Digital Imaging and Communications in Medicine (DICOM)

Supplement 208: Extension of DICOM Encapsulation for 3D Manufacturing Models

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Scope and Field of Application

This supplement extends the DICOM standard to better addresses two aspects of medical 3D manufacturing, as well as similar new uses of medical DICOM data in the fields of Virtual Reality, Augmented Reality, and Mixed Reality.

These extensions fall in three areas:

1) Support for a new 3D model type: Object File (OBJ)
2) Identification which models a part of a group intended for assembly into a larger object
3) Persistently indicating a preferred color for manufacturing or display of a model

OBJ Encapsulation

With respect to 1 above, the supplement will incorporate not just Object Files (OBJ), but also any supporting Material Library Files (MTL) and texture map files (JPG or PNG) on which an OBJ may rely. This is accomplished in a manner consistent

OBJ has high adoption among advanced and color 3D print users as well as virtual/augmented/mixed reality users. OBJ also has capabilities beyond that of the STL model type previously incorporated.

Specifically, the OBJ file format has the optional capability of storing detailed multi-vertex-based polygon color information via the companion MTL file. As well, the MTL file format may also optionally reference texture image files. This allows the option to

OBJ, while not a binary file format, is not designed for human readability.

As with Encapsulated STL, the new Encapsulated OBJ, Encapsulated MTL and texture image IODs allow 3D manufacturing models to be exchanged between various types of equipment using DICOM messages. This adds the ability to store, query and retrieve complete OBJ models as DICOM objects. Updates are addressed by storing new instances, with reference back to earlier instances similar to the IOD for STL encapsulation.

Grouping by Assembly and Component Color

The supplement will also address supplemental needs for the already existing 3D Model encapsulation specification, whether STL or OBJ. These needs become apparent when multiple models are intended as parts of a larger assembly (e.g. a implant with multiple interlocking parts, or an assembly showing arteries/veins/lung/ribs as distinct materials).

In this situation a user would want to be able to distinguish groups of models that are parts of the same assembly, from other models that are not. While a convention could be adopted that leveraged DICOM study or series membership, but it would merely be a convention. The user community would want this assembly group membership to be unambiguously identifiable in the standard in order to avoid lengthy errors due to manufacturing the wrong component or omitting a component altogether.

Likewise, there is a convention of color coding the parts of such assemblies to disambiguate the models by function (e.g. veins blue, arteries red, bone white, lungs pink, etc.) As STL is a colorless format and OBJ's complex color/texture options are not always appropriate, an optional preferred whole-model color attribute has been made available.

OPEN ISSUES TABLE

#	Question	Comments
1	OBJ is a relatively old standard (circa 1992). There are more modern ones like X3D, AMF, and 3MF that are more sophisticated. Why was not one of those more advanced formats selected?	Additional file types were included in the original version of SUP208 – but WG17 was specifically directed by WG06 not to take that approach. Instead, we were told to focus on a single file type that was most desired beyond STL. OBJ was selected based on polling of the medical 3D printing and VR/AR/MR communities as to adoption and use of the file formats. After STL, OBJ is currently the most commonly used format in medical 3D printing. Likewise, OBJ is the VR/AR/MR community's primary format. It is unclear which of the other 3 formats may have take-over this role within the wider industry in the future. All have proponents, but there is no clear leader yet If one advanced format does emerge as dominant in medical uses, it can be evaluated and, potentially, added via a future supplement.
2	Why not encapsulate most or all of the 3D model formats, rather than just STL and OBJ?	WG06 advised WG17 that it is undesirable from the perspective of standards to support too many model format variants. This increases the likelihood that two vendor systems will not actually be able to intercommunicate and share data. It is better to support based on high-use and add new formats sparingly based on demand.
3	Why are the supporting files (MTL and texture maps) not simply stored as attributes of the OBJ encapsulation? Why create 3 new kinds of IOD?	WG17 was advised that experienced DICOM standards experts that a multi-component encapsulation approach has been historically undesirable and unlikely to be approved. There were also technical implementation concerns about this potentially leading to very large objects.
4	Will the approach in this document require both OBJ and MTL to be registered with IANA as recognized MIME types?	Yes. This has been done by MITA before (including in the case of STL models) and the process is well understood.
5	Is sRGBA the most appropriate encoding for color information?	The sRGB and sRGBA color notation from W3C is used in several XML-based 3D model file formats (though not in STL or OBJ). So, it is familiar to the community. It is also very compact, requiring a single attribute to convey a wide range of value.

