Radiation Oncology TC F2F Meeting 9-13 Dec 2019

IPDW and TDIC Profiles – Missing Transactions and Contents for positioning review?

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Goals

1. Present workflow definition issues experienced in trying to achieve interoperability for Positioning Review of 6 dof* positioning using kV/kV stereotaxic imaging.
2. Present issues experienced in trying to use RT Image and TDIC for Positioning Review of 6 dof* positioning using kV/kV stereotaxic imaging.
3. Analyze currrent profiles (BRTO-II, IPDW, TPIC, TDIC) to identify potential improvments opportunities.

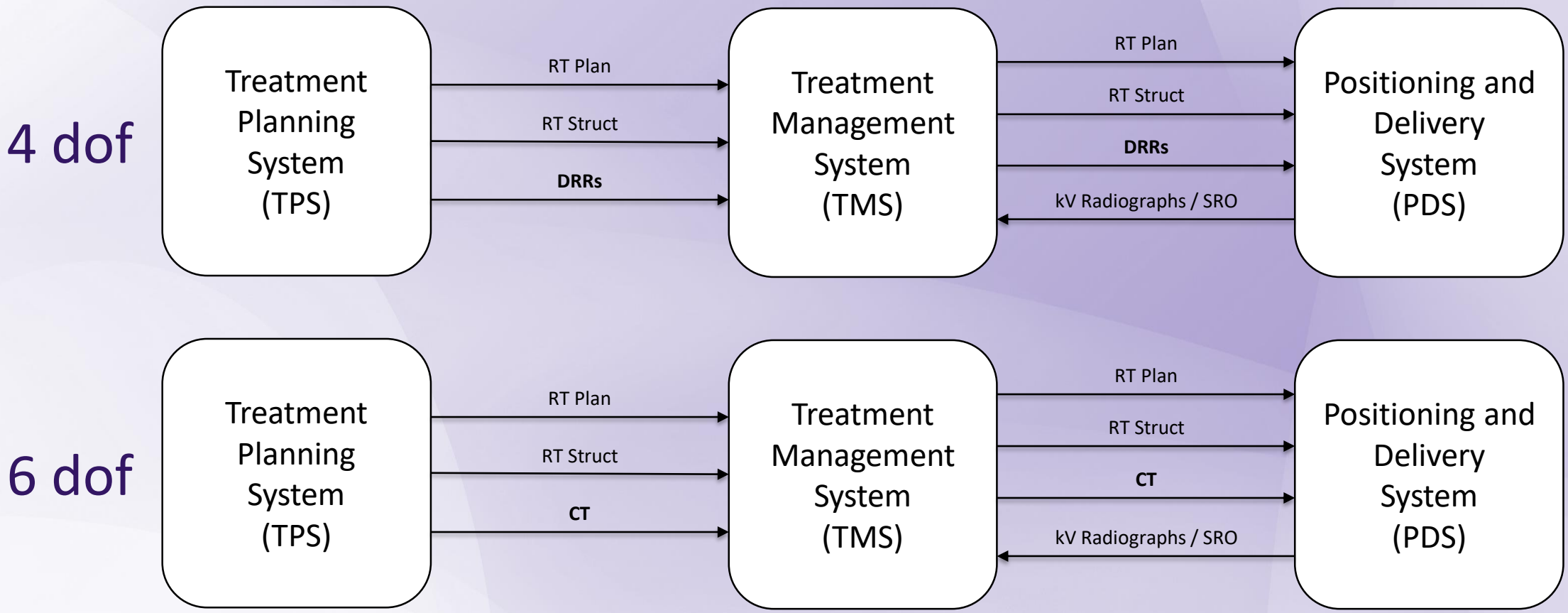
* degrees of freedom

1

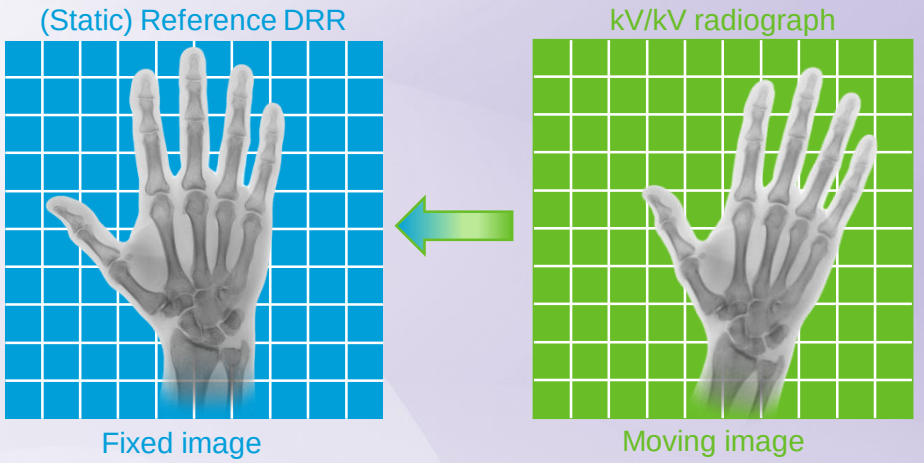
Workflow Definition Issues for Positioning Review

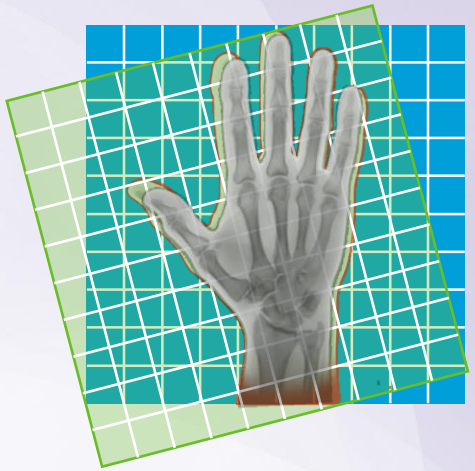
with 6 degree of freedom positioning using kV/kV stereotaxic imaging

Data Flow for 4 dof vs 6 dof kV/kV positioning

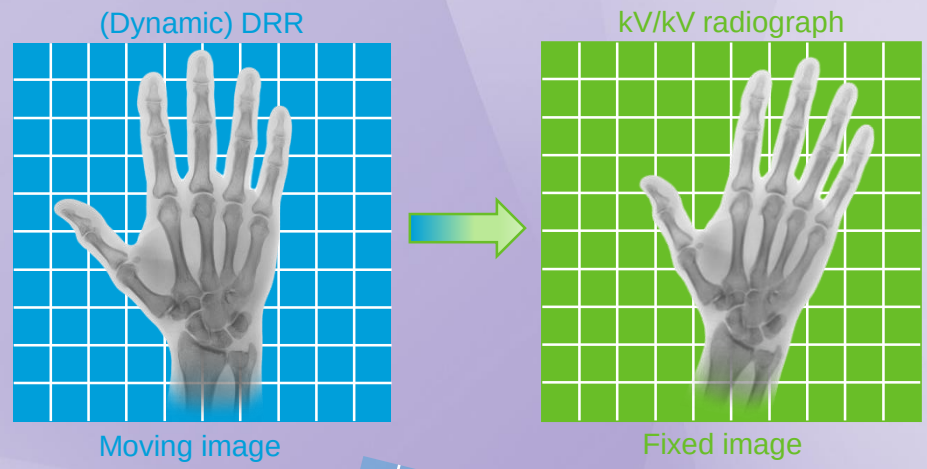


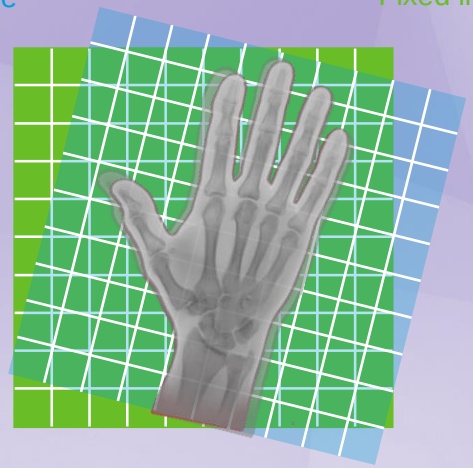
4 dof vs 6 dof positioning





2D/2D Image Registration (4 dof) – not fully accurate if pitch/roll is present





2D/3D Image Registration (6 dof)

Reference DRRs differ from Daily DRRs as **Daily DRRs are re-projected from the CT** to match the Daily patient position

