Digital Imaging and Communications in Medicine (DICOM)

Supplement 188: Multi-energy CT Images

Prepared by:

DICOM Standards Committee, Working Groups 21

1300 N. 17th Street, Suite 900

Rosslyn, Virginia 22209 USA

VERSION: Public comment

Developed pursuant to DICOM Work Item WI-2013-08-A

Table of Contents

72 **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
07	17 Sept 2015	Updated before WG06 FR
08	18 Sept 2015	Updated after WG06 FR
09-15	19. Jan 2016	Updated in WG21 Meetings
16	13. Sept 2016	Updated in WG21 Meeting before presentation to WG06
17	11.Nov 2016	Updated after WG06 T-CON

OPEN ISSUES

1	A naïve display system can receive a multi-energy (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 (VMI, images similar to those obtained with mono-energetic x-ray beam, in keV), attenuation highly depends on the beam energy (keV), so CT pixel values in VMI images can be very different from those in conventional CT images. Without proper labeling of such images, including the specific keV value used, the reviewer can come to wrong conclusions. 2. HU-based 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. 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.
2	Which condition for ME CT Image Characteristics can be defined to make it mandatory? ME 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.
3	Is there a need to support synthetic KVP? Currently we support the possibility to set the attributes for KVP in the standard CT Image. The KVP attribute can be used in case of synthetic KVP in a Multi-energy CT Image. This means the image is identical as if it was generated by a single energy acquisition. Decision: We start with a new attribute for “synthetic” KVP (RR).

Commented [OK1]: Rob: Since kvp is Type 2, leave it empty; software has to be prepared for it to be missing since it's Type 2. New attributes for Synthetic KVP and Synthetic KVP Derivation Method – 1C if the value in KVP is synthetic, so existing viewers say KVP is missing, new viewers can look at the attribute and flag/explain to the user.

Commented [CHM2]: Is synthetic KVP really what is meant here? KVP is the peak tube potential setting on the x-ray tube and there is no way to synthesize this. There is however a synthetic keV virtual monoenergetic image. Is that is what is being talked about?

Commented [OK3]: Reinhardt – If two images with different kvp are blended, what do you put in the kvp of the blended image? A "nominal" kvp?
Cynthia – if it "behaves" like a 120 then we could put 120 but there is no standard method to choose what number to put there. It's not just "the number in the middle"
Juan – might be what the user/operator chooses.
Shuai – so we need a number in the header, but can't define how its populated. So it should not be required, and it should be clear this is "effective" not the "real" kvp.
Reinhardt – so we should use a different tag and leave kvp empty in this case.
Cynthia – agree. Different tag, could be confusing for dose calculations etc. Might need a tag to describe the method they used to derive the effective kv. If it's a well defined set of a few methods we can use a code list. If it could vary per person, then a text description.

Commented [AF4]: This is confusing to me. A 120 keV VMI would not look like a 120 kVp image, if I am interpreting this correctly. In my opinion kVp and keV should be clearly differentiated, as the difference may otherwise be missed by a clinical audience.

Commented [MPS5]: Yes, I think. And this is tied up with open issue 1, a single solution to address both of these is needed

4	Is there a reasonable value for Exposure ms and Exposure mAs for each phase when using a switching source? Currently within the Multi-Energy Image the Exposure ms and Exposure mAs are excluded. The difficulty of providing an accurate exposure time (in ms) or exposure (tube current and time product, in mAs) lies in the fact that tube potential (kV) switching doesn't happen immediately, it takes a short but non-zero time. This means there is a transition period that the tube potential is in between of the low and high kV. This transition period can't be ignored as that would underestimate the exposure time and exposure for each kV. However, it is difficult to accurately determine which part of the transition period belongs to which kV, which consequently makes it difficult to provide accurate information about exposure time or exposure for the switching source technology. Proposal will consider these aspects (Brad). Nominal attributes for "recalculated" attributes e.g. "Nominal Exposure mAs". Explain, what you can use the nominal value (e.g. in calculation of dose).
5	Are there sufficient codes for the different modification types defined in this supplement (see Material Modification Sequence (xxx8,yyy3))?
6	Is there any problem with defining Image Type value 1 and 2 for Multi-Energy images to be ORIGINAL/PRIMARY for all images?
7	Suggest an appropriate place in the standard for Section Z.4 CLASSIFICATION OF MULTI-ENERGY IMAGES.
8	Part 17 will be provided with letter ballot and will include: • Add an Annex with examples of implementation (ME- Image Material Segmentation, Material Quantification, …) • Examples for each ME-Image Type. Is this sufficient, or do we need to add more information on Multi-energy images?
9	Question to WG06: Shall Color Images be defined in this supplement or to leave it out of scope of the supplement? Color images are just defined like in the existing standard. Mention it can be done but don't go into details. It is entirely possible that in the future, specific color needs will become apparent and modifications to existing color mechanisms or creating a new IOD may be done at that time. – Can close this issue.

Commented [MPS6]: Assuming it is always going to be split evenly, I see nothing wrong with half the gantry rotation time for the exposure

Commented [OK8]: Cynthia – dwell time might not be the same at each. Definitely different in some implementations.
Shuai – have the nominal and actual phase duration (considers transition time) so seems like this could be filled.
Brad – depends on hardware and other factors so it might not be accurately "predictable" so basing calculations on it might not be appropriate.

TODO WG-21 will try to propose a solution that considers this concept.

Commented [OK7]: Rob: Consider prohibiting these attributes since they "don't mean the same thing" and alternate attributes that populate what we DO know. Nominal is fine IF you are confident you have a good calculation for it.
Kevin: Cynthia's comment about using a value that corresponds to what it "looks like".
Kevin: For Dose purposes, we need updates to RDSR and should steer people away from using the header values for dose tracking. Header should be geared toward diagnostics and image processing.
Wim: For the diagnostics, in some ways it seems like the MR transition to 3T where rads had to "relearn" how to interpret the images. So the old values being populated poorly doesn't really help. So leave them blank if you can then they can learn the new attributes.

Commented [OK9]: Wim: MR had the same kind of issues. Half of the PACS systems were rejecting the color LUT images. Presentation States (Blending or Non-blending) let you address color later.
Kevin: Likely workstations will have standard rendering patterns to the color information might not need to be externalized initially while we learn what we want to do.
Reinhard: Agree.

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 monoenergetic 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 monoenergetic 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	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

3	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.
4	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.
5	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.
6	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.
7	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 merge 70 KVP will result in equivalent to 90 KVP)
8	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.
9	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.

Commented [RGJ(NUDC10]: Not clear how this example possible in ME.

Commented [RR11]: See open issues (3)

Commented [MPS12]: What needs defining by AAPM or the working group? What should be included in the Image Quality Reference Parameter Field?

Commented [OK13]: Reinhart – For a CP we need a clear definition of the quality reference parameters from AAPM.
No urgent timing. Can publish without.
Mark – Will hold the discussion between the AAPM experts in WG-21 mailing list so we all stay on the same page.

10	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.