#	Question	Comments
		But it does not appear to be used in DICOM before. It also allows a wide variety of notation forms, which may complicate implementation. The use of a simpler approach based on storing 3 or 4 distinct numeric values (for RGB and RGBA, respectively) would also be acceptable. This would also match the approach taken by OBJ does in vertex/polygon coloring. It should also be noted that per the specification (https://www.w3.org/TR/css-color-3/) including alpha-channel precludes the use of the compact hexadecimal notation (i.e. "`#FF0000`" is one valid way to express 100% opaque pure red in sRGB, but "`#FF000088`" is **not** a valid way to present 50% opaque pure red in sRGBA). One of the alternate notations must be used if alpha-channel is present (e.g. "`rgba(100%,0%,0%,1)`")
6	Why is encapsulation not used for texture map images?	WG17 received guidance that introducing a blanket method encapsulation of common image formats would not be well received. It was felt that this would invite misuse and, given that DICOM is an imaging format, this is one area where data translation is likely reasonable. WG17 thus encouraged to use one of DICOM's existing image representation methods instead. This will require the encapsulating software to be able to interpret and transform texture map images. Likewise, it will require the de-encapsulating software to be able to interpret the DICOM image format used, and recreate the destination file type.
7	Why was the VL Photographic Image IOD selected to represent texture map images? Isn't there a better choice?	VL Photographic Image was selected for two reasons: 1. It has characteristics capable of storing all the pixel data, regardless of whether the texture began as a PNG, JPEG, or other OBJ supported texture file 2. There was precedence for this type of exact use in **C.27.6.1 UV Mapping Attribute Description**, which also requires texture map images.
8	Is there not a risk that existing software may mistake Texture Map Images as being a patient's clinical images, and thus be mistakenly shown directly to the user.	It was felt that requiring the use of the "FOR PROCESSING" value in the Presentation Intent Type (0008,0068) combined with specifying "M3D" as the modality would be sufficient to prevent this.

#	Question	Comments
9	Should the standard allow all currently supported image formats to be used for a texture map? JPEG and PNG cover most usage, but an MTL file could use BMP, TIFF, or TGA as well. This places an onus on the downstream de-encapsulation recipient to be able to write out a VL Photographic Image IOD in a wide variety of format (since the extension needs to match the MTL).	A constraint could be added that would move require encapsulation creating software to force MTL files to contain only JPEG or PNG references.
10	Was creating a completely new Texture Map Image IOD considered?	Yes. But as this would be inconsistent with the approach taken with **C.27.6.1 UV Mapping Attribute Description** this was rejected. If the inconsistency is not considered significant, a new IOD specifically for texture map images would be a perfectly acceptable approach.
11	Rather than using the new *Referenced Instance Sequence* attribute to referenced texture map images, could the *Referenced Image Sequence* be used instead?	The *Referenced Image Sequence* is not appropriate in the Encapsulated OBJ, as the referenced Encapsulated MTL IOD is not an image. The *Reference Image Sequence* could be used in the Encapsulated MTL for the set of texture map images, since the referenced IODs are images. But it was decided to use the same attribute in both instances for better consistency between the OBJ and MTL encapsulations.
12	The definitions of encapsulated STL, OBJ, and MTL have a lot common content that is repeated (e.g. the Entity Relationship Models and tables of included Modules). Could A.85 be restructured so that the common text is shared at the Encapsulated 3D Manufacturing IOD level?	Yes. This should be considered. However, when this was attempted, the resulting editing directives severely hampered readability of this document. We recommend any re-ordering of the sections should be left to a final edit, once the reviewers are comfortable with the main concepts.

