Digital Imaging and Communications in Medicine (DICOM)

Supplement 188: Multi-energy CT Images

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DOCUMENT HISTORY

Document Version	Date	Content
01	15 Sep 2013	Initial Outline
02	17 Sep 2013	Updated after WG21 tcon Sep 16
03	09 Dec 2013	Updated after Dec 6 Meeting in Chicago IL
04	26 Jul 2014	Updated after Jul 23 Meeting in Austin TX
05	15 Apr 2015	Updated after March 2015 meeting in Vienna
06	06 Jul 2015	Updated after June 2015 presentation to WG6
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08	18 Sept 2015	Updated after WG06 FR
09	19. Jan 2016	Updated in WG21 Meeting

Things highlighted in yellow are issues/items in need of further review/resolution/attention.
Things highlighted in blue are just reminders for the editor about editing work that needs to be done.
Things in italic are notes to the reviewers

TODO LIST

Description	Owner
Proposals for different solutions for Visualization	
Provide description of capabilities of viewers of different levels (with their limitations) (SG) and get a risk assessment (DC)	SG,DC
Work through Mark Armstrong (ACR) to get radiologist to enumerate the risks if any – after having examples from Diana and Shuai	
Add an Annex with examples of implementation (ME- Image Material Segmentation, Material Quantification, …)	
Can we mark Virtual Non-Contrast images in the same attributes as regular Contrast, to ensure this will be displayed by PACS? – Need proper labelling! May also affect billing (with/wo contrast) Yes we should record the image with contrast tags. The Image Type must be properly set to VMI. -> Add a note in the contrast tags/module which says: even in VNC these tags are to be filled with contrast information	
We get strong wished that dose index, noise index, dose modulation and noise target should be defined. This is strongly related to CT physics and cannot be defined upfront by the DICOM WG21 group. We propose that the definition shall come from the CT standardization group or AAPM. Come up with a definition within a ChangeProposal for the different mentioned topics.	

Define examples for each ME-Image Type and Segmentation object. This will be added to Part 17. Check during that work if parameters are sufficient.	Each vendor

OPEN ISSUES

1	Replacement Material Correction value for COMPENSATED needs to be clarified. (each vendor) Revisit Multi-energy CT Image Macro Attributes in terms of structure and future enhancements.
2	Are there any safety issues for mixed ME-Images and represented as Standard CT Image?

CLOSED ISSUES

1	DICOM does not enforce PACS/Display to present specific attributes, therefore there is little chance new important attributes we introduce here (e.g., keV for monochromatic image) will be presented to the users. It is suggested to contact IHE to advice on possible new or extension of an existing profile There may be a risk that the ME images will be misinterpreted as the conventional ones when displayed on a PACS/Workstation. For monochromatic images we stay with the existing CT IOD and Enhanced CT IODs. No high risk is seen in discussion with WG06. If the Image Type and Series Description is filled correctly, the risk is mitigated enough. These are already standardized attributes which are commonly used.
2	Shall we define a separate “Multi-energy” raw data? It is recommended that the existing RAW IOD can be used for this, with additional descriptions; it is too pre-mature to define common properties of raw/source data
3	Rescale Intercept. We can have negative value for base or material-free images - shall we constrain it to positive values for material-only images? Close; this is mathematically correct and thus has to be stored as is
4	Multi-energy Imaging is an evolving field. Do we need a standard mechanism to keep “raws” for later processing other than standard Raw IOD? NO (closed)
5	How can an unambiguous and reproducible definition/decomposition look like? Are there other procedures possible to standardize such decomposition? Closed: no cross-vendor standard exists.
6	How/Where Metal Artifact Reduction fits? Probably not Material-Suppression Image since it may be applied in the reconstruction time and affects pixels other than metals. Closed: using high keV in VMI images. No need anything in addition.
7	Dual-Spiral Scanning: no need since in Multi-energy scanning dual spiral scan in fact is a sequence of two separate spiral scans
8	Decomposition Base Materials: there was a comment (by Philips) that his is not mature yet, so shall be optional. Decision: It is important to be included – shall stay as Type 1
9	Dual-Energy Ratio: does this belong to acquisition/recon rather than to Decomposition Macro? Decision: This belongs to decomposition since one can get different ratios from the same acquisition

10	There are images that are similar to conventional CT image but created from Multi-energy raw data. Examples: Low Energy Image, High Energy Image, “QC” Image. Normally such images are intended as a basis to generate other types of images or for acquisition quality control, and not necessarily for diagnostic purposes. There is a risk of mis-interpretation, for instance, when comparing “conventional” ME/CT images with prior exam scanned with no-ME acquisition. The risk is primarily with the measurements rather than with visual interpretation. Shall such images be identifiable (distinguishable from a conventional single-energy CT) in some way? WG21 decision: to put these images out of scope of this supplement.
11	Standardized Color Maps: no standardization needed (out of scope)
12	Acquisition and other modality-specific attributes needed to interpret the image shall be included in all the ME Images
13	Floating Point values: none identified to need this beyond what can be done with Real World Value Mapping
14	Do we need a range for VMI keV values? NO
15	What are the different image production chains of each of the vendors since all will have to be accommodated, and what each needs to be recorded? One key distinction is weather decomposition is performed in projection/sinogram space or in image space. To be provided by vendors – for now (WIP) It is not needed to describe the specific image production chain vender specific. The defined attributes are sufficient.
16	Shall we have some Series-level attribute in order to query?, e.g., “Series Type” and thus to require such images to be in a separate series? Is there any clinical value in this separation? WG6 recommends not providing new query attributes. The question remains how processing applications/workstations can find/identify ME images – is Image Type with specific Value 3 or Value 4 sufficient? Or shall we put a special flag for this? We will allow storing different types of ME-Images in one series. No query attribute on series level is needed. Image Type Value 3 and 4 specify CT ME-Images.
17	Image Type of VMI Images. It is defined use ORIGINAL unless there is a specific case requiring it to be DERIVED. WG6 recommends leaving it to the vendor to decide if the image is ORIGINAL or DERIVED. Recommendation from WG21 is to set Image Type Value1 to ORIGINAL.
18	What does mean “fully equivalent to standard acquisition”? Every image that can be interpreted on HU-scale, independent of the used spectrum? Need to be discussed again after we have more specific parameters defined. Another option would be to flag any image that is generated during a Multi-energy acquisition. If the ME-images are generated in the same scan then we can fill out the Image Reference Sequence to get the different spectra of the acquisition. Already changed in the document. No need to discuss this further on.
19	In order to extend CT IOD with ME attributes, we introduced a new module – “Multi-energy CT Image”. Alternatively we could put an optional ME sequence inside the existing CT Image Module. Is the later a better approach? The recommendation is not to extend the CT IOD with a new module, but to extend the existing CT Image Module with optional macros or sequences.