76

Scope and Field of Application

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

It introduces a description of ME imaging techniques. While different vendors apply different techniques to achieve ME Images, there is large commonality in the generated diagnostic images.

Z1. DEFINITIONS

Multi-energy CT Imaging:
Multi-energy (ME) CT imaging involves techniques, including scanning, reconstruction, and processing, and the use of multiple parts of the x-ray beam energy spectrum, whether source(s) generate different parts of the spectrum or the spectra are differentiated by the detector(s).

Z.2 USE CASES

- Key use cases of Multi-energy CT include:
- Allowing better differentiation of materials that look similar on conventional CT images, e.g., to differentiate Iodine and Calcium in vascular structures or to differentiate vascular structures from adjacent bone.
- Generate virtual non-contrast images from a contrast-enhanced image rather then having to scan the patient twice.
- Allowing to reduce beam hardening artifacts.
- Enhancing the effect of contrast such as Iodine and soft tissue

Z.3 OBJECTIVES

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

1. Making Multi-energy information available to rendering and processing applications and clinical display
2. To provide new essential ME information (acquisition, reconstruction and processing attributes) within the IOD.
3. To facilitate fast and easy adoption of this supplement across the imaging community, both modalities and PACS/Displays.
4. To minimize the risk of misinterpretation or incorrect measurements when ME images are displayed by a display that does not support the new attributes of the ME-image.
5. To adapt existing attributes of the CT / Enhanced CT IOD to fit ME techniques.

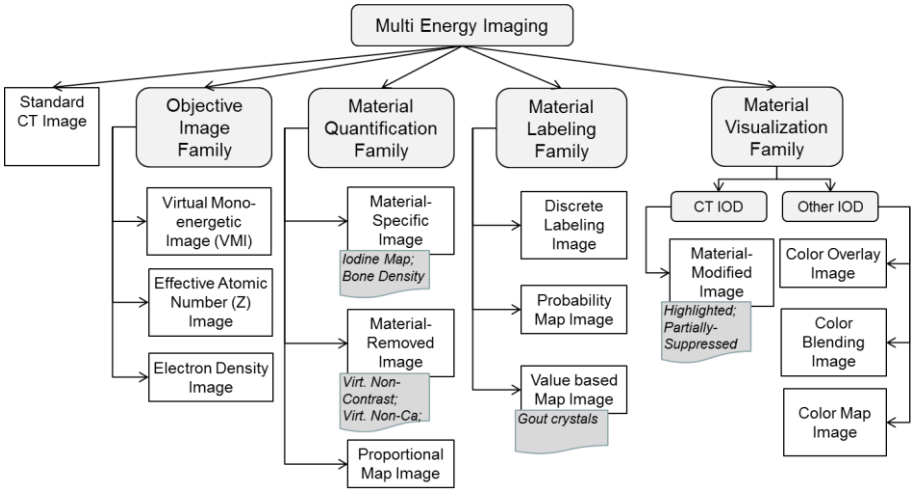
Commented [CHM14]: Be consistent throughout document. Either abbreviate ME everywhere after the first use or don't. But be consistent.

Commented [CHM15]: Can involve one spectrum or two, so any reference to spectra needs to be plural

Commented [AF16]: I believe this description could be phrased more accurately. A single energy CT image also uses multiple energies from the spectrum to generate an image. Rather, in ME CT two (or more) different x-ray spectra are use, or alternatively different portions of the same x-ray spectrum (e.g. photon counting CT).

Z.4 CLASSIFICATION OF MULTI-ENERGY IMAGES

The following ME Image Types and families are addressed in this supplement:



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

Objective Image Family:

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

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

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

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

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

- **Material-Removed Image**.
  An image with the attenuation contribution of one or more materials removed. Each pixel value

Commented [AF17]: Virt. Non-C – explicitly say virtual non-contrast
AN – explicitly say atomic number
-OK

Commented [CHM18]: Spell out AN (atomic number) in objective image family
- Ok

Commented [CHM19]: Is the data are acquired with two spectra,the images are not conventional. They may be conventional appearing but they are still ME. I suggest another term other than conventional here.

Commented [CHM20]: While some vendors use this term (monochromatic), as technically in physics and optics the term chromatic represents energy, most physicians are not familiar with this terminology and so in the clinical world the term multi-energetic is preferred. I suggest using both terms here once, noting their equivalency, and then sticking with multienergetic.

Commented [CHM21]: List in the same order that is given in the diagram

Commented [CHM22]: N has not been defined

Commented [CHM23]: How does user know if pixel value is absolute or relative. There should be a defined term for relative electron density.

Commented [RR24]: New definition shall be worked out.
-Shlomo & Shuai

may be adjusted to represent the attenuation as if the pixel was filled with the remaining materials. For pixels that did not contain any of the removed material(s), the pixel values are unchanged. For example, in virtual-unenhanced (VUE) or virtual-non-contrast (VNC) image the attenuation contribution of the contrast material is removed from each pixel.

- **Proportional Map Image.** Each pixel value represents the proportion of a specific material present in the pixel. Since Proportional Map Images are generated as a set, the sum of all the Proportional Map Images is 1 for each pixel.

Material Labeling Image Family: These image types classify materials, where each pixel identifies material(s) in that pixel. This can serve as the basis for visualization of different materials, e.g. for coloring of specific material, enhancing or suppressing certain materials. The following image types belong to this family:

- **Discrete Labeling Image.** Each pixel value is an index corresponding to one or more materials from a list or vector of the known materials
- **Probability Map Image.** Each pixel value is the probability that the pixel contains some amount of specified material.
- **Value-Based Map Image.** Each pixel represents a certain value for a specified material (the exact interpretation of the value range has to be defined by the user).

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

- **Material-Modified Image.** CT Image where pixel values have been modified to highlight a certain target material (either by partially suppressing the background or by enhancing the target material), or to partially suppress the target material. The image units are still HU, so they may be presented similarly to conventional CT Images.The values of some pixels in the Material-Modified Image are intentionally distorted for better visualization of certain materials (i.e. making tendon more visible). Thus the image may not be used for quantification, unlike Material-Removed Image which can.
- **Color Image.** Implementations of Material Visualization Images use existing DICOM objects (Blending Presentation State, Parametric Blending (with color LUT), Secondary Capture Image (used as fallback)). (Note that Enhanced CT IOD has color features as well)

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

Commented [RR25]: Reminder: Definition should capture this case of replacement.

Commented [OK26]: Wim: Can we use this to promote the Parametric Map IOD? There is a critical mass/chicken-egg problem. If you do fractional pixel values then windowing will break.
WG21 will continue to dicuss this topic. Where do we draw the line between what belongs in conventional IOD and what belongs in Parametric Maps etc.

Commented [RGJ(NUDC27]: Example?

Commented [RR28]: ToDo add an attribute for PMI to point to the other instances in a "set". Consider making a shall or explain the total sum of 1.
WG06: OK to point to the others. Just explain. Don't bother with a SHALL for the sum of 1. Not clear where you'd put the shall and there will be technical challenges to get it exactly right to many decimals.

