



# Automated monitoring of treatment delivery

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# Record and Verify Systems

## **Early generation of R&V Systems are;**

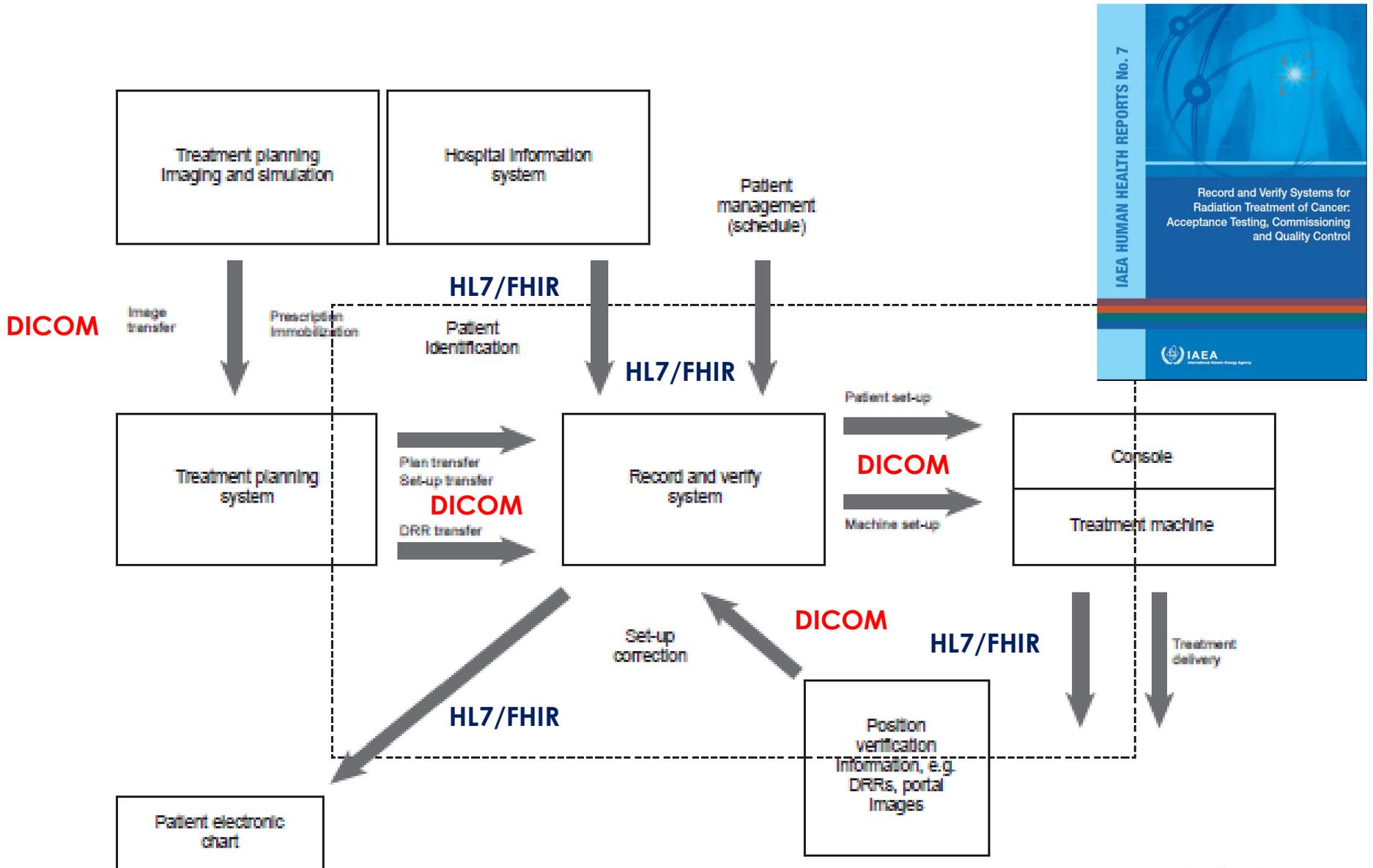
- computerized systems attached to individual treatment machines,
- designed to capture, before each beam delivery, several treatment parameters accessible through encoders and to compare them to the intended parameters,
- parameters entered manually or automatically transferred from the TPS or captured on the first treatment day to serve as a reference for the following fractions, and
- allowed partial or fully automated set-up