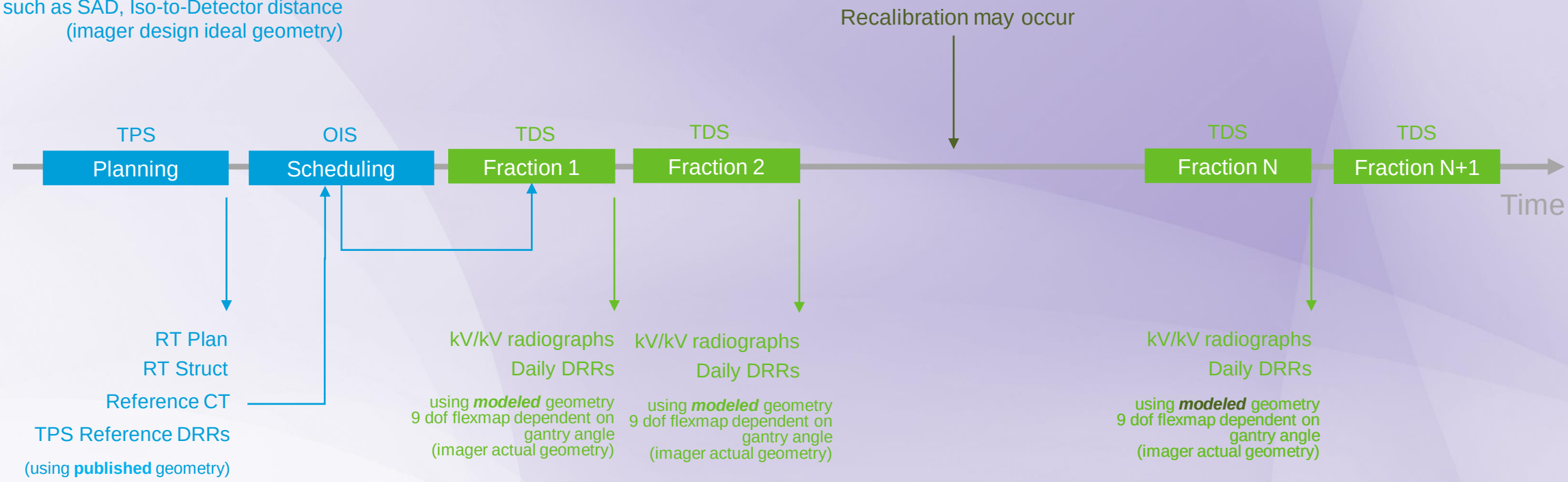
Published vs Modeled Imager Geometry

TPS: Treatment Planning System
OIS: Oncology Information System
TDS: Treatment Delivery System

TPS

Machine Characterization

Definition of imagers geometry using ***published*** parameters such as SAD, Iso-to-Detector distance (imager design ideal geometry)



Reference DRRs differ from Daily DRRs as **Daily DRRs are re-projected from the CT** to match the Daily patient position **using modeled geometry** and **actual gantry angle**

Positioning Review

- The TMS has to use
  - the Imager Modeled Geometry
  - the Actual Gantry Angle
  - the Spatial Registration

  in order to generate DRRs for positioning review

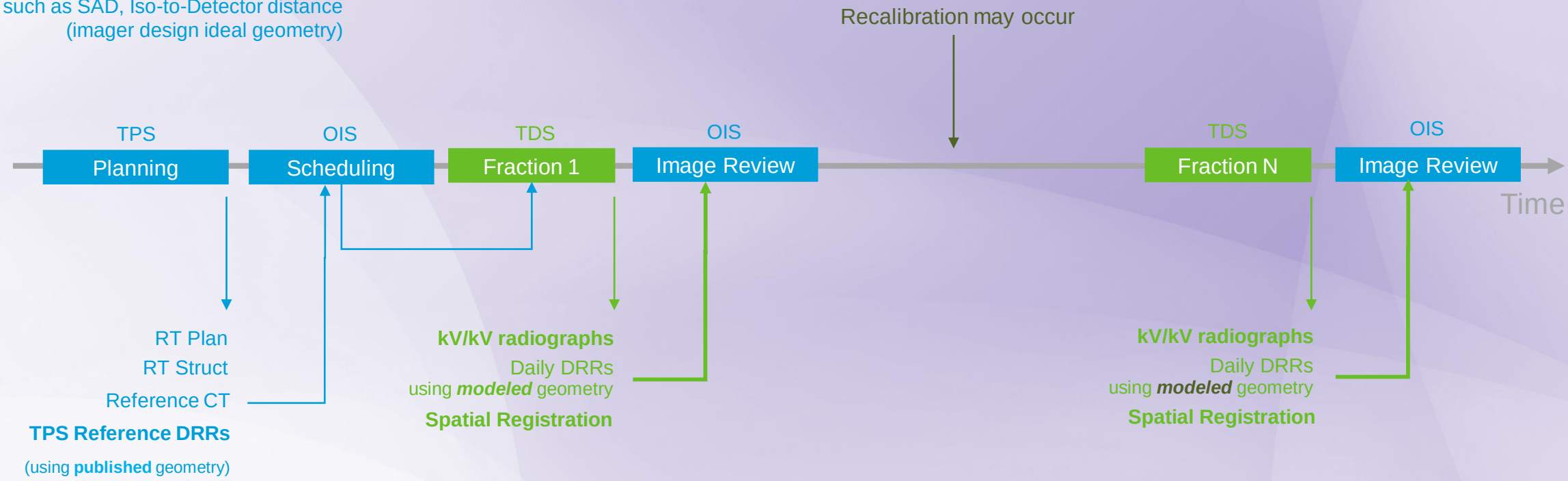
  This should be possible using the geometry encoded into the radiographs RT images (See Section 2)

What about the TPS-generated DRR?

TPS: Treatment Planning System
OIS: Oncology Information System
TDS: Treatment Delivery System

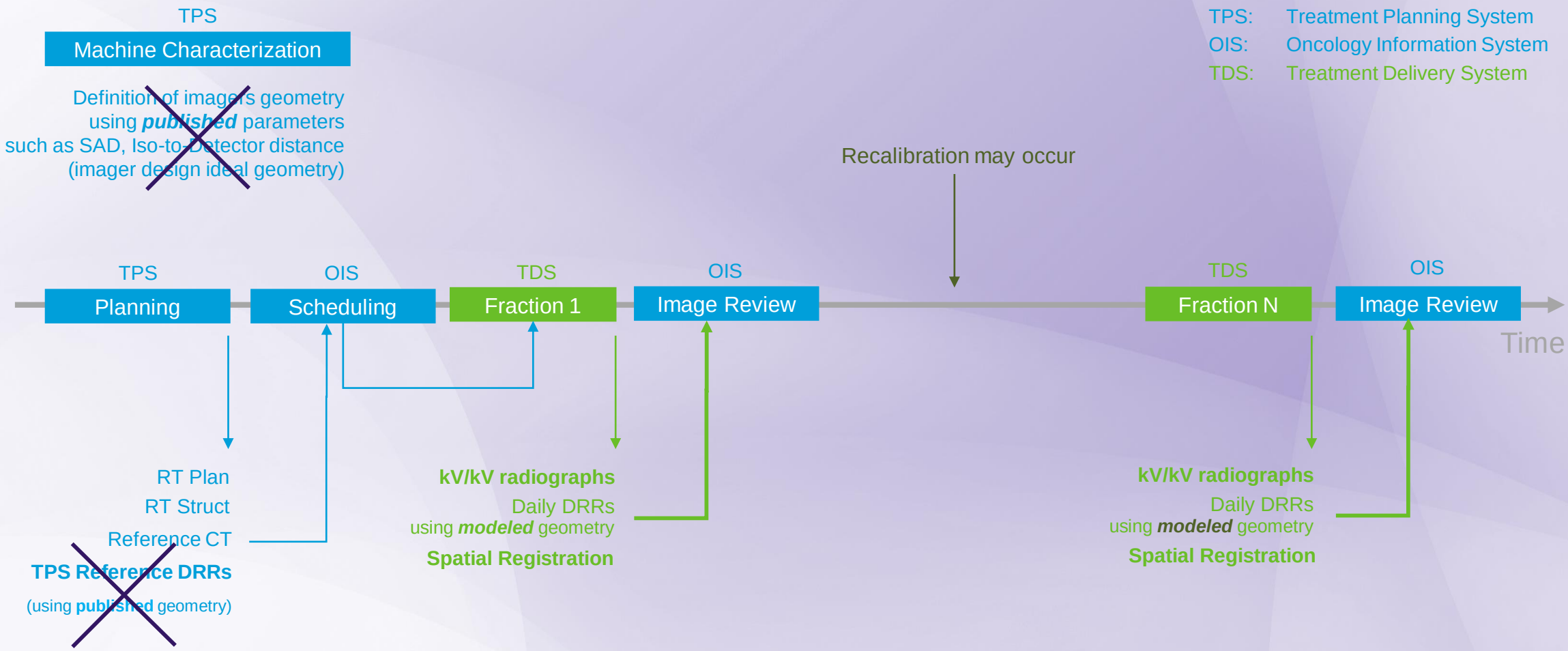
TPS
Machine Characterization

Definition of imagers geometry using ***published*** parameters such as SAD, Iso-to-Detector distance (imager design ideal geometry)



TPS Reference DRRs are not consistent with Daily DRRs, even before image registration

Option 1



No TPS Reference DRRs, No problem

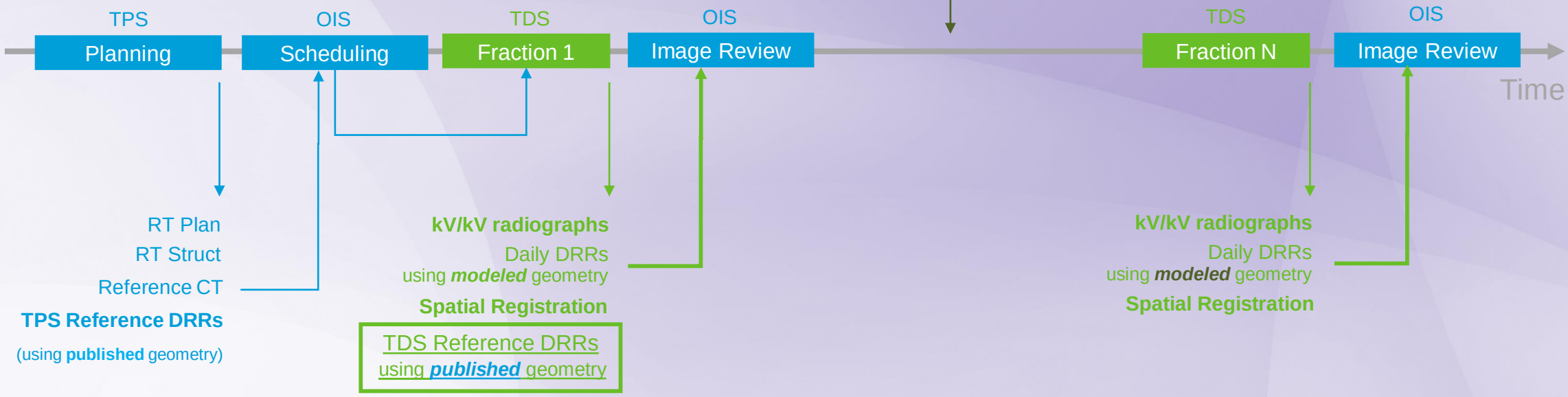
Option 2

TPS: Treatment Planning System
OIS: Oncology Information System
TDS: Treatment Delivery System