20	If we use CT IOD – are there any risks of re-using standard tags inside the new ME sequences when an application goes scrolling for a particular tag and assumes this instance of the tag is what it is looking for? This is a known way how to reuse existing tags within different nesting levels. Therfore we see no risk.
21	Do we need to include conventional (equivalent) CT images generated by ME scanner? E.g., to include ME Acquisition attributes? Yes we do want to use this explicitly. E.g. in case of the creation of conventional CT images out of two energy levels (100 KVP + 70 KVP = 90 KVP)

Scope and Field of Application

This Supplement defines new types of images generated by Multi-energy CT scanners.

Z1. DEFINITIONS

Multi-energy CT Imaging:
CT Multi-energy (ME) imaging techniques including scanning, reconstruction, processing, when the scanner utilizes multiple energies from the X-Ray beam spectrum.

The new CT Multi-energy introduces details to describe ME imaging techniques. While different vendors apply different techniques to achieve Multi-energy Images, there is large commonality in the generated diagnostic images.

Z.2 USE CASES

The primary focus of this supplement includes:

- Making Multi-energy information available to rendering, processing applications and clinical display
- Allowing better differentiation of materials that look similar on conventional CT images, e.g., to differentiate Iodine and Calcium in vascular structures
- Accurate description of virtual non-contrast acquisition, when the “virtual/artificial non-contrast” image is generated out of the contrast image

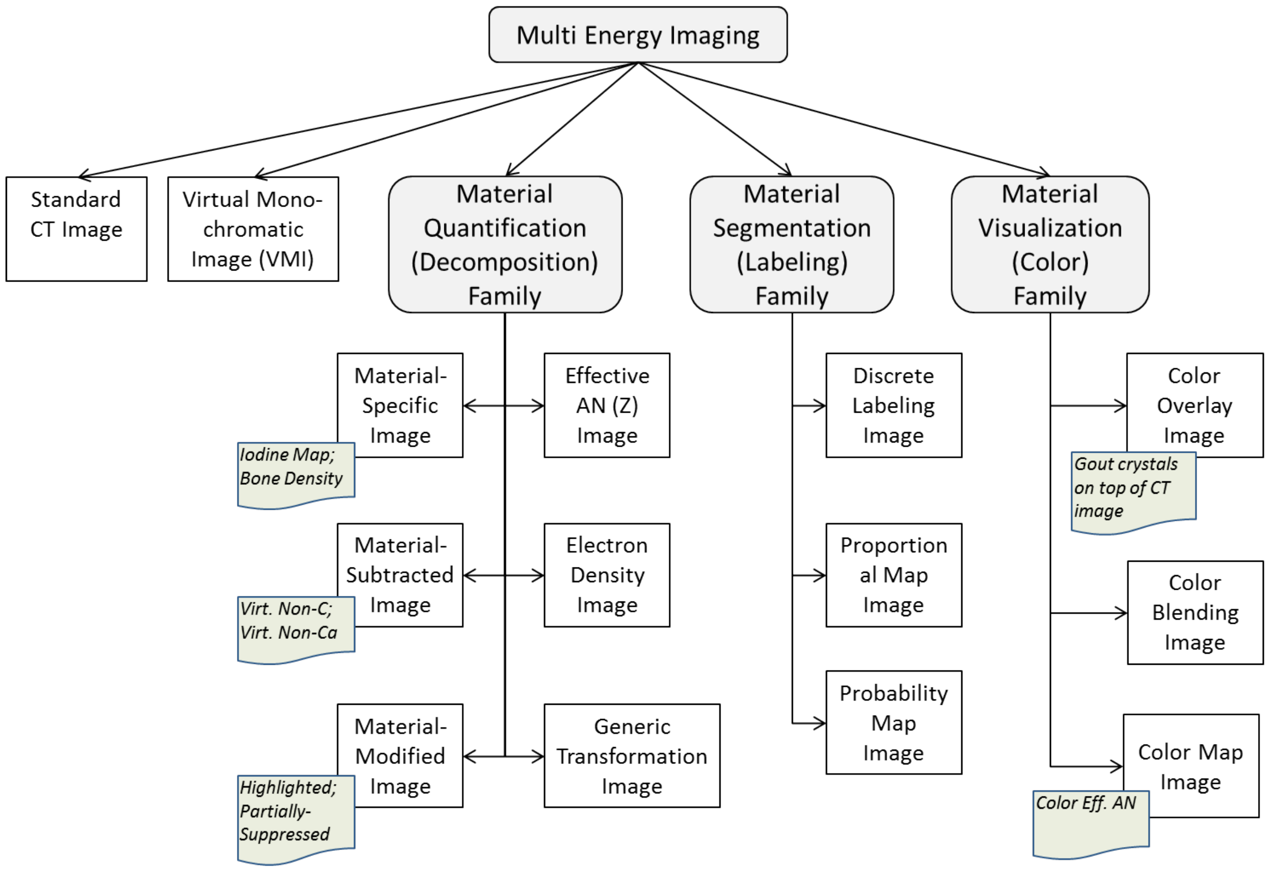
Z.3 OBJECTIVES

When defining this supplement, the following objectives / goals have been considered:

1. To provide new essential ME information (acquisition, reconstruction and processing attributes) within the IOD.
2. To facilitate fast and easy adoption of this supplement across the imaging community, both modalities and PACS/Displays.
3. To address (or at least to minimize) the risk of mis-interpretation when the ME images are displayed by a display does not support the new attributes of the ME-image, including incorrect measurements
4. To adapt existing attributes of the CT / Enhanced CT IOD to fit ME techniques.

Z.4 CLASSIFICATION OF ME IMAGES

The following ME Image Types are addressed in this supplement:



- **Standard CT Image (CT Image IOD, Enhanced CT Image IOD).** Images created using ME techniques. E.g. in case of the creation of conventional CT images out of two energy levels or images created only one of the multiple energies acquired. No new image type definitions are needed but new optional attributes are needed (filled).

- **Virtual Monochromatic Image (VMI).** This is essentially a CT image that is analogous to an image created by a monochromatic (of a specific keV value) X-Ray beam. E.g. in certain cases the image impression (quality) will allow a better iodine representation and better metal artifact reduction.

Material Quantification Images. These image types characterize the elemental composition of materials in the image. They provide material quantification in 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 category:

- **Material-Specific Image.** Image presenting a specific material.

- **Material-Subtracted Image**. Image with one or more materials subtracted. Pixel values may have been corrected for displacement of one material by another material.

- **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 is basically still HU-based, however the pixel values are modified HU, although they may be presented similarly. The Material-Modified image is primarily used for better visualization of the target materials

- **Effective Atomic Number Image (EANI)**. A CT image where each pixel represents Effective Atomic Number (aka “Effective Z”) of that pixel.

- **Electron Density Image (EDI)**.Each pixel represents a number of electrons per unit volume. Electron density is used e.g. in radiotherapy. This can be represented as absolute values of electron density (units 10^{23} /cc) or as a relative ED/ED_{Water} ratio (N/Nw).

- **Generic Transformation Image (GTI)**. Generic mathematical transformation Monochromatic equivalent of this image in keV of acquired ME data, intended to enhance differences between materials. The pixel value describes chemical values and is a characterization of the target materials. The result can be measured in units – mg/ml, ratio, etc.. The difference to EDI, EANI and other types of Material Quantification Images is the specification of a custom specific generic transformation.

