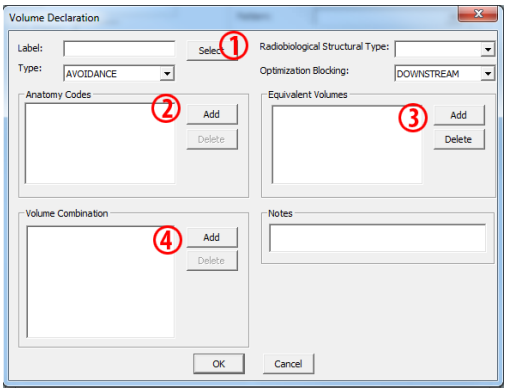


Figure A.19: CVolumeDeclDlg

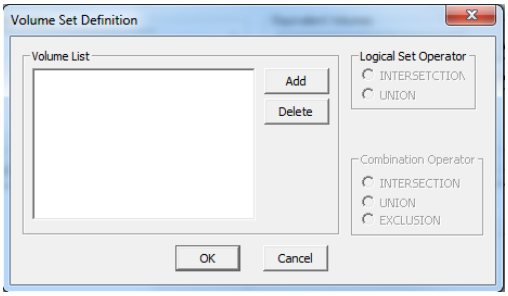


Figure A.20: CCvCombDefDlg

CVolumeDeclDlg As mentioned before the volume declaration is outsourced into a separate dialog. In this dialog the user can declare a complete new volume or select an existing one (1). Furthermore, equivalent *Conceptual Volumes* can be specified (3) and the previously mentioned volume combination can be triggered (4). The specification of the *Anatomy Codes* (2) is equal to the *Segment Codes* in *RT Segmentation Properties* (fig. A.5).

CCvCombDefDlg The volume combination is performed in the following manner: The listed volumes in this dialog are combined by the *Logical Set Operator* (2 in fig. A.21) and form a *Volume Set*. *Volume Sets* can be combined by the *Combination Operator* (3). A *Volume Set* is combined with the result of the previous set(s) accordingly.

CCvSelectionDlg Existing *Conceptual Volumes* can be selected in this dialog to define a prescription for these volumes. This dialog is similar to the *CCvSelectionDlg* of the *RT Segmentation Properties Creator* (fig. A.3). But it allows the user to select a concrete *Conceptual Volume* and does not just list the volumes.

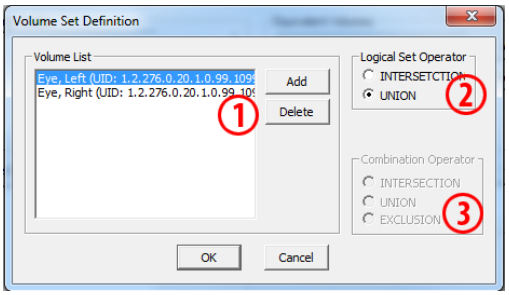


Figure A.21: Definition of a *Volume Set*

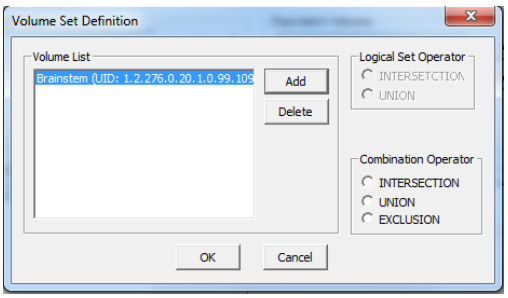


Figure A.22: Combination of *Volume Sets*

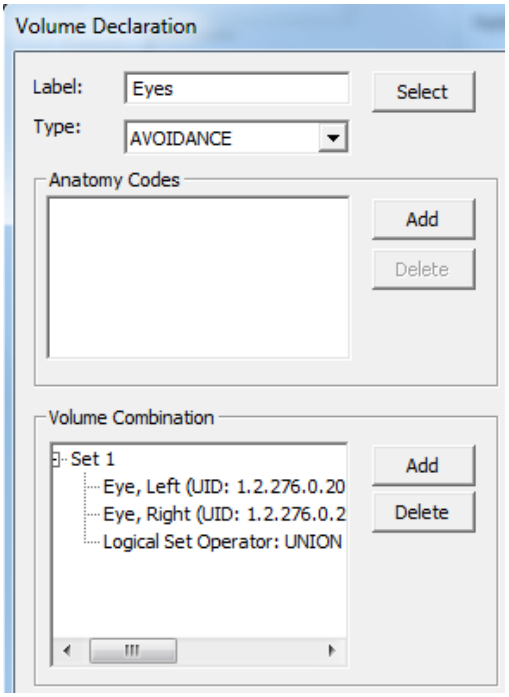


Figure A.23: Volume Combination as *Conceptual Volume* "Eyes"

