Digital Imaging and Communications in Medicine (DICOM)

Supplement 188: Multi-energy CT Images

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Table of Contents

Scope and Field of Application

This Supplement extends the CT Image IOD and Enhanced CT Image IOD to support new types of images generated by Multi-energy (ME) CT scanners.

It describes various ME imaging techniques. While different vendors apply different techniques to achieve Multi-energy images, there is large commonality in the generated diagnostic images. It adapts existing attributes of the CT / Enhanced CT IOD to fit ME techniques.

DEFINITIONS

Multi-energy CT Imaging:
Multi-energy CT acquires pixel information which correlates to different X-Ray spectra to enable differentiation, quantification and classification of different types of tissues.

To detect the different X-Ray spectra, Multi-energy (ME) CT imaging uses combinations of different Source(s) and Detector(s) technologies such as current switching X-Ray tubes, spectral detectors, multi-layer detectors, multi-source and detector pairs.

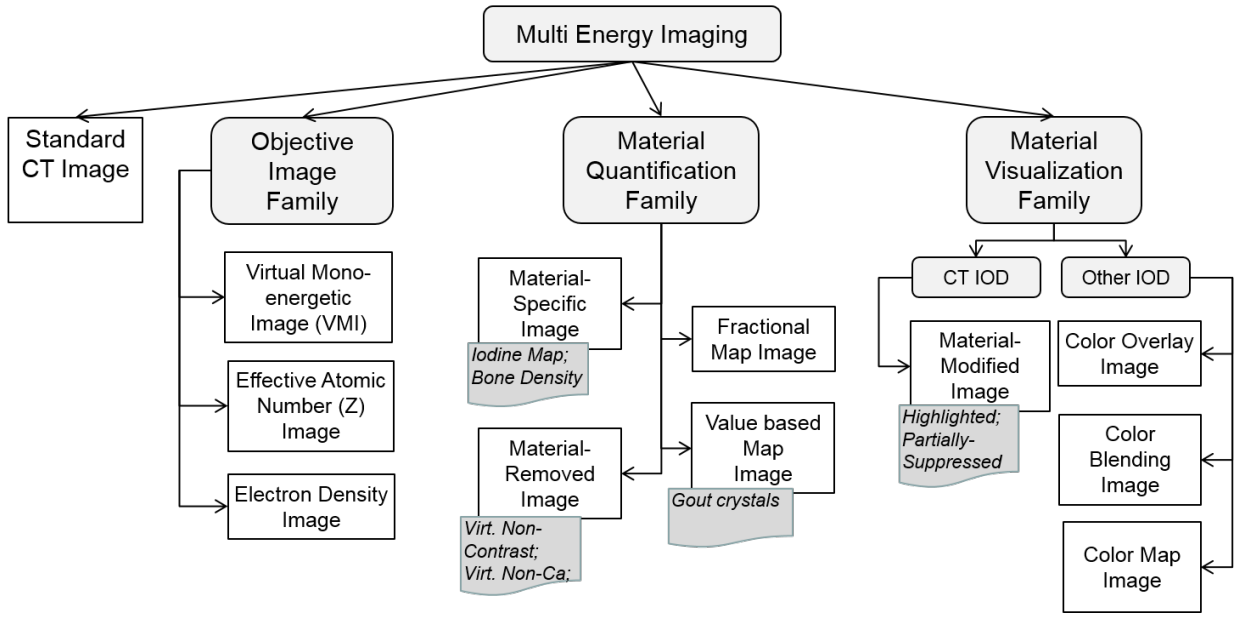
USE CASES

Multi-energy CT data can be reconstructed and processed in different ways to serve a variety of purposes.

- Differentiate materials that look similar on conventional CT images, e.g., to differentiate Iodine and Calcium in vascular structures or to differentiate vascular structures from adjacent bone.
- Quantify base materials to accurately define tissues and organs. The intent is to quantify materials, and to extract regions and organs based on their composition.
- Generate virtual non-contrast images from a contrast-enhanced image rather than having to scan the patient twice.
- Reduce beam hardening artifacts.
- Enhance the effect of contrast such as highlighting Iodine and soft tissue.

CLASSIFICATION OF MULTI-ENERGY IMAGES

The following Multi-energy image Types and families are addressed in this supplement:



Standard CT Image (CT Image IOD, Enhanced CT Image IOD). Images created using ME techniques, for example, in case of the creation of conventional appearing CT images out of two energy spectra or images created with only one of the multiple energies acquired. No new image type definitions are needed but new optional attributes are needed.

Objective Image Family:

- **Virtual Monoenergetic Image.** Each real-world value mapped pixel represents CT Hounsfield units and is analogous to a CT image created by a monoenergetic (of a specific keV value) X-Ray beam. In certain cases, the image impression (quality) will allow a better iodine representation and better metal artifact reduction. Monoenergetic images are sometimes colloquially referred to as monochromatic images.

- **Effective Atomic Number Image**. Each real-world value mapped pixel represents Effective Atomic Number (aka "Effective Z") of that pixel.

- **Electron Density Image**. Each real-world value mapped pixel represents a number of electrons per unit volume (N) in units of 10^{23} /ml or a relative electron density to water (N/N_{Water}). Electron density is used commonly in radiotherapy.

Material Quantification Image Family: These image types characterize the elemental composition of materials in the image. They provide material quantification using a physical scale. Pixel values can be in HU or in equivalent material concentration (e.g., mg/ml). The following image types belong to this family:

- **Material-Specific Image.** Each real-world value mapped pixel value represents a property of a material such as attenuation, concentration or density.

- **Material-Removed Image**. An image where the attenuation contribution of one or more materials has been removed. Each real-world value mapped pixel may be adjusted to represent the attenuation as if the pixel was filled with the remaining materials. For pixels that did not contain any of the removed material(s), the pixel values are unchanged. For example, in virtual-unenhanced (VUE) or virtual-non-contrast (VNC) image the attenuation contribution of the contrast material is removed from each pixel.

- **Fractional Map Image.** Each real-world value mapped pixel represents the fraction of a specific material present in the pixel. Since Fractional Map Images are generated as a set, the sum of the real-world values for all the Fractional Map Images is 1 for each pixel.

- **Value-Based Map Image.** Each real-world value mapped pixel represents a certain value for a specified material (the exact interpretation of the value range has to be defined by the user).

Material Visualization Image Family: These image types allow visualizing material content, usually with colors (color maps, color overlays, blending, etc.)

- **Material-Modified Image.** CT Image where pixel values have been modified to highlight a certain target material (either by partially suppressing the background or by enhancing the target material), or to partially suppress the target material. The image units are still HU, so they may be presented similarly to conventional CT Images. The values of some pixels in the Material-Modified Image are intentionally distorted for better visualization of certain materials (i.e. making tendon more visible). Thus, the image may not be used for quantification, unlike Material-Removed Image which can.

- **Color Image.** Implementations of Material Visualization Images use existing DICOM objects (Blending Presentation State, Secondary Capture Image (used as fallback)).

Changes to NEMA Standards Publication PS 3.3

Digital Imaging and Communications in Medicine (DICOM)

Part 3: Information Object Definitions

<Modify CT Image IOD Module due to Multi-energy Image Format>

A.3.3 CT Image IOD Module Table

Table A.3-1 specifies the Modules of the CT Image IOD.

Table A.3-1. CT Image IOD Modules

IE	Module	Reference	Usage
Image	General Image	C.7.6.1	M
	…		
	CT Image	C.8.2.1	M
	Multi-energy CT Image	**C.8.2.2**	**C - Required if Multi-energy CT Acquisition (0018,9361) is YES.**
	…		

<Add CT Image IOD Content Constraints due to Multi-energy Image Format>

A.3.3.1 CT Image IOD Content Constraints

If Multi-energy CT Acquisition (0018,9361) is YES the following constraints will apply:

- The Contrast/Bolus Module shall be present if contrast was administered even if images are processed to remove contrast information from the pixels, e.g. Virtual Non-Contrast images.
- The Real World Value Mapping Sequence (0040,9096) shall be present in the General Image Module.
- The Defined CID for Measurement Units Code Sequence (0040,08EA) in the Real World Value Mapping Sequence (0040,9096) is CID 301 “Multi-energy Material Units Codes”.

<Modify Enhanced CT Image IOD Module due to Multi-energy Image Format>

A.38.1.3 Enhanced CT Image IOD Module Table

Table A.38-1 specifies the Modules of the Enhanced CT Image IOD.

Table A.38-1. Enhanced CT Image IOD Modules

IE	Module	Reference	Usage
Image	Image Pixel	C.7.6.3	M

IE	Module	Reference	Usage
	…		
	Frame Extraction	C.12.3	C – Required if the SOP Instance was created in response to a Frame-Level retrieve request
	Enhanced Multi-energy CT Acquisition	**C.8.15.4**	**C – Required if Multi-energy CT Acquisition (0018,9361) is YES.**

<Modify Enhanced CT Image IOD Content Constraints due to Multi-energy Image Format>

A.38.1.3.1 Enhanced CT Image IOD Content Constraints

The General Image Module, Overlay Plane Module and VOI LUT Module shall not be used in a Standard Extended SOP Class of the Enhanced CT Image.

Note

1. In order to annotate images, whether during acquisition or subsequently, SOP Instances of the Grayscale Softcopy Presentation State Storage or the Structured Report Storage SOP Classes that reference the image SOP Instance, may be used.

   No standard mechanism is provided for inclusion of annotations within the image SOP Instance itself, and implementers are discouraged from using private extensions to circumvent this restriction.

   Grayscale Softcopy Presentation State Storage Instances that are generated during acquisition may be referenced from the Image SOP Instance by using the Referenced Grayscale Presentation State Sequence in the Enhanced CT Image Module. See Section C.8.15.2.

2. The Curve Module (Retired) was previously include in the list of Modules that shall not be present, but has been retired from DICOM. It is still not permitted to be present. See PS3.3-2004.

3. The Specimen Identification Module was previously included in this IOD but has been retired, and its functionality replaced by the Specimen Module. See PS3.3-2008.
4. **The Enhanced Contrast/Bolus Module will be present even if images are processed to remove contrast information from the pixels, e.g. Virtual Non-Contrast images.**

< Modify Enhanced CT Image Functional Group Macros due to Multi-energy CT Image Format>

A.38.1.4 Enhanced CT Image Functional Group Macros

Table A.38-2 specifies the use of the Functional Group Macros used in the Multi-frame Functional Group Module for the Enhanced CT Image IOD.

…		
Real World Value Mapping	C.7.6.16.2.11	**~~U~~C - Required if Multi-energy CT Acquisition (0018,9361) is YES. May be present otherwise.**

…		
CT Additional X-Ray Source	C.8.15.3.11	C - Required if the image is reconstructed from a system with multiple X-Ray sources
Multi-energy CT Processing	**C.8.15.3.13**	**C - Required if the image pixel data contains the results of Multi-energy material processing.**
Multi-energy CT Characteristics	**C.8.15.3.12**	**U**

The defined CID for Measurement Units Code Sequence (0040,08EA) in the Real World Value Mapping Sequence (0040,9096) is CID 301 "Multi-energy Material Units Codes".

<Modify CT Module due to Multi-energy Image Format>

C.8.2 CT Modules

This Section describes the CT Image Module. This Module contains all Attributes that are specific to CT images.

