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
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09-15	19. Jan 2016	Updated in WG21 Meetings
16	13. Sept 2016	Updated in WG21 Meeting before presentation to WG06

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
Add an Annex with examples of implementation (ME- Image Material Segmentation, Material Quantification, …)	
Define examples for each ME-Image Type. This will be added to Part 17. Check during that work if parameters are sufficient. (in work)	Each vendor

OPEN ISSUES

1	Alternative solution for defining the Acquisition is to have a “SourceSequence” (that constitutes multiple pass, multiple switching, and or multiple tube), a “DetectorSequence” (that constitutes multiple detectors, multiple layers and or multiple photon bins) and a Path Sequence (lists the source and bin used create each data set and the weight to apply). Advice from WG06 is needed.

2	A naïve display system can receive a ME-image and will not recognize it as ME-image but rather display the image as a conventional CT image. What risks does this pose and how shall we mitigate them? **Examples of potential clinical misinterpretation** 1. For virtual mono-energetic images (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 ME 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 ME 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. ~~3.~~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.
3	Multi-energy CT Image Characteristics for Enhanced CT Images is Type U, because it is very hard to define a condition. The different ME image families do not require a characteristic in all cases.

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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. Therefore 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)
22	Rework of Segmentation into CT IOD (Standard and Enhanced) WG21: After discussion about the proposals of WG06 about the usage of Segmentation IOD, we came to the conclusion to skip this approach and follow the idea of self-contained objects. This was mainly because of the importance of the CT Acquisition parameters available for the interpretation of the images. We try to enrich the ME-Image section by the needed attributes for Discrete, Probability and Proportional Image Types.
23	Proposals for different solutions for Visualization
24	Provide description of capabilities of viewers of different levels (with their limitations) (SG) and get a risk assessment (DC) PowerPoint created for WG06 review
26	Work through Mark Armstrong (ACR) to get radiologist to enumerate the risks if any – after having examples from Diana and Shuai
27	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 VNC. -> Add a note in the contrast tags/module which says: even in VNC these tags are to be filled with contrast information Done (see Note extension)

28	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. We will not address this in this supplement. It is an open topic for the next wg21 work item.
29	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. Defined in the supplement
30	Are there any safety issues for mixed ME-Images and represented as Standard CT Image? Moved to the list of concerns and shall be extended through reviewer comments.
31	As I could find out, the standard practice (including Radiotherapy) is to define Electron Density indeed as a relative (normalized to water) ED/EDWater ratio (N/Nw), where N is number of electrons per unit volume, and Nw is number of electrons in the same unit of water (3.47 *10^22 electrons per cubic centimeter) at standard temperature (room temperature of 25 centigrade, or, more accurately, 300 Kelvin) and pressure (1 atmosphere). The actual (World Value) range will be between 0 and 3 or 4. In order to allow sufficient dynamic range and accuracy for the ED values, and at the same time to align with the common usage of 12-bit values for CT IOD, I would suggest to use Rescale Intercept = 0 and Rescale Slope = 0.001, but of cause we can leave for a vendor to define the appropriate Rescale values. Using Rescaling of 0.001 might give problems for systems that can't handle small (floating point) values for windowing as your window width will be in the range of 3 to 4. It might be better to use the Real World Value Mapping Sequence (0040,9096) and make that mandatory to avoid this problem. Would be the first but as you are introducing new type of data it might be good to make this step. RealWorldValue Mapping may not solve this issue due to missing implementations. Otherwise PET images are widely spread and need a similar scaling capability. Therefore the risk is considered not high.