TPS
Machine Characterization

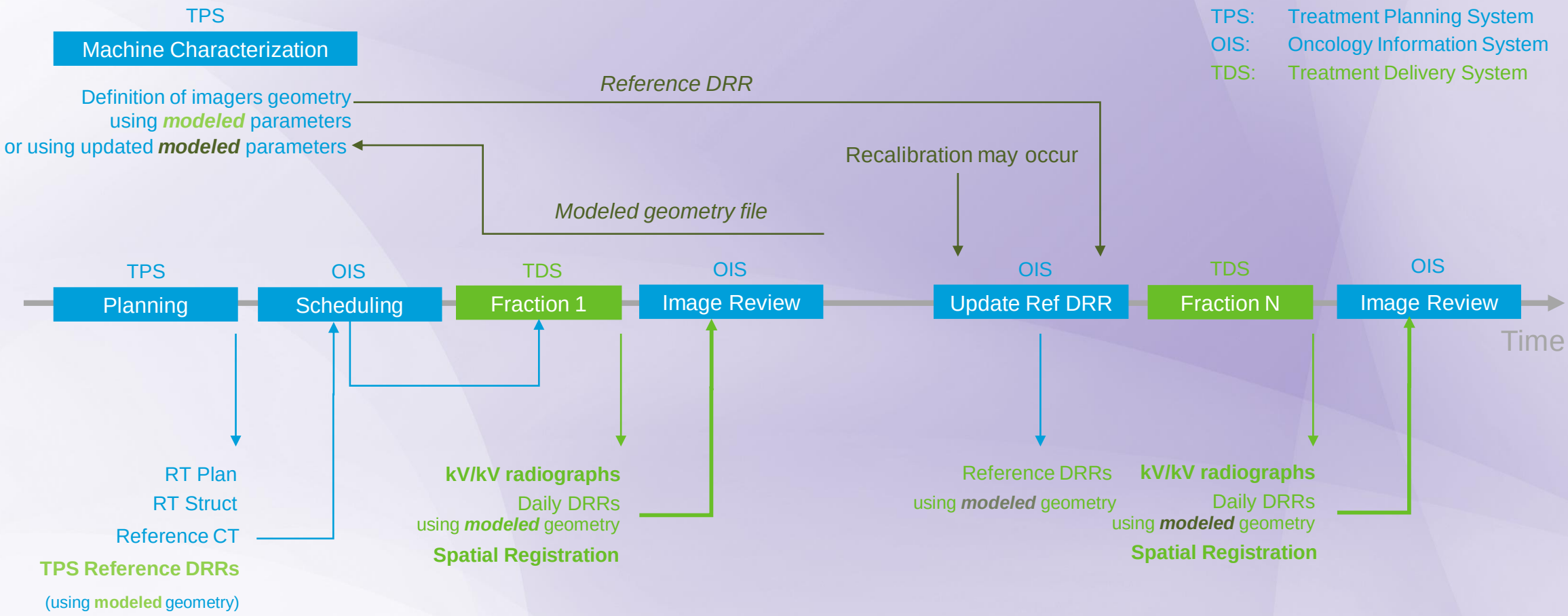
Definition of imagers geometry using ***published*** parameters such as SAD, Iso-to-Detector distance (imager design ideal geometry)

Recalibration may occur



Generation of DRRs by Treatment Delivery Machine can be verified during Commissioning, QA, first or every fraction of every patient (fusion of both reference DRR)

Option 3



TPS Reference DRRs are with Daily DRRs, before image registration

Users interviews

- Medical Physicists from the Proton users community were presented this workflow challenge.

- All Medical Physicists selected option 2
- All Medical Physicists would check DRR consistency between TPS DRR and TDS DRRs during commissioning only.

2

RT Image/TDIC issues for Positioning Review

with 6 degree of freedom positioning using kV/kV stereotaxic imaging

Encoding Modeled Geometry in RT Image

- Challenge: represent perfectly the 9 dof modeled digital radiograph (DR) acquisition geometry into the geometry of the DICOM RT Image modality for all gantry angles

  So it is possible to perform DRR projection based on the exact same geometry as the DR acquisition

- 3 approaches:
  - Comply strictly to the DICOM standard
  - Extend the DICOM standard slightly
  - Extend the DICOM standard the DICOM 2nd gen RT Objects way

DR Acquisition Geometry

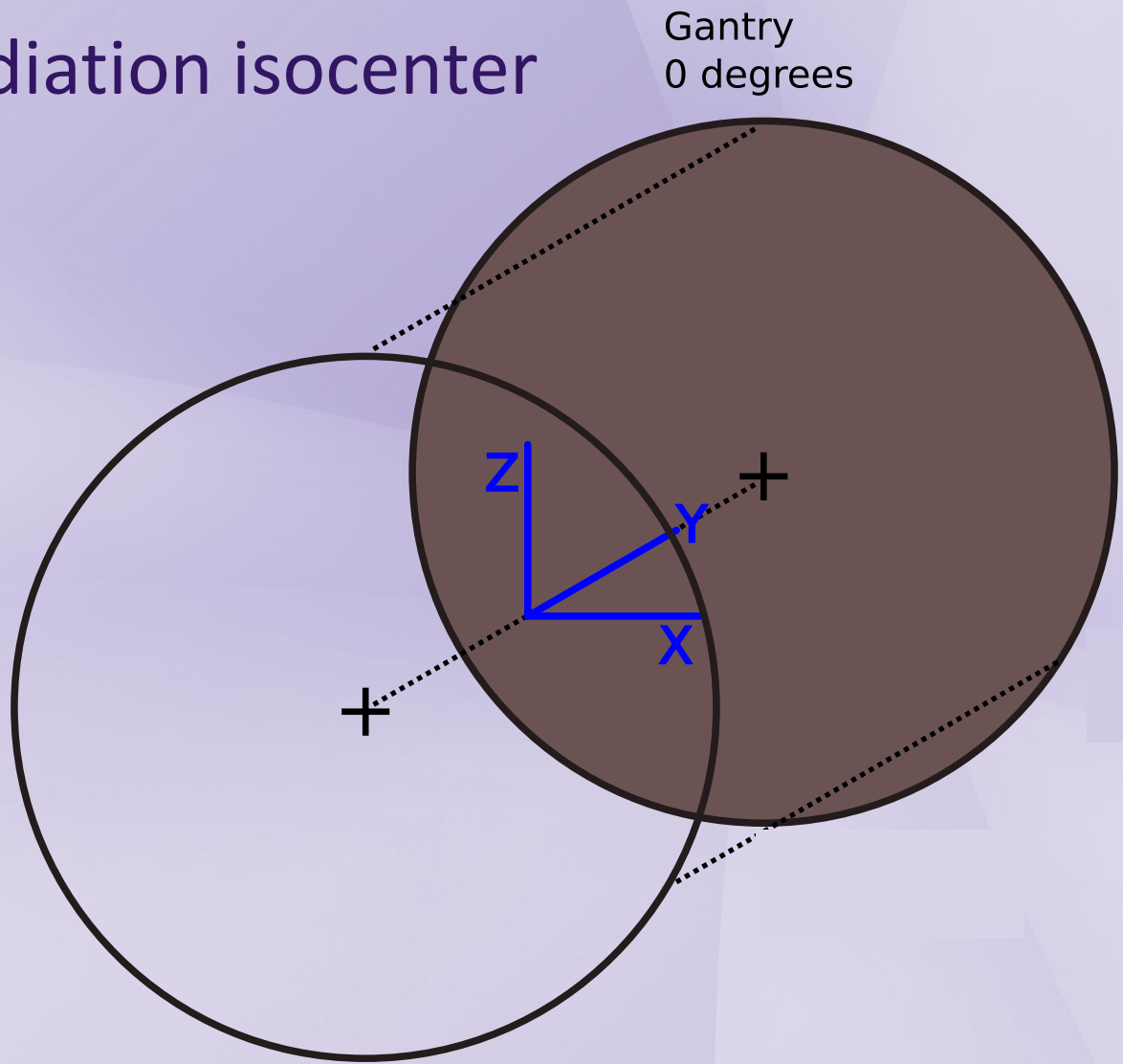
- DR acquisition geometry is defined by the geometry of the image into the X-Ray receptor.
- The X-Ray receptor, with the X-Ray source, are defined geometrically in an acquisition axis in a gantry.
- This geometry can be described by a hierarchy of coordinate system (CS)
  - The IEC-Fixed Reference System (‘f’)
  - The IEC-gantry CS (‘g’)
  - The IEC X-ray receptor CS (‘r’)
  - The Pixels CS
- Alternatively:

  The IEC Imager CS (‘i’)

  The IEC focus CS (‘o’)