C.8.2.1 CT Image Module

The table in this Section contains IOD Attributes that describe CT images.

Table C.8-3. CT Image Module Attributes

Attribute Name	Tag	Type	Attribute Description
Image Type	(0008,0008)	1	Image identification characteristics. See Section C.8.2.1.1.1 for specialization.
Multi-energy CT Acquisition	**(0018,9361)**	**3**	**Indicates whether the image is created by means of Multi-energy technique.** **Enumerated Values:** **YES** **NO**
…			
Rescale Intercept	(0028,1052)	1	The value b in relationship between stored values (SV) and the output units. Output units = m*SV+b If Image Type (0008,0008) Value 1 is ORIGINAL and Value 3 is not LOCALIZER**, and Multi-energy CT Acquisition (0018,9361) is either absent or NO**, output units shall be Hounsfield Units (HU).
Rescale Type	(0028,1054)	1C	Specifies the output units of Rescale Slope (0028,1053) and Rescale Intercept (0028,1052). See Section C.11.1.1.2 for Defined Terms and

Attribute Name	Tag	Type	Attribute Description
			further explanation. Required if Rescale Type is not HU (Hounsfield Units)**, or Multi-energy CT Acquisition (0018,9361) is YES.** May be present otherwise.
…			
KVP	(0018,0060)	2	Peak kilo voltage output of the X-Ray generator used. **Shall be empty if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362).**
…			
Scan Options	(0018,0022)	3	Parameters of scanning sequence. **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).**
Data Collection Diameter	(0018,0090)	3	The diameter in mm of the region over which data were collected **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).**
…			
Distance Source to Detector	(0018,1110)	3	Distance in mm from source to detector center. Note This value is traditionally referred to as Source Image Receptor Distance (SID). **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).**
Distance Source to Patient	(0018,1111)	3	Distance in mm from source to isocenter (center of field of view). Note This value is traditionally referred to as Source Object Distance (SOD) **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT**

Attribute Name	Tag	Type	Attribute Description
			Acquisition Sequence (0018,9362).
Exposure Time	(0018,1150)	3	Time of x-ray exposure in msec. If Acquisition Type (0018,9302) equals SPIRAL, the value of this attribute shall be Revolution Time (0018,9305) divided by the Spiral Pitch Factor (0018,9311). See Section C.8.15.3.8.1 and Section C.8.15.3.2.1. **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).**
X-Ray Tube Current	(0018,1151)	3	X-Ray Tube Current in mA. **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).**
Exposure	(0018,1152)	3	The exposure expressed in mAs, for example calculated from Exposure Time and X-Ray Tube Current. **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).**
Exposure in μAs	(0018,1153)	3	The exposure expressed in μAs, for example calculated from Exposure Time and X-Ray Tube Current. **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).**
Filter Type	(0018,1160)	3	Label for the type of filter inserted into the x-ray beam. **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).**
Generator Power	(0018,1170)	3	Power in kW to the x-ray generator. **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not**

Attribute Name	Tag	Type	Attribute Description
			the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).
Focal Spot(s)	(0018,1190)	3	Size of the focal spot in mm. For devices with variable focal spot or multiple focal spots, small dimension followed by large dimension. **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).**
Single Collimation Width	(0018,9306)	3	The width of a single row of acquired data (in mm). Note Adjacent physical detector rows may have been combined to form a single effective acquisition row. **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items of the Multi-energy CT Acquisition Sequence (0018,9362).**
Total Collimation Width	(0018,9307)	3	The width of the total collimation (in mm) over the area of active x-ray detection. Note This will be equal the number of effective detector rows multiplied by single collimation width. **Shall not be present if this Attribute is present in Multi-energy CT Acquisition Sequence (0018,9362) and the value of this Attribute is not the same in all Items CT Acquisition Sequence (0018,9362).**
…			
Isocenter Position	(300A,012C)	3	Isocenter coordinates (x,y,z), in mm. Specifies the location of the machine isocenter in the patient-based coordinate system associated with the Frame of Reference. It allows transformation from the equipment-based coordinate system to the patient-based coordinate system.
Include Table 10-27 "RT Equipment Correlation Macro Attributes Description"			

208

<Modify CT Image Attribute due to Multi-energy CT Image Format>

C.8.2.1.1 CT Image Attribute Descriptions

C.8.2.1.1.1 Image Type

For CT Images, Image Type (0008,0008) is specified to be Type 1.

Defined Terms for Value 3:

AXIAL ~~**identifies**~~ a CT ~~**Axial**~~ **Cross-sectional** Image

LOCALIZER ~~**identifies**~~ a CT Localizer Image

Note

~~**Axial in this context means any c**~~**C**ross-sectional image~~**s, and**~~ include~~**s** transverse, coronal, sagittal and oblique images.

Image Type (0008,0008) Value 4 shall be present if Multi-energy CT Acquisition (0018,9361) has a value of YES.

Defined Terms for Value 4 for Multi-energy CT Images:

VMI	**a Virtual Monoenergetic Image. Each real-world value mapped pixel represents CT Hounsfield units and is analogous to a CT image created by a monoenergetic (of a specific keV value) X-Ray beam.**
MAT_SPECIFIC	**a Material-Specific Image. Each real-world value mapped pixel value represents a property of a material such as attenuation, concentration or density.**
MAT_REMOVED	**An image with the attenuation contribution of one or more materials removed. For pixels that did not contain any of the removed material(s), the pixel values are unchanged.**
MAT_FRACTIONAL	**a Material-Fractional Image. Each real-world value mapped pixel represents the fraction of a voxel occupied by a material.**
EFF_ATOMIC_NUM	**an Effective Atomic Number Image. Each real-world value mapped pixel represents Effective Atomic Number of the materials in the voxel.**
ELECTRON_DENSITY	**an Electron Density Image. Each real-world value mapped pixel represents the number of electrons per unit volume or the electron density relative to water.**
MAT_MODIFIED	**a Material-Modified Image. CT Image where real-world value mapped pixels have been modified to highlight a certain target material (either by partially suppressing the background or by enhancing the target material), or to partially suppress the target material.**
MAT_VALUE_BASED	**a Value-Based Image. CT Image where real-world value mapped pixels represent a certain value for a specified**

material

Note

Multi-energy CT images are not necessarily DERIVED and may be ORIGINAL\PRIMARY.

When an image is created by a generic transformation an implementation-specific Value 4 may be provided.

< Add sections due to Multi-energy CT Image Format>

C.8.2.2 Multi-energy CT Image Module

The table in this Section contains IOD Attributes that describe a Multi-energy CT image.

Table C.8.2.2-1. Multi-energy CT Image Attributes

Attribute Name	Tag	Type	Attribute Description
Multi-energy CT Acquisition Sequence	(0018,9362)	1	The attributes of a Multi-energy CT Image acquisition. One Item shall be included in this Sequence.
>Multi-energy Acquisition Description	(0018,937B)	3	Human readable summary of the Multi-Energy technique applied during the acquisition.
>Include Table C.8.2.2-2 "Multi-energy CT X-Ray Source Macro Attributes"			
>Include Table C.8.2.2-3 "Multi-energy CT X-Ray Detector Macro Attributes"			
>Include Table C.8.2.2-4 "Multi-energy CT Path Macro Attributes"			
>Include Table C.8-124. "CT Exposure Macro Attributes"			
>Include Table C.8-125. "CT X-Ray Details Sequence Macro Attributes"			
>Include Table C.8-119. "CT Acquisition Details Macro Attributes"			
>Include Table C.8-122. "CT Geometry Macro Attributes"			
Multi-energy CT Processing Sequence	(0018,9363)	3	How the acquired Multi-energy data was processed to generate this image. Only a single Item is permitted in this Sequence.
>Include Table C.8.15.3.13-1 "Multi-energy CT Processing Macro Attributes"			

Attribute Name	Tag	Type	Attribute Description
Multi-energy CT Characteristics Sequence	(0018,9364)	1C	Multi-energy characteristics of the generated image. Required if Image Type (0008,0008) Value 4 is VMI. May be present otherwise. Only a single Item shall be included in this Sequence.
>Include Table C.8.15.3.12-1 "Multi-energy CT Characteristics Macro Attributes"			

232 **C.8.2.2.1 Multi-energy CT X-Ray Source Macro**

Attributes for the CT X-Ray Source(s).

234 **Table C.8.2.2-2. Multi-energy CT X-Ray Source Macro Attributes**

Attribute Name	Tag	Type	Attribute Description
Multi-energy CT X-Ray Source Sequence	(0018,9365)	1	X-Ray Source (see section C.8.2.2.1.1) information. One or more Items shall be included in this Sequence.
>X-Ray Source Index	(0018,9366)	1	Identification number of this item in the Multi-energy CT X-Ray Source Sequence. The number shall be 1 for the first Item and increase by 1 for each subsequent Item.
>X-Ray Source ID	(0018,9367)	1	Identifier of the physical X-Ray source. This might be the serial number. The X-Ray Source ID (0018,9367) will have the same value for different values of X-Ray Source Index (0018,9366) if a single source generates different nominal energies.
>Multi-energy Source Technique	(0018,9368)	1	Technique used to acquire Multi-energy data. Defined Terms: **SWITCHING_SOURCE** a physical X-Ray source (tube) uses beam mode switching **CONSTANT_SOURCE** a physical X-Ray source (tube) uses a beam with constant characteristics
>Source Start Date Time	(0018,9369)	1	The date and time this X-Ray source (see section C.8.2.2.1.1) was first used in this Multi-energy acquisition.
>Source End Date Time	(0018,936A)	1	The date and time this X-Ray source (see section C.8.2.2.1.1) was last used in this Multi-

Attribute Name	Tag	Type	Attribute Description
			energy acquisition.
>Switching Phase Number	(0018,936B)	1C	A number, unique within the sequence, to identify the switching phase. Required if Multi-energy Source Technique (0018,9368) is “SWITCHING_SOURCE”.
>Switching Phase Nominal Duration	(0018,936C)	3	Duration, in microseconds, that the energy is nominally in the target KV for this switching phase. I.e. the Switching Phase Nominal Duration does not include the Switching Phase Transition Duration (0018,936D). The target KV is the value of KVP (0018,0060) for the item in the CT X-Ray Details Sequence (0018,9325) that identifies the Multi-energy CT Path Index (0018,937A) that corresponds to this X-Ray Source. Note Applicable if Multi-energy Source Technique (0018,9368) is “SWITCHING_SOURCE”.
>Switching Phase Transition Duration	(0018,936D)	3	Duration, in microseconds, that the energy has left the target KV for this switching phase, but has not yet reached the target KV for the next phase. The target KV is the value of KVP (0018,0060) for the item in the CT X-Ray Details Sequence (0018,9325) that identifies the Multi-energy CT Path Index (0018,937A) that corresponds to this X-Ray Source. Note Applicable if Multi-energy Source Technique (0018,9368) is “SWITCHING_SOURCE”.
>Generator Power	(0018,1170)	3	Power in kW going into the X-Ray generator.

C.8.2.2.1.1 Multi-energy X-Ray Source Description

Each item in the Multi-energy CT X-Ray Source Sequence (0018,9365) might describe either a constant source, a constant source with energy selective filter or one output corresponding to a specific energy of a KV switching source. The attributes will refer to a source, meaning one item in the Multi-energy CT X-Ray Source Sequence (0018,9365). The attributes use the phrase “physical X-Ray Source” when it is necessary to refer to the actual device (tube) rather than the current item.