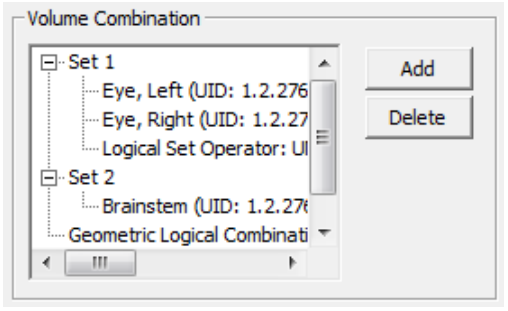


Figure A.24: Combination of Two *Volume Sets* to a New *Conceptual Volume*

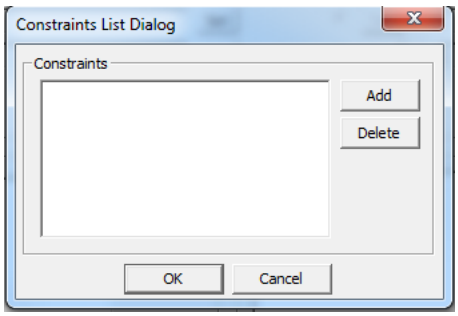


Figure A.25: CConstraintsListDlg

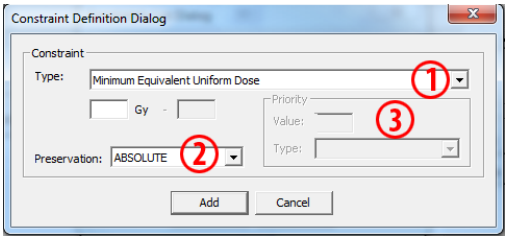


Figure A.26: CConstraintDefinitionDlg

CConstraintsListDlg Similar to the *CPrescriptionDlg* (fig. A.17) this dialog shows an overview of the constraints specified for a volume.

CConstraintDefinitionDlg This dialog enables the user to specify constraints / dosimetric objectives for an anatomy. According to the selected type (1) the text fields (and their units) are adapted. If the *Preservation* (2) *NOT_ABSOLUTE* is chosen a *Priority* (3) has to be specified. The type *(S147009, SUP147001, "Prescription Dose")* is not available in this dialog, hence, it is specified in *CPrescriptionDefinition*Dlg (fig. A.18).

CAnnotationDlg In case of any missing prescription relevant information this dialog enables the user to catch up on this. Depending on the selected annotation type the corresponding fields are enabled to enter the desired values. For *TEXT* types only one item per type is allowed. *CODE* and *NUMERIC* types do not have such a limitation.

B Second-Generation Output

The following extracts of DICOM dumps shall provide an overview how future second-generation objects may look like. Private attributes are used to represent newly introduced attributes of Supplement 147. These attributes are encoded as presented in 3.4.1.

An important thing to notice is that the *Private Creator Code* definitions in front of sequences using private attributes (→ Supplement 147), are removed. Moreover, the line numbering in the listings does not correspond with the line numbers in a DICOM dump output file and is only used to facilitate an easier navigation within a listing.