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

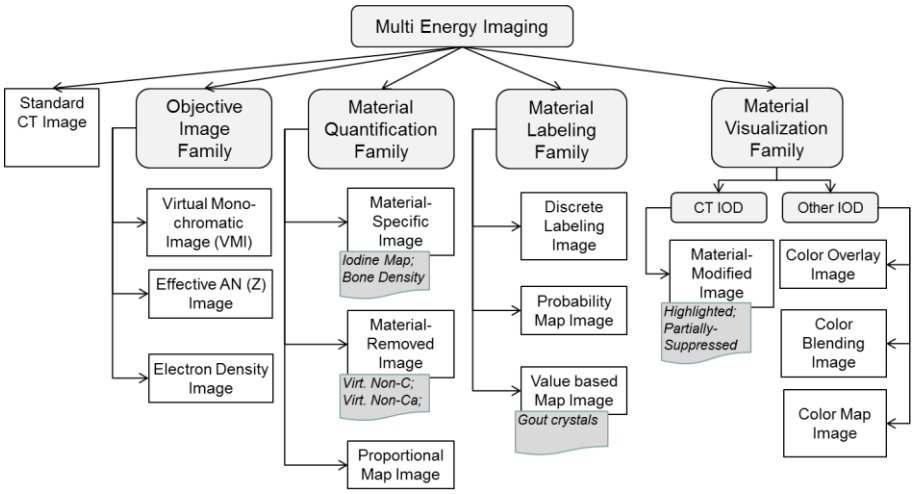
Z.3 OBJECTIVES

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 MUNLTI-ENERGYE 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).

Objective Images:

- **Effective Atomic Number Image (EANI)**. 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 (units 10^{23} /cc) or a relative ED/ED_{Water} ratio (N/Nw). 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).~~
- **Virtual Monochromatic Image (VMI).** Each pixel represents values of CT Hounsfield units and~~This is essentially a CT image that~~ is analogous to a~~n~~ CT 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:

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WG 06:
Move parts to Part 17 later!!

- **Material-Specific Image.** Each pixel value represents ~~Image presenting~~ the density of a specific material.

- **Material-Removed Image**. ~~Image with one or more materials removed.~~ Pixel values may have been corrected for displacement of one material by another material (i.e. VNC, VNCa). Image with one or more materials removed.

- **Proportional Map Image.** Each pixel value represents ~~Pixels describe~~ the proportional part of a material (mass mixing fraction/ration) comprising this pixel.

Material 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.** Each pixel represents an index corresponding to one or more materials from a list/vector of the known materials

- **Probability Map Image.** Each pixel represents the probability that this pixel contains certain specified material, regardless of its amount.

- **Value based Map Image.** Each pixel represents a certain value for a specified material range (the exact interpretation of the value 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.)

- **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. (i.e. tendon enhancement Image)

- **Color Image.** 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

Multi-energy Attributes Organization Structure – for reference only:

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- C.8.2.1 CT Image Module
  - Table X-1 “Multi-energy CT Macro Attributes" (added)
    - Multi-energy CT Acquisition Sequence (1C)
      - >Table X-4 “Multi-energy CT Acquisition Macro Attributes”
        - Table X-3 “Common CT Acquisition Macro”

- Multi-energy CT Processing Sequence (1C)
  - >Table X-5 “Multi-energy CT Processing Macro Attributes”
- Multi-energy CT Characteristics Sequence (1C)
  - >Table X-2 “Multi-energy CT Characteristics Macro Attributes”

- C.8.15.3.9 CT X-Ray Details Macro (for Enhanced CT IOD only)
  - CT X-Ray Details Sequence

Changes to NEMA Standards Publication PS 3.2

Digital Imaging and Communications in Medicine (DICOM)

Part 3: Information Object Definitions

<*Modify CT Contrast/Bolus Module ~~modifications~~ due to Multi-energy Image Format*>

C.7.6.4 CONTRAST/BOLUS MODULE

Note:

1. Flow duration is an alternate method of specifying stop time
2. Flow rate allows for stepped injections by being capable of multiple values (1,N) instances.
3. For a 100 ml injection of 76% Diatrizoate and meglumine/sodium, diluted 1:1,
   - the Contrast/Bolus Agent would be "76% Diatrizoate" as text
   - the Contrast/Bolus Volume would be 100 ml,
   - the Contrast/Bolus Total Dose would be 50 ml,
   - the Contrast/Bolus Ingredient would be "IODINE",
   - the Contrast/Bolus Ingredient Concentration would be 370mg/ml.
4. **Even if images are processed where contrast information is removed from pixels, e.g. in Virtual Non-Contrast, these attributesshall be present.**