C.8.2.2.2 Multi-energy CT X-Ray Detector Macro

Attributes for the CT X-Ray Detector(s).

Table C.8.2.2-3. Multi-energy CT X-Ray Detector Macro Attributes

Attribute Name	Tag	Type	Attribute Description

Attribute Name	Tag	Type	Attribute Description
Multi-energy CT X-Ray Detector Sequence	(0018,936F)	1	X-Ray Detector (see section C.8.2.2.2.1) information. One or more Items shall be included in this Sequence.
>X-Ray Detector Index	(0018,9370)	1	Identification number of this item in the Multi-energy CT X-Ray Detector Sequence. The number shall be 1 for the first Item and increase by 1 for each subsequent Item.
>X-Ray Detector ID	(0018,9371)	1	Identifier of the physical X-Ray detector. This might be the serial number. When a single detector discriminates different energies, the X-Ray Detector ID (0018,9371) will have the same value in different Items of Multi-energy CT X-Ray Detector Sequence (0018,936F).
>Multi-energy Detector Type	(0018,9372)	1	Technology used to detect multiple energies. Defined Terms: **INTEGRATING –** physical detector integrates the full X-Ray spectrum. **MULTILAYER –** physical detector layers absorb different parts of the X-Ray spectrum **PHOTON_COUNTING –** physical detector counts photons with energy discrimination capability
>X-Ray Detector Label	(0018,9373)	3	Label of this item in the Multi-energy CT X-Ray Detector Sequence. Note The label might be High, Low or some nominal bin energy.
>Nominal Max Energy	(0018,9374)	1C	Nominal maximum energy in keV of photons that are integrated/counted by the detector (see section C.8.2.2.2.1). Due to energy resolution limits of the detector, some photons above the nominal maximum may be counted. Required if Multi-energy Detector Type (0018,9372) is PHOTON_COUNTING. May be present otherwise.
>Nominal Min Energy	(0018,9375)	1C	Nominal minimum energy in keV of photons that are integrated/counted by the detector (see section C.8.2.2.2.1). Due to energy resolution limits of the detector, some photons below the nominal minimum may be counted. Required if Multi-energy Detector Type (0018,9372) is PHOTON_COUNTING. May be present otherwise.

>Effective Bin Energy	(0018,936E)	3	Energy of the heterogeneous (polychromatic) photon beam represented by this detector (see section C.8.2.2.2.1) calculated as if it were monochromatic. Note E.g. this can be calculated based on the beam spectrum or derived from the attenuation of phantom measurement.

C.8.2.2.2.1 Multi-energy X-Ray Detector Description

Each item in the Multi-energy CT X-Ray Detector Sequence (0018,936F) might describe either an integrating detector or one output corresponding to a specific spectrum of a physical detector like:

- One layer of a multi-layer detector
- One energy bin of a photon counting detector
- One energy threshold of a photon counting detector

The sequence attribute descriptions will refer to a detector, meaning one item in the Multi-energy CT X-Ray Detector Sequence (0018,936F). The attributes use the phrase “physical detector” when it is necessary to refer to the actual device rather than the current item.

C.8.2.2.3 Multi-energy CT Path Macro

A Multi-energy CT Path is an X-Ray source paired with a corresponding X-Ray detector for a particular energy level.

Table C.8.2.2-4. Multi-energy CT Path Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Multi-energy CT Path Sequence	(0018,9379)	1	Describes the paths corresponding to each energy level of a Multi-energy acquisition. Each path consists of a source (see section C.8.2.2.1.1) and a detector (see section C.8.2.2.2.1). Two or more Items shall be included in this Sequence. See also C.8.2.2.1 Multi-energy CT X-Ray Source Macro and C.8.2.2.2 Multi-energy CT X-Ray Detector Macro.
>Multi-energy CT Path Index	(0018,937A)	1	Identification number of the element in the Multi-energy CT Path Sequence. The number shall be 1 for the first Item and increase by 1 for each subsequent Item.
>Referenced X-Ray Source Index	(0018,9377)	1	References the X-Ray Source Index (0018,9366) in the Multi-energy CT X-Ray Source Sequence (0018,9365) in this path.
>Referenced X-Ray Detector Index	(0018,9376)	1	References the X-Ray Detector Index (0018,9370) in the Multi-energy CT X-Ray

Attribute Name	Tag	Type	Attribute Description
			Detector Sequence (0018,936F) in this path.

<Modify Enhanced CT Image due to Multi-energy Image Format>

C.8.15.2 Enhanced CT Image Module

This section describes the Enhanced CT Image Module. Table C.8-114 specifies the attributes of the Enhanced CT Image Module.

Table C.8-114. Enhanced CT Image Module Attributes

Attribute Name	Tag	Type	Attribute Description
Image Type	(0008,0008)	1	Image characteristics. See Section C.8.16.1 and Section C.8.15.2.1.1.
Multi-energy CT Acquisition	**(0018,9361)**	**3**	**Indicates whether the image is created by means of Multi-energy technique.** **Enumerated Values:** **YES** **NO**
…			
Include Table 10-27 "RT Equipment Correlation Macro Attributes Description"			

C.8.15.3.3 CT Acquisition Details Macro

Table C.8-119 specifies the attributes of the CT Acquisition Details Functional Group Macro.

Table C.8-119. CT Acquisition Details Macro Attributes

Attribute Name	Tag	Type	Attribute Description
CT Acquisition Details Sequence	(0018,9304)	1	Contains the attributes defining the details of the acquisition. **If Multi-energy CT Acquisition (0018,9361) is NO or is absent, o~~O~~nly** a single Item shall be included in this Sequence. **If Multi-energy CT Acquisition (0018,9361) is YES, one or more Items shall be included in this Sequence.**
>Referenced Path Index	**(0018,9378)**	**1C**	**References the X-Ray Path Index (0018,937A) in the Multi-energy CT Path Sequence (0018,9379) for this exposure.** **Note** **This attribute may contain multiple values if this item describes multiple paths.** **Required if Multi-energy CT Acquisition**

Attribute Name	Tag	Type	Attribute Description
			(0018,9361) is YES.
>Rotation Direction	(0018,1140)	1C	Direction of rotation of the source about the gantry, as viewed while facing the gantry where the table enters the gantry. Enumerated Values: CW clockwise CC counter clockwise Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL and Acquisition Type (0018,9302) is other than CONSTANT_ANGLE. Otherwise may be present if Frame Type (0008,9007) Value 1 of this frame is DERIVED and Acquisition Type (0018,9302) is other than CONSTANT_ANGLE.
>Revolution Time	(0018,9305)	1C	The time in seconds of a complete revolution of the source around the gantry orbit. This value is independent of the Reconstruction Angle (0018,9319) of the frame. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL and Acquisition Type (0018,9302) is other than CONSTANT_ANGLE. Otherwise may be present if Frame Type (0008,9007) Value 1 of this frame is DERIVED and Acquisition Type (0018,9302) is other than CONSTANT_ANGLE.
>Single Collimation Width	(0018,9306)	1C	The width of a single row of acquired data (in mm). Note Adjacent physical detector rows may have been combined to form a single effective acquisition row. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Total Collimation Width	(0018,9307)	1C	The width of the total collimation (in mm) over the area of active x-ray detection. Note This will be equal to the number of effective detector rows multiplied by single collimation width. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Table Height	(0018,1130)	1C	The distance in mm from the top of the patient table to the center of rotation of the source (i.e.,

Attribute Name	Tag	Type	Attribute Description
			the data collection center or isocenter). The distance is positive when the table is below the data collection center. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Gantry/Detector Tilt	(0018,1120)	1C	Nominal angle of tilt in degrees of the scanning gantry. Not intended for mathematical computations. Zero degrees means the gantry is not tilted, negative degrees are when the top of the gantry is tilted away from where the table enters the gantry. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Data Collection Diameter	(0018,0090)	1C	The diameter in mm of the region over which data were collected. See Section C.8.15.3.6.1. Note In the case of an Acquisition Type (0018,9302) of CONSTANT_ANGLE, the diameter is that in a plane normal to the central ray of the diverging X-Ray beam as it passes through the data collection center. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.

< Modify CT Geometry Macro due to Multi-energy CT Image Format>

C.8.15.3.6 CT Geometry Macro

Table C.8-122 specifies the attributes of the CT Geometry Functional Group Macro.

Table C.8-122. CT Geometry Macro Attributes

Attribute Name	Tag	Type	Attribute Description
CT Geometry Sequence	(0018,9312)	1	Contains the attributes defining the CT geometry. **If Multi-energy CT Acquisition (0018,9361) is NO or is absent, o~~O~~**nly a single Item shall be included in this Sequence. **If Multi-energy CT Acquisition (0018,9361) is YES, one or more Items shall be included in this Sequence.**
>Referenced Path Index	**(0018,9378)**	**1C**	**References the Path Index (0018,937A) in the**

Attribute Name	Tag	Type	Attribute Description
			Multi-energy CT Path Sequence (0018,9379) for this geometry. **Note:** **This attribute may contain multiple values if this item describes multiple paths.** **Required if Multi-energy CT Acquisition (0018,9361) is YES.**
>Distance Source to Detector	(0018,1110)	1C	Distance in mm from source to detector center. See Section C.8.15.3.6.1. Note This value is traditionally referred to as Source Image Receptor Distance (SID). Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Distance Source to Data Collection Center	(0018,9335)	1C	Distance in mm from source to data collection center. See Section C.8.15.3.6.1. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.

< *Modify CT Exposure Macro due to Multi-energy CT Image Format*>

C.8.15.3.8 CT Exposure Macro

Table C.8-124 specifies the attributes of the CT Exposure Functional Group Macro.