Commented [CHM29]: Etc. is not used when e.g. is used

Commented [CHM30]: This is not clear.

Commented [CHM31]: Tendon enhancement is not a commonly used application. Iodine enhancement is and it makes more sense to use that example to make it clear where iodine maps overlaid on the original or mixed image belongs.

Commented [CHM32]: This isn't really a definition but tells more how color maps are treated. Can you make it a definition?

Commented [RR33]: Question to WG06: shall this be defined or to leave it out of scope of the supplement?

Commented [RR34]: Remove ore put it under Color Images?

Commented [AF35]: this paragraph seems out of place, as not related to the figure above. also, why only gout?if clinical examples should be included, then maybe we should mention the more relevant under each sub-image in the paragraphs above?

Commented [RR36]: WG21:
This is a example not a use case! Rethink

Commented [CHM37]: Is this supposed to be under or part of the color image section. It doesn't seem to fit into the pattern of this section. It seems to be implementation options about color images.

Changes to NEMA Standards Publication PS 3.3

Digital Imaging and Communications in Medicine (DICOM)

Part 3: Information Object Definitions

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

A.38.1.3 Enhanced CT Image IOD Module Table

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

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

IE	Module	Reference	Usage
Image	Image Pixel	C.7.6.3	M
	…		
	Frame Extraction	C.12.3	C - Required if the SOP Instance was created in response to a Frame-Level retrieve request
	Multi-energy CT Acquisition	**C.8.15.X1**	**C - Required if the image is acquired by means of multi-energy technique.**

Commented [OK38]: Can we use the Flag here instead of realworld condition – make sure it's not circular.

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

A.38.1.4 Enhanced CT Image Functional Group Macros

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

…		
CT Additional X-Ray Source	C.8.15.3.11	C - Required if the image is reconstructed from a system with multiple X-Ray sources
Multi-energy CT Processing	**C.8.15.3.X2**	**C - Required if the image pixel data contains the results of multi-energy material processing.**
Multi-energy CT Characteristics	**C.8.15.3.X1**	**U**

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

C.7.6.4 Contrast/Bolus Module

This Module shall be present even if images are processed where contrast information is removed from pixels, e.g. in Virtual Non-Contrast.

Commented [CHM39]: The rules for when to use Bold and underline aren't obvious so I followed the pattern started above.
WG21: Editor style for DICOM to track changes in the standard

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

C.8.2 CT Modules

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

190 #### C.8.2.1 CT Image Module

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

192 **Table C.8-3. CT Image Module Attributes**

Attribute Name	Tag	Type	Attribute Description
Image Type	(0008,0008)	1	Image identification characteristics. See Section C.8.2.1.1.1 for specialization.
…			
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 (xxx2,yyy1) is either absent or N**, output units shall be Hounsfield Units (HU).
Rescale Type	(0028,1054)	1C	Specifies the output units of Rescale Slope (0028,1053) and Rescale Intercept (0028,1052). See Section C.11.1.1.2 for Defined Terms and further explanation. Required if the Rescale Type is not HU (Hounsfield Units) **or CT Multi-energy Flag (xxx2,yyy1) is Y**. May be present otherwise.
…			
KVP	(0018,0060)	2	Peak kilo voltage output of the X-Ray generator used. **Shall be empty if this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are different.**
…			
Scan Options	(0018,0022)	3	Parameters of scanning sequence. **Shall be absent if this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.**
Data Collection Diameter	(0018,0090)	3	The diameter in mm of the region over which data were collected

Commented [MPS40]: For all the fields that would be absent if the values don't match that of the ME object… What would be case for all these for "mixed" or traditional CT image- if a mixed image is generated and used for interpretation we need some of these in traditional fields for overlays

WG21: corresponds to OpenIssue 3
Adding a new tag "nominal …"
Does this affect seriously the interpretation if it is empty.

Attribute Name	Tag	Type	Attribute Description
			Shall be absent if this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.
…			
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 this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.**
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 this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.**
X-Ray Tube Current	(0018,1151)	3	X-Ray Tube Current in mA. **Shall be absent if this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.**
Exposure	(0018,1152)	3	The exposure expressed in mAs, for example calculated from Exposure Time and X-Ray Tube Current. **Shall be absent if this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.**
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 this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.**
Filter Type	(0018,1160)	3	Label for the type of filter inserted into the x-ray beam. **Shall be absent if this Attribute is present in Multi-energy CT Acquisition Sequence**

Attribute Name	Tag	Type	Attribute Description
			(xxx2,yyy2) and the values are not the same in all Items.
Generator Power	(0018,1170)	3	Power in kW to the x-ray generator. **Shall be absent if this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.**
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 this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.**
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 this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.**
Total Collimation Width	(0018,9307)	3	The width of the total collimation (in mm) over the area of active x-ray detection. **Note** *This will be equal the number of effective detector rows multiplied by single collimation width.* **Shall be absent if this Attribute is present in Multi-energy CT Acquisition Sequence (xxx2,yyy2) and the values are not the same in all Items.**
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 C.8-X2 "Multi-energy CT Macro Attributes"			

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

C.8.2.1.1 CT Image Attribute Descriptions

C.8.2.1.1.1 Image Type

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

Defined Terms for Value 3:

AXIAL ~~**identifies**~~ a CT Axial 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 Monoenergetic Image. Each pixel represents CT Hounsfield units and is analogous to a CT image created by a monoenergetic (of a specific keV value) X-Ray beam.**
MAT_SPECIFIC	**a Material-Specific Image. Each pixel value represents the density of a specific material.**
MAT_REMOVED	**An image with the attenuation contribution of one or more materials removed. Each pixel value is adjusted to represent the attenuation as if the pixel was filled with the remaining materials. For pixels that did not contain any of the removed material(s), the pixel values are unchanged.**
MAT_PROPORTIONAL	**a Material-Proportional Image. Each pixel represents a proportion of 1 of a material.**
EFF_ATOMIC_NUM	**an Effective Atomic Number Image. Each pixel represents Effective Atomic Number**
ELECTRON_DENSITY	**an Electron Density Image. Each pixel represents a number of electrons per unit volume (N) in units 1023 /ml) or a relative electron density to water (N/N_{Water}).**
MAT_MODIFIED	**a 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.**
MAT_LABELING	**a Material-Labeling Image. Each pixel represents a value indirectly describing identified material(s).**

Note:

Commented [RR41]: WG21 Editorial changes are rejected due to Line 212

Commented [RGJ(NUDC42]: Eg. In siemens, if you save an iodine density image, it generates dicoms which instead of iodine, they display 'HU' values (eg enhancement solely due to iodine).

Another issue here: how to address window level settings? Eg image indeed a 'density' image, then how to set up WL/WW. Would a regular PACS support this? Eg in this case is not integer numbers.

WG 21: First part: in alignment with the definition
Second issue: window levels are different between vendors. One option can be RVM. Homework for all WG21 members to clarify offline.