  The transformation is described as attribute in the image. Focus is on the interpretation rather than generation of the image. It is used e.g. to reduce partial volume effects which can occur in case of kidney stone detection.

Material Segmentation (Labeling) Images. These image types provide classification of the materials, where each pixel contains values indirectly describing identified material(s) in this pixel. They can serve as basis for visualization of different materials e.g. coloring of specific material, enhancing/suppressing certain materials, etc. The following image types belong to this category:

- **Discrete Labeling Image.** Pixel value is an index corresponding to one or more materials from a list/vector of the known materials

- **Proportional Map Image.** Pixels describe proportional part of various materials (mass mixing fraction/ration) comprising this pixel. Multiple materials are supported.

- **Probability Map Image.** Pixels describe the probability that this pixel is classified as one or more of the multiple defined materials (the exact definition of the probability map has to be defined by the user).

Material Visualization Images. These image types allow visualizing material content in a certain user-convenient way, usually with colors (color maps, color overlays, blending, etc.)

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

Clinical Use Cases:

- Gout crystals can be displayed with color encoding by using Blending Presentation State Objects. For interpretation a color legend shall be displayed to the user (e.g. as graphics overlay). A fallback solution could be the creation of Secondary Capture Images with RGB values.
- Export a color image to a legacy PACS can be realized with Secondary Capture Image

Changes to NEMA Standards Publication PS 3.2

Digital Imaging and Communications in Medicine (DICOM)

Part 3: Information Object Definitions

ME Attributes Organization Structure – for reference only – will be removed from the final text

- C.8.2.1 CT Image Module
  - Table X-1 “Multi-energy CT Macro Attributes" (added)
    - Multi-energy CT **Acquisition** Sequence (1C)
      - >Table X-2 “Multi-energy CT Acquisition Macro Attributes”
        - Multi-energy CT X-Ray Beam Sequence (1)
          - >Table X.5 “Multi-energy CT X-Ray Beam Macro”
            - Table X-100 “Common CT Acquisition Macro”
    - Multi-energy CT **Material Decomposition** Sequence (1C)
      - >Table X-3 “Multi-energy CT Material Decomposition Macro Attributes”
    - Multi-energy CT **Image** Sequence (1C)
      - >Table X-4 “Multi-energy CT Image Macro Attributes”
- C.8.15.3.9 CT X-Ray Details Macro (for Enhanced CT IOD only)
  - CT X-Ray Details Sequence

<CT Module modifications 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.

Attribute Name	Tag	Type	Attribute Description
Image Type	(0008,0008)	1	Image identification characteristics. See Section C.8.2.1.1.1 for specialization.
…			
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 the Rescale Type is not HU (Hounsfield Units). May be present otherwise.
KVP	(0018,0060)	2	Peak kilo voltage output of the X-Ray generator used. **Shall be empty if not applicable for a Multi-energy Image.**
Acquisition Number	(0020,0012)	2	A number identifying the single continuous gathering of data over a period of time that resulted in this image
Scan Options	(0018,0022)	3	Parameters of scanning sequence. **Shall be absent if not applicable for a Multi-energy Image.**
Data Collection Diameter	(0018,0090)	3	The diameter in mm of the region over which data were collected **Shall be absent if not applicable for a Multi-energy Image.**
…			
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 be absent if not applicable for a Multi-energy Image.**
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 be absent if not applicable for a Multi-energy Image.**
X-Ray Tube Current	(0018,1151)	3	X-Ray Tube Current in mA.

Attribute Name	Tag	Type	Attribute Description
			Shall be absent if not applicable for a Multi-energy Image.
Exposure	(0018,1152)	3	The exposure expressed in mAs, for example calculated from Exposure Time and X-Ray Tube Current. **Shall be absent if not applicable for a Multi-energy Image.**
Exposure in μAs	(0018,1153)	3	The exposure expressed in μAs, for example calculated from Exposure Time and X-Ray Tube Current. **Shall be absent if not applicable for a Multi-energy Image.**
Filter Type	(0018,1160)	3	Label for the type of filter inserted into the x-ray beam. **Shall be absent if not applicable for a Multi-energy Image.**
Generator Power	(0018,1170)	3	Power in kW to the x-ray generator. **Shall be absent if not applicable for a Multi-energy Image.**
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 be absent if not applicable for a Multi-energy Image.**
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 be absent if not applicable for a Multi-energy Image.**
Total Collimation Width	(0018,9307)	3	The width of the total collimation (in mm) over the area of active x-ray detection. **Note**

Attribute Name	Tag	Type	Attribute Description
			This will be equal the number of effective detector rows multiplied by single collimation width. **Shall be absent if not applicable for a Multi-energy Image.**
…			To do.
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"			
Include Table X-1 "Multi-energy CT Macro Attributes"			

<CT Image Attribute modifications 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 Image

LOCALIZER ~~identifies~~ a CT Localizer Image

Note:

Axial in this context means any cross-sectional image, and includes transverse, coronal, sagittal and oblique images.

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

VMI **a Virtual Monochromatic Image**

MAT_SPECIFIC **a Material-Specific Image**

MAT_SUBTRACTED **a Material-Subtracted Image**

EFF_ATOMIC_NUM **an Effective Atomic Number Image**

ELECTRON_DENSITY **an Electron Density Image**

MAT_MODIFIED **a Material-Modified Image**

GTI **a Generic Transformation Image**

Note

Axial in this context means any cross-sectional image, and includes transverse, coronal, sagittal and oblique images.

Note:

Multi-energy Virtual Monochromatic and Material Quantification are not necessarily derived and may beORIGINAL\PRIMARY

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

< Rescale Type added to CT section due to Multi-energy CT Image Format>

C.8.2.1.1.X Rescale Type

Specifies the units of the output of the rescale operation.

Defined Terms:

HU
Hounsfield Units (CT); used also for Multi-energy Virtual Monochromatic Image

MGML
Material density in mg/ml; used for Multi-energy Material-Specific Image

Z_EFF
Effective Atomic Number (aka Effective-Z)

ED
Electron density in units of 10^{23} /cc

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; used for Multi-energy Material-Modified Image

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

X.100 COMMON CT ACQUISITION ATTRIBUTES

This macro specifies the common attributes for CT Acquisition.