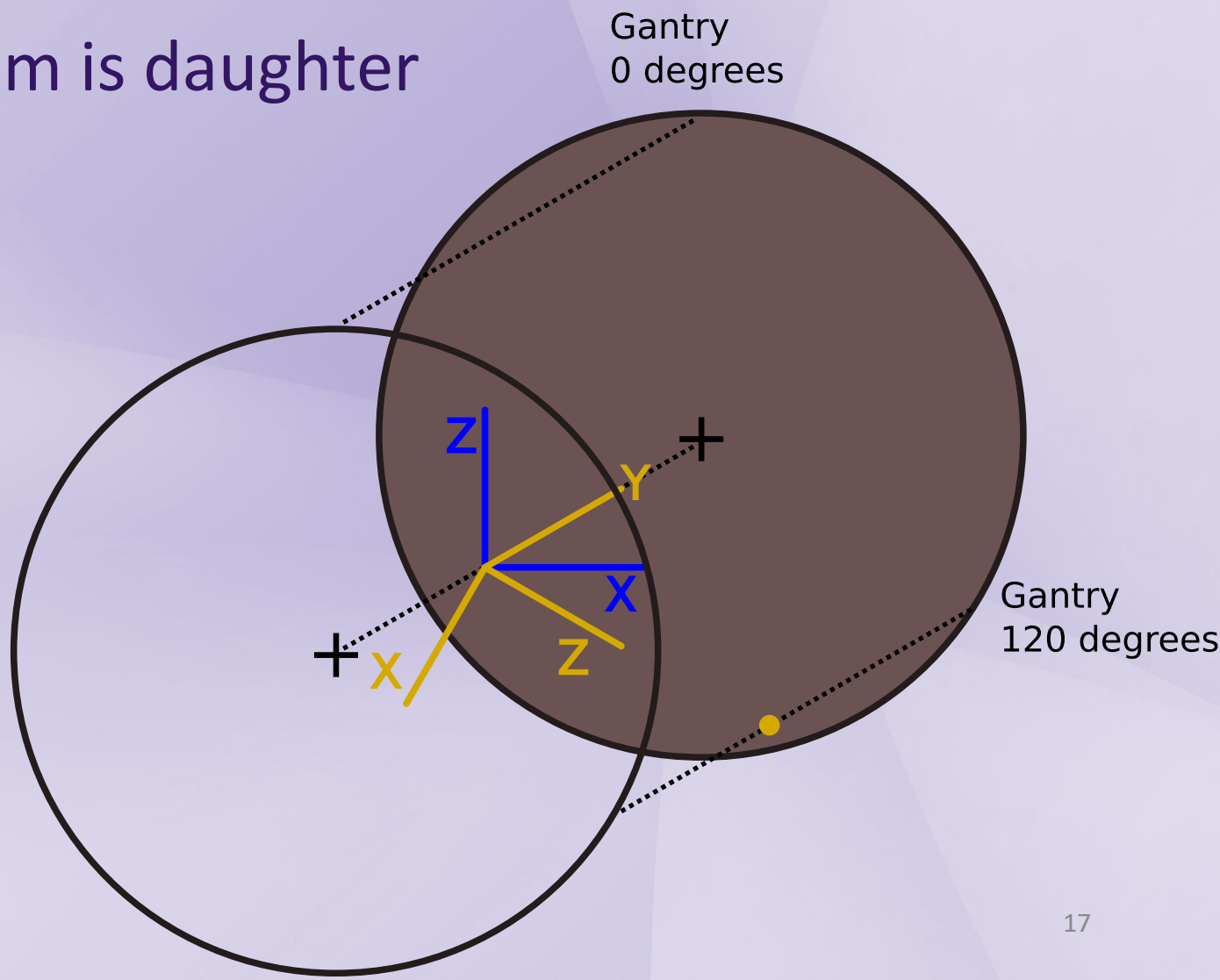
The room IEC-Fixed Reference System

- Origin of IEC Fixed is the radiation isocenter



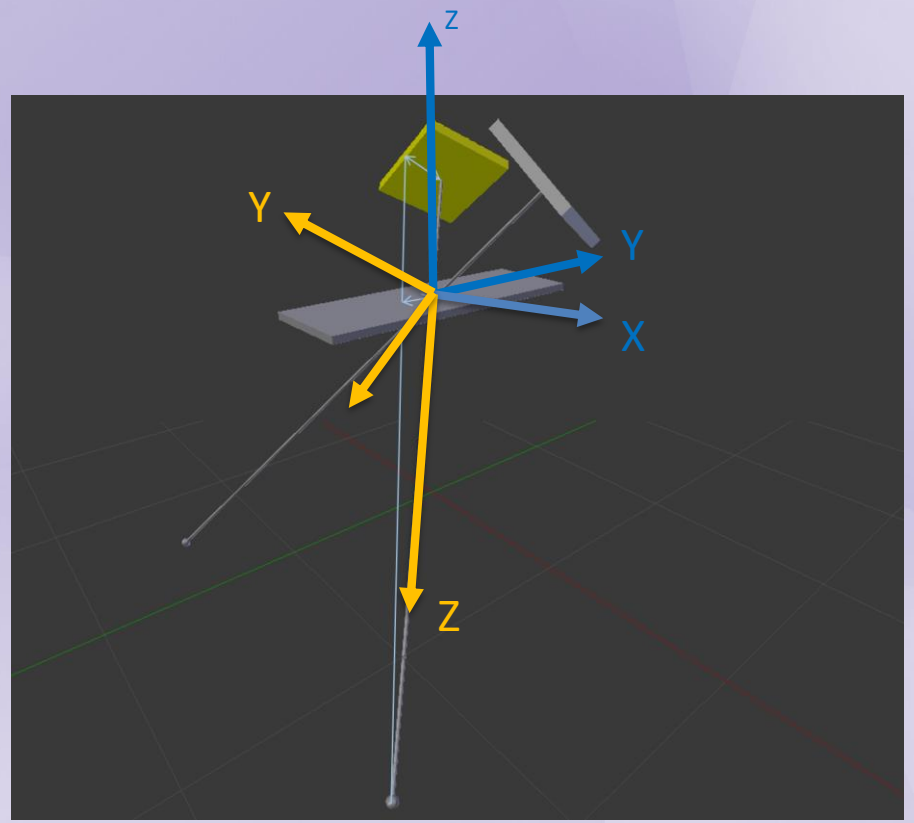
IEC-Gantry CS

- The gantry coordinate system is daughter of IEC-Fixed RS
- The gantry CS is rotated by the gantry roll angle



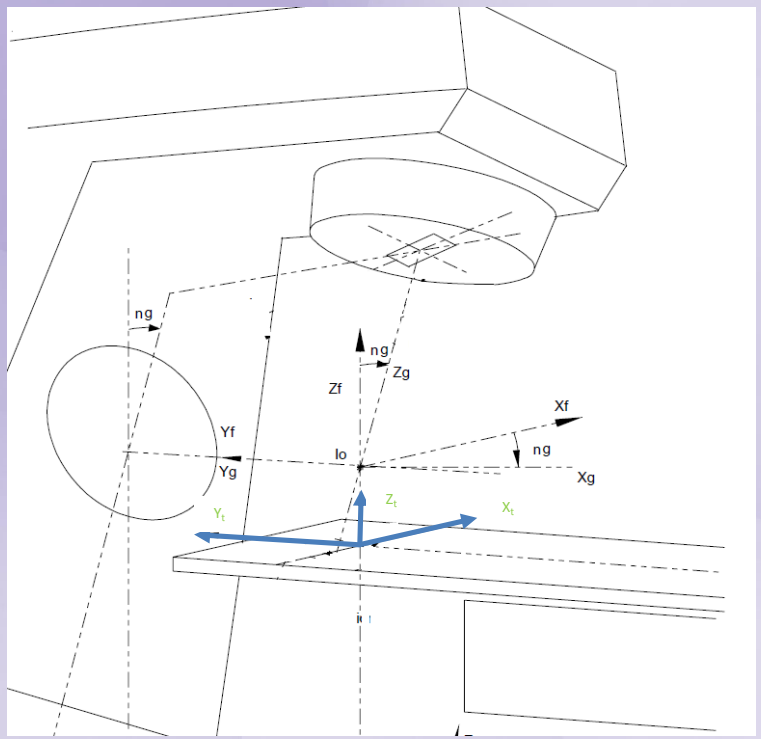
DICOM Gantry CS

- The gantry coordinate system is daughter of IEC-Fixed RS
- Gantry roll angle (R_y)
- Gantry pitch angle (R_x)
- DICOM defines a virtual IEC gantry CS adding gantry pitch.