# Record and Verify Systems

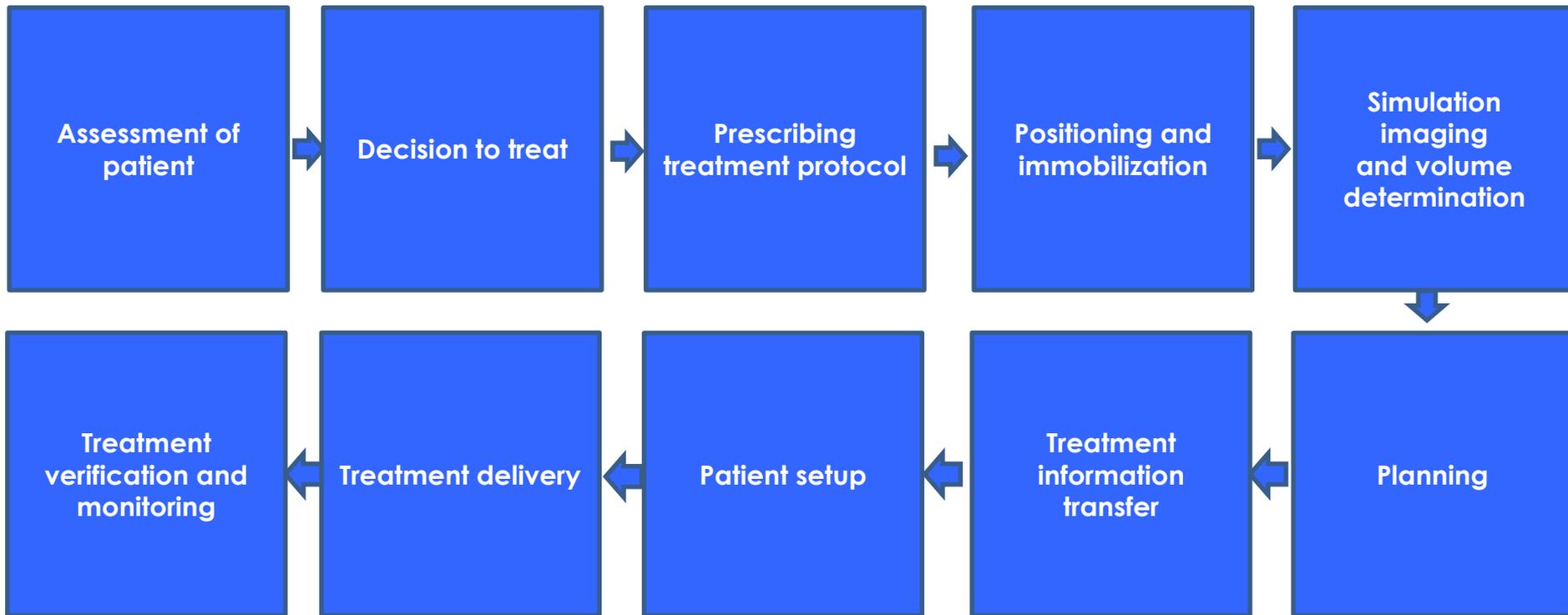
## Present day R&V Systems are:

- Capable of all record, verify and assisted-setup functions,
- complete radiotherapy information management systems that interface with imaging systems, treatment planning computers and treatment delivery systems,
- capable of scheduling, data analysis, clinical assessment tools, image and photographic storage capabilities, dose alert functionality, intranet messaging services, and gateway and billing capabilities.

# Data Exchange in Radiotherapy



# Comprehensive Radiotherapy Workflow



“**IT** plays a very important role in the continuum of radiotherapy; starting from decision support system to radiation treatment to response assessment to survivorship.