Table X-100
Common CT Acquisition Attributes

Attribute Name	Tag	Type	Attribute Description
KVP	(0018,0060)	1C	Nominal Peak (max energy for switching technology) kilo voltage output of the X-Ray generator used. Due to limitations of the generating hardware the actual voltage may not reach the nominal peak value Required if Image Type Value 1 is ORIGINAL may be present otherwise
X-Ray Tube Current in mA	(0018,9330)	1	Nominal X-Ray tube current in milliamperes.
Data Collection Diameter	(0018,0090)	1	The diameter in mm of the region over which data were collected.
Distance Source to Detector	(0018,1110)	1	Distance in mm from source to detector center. **Note** *This value is traditionally referred to as Source Image Receptor Distance (SID).*
Focal Spot(s)	(0018,1190)	1	Used nominal size of the focal spot in mm. For devices with variable focal spot or multiple focal spots, small dimension followed by large dimension.
Filter Type	(0018,1160)	1	Type of filter(s) inserted into the X-Ray beam. Defined Terms: WEDGE BUTTERFLY STRIP MULTIPLE NONE Note: Multiple filters can be expressed by a combination of terms, e.g., BUTTERFLY+WEDGE

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 GOLD TIN Required if Filter Type is not NONE
Generator Power	(0018,1170)	3	Power in kW to the x-ray generator.
Exposure in mAs	(0018,9332)	1	The exposure expressed in milliampere seconds, for example calculated from exposure time and X-Ray tube current.
Exposure Time	(0018,1150)	1	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. If X-Ray Sources (gggg,eeee) equal "SINGLE_SWITCHING", the value of this attribute shall consider mode proportion (gggg,eeee) (e.g. multiply value)
Exposure Modulation Type	(0018,9323)	1	A multivalued label describing the type of exposure modulation used for the purpose of limiting the dose. Defined Terms: NONE
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.*

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.*
			… other attributes from CT Image will be added

X.1 MULTI-ENERGY CT MACRO ATTRIBUTES

Table X-1 specifies the Multi-energy attributes

Table X-1
Multi-energy CT Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Multi-energy Flag	(xxxx,yyyy)	1C	Indicates whether the image is created by means of Multi-energy technique Enumerated Values: Y N Required if the image is created by means of Multi-energy technique. May be present otherwise
Multi-energy CT Acquisition Sequence	(xxxx,yyyy)	1C	Sequence that describes the attributes of a Multi-energy Image acquisition. Only a single Item is permitted in this sequence. Required if CT Multi-energy Flag (xxxx,yyyy) is equal Y
>Include Table X-2 "Multi-energy CT Acquisition Macro Attributes"			
Multi-energy CT Material Decomposition Sequence	(xxxx,yyyy)	1C	Sequence that describes the attributes of material decomposition attributes. Only a single Item is permitted in this sequence. Required if CT Multi-energy Flag (xxxx,yyyy) is equal Y and a Material Decomposition is performed

Attribute Name	Tag	Type	Attribute Description
			May be present otherwise.
> Include Table X-3 “Multi-energy CT Material Decomposition Macro Attributes”			
Multi-energy CT Image Sequence	(xxxx,yyyy)	1C	Sequence that describes the attributes of a Multi-energy Image. Only a single Item is permitted in this sequence. Required if Multi-energy CT Material Decomposition Sequence (xxxx,yyyy) is present or Type Value 4 is EQUAL to VMI. May be present otherwise.
>Include Table X-4 “Multi-energy CT Image Macro Attributes”			

< Changes to *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.

…		
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 Acquisition	**X.2**	**C - Required if the image is acquired by means of Multi-energy technique**, may be present otherwise.
Multi-energy CT Material Decomposition	**X.3**	**U**
Multi-energy CT Image	**X.4**	**U**

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

X.2 MULTI-ENERGY CT ACQUISITION MACRO

This macro defines Multi-energy CT acquisition attributes.

Table X-2.
Multi-energy CT Acquisition Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Multi-energy Acquisition Technique	(xxxx,yyyy)	1	Technique used to acquire Multi-energy data. Defined Terms: **SINGLE_PASS** one scan pass of the anatomic area **MULTI_PASS** two or more consecutive scan passes of the same anatomic area **SINGLE_SOURCE** single X-Ray source (tube) is used without beam mode switching **SWITCHING_SOURCE** a X-Ray source (tube) is used with beam mode switching **MULTIPLE_SOURCE** two or more X-Ray sources (tubes)are used Multiple values are permitted.
Multi-energy Detection Technique	(xxxx,yyyy)	1	Technology used to detect multiple energies. Defined Terms: **INTEGRATING** conventional (energy-integrating) detector **MULTILAYER** detector layers absorb different parts of the X-Ray spectrum **PHOTON_COUNTING** detector counts photons with energy discrimination capability
Switching Cycle Duration	(xxxx,yyyy)	1C	Duration, in microsec, of the complete switching cycle. One cycle is the amount of time it takes to complete all switching phases once. Required if Multi-energy Acquisition Technique (xxxx,yyyy) contains **SWITCHING_SOURCE value.** Shall not be present otherwise

Attribute Name	Tag	Type	Attribute Description
Multi-energy CT X-Ray Beam Sequence	(xxxx,yyyy)	1	Contains the attributes describing beam parameters in a multiple X-Ray source system or a Multi-energy acquisition. Multiple Beams are used to achieve Multi-energy Images. Each item in the sequence describes one beam. Examples: • Dual-energy would involve two tubes: this will be modeled using two beams • With KV switching, the tube alternates between the two modes • With sequential scanning, a single source is used for each rotation • Photon counting One or more Items are permitted in this sequence.
Include Table X.5 "Multi-energy CT X-Ray Beam Macro Attributes"			

268 **X.5 MULTI-ENERGY CT X-RAY BEAM MACRO ATTRIBUTES**

The table in this Section contains Attributes that describe Multi-energy CT X-Ray Beam.

Attribute Name	Tag	Type	Attribute Description
Acquisition Number	(0020,0012)	1C	A number identifying the single continuous gathering of data over a period of time that resulted in this image Required if more than scan passes are used, may be present otherwise
Energy Bins Sequence	(xxxx,yyyy)	1C	The attributes of energy detector bins. Required if Multi-energy Detection is PHOTON_COUNTING. Shall not be present otherwise Two or more items shall be included in this sequence.
>Bin Number	(xxxx,yyyy)	1	Describes a unique number of the Bin
>Energy Weighting Factor	(xxxx,yyyy)	3	Relative weight of this beam energy according to the total exposed energy. Sum of Bin Weighting

Attribute Name	Tag	Type	Attribute Description
			Factors shall be 1
>Mean Photon Energy	(xxxx,yyyy)	1	Mean energy in keV of detected photons in this bin.
X-Ray Source Number	(xxxx,yyyy)	1C	Unique number of a X-Ray source Required if more than one X-Ray source will be used for the acquisition, may be present otherwise
Switching Flag	(xxxx,yyyy)	1	Using switching technique Defined Term: Y N
Switching Phase	(xxxx,yyyy)	1C	Unique number to identify the switching phase Required if Switching Flaf is Y shall not be present otherwise
Switching Phase Duration	(xxxx,yyyy)	1C	Duration, in microsec, of this switching phase. Required if Switching Flag (xxxx,yyyy) is Y shall not be present otherwise
Switching Phase Proportion	(xxxx,yyyy)	1C	Percentage of time spent in this phase between 0 and 1. Required if Switching Flag (xxxx,yyyy) equal “Y” shall not be present otherwise
X-Ray Detector Number	(xxxx,yyyy)	1	Unique number of a X-Ray detector
Multi-energy Detection Technique	(xxxx,yyyy)	1	Technology used to detect multiple energies. Defined Terms: **INTEGRATING** conventional (energy-integrating) detector **MULTILAYER** detector layers absorb different parts of the X-Ray spectrum **PHOTON_COUNTING** detector counts photons with energy discrimination capability
Energy Weighting Factor	(xxxx,yyyy)	3	Sum of Beam weighting factors shall be 1

Attribute Name	Tag	Type	Attribute Description
Include [Table X-100 "Common CT Acquisition Macro Attributes"]			
Additional Attributes may be added from CT Image Module if they are different for different beams			

X.3 MULTI-ENERGY CT MATERIAL DECOMPOSITION MACRO

This macro defines Multi-energy CT material decomposition attributes.