Commented [RGJ(NUDC43]: Generating:
-Mat modified and mat labeling images involves lots of 'postprocessing'. Eg thresholds, etc. This may vary greatly depending on manufacturer's approach. As written, this seems to be provided by 'Siemens' experience (which is fine… I'm with Siemens) but not clear how prescriptive this should be within the DICOM framework.
WG 21: Split MAT_Labeling into 3 codes Discrete, Probability, ValueBased -> RR

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

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

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

C.8.2.1.1.X1 Recommended Rescale Type for Multi-energy CT Image

In case of Multi-energy CT Images for recommended assignment of Rescale Types to Image Type attributes.

Each Multi-energy Image Type may have multiple recommended Rescale Types.

Table C.8-X1. Recommended Rescale Type for Multi-energy CT Image

Multi-energy Image Family	Recommended Rescale Type	Image Type Value 4
Objective Image Family		
Virtual Monoenergetic Image	HU	VMI
Effective AN (Z) Image	Z_EFF	EFF_ATOMIC_NUM
Electron Density Image	ED	ELECTRON_DENSITY
	ED_N	ELECTRON_DENSITY
Material Quantification Family		
Material-Specific Image	MG_ML	MAT_SPECIFIC
	HU	MAT_SPECIFIC
Material-Removed Image	HU	MAT_REMOVED
	HU_MOD	MAT_REMOVED
Proportional Map Image	PCT	MAT_PROPORTIONAL
Material Labeling Family		
Discrete Labeling Image	US	MAT_LABELING
Probability Map Image	PCT	MAT_LABELING
Value-based Map Image	US	MAT_LABELING
Material Visualization Family		
Material-Modified Image	HU_MOD	MAT_MODIFIED

Commented [OK46]: Harmonize with CP1700 (see new CP DAC398-02 in March folder)

Commented [OK44]: Wim: Can we tell people to only use Rescale for viewing purposes but to use RWVM for doing any calculation or processing.

Commented [OK45]: Christof: Many vendors in RT likely assume that it is always HU without looking at the value so there is some risk.

Commented [RR47]: Mandatory?
WG21 to be discussed.

Commented [RGJ(NUDC48]: Not clear what's meant. The VMIs will be displaying 'HU' values too.

WG21 : Yes this is meant. VMI shall display HU

Commented [RGJ(NUDC49]: So, is intention that both mg/mL and HU due to density are supported? Makes sense.

WG21: Yes this is the intension

Commented [RGJ(NUDC50]: Hard to follow acronyms

WG21: US is the definition of unspecified see C.11.1.1.2 Modality LUT and Rescale Type

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

C.8.2.1.X1 Multi-energy CT Macro

Table C.8-X2 specifies the Multi-energy attributes to enhance the CT Image Module

224 **Table C.8-X2. Multi-energy CT Macro Attributes**

Attribute Name	Tag	Type	Attribute Description
CT Multi-energy Flag	(xxx2,yyy1)	1C	Indicates whether the image is created by means of Multi-energy technique Enumerated Values: Y N Required if the image is acquired by means of multi-energy technique. May be present otherwise
Multi-energy CT Acquisition Sequence	(xxx2,yyy2)	1C	The attributes of a Multi-energy Image acquisition. Required if CT Multi-energy Flag (xxx1,yyy1) is equal Y One Item shall be included in this Sequence.
>*Include Table C.8-X3 "Multi-energy CT X-Ray Source Macro Attributes"*			See C.8.2.1.X1.1
>*Include Table C.8-X4 "Multi-energy CT X-Ray Detector Macro Attributes"*			See C.8.2.1.X1.2
>*Include Table C.8-X5 "Multi-energy CT Pairing Macro Attributes"*			See C.8.2.1.X1.3
>*Include Table C.8-124. "CT Exposure Macro Attributes"*			See C.8.15.3.8
>*Include Table C.8-125. "CT X-Ray Details Sequence Macro Attributes"*			See C.8.15.3.9
>*Include Table C.8-119. "CT Acquisition Details Macro Attributes"*			See C.8.15.3.3
>*Include Table C.8-122. "CT Geometry Macro Attributes"*			See C.8.15.3.6
Multi-energy CT Processing Macro Sequence	(xxx2,yyy3)	3	Method and result of the processing of Multi-energy data. Only a single Item is permitted in this Sequence.
>*Include Table C.8-X10 "Multi-energy CT Processing Macro Attributes"*			
Multi-energy CT Characteristics Macro Sequence	(xxx2,yyy4)	1C	The attributes of a Multi-energy Image. Required if CT Multi-energy Flag (**xxx2**,yyy1) is Y. Only a single Item shall be included in this Sequence.

Commented [OK51]: Check if DICOM usually does YES NO rather than Y N.

Attribute Name	Tag	Type	Attribute Description
>Include Table C.8-X7 "Multi-energy CT Characteristics Macro Attributes"			

226 **C.8.2.1.X1.1 Multi-energy CT X-Ray Source Macro**

This macro specifies the attributes for CT Image X-Ray Source.

228 **Table C.8-X3. Multi-energy CT X-Ray Source Macro Attributes**

Attribute Name	Tag	Type	Attribute Description
Multi-energy CT X-Ray Source Sequence	(xxx3,yyy1)	1	X-Ray Source information. One or more Items shall be present.
>X-Ray Source Index	(xxx3,yyy2)	1	Identification number of this item in the Multi-energy CT X-Ray Source Sequence. The number shall be 1 for the first Item and increase by 1 for each subsequent Item.
>X-Ray Source ID	(xxx3,yyy3)	1	Identifier of the X-Ray source. The X-Ray Source ID (xxx3,yyy3) will have the same value for different values of X-Ray Source Index (xxx3,yyy2) if the single source generates different nominal energies.
>Multi-energy Source Technique	(xxx3,yyy4)	1	Technique used to acquire Multi-energy data. Defined Terms: SWITCHING_SOURCE an X-Ray source (tube) is used with beam mode switching CONSTANT_SOURCE a X-Ray source (tube) using a beam with constant characteristics
>Switching Phase Number	(xxx3,yyy5)	1C	A number unique within the sequence to identify the switching phase. Required if Multi-energy Source Technique (xxx3,yyy4) is "SWITCHING_SOURCE".
>Switching Phase Nominal Duration	(xxx3,yyy6)	3	Duration, in microseconds, that the energy is in the target KV for this switching phase. Note Applicable if Multi-energy Source Technique (xxx3,yyy4) is "SWITCHING_SOURCE".
>Switching Phase Transition Duration	(xxx3,yyy7)	3	Duration, in microseconds, that the energy has left the target KV for this switching phase, but has not yet reached the target KV for the next phase. Note Applicable if Multi-energy Source Technique (xxx3,yyy4) is "SWITCHING_SOURCE".
>Generator Power	(0018,1170)	3	Power in kW to the x-ray generator.

Commented [RR52]: Add an explanation. Example for the different use cases (dual source, switching, multilayer detector etc.)