<*Modify 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 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 CT Multi-energy Flag (xxx1,yyy1) is absent or N**, output units shall be Hounsfield Units (HU).
Rescale Type	(0028,1054)	1C	Specifies the output units of Rescale Slope

Attribute Name	Tag	Type	Attribute Description
			(0028,1053) and Rescale Intercept (0028,1052). See Section C.11.1.1.2 **and C.8.2.1.1.X1** for Defined Terms and 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.**
…			
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.**

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Attribute Name	Tag	Type	Attribute Description
X-Ray Tube Current	(0018,1151)	3	X-Ray Tube Current in mA. **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.**
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"			

< 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.4**	**C - Required if the image is acquired by means of multi-energy technique.**
Multi-energy CT Material Processing	**X.5**	**C - Required if the image pixel data contains the results of multi-energy material processing.**
Multi-energy CT Image Characteristics	**X.2**	**U**

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<*Modify 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_REMOVED **a Material-Removed Image**

MAT_PROPORTIONAL **a Material-Proportional Image**

EFF_ATOMIC_NUM **an Effective Atomic Number Image**

ELECTRON_DENSITY **an Electron Density Image**

MAT_MODIFIED **a Material-Modified Image**

MAT_LABELING **a ~~Material~~ Material-Labeling Image**

Note

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

Note:

Multi-energy images except Material Labeling Images ~~Virtual Monochromatic and Material Quantification~~ are not necessarily ~~derived~~ DERIVED and may be ORIGINAL\PRIMARY

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

< Add *Rescale Type ~~added~~ to CT Image Attribute Descriptions ~~section~~ due to Multi-energy CT Image* Format>

C.8.2.1.1.X1 Rescale Type

Specifies the units of the output of the rescale operation.

Defined Terms:

Commented [RR2]: Check for explanation of each of the terms
Yes – see introduction

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HU
Hounsfield Units (CT);

MGML
mg/ml;

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

ED
10^{23} electrons/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;

PCT
Percentage (%)

< Add *Multi-energy Rescale Type mapping table to CT Image Attribute Descriptions due to Multi-energy CT Image* Format>

C.8.2.1.1.X2 Relationship for Multi-energy Image Type to Rescale Type mapping

Table C.8.2.1.1.X2-1 Relationship for Multi-energy Image Type to Rescale Type mapping

Image Type	Recommended Rescale Type
Objective Image Family	
Virtual Mono-chromatic Image	HU
Effective AN (Z) Image	Z_EFF
Electron Density Image	ED/EDW
Material Quantification Family	
Material-Specific Image	MGML
Material-Removed Image	HU/HU_MOD
Proportional Map Image	PCT
Material Labeling Family	

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Image Type	Recommended Rescale Type
Discrete Labeling Image	US
Probability Map Image	PCT
Value based Map Image	US
Material Visualization Family	
Material-Modified Image	HU_MOD

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< Add ~~New section~~ *Multi-energy CT Macro Attributes due to Multi-energy CT Image Format* >

X.1 MULTI-ENERGY CT MACRO ATTRIBUTES

Commented [RR3]: Go on with WG06

Table X-1 specifies the Multi-energy attributes to enhance the CT Image Module

Table X-1 Multi-energy CT Macro Attributes

Attribute Name	Tag	Type	Attribute Description
CT Multi-energy Flag	(xxx1,yyy1)	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 Macro Sequence	(xxx1,yyy2)	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 (xxx1,yyy1) is equal Y
>Include Table X-4 "Multi-energy CT Acquisition Macro Attributes"			

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Question to WG06
How about existing implementations, which create ME-Images. Are they invalid as soon as the new standard will be released?
-> Type 3?