Table X-3
Multi-energy CT Material Decomposition Attributes

Attribute Name	Tag	Type	Attribute Description
Decomposition Method	(xxxx,yyyy)	1	Defined Terms: **PROJECTION_BASED** primary decomposition is performed in projection space (i.e. sinograms) **IMAGE_BASED** primary decomposition is performed on images, i.e. the different energy sinograms are reconstructed into images before performing the decomposition **HYBRID** mixture of PROJECTION_BASED and IMAGE_BASED decomposition techniques
Decomposition Description	(xxxx,yyyy)	3	Vendor-specific description of decomposition method
Decomposition Base Materials Sequence	(xxxx,yyyy)	1	Base Materials used for decomposition. May contain 2 or more items.
>Material Code Sequence	(xxxx,yyyy)	1	Nominal material. Only one item shall be permitted
>>Include Table 8.8-1-a "Basic Code Sequence Macro Attributes"			Baseline CID is CID-X1
>Multi-energy Base Material Attenuation Sequence	(xxxx,yyyy)	3	Attenuation curve of the material Two or more items shall be present.
>> Monochromatic	(xxxx,yyyy)	1	Monochromatic equivalent in keV

Attribute Name	Tag	Type	Attribute Description
Energy Equivalent			
>>X-Ray Mass Attenuation Coefficient	(xxxx,yyyy)	1	Attenuation of this material at the specific Monocromatic Equivalent.
>>Base Material CT Value Ratio	(xxxx,yyyy)	3	If Multi-energy Detection is PHOTON_COUNTING it is calculated as nominal CT Value for current Beam and Bin / nominal CT Value Beam 1 Bin 1 ELSE it is calculated as nominal CT Value for current Beam / nominal CT Value Beam 1

X.4 MULTI-ENERGY CT IMAGE MACRO ATTRIBUTES

This macro specifies the attributes that describe Multi-energy CT Image.

Table X-4
Multi-energy CT Image Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Monochromatic Energy Equivalent	(xxxx,yyyy)	1C	Monochromatic equivalent in keV. Required if Image Type Value 4 is “VMI” May be present otherwise
Generic Transformation Type	(xxxx,yyyy)	3	Type of generic transformation procedure Defined Terms: NON_LINEAR LINEAR
Generic Transformation Description	(xxxx,yyyy)	3	Human-readable description of the generic transformation procedure
Material Modification Description	(xxxx,yyyy)	3	Human-readable description of the material modifications made to this image
Specific Material Code Sequence	(xxxx,yyyy)	1C	The specific material present in this image. Only a single item shall be present. Required if Image Type Value 4 is MAT_SPECIFIC May be present otherwise
>Include Table 8.8-1-a “Basic Code Sequence Macro Attributes”			Baseline CID is CID-X1
Material Modification Sequence	(xxxx,yyyy)	1C	Materials that have been intentionally affected when the image was created. Required if Image Type Value 4 is MAT_MODIFIED May be present otherwise One or more items shall be present.
>Modification Type	(xxxx,yyyy)	1	Defined Terms: **SUBTRACTED** – Image with one or more materials subtracted, i.e. set to a fixed value. **HIGHLIGHTED** – Image where pixel values have been modified to highlight a certain target material by partially suppressing the background and/or by enhancing the modified material **SUPPRESSED** – CT Image where pixel values have been modified to partially suppress the

Attribute Name	Tag	Type	Attribute Description
			modified material **REPLACED** – CT Image where pixel values of modified material have been replaced by one or more other materials
>Material Code Sequence	(xxxx,yyyy)	2	The modified material. Only a single item shall be present.
>>Include Table 8.8-1-a "Basic Code Sequence Macro Attributes"			Baseline CID is CID-X1
> Correction Type	(xxxx,yyyy)	1	How the pixels have been corrected. Defined terms: **CONSTANT** – pixels are replaced by a constant value **RECALCULATED** – pixels are recalculated by vendor-specific method **COMPENSATED** – pixels are replaced by other materials
>Correction Value	(xxxx,yyyy)	1C	The constant value used to replace the affected pixels Required if Displacement Correction is CONSTANT
>Correction Description	(xxxx,yyyy)	3	Common description of the correction action on the image pixels.
>Replacement Material Sequence	(xxxx,yyyy)	1C	Materials that replace the modified material. Required if Displacement Correction is COMPENSATED One or more items shall be present.
>>Material Name	(xxxx,yyyy)	1	Name of the Material.
>>Material Code Sequence	(xxxx,yyyy)	2	The modified material. Only a single item shall be present.
>>>Include Table 8.8-1-a "Basic Code Sequence Macro Attributes"			Baseline CID is CID-X1

<Segmentation IOD modifications due to Multi-energy CT Image Format>

A.51 SEGMENTATION IOD

A.51.1 SEGMENTATION IOD DESCRIPTION

The Segmentation Information Object Definition (IOD) specifies a multi-frame image representing a classification of pixels in one or more referenced images. Segmentations are either binary or fractional. If the referenced images have a defined frame of reference, the segmentation instance shall have the same frame of reference and is not required to have the same spatial sampling or extent as the referenced images. If the referenced image does not have a defined frame of reference, the segmentation instance shall have the same spatial sampling and extent as the referenced image.

~~**The Segmentation IOD does not include the full set of acquisition parameters of the referenced images, e.g., cardiac phase. An application rendering or processing the segmentation may need to access the referenced images for such information.**~~

The Segmentation IOD may include a subset of acquisition parameters. If the Segmentation IOD does not contain essential parameters, e.g., cardiac phase, an application rendering or processing the segmentation may need to access the referenced images for such information.

A.51.2 SEGMENTATION IOD ENTITY-RELATIONSHIP MODEL

The E-R Model in Section A.1.2 depicts those components of the DICOM Information Model that directly reference the Segmentation IOD. The Segmentation is a kind of Image

A.51.3 SEGMENTATION IOD MODULE TABLE

Table A.51-1. Segmentation IOD Modules

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	General Series	C.7.3.1	M
	Segmentation Series	C.8.20.1	M
	Clinical Trial Series	C.7.3.2	U
Frame of Reference	Frame of Reference	C.7.4.1	C - Required if Derivation Image Functional Group (C.7.6.16.2.6) is not present. May be present otherwise.