IEC Table Top CS

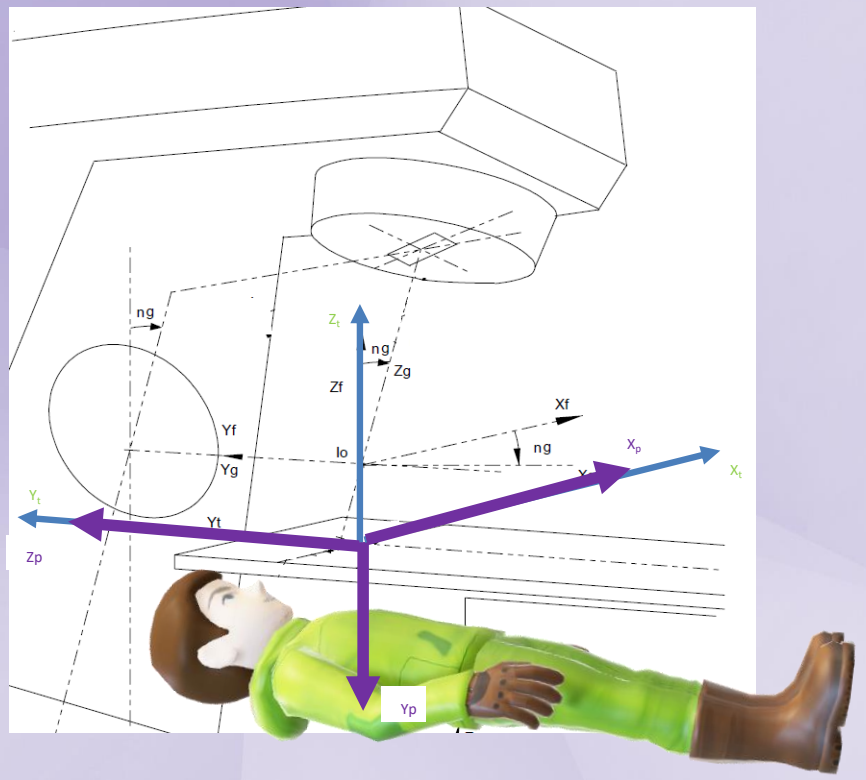
- Attached to table top
- « Grand-daughter » of IEC-Fixed CS
- Origin definition: sensible only for non-robotic couch



DICOM Patient CS

- DICOM Patient CS ≠ IEC Patient CS
- Daughter of Table-Top CS
- Depends on Patient Position (0018,5100)

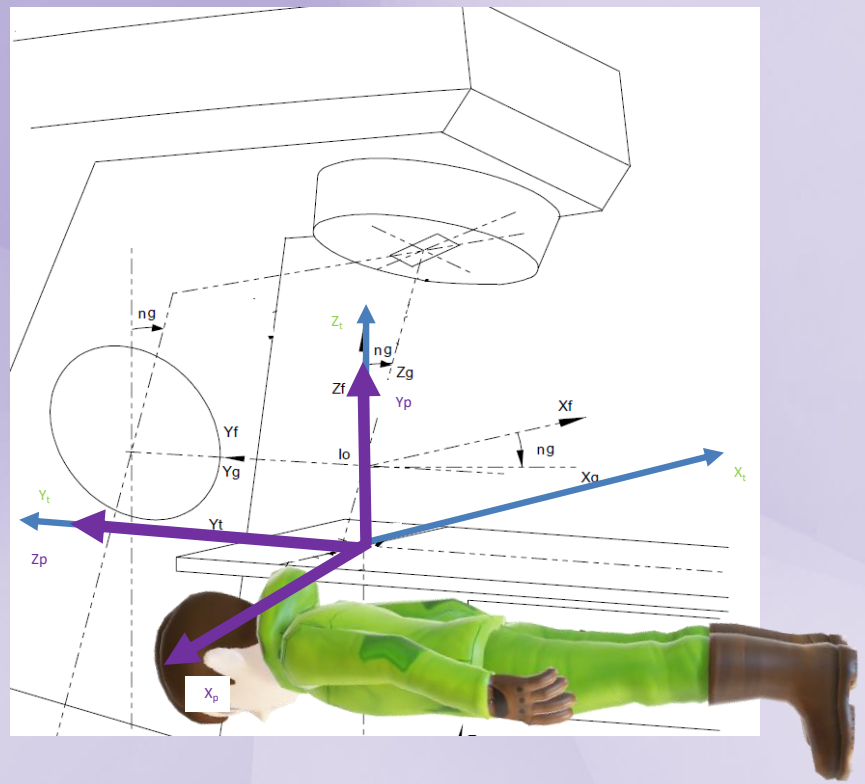
HFS



DICOM Patient CS

- DICOM Patient CS ≠ IEC Patient CS
- Daughter of Table-Top CS
- Depends on Patient Position (0018,5100)

HFP



STRICT DICOM STANDARD

Strict DICOM Standard RT Image Attributes

- Frame of reference:
  - 3D coordinate system
  - Locates DR in IEC Fixed CS

Attribute Name	Tag	Type	Attribute Description
Gantry Angle	(300A,011E)	3	Treatment machine gantry angle, i.e., orientation of IEC GANTRY coordinate system with respect to IEC FIXED REFERENCE coordinate system (degrees).
Gantry Pitch Angle	(300A,014A)	3	Gantry Pitch Angle. i.e., the rotation of the IEC GANTRY coordinate system about the X-axis of the IEC GANTRY coordinate system (degrees). See Section C.8.8.25.6.5.
Radiation Machine SAD	(3002,0022)	2	Radiation source to Gantry rotation axis distance of radiation machine used in acquiring or computing image (mm).
RT Image SID	(3002,0026)	2	Distance from radiation machine source to image plane (in mm) along radiation beam axis. See Section C.8.8.2.3.
X-Ray Image Receptor Translation	(3002,000D)	3	Position in (x,y,z) coordinates of origin of IEC X-RAY IMAGE RECEPTOR System in the IEC GANTRY coordinate system (mm). See Note 2.
X-Ray Image Receptor Angle	(3002,000E)	2	X-Ray Image Receptor Angle i.e., orientation of IEC X-RAY IMAGE RECEPTOR coordinate system with respect to IEC GANTRY coordinate system (degrees). See Section C.8.8.2.2.
RT Image Position	(3002,0012)	2	The x and y coordinates (in mm) of the upper left hand corner of the image, in the IEC X-RAY IMAGE RECEPTOR coordinate system. This is the center of the first pixel transmitted. See Section C.8.8.2.7.
RT Image Orientation	(3002,0010)	2C	The direction cosines of the first row and the first column with respect to the IEC X-RAY IMAGE RECEPTOR coordinate system. Required if RT Image Plane (3002,000C) is NON_NORMAL. May be present otherwise.
Image Plane Pixel Spacing	(3002, 0011)	2	Physical distance (in mm) between the center of each image pixel, specified by a numeric pair - adjacent row spacing (delimiter) adjacent column spacing. See Section C.8.8.2.3 and Section 10.7.1.3 for further explanation
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 IEC coordinate system to the patient-based coordinate system.
Frame of Reference UID	(0020,0052)	1	Uniquely identifies the frame of reference

Strict DICOM Standard RT Image Attributes

Attribute Name	Tag
Table Top Longitudinal Position	(300A,0129)
Table Top Lateral Position	(300A,012A)
Patient Support Angle	(300A,0122)
Table Top Pitch Angle	(300A,0140)
Table Top Roll Angle	(300A,0144)

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{FRS} = R_z . T . R_x . R_y . \begin{bmatrix} x \\ y \\ 0 \\ 1 \end{bmatrix}_{TTCS} .$$

Strict DICOM Standard: Image CS

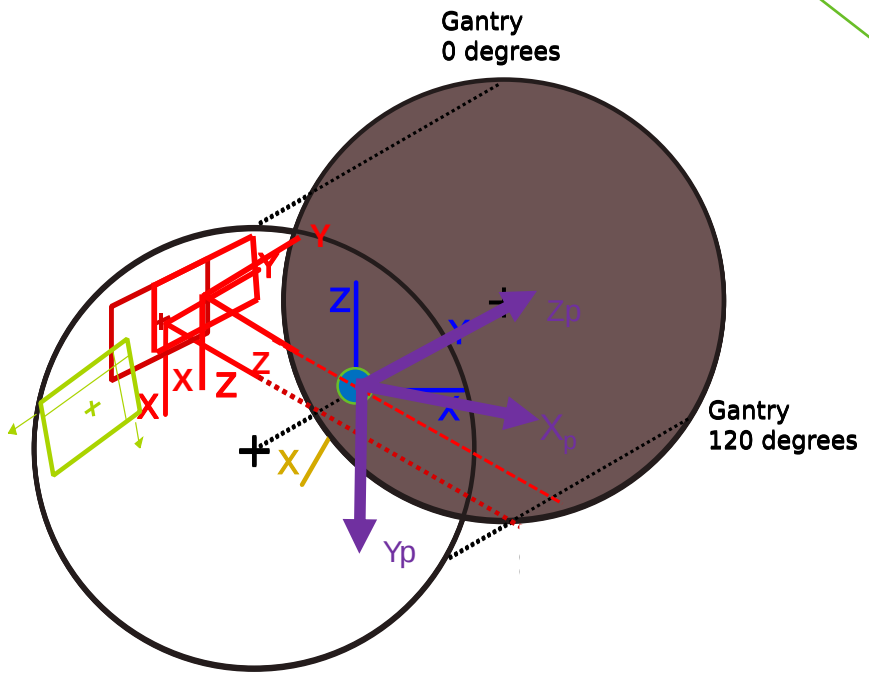
- ‘f’ to pixel

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{FRS} = R(\theta_{Y,gtry}) \,.\, R(\theta_{X,gtry}) \,.\, R(\theta_{Z,IR}) \,.\, T(X_{XIR}, Y_{XIR}, Z_{XIR}) \,.\, \begin{bmatrix} D_{X,x}.\Delta_x & D_{Y,x}.\Delta_y & 0 & S_x \\ D_{X,y}.\Delta_x & D_{Y,y}.\Delta_y & 0 & S_y \\ D_{X,z}.\Delta_x & D_{Y,z}.\Delta_y & 1 & S_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \,.\, \begin{bmatrix} x \\ y \\ 0 \\ 1 \end{bmatrix}_{PXL}$$

- ‘f’ to ‘p’

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{FRS} = M_{f \to tt} \quad M_{tt \to p} \,.\, \begin{bmatrix} x \\ y \\ 0 \\ 1 \end{bmatrix}_{p}$$