Attribute Name	Tag	Type	Attribute Description
Multi-energy CT Processing Macro Sequence	(xxx1,yyy3)	3	Method and result of the processing of the acquired projection data. Only a single Item shall be included in this Sequence.
> *Include Table X-5 "Multi-energy CT Material Processing Macro Attributes"*			
Multi-energy CT Characteristics Macro Sequence	(xxx1,yyy4)	1C	Sequence that describes the attributes of a Multi-energy Image. Only a single Item shall be included in this Sequence. Required if CT Multi-energy Flag (xxx1,yyy1) is equal Y
>*Include Table X-2 "Multi-energy CT Characteristics Macro Attributes"*			

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X.2 MULTI-ENERGY CT IMAGE CHARACTERISTICS ATTRIBUTES

270 This macro specifies the common attributes for CT Image Characteristics.

Table X-2 Multi-energy CT Image Characteristics Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Monochromatic Energy Equivalent	(xxx2,yyy1)	1C	Monochromatic equivalent in keV. Required if Type Value 4 is EQUAL to VMI. May be present otherwise. Note: If VMI image is used as source for Material Removed or Material Modified Image, then this value reflects the keV Value of this VMI image
Monochromatic Algorithm Identification Description	(xxx2,yyy2)	3	Description of algorithm used to create the monochromatic image.
Multi-energy Quantification CT Image Sequence	(xxx2,yyy3)	1C	Sequence that describes the attributes of a Multi-energy Quantification Image. Only a single Item is permitted in this sequence. Required if Type Value 4 is EQUAL to MAT_SPECIFIC or MAT_REMOVED

Attribute Name	Tag	Type	Attribute Description
			MAT_MODIFIED or MAT_PRPORTIONAL. May be present otherwise.
>Include Table X-6 "Multi-energy Quantification Macro Attributes"			
Multi-energy Labeling CT Image Sequence	(xxx2,yyy4)	1C	Sequence that describes the attributes of a Multi-energy Image. Only a single Item is permitted in this sequence. Required if Type Value 4 is EQUAL to MAT_LABELING. May be present otherwise.
>Include Table X-7 "Multi-energy Labeling CT Image Macro Attributes"			

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

X.3 COMMON CT ACQUISITION ATTRIBUTES

This macro specifies the common attributes for CT Acquisition.

Table X-3 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)	1C	The exposure expressed in milliampere seconds, for example calculated from exposure time and X-Ray tube current. Required if Multi-energy Source Technique (xxx4,yyy3) not equal “SWITCHING_SOURCE” May be present otherwise.
Exposure Time	(0018,1150)	1C	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.

			Required if Multi-energy Source Technique (xxx4,yyy3) not equal “SWITCHING_SOURCE” May be present otherwise.
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.*

278 < ~~New~~ Add *sections due to Multi-energy CT Image Format>*

X.4 MULTI-ENERGY CT ACQUISITION MACRO

280 This macro defines Multi-energy CT acquisition attributes.

Table X-4. Multi-energy CT Acquisition Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Multi-energy CT Acquisition Sequence	(xxx4,yyy1)	1	
>X-Ray Source ID	(xxx4,yyy2)	1	Unique number of a X-Ray source
>Manufacturer's Model Name	(0008,1090)	3	Manufacturer's model name of the X-Ray source.
>Multi-energy Source Technique	(xxx4,yyy3)	1	Technique used to acquire Multi-energy data. Defined Terms: **SWITCHING_SOURCE** a X-Ray source (tube) is used with beam mode switching **CONSTANT_SOURCE** a conventional X-Ray source (tube) is used
>Switching Phase	(xxx4,yyy4)	1C	Unique number to identify the switching phase

Commented [RR5]:
Question to WG 06: Consider advice about providing a configuration panel setting for 3rd party service to update the system value for this field