Commented [CHM53]: For dual source, there are two sources and hence two kVp settings. One of the sources includes additional beam filtration. Can that information be included (what type of filter, thickness of filter)

Also, there is a form of single source ME-CT that uses a split filter (2 materials evenly split longitudinally) How can the presence of this filter and the filter information be included?

WG21:
This was the intention of using "virtual" source and detector and defining the pairing of each combination. By referencing the paring (C.8.2.1.X1.3 Multi-energy CT Pairing Macro), each filter setting can be addressed.

Commented [RGJ(NUDC54]: How are approaches based on added filtration (eg split filter such as Siemens twinbeam) be included?

WG21: see above.

Commented [CHM55]: Because the kV switching is not instantaneous (square wave) this wil be hard to ascertain. It is more of a sine wave …

WG21: Understood. This is covered by "Nominal Duration"
Suggestion: Kevin (ask Brad for a diagram)

Commented [RR56]: More accurate description and example.

230 **C.8.2.1.X1.2 Multi-energy CT X-Ray Detector Macro**

This macro specifies the attributes for CT Image X-Ray Detector.

232 **Table C.8-X4. Multi-energy CT X-Ray Detector Macro Attributes**

Attribute Name	Tag	Type	Attribute Description
Multi-energy CT X-Ray Detector Sequence	(xxx4,yyy1)	1	X-Ray Detector information. One or more Items shall be present.
>X-Ray Detector Index	(xxx4,yyy2)	1	Identification number of this item in the Multi-energy CT X-Ray Detector Sequence. The number shall be 1 for the first Item and increase by 1 for each subsequent Item.
>X-Ray Detector ID	(xxx4,yyy3)	1	Identifier of the X-Ray detector. The X-Ray Detector ID (xxx4,yyy3) will have the same value for different values of X-Ray Detector Index (xxx4,yyy2) if the single detector discriminates different energies.
>Multi-energy Detector Type	(xxx4,yyy4)	1	Technology used to detect multiple energies. Defined Terms: **INTEGRATING** detector integrates the full X-Ray spectrum. **MULTILAYER** detector layers absorb different parts of the X-Ray spectrum **PHOTON_COUNTING** detector counts photons with energy discrimination capability
>Nominal Bin Energy	(xxx4,yyy7)	1C	Nominal Bin energy in keV of detected photons in this bin. Required if Multi-energy Detector Type (xxx4,yyy4) is PHOTON_COUNTING
>Max Bin Energy	(xxx4,yyy8)	3	Nominal maximum energy in keV of photons that are integrated/counted by the detector in this bin.
>Min Bin Energy	(xxx4,yyy9)	3	Nominal minimum energy in keV of photons that are integrated/counted by the detector in this bin.

Commented [RGJ(NUDC57]: Fantastic that 'future' technologies thought of already as part of this effort.

Commented [AF58]: How would this value be determined? Effective energy for the photons in that bin? What is the purpose to make it mandatory on photon counting images?

WG21: More precise definition for this description. (RR) Useful for material decomposition, can effective energy can be provided also for other technologies?

234 **C.8.2.1.X1.3 Multi-energy CT Pairing Macro**

This macro specifies the attributes for CT Image Reference Acquisition.

236 **Table C.8-X5. Multi-energy CT Pairing Macro Attributes**

Attribute Name	**Tag**	**Type**	**Attribute Description**
Multi-energy CT Pairing Sequence	(xxx5,yyy1)	1	Describes the pairing of the source and detector and associated details. Two or more Items are required if the image is acquired by means of multi-energy technique
>Multi-energy CT Pairing Index	(xxx5,yyy2)	1	Identification number of the element in the Multi-energy CT Pairing Sequence. The number shall be 1 for the first Item and increase by 1 for each subsequent Item.

Attribute Name	Tag	Type	Attribute Description
>X-Ray Source Index	(xxx3,yyy2)	1	Identifying number corresponding to the X-Ray Source Index described in the Multi-energy CT X-Ray Source Macro.
>X-Ray Detector Index	(xxx4,yyy2)	1	Identifying number corresponding to the X-Ray Detector Index described in the Multi-energy CT X-Ray Detector Macro.
> Scan Pass Number	(xxx5,yyy4)	1C	A number identifying the single continuous gathering of data over a period of time. This is not the ID of this item of the Sequence Required if more than one scan pass is used, May be present otherwise
>Scan Pass Date Time	(0008,0022)	1C	The date and time the acquisition of data started. Required if more than one scan pass is used, May be present otherwise
>Energy Weighting Factor	(xxx4,yy11)	1C	The weighting factor of the data from this Sequence Item in a Multi-energy weighted average image. The value shall be between 0.0 and 1.0. Required if one Derivation Code Sequence (0008,9215) Item value is (113097, DCM, "Multi-energy proportional weighting") Sum of Energy Weighting Factors shall be 1
>Multi-energy Acquisition Description	(xxx5,yyy3)	3	Human readable description of the Multi-Energy Acquisition

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

240 **C.8.15.3.8 CT Exposure Macro**

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

242 **Table C.8-124. CT Exposure Macro Attributes**

Attribute Name	Tag	Type	Attribute Description
CT Exposure Sequence	(0018,9321)	1	Contains the attributes defining exposure information. **One or more Items shall be included in this Sequence if the image is acquired by means of multi-energy technique otherwise only~~Only~~** a single Item shall be included in this Sequence.
> Multi-energy Source Index	**(xxx5,yyy2)**	**1C**	**References the Item in the Multi-energy CT Source Macro for which exposure details are specified here.**

Attribute Name	Tag	Type	Attribute Description
			Required if this image is acquired by means of multi-energy technique.
>Exposure Time in ms	(0018,9328)	1C	Duration of exposure for this frame in milliseconds. If Acquisition Type (0018,9302) equals SPIRAL the duration of the exposure time for this frame shall be Revolution Time (0018,9305) divided by the Spiral Pitch Factor (0018,9311). See Section C.8.15.3.8.1. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. **Shall not be present if Multi-energy Source Technique (xxx3,yyy4) is "SWITCHING_SOURCE".** May be present otherwise.
>X-Ray Tube Current in mA	(0018,9330)	1C	Nominal X-Ray tube current in milliamperes. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Exposure in mAs	(0018,9332)	1C	The exposure expressed in milliampere seconds, for example calculated from exposure time and X-Ray tube current. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. **Shall not be present if Multi-energy Source Technique (xxx3,yyy4) is "SWITCHING_SOURCE".** May be present otherwise.
>Exposure Modulation Type	(0018,9323)	1C	A label describing the type of exposure modulation used for the purpose of limiting the dose. Defined Terms: **NONE** Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Estimated Dose Saving	(0018,9324)	2C	A percent value of dose saving due to the use of Exposure Modulation Type (0018,9323). A negative percent value of dose savings reflects an increase of exposure. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL and Exposure Modulation Type (0018,9323) is not equal to NONE. Otherwise may be present if Frame Type (0008,9007) Value 1 of this frame is DERIVED

Commented [CHM59]: Here you specifically omit the kV switching exposure time (at a given kV, I assume). If this is the same concept as above, perhaps it should be exempted above also.