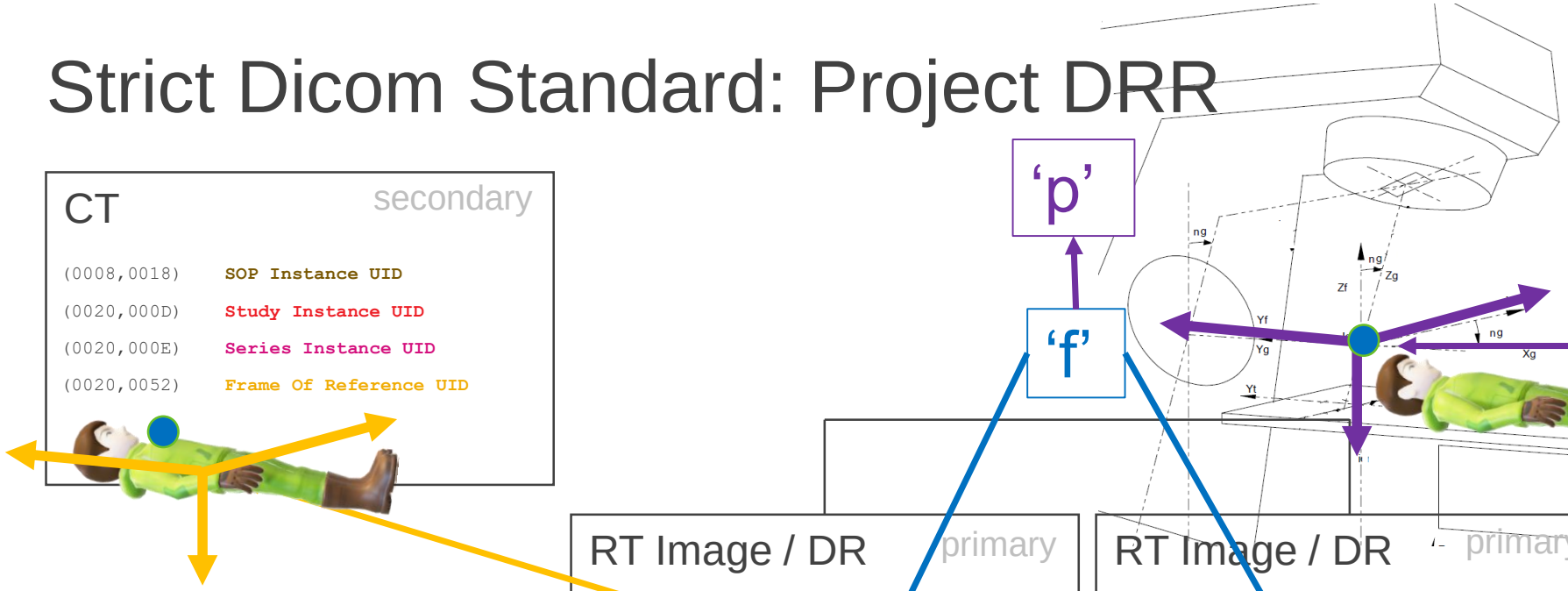
HFS



Attribute Name	Tag
Table Top Longitudinal Position	(300A,0129)
Table Top Lateral Position	(300A,012A)
Patient Support Angle	(300A,0122)
Table Top Pitch Angle	(300A,0140)
Table Top Roll Angle	(300A,0144)

(0,0,0)

Strict Dicom Standard: Project DRR



CT — secondary

(0008,0018)	SOP Instance UID
(0020,000D)	Study Instance UID
(0020,000E)	Series Instance UID
(0020,0052)	Frame Of Reference UID

RT Image / DR — primary

(0008,0018)	SOP Instance UID
(0020,000D)	Study Instance UID
(0020,000E)	Series Instance UID
(0020,0052)	Frame Of Reference UID

RT Image / DR — primary

(0008,0018)	SOP Instance UID
(0020,000D)	Study Instance UID
(0020,000E)	Series Instance UID
(0020,0052)	Frame Of Reference UID

Tag Name	Symbol	Tag Name	Symbol
Gantry angle	$\theta_{Y,gtry}$	Gantry angle	$\theta_{Y,gtry}$
Gantry pitch	$\theta_{X,gtry}$	Gantry pitch	$\theta_{X,gtry}$
X-ray image receptor translation	$X_{XIR}, Y_{XIR}, Z_{XIR}$	X-ray image receptor translation	$X_{XIR}, Y_{XIR}, Z_{XIR}$
Xray image receptor angle	$\theta_{Z,IR}$	Xray image receptor angle	$\theta_{Z,IR}$
RT image position	S_x, S_Y, S_Z	RT image position	S_x, S_Y, S_Z
RT image orientation	$R(D_{X,IR}, D_{Y,IR})$	RT image orientation	$R(D_{X,IR}, D_{Y,IR})$
Pixel spacing	$\Delta_x, \Delta_y, \Delta_z$	Pixel spacing	$\Delta_x, \Delta_y, \Delta_z$
Isocenter Position	$(X,Y,Z)_{FRS}$	Isocenter Position	$(X,Y,Z)_{FRS}$

Spatial Registration

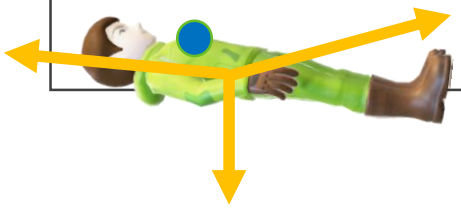
(0008,0018)	SOP Instance UID
(0020,000D)	Study Instance UID
(0020,000E)	Series Instance UID
(0020,0052)	Frame Of Reference UID
(3006,0014)	Referenced Series SEQ
(0020,000E)	> Ref Series Instance UID
(0020,000E)	> Ref Series Instance UID
(0070,0308)	Registration SEQ
(0008,1140)	> Ref Image SEQ
(0008,1150)	>> Ref SOP Class UID
(0008,1155)	>> Ref SOP Instance UID
(0020,0052)	> Frame Of Reference UID
(0070,0309)	> Matrix Registration SEQ
(0070,030A)	>> Matrix SEQ
(0070,030C)	>>> FOR Tr Matrix
(3006,00C6)	>> Reg Type Code SEQ
(0008,0100)	>>> Code Value *(125021)*
(0008,0104)	>>> Code Meaning *(identity)*
(0008,1140)	> Ref Image SEQ
(0008,1150)	> Ref SOP Class UID
(0008,1155)	> Ref SOP Instance UID
…	
(0020,0052)	> Frame Of Reference UID
(0070,0309)	> Matrix Registration SEQ
(0070,030A)	>> Matrix SEQ
(0070,030C)	>>> FOR Tr Matrix
(3006,00C6)	>> Reg Type Code SEQ
(0008,0100)	>>> Code Value
(0008,0104)	>>> Code Meaning

Enough information to project DRR from CT

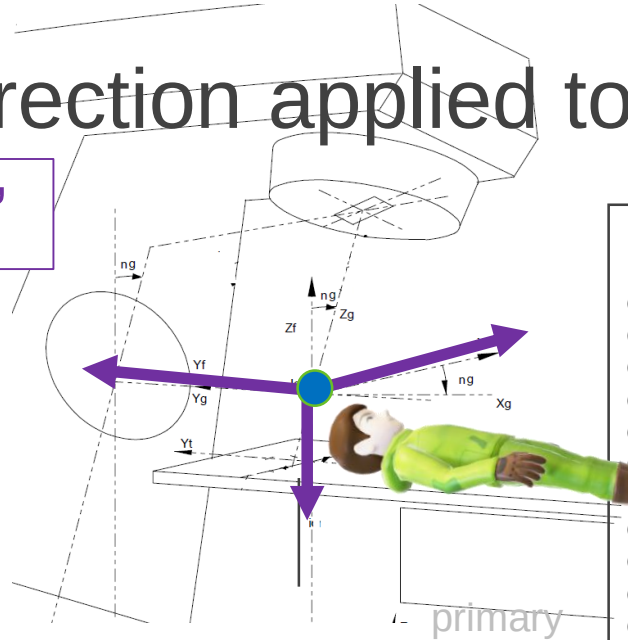
Strict Dicom Standard: Was correction applied to TT ?

CT secondary

(0008,0018)	**SOP Instance UID**
(0020,000D)	**Study Instance UID**
(0020,000E)	**Series Instance UID**
(0020,0052)	**Frame Of Reference UID**



‘p’



Spatial Registration

(0008,0018)	SOP Instance UID
(0020,000D)	Study Instance UID
(0020,000E)	Series Instance UID
(0020,0052)	**Frame Of Reference UID**
(3006,0014)	Referenced Series SEQ
(00 ,00E)	> Ref Series Instance UID
(,00E)	> Ref Series Instance UID
(0070,0308)	Registration SEQ
(0008,1140)	> Ref Image SEQ
(0008,1150)	>> Ref SOP Class UID
(0008,1155)	>> Ref SOP Instance UID
(0008,1150)	>> Ref SOP Class UID
(0008,1155)	>> Ref SOP Instance UID
(0020,0052)	> Frame Of Reference UID
(0070,0309)	> Matrix Registration SEQ
(0070,030A)	>> Matrix SEQ
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(3006,00C6)	>> Reg Type Code SEQ
(0008,0100)	>>> Code Value *(125021)*
(0008,0104)	>>> Code Meaning *(identity)*
(0008,1140)	> Ref Image SEQ
(0008,1150)	> Ref SOP Class UID
(0008,1155)	> Ref SOP Instance UID
	…
(0020,0052)	> Frame Of Reference UID
(0070,0309)	> Matrix Registration SEQ
(0070,030A)	>> Matrix SEQ
(0070,030C)	>>> FOR Tr Matrix
(3006,00C6)	>> Reg Type Code SEQ
(0008,0100)	>>> Code Value
(0008,0104)	>>> Code Meaning