Attribute Name	Tag	Type	Attribute Description
			Required if Multi-energy Source Technique (xxx4,yyy3) contains “SWITCHING_SOURCE”.
>Switching Phase Nominal Duration	(xxx4,yyy5)	3	Duration, in microseconds, that the energy is in the target range for this switching phase. Applicable if Multi-energy Source Technique (xxx4,yyy3) contains “SWITCHING_SOURCE”.
>Switching Phase Transition Duration	(xxx4,yyy6)	3	Duration, in microseconds, during which the energy has left the target range for this switching phase, but has not yet reached the target range for the next. Applicable if Multi-energy Source Technique (xxx4,yyy3) contains “SWITCHING_SOURCE”.
>*Include Table X-100 “Common CT Acquisition Macro Attributes”*			See X.4.1
>X-Ray Detector ID	(xxx4,yyy7)	1	Unique number identifying the X-Ray detector
>Multi-energy Detection Technique	(xxx4,yyy8)	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 Bin Sequence	(xxx4,yyy9)	3	The attributes of energy detector bins. One or more items shall be included in this sequence.
>>Bin ID	(xxx4,yy10)	1	Describes a unique number of the Bin for the acquisition
>>Mean Photon Energy	(xxx4,yy11)	1C	Mean energy in keV of detected photons in this bin with empty gantry (air scan); photon flux detected in the detector bin and weighted by respective generated signal. Required if Multi-energy Detection Technique (xxx4,yyy8) is PHOTON_COUNTING
>>Max Bin Energy	(xxx4,yy12)	3	Nominal maximum energy in keV of photons that are integrated/counted by the detector in this bin.
>>Min Bin Energy	(xxx4,yy13)	3	Nominal minimum energy in keV of photons that are integrated/counted by the detector in this bin.

Commented [RR6]:
Question to WG06: Requested by Clinicians (may not be filled by vendors). What is the advice to go on with that.

>>Bin Weighting Factor	(xxx4,yy14)	1C	The weighting factor of the data from this Bin in a multi energy composition image. Required if one Derivation Code Sequence (0008,9215) Item value is (113097, DCM, "Multi-energy proportional weighting"). Sum of Bin Weighting Factors shall be 1
>Energy Weighting Factor	(xxx4,yy15)	1C	The weighting factor of the data from this 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 one Derivation Code Sequence (0008,9215) Item value is (113097, DCM, "Multi-energy proportional weighting").and Bin Weighting Factor is not present. Sum of Beam weighting factors shall be 1
>Acquisition Number	(0020,0012)	1C	A number identifying the single continuous gathering of data over a period of time that resulted in this image. This is not the ID of this item of the Sequence Required if more than one scan pass is used, May be present otherwise
>Acquisition Date	(0008,0022)	1C	The date the acquisition of data that resulted in this image started Required if more than one scan pass is used, May be present otherwise
>Acquisition Time	(0008,0032)	1C	The time the acquisition of data that resulted in this image started Required if more than one scan pass is used, May be present otherwise
>Multi-energy Acquisition Description	(xxx4,yy16)	3	Human readable description of the Multi-Energy Acquisition

X.4.1 USAGE OF MULTIPLE FILTER SETTINGS

Multi-filter have to be careful described by two items with different filter descriptions.

Example:

correct: A+B for path one, A+C for path 2

wrong:A+B+C

X.5 MULTI-ENERGY CT PROCESSING MACRO

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

Table X-5 Multi-energy CT Processing Attributes

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Attribute Name	Tag	Type	Attribute Description
Decomposition Method	(xxx5,yyy1)	1	Defined Terms: **PROJECTION_BASED** the acquired projection data was decomposed into basis projection data (i.e. sinograms) **IMAGE_BASED** the acquired projection data was reconstructed into images before being decomposed into basis image data **Notes:** 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	(xxx5,yyy2)	3	Description of decomposition method
Decomposition Algorithm Identification Sequence	(xxx5,yyy3)	3	Algorithm used for decomposition of the acquired data One or more Items are permitted in this Sequence.
>Decomposition Algorithm Identification Description	(xxx5,yyy4)	3	Description of decomposition algorithm
Decomposition Sequence	(xxx5,yyy5)	3	Materials used to create result images.
>Material Code Sequence	(xxx5,yyy6)	1	Nominal material for Multi-energy CT processing Only a single Item shall be included in this Sequence
>>Include Table 8.8-1-a "Basic Code Sequence Macro Attributes"			Baseline CID is CID-X1
> Material Attenuation Sequence	(xxx5,yyy7)	3	Attenuation curve of the material Two or more Items shall be included in this Sequence. Note: Attenuation curves for non standard materials can be generated by NIST http://physics.nist.gov/PhysRefData/Xco

Attribute Name	Tag	Type	Attribute Description
			m/html/xcom1.html
>> Photon Energy	(xxx5,yyy8)	1	Photon energy in keV
>>X-Ray Mass Attenuation Coefficient	(xxx5,yyy9)	1	Attenuation of this material at the specific Photon energy. Normalized to material density.