# Hierarchical Organization of RVS Database

- Patient (unique ID): administrative data and identification photograph
- Treatment course: diagnostic and anatomical site
- Treatment plan (group of beams)
  - Prescription
    - dose point(s)/volumes
    - total dose, dose/fraction, breakpoints
  - Beam (field) (used either for set-up or treatment),
  - machine, modality, energy
  - MUs, time, MU rate (except for set-up)
  - mechanical set-up (collimator, gantry, table, etc.)
  - accessories (wedge, block, MLC, etc.)
  - tolerance table
  - reference image
  - field or set-up photographs
  - dose per field
  - free comments
- Treatment schedule

# Record and Verify System GUI

The screenshot displays the Record and Verify System GUI for a treatment plan. The interface is divided into several sections:

- Left Panel (Treatment Plan):** Lists treatment fractions. The selected fraction is "2.4 Arc4 - 2.4 Arc4" with a MU of 0/419. Other fractions include "2.3 Arc3 - 2.3 Arc3" (0/398), "2.1 Arc1 - 2.1 Arc1" (0/367), "2.2 Arc2 - 2.2 Arc2" (0/380), "1.3 Arc3 - 1.3 Arc3" (0/338), "1.4 Arc4 - 1.4 Arc4" (0/433), "1.1 Arc1 - 1.1 Arc1" (0/478), and "1.2 Arc2 - 1.2 Arc2" (0/357).
- Top Center (Video):** A live video feed of the patient in the treatment room. A yellow text overlay reads "does not record dose." Below the video are icons for key, folder, and a clock.
- Center (Status Bar):** A progress bar with stages: Preview (green), Prepare, Ready, Beam On, and Record. A text prompt says "To apply beam parameters, press Prepare."
- Bottom Center (Beam Parameters):**

Beam	Plan	Actual	Geometry	Plan	Actual
Beam Type	DYNAMIC (VMAT)		Gantry Rtn	295.0	359.5
Energy Type	10xFFF		Gantry Stop	180.0E	
MU	419		Coll Rtn	15.0	0.2
Dose Rate	2400	0	Y1	3.0	8.0
Time	1.00		Y2	3.0	6.5
EDW	None	None	X1	2.6	5.4
Int Mount	No Accy	No Accy	X2	2.5	8.7
Acc Mount	No Accy	No Accy	Couch Vrt	15.75	66.47
e-Aperture	No Accy	No Accy	Lng	120.18	56.87
Comp Mount	No Accy	No Accy	Lat	4.88	0.00
Bolus	None		Rtn	0.0	0.0
			Tol. Table	A LUNG	
- Bottom Right (Beam's Eye View):** A circular diagram showing the beam's path through the patient. The patient's outline is in blue. The diagram is labeled with X1, X2, Y1, and Y2. Coordinates are shown as Y=14.5 and X=14.1. The MLC is set to "Arc Dynamic".
- Bottom (Navigation):** Buttons for "Tools", "Setup Notes", "Close Patient", "Machine Overrides", "Acquire", "Edit", "Go To", "Apply", and "Cancel".

# RVS Functionalities

- Delivery System set-up (including patient positioner system)
  - If any of the set-up parameters does not match its intended value within the limits prescribed in the tolerance table, treatment delivery is prohibited, and a warning is given to the user.
- Monitor Units and Dose
  - ‘consistency checks’ in terms of data transfer from the source of primary dose calculation to the RVS.
- Verification of patient positioning (image comparison 2D/3D)
- Treatment data recording
  - number of MUs actually delivered from each beam at each fraction, with proper indication of the machine, course, plan and fraction identification, and exact time at which Tx delivered

# Reducing Computer Errors

- Prevent errors from occurring
  - Robust system design. For example, one could simplify the choices presented to users so that they can't enter combinations of user input that lead to unanticipated software states,
- For systems that already exist;
  - Subsequent versions should be developed with engineers required to analyze the errors and warnings and see if there is a way to prevent the user from getting to the conditions that lead to these messages.

## The Radiation Boom

### Radiation Offers New Cures, and Ways to Do Harm



Scott Jerome-Parks

- MD requests tweak of plan to spare teeth
- Data transfer software crashes; allows corrupted data to be sent to machine
  - But gave a warning and allowed a choice
- Physicist makes the wrong choice
  - No QA checks were done
- Rush to treat
  - Therapists inattention
- Patient receives 13 Gy/fx; 3 fx; in 3 days
  - Patient was in agony after first Tx. Nurses and physicians ignored this symptom

# What happened?

- March 14, 2005
  - Re-optimization work on “New Plan” starts on workstation 2 (WS2).
  - Treatment plan is changed. Existing fluence maps are deleted and re-optimized. New optimal fluence maps are saved to DB.
  - Final calculations are started, where MLC motion control points for IMRT are generated. Normal completion.