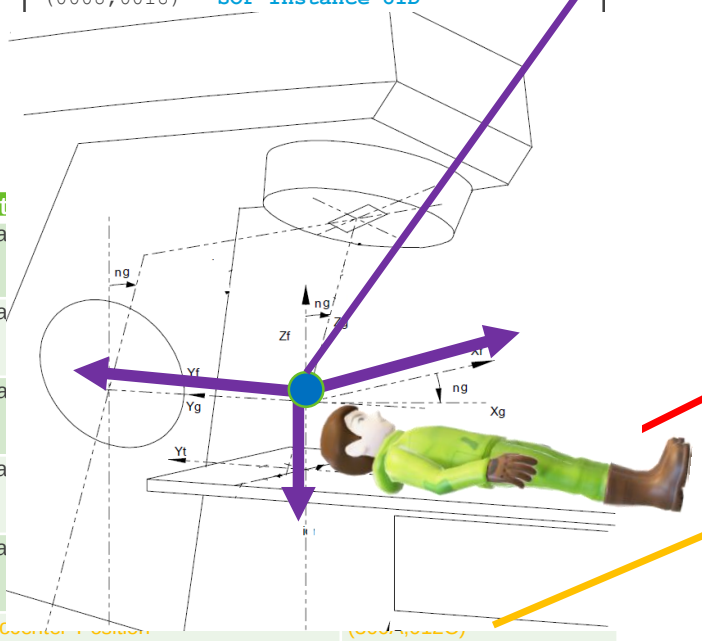
Strict Dicom Standard: Was correction applied to TT ?

CT secondary

(0008,0018) SOP Instance UID
(0020,000D) Study Instance UID
(0020,000E) Series Instance UID
(0020,0052) Frame Of Reference UID

RT (Ion) Plan

(0008,0018) SOP Instance UID



HFS

'p'

'p'$_{CT}$

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_p = M_{reg} \cdot \begin{bmatrix} x \\ y \\ 0 \\ 1 \end{bmatrix}_{CT}$$

TT is at wrong place during imaging

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_p = M_{err}\ M_{FRS-tt}\ M_{tt\to p}\ .T(-iso) \cdot \begin{bmatrix} x \\ y \\ 0 \\ 1 \end{bmatrix}_{CT}$$

$$M_{reg} = M_{err}\ M_{FRS-tt}\ M_{tt\to p}\ .T(-iso)$$

$$P_{treat} = M_{err}^{-1}\ .P_{img}$$

TT position
In treat. record

TT pos. In
DR

Spatial Registration

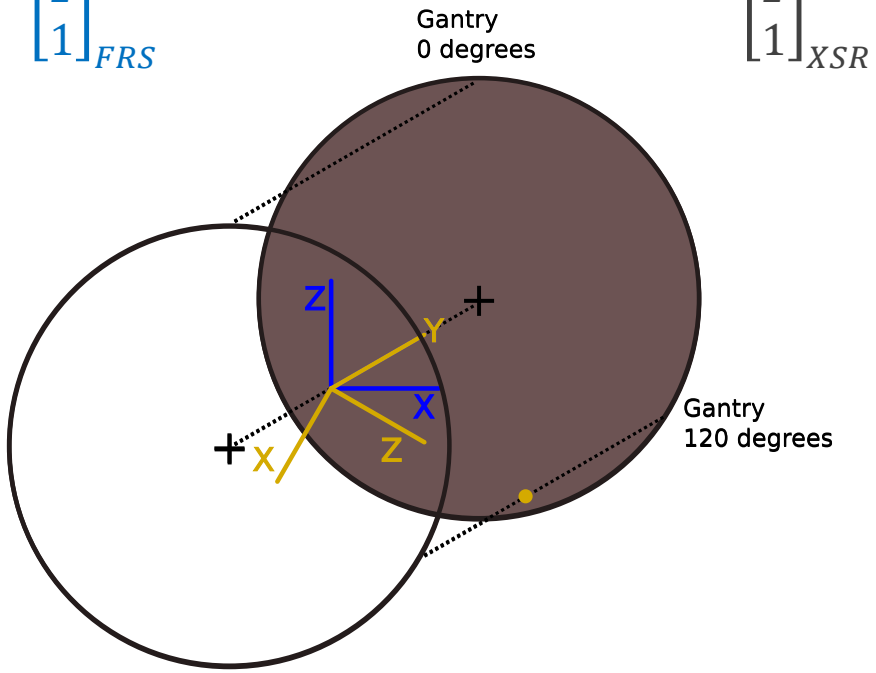
(0008,0018) SOP Instance UID
(0020,000D) Study Instance UID
(0020,000E) Series Instance UID
(0020,0052) Frame Of Reference UID
(3006,0014) Referenced Series SEQ
(0020,00E) > Ref Series Instance UID
(0020,00E) > Ref Series Instance UID
(0070,0308) Registration SEQ
(0008,1140) > Ref Image SEQ
(0008,1150) >> Ref SOP Class UID
(0008,1155) >> Ref SOP Instance UID
(0008,1150) >> Ref SOP Class UID
(0008,1155) >> Ref SOP Instance UID
(0020,0052) > Frame Of Reference UID
(0070,0309) > Matrix Registration SEQ
(0070,030A) >> Matrix SEQ
(0070,030C) >>> FOR Tr Matrix
(3006,00C6) >> Reg Type Code SEQ
(0008,0100) >>> Code Value *(125021)*
(0008,0104) >>> Code Meaning *(identity)*
(0008,1140) > Ref Image SEQ
(0008,1150) > Ref SOP Class UID
(0008,1155) > Ref SOP Instance UID
...
(0020,0052) > Frame Of Reference UID
(0070,0309) > Matrix Registration SEQ
(0070,030A) >> Matrix SEQ
(0070,030C) >>> FOR Tr Matrix
(3006,00C6) >> Reg Type Code SEQ
(0008,0100) >>> Code Value
(0008,0104) >>> Code Meaning

MODIFICATION OF DICOM STANDARD (CP)

Extend the standard: Define the X-Ray Source CS

- Add a multi valued attribute **X-Ray Image Source Position** to define the X, Y, Z translation (in mm) of the source into the gantry CS

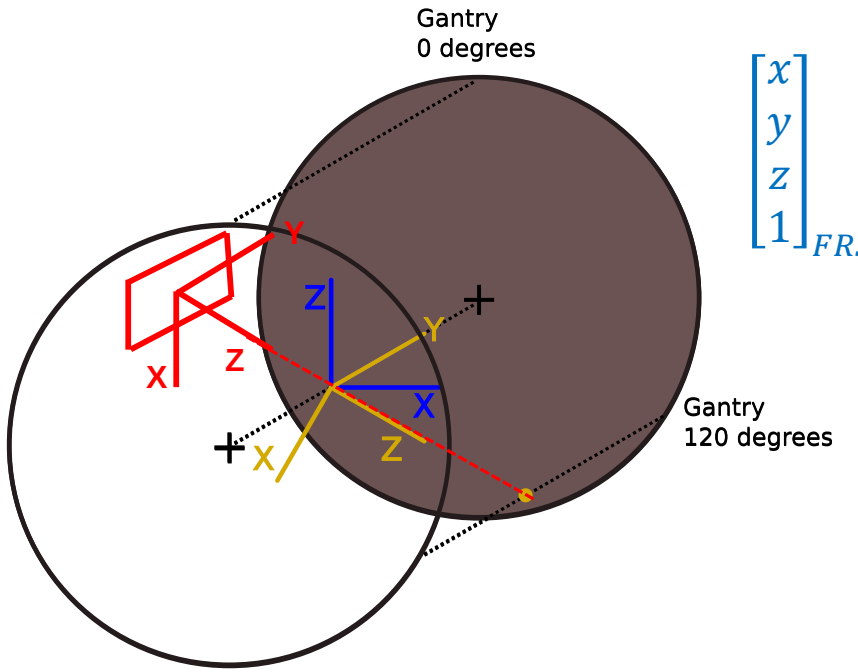
$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{FRS} = R(\theta_{Y,gtry}) \cdot R(\theta_{X,gtry}) \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{XSR}$$



Extend the standard: Extend the X-ray Receptor CS

- For the X-ray receptor, add two attributes:
  - **X-Ray Image Receptor Pitch Angle (in degree)**
  - **X-Ray Image Receptor Roll Angle (in degree)**

Tag Name	Symbol
Gantry angle	$\theta_{Y,gtry}$
Gantry pitch	$\theta_{X,gtry}$



$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{FRS} = R(\theta_{Y,gtry}) \cdot R(\theta_{X,gtry}) \cdot R(\theta_{Z,IR}) \cdot R(\theta_{Y,IR}) \cdot R(\theta_{X,IR}) \cdot T(X_{XIR}, Y_{XIR}, Z_{XIR}) \cdot \begin{bmatrix} x \\ y \\ 0 \\ 1 \end{bmatrix}_{XIR}$$

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{FRS} = M_{XIR\ FRS} \cdot \begin{bmatrix} \Delta_x & 0 & 0 & S_x \\ 0 & \Delta_y & 0 & S_y \\ 0 & 0 & 1 & S_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ 0 \\ 1 \end{bmatrix}_{PXL}$$