Table C.8-124. CT Exposure Macro Attributes

Attribute Name	**Tag**	**Type**	**Attribute Description**
CT Exposure Sequence	(0018,9321)	1	Contains the attributes defining exposure information **If Multi-energy CT Acquisition (0018,9361) is NO or is absent, o~~O~~**nly a single Item shall be included in this sequence. **If Multi-energy CT Acquisition (0018,9361) is YES, one or more Items shall be included in this Sequence.**
>Referenced X-Ray Source Index	**(0018,9377)**	**1C**	**References the X-Ray Source Index (0018,9366) in the Multi-energy CT X-Ray Source Sequence (0018,9365) for which exposure details are specified here.**

Attribute Name	Tag	Type	Attribute Description
			Note **This attribute may contain multiple values if this item summarizes the total exposure from multiple sources e.g. from multiple switching phases from a switching source.** **Required if Multi-energy CT Acquisition (0018,9361) is YES.**
>Exposure Time in ms	(0018,9328)	1C	Duration of exposure for this frame in milliseconds. If Acquisition Type (0018,9302) equals SPIRAL the duration of the exposure time for this frame shall be Revolution Time (0018,9305) divided by the Spiral Pitch Factor (0018,9311). See Section C.8.15.3.8.1. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL**, or if Image Type (0008,0008) Value 1 is ORIGINAL and Multi-energy CT Acquisition (0018,9361) is YES**. May be present otherwise.
>X-Ray Tube Current in mA	(0018,9330)	1C	Nominal X-Ray tube current in milliamperes. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Exposure in mAs	(0018,9332)	1C	The exposure expressed in milliampere seconds, for example calculated from exposure time and X-Ray tube current. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Exposure Modulation Type	(0018,9323)	1C	A label describing the type of exposure modulation used for the purpose of limiting the dose. Defined Terms: **NONE** Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Estimated Dose Saving	(0018,9324)	2C	A percent value of dose saving due to the use of Exposure Modulation Type (0018,9323). A negative percent value of dose savings reflects an increase of exposure. Required if Frame Type (0008,9007) Value 1 of

Attribute Name	Tag	Type	Attribute Description
			this frame is ORIGINAL and Exposure Modulation Type (0018,9323) is not equal to NONE. Otherwise may be present if Frame Type (0008,9007) Value 1 of this frame is DERIVED and Exposure Modulation Type (0018,9323) is not equal to NONE.
>CTDIvol	(0018,9345)	2C	Computed Tomography Dose Index ($CTDI_{vol}$), in mGy according to IEC 60601-2-44, Ed.2.1 (Clause 29.1.103.4), The Volume $CTDI_{vol}$. It describes the average dose for this frame for the selected CT conditions of operation. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>CTDI Phantom Type Code Sequence	(0018,9346)	3	The type of phantom used for CTDI measurement according to IEC 60601-2-44. Only a single Item is permitted in this Sequence.
>>Include Table 8.8-1 "Code Sequence Macro Attributes"			*Defined CID 4052 "Phantom Devices".*
>Water Equivalent Diameter	(0018,1271)	3	The diameter, in mm, of a cylinder of water having the same X-Ray attenuation as the patient for this reconstructed slice (e.g., as described in [AAPM Report 220]).
>Water Equivalent Diameter Method Code Sequence	(0018,1272)	1C	The method of calculation of Water Equivalent Diameter (0018,1271). Required if Water Equivalent Diameter (0018,1271) is present. Only a single Item is permitted in this Sequence.
>>Include Table 8.8-1 "Code Sequence Macro Attributes"			*Defined CID 10024 "Water Equivalent Diameter Method".*

282 *< Modify CT X-Ray Details Macro due to Multi-energy CT Image Format>*

C.8.15.3.9 CT X-Ray Details Macro

284 Table C.8-125 specifies the attributes of the CT X-Ray Details Functional Group Macro.

Table C.8-125. CT X-Ray Details Sequence Macro Attributes

Attribute Name	Tag	Type	Attribute Description
CT X-Ray Details Sequence	(0018,9325)	1	Contains the attributes defining the x-ray information. **If Multi-energy CT Acquisition (0018,9361) is NO or is absent, o~~O~~**nly a single Item shall be

Attribute Name	Tag	Type	Attribute Description
			included in this Sequence. **If Multi-energy CT Acquisition (0018,9361) is YES, one or more Items shall be included in this Sequence.**
>Referenced Path Index	**(0018,9378)**	**1C**	**References the Multi-energy CT Path Index (0018,937A) in the Multi-energy CT Path Sequence (0018,9379) for these X-Ray details.** **Note:** **This attribute may contain multiple values if this item describes the X-Ray details from multiple paths.** **Required if Multi-energy CT Acquisition (0018,9361) is YES.**
>KVP	(0018,0060)	1C	**Nominal p**~~**P**~~eak kilovoltage output of the x-ray generator used. **If Multi-energy Source Technique (0018,9368) in Multi-energy CT X-Ray Source Sequence (0018,9365) (of the referenced Multi-energy CT Path Index (0018,937A)) is "SWITCHING_SOURCE", this value is the nominal peak value for a switching phase. The switching phase is identified by the value of X-Ray Source Index (0018,9366) in the Multi-energy CT Path Sequence (0018,9379) corresponding to the value of Referenced Path Index (0018,9378) in this Sequence.** **Due to limitations of the generating hardware the actual voltage may not reach the nominal peak value.** Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Focal Spot(s)	(0018,1190)	1C	Used nominal size of the focal spot in mm. The attribute may only have one or two values, for devices with variable focal spot, small dimension followed by large dimension Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Filter Type	(0018,1160)	1C	Type of filter(s) inserted into the X-Ray beam. Defined Terms: **WEDGE** **BUTTERFLY** **MULTIPLE** **FLAT** **SHAPED**

Attribute Name	Tag	Type	Attribute Description
			NONE Note Multiple type of filters can be expressed by a combination, e.g., BUTTERFLY+WEDGE. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Filter Material	(0018,7050)	1C	The X-Ray absorbing material used in the filter. May be multi-valued. Defined Terms: **MOLYBDENUM** **ALUMINUM** **COPPER** **RHODIUM** **NIOBIUM** **EUROPIUM** **LEAD** **MIXED** **TIN** **TUNGSTEN** **BRASS** Note MIXED may be used to indicate a filter type of complex composition for which listing the individual materials would be excessive or undesirable; it is not intended to mean "unknown". Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL and the value of Filter Type (0018,1160) is other than NONE. May be present otherwise.
>Calcium Scoring Mass Factor Patient	(0018,9351)	3	The calibration factor for the calcium mass score. These factors incorporate the effects of KV value of the CT image the patient size. machine specific corrections See Section C.8.2.1.1.7.
>Calcium Scoring Mass Factor Device	(0018,9352)	3	The calibration factors for the calcium mass score of the device. These factors incorporate the effects of KV value of the CT image machine specific corrections This a multi-value attribute, the first value

Attribute Name	Tag	Type	Attribute Description
			specifies the mass factor for a small patient size, the second value for a medium patient size and the third value for a large patient size. See Section C.8.2.1.1.7.
>Energy Weighting Factor	(0018,9353)	1C	**The weighting factor of the data from this Sequence Item.** ~~**The weighting factor of the data from the primary source in a multiple energy composition image. This factor incorporates the effects of the specific X-Ray source and kV value examination specific characteristics.**~~ Required if Frame Type (0008,9007) Value 4 of this frame is ENERGY_PROP_WT May be present otherwise.

286

<Add new macros and modules>

288 **C.8.15.3.12 Multi-energy CT Characteristics Macro**

This macro specifies the attributes for CT Image Characteristics.

290 **Table C.8.15.3.12-1. Multi-energy CT Characteristics Macro Attributes**

Attribute Name	Tag	Type	Attribute Description
Monoenergetic Energy Equivalent	(0018,937C)	1C	Single energy equivalent in keV. Required if Image Type (0008,0008)Value 4 is EQUAL to VMI. May be present otherwise. Note: If the Image Type Value 4 is (MAT_REMOVED, MAT_MODIFIED) and a VMI image was used as the source then this value reflects the keV value of the VMI image.
Derivation Algorithm Sequence	(0022,1612)	3	Software algorithm that performed the derivation.
>Include Table 10-19 "Algorithm Identification Macro Attributes"			
Performed Processing Parameters Sequence	(0074,1212)	3	Parameters used to perform the derivation algorithm. Note Implementers are encouraged to put the Algorithm Parameters here instead of in Algorithm Parameters (0066,0032) in the Algorithm Identification Macro

Attribute Name	Tag	Type	Attribute Description
			One or more items are permitted in this Sequence.
>Include Table 10-2a "Content Item with Modifiers Macro Attributes"			

292 **C.8.15.3.13 Multi-energy CT Processing Macro**

This macro defines the attributes for Multi-energy CT processing.

294 **Table C.8.15.3.13-1. Multi-energy CT Processing Attributes**

Attribute Name	Tag	Type	Attribute Description
Decomposition Method	(0018,937E)	1	Method used to decompose the acquired Multi-energy CT data into basis data. Defined Terms: **PROJECTION_BASED -** the acquired projection data was fully decomposed into basis projection data (i.e. sinograms) **IMAGE_BASED -** the acquired projection data was fully reconstructed into images before being decomposed into basis image data **HYBRID -** the acquired projection data was reconstructed using knowledge in both projection and image space to produce basis image data. Decomposition and image reconstruction may be performed in a one-step approach. Note 1. Basis images and basis projection data are not necessarily instantiated as DICOM instances. 2. There may be additional processing steps (e.g. linear combination of basis data) creating the result image
Decomposition Description	(0018,937F)	3	Description of decomposition method
Decomposition Algorithm Identification Sequence	(0018,9380)	3	Algorithm used for decomposition of the acquired data. One or more Items are permitted in this Sequence.
>Include Table 10-19 "Algorithm Identification Macro Attributes"			

Attribute Name	Tag	Type	Attribute Description
Decomposition Material Sequence	(0018,9381)	3	Basis materials used in the decomposition process. Two or more Items are permitted in this Sequence.
>Material Code Sequence	(0018,937D)	1	Nominal material for Multi-energy CT processing. Only a single Item shall be included in this Sequence.
>>Include Table 8.8-1 "Code Sequence Macro Attributes"			Baseline CID 300 "Multi-energy Relevant Material Codes".
>Material Attenuation Sequence	(0018,9382)	3	Attenuation curve of the material, defined as a set of points. Two or more Items are permitted in this Sequence. Note Attenuation curves for non-standard materials can be generated by NIST http://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html
>>Photon Energy	(0018,9383)	1	Photon energy in keV.
>>X-Ray Mass Attenuation Coefficient	(0018,9384)	1	Attenuation of this material at the specific Photon Energy (0018,9383), normalized to material density.

C.8.15.4 Enhanced Multi-energy CT Acquisition Module

Table C.8.15.4-1 specifies the Attributes that describe the Multi-energy CT Acquisition technique in the Enhanced CT Image.

Table C.8.15.4-1. Enhanced Multi-energy CT Acquisition Module Attributes

Attribute Name	Tag	Type	Attribute Description
Include Table C.8.2.2-2 "Multi-energy CT X-Ray Source Macro Attributes"			See C.8.2.2.1.
Include Table C.8.2.2-3 "Multi-energy CT X-Ray Detector Macro Attributes"			See C.8.2.2.2.
Include Table C.8.2.2-4 "Multi-energy CT Path Macro Attributes"			See C.8.2.2.3.

< Modify C.11.1.1.2 Modality LUT and Rescale Type due to Multi-energy CT Image Format>

C.11.1.1.2 Modality LUT and Rescale Type

Specifies the units of the output of the Modality LUT or rescale operation.

Defined Terms:

OD The number in the LUT represents thousands of optical density. That is, a value of 2140 represents an optical density of 2.140.

HU Hounsfield Units (CT)

US Unspecified

MGML mg/ml

Z_EFF Effective Atomic Number (i.e., Effective-Z)

ED Electron density in 10^{23} electrons/ml

EDW Electron density normalized to water in units of N/Nw where N is number of electrons per unit volume, and Nw is number of electrons in the same unit of water at standard temperature and pressure.

HU_MOD Modified Hounsfield Unit

PCT Percentage (%)

Other values are permitted, but are not defined by the DICOM Standard.

<Add Recommended Rescale Type assignments for Multi-energy CT Image section>

C.11.1.1.2.1 Recommended Rescale Type assignments for Multi-energy CT Image

Multi-energy CT Images can have multiple assignments of Rescale Types to Image Type attributes. These are the recommended assignments for Rescale Type and real-world value mapping attributes.