IE	Module	Reference	Usage
Equipment	General Equipment	C.7.5.1	M
	Enhanced General Equipment	C.7.5.2	M
Segmentation	General Image	C.7.6.1	M
	Image Pixel	C.7.6.3	M
	Segmentation Image	C.8.20.2	M
	Multi-frame Functional Groups	C.7.6.16	M
	Multi-frame Dimension	C.7.6.17	M
	Specimen	C.7.6.22	U
	Common Instance Reference	C.12.2	C - Required if Derivation Image Functional Group (C.7.6.16.2.6) is present.
	SOP Common	C.12.1	M
	Frame Extraction	C.12.3	C - Required if the SOP Instance was created in response to a Frame-Level retrieve request

Segmentation Attributes Organization Structure – for reference only – will be removed from the final text

- C.8.20.2 Segmentation Image Module
    - Segment Sequence (0062,0002) (1-N)
        - >Table C.8.20-4 “Segment Description Macro Attributes”
            - Segmented Property Category Code Sequence (0062,0003)
                - *Baseline CID 7150 “Segmentation Property Categories”*
                    - New code added: “Material”
            - Segmented Property Type Code Sequence (0062,000F)
                - *Baseline CID 7XX1 “Material Segmentation Types” – added*
            - Specific Material Code Sequence (added)
    - A.51.5 Segmentation Functional Groups enhanced with CT specific acquisition parameters(added)

< Segmentation Type and Segmentation Fractional Type modifications due to Multi-energy CT Image Format>

C.8.20.2.3 Segmentation Type and Segmentation Fractional Type

A Segmentation Type (0062,0001) of BINARY indicates the segmented property is present with a value of 1 and absent with a value of 0.

For a Segmentation Type (0062,0001) of FRACTIONAL the segmented property is defined as a value from zero to the Maximum Fractional Value (0062,000E). A FRACTIONAL segmentation shall be further specified via Segmentation Fractional Type (0062,0010).

Enumerated Values of Segmentation Fractional Type (0062,0010):

PROBABILITY Defines the probability, as a percentage, that the segmented property occupies the spatial area defined by the voxel **or constitutes the partial mass of the voxel**

OCCUPANCY Defines the percentage of the voxel area occupied by **or partial density of** the segmented property.

For Material Category, the following specification is applicable:

- **For Discrete Labeling Type, the Segmentation Type (0062,0001) is BINARY.**
- **For Probability Type, the Segmentation Type (0062,0001) is FRACTIONAL, and the Segmentation Fractional Type (0062,0010) is PROBABILITY. The Maximum Fractional Value (0062,000E) for these types is up to a vendor.**
- **For Proportional Type, the Segmentation Type (0062,0001) is FRACTIONAL, and the Segmentation Fractional Type (0062,0010) is OCCUPANCY accordingly. The Maximum Fractional Value (0062,000E) for these types is up to a vendor.**

C.8.20.4 Segmentation Macros

The following sections contain macros specific to the Segmentation IOD.

C.8.20.4.1 Segment Description Macro

Table C.8.20-4 specifies the attributes of the Segment Description Macro.

Table C.8.20-4. Segment Description Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Segment Number	(0062,0004)	1	Identification number of the segment. The value of Segment Number (0062,0004) shall be unique within the Segmentation instance in which it is created. See Section C.8.20.2.4.
Segment Label	(0062,0005)	1	User-defined label identifying this segment. This may be the same as Code Meaning (0008,0104) of Segmented Property Type Code Sequence (0062,000F).
Segment Description	(0062,0006)	3	User-defined description for this segment.
Segment Algorithm Type	(0062,0008)	1	Type of algorithm used to generate the segment.

Attribute Name	Tag	Type	Attribute Description
			Enumerated Values: **AUTOMATIC** calculated segment **SEMIAUTOMATIC** calculated segment with user assistance **MANUAL** user-entered segment
Include Table 10-7 “General Anatomy Optional Macro Attributes”			May be not be necessary if the anatomy is implicit in the Segmented Property Type Code Sequence.
Segmented Property Category Code Sequence	(0062,0003)	1	Sequence defining the general category of this segment. Only a single item shall be included in this sequence.
>Include Table 8.8-1 “Code Sequence Macro Attributes”			*Baseline CID 7150 “Segmentation Property Categories”.*
Segmented Property Type Code Sequence	(0062,000F)	1	Sequence defining the specific property type of this segment. Only a single item shall be included in this sequence.
>Include Table 8.8-1 “Code Sequence Macro Attributes”			*Baseline CID 7151 “Segmentation Property Types”.*
>Segmented Property Type Modifier Code Sequence	(0062,0011)	3	Sequence defining the modifier of the property type of this segment. One or more Items are permitted in this sequence.
>>Include Table 8.8-1 “Code Sequence Macro Attributes”			*Baseline CID 244 “Laterality”.*
Specific Material Code Sequence	**(gggg,eeee)**	**1C**	**The specific material defined by this segment.** **Only a single item shall be present.** **Required if Segmentation Category is Material. Shall not be present otherwise.**
>Material Name	**(xxxx,yyyy)**	**1**	**Name of the Material.**
>Include Table 8.8-1-a “Basic Code Sequence Macro Attributes”			**Baseline CID is CID-X1**

<Segmentation Functional Goups modifications due to Multi-energy CT Image Format>

A.51.5 Segmentation Functional Groups

Table A.51-2 specifies the use of the Functional Group Macros used in the Multi-frame Functional Group Module for the Segmentation IOD.

Functional Group Macro	Section	Usage
…		
Segmentation	C.8.20.3.1	M
Multi-energy CT Acquisition	**X.2**	**C - Required if the image is acquired by means of Multi-energy technique**, may be present otherwise.
Multi-energy CT Material Decomposition	**X.3**	**U**

CID 7150 Segmentation Property Categories

Type: **Extensible**

Version: **20140627**

Table CID 7150. Segmentation Property Categories

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-CT Concept ID	UMLS Concept Unique ID
SRT	T-D0050	Tissue	85756007	C0040300
SRT	T-D000A	Anatomical Structure	123037004	C1268086
SRT	A-00004	Physical object	260787004	C0085089
SRT	M-01000	Morphologically Altered Structure	49755003	C0221198
SRT	R-42019	Function	246464006	C0542341
SRT	R-42018	Spatial and Relational Concept	309825002	C0587374
SRT	T-D0080	Body Substance	91720002	C0504082
DCM	**tbd**	**Material**		

CID 7151 Segmentation Property Types

Type: **Extensible**
Version: **20130617**

Table CID 7151. Segmentation Property Types

Coding Scheme Designator	Code Value	Code Meaning
Include CID 7159 “Lesion Segmentation Types”		
Include CID 7160 “Pelvic Organ Segmentation Types”		
Include CID 7161 “Physiology Segmentation Types”		
Include CID 7165 “Abstract Segmentation Types”		
Include CID 7XX1 "Material Segmentation Types”		

CID 7XX1 Material Segmentation Types

Type: **Extensible**
Version: **20150707**

Table CID 7XX1. Material Segmentation Types

Coding Scheme Designator	Code Value	Code Meaning
DCM	**NewCode2-1**	**Discrete Labeling**
DCM	**NewCode2-2**	**Proportional Labeling**
DCM	**NewCode2-3**	**Probability Labeling**

Changes to NEMA Standards Publication PS 3.6-2011

Digital Imaging and Communications in Medicine (DICOM)

Part 6: Data Dictionary

Add the following rows to Section 6

Tag	Name	Keyword	VR	VM
(yym4,m4x2)	Attribute Tag		AT	1

Changes to NEMA Standards Publication PS 3.16-2011

Digital Imaging and Communications in Medicine (DICOM)

Part 16: Content Mapping Resource

CID NewCID-1 Multi-energy Material Codes

Codes for materials used in Multi-energy Images.