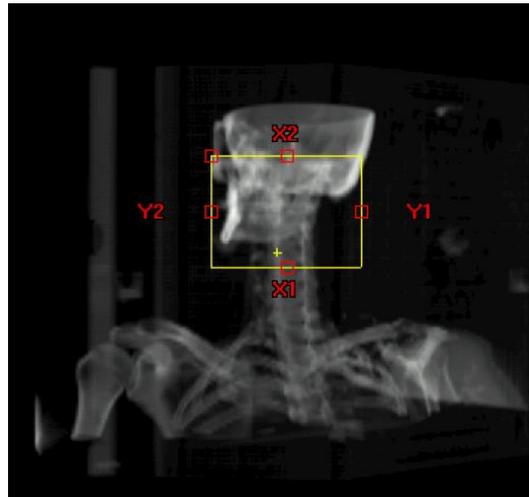
Multi Leaf Collimator  
(MLC)



# What happened?

- March 14, 2005, 11 a.m.
  - “Save all” is started. All new and modified data should be saved to the DB.
  - In this process, data is sent to a **holding area** on the server, and **not saved permanently until ALL data elements have been received.**
  - In this case, data to be saved included: (1) actual fluence data, (2) a DRR and (3) the MLC control points

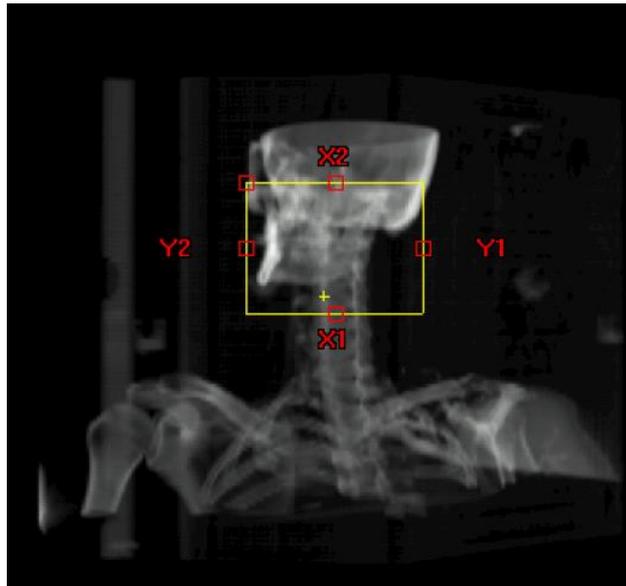
A Digitally Reconstructed Radiograph (DRR) of the patient



# What happened?

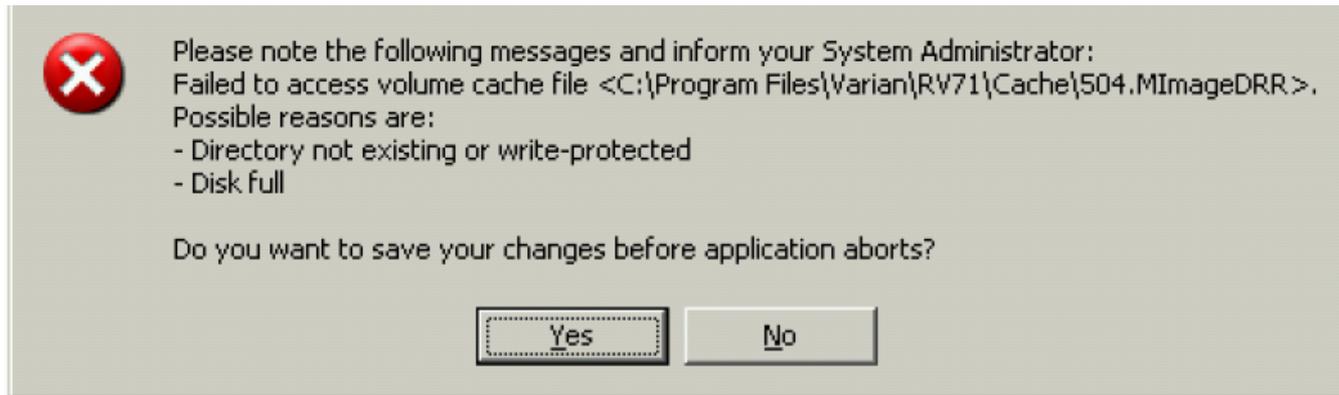
- March 14, 2005, 11 a.m.
- The actual fluence data is saved normally.
  - Next in line is the **DRR**. The “Save all” process continues with this, but is **not completed**.
  - Saving of **MLC control point data** would be after the DRR, but **will not start** because of the above.