CLOSED ISSUES TABLE

#	Question	Comments

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Changes to NEMA Standards Publication PS 3.2-2018x

Digital Imaging and Communications in Medicine

Part 2: Conformance

Item: Add to table A.1-2 categorizing SOP Classes:

The SOP Classes are categorized as follows:

Table A.1-2
UID VALUES

UID Value	UID NAME	Category
…	…	…
1.2.840.10008.5.1.4.1.1.xxx2	**Encapsulated OBJ Storage SOP Class**	**Transfer**
…	…	…

Changes to NEMA Standards Publication PS 3.3-2018x

Digital Imaging and Communications in Medicine (DICOM)

2 Normative References

90

Item: Add normative reference

2.6 Other References

…

95 OBJ/MTL: Wavefront Technologies. 1992. Object Files (.obj), Advanced Visualizer.

Changes to NEMA Standards Publication PS 3.3-2018x

Digital Imaging and Communications in Medicine (DICOM)

Part 3: Information Object Definitions

Modify Section A.1.4 Overview of the Composite IOD Module Content – Insert 2 new IODs

100 **Table A.1-3**
COMPOSITE INFORMATION OBJECT MODULES OVERVIEW – MORE NON-IMAGES

IODs Modules	…	Enc OBJ	Enc MTL	…
Patient		M	M	
Patient Summary				
Clinical Trial Subject		U	U	
General Study		M	M	
Patient Study		U	U	
Clinical Trial Study		U	U	
Study Content				
Encapsulated Document Series		M	M	
Clinical Trial Series		U	U	
…				
General Equip.		M	M	
Enhanced General Equip.		M	M	
…				
Encapsulated Document		M	M	
…				

SOP Common		**M**	**M**	
…				
Manufacturing 3D Model		**M**	**M**	

Modify Section A.32.4.3.1 Allow for M3D modality designation, when images are texture maps

A.32.4.3 VL Photographic Image IOD Content Constraints

105

A.32.4.3.1 Modality

The value of Modality (0008,0060) shall be **M3D only if the image is a texture map of an Encapsulated 3D Manufacturing Model.**

In all other cases the value of Modality (0008,0060) shall be XC.

110

Modify Annex A.85 – Insert new section for Encapsulated OBJ and MTL IODs after A.85.1 (STL)

A.85.X Encapsulated OBJ IOD

A.85.X.1 Encapsulated OBJ IOD Description

The Encapsulated OBJ Information Object Definition (IOD) describes a 3D model in OBJ format. Any supporting material library file (MTL) and supporting 2D texture map image files are addressed in other distinct IODs (see A.85.Y.1 and XXXX).

A.85.X.2 Encapsulated OBJ Entity-Relationship Model

This IOD uses the E-R Model in Section A.1.2, with only the Encapsulated Document IE below the Series IE.

A.85.X.3 Encapsulated OBJ IOD Module Table

Table A.85.X-1 specifies the Encapsulated OBJ IOD Modules.

Table A.85.X-1
Encapsulated OBJ IOD MODULES

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
	Clinical Trial Subject	C.7.1.3	U
Study	General Study	C.7.2.1	M
	Patient Study	C.7.2.2	U
	Clinical Trial Study	C.7.2.3	U
Series	Encapsulated Document Series	C.24.1	M
	Clinical Trial Series	C.7.3.2	U
Frame of Reference	Frame of Reference	C.7.4.1	M
Equipment	General Equipment	C.7.5.1	M
	Enhanced General Equipment	C.7.5.2	M
Encapsulated Document	Encapsulated Document	C.24.2	M
	Manufacturing 3D Model	C.24.Y	M
	SOP Common	C.12.1	M
	Common Instance Reference	C.12.2	C - Required if other instances are referenced

A.85.X.4 Encapsulated OBJ IOD Content Constraints

A.85.X.4.1 Encapsulated Document

The Encapsulated Document (0042,0011) Attribute shall contain an ASCII OBJ byte stream [OBJ/MTL 1992].