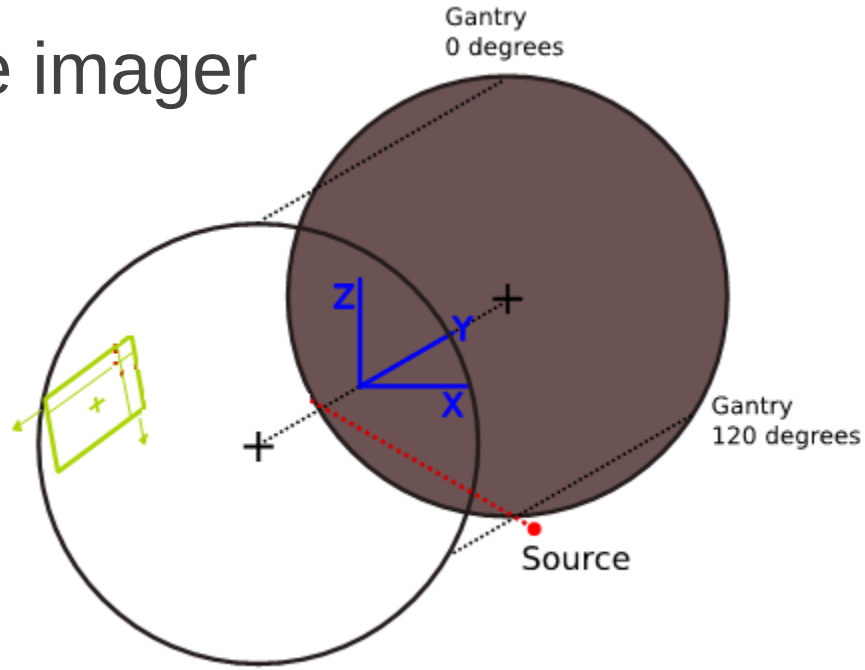
Tag Name	Symbol
RT image position	S_x, S_Y, S_Z
Pixel spacing	Δ_x, Δ_y

MODIFICATION OF DICOM STANDARD (CP) AS IN 2ND GENERATION RT OBJECTS

Using IEC imager CS: 2nd gen Dicom objects

- Add attributes fully defining the geometry of the imager
- IEC Imager CS: One matrix does it all

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{FRS} = \begin{bmatrix} a_{1,1}(\theta_g) & a_{1,2}(\theta_g) & a_{1,3}(\theta_g) & a_{1,4}(\theta_g) \\ a_{2,1}(\theta_g) & a_{2,2}(\theta_g) & a_{2,3}(\theta_g) & a_{2,4}(\theta_g) \\ a_{3,1}(\theta_g) & a_{3,2}(\theta_g) & a_{3,3}(\theta_g) & a_{3,4}(\theta_g) \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{IEC-imgrCS}$$



$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{FRS} = \mathrm{M} \cdot \begin{bmatrix} \Delta_x & 0 & 0 & S_x \\ 0 & \Delta_y & 0 & S_y \\ 0 & 0 & 1 & S_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ 0 \\ 1 \end{bmatrix}_{PXL}$$

Symbol	Attribute name
$M = [\ \ ]$	IEC Imager 4*4 matrix
$X_{XIR}, Y_{XIR}, Z_{XIR}$	IEC FRS Source position

Tag Name	Symbol
RT image position	S_x, S_Y, S_Z
Pixel spacing	Δ_x, Δ_y
Isocenter Position	$(X,Y,Z)_{FRS}$

AAMI RT3 experience

- Tried to draft fixed imager geometry characterization based on IEC61217 coordinate systems and DICOM attributes
  - Was removed from the scope of the standard subsequently to negative vote comments requesting more/better definition.

Imager Geometry for the TPS

- To allow TPS to generate DRR with the same geometry as an actual imager
- Flex map definition
- TPS interpolate the angles (linear interpolation)

Gantry angle (°)	X-Ray Source position in FRS (mm)	X-Ray Flat panel 4*4 matrix (mm) in FRS
0°	X, Y, Z	$\begin{bmatrix} a_{1,1}(\theta_g) & a_{1,2}(\theta_g) & a_{1,3}(\theta_g) & a_{1,4}(\theta_g) \\ a_{2,1}(\theta_g) & a_{2,2}(\theta_g) & a_{2,3}(\theta_g) & a_{2,4}(\theta_g) \\ a_{3,1}(\theta_g) & a_{3,2}(\theta_g) & a_{3,3}(\theta_g) & a_{3,4}(\theta_g) \\ 0 & 0 & 0 & 1 \end{bmatrix}$
1°	X, Y, Z	
…		

Room Isocenter (mm) in FRS : (0,0,0)

3

IHE-RO Profiles Analysis

In regards to support for 6 degree of freedom positioning using kV/kV stereotaxic imaging

TDIC Actors and Transactions

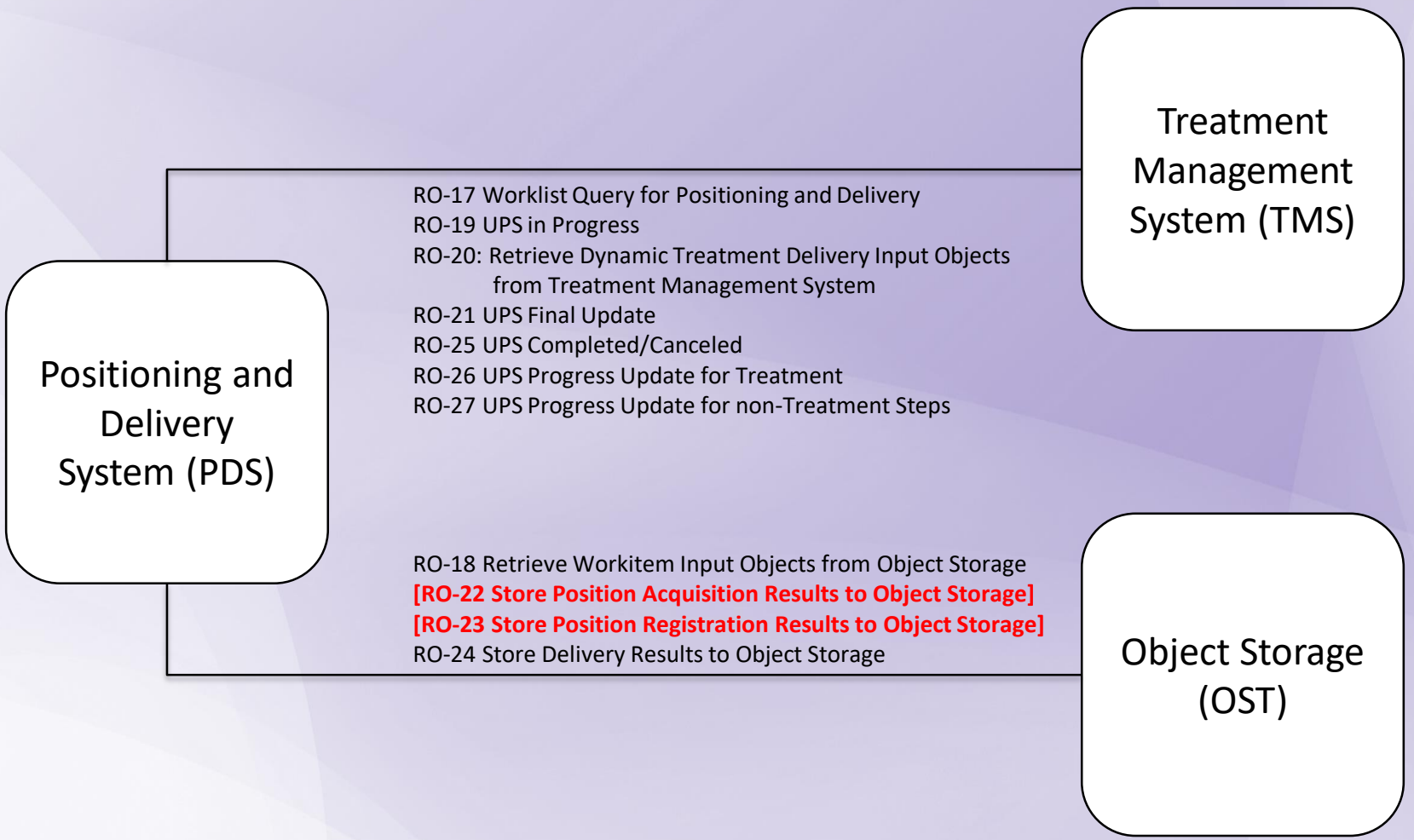
What is the Workflow requiring TDIC?

- TDIC implicitly introduces "**Positioning Review**" with a short definition:

  Safe and unambiguous review of image registration and the resulting position correction which had been suggested during a particular treatment session

- Is Positioning Review a Workflow or a Use Case of IPDW workflow?
  - IPDW Workflow explicitly includes Patient Positioning, Patient Monitoring and Radiation Delivery Use Cases.
  - IPDW defines Patient Position Verification (Acquisition), Patient Registration and Patient Position Correction procedures

IPDW Workflow, Actors and Transactions



What are the activities of Positioning Review?

- Fusion Display of the acquired and reference images
  - without registration for Patient Position Verification (A)
  - with registration computed by PDS for Patient Registration (A+R)
  - without registration computed by PDS for Patient Registration (A+R)
  - with a new registration computed by Positioning Review application
- Approval/Rejection of images
- Input of comments for next positioning session

A: Acquisition UPS
R: Registration UPS

What are the issues?

For Positioning Review,

No transactions defined for

- Storage of Position Correction Instruction (as there is no such DICOM object in DICOM 1st Gen but RT Record can be used to assess if corection was aplied and infer the correction in this case.
- Storage of daily DRR RT Image produced by the PDS

No information available in Content for

- 9 dof characterization of imagers geometry.

What are the issues?

- No transaction for exchange of reference DRR images between TPS and TMS (corresponding to TPIC content profile)
- Transaction for exchange of reference DRR images between TMS and PDS (corresponding to TPIC content profile) is implicitly defined
  - In RO-18 Retrieve Workitem Input Objects from Object Storage