Table CID-X1
Multi-energy Material Codes *(need a better name)*
Type : Extensible Version : yymmdd

Coding Scheme Designator (0008,0102)	Code Value (0008,0100)	Code Meaning (0008,0104)
SRT	C-11400	Iodine
SRT	C-17800	Gadolinium
SRT	C-12200	Barium
SRT	C-10120	Water
SRT	C-130F9	Iron
SRT	T-D008A	Fat
DCMXXX	NewCode1-01	**Calcium**
DCMXXX	NewCode1-02	**Uric Acid**
DCMXXX	NewCode1-03	**HAP**

CID NewCID-2 Multi-energy Material Units Codes

Codes for material units used in Multi-energy Images.

Table CID-X2
Multi-energy Material Units Codes
Type : Extensible Version : yymmdd

Coding Scheme Designator (0008,0102)	Code Value (0008,0100)	Code Meaning (0008,0104)
UCUM	mg/cm3	mg/cm^3
UCUM	hnsf'U	Hounsfield Unit
DCMXXX	cnt/cc	Electron Density
DCMXXX	NewCode2-02	Effective Atomic Number
DCMXXX	NewCode2-03	Modified Hounsfield Unit

Coding Scheme Designator (0008,0102)	Code Value (0008,0100)	Code Meaning (0008,0104)
DCMXXX	mg/ml	Milligram per milliliter

Changes to NEMA Standards Publication PS 3.17-2011

Digital Imaging and Communications in Medicine (DICOM)

Part 17: Explanatory Information

Add the following New Annex to Part 17 (WW is a placeholder)

Annex WW Place Holder (Informative)

WW1 IOD FOR VMI AND MATERIAL QUANTIFICATION IMAGES

Image Type	Units	IOD Choices
Virtual Monochromatic Image (VMI)	HU	CT IOD and Enhanced CT IOD
Material Quantification images:		
Material-Specific Image	HU or concentration, e.g. mg/ml	Can be realized by CT IOD with optional RWVM
Material-Subtracted Image	HU (modified)	Can be realized by CT IOD with optional RWVM describing corrected displacement vs suppressed vs. highlighted vs simple material specific. Consider setting Image Type to DERIVED to indicate to naïve displays that pixels were modified
Material-Modified Image	HU (modified)	Can be realized by CT IOD with optional RWVM Image Type = DERIVED Look at U/S Part 17 Annex QQ for concepts Can be paired with segmentation to indicate which pixels were modified
Effective Atomic Number Image	Unitless	Can be realized by CT IOD with optional RWVM

Electron Density Image	1/volume (e.g., cnt/cc, 1023/cc, mol/mg); might also represent as 1000*(N-Nw)/Nw which is analogous to HU	Can be realized by CT IOD with optional RWVM rethink new IOD due to compatibility to RT-Systems, can be described also in HU (see Unist description). CT IOD will be adopted faster

Basically, we have a choice of using (extending) existing CT IODs (legacy or Enhanced CT) vs. defining a new IOD.

For proper interpretation it will be necessary for certain new details to be communicated to the radiologist. This can be mandated to a new IOD.

Conversely the existing IOD is widely supported; it would be advantageous to find a way to communicate the new details reliably in the CT IOD.

Clinical examples of potential misinterpretation

1. For virtual mono-energetic images (images similar to those obtained with mono-energetic x-ray beam, in keV), as attenuation highly depends on the beam energy (keV), CT numbers in VMI images can be very different from those in standard poly-energetic images. Without proper labeling of such images, including the specific keV value used, the reviewer can come to wrong conclusions. Clinical example: tbd

2. HU-based ME images where CT values have been modified for specific materials (suppressed, highlighted, etc.) look similar to “normal” 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. Clinical example: tbd

3. CT number difference between contrast scan and non-contrast scan is used to differentiate renal mass and cyst, as renal mass is enhanced in contrast scans while cyst is not. What type of ME image can cause this misinterpretation?

4. In certain types of ME images (effective atomic number, electron density, material-specific image containing material concentration), pixel values do not represent CT number. Common ROI tool placed on such 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.

How to guarantee adequate and safe display by naïve receivers

1. To guarantee that the created ME images contain the necessary information. A number of new attributes will be defined. These attributes will be added to the ME images, either as an extension to the existing IODs, or as part of new, ME-specific, IODs. However, we cannot mandate using any new specific attribute for existing IOD. Is there any workaround (ask WG6):

    - Can we say that specific attribute is Type 1 if the system supports ME imaging? Yes only for new attributes; what about standard attributes, like Image Type? Ok to extend with new values and make them mandatory if the image is ME

    - Can we say that specific attribute is Type 1C if the units for pixels are not in HU? Not for existing attributes; ok for new

    - Shall we rather define an optional SQ with mandatory ME attributes?

2. To add Real-World Value Mapping to CT IOD to accurately describe the non-HU values. There are several concerns with this approach:

    - RWVM is not specified today for CT images or widely implemented in the field (is this correct?). As a result, the units can be misinterpreted by the display application

    - Rescale Slope and Rescale Intercept are Type-1 for CT image (if it is ORIGINAL); there is potential conflict between rescale attributes and RWVM. If we define image type as DERIVED, we avoid Type-1 requirement for Rescale Slope/Intercept, so they can be omitted.

    - As a consequence, Rescale attributes shall be used if possible; for specific cases (to be identified) RWVM may be considered.

3. To describe the need and recommendations for good labeling in the informative section (e.g., to display keV value for VMI images; to display material + concentration for measurements, etc.). DICOM alone cannot enforce PACS/Display to present specific attributes therefore there is little chance new important attributes we introduce here will be presented to the users. It is suggested to contact IHE to advice on possible new or extension of an existing profile

4. Can we “orchestrate” the object in such a way that naïve display will either success or fail? For instance, we can put rescale attributes to zero for non-HU ME images. – ask WG6

5. Can we extend Image Type value 4 for CT IOD? Yes

In addition, with existing CT IOD we might not be able to mandate full documentation in Conformance Statement of the different image types supported by a given product. – WG6

Homework: define cases for Naïve Success, Obvious Failure, Subtle Failure

Considering all the above, the WG21 current recommendation is to use the existing CT IOD and Enhanced CT IOD for these types of ME images.

The rest of this supplement is based on this approach.

WW2 IOD FOR MATERIAL SEGMENTATION IMAGES

The following image types are to be supported:

- **Discrete Labeling Image.** Pixel value is an index corresponding to one or more materials from a list/vector of the known materials
- **Proportional Map Image.** Pixels describe proportional part of various materials (mass mixing fraction/ration) comprising this pixel. Multiple materials are supported.
- **Probability Map Image.** Pixels describe the probability that this pixel is classified as one or more of the multiple defined materials (the exact definition of the probability map has to be defined by the user).