Note

1. The Frame Of Reference UID (0020,0052) is an identifier for the origin and axes implicit in the OBJ data.

A.85.X.4.2 MIME Type of Encapsulated Document

Enumerated Values:

model/obj

A.85.X.4.3 Modality

Enumerated Values:

M3D

A.85.Y Encapsulated MTL IOD

A.85.Y.1 Encapsulated MTL IOD Description

The Encapsulated MTL Information Object Definition (IOD) describes in MTL format a materials library used by an Encapsulated OBJ 3D model (see A.85.1). A supporting Encapsulated MTL may or may not be present for any Encapsulated OBJ. Any supporting 2D texture map image files are addressed in other distinct IODs (see XXXX).

A.85.Y.2 Encapsulated MTL Entity-Relationship Model

This IOD uses the E-R Model in Section A.1.2, with only the Encapsulated Document IE below the Series IE.

A.85.Y.3 Encapsulated MTL IOD Module Table

Table A.85.X-1 specifies the Encapsulated MTL IOD Modules.

Table A.85.Y-1
Encapsulated MTL IOD MODULES

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
	Clinical Trial Subject	C.7.1.3	U
Study	General Study	C.7.2.1	M
	Patient Study	C.7.2.2	U
	Clinical Trial Study	C.7.2.3	U
Series	Encapsulated Document Series	C.24.1	M
	Clinical Trial Series	C.7.3.2	U
Frame of Reference	Frame of Reference	C.7.4.1	M
Equipment	General Equipment	C.7.5.1	M
	Enhanced General Equipment	C.7.5.2	M
Encapsulated Document	Encapsulated Document	C.24.2	M
	Manufacturing 3D Model	C.24.Y	M
	SOP Common	C.12.1	M
	Common Instance Reference	C.12.2	C - Required if other instances are referenced

A.85.Y.4 Encapsulated MTL IOD Content Constraints

A.85.Y.4.1 Encapsulated Document

The Encapsulated Document (0042,0011) Attribute shall contain an ASCII MTL byte stream [OBJ/MTL 1992].

A.85.Y.4.2 MIME Type of Encapsulated Document

Enumerated Values:

model/mtl

A.85.Y.4.3 Modality

Enumerated Values:

M3D

Modify PS3.3 Annex C.7.6.1 to allow preservation of referenced file name (see C.35.1 for further context).

C.7.6.1 General Image Module

Table C.7-9 specifies the Attributes that identify and describe an image within a particular Series.

Table C.7-9 General Image Module Attributes

Attribute Name	Tag	Type	Attribute Description
…			
Referenced Name	**(aaa1,bbb3)**	**3**	**The file name under which the object is referred to within an encapsulated object. Preservation in this attribute allows the file name to be reconstituted when needed to preserve referential integrity from the encapsulated object.**
…			

Modify PS3.3 Annex C.8.12.1 to allow indication that an image is not intended for presentation (i.e. when it is a texture map)

C.8.12.1 General Image Module

Table C.8-77 specifies the Attributes that describe a VL Image produced by Endoscopy (ES), General Microscopy (GM), Automated- Stage Microscopy (SM), External-camera Photography (XC), or other VL imaging Modalities.

Table C.8-77 VL Image Module Attributes

Attribute Name	Tag	Type	Attribute Description
…			
Presentation Intent Type	**(0008,0068)**	**3**	**Identifies whether the intent of the image is for processing (e.g. is a texture map) or presentation (e.g. is directly interpretable by humans).** **Enumerated Values:** **FOR PRESENTATION** **FOR PROCESSING**
…			

Modify PS3.3 Annex C.35 to broaden language to cover new encapsulations, add new attributes and define associated terms.

180 **C.35.1 Manufacturing 3D Model Module**

Table C.35.1-1 defines attributes specific to models used in medical 3D manufacturing.