Table C.11.1.1.2.1-1. Recommended Rescale Type assignments for Multi-energy CT Image

Multi-energy Image Family	Recommended Rescale Type	Image Type Value 4	Intercept	Slope	RWV First & Last Values mapped	RWV Intercept	RWV Slope	RWV LUT Label	RWV Measurement Units
Objective Image Family									
Virtual Monoenergetic Image	HU	VMI	-1024	1	0/4095	-1024	1	VMI	hnsf'U
Effective AN (Z) Image (see note1)	10^-2 Z_EFF	EFF_ATOMIC_NUM	0	1	0/4000	0	0.01	EFF_ATOMIC_NUM	129320

Multi-energy Image Family	Recommended Rescale Type	Image Type Value 4	Intercept	Slope	RWV First & Last Values mapped	RWV Intercept	RWV Slope	RWV LUT Label	RWV Measurement Units
Electron Density Image	10^-2 ED	ELECTRON_DENSITY	0	1	0/4000	0	0.01	ELECTRON_DENSITY	10*23/ml
	10^-3 EDW	ELECTRON_DENSITY	0	1	0/4000	0	0.001	ELECTRON_DENSITY	ratio
Material Quantification Family									
Material-Specific Image	10^-2 MGML	MAT_SPECIFIC	(0) – (-10)	1	0/4000	-3	0.01	MAT_SPECIFIC	mg/cm3
	HU	MAT_SPECIFIC	-1024	1	0/4095	-1024	1	MAT_SPECIFIC	hnsf'U
Material-Removed Image (see note2)	HU	MAT_REMOVED	-1024	1	0/4095	-1024	1	MAT_REMOVED	hnsf'U
	HU_MOD	MAT_REMOVED	-1024	1	0/4095	-1024	1	MAT_REMOVED	129321
Fractional Map Image	10^-1 %	MAT_FRACTIONAL	0	1	0/1000	0	0.1	MAT_FRACTIONAL	%
Value-based Map Image	US	MAT_VALUE_BASED	0	1	0/100	0	1	MAT_VALUE_BASED	US
Material Visualization Family									
Material-Modified Image	HU_MOD	MAT_MODIFIED	-1024	1	0/4095	-1024	1	MAT_MODIFIED	129321

Note 1. This example assumes a scaling of 0.01 for the Effective Atomic Number which would be reasonable for images for which the effective atomic number was not greater than 40 for any pixels.

2. The real-world value mapped pixels in the image may have been adjusted to represent the attenuation as if the pixel was filled with the remaining materials to preserve the relationship between the HU value of the pixel and the materials contained (shown as HU in the first row), or they may have not been adjusted (shown as HU_MOD).

Changes to NEMA Standards Publication PS 3.6

Digital Imaging and Communications in Medicine (DICOM)

Part 6: Data Dictionary

334 ***Add the following rows to Section 6***

Tag	Name	Keyword	VR	VM
(0018,9361)	Multi-energy CT Acquisition	MultienergyCTAcquisition	CS	1
(0018,9362)	Multi-energy CT Acquisition Sequence	MultienergyCTAcquisitionSequence	SQ	1
(0018,9363)	Multi-energy CT Processing Sequence	MultienergyCTProcessingSequence	SQ	1
(0018,9364)	Multi-energy CT Characteristics Sequence	MultienergyCTCharacteristicsSequence	SQ	1
(0018,9365)	Multi-energy CT X-Ray Source Sequence	MultienergyCTXRaySourceSequence	SQ	1
(0018,9366)	X-Ray Source Index	XRaySourceIndex	US	1
(0018,9367)	X-Ray Source ID	XRaySourceID	UC	1
(0018,9368)	Multi-energy Source Technique	MultienergySourceTechnique	CS	1
(0018,9369)	Source Start Date Time	SourceStartDateTime	DT	1
(0018,936A)	Source End Date Time	SourceEndDateTime	DT	1
(0018,936B)	Switching Phase Number	SwitchingPhaseNumber	US	1
(0018,936C)	Switching Phase Nominal Duration	SwitchingPhaseNominalDuration	DS	1
(0018,936D)	Switching Phase Transition Duration	SwitchingPhaseTransitionDuration	DS	1
(0018,936E)	Effective Bin Energy	EffectiveBinEnergy	DS	1
(0018,936F)	Multi-energy CT X-Ray Detector Sequence	MultienergyCTXRayDetectorSequence	SQ	1
(0018,9370)	X-Ray Detector Index	XRayDetectorIndex	US	1
(0018,9371)	X-Ray Detector ID	XRayDetectorID	UC	1
(0018,9372)	Multi-energy Detector Type	MultienergyDetectorType	CS	1
(0018,9373)	X-Ray Detector Label	XRayDetectorLabel	ST	1
(0018,9374)	Nominal Max Energy	NominalMaxEnergy	DS	1
(0018,9375)	Nominal Min Energy	NominalMinEnergy	DS	1
(0018,9376)	Referenced X-Ray Detector Index	ReferencedXRayDetectorIndex	US	1-n
(0018,9377)	Referenced X-Ray Source Index	ReferencedXRaySourceIndex	US	1-n
(0018,9378)	Referenced Path Index	ReferencedPathIndex	US	1-n

Tag	Name	Keyword	VR	VM
(0018,9379)	Multi-energy CT Path Sequence	MultienergyCTPathSequence	SQ	1
(0018,937A)	Multi-energy CT Path Index	MultienergyCTPathIndex	US	1
(0018,937B)	Multi-energy Acquisition Description	MultienergyAcquisitionDescription	UT	1
(0018,937C)	Monoenergetic Energy Equivalent	MonoenergeticEnergyEquivalent	FD	1
(0018,937D)	Material Code Sequence	MaterialCodeSequence	SQ	1
(0018,937E)	Decomposition Method	DecompositionMethod	CS	1
(0018,937F)	Decomposition Description	DecompositionDescription	UT	1
(0018,9380)	Decomposition Algorithm Identification Sequence	DecompositionAlgorithmIdentificationSequence	SQ	1
(0018,9381)	Decomposition Material Sequence	DecompositionMaterialSequence	SQ	1
(0018,9382)	Material Attenuation Sequence	MaterialAttenuationSequence	SQ	1
(0018,9383)	Photon Energy	PhotonEnergy	DS	1
(0018,9384)	X-Ray Mass Attenuation Coefficient	XRayMassAttenuationCoefficient	DS	1

Changes to NEMA Standards Publication PS 3.16

Digital Imaging and Communications in Medicine (DICOM)

Part 16: Content Mapping Resource

CID 300 Multi-energy Relevant Materials

Concepts for materials relevant to Multi-energy Imaging.

Table CID 300
Multi-energy Relevant Materials
Type : Extensible Version : 20181109

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-CT Concept ID
SRT	C-11400	Iodine	44588005
SRT	C-17800	Gadolinium	58281002
SRT	C-12200	Barium	39290007
SRT	C-10120	Water	11713004
SRT	C-130F9	Iron	105840005
SRT	T-D008A	Fat	256674009
SRT	C-14300	Calcium	5540006
SRT	F-61470	Uric Acid	1710001
SRT	C-14314	Calcium Hydroxyapatite	256579008
SRT	C-13700	Silver	41967008
SRT	C-14600	Gold	2309006
SRT	C-16600	Titanium	1166006
SRT	C-15600	Tantalum	45215009
SRT	C-14700	Hafnium	50672002
SRT	T-D048E	Renal stone	386103008
SRT	C-10940	Silicon	51420009
SRT	C-22301	Silicone	13652007
SRT	C-15300	Platinum	84847000
SRT	C-16200	Yttrium	63754004
SRT	C-12500	Bismuth	23172004
SRT	F-6121C	Cobalt-chromium alloy	256526003
SRT	F-61165	Nickel cobalt chromium	261249004
SRT	C-12013	Aluminum Oxide	83881004

CID 301 Multi-energy Material Units

Codes for material units used in Multi-energy Images.

Table CID 301
Multi-energy Material Units
Type : Extensible Version : 20181109

Coding Scheme Designator	Code Value	Code Meaning
UCUM	mg/cm3	mg/cm^3
UCUM	[hnsf'U]	Hounsfield Unit
UCUM	10*23/ml	Electron Density
DCM	129320	Effective Atomic Number
DCM	129321	Modified Hounsfield Unit
UCUM	mg/ml	mg/ml
UCUM	%	Percent

< Modify Table D-1. DICOM Controlled Terminology Definitions and add new Codes to existing Table due to Multi-energy CT Image Format>

Code Value	Code Meaning	Definition	Notes
129320	Effective Atomic Number	The average atomic number for a compound or mixture of materials. There are a variety of methods for estimating this value for a given compound.	
129321	Modified Hounsfield Unit	Modified pixel values within the Hounsfield Unit Value range.	
129322	Value-based Image	Each real-world value mapped pixel represents a certain value for a specified material (the exact interpretation of the value range has to be defined by the user).	
129323	Material Specific Image	Each real-world value mapped pixel value represents a property the attenuation of a material such as attenuation, concentration or density.	
129324	Material Removed Image	Image with the attenuation contribution of one or more materials removed. For pixels that did not contain any of the removed material(s), the pixel values are unchanged.	
129325	Material Highlighted	Image where pixel values have been	

	Image	modified to highlight a certain target material by partially suppressing the background and/or by enhancing the modified material.	
129326	Material Suppressed Image	Image where pixel values have been modified to partially suppress the modified material (opposite to Material Highlighted image).	
129327	Material Recalculated Image	Image where pixels are recalculated by a vendor-specific method.	
129328	Volume Occupancy Image	Each real-world value mapped pixel represents a fraction, by volume, occupied by the material.	
129329	Mass Occupancy Image	Each real-world value mapped pixel represents a fraction, by mass, occupied by the material.	

Changes to NEMA Standards Publication PS 3.17

Digital Imaging and Communications in Medicine (DICOM)

Part 17: Explanatory Information

JJJJ. Multi-energy CT Imaging (Informative)

JJJJ.1 DOMAIN OF APPLICATION

Multi-energy CT acquires pixel information which correlates to different X-Ray spectra to enable differentiation, quantification and classification of different types of tissues.

To detect the different X-Ray spectra, Multi-energy (ME) CT imaging uses combinations of different Source(s) and Detector(s) technologies such as current switching X-Ray tubes, spectral detectors, multi-layer detectors, multi-source and detector pairs.

JJJJ.2 USE CASES

Multi-energy CT data can be reconstructed and processed in different ways to serve a variety of purposes.

- Differentiate materials that look similar on conventional CT images, e.g., to differentiate Iodine and Calcium in vascular structures or to differentiate vascular structures from adjacent bone.
- Quantify base materials to accurately define tissues and organs. The intent is to quantify materials, and to extract regions and organs based on their composition.
- Generate virtual non-contrast images from a contrast-enhanced image rather than having to scan the patient twice.
- Reduce beam hardening artifacts.
- Enhance the effect of contrast such as highlighting Iodine and soft tissue.