B.1 IMRT Step and Shoot RT Plan

B.1.1 RT Segmentation Properties

```
(3147,1331) SQ (Sequence with explicit length #=1)
  (fffe,e000) na (Item with explicit length #=2)
    (0008,1150) UI =RTStructureSetStorage
    (0008,1155) UI [1.3.6.1.4.1.22213.2.4273.115]
  (fffe,e00d) na (ItemDelimitationItem for re-encoding)
```

Listing B.1: RT Segmentation Properties Object - Annotated Volume Definition Instance

```
(3147,1342) SQ (Sequence with explicit length #=15)
  (fffe,e000) na (Item with explicit length #=8)
    (3147,1343) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=3)
        (3006,0084) IS [1]
        (3147,1301) UI
            [1.2.276.0.20.1.0.99.109941754338.5572.1354280251.502462]
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
    (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
    (3147,134d) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=4)
        (3147,1347) SQ (Sequence with explicit length #=1)
          (fffe,e000) na (Item with explicit length #=3)
            (0008,0100) SH [S147050]
            (0008,0102) SH [99SUP147]
            (0008,0104) LO [Target]
```

```
          (fffe,e00d) na (ItemDelimitationItem for re-encoding)
        (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
        (3147,1348) SQ (Sequence with explicit length #=1)
          (fffe,e000) na (Item with explicit length #=3)
            (0008,0100) SH [S147081]
            (0008,0102) SH [99SUP147]
            (0008,0104) LO [Avoidance]
          (fffe,e00d) na (ItemDelimitationItem for re-encoding)
        (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
        (3147,134a) SQ (Sequence with explicit length #=0)
        (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
    (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
    (3147,51e4) ST [Avoidance]
    (3147,51e5) LO [Avoidance]
    (3147,9121) US 1
  (fffe,e00d) na (ItemDelimitationItem for re-encoding)
```

Listing B.2: RT Segmentation Properties Object - Avoidance Volume

```
(3147,1342) SQ (Sequence with explicit length #=15)
  (fffe,e000) na (Item with explicit length #=8)
    (3147,1343) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=3)
        (3006,0084) IS [12]
        (3147,1301) UI
            [1.2.276.0.20.1.0.99.109941754338.5572.1354280252.967462]
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
    (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
    (3147,134d) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=4)
        (3147,1347) SQ (Sequence with explicit length #=1)
          (fffe,e000) na (Item with explicit length #=3)
            (0008,0100) SH [S147050]
            (0008,0102) SH [99SUP147]
            (0008,0104) LO [Target]
          (fffe,e00d) na (ItemDelimitationItem for re-encoding)
        (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
        (3147,1348) SQ (Sequence with explicit length #=1)
          (fffe,e000) na (Item with explicit length #=3)
            (0008,0100) SH [S147078]
            (0008,0102) SH [99SUP147]
            (0008,0104) LO [PTV]
          (fffe,e00d) na (ItemDelimitationItem for re-encoding)
        (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
        (3147,134a) SQ (Sequence with explicit length #=0)
        (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
    (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
    (3147,51e4) ST [PTV 61.2 Gy]
```

```
30      (3147,51e5) LO [PTV 61.2 Gy]
        (3147,9121) US 12
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
```

Listing B.3: RT Segmentation Properties Object - Target Volume Object

B.1.2 RT Physician Intent

```
    (3147,9940) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=14)
        (3147,9118) US 1
        (3147,9902) LO [ROI 12 Presc.]
 5      (3147,9920) SQ (Sequence with explicit length #=3)
          (fffe,e000) na (Item with explicit length #=9)
            (3147,1346) SQ (Sequence with explicit length #=1)
              (fffe,e000) na (Item with explicit length #=4)
                (3147,1301) UI
                    [1.2.276.0.20.1.0.99.109941754338.5572.1354280251.502462]
10              (3147,1302) SQ (Sequence with explicit length #=1)
                  (fffe,e000) na (Item with explicit length #=2)
                    (0008,1150) UI [1.2.840.10008.5.1.4.1.1.481.147.4]
                    (0008,1155) UI
                        [1.2.276.0.20.1.4.99.109941754338.5572.1354280251.448462]

                  (fffe,e00d) na (ItemDelimitationItem for re-encoding)
15              (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
                (3147,1311) CS [NO]
              (fffe,e00d) na (ItemDelimitationItem for re-encoding)
            (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
            (3147,9922) LO [Avoidance]
20          (3147,9928) ST (no value available)
            (3147,9930) CS [OAR]
            (3147,9933) US (no value available)
            (3147,9935) CS [NONE]
            (3147,993a) SQ (Sequence with explicit length #=0)
25          (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
          (fffe,e00d) na (ItemDelimitationItem for re-encoding)
```