Table C.35.1-1 Manufacturing 3D Model Module Attributes

Attribute Name	Tag	Type	Attribute Description
Measurement Units Code Sequence	(0040,08EA)	1	Units of distance for the coordinate system for the encapsulated **~~STL~~ 3D Manufacturing Model** file Only a single Item shall be included in this Sequence.
>Include Table 8.8-1 "Code Sequence Macro Attributes"			DCID 7063 "Model Scale Units".
Model Modification	(0068,7001)	3	Specifies whether a modification of the observed anatomy (other than mirroring) was used to create the model (e.g. simulating an expected surgical result). In the negative, the model follows the observed patient anatomy in the source data. Enumerated Values: **YES** **NO**
Model Mirroring	(0068,7002)	3	Specifies whether mirroring of anatomy from the other side of the patient was used to create the model Enumerated Values: **YES** **NO**
Model Usage Code Sequence	(0068,7003)	3	Specifies the use for which the manufactured object is intended. Only a single Item shall be permitted in this Sequence.
>Include Table 8.8-1 "Code Sequence Macro Attributes"			*BCID 7064 "Model Usage".*
Content Description	(0070,0081)	3	A description of the model.
Icon Image Sequence	(0088,0200)	3	A preview image representing the rendered model. Only a single item shall be permitted in this Sequence.
>Include Table 7-11b "Image Pixel Macro Attributes"			See Section C.7.6.1.1.6 for further explanation.
Derivation Algorithm Sequence	(0022,1612)	3	Software algorithm that created the 3D model. Only a single Item shall be included in this Sequence.
Model Group	**(aaa1,bbb1)**	**3**	**UID shared by manufacturing models that are considered distinct parts within the same assembly.**
Preferred Color	**(aaa1,bbb2)**	**3**	**Preferred sRGBA color recommended to be used for the model when visually representing and selecting material for manufacturing. This would typically be used to visually distinguish between models that are part of the same assembly and/or provide best analog to real world appearance.** **This may be ignored if individual colors have been specified inside the encapsulated model for individual**

			polygons and/or vertices may be specified (when encapsulated format allows this).
Referenced Name	**(aaa1,bbb3)**	**3**	**The file name under which the object is referred to within an encapsulated object. Preservation in this attribute allows the file name to be reconstituted when needed to preserve referential integrity from the encapsulated object.**
Referenced Instance Sequence	**(0008,114A)**	**3**	**Sequence of UIDs corresponding to supporting instances referenced within the encapsulated model.** **In an Encapsulated OBJ, only a single item shall be permitted in this sequence and that item shall be the UID of a Encapsulated MTL instance.** **In an Encapsulated MTL, all items shall be UIDs of VL Photographic Image instances (representing texture map resources).**
>Include Table 7-11b "Image Pixel Macro Attributes"			See Section C.7.6.1.1.6 for further explanation.

Changes to NEMA Standards Publication PS 3.4-2018x

Digital Imaging and Communications in Medicine (DICOM)

Part 4: Service Class Specifications

Modify Annex B.5 Standard SOP Classes – add 3 new items

B.5 STANDARD SOP CLASSES

Table B.5-1
STANDARD SOP CLASSES

SOP Class Name	SOP Class UID	IOD (See PS 3.3)
…		
Encapsulated OBJ Storage	**1.2.840.10008.5.1.4.1.1.xxx1**	**Encapsulated OBJ IOD**
Encapsulated MTL Storage	**1.2.840.10008.5.1.4.1.1.xxx2**	**Encapsulated MTL IOD**
…		

Changes to NEMA Standards Publication PS 3.6-2018x

Digital Imaging and Communications in Medicine (DICOM)

Part 6: Data Dictionary

Modify PS3.6 Table 6-1. Registry of DICOM Data Elements to add the following elements in the correct order.

Table 6-1. Registry of DICOM Data Elements

Tag	Name	Keyword	VR	VM	
…	…	…	…	…	
(aaa1,bbb1)	**Model Group**	**ModelGroup**	**UI**	**1**	
(aaa1,bbb2)	**Preferred Color**	**PreferredColor**	**LO**	**1**	
…					

Modify PS3.6 Annex A Registry of DICOM unique identifiers (UID) – add new item.