294 **X.6 MULTI-ENERGY QUANITIFICATION MACRO ATTRIBUTES**

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

296 **Table X-6 Multi-energy Quantification Macro Attributes**

Attribute Name	Tag	Type	Attribute Description
Material Modification Description	(xxx6,yyy1)	3	Human-readable description of the material modifications made to this image
Specific Material Code Sequence	(xxx6,yyy2)	1C	The specific material present in this image. Only a single item shall be present. Required if Image Type Value 4 is MAT_SPECIFIC or MAT_PROPORTIONAL May be present otherwise
>Include Table 8.8-1-a "Basic Code Sequence Macro Attributes"			Baseline CID is CID-X1
Material Modification Sequence	(xxx6,yyy3)	1C	Materials that have been intentionally affected when the image was created. Required if Image Type Value 4 is MAT_MODIFIED or MAT_REMOVED May be present otherwise One or more items shall be present.
>Modification Type	(xxx6,yyy4)	1	Type of modification applied to this material 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 modified material (opposite to HIGHLIGHTED) **COMPENSATED** – CT Image where pixel values have been modified to remove specific material components. **RECALCULATED** – pixels are recalculated by vendor-specific method
>Material Code Sequence	(xxx5,yyy6)	2	The modified material. Only a single item shall be present.

Attribute Name	Tag	Type	Attribute Description
>>Include Table 8.8-1-a "Basic Code Sequence Macro Attributes"			Baseline CID is CID-X1
>Correction Value	(xxx6,yyy6)	1C	The constant value used to replace the affected pixels Required if Modification Type is SUBTRACTED
>Modification Description	(xxx6,yyy7)	3	Common description of the modification action on the image pixels.

X.7 MULTI-ENERGY LABELING MACRO ATTRIBUTES

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

Table X-7 Multi-energy Labeling Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Material Labeling Type	(xxx7,yyy1)	1	Describes the type of material labeling. Defined Terms: **DISCRETE** – Image where pixel value is an index corresponding to one or more materials specified by the Material Labeling Sequence attribute **PROPORTIONAL** – Image where pixel value describes proportional part of the material (mass mixing fraction/ration) comprising this pixel. This material is specified by the Specific Material Code Sequence attribute. Rescale Slope shall be used to express the fraction value. **PROBABILITY** – Image where pixel value describes the probability that this pixel is classified as the material specified by the Specific Material Code Sequence attribute. Rescale Slope shall be used to express the fraction value. **VALUEBASED** – Image pixel with concrete values which represent a characteristic of the chemical differences, optimized for the materials coded in the Specific Material Code Sequence attribute.
Material Labeling Sequence	(xxx7,yyy2)	1	Materials that are labeled in this image. IF Material Labeling Type is PROPABILITY only a single Item shall be present

Attribute Name	Tag	Type	Attribute Description
>Include Table 8.8-1-a "Basic Code Sequence Macro Attributes"			Baseline CID is CID-X1
>Material Index	(xxx7,yyy3)	1C	Index that is used in image pixel values. Index 0 is used to indicate no material. Required if Material Labeling Type is DESCRETE
>Material Value Range	(xxx7,yyy4)	3	Multi value range definition for the specific material MIN/MAX for Material Labeling Type VALUEBASED

304 **Changes to NEMA Standards Publication PS 3.6-2011**

Digital Imaging and Communications in Medicine (DICOM)