JJJJ.3 CLASSIFICATION OF MULTI-ENERGY IMAGES

The following Multi-energy image types and families are addressed in this supplement:

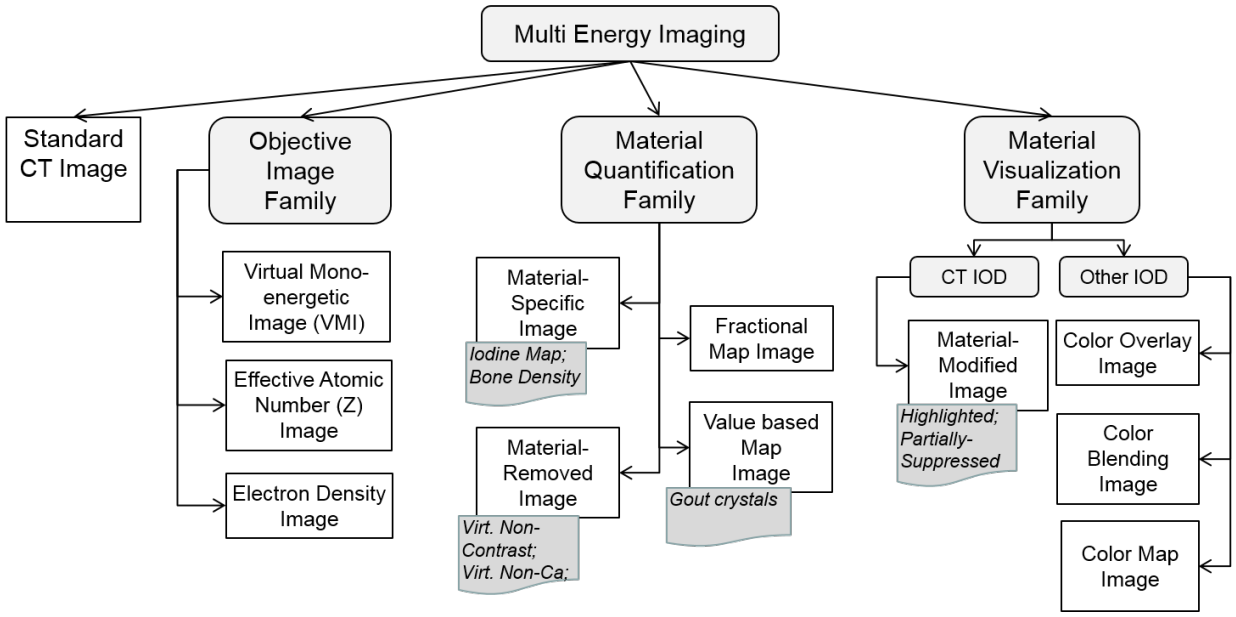


Figure JJJJ.3-1 Classification of Multi-energy Images

Standard CT Image (CT Image IOD, Enhanced CT Image IOD). Images created using ME techniques, for example, in case of the creation of conventional appearing CT images out of two energy spectra or images created with only one of the multiple energies acquired. No new image type definitions are needed but new optional attributes are needed.

Objective Image Family:

- **Virtual Monoenergetic Image.** Each real-world value mapped pixel represents CT Hounsfield units and is analogous to a CT image created by a monoenergetic (of a specific keV value) X-Ray beam. In certain cases, the image impression (quality) will allow a better iodine representation and better metal artifact reduction. Monoenergetic images are sometimes colloquially referred to as monochromatic images.

- **Effective Atomic Number Image**. Each real-world value mapped pixel represents Effective Atomic Number (aka “Effective Z”) of that pixel.

- **Electron Density Image**. Each real-world value mapped pixel represents a number of electrons per unit volume (N) in units of 10^{23} /ml or a relative electron density to water (N/N_{Water}). Electron density is used commonly in radiotherapy.

Material Quantification Image Family: These image types characterize the elemental composition of materials in the image. They provide material quantification using a physical scale. Pixel values can be in HU or in equivalent material concentration (e.g., mg/ml). The following image types belong to this family:

- **Material-Specific Image.** Each real-world value mapped pixel value represents a property of a material such as attenuation, concentration or density.

- **Material-Removed Image**. An image where the attenuation contribution of one or more materials has been removed. Each real-world value mapped pixel may be adjusted to represent the attenuation as if the pixel was filled with the remaining materials. For pixels that did not contain any of the removed material(s), the pixel values are unchanged. For example, in virtual-unenhanced (VUE) or virtual-non-contrast (VNC) image the attenuation contribution of the contrast material is removed from each pixel.

- **Fractional Map Image.** Each real-world value mapped pixel represents the fraction of a specific material present in the pixel. Since Fractional Map Images are generated as a set, the sum of the real-world values for all the Fractional Map Images is 1 for each pixel.

- **Value-Based Map Image.** Each real-world value mapped pixel represents a certain value for a specified material (the exact interpretation of the value range has to be defined by the user).

Material Visualization Image Family: These image types allow visualizing material content, usually with colors (color maps, color overlays, blending, etc.)

- **Material-Modified Image.** CT Image where pixel values have been modified to highlight a certain target material (either by partially suppressing the background or by enhancing the target material), or to partially suppress the target material. The image units are still HU, so they may be presented similarly to conventional CT Images. The values of some pixels in the Material-Modified Image are intentionally distorted for better visualization of certain materials (i.e. making tendon more visible). Thus, the image may not be used for quantification, unlike Material-Removed Image which can.

- **Color Image.** Implementations of Material Visualization Images use existing DICOM objects (Blending Presentation State, Secondary Capture Image (used as fallback)).

JJJJ.4 PRESENTATION OF MULTI-ENERGY IMAGES BY LEGACY DISPLAY SYSTEMS

A legacy, naïve display system can receive a multi-energy (ME) image and may not recognize it as ME-image but rather display the image as a conventional CT image. This may potentially cause clinical misinterpretation, for instance, in the following scenarios:

1. For virtual mono-energetic images (VMI, images similar to those obtained with mono-energetic x-ray beam, in keV), attenuation highly depends on the beam energy (keV), so CT pixel values in VMI images can be very different from those in conventional CT images. Without proper labeling of such images, including the specific keV value used, the reviewer can come to wrong conclusions.

2. HU-based Multi-energy images where CT pixel values have been modified for specific materials (suppressed, highlighted, etc.) look similar to conventional CT images. Without proper labeling of such images, including the identification of the affected materials and the way of modification, the reviewer can come to wrong conclusions.

3. In certain types of Multi-energy images (effective atomic number, electron density, material-specific image containing material concentration), CT pixel values do not represent HU values. Common ROI tools used on such an image will measure and display an average value. Since non-HU values are quite unusual in CT IOD images, there is a significant risk that a common “naïve” display will either omit the units of measurements (leaving user to assume the material or units), or (which is even worse) will display “HU” units instead.

4. In case of Virtual Non-Contrast images, the pixel values are modified (contrast is removed and pixel values may have been corrected for displacement of one material by another material). Since pixels are modified, there is a risk that the modification is incomplete or the replacement is not adequate.

JJJJ.5. EXAMPLES OF IMPLEMENTATION

These are examples how the attributes can be set for each image family (JJJJ.3 Classification of Multi-energy images).

The structure and content of a Multi-energy CT instance also depends on the architecture of the acquisition device, e.g. multiple sources and multiple detectors vs. switching source and single detector, etc. A variety of architectures will be shown in the following examples, but an example will not be shown for every architecture.

JJJJ.5.1 Examples for Objective Image Family

JJJJ.5.1.1 Example Multiple Physical Sources and Multiple Physical Detectors

This example shows an Effective Atomic Number image acquired on an acquisition device with multiple physical sources and multiple physical detectors.

Table JJJJ.5.1.1-1 CT Image Module Attributes

Attribute Name	Tag	Values
Image Type	(0008,0008)	ORIGINAL\ PRIMARY\ AXIAL\ EFF_ATOMIC_NUM
Multi-energy CT Acquisition	(0018,9361)	YES

Attribute Name	Tag	Values
…		
Rescale Intercept	(0028,1052)	-102.4
Rescale Slope	(0028,1053)	0.1
Rescale Type	(0028,1054)	Z_EFF
…		
KVP	(0018,0060)	{null value because it is described below}
…		
Distance Source to Detector	(0018,1110)	1000
Distance Source to Patient	(0018,1111)	500
Exposure Time	(0018,1150)	1000
Single Collimation Width	(0018,9306)	0.6
Total Collimation Width	(0018,9307)	38,4
…		
Include Table 10-27 "RT Equipment Correlation Macro Attributes Description"		

462 ***Table JJJJ.5.1.1-2.*** **Multi-energy CT Image Attributes**

Attribute Name	Tag	Values
Multi-energy CT Acquisition Sequence	(0018,9362)	
>Multi-energy Acquisition Description	(0018,937B)	Dual Source Dual Energy
>Include Table JJJJ.5.1.1-3 "Multi-energy CT X-Ray Source Macro Attributes"		
>Include Table JJJJ.5.1.1-4 "Multi-energy CT X-Ray Detector Macro Attributes"		
>Include Table JJJJ.5.1.1-5 "Multi-energy CT Path Macro Attributes"		
>Include Table JJJJ.5.1.1-6. "CT Exposure Macro Attributes"		
>Include Table JJJJ.5.1.1-7. "CT X-Ray Details Sequence Macro Attributes"		
>Include Table JJJJ.5.1.1-8. "CT Acquisition Details Macro Attributes"		

Attribute Name	Tag	Values
>Include Table JJJJ.5.1.1-9. "CT Geometry Macro Attributes"		
Multi-energy CT Processing Sequence	(0018,9363)	
>Include Table JJJJ.5.1.1-10 "Multi-energy CT Processing Macro Attributes"		

464 ***Table JJJJ.5.1.1-3.*** **Multi-energy CT X-Ray Source Macro Attributes**

Attribute Name	Tag	Values
Multi-energy CT X-Ray Source Sequence	(0018,9365)	
ITEM 1		
>X-Ray Source Index	(0018,9366)	1
>X-Ray Source ID	(0018,9367)	Tube A
>Multi-energy Source Technique	(0018,9368)	CONSTANT_SOURCE
>Source Start Date Time	(0018,9369)	2018.05.01 13:22:03
>Source End Date Time	(0018,936A)	2018.05.01 13:22:20
>Generator Power	(0018,1170)	100
ITEM 2		
>X-Ray Source Index	(0018,9366)	2
>X-Ray Source ID	(0018,9367)	Tube B
>Multi-energy Source Technique	(0018,9368)	CONSTANT_SOURCE
>Source Start Date Time	(0018,9369)	2018.05.01 13:22:03
>Source End Date Time	(0018,936A)	2018.05.01 13:22:20
>Generator Power	(0018,1170)	100

466 ***Table JJJJ.5.1.1-4.*** **Multi-energy CT X-Ray Detector Macro Attributes**

Attribute Name	Tag	Values
Multi-energy CT X-Ray Detector Sequence	(0018,936F)	
ITEM 1		
>X-Ray Detector Index	(0018,9370)	1
>X-Ray Detector ID	(0018,9371)	Detector A
>Multi-energy Detector	(0018,9372)	INTEGRATING

Attribute Name	Tag	Values
Type		
>X-Ray Detector Label	(0018,9373)	High-Energy
>Nominal Max Energy	(0018,9374)	150
>Nominal Min Energy	(0018,9375)	35
>Effective Bin Energy	(0018,936E)	90
ITEM 2		
>X-Ray Detector Index	(0018,9370)	2
>X-Ray Detector ID	(0018,9371)	Detector B
>Multi-energy Detector Type	(0018,9372)	INTEGRATING
>X-Ray Detector Label	(0018,9373)	Low-Energy
>Nominal Max Energy	(0018,9374)	100
>Nominal Min Energy	(0018,9375)	35
>Effective Bin Energy	(0018,936E)	60