WG21:
Already as homework accepted

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

Commented [RR60]: WG21 to discuss with WG06: Top-Level CTDIvol shall be present as the summation of each individual source (use CTDIvol attribute of standard image) -> update definition depending on ME-Image

Commented [OK61]: Need to update the definition if we want to use it since MECT isn't covered in 60601-2-44 yet.

Commented [RGJ(NUDC62]: Just a question of interpretation as of dual-source approaches to ME-CT.

Does this mean the only CTDIvol to be recorded is the 'overall'/combined value?
WG21: It will summarize source specific, not over all sources

Commented [RR63]: Dependent on Spectrum

Commented [RGJ(NUDC64]: This is great but not clear why it belongs to ME-CT. And AAPM report 220 is not about ME-CT.

WG21: Is already in the standard not ME-specific. Reuse from standard. Is there a guidance for ME-specific images?

Commented [RGJ(NUDC65]: Same as prior comment
WG21: see above

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

C.8.15.3.9 CT X-Ray Details Macro

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

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

Attribute Name	Tag	Type	Attribute Description
CT X-Ray Details Sequence	(0018,9325)	1	Contains the attributes defining the x-ray information. **One or more Items shall be included in this Sequence if the image is acquired by means of multi-energy technique otherwise only~~Only~~** a single Item shall be included in this Sequence.
> Multi-energy Pairing Index	**(xxx5,yyy2)**	**1C**	**Identifying number corresponding to the Multi-energy Acquisition Index (xxx5,yyy2)**

Attribute Name	Tag	Type	Attribute Description
			described in the Multi-energy CT Pairing Macro **Required if the image is acquired by means of multi-energy technique.**
>KVP	(0018,0060)	1C	**Nominal** Peak kilovoltage output of the x-ray generator used. **If Multi-energy Source Technique (xxx3,yyy4) is "SWITCHING_SOURCE", this value is the target KV for a switching phase. The switching phase is identified by the X-Ray Source Index value in the Multi-energy CT Pairing Sequence (xxx5,yyy2) identified by the Multi-energy CT Pairing index value in this Sequence.** **Due to limitations of the generating hardware the actual voltage may not reach the nominal peak value** Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Focal Spot(s)	(0018,1190)	1C	Used nominal size of the focal spot in mm. The attribute may only have one or two values, for devices with variable focal spot, small dimension followed by large dimension Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Filter Type	(0018,1160)	1C	Type of filter(s) inserted into the X-Ray beam. Defined Terms: **WEDGE** **BUTTERFLY** **MULTIPLE** **FLAT** **SHAPED** **NONE** Note Multiple type of filters can be expressed by a combination, e.g., BUTTERFLY+WEDGE. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Filter Material	(0018,7050)	1C	The X-Ray absorbing material used in the filter. May be multi-valued. Defined Terms: **MOLYBDENUM** **ALUMINUM**

Attribute Name	Tag	Type	Attribute Description
			COPPER **RHODIUM** **NIOBIUM** **EUROPIUM** **LEAD** **MIXED** Tin?? Note MIXED may be used to indicate a filter type of complex composition for which listing the individual materials would be excessive or undesirable; it is not intended to mean "unknown". Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL and the value of Filter Type (0018,1160) is other than NONE. May be present otherwise.
>Calcium Scoring Mass Factor Patient	(0018,9351)	3	The calibration factor for the calcium mass score. These factors incorporate the effects of KV value of the CT image the patient size. machine specific corrections See Section C.8.2.1.1.7.
>Calcium Scoring Mass Factor Device	(0018,9352)	3	The calibration factors for the calcium mass score of the device. These factors incorporate the effects of KV value of the CT image machine specific corrections This a multi-value attribute, the first value specifies the mass factor for a small patient size, the second value for a medium patient size and the third value for a large patient size. See Section C.8.2.1.1.7.
>Energy Weighting Factor	(0018,9353)	1C	The weighting factor of the data from the primary source in a multiple energy composition image. This factor incorporates the effects of the specific X-Ray source and kV value examination specific characteristics. Required if Required if Frame Type (0008,9007) Value 4 of this frame is ENERGY_PROP_WT. May be present otherwise.

Commented [CHM66]: Add a defined term TIN. Can filter thickness be added as a Tag?

WG21:
TIN is OK.
If Filter thickness is needed, we need a CP , it is not ME-related
-> WG21 discussion

Commented [RGJ(NUDC67]: Why is calcium score related to MECT?

Calcium score is primarily associated with cardiac CT only.

WG21: No it is not related. Reused from standard. See above with Water Diameter.

Commented [RR68]: **MARKER for next Meeting with AAPM to go on**

250

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

252

C.8.15.3.3 CT Acquisition Details Macro

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

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

Attribute Name	Tag	Type	Attribute Description
CT Acquisition Details Sequence	(0018,9304)	1	Contains the attributes defining the details of the acquisition. **One or more Items shall be included in this Sequence if the image is acquired by means of multi-energy technique otherwise only~~Only~~** a single Item shall be included in this Sequence.
> Multi-energy Acquisition Index	**(xxx5,yyy2)**	**1C**	**Identifying number corresponding to the Multi-energy Acquisition Index (xxx5,yyy2) described in the Multi-energy CT Pairing Macro** **Required if the image is acquired by means of multi-energy technique.**
>Rotation Direction	(0018,1140)	1C	Direction of rotation of the source about the gantry, as viewed while facing the gantry where the table enters the gantry. Enumerated Values: CW clockwise CC counter clockwise Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL and Acquisition Type (0018,9302) is other than CONSTANT_ANGLE. Otherwise may be present if Frame Type (0008,9007) Value 1 of this frame is DERIVED and Acquisition Type (0018,9302) is other than CONSTANT_ANGLE.
>Revolution Time	(0018,9305)	1C	The time in seconds of a complete revolution of the source around the gantry orbit. This value is independent of the Reconstruction Angle (0018,9319) of the frame. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL and Acquisition Type (0018,9302) is other than CONSTANT_ANGLE. Otherwise may be present if Frame Type (0008,9007) Value 1 of this frame is DERIVED and Acquisition Type (0018,9302) is other than CONSTANT_ANGLE.
>Single Collimation Width	(0018,9306)	1C	The width of a single row of acquired data (in mm). Note Adjacent physical detector rows may have been combined to form a single effective acquisition row.

Attribute Name	Tag	Type	Attribute Description
			Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Total Collimation Width	(0018,9307)	1C	The width of the total collimation (in mm) over the area of active x-ray detection. Note This will be equal to the number of effective detector rows multiplied by single collimation width. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Table Height	(0018,1130)	1C	The distance in mm from the top of the patient table to the center of rotation of the source (i.e., the data collection center or isocenter). The distance is positive when the table is below the data collection center. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Gantry/Detector Tilt	(0018,1120)	1C	Nominal angle of tilt in degrees of the scanning gantry. Not intended for mathematical computations. Zero degrees means the gantry is not tilted, negative degrees are when the top of the gantry is tilted away from where the table enters the gantry. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Data Collection Diameter	(0018,0090)	1C	The diameter in mm of the region over which data were collected. See Section C.8.15.3.6.1. Note In the case of an Acquisition Type (0018,9302) of CONSTANT_ANGLE, the diameter is that in a plane normal to the central ray of the diverging X-Ray beam as it passes through the data collection center. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.