Annex A Registry of DICOM unique identifiers (UID) (Normative)

Table A-1 lists the UID values that are registered and used throughout the Parts of the DICOM Standard. This central registry ensures that when additional UIDs are assigned, non-duplicate values are assigned.

Table A-1
UID VALUES

UID Value	UID NAME	UID TYPE	Part
…			
1.2.840.10008.5.1.4.1.1.xxx1	**Encapsulated OBJ Storage**	**SOP Class**	**PS 3.4**
1.2.840.10008.5.1.4.1.1.xxx2	**Encapsulated MTL Storage**	**SOP Class**	**PS 3.4**
…			

Changes to NEMA Standards Publication PS 3.17-2018x

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Part 17: Informative

Addition to PS3.17 Append new Annex containing informative information on the creation of encapsulated OBJ/MTL objects and Texture-Maps

HHHH Encapsulated OBJ (Informative)

The goal of encapsulating a 3D manufacturing model file of the OBJ type inside a DICOM instance rather than transforming the data into a different representation is to facilitate preservation of the 3D file in the exact form that it is used with extant manufacturing devices, while at the same time unambiguously associating it with the patient for whose care the model was created and the images from which the model was derived.

The OBJ case is slightly more complicated than that of STL, when the OBJ has supporting files (material library and texture maps).

HHHH.1 Example Encoding

Below are tables showing example excerpts for encoding of OBJ files and associated preview bitmap images [optional], materials library file (MTL) [optional], and texture map images [optional] for two patients.

Example A:

Patient A will shortly be undergoing a complex partial nephrectomy to remove lesions on a kidney. A 3D manufacturing model (encoded in OBJ) was created to manufacture a surgical planning aid representing the patient's unique anatomy.

A model was constructed from a CT (CT1) dataset. The model was created on July 16, 2017 at 1:04:34 PM. The model was initially created as a colorless OBJ file. Clinicians requested that the lesions be colored; an OBJ file was generated. The model is expressed as a single OBJ file with two (2) texture maps encoded as PNG.

A preview image was created showing the rendered 3D object.

In this example, the creator of the model inscribed the patient's medical record number on a side of the model, to avoid the possibility of a wrong patient error.

Table HHHH.2
Encapsulated OBJ Example A (Encapsulated Document Series and Document Values)

Attribute Name	Tag	Example Value	Comments
Modality	(0008,0060)	MODEL	
…			

Attribute Name	Tag	Example Value	Comments
Series Description	(0008,103E)	3DP Models	
…			
Content Date	(0008,0023)	20170716	
Content Time	(0008,0033)	13:00:34	
Acquisition DateTime	(0008,002A)	20170716 13:00:34	
Image Laterality	(0020,0062)	U	
Burned In Annotation	(0028,0301)	YES	
Recognizable Visual Features	(0028,0302)	NO	
Source Instance Sequence	(0042,0013)	A sequence referencing CT1 source images and MR1 source images	Images from 2 studies are included because they both provided source data.
%item			
>Referenced SOP Class UID	(0008,1150)	1.2.840.10008.5.1.4.1.1.2.1	Referenced object is an Enhanced CT Image Storage
>Referenced SOP Instance UID	(0008,1155)	2.999.89235.5951.35894.153	The multi-frame CT image from study CT1
%enditem			
Document Title	(0042,0010)	Cardiac Model 2	
Concept Name Code Sequence	(0040,A043)		
%item			
		(85041-2, LN, “MR XXX 3D model”)	From CID 7xx1. LOINC code for MR derived 3D model
%enditem			
Predecessor Documents Sequence	(0040,A360)	A sequence referencing the UID of the earlier encapsulated OBJ	The earlier encapsulated OBJ is included so that end users can understand how this model relates to
%item			>Include Table C.17-3 'Hierarchical SOP Instance Reference Macro'
> Study Instance UID	(0020,000D)	2.999.1241.1515.15151.515.62	
> Reference Series Sequence	(0008,1115)		
%item			
>> Series Instance UID	(0020,000E)	2.999.89235.5951.35894.151	