Listing B.4: RT Physician Intent Object - OAR Prescription

```
(fffe,e000) na (Item with explicit length #=9)
  (3147,1346) SQ (Sequence with explicit length #=1)
    (fffe,e000) na (Item with explicit length #=4)
      (3147,1301) UI
          [1.2.276.0.20.1.0.99.109941754338.5572.1354280252.967462]
      (3147,1302) SQ (Sequence with explicit length #=1)
        (fffe,e000) na (Item with explicit length #=2)
          (0008,1150) UI [1.2.840.10008.5.1.4.1.1.481.147.4]
          (0008,1155) UI
              [1.2.276.0.20.1.4.99.109941754338.5572.1354280251.448462]

        (fffe,e00d) na (ItemDelimitationItem for re-encoding)
      (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
      (3147,1311) CS [NO]
    (fffe,e00d) na (ItemDelimitationItem for re-encoding)
  (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
  (3147,9922) LO [PTV 61.2 Gy]
  (3147,9928) ST (no value available)
  (3147,9930) CS [TARGET]
  (3147,9933) US (no value available)
  (3147,9935) CS [NONE]
  (3147,993a) SQ (Sequence with explicit length #=0)
  (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
(fffe,e00d) na (ItemDelimitationItem for re-encoding)
```

Listing B.5: RT Physician Intent Object - Target Prescription

B.1.3 RT Radiation Set

```
(3147,9b26) SQ (Sequence with explicit length #=4)
  (fffe,e000) na (Item with explicit length #=2)
    (0008,1150) UI [1.2.840.10008.5.1.4.1.1.481.147.5.2]
    (0008,1155) UI
        [1.2.276.0.20.1.4.99.109941754338.5572.1354280255.488462]
  (fffe,e00d) na (ItemDelimitationItem for re-encoding)
  (fffe,e000) na (Item with explicit length #=2)
    (0008,1150) UI [1.2.840.10008.5.1.4.1.1.481.147.5.2]
    (0008,1155) UI
        [1.2.276.0.20.1.4.99.109941754338.5572.1354280255.875462]
  (fffe,e00d) na (ItemDelimitationItem for re-encoding)
  (fffe,e000) na (Item with explicit length #=2)
    (0008,1150) UI [1.2.840.10008.5.1.4.1.1.481.147.5.2]
    (0008,1155) UI
        [1.2.276.0.20.1.4.99.109941754338.5572.1354280256.341462]
  (fffe,e00d) na (ItemDelimitationItem for re-encoding)
```

Listing B.6: RT Radiation Set Object - Referenced <RT Radiations>

B.1.4 C-Arm Photon Radiation

```
(3147,51c0) SQ (Sequence with explicit length #=1)
  (fffe,e000) na (Item with explicit length #=11)
    (300a,00c6) CS [PHOTON]
    (3147,51c1) SH [6.000000MVPFF]
    (3147,51c2) ST [6.000000MV - PHOTON - Flattening Filter Beam]
    (3147,51c3) LO [1.2.276.0.20.3.25153010009226.3396.1340174449.10.352]
    (3147,51c5) IS [6]
    (3147,51c8) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=3)
        (0008,0100) SH [S147560]
        (0008,0102) SH [99SUP147]
        (0008,0104) LO [Flattening Filter Beam]
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
    (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
    (3147,51c9) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=3)
        (0008,0100) SH [MV]
        (0008,0102) SH [UCUM]
        (0008,0104) LO [Mega-volt]
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
    (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
    (3147,9113) US 1
    (3147,9141) US 1
  (fffe,e00d) na (ItemDelimitationItem for re-encoding)
(fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
```