256

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

258

C.8.15.3.6 CT Geometry Macro

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

Table C.8-122. CT Geometry Macro Attributes

Attribute Name	Tag	Type	Attribute Description
CT Geometry Sequence	(0018,9312)	1	Contains the attributes defining the CT geometry. **One or more Items shall be included in this Sequence if the image is acquired by means of multi-energy technique otherwise only~~Only~~** a single Item shall be included in this Sequence.
> Multi-energy Acquisition Index	**(xxx5,yyy2)**	**1C**	**Identifying number corresponding to the Multi-energy Acquisition Index (xxx5,yyy2) described in the Multi-energy CT Pairing Macro** **Required if the image is acquired by means of multi-energy technique.**
>Distance Source to Detector	(0018,1110)	1C	Distance in mm from source to detector center. See Section C.8.15.3.6.1. Note This value is traditionally referred to as Source Image Receptor Distance (SID). Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.
>Distance Source to Data Collection Center	(0018,9335)	1C	Distance in mm from source to data collection center. See Section C.8.15.3.6.1. Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL. May be present otherwise.

Commented [MPS69]: Would this be different for two different detector layers in Philips set up?

WG21: No it will be the same.

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

C.8.15.X1 Multi-energy CT Acquisition Module

Table C.8-X6 specifies the Attributes that describe the Multi-energy acquisition technique in the Enhanced Image.

Table C.8-X6. Multi-energy CT Acquisition Module Attributes

Attribute Name	Tag	Type	Attribute Description
>*Include Table C.8-X3 "Multi-energy CT X-Ray Source Macro Attributes"*			See C.8.2.1.X1.1
>*Include Table C.8-X4 "Multi-energy CT X-Ray Detector Macro Attributes"*			See C.8.2.1.X1.2

Attribute Name	Tag	Type	Attribute Description
>*Include Table C.8-X5 "Multi-energy CT Pairing Macro Attributes"*			See C.8.2.1.X1.3

270

C.8.15.3.X1 Multi-energy CT Characteristics Macro

272 This macro specifies the attributes for CT Image Characteristics.

Table C.8-X7. Multi-energy CT Characteristics Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Monoenergetic Energy Equivalent	(xxx7,yyy1)	1C	Single energy equivalent in keV. Required if Type Value 4 is EQUAL to VMI. May be present otherwise. Note: If the Image Type Value 4 is (MAT_REMOVED, MAT_MODIFIED) and a VMI image was used as the source then this value reflects the keV Value of the VMI image.
Monoenergetic Algorithm Sequence	(xxx7,yyy2)	3	Algorithm used to create the monoenergetic image.
>*Include Table 10-19 Algorithm Identification Attributes*			
Multi-energy CT Quantification Sequence	(xxx7,yyy3)	1C	Contains the attributes providing material quantification information. Required if Type Value 4 is MAT_SPECIFIC or MAT_REMOVED MAT_MODIFIED or MAT_PROPORTIONAL. May be present otherwise. Only a single Item is permitted in this sequence.
>*Include Table C.8-X8 "Multi-energy CT Quantification Macro Attributes"*			
Multi-energy CT Labeling Sequence	(xxx7,yyy4)	1C	Contains the attributes providing classification information of materials. Required if Type Value 4 is MAT_LABELING. May be present otherwise. Only a single Item is permitted in this sequence.

Commented [RGJ(NUDC70]: Not clear what it means by 'algorithm' used to create VMI.

Which are the 'algorithms'? eg image vs projection domain?

WG21: It's the vendor specific description of the vendor, not a description of the family.
➔ Describe in Tag: Algorithm description …

Attribute Name	Tag	Type	Attribute Description
>Include Table C.8-X9 *"Multi-energy CT Labeling Macro Attributes"*			

274

C.8.15.3.X1.1 Multi-energy CT Quantification Macro

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

Table C.8-X8. Multi-energy CT Quantification Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Material Quantification Description	(xxx8,yyy1)	3	Human-readable description of the material quantification process used to generate this image
Specific Material Code Sequence	(xxx8,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
>Include Table 8.8-1-a "Basic Code Sequence Macro Attributes"			Baseline CID is CID-X1
Material Modification Sequence	(xxx8,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 One or more items shall be present.
>Modification Type	(xxx8,yyy4)	1	Type of modification applied to this material Defined Terms: **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) **SUBTRACTED** – Image with one or more materials subtracted, i.e. set to a fixed value. **COMPENSATED** – CT Image where pixel values have been modified to remove specific material components.

Commented [CHM71]: How does this differ from subtracted or suppressed?

WG21: Proposal for definitions of SUBTRACTED and COMPENSATED
➔Combine Subtracted and Compensated; MAT_REMOVED!

Attribute Name	Tag	Type	Attribute Description
			RECALCULATED – pixels are recalculated by vendor-specific method
>Material Code Sequence	(xxx8,yyy5)	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 Value	(xxx8,yyy6)	1C	The constant value used to replace the affected pixels Required if Modification Type is SUBTRACTED
>Modification Description	(xxx8,yyy7)	3	Common description of the modification action on the image pixels.

Commented [RR72]: TYPE 3
If the subtracted pixels are set to a fixed value then …

278

C.8.15.3.X1.2 Multi-energy CT Labeling Macro

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

Table C.8-X9. Multi-energy CT Labeling Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Material Labeling Type	(xxx9,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 is 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 is 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	(xxx9,yyy2)	1	Materials that are labeled in this image.

Attribute Name	Tag	Type	Attribute Description
			IF Material Labeling Type is PROPABILITY only a single Item shall be present
>Include Table 8.8-1-a "Basic Code Sequence Macro Attributes"			Baseline CID is CID-X1
>Material Index	(xxx9,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	(xxx9,yyy4)	3	Typical multi value range definition for the specific material MIN/MAX for Material Labeling Type VALUEBASED

282

284 **C.8.15.3.X2 Multi-energy CT Processing Macro**

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

286 **Table C.8-X10. Multi-energy CT Processing Attributes**

Attribute Name	Tag	Type	Attribute Description
Decomposition Method	(xx10,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	(xx10,yyy2)	3	Description of decomposition method
Decomposition Algorithm Identification Sequence	(xx10,yyy3)	3	Algorithm used for decomposition of the acquired data One or more Items are permitted in this Sequence.