306 **Part 6: Data Dictionary**

Add the following rows to Section 6

Tag	Name	Keyword	VR	VM
(xxx1,yyy1)	CT Multi-energy Flag	CTMultiEnergyFlag	CS	1
(xxx1,yyy2)	Multi-energy CT Acquisition Macro Sequence	MultiEnergyCTAcquisitionMacroSequence	SQ	1
(xxx1,yyy3)	Multi-energy CT Processing Macro Sequence	MultiEnergyCTProcessingMacroSequence	SQ	1
(xxx1,yyy4)	Multi-energy CT Characteristics Macro Sequence	MultiEnergyCTCharacteristicsMacroSequence	SQ	1
(xxx2,yyy1)	Monochromatic Energy Equivalent	MonochromaticEnergyEquivalent	DS	1
(xxx2,yyy2)	Monochromatic Algorithm Identification Description	MonochromaticAlgorithmIdentificationDescription	ST	1
(xxx2,yyy3)	Multi-energy Quantification CT Image Sequence	MultiEnergyQuantificationCTImageSequence	SQ	1
(xxx2,yyy4)	Multi-energy Labeling CT Image Sequence	MultiEnergyLabelingCTImageSequence	SQ	1
(xxx4,yy10)	Bin ID	BinID	US	1
(xxx4,yy11)	Mean Photon Energy	MeanPhotonEnergy	DS	1
(xxx4,yy12)	Max Bin Energy	MaxBinEnergy	DS	1
(xxx4,yy13)	Min Bin Energy	MinBinEnergy	DS	1

Tag	Name	Keyword	VR	VM
(xxx4,yy14)	Bin Weighting Factor	BinWeightingFactor	DS	1
(xxx4,yy15)	Energy Weighting Factor	EnergyWeightingFactor	DS	1
(xxx4,yy16)	Multi-energy Acquisition Description	MultiEnergyAcquisitionDescription	ST	1
(xxx4,yyy1)	Multi-energy CT Acquisition Sequence	MultiEnergyCTAcquisitionSequence	SQ	1
(xxx4,yyy2)	X-Ray Source ID	XRaySourceID	US	1
(xxx4,yyy3)	Multi-energy Source Technique	MultiEnergySourceTechnique	CS	1
(xxx4,yyy4)	Switching Phase	SwitchingPhase	US	1
(xxx4,yyy5)	Switching Phase Nominal Duration	SwitchingPhaseNominalDuration	DS	1
(xxx4,yyy6)	Switching Phase Transition Duration	SwitchingPhaseTransitionDuration	DS	1
(xxx4,yyy7)	X-Ray Detector ID	XRayDetectorID	US	1
(xxx4,yyy8)	Multi-energy Detection Technique	MultiEnergyDetectionTechnique	CS	1
(xxx4,yyy9)	Energy Bin Sequence	EnergyBinSequence	SQ	1
(xxx5,yyy1)	Decomposition Method	DecompositionMethod	CS	1
(xxx5,yyy2)	Decomposition Description	DecompositionDescription	ST	1
(xxx5,yyy3)	Decomposition Algorithm Identification Sequence	DecompositionAlgorithmIdentificationSequence	SQ	1
(xxx5,yyy4)	Decomposition Algorithm Identification Description	DecompositionAlgorithmIdentificationDescription	ST	1
(xxx5,yyy5)	Decomposition Sequence	DecompositionSequence	SQ	1
(xxx5,yyy6)	Material Code Sequence	MaterialCodeSequence	SQ	1
(xxx5,yyy7)	Material Attenuation Sequence	MaterialAttenuationSequence	SQ	1
(xxx5,yyy8)	Photon Energy	PhotonEnergy	DS	1
(xxx5,yyy9)	X-Ray Mass Attenuation Coefficient	XRayMassAttenuationCoefficient	DS	1
(xxx6,yyy1)	Material Modification Description	MaterialModificationDescription	ST	1
(xxx6,yyy2)	Specific Material Code Sequence	SpecificMaterialCodeSequence	SQ	1
(xxx6,yyy3)	Material Modification Sequence	MaterialModificationSequence	SQ	1
(xxx6,yyy4)	Modification Type	ModificationType	CS	1
(xxx6,yyy6)	Correction Value	CorrectionValue	DS	1
(xxx6,yyy7)	Modification Description	ModificationDescription	ST	1

Tag	Name	Keyword	VR	VM
(xxx7,yyy1)	Material Labeling Type	MaterialLabelingType	CS	1
(xxx7,yyy2)	Material Labeling Sequence	MaterialLabelingSequence	SQ	1
(xxx7,yyy3)	Material Index	MaterialIndex	US	1
(xxx7,yyy4)	Material Value Range	MaterialValueRange	DS	2

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
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)