Listing B.7: C-Arm Photon Radiation Object - Beam Mode Sequence

B.2 Wedge Beam Modification

B.2.1 Motorized Wedge

```
(3147,5062) SQ (Sequence with explicit length #=1)
  (fffe,e000) na (Item with explicit length #=23)
    (0008,0070) LO (no value available)
    (0008,1090) LO (no value available)
    (0018,1000) LO (no value available)
    (0018,1020) LO (no value available)
    (2200,0005) LT (no value available)
    (2200,0006) CS (no value available)
    (300a,00d5) IS [60]
    (300a,00d6) DS (no value available)
    (300a,00d8) DS [0]
    (3147,1324) LO (no value available)
    (3147,1326) LO (no value available)
    (3147,5025) LO [Type: MOTORIZED, Angle: 60, Orientation: 0.000000]
    (3147,5026) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=4)
        (0008,0100) SH [S147442]
        (0008,0102) SH [99SUP147]
        (0008,0103) SH [Sup. 147 Rev. 34]
        (0008,0104) LO [Dynamic Wedge]
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
    (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
    (3147,9112) US 1
    (3147,954b) ST (no value available)
    (3147,954d) LO (no value available)
    (3147,9bb0) UI (no value available)
  (fffe,e00d) na (ItemDelimitationItem for re-encoding)
(fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
```

Listing B.8: C-Arm Photon Radiation Object - Motorized Wedge Definition

```
(3147,5110) CS [PHOTON]
(3147,5113) CS [MU]
(3147,5114) CS [SOURCE]
(3147,51a0) UI [1.2.840.10008.1.147.1]
(3147,51c0) SQ (Sequence with explicit length #=1)
  (fffe,e000) na (Item with explicit length #=11)
    (300a,00c6) CS [PHOTON]
    (3147,51c1) SH [6.000000MVPFF]
    (3147,51c2) ST [6.000000MV - PHOTON - Flattening Filter Beam]
    (3147,51c3) LO [1.2.276.0.20.3.25153010009226.4048.1340116496.6.584]
    (3147,51c5) IS [6]
    (3147,51c8) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=4)
        (0008,0100) SH [S147560]
        (0008,0102) SH [99SUP147]
        (0008,0103) SH [Sup. 147 Rev. 34]
        (0008,0104) LO [Flattening Filter Beam]
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
    (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
    (3147,51c9) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=3)
        (0008,0100) SH [Mega-volt]
        (0008,0102) SH [99SUP147]
        (0008,0103) SH [Sup. 147 Rev. 34]
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
    (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
    (3147,9113) US 1
    (3147,9141) US 1
  (fffe,e00d) na (ItemDelimitationItem for re-encoding)
(fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
```

Listing B.9: C-Arm Photon Radiation Object - Beam Mode Motorized Wedge

B.2.2 Virtual Wedge

```
(3147,5062) SQ (Sequence with explicit length #=1)
  (fffe,e000) na (Item with explicit length #=23)
    (0008,0070) LO (no value available)
    (0008,1090) LO (no value available)
    (0018,1000) LO (no value available)
    (0018,1020) LO (no value available)
    (2200,0005) LT (no value available)
    (2200,0006) CS (no value available)
    (300a,00d5) IS [30]
    (300a,00d6) DS (no value available)
    (300a,00d8) DS [180]
    (3147,1324) LO (no value available)
    (3147,1326) LO (no value available)
    (3147,5025) LO [Type: DYNAMIC, Angle: 30, Orientation: 180.000000]
    (3147,5026) SQ (Sequence with explicit length #=1)
      (fffe,e000) na (Item with explicit length #=4)
        (0008,0100) SH [S147441]
        (0008,0102) SH [99SUP147]
        (0008,0103) SH [Sup. 147 Rev. 34]
        (0008,0104) LO [Motorized Wedge]
      (fffe,e00d) na (ItemDelimitationItem for re-encoding)
    (fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
    (3147,9112) US 1
    (3147,954b) ST (no value available)
    (3147,954d) LO (no value available)
    (3147,9bb0) UI (no value available)
  (fffe,e00d) na (ItemDelimitationItem for re-encoding)
(fffe,e0dd) na (SequenceDelimitationItem for re-encod.)
```

Listing B.10: C-Arm Photon Radiation Object - Virtual Wedge Definition

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Declaration of Academic Honesty

Hereby, I declare that I have composed this work

Analysis of New Concepts and Definitions in

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Based on an Experimental Implementation

completely independently and did not use any other than the specified sources and tools, and quotes have been indicated. This work has neither been previously submitted to another authority nor has it been published yet.

Munich, December 12, 2012

Signature