Examples (RR):

Discrete Labeling Image:

Measurement Units – Index
LUT Explanation – ID1 = Water, ID2 = Bone, …
LUT Label – Material Labeling

Proportional Map Image:

Measurement Units – Percent water
LUT Explanation –Decomposition Water, Bone, SoftTissue…
LUT Label – ProportionalMapImage

Probability Map Image:

Measurement Units – Percent Calcium
LUT Explanation –Decomposition Urat, Calcium…
LUT Label – PropabilityMapImage

The following alternatives are being discussed:

1. Segmentation IOD
2. CT IOD with RWVM
3. Parametric Maps IOD (Sup. 172)
4. New IOD
5. Secondary Capture image can be used as a fallback

WG6 Recommendation: to use Segmentation IOD

WW2.1 SOLUTION PACKAGE DESCRIPTION: HOW TO BUILD ME SEGMENTATION IMAGES USING SEGMENTATION IOD

The following Use Cases are supported with this solution package:

UC1:

The Segmentation IOD used for Material Segmentation is created either directly from the raw/sinogram data or from other ME images (e.g., High-Energy/Low-Energy pair, a pair of two Virtual Mono-Energetic images, etc.). This IOD contains (as an extension of the current standard) all the relevant acquisition, reconstruction and material-decomposition attributes. This IOD can later be used for advance material quantification analysis, processing and visualization.

UC2:

An application that supports Segmentation IOD usually renders volumetric representation of the defined segments. Such application would render the Material Segmentation images without any change (each material to be rendered as a “segment”), although the clinical value of such visualization is not clear.

UC3:

Blending Softcopy Presentation State IOD can be used for visualization, when ME Segmentation IOD is one of the objects to be blended, while another object can be a corresponding original CT image or an ME image.

UC4:

Pseudo-color Softcopy Presentation State IOD is used to render the Segmentation IOD in a desire way (e.g., different colors for different materials).

<u>Objects that are created for the solution package are:</u>

- Segmentation IOD (with extension for acquisition, reconstruction and material decomposition attributes)
- Blending Softcopy Presentation State IOD (optional)
- Pseudo-color Softcopy Presentation State IOD (optional)

<u>Benefits:</u>

- Full set of ME-related attributes is available for analysis, processing and visualization
- No mis-interpretation with native clinical CT images due to a different IOD used

<u>Drawbacks:</u>

- Segmentation IOD is probably not widely supported today
- High adaptation barrier: the applications will have to be developed/modified to fully benefit from the material information contained in these objects.

- Not clear if the Segmentation IOD (when created directly from the sinograms) can be used without the reference to the "source" images

WW2.2 DESCRIPTION SOLUTION PACKAGES HOW TO BUILD ME-IMAGES FOR SEGMENTATION IMAGES CT IMAGE IOD (WITH MATERIAL SPECIFIC CODE)

The following Use Cases are supported with this solution package:

UC1:

The result images can be displayed natively on PACS & workstation. Additionally any information can be visualized. Any interaction that is available for conventional CT images (windowing, measurements, ROI, …) can be done. Measurements are valid. All information (e.g. uric acid concentration) is valid, coded in Slope/Intercept or RWVM tags.

UC2:

Complex image visualization can be achieved on workstations (colored display, blending operation, volume measurement).

UC3:

The result images can be used for further processing with advanced algorithms like on native images.

<u>Objects that are created for the solution package are</u>

- CT Image IOD (with Material specific code)
- Blending Presentation State

<u>Benefits:</u>

- Any system can accept, display and handle these images
- Can be realized by mainly modifying of CT Image IOD and CT Enhanced IOD only
- Adaptation barrier low (no additional format needed)
- No mis-interpretation with native clinical CT images due to clear visual difference
- Multiple Materials are supported with Enhanced CT IOD (multiple dimensions)

<u>Drawbacks:</u>

- Images are not always self-explaining
- Single material support in Standard Image IOD

WW2.3 VARIOUS DISCUSSIONS ON SEGMENTATION IMAGES

1. Segmentation/Parametric IODs are Multiframe objects. What would be a relation between Material Quantification and Material Segmentation images (1-to-1, N-to-1)?

2. Segmentation IOD is based on Anatomy – shall be replaced/extended to Material add new code for 7150; link out CID to CID 7151

3. Segmentation is referencing sources images. What is “source” in ME case? Ask WG6; maybe we can skip this referencing

4. Segmentation/Parametric IODs do not include the full set of acquisition and other modality-specific parameters of any acquired images from which they were derived, e.g., cardiac phase. An application rendering or processing them may need to access the source images for such information. Shall these attributes be included?

5. There is no clear/significant advantage of using floating point pixel values – an essential feature of Parametric Map.

6. Can we use Enhanced CT IOD with 2nd dimension describing multiple materials?

7. Comment (RR) on Probability Map: Urate or non-Urate classification as numbers (e.g. kidney stones). Calculation formula for values: ((Xlow-BASElow)/(Xhigh-BASEhigh) – Threshold) * SCALE; SCALE can be e.g. 100. Effective atomic number at small kidney stones is very difficult (partial volume effects).

8. Some concern that for our purposes there may be gaps in the metadata of the segmentation object. Does the segmentation object depend on the presence of a referenced source image for various anatomical and clinical details? Or can the segmentation object stand-alone without an accessible source object. In our case, we do not have a source object in the same sense since the “segmentation” material object is generated directly/computationally from sinogram data.

9. Is 8 bits sufficient? precision = 1/256 (0.004) – calc the same for mg/ml – TODO

TODO:

1) In this doc we need to document segmentation property category (for material) and segmentation property types for all the materials (CID-X1).

2) Draft paragraph/example how seg attributes would be set for our use cases for 3 types of Mat. Segmentation/Labeling

3) Open issue: ask WG6 whether we need a new IOD based on Seg IOD that includes Acq module etc. or generic Seg IOD is appropriate

4) Sketch a few ME display use cases and what mechanisms might be used to support them. Open issue: what kind of normative/informative text around these use cases.

5) Is it appropriate/feasible to use RWVM for any of this?

To put into the informative annex: Profile the use of Segmentation IOD for ME mapping

Closed Questions:

1. Do we want to include visualization techniques within Seg. Object? - NO
2. No color support - does this hurt? No, since we don’t include visualization techniques.
3. Shall we have “all-in-one” object (conventional HU pixels plus material segmentation maps)? – NO

WW3 IOD FOR MATERIAL VISUALIZATION IMAGES

Use Cases for Material Visualization:

- Highlighting of materials that are not well separated from others.
- Increasing the HU value of tendons compared to muscle based on dual energy information. → Better VRT visualization
- Coloring of kidney stones and bone removal
- Coloring of gout

Presentation patterns:

1) Color overlay on gray scale images vs. pseudo-color image

- Color overlay example: Gout crystals with different concentration to be visualized with different color shades – use Segmentation IOD?
- Pseudo-color example: tissue characterization

2) Blending different ME image types – use existing Blending PS IOD?

3) “Simple” color map (e.g., for Eff. AN or El. Density)

Do we need Standardized Color Maps?