Attribute Name	Tag	Example Value	Comments
>> Referenced SOP Sequence	(0008,1199)		
%item			
>>> Referenced SOP Class UID	(0008,1150)	1.2.840.10008.5.1.4.1.1.xxxx	Encapsulated OBJ SOP Class
>>> Referenced SOP Instance UID	(0008,1155)	2.999.1241.1515.15151.515.68	
%enditem			
%enditem			
%item			
>>Purpose of Reference Code Sequence	(0040,A170)		
%item			
		(abcdefg01, DCM, “Version prior to further segmentation”)	From CID 7xx2. This model modified the earlier one to achieve more fine-grained segmentation
%enditem			
%enditem			
%enditem			
MIME Type of Encapsulated Document	(0040,0012)	model/obj	
Encapsulated Document	(0042,0011)	Byte stream representing the OBJ file.	
Icon Image Sequence	(0088,0200)	Sequence containing an image	The pre-rendered preview image

250 **Table HHHH.3**
Encapsulated OBJ Example A (Manufacturing 3D Model Module Values)

Attribute Name	Tag	Example Value	Comments
Model Modification	(0068,7001)	NO	
Model Mirroring	(0068,7002)	NO	
Model Usage Code Sequence	(0068,7003)		
%item			
		PLANNING	
%enditem			
Units of measurement	(0040,08EA)		

Attribute Name	Tag	Example Value	Comments
%item			
		(mm, UCUM, "mm")	
%enditem			
Referenced Instance Sequence	(0008,114A)		
%item			
>> Encapsulated MTL Instance UID	(0020,000E)	2.999.89235.5951.35894.751	UID of the encapsulated MTL file (see below) supporting this OBJ model
%enditem			

Since the above OBJ file contains a reference to a materials library file (in aaa1,bbb4), this file's contents must likewise be encoded in DICOM, as shown in the tables below. While the software chose to omit the preview image (since it is optional and already present in the OBJ file), for the most part, the DICOM attribute values will be identical to the OBJ file above. This is indicated by the … row). .

Table HHHH.4
Encapsulated MTL Example A (Encapsulated Document Series and Document Values)

Attribute Name	Tag	Example Value	Comments
…			
MIME Type of Encapsulated Document	(0040,0012)	model/mtl	
Encapsulated Document	(0042,0011)	Byte stream representing the MTL file.	

Things diverge further in the 3DM module values section of the header.

Table HHHH.5
Encapsulated MTL Example A (Manufacturing 3D Model Module Values)

Attribute Name	Tag	Example Value	Comments
…			
Referenced Name	(aaa1,bbb3)	"heart-materials.mtl"	The name of the file from which this object was created, and under which it was referenced by the OBJ file
Referenced Instance Sequence	(0008,114A)		
%item			
>> VL Photographic Image Instance UID		2.999.89235.5951.35894.841	Reference to texture image used for **normal** cardiac tissue
>> VL Photographic Image Instance UID		2.999.89235.5951.35894.842	Reference to texture image used for **diseased** cardiac tissue
%enditem			

The above MTL file contains references to two texture images (see Referenced Instance Sequence above) and these likewise need to be encoded in DICOM. The VL Photographic Image object is used to represent such texture images in DICOM. An abbreviated version of the first of these two object's image headers is shown in the table below, focusing on how these relate to use with an MTL object.

Table HHHH.6
VL Photographic Image Example A (Manufacturing 3D Model Module Values)

Attribute Name	Tag	Example Value	Comments
…			
Referenced Name	(aaa1,bbb3)	"norm-card-tissue.png"	The name of the file from which this object was created, and under which it was referenced by the MTL file. Includes file type extension.
Presentation Intent Type	(0008,0068)	"FOR PROCESSING"	Let viewing software know that these images are not intended to be shown directly to the user.
…			

FUTURE DIRECTION:

Further examples (mix of both STL and OBJ) should be created covering preferred color and assembly grouping.