468 ***Table JJJJ.5.1.1-5*. Multi-energy CT Path Macro Attributes**

Attribute Name	Tag	Values
Multi-energy CT Path Sequence	(0018,9379)	
ITEM 1		
>Multi-energy CT Path Index	(0018,937A)	1
>X-Ray Source Index	(0018,9366)	1
>X-Ray Detector Index	(0018,9370)	1
ITEM 2		
>Multi-energy CT Path Index	(0018,937A)	2
>X-Ray Source Index	(0018,9366)	2
>X-Ray Detector Index	(0018,9370)	2

470 ***Table JJJJ.5.1.1-6. CT Exposure Macro Attributes***

Attribute Name	Tag	Values
CT Exposure Sequence	(0018,9321)	
ITEM 1		

Attribute Name	Tag	Values
>Referenced X-Ray Source Index	(0018,9377)	1
>Exposure Time in ms	(0018,9328)	1000
>X-Ray Tube Current in mA	(0018,9330)	500
>Exposure in mAs	(0018,9332)	500
>Exposure Modulation Type	(0018,9323)	CD4D
>CTDIvol	(0018,9345)	5
ITEM 2		
>Referenced X-Ray Source Index	(0018,9377)	2
>Exposure Time in ms	(0018,9328)	1000
>X-Ray Tube Current in mA	(0018,9330)	250
>Exposure in mAs	(0018,9332)	250
>Exposure Modulation Type	(0018,9323)	CD4D
>CTDIvol	(0018,9345)	5

472

Table JJJJ.5.1.1-7. CT X-Ray Details Sequence Macro Attributes

Attribute Name	Tag	Values
CT X-Ray Details Sequence	(0018,9325)	
ITEM 1		
>Referenced Path Index	(0018,9378)	1
>KVP	(0018,0060)	150
>Focal Spot(s)	(0018,1190)	1.2
>Filter Type	(0018,1160)	WEDGE2
>Filter Material	(0018,7050)	MIXED

Attribute Name	Tag	Values
ITEM 2		
>Referenced Path Index	(0018,9378)	2
>KVP	(0018,0060)	100
>Focal Spot(s)	(0018,1190)	1.2
>Filter Type	(0018,1160)	WEDGE2+FLAT
>Filter Material	(0018,7050)	TIN

474

Table JJJJ.5.1.1-8. CT Acquisition Details Macro Attributes

Attribute Name	Tag	Values
CT Acquisition Details Sequence	(0018,9304)	
ITEM 1		
>Referenced Path Index	(0018,9378)	1
>Rotation Direction	(0018,1140)	CW
>Revolution Time	(0018,9305)	0.5
>Single Collimation Width	(0018,9306)	0.6
>Total Collimation Width	(0018,9307)	38.4
>Table Height	(0018,1130)	88.5
>Gantry/Detector Tilt	(0018,1120)	0
>Data Collection Diameter	(0018,0090)	500
ITEM 2		
>Referenced Path Index	(0018,9378)	2
>Rotation Direction	(0018,1140)	CW
>Revolution Time	(0018,9305)	0.5
>Single Collimation Width	(0018,9306)	0.6
>Total Collimation Width	(0018,9307)	38.4
>Table Height	(0018,1130)	88.5
>Gantry/Detector Tilt	(0018,1120)	0
>Data Collection Diameter	(0018,0090)	350

476

Table JJJJ.5.1.1-9. CT Geometry Macro Attributes

Attribute Name	Tag	Values
CT Geometry Sequence	(0018,9312)	
ITEM 1		
>Referenced Path Index	(0018,9378)	1\2
>Distance Source to Detector	(0018,1110)	1000
>Distance Source to Data Collection Center	(0018,9335)	500

478

480 ***Table JJJJ.5.1.1-10*. Multi-energy CT Processing Attributes**

Attribute Name	Tag	Values
Decomposition Method	(0018,937E)	HYBRID
Decomposition Description	(0018,937F)	iBHC + MAT DECOMP

482 **JJJJ.5.1.2 Example Single Source Multi-layer Detector**

This example shows a type Effective Atomic Number image acquired on an acquisition device with a single
484 source and multi-layer detector.

Table JJJJ.5.1.2-1 CT Image Module Attributes

Attribute Name	Tag	Values
Image Type	(0008,0008)	ORIGINAL\ PRIMARY\ AXIAL\ EFF_ATOMIC_NUM
Multi-energy CT Acquisition	(0018,9361)	YES
…		
Rescale Intercept	(0028,1052)	0
Rescale Slope	(0028,1053)	1.3
Rescale Type	(0028,1054)	10^-2 Z_EFF
…		
KVP	(0018,0060)	{null value because it is described below}

Attribute Name	Tag	Values
…		
Scan Options	(0018,0022)	AXIAL
Data Collection Diameter	(0018,0090)	500
…		
Distance Source to Detector	(0018,1110)	1040
Distance Source to Patient	(0018,1111)	570
Exposure Time	(0018,1150)	750
X-Ray Tube Current	(0018,1151)	440
Exposure	(0018,1152)	330
Single Collimation Width	(0018,9306)	0.625
Total Collimation Width	(0018,9307)	20.0
…		
Include Table 10-27 "RT Equipment Correlation Macro Attributes Description"		

486

***Table JJJJ.5.1.2-2*. Multi-energy CT Image Attributes**

Attribute Name	Tag	Values
Multi-energy CT Acquisition Sequence	(0018,9362)	
>Multi-energy Acquisition Description	(0018,937B)	
>Include Table JJJJ.5.1.2-3 "Multi-energy CT X-Ray Source Macro Attributes"		
>Include Table JJJJ.5.1.2-4 "Multi-energy CT X-Ray Detector Macro Attributes"		
>Include Table JJJJ.5.1.2-5 "Multi-energy CT Path Macro Attributes"		
>Include Table JJJJ.5.1.2-6. "CT Exposure Macro Attributes"		

Attribute Name	Tag	Values
>Include Table JJJJ.5.1.2-7. "CT X-Ray Details Sequence Macro Attributes"		
>Include Table JJJJ.5.1.2-8. "CT Acquisition Details Macro Attributes"		
>Include Table JJJJ.5.1.2-9. "CT Geometry Macro Attributes"		
Multi-energy CT Processing Sequence	(0018,9363)	
>Include Table JJJJ.5.1.2-10 "Multi-energy CT Processing Macro Attributes"		

488

Table JJJJ.5.1.2-3. **Multi-energy CT X-Ray Source Macro Attributes**

Attribute Name	Tag	Values
Multi-energy CT X-Ray Source Sequence	(0018,9365)	
ITEM 1		
>X-Ray Source Index	(0018,9366)	1
>X-Ray Source ID	(0018,9367)	Tube A
>Multi-energy Source Technique	(0018,9368)	CONSTANT_SOURCE
>Source Start Date Time	(0018,9369)	2018.05.01 13:22:03
>Source End Date Time	(0018,936A)	2018.05.01 13:22:20

490

Table JJJJ.5.1.2-4. **Multi-energy CT X-Ray Detector Macro Attributes**

Attribute Name	Tag	Values
Multi-energy CT X-Ray Detector Sequence	(0018,936F)	
ITEM 1		
>X-Ray Detector Index	(0018,9370)	1
>X-Ray Detector ID	(0018,9371)	Detector A
>Multi-energy Detector Type	(0018,9372)	MULTILAYER
>X-Ray Detector Label	(0018,9373)	High-Energy
ITEM 2		
>X-Ray Detector Index	(0018,9370)	2

Attribute Name	Tag	Values
>X-Ray Detector ID	(0018,9371)	Detector A
>Multi-energy Detector Type	(0018,9372)	MULTILAYER
>X-Ray Detector Label	(0018,9373)	Low-Energy

492

***Table JJJJ.5.1.2-5*. Multi-energy CT Path Macro Attributes**

Attribute Name	Tag	Values
Multi-energy CT Path Sequence	(0018,9379)	
ITEM 1		
>Multi-energy CT Path Index	(0018,937A)	1
>X-Ray Source Index	(0018,9366)	1
>X-Ray Detector Index	(0018,9370)	1
ITEM 2		
>Multi-energy CT Path Index	(0018,937A)	2
>X-Ray Source Index	(0018,9366)	1
>X-Ray Detector Index	(0018,9370)	2

494

Table JJJJ.5.1.2-6. CT Exposure Macro Attributes

Attribute Name	Tag	Values
CT Exposure Sequence	(0018,9321)	
ITEM 1		
>Referenced X-Ray Source Index	(0018,9377)	1
>Exposure Time in ms	(0018,9328)	750
>X-Ray Tube Current in mA	(0018,9330)	440
>Exposure in mAs	(0018,9332)	330
>Exposure Modulation Type	(0018,9323)	NONE
>CTDIvol	(0018,9345)	34.9

496

498 ***Table JJJJ.5.1.2-7. CT X-Ray Details Sequence Macro Attributes***

Attribute Name	Tag	Values
CT X-Ray Details Sequence	(0018,9325)	
ITEM 1		
>Referenced Path Index	(0018,9378)	1\2
>KVP	(0018,0060)	120
>Focal Spot(s)	(0018,1190)	1.4
>Filter Type	(0018,1160)	NONE
>Filter Material	(0018,7050)	

500 ***Table JJJJ.5.1.2-8. CT Acquisition Details Macro Attributes***

Attribute Name	Tag	Values
CT Acquisition Details Sequence	(0018,9304)	
ITEM 1		
>Referenced Path Index	(0018,9378)	1
>Rotation Direction	(0018,1140)	CW
>Revolution Time	(0018,9305)	0.75
>Single Collimation Width	(0018,9306)	0.625
>Total Collimation Width	(0018,9307)	20.0
>Table Height	(0018,1130)	88.5
>Gantry/Detector Tilt	(0018,1120)	0
>Data Collection Diameter	(0018,0090)	500

502 ***Table JJJJ.5.1.2-9. CT Geometry Macro Attributes***

Attribute Name	Tag	Values
CT Geometry Sequence	(0018,9312)	
ITEM 1		
>Referenced Path Index	(0018,9378)	1

Attribute Name	Tag	Values
>Distance Source to Detector	(0018,1110)	1140
>Distance Source to Data Collection Center	(0018,9335)	570

504 ***Table JJJJ.5.1.2-10*. Multi-energy CT Processing Attributes**

Attribute Name	Tag	Values
Decomposition Method	(0018,937E)	PROJECTION_BASED
Decomposition Description	(0018,937F)	Photo-Electric / Compton Scattering Decomposition

506 **JJJJ.5.2 Examples for Material Quantification Image Family:**

JJJJ.5.2.1 Example Switching Source Integrating Detector

508 This example shows a Material Specific image acquired on an acquisition device with single switching sources and integrating detector.