Attribute Name	Tag	Type	Attribute Description
>Decomposition Algorithm Identification Description	(xx10,yyy4)	3	Description of decomposition algorithm
Decomposition Sequence	(xx10,yyy5)	3	Materials used to create result images.
>Material Code Sequence	(xxx8,yyy5)	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	(xx10,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/Xcom/html/xcom1.html
>> Photon Energy	(xx10,yyy8)	1	Photon energy in keV
>>X-Ray Mass Attenuation Coefficient	(xx10,yyy9)	1	Attenuation of this material at the specific Photon energy. Normalized to material density.

Commented [RGJ(NUDC73]: Not clear what 'description' must be provided here.

WG: Add more description.

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

C.11.1.1.2 Modality LUT and Rescale Type

Specifies the units of the output of the Modality LUT or rescale operation. Defined Terms:

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

HU Hounsfield Units (CT)

US Unspecified

MG_ML mg/ml

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

ED 10^{23} electrons/ml

ED_N 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 (%)

304

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

306 **For Rescale Types recommended to be used in case of Multi-energy CT Images see Section C.8.2.1.1.X1**

308 ## Changes to NEMA Standards Publication PS 3.6-2011

Digital Imaging and Communications in Medicine (DICOM)

310 ## Part 6: Data Dictionary

Add the following rows to Section 6

Tag	Name	Keyword	VR	VM
(xxx2,yyy1)	CT Multi-energy Flag	CTMultiEnergyFlag	CS	1
(xxx2,yyy2)	Multi-energy CT Acquisition Sequence	MultiEnergyCTAcquisitionSequence	SQ	1
(xxx2,yyy3)	Multi-energy CT Processing Macro Sequence	MultiEnergyCTProcessingMacroSequence	SQ	1
(xxx2,yyy4)	Multi-energy CT Characteristics Macro Sequence	MultiEnergyCTCharacteristicsMacroSequence	SQ	1
(xxx3,yyy1)	Multi-energy CT X-Ray Source Sequence	Multi-energyCTX-RaySourceSequence	SQ	1
(xxx3,yyy2)	X-Ray Source Index	X-RaySourceIndex	US	1
(xxx3,yyy3)	X-Ray Source ID	X-RaySourceID	US	1
(xxx3,yyy4)	Multi-energy Source Technique	Multi-energySourceTechnique	CS	1
(xxx3,yyy5)	Switching Phase Number	SwitchingPhaseNumber	US	1
(xxx3,yyy6)	Switching Phase Nominal Duration	SwitchingPhaseNominalDuration	DS	1
(xxx3,yyy7)	Switching Phase Transition Duration	SwitchingPhaseTransitionDuration	DS	1
(xxx4,yy10)	Bin Weighting Factor	BinWeightingFactor	DS	1
(xxx4,yy11)	Energy Weighting Factor	EnergyWeightingFactor	DS	1
(xxx4,yyy1)	Multi-energy CT X-Ray Detector Sequence	Multi-energyCTX-RayDetectorSequence	SQ	1
(xxx4,yyy2)	X-Ray Detecor Index	X-RayDetecorIndex	US	1
(xxx4,yyy2)	X-Ray Detector Index	X-RayDetectorIndex	US	1

Tag	Name	Keyword	VR	VM
(xxx4,yyy3)	X-Ray Detector ID	X-RayDetectorID	US	1
(xxx4,yyy4)	Multi-energy Detector Type	Multi-energyDetectorType	CS	1
(xxx4,yyy5)	Energy Bin Sequence	EnergyBinSequence	SQ	1
(xxx4,yyy6)	Bin ID	BinID	US	1
(xxx4,yyy7)	NominalBinEnergy	NominalBinEnergy	DS	1
(xxx4,yyy8)	Max Bin Energy	MaxBinEnergy	DS	1
(xxx4,yyy9)	Min Bin Energy	MinBinEnergy	DS	1
(xxx5,yyy1)	Multi-energy CT Pairing Sequence	Multi-energyCTPairingSequence	SQ	1
(xxx5,yyy2)	Multi-energy Acquisition Index	Multi-energyAcquisitionIndex	US	1
(xxx5,yyy3)	Multi-energy Acquisition Description	MultiEnergyAcquisitionDescription	ST	1
(xxx7,yyy1)	Monoenergetic Energy Equivalent	MonoenergeticEnergyEquivalent	DS	1
(xxx7,yyy2)	Monoenergetic Algorithm Sequence	MonoenergeticAlgorithmSequence	SQ	1
(xxx7,yyy3)	Multi-energy Quantification CT Image Sequence	Multi-energyQuantificationCTImageSequence	SQ	1
(xxx7,yyy4)	Multi-energy Labeling CT Image Sequence	Multi-energyLabelingCTImageSequence	SQ	1
(xxx8,yyy1)	Material Modification Description	MaterialModificationDescription	ST	1
(xxx8,yyy2)	Specific Material Code Sequence	SpecificMaterialCodeSequence	SQ	1
(xxx8,yyy3)	Material Modification Sequence	MaterialModificationSequence	SQ	1
(xxx8,yyy4)	Modification Type	ModificationType	CS	1
(xxx8,yyy5)	Material Code Sequence	MaterialCodeSequence	SQ	1
(xxx8,yyy6)	Correction Value	CorrectionValue	DS	1
(xxx8,yyy7)	Modification Description	ModificationDescription	ST	1
(xxx9,yyy1)	Material Labeling Type	MaterialLabelingType	CS	1
(xxx9,yyy2)	Material Labeling Sequence	MaterialLabelingSequence	SQ	1
(xxx9,yyy3)	Material Index	MaterialIndex	US	1
(xxx9,yyy4)	Material Value Range	MaterialValueRange	DS	2
(xx10,yyy1)	Decomposition Method	DecompositionMethod	CS	1

Tag	Name	Keyword	VR	VM
(xx10,yyy2)	Decomposition Description	DecompositionDescription	ST	1
(xx10,yyy3)	Decomposition Algorithm Identification Sequence	DecompositionAlgorithmIdentification Sequence	SQ	1
(xx10,yyy4)	Decomposition Algorithm Identification Description	DecompositionAlgorithmIdentification Description	ST	1
(xx10,yyy5)	Decomposition Sequence	DecompositionSequence	SQ	1
(xx10,yyy7)	Material Attenuation Sequence	MaterialAttenuationSequence	SQ	1
(xx10,yyy8)	Photon Energy	PhotonEnergy	DS	1
(xx10,yyy9)	X-Ray Mass Attenuation Coefficient	X-RayMassAttenuationCoefficient	DS	1

312

Commented [RGJ(NUDC74]: List feel a bit too long, considering the size of the typical fields already in dicom. This feels as long as currently is for CT. Would that be a problem?

WG21: Should be OK

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
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	10^{23} /ml	Electron Density
DCMXXX	NewCode2-02	Effective Atomic Number
DCMXXX	NewCode2-03	Modified Hounsfield Unit
DCMXXX	mg/ml	Milligram per milliliter

Commented [RGJ(NUDC75]: How would other materials be handled?

Arguably, many materials listed are in 'research' and not used clinically.

If plan is to be inclusive then there will be more materials which can become relevant, others already might be (eg 'gold').

WG21: Can be extended.

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)