510 **Table JJJJ.5.2.1-1 CT Image Module Attributes**

Attribute Name	Tag	Values
Image Type	(0008,0008)	ORIGINAL\ PRIMARY\ AXIAL\ MAT_SPECIFIC
Multi-energy CT Acquisition	(0018,9361)	YES
…		
Rescale Intercept	(0028,1052)	0
Rescale Slope	(0028,1053)	1
Rescale Type	(0028,1054)	10^-2 MGML
…		
KVP	(0018,0060)	{null value because it is described below}
…		
Single Collimation Width	(0018,9306)	0.625
Total Collimation Width	(0018,9307)	80.0

Attribute Name	Tag	Values
…		
Include Table 10-27 "RT Equipment Correlation Macro Attributes Description"		

512 ***Table JJJJ.5.2.1-2.*** **Multi-energy CT Image Attributes**

Attribute Name	Tag	Values
Multi-energy CT Acquisition Sequence	(0018,9362)	
>Multi-energy Acquisition Description	(0018,937B)	KV Switching Technique
>Include Table JJJJ.5.2.1-3 "Multi-energy CT X-Ray Source Macro Attributes"		
>Include Table JJJJ.5.2.1-4 "Multi-energy CT X-Ray Detector Macro Attributes"		
>Include Table JJJJ.5.2.1-5 "Multi-energy CT Path Macro Attributes"		
>Include Table JJJJ.5.2.1-6. "CT Exposure Macro Attributes"		
>Include Table JJJJ.5.2.1-7. "CT X-Ray Details Sequence Macro Attributes"		
>Include Table JJJJ.5.2.1-8. "CT Acquisition Details Macro Attributes"		
>Include Table JJJJ.5.2.1-9. "CT Geometry Macro Attributes"		
Multi-energy CT Processing Sequence	(0018,9363)	
>Include Table JJJJ.5.2.1-10 "Multi-energy CT Processing Macro Attributes"		

514 ***Table JJJJ.5.2.1-3.*** **Multi-energy CT X-Ray Source Macro Attributes**

Attribute Name	Tag	Values
Multi-energy CT X-Ray Source Sequence	(0018,9365)	
ITEM 1		
>X-Ray Source Index	(0018,9366)	1

Attribute Name	Tag	Values
>X-Ray Source ID	(0018,9367)	Tube A
>Multi-energy Source Technique	(0018,9368)	SWITCHING_SOURCE
>Source Start Date Time	(0018,9369)	2018.05.01 13:22:03
>Source End Date Time	(0018,936A)	2018.05.01 13:22:20
>Switching Phase Number	(0018,936B)	1
>Switching Phase Nominal Duration	(0018,936C)	100
>Switching Phase Transition Duration	(0018,936D)	10
>Generator Power	(0018,1170)	120
ITEM 2		
>X-Ray Source Index	(0018,9366)	2
>X-Ray Source ID	(0018,9367)	Tube A
>Multi-energy Source Technique	(0018,9368)	SWITCHING_SOURCE
>Source Start Date Time	(0018,9369)	2018.05.01 13:22:03
>Source End Date Time	(0018,936A)	2018.05.01 13:22:20
>Switching Phase Number	(0018,936B)	2
>Switching Phase Nominal Duration	(0018,936C)	100
>Switching Phase Transition Duration	(0018,936D)	10
>Generator Power	(0018,1170)	100

516 ***Table JJJJ.5.2.1-4*. Multi-energy CT X-Ray Detector Macro Attributes**

Attribute Name	Tag	Values
Multi-energy CT X-Ray Detector Sequence	(0018,936F)	
ITEM 1		
>X-Ray Detector Index	(0018,9370)	1
>X-Ray Detector ID	(0018,9371)	Detector A
>Multi-energy Detector Type	(0018,9372)	INTEGRATING

518 ***Table JJJJ.5.2.1-5*. Multi-energy CT Path Macro Attributes**

Attribute Name	Tag	Values

Attribute Name	Tag	Values
Multi-energy CT Path Sequence	(0018,9379)	
ITEM 1		
>Multi-energy CT Path Index	(0018,937A)	1
>X-Ray Source Index	(0018,9366)	1
>X-Ray Detector Index	(0018,9370)	1
ITEM 2		
>Multi-energy CT Path Index	(0018,937A)	2
>X-Ray Source Index	(0018,9366)	2
>X-Ray Detector Index	(0018,9370)	1

520 **Table JJJJ.5.2.1-6. CT Exposure Macro Attributes**

Attribute Name	Tag	Values
CT Exposure Sequence	(0018,9321)	
ITEM 1		
>Referenced X-Ray Source Index	(0018,9377)	1\2
>Exposure Time in ms	(0018,9328)	500
>X-Ray Tube Current in mA	(0018,9330)	300
>Exposure in mAs	(0018,9332)	150
>Exposure Modulation Type	(0018,9323)	NONE
>CTDIvol	(0018,9345)	10

522

Table JJJJ.5.2.1-7. CT X-Ray Details Sequence Macro Attributes

Attribute Name	Tag	Values
CT X-Ray Details Sequence	(0018,9325)	
ITEM 1		

Attribute Name	Tag	Values
>Referenced Path Index	(0018,9378)	1
>KVP	(0018,0060)	80
>Focal Spot(s)	(0018,1190)	0.5\0.5
>Filter Type	(0018,1160)	NONE
ITEM 2		
>Referenced Path Index	(0018,9378)	2
>KVP	(0018,0060)	140
>Focal Spot(s)	(0018,1190)	0.5\0.5
>Filter Type	(0018,1160)	NONE

524

Table JJJJ.5.2.1-8. CT Acquisition Details Macro Attributes

Attribute Name	Tag	Values
CT Acquisition Details Sequence	(0018,9304)	
ITEM 1		
>Referenced Path Index	(0018,9378)	1\2
>Rotation Direction	(0018,1140)	CW
>Revolution Time	(0018,9305)	0.5
>Single Collimation Width	(0018,9306)	0.625
>Total Collimation Width	(0018,9307)	80.0
>Table Height	(0018,1130)	88.5
>Gantry/Detector Tilt	(0018,1120)	0
>Data Collection Diameter	(0018,0090)	500

526

Table JJJJ.5.2.1-9. CT Geometry Macro Attributes

Attribute Name	Tag	Values
CT Geometry Sequence	(0018,9312)	
ITEM 1		
>Referenced Path Index	(0018,9378)	1\2

Attribute Name	Tag	Values
>Distance Source to Detector	(0018,1110)	1140
>Distance Source to Data Collection Center	(0018,9335)	570

528

***Table JJJJ.5.2.1-10*. Multi-energy CT Processing Attributes**

Attribute Name	Tag	Values
Decomposition Method	(0018,937E)	PROJECTION_BASED
Decomposition Material Sequence	(0018,9381)	
ITEM 1		
>Material Code Sequence	(0018,937D)	
>>Include Table 8.8-1 "Code Sequence Macro Attributes"		*(C-10120, SRT, "Water")*
ITEM 2		
>Material Code Sequence	(0018,937D)	
>>Include Table 8.8-1 "Code Sequence Macro Attributes"		*(C-11400, SRT, "Iodine")*

530

532 KKKK. Encoding Quantitative Image Family Parameters (Informative)

KKKK.1 ENCODING OF QUANTITATIVE IMAGE FAMILY PARAMETERS WITH RWVM

534 In this example, the real-world value mapped pixel value represents attenuation of water. The pixel values range from 0 to 4095 like a conventional CT Image and are mapped starting from -1024.

536 **Table KKKK.1-1. Example Material Specific Images for the Real World Value Mapping Macro**

Attribute	Tag	Value	Comment
Real World Value Mapping Sequence	(0040,9096)		
ITEM 1			
>Real World Value First Value Mapped	(0040,9216)	0	
>Real World Value Last Value Mapped	(0040,9211)	4095	
>Real World Value Intercept	(0040,9224)	-1024	

Attribute	Tag	Value	Comment
>Real World Value Slope	(0040,9225)	1	
>LUT Explanation	(0028,3003)	“Water component of image with water and iodine as base materials”	
>LUT Label	(0040,9210)	MAT_SPECIFIC	Per guidance in PS3.3 Section C.11.1.1.2.1 "Recommended Rescale Type Assignments For Multi-energy CT Image" this corresponds to Image Type Value 4
>Measurement Units Code Sequence	(0040,08EA)		
>>Include Table 8.8-1 "Code Sequence Macro Attributes"		([hnsf'U], UCUM, "Hounsfield unit")	
>Quantity Definition Sequence	(0040,9220)		
>>CODE (F-61002, SRT, ”Substance”)		(C-10120, SRT, “Water”)	
>>CODE (G-C036, SRT, "Measurement Method”)		(129323, DCM, "Material Specific image")	

This example shows how to use the Table C.7.6.16-12b “Real World Value Mapping Item Macro Attributes” in PS3.3 to describe pixel values of the encoding of Quantitative Image Family parameters, by adding coded concepts to the RWVM that describe the material, the method and the value range in case of Value-based images.

In this example, a Value-based material map image has been created where pixel values between 0 and 20 correspond to voxels that are associated with Uric Acid and pixel values between 20 and 40 correspond to voxels that are associated with Calcium:

- In the Quantity Definition Sequence (F-61002, SRT, ”Substance”) is used to indicate that the pixel value in the specified range is deemed to represent the presence of that substance, regardless of the actual pixel value within that range. It would be inappropriate to use (G-C1C6, SRT, "Quantity") since the transformed pixel values do not represent a quantitative value.
- The measurement method of (113250, DCM, "Value-based material image") might be replaced by a more specific code that actually described the method of computation such as “Gaussian distribution”.
- For the sake of illustration in this image a pixel value of 20 maps to both “Uric Acid” and “Calcium”.

Table KKKK.1-2. Example Value Based Images for the Real World Value Mapping Macro

Attribute	Tag	Value	Comment
Real World Value Mapping Sequence	(0040,9096)		
ITEM 1			

Attribute	Tag	Value	Comment
>Real World Value First Value Mapped	(0040,9216)	0	
>Real World Value Last Value Mapped	(0040,9211)	20	
>Real World Value Intercept	(0040,9224)	0	
>Real World Value Slope	(0040,9225)	1	
>LUT Explanation	(0028,3003)	“Value-based substance map for kidney stone”	
>LUT Label	(0040,9210)	MAT_ VALUE_BASED	
>Measurement Units Code Sequence	(0040,08EA)		
>>Include Table 8.8-1 "Code Sequence Macro Attributes"		(1, UCUM, "no units")	
>Quantity Definition Sequence	(0040,9220)		
>>CODE (F-61002, SRT, ”Substance”)		(F-61470, SRT, "Uric Acid")	
>>CODE (G-C036, SRT, "Measurement Method”)		(129322, DCM, "Value-based image")	
ITEM 2			
>Real World Value First Value Mapped	(0040,9216)	20	
>Real World Value Last Value Mapped	(0040,9211)	40	
>Real World Value Intercept	(0040,9224)	0	
>Real World Value Slope	(0040,9225)	1	
>LUT Explanation	(0028,3003)	“Value-based substance map for kidney stone”	
>LUT Label	(0040,9210)	MAT_ VALUE_BASED	
>Measurement Units Code Sequence	(0040,08EA)	(1, UCUM, "no units")	
>>Include Table 8.8-1 "Code Sequence Macro Attributes"			
>Quantity Definition Sequence	(0040,9220)		
>>CODE (F-61002, SRT, ”Substance”)		(C-14300, SRT, "Calcium")	
>>CODE (G-C036, SRT, "Measurement		(129322, DCM, "Value-	

Attribute	Tag	Value	Comment
Method”)		based image")	

554