A Digitally Reconstructed Radiograph (DRR) of the patient



# What happened?

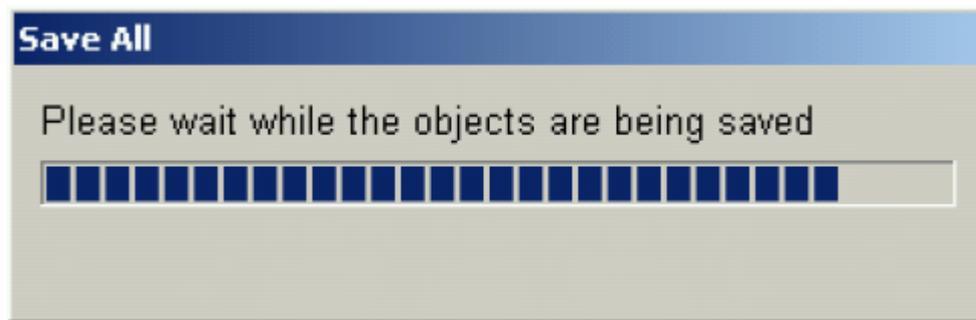
- March 14, 2005, 11 a.m.
  - An error message is displayed.
  - The user presses “Yes”, which begins a second, separate, save transaction.
  - MLC control point data is moved to the holding area.



The transaction error message displayed

# What happened?

- March 14, 2005, 11.a.m.
  - The DRR is, however, still locked into the faulty first attempt to save.
  - This means the second save won't be able to complete.
  - The software would have **appeared to be frozen**.



The frozen state of the second "Save All" progress indication

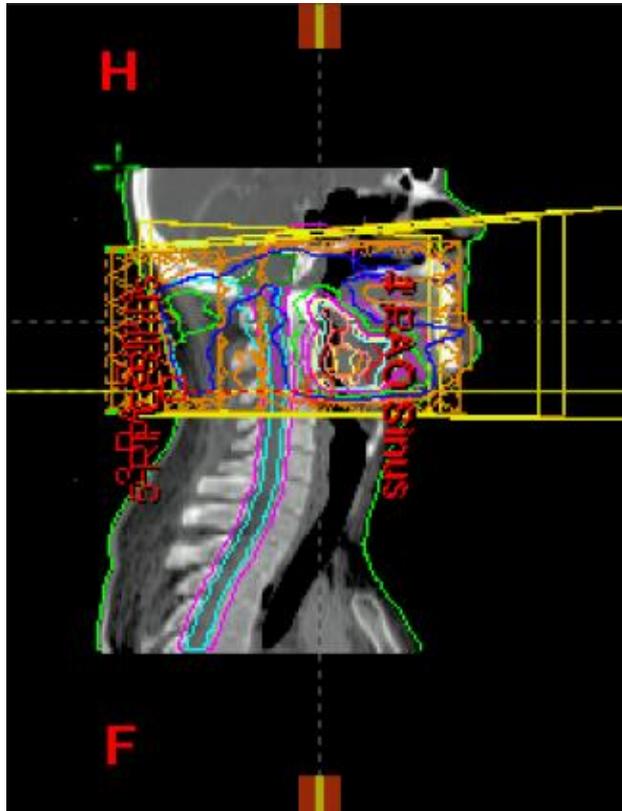
# What happened?

- March 14, 2005, 11.a.m.
  - The user then **terminated the TPS software manually**, probably with Ctrl-Alt-Del or Windows Task Manager
  - At manual termination, the DB performs a “**roll-back**” to return the data in the holding area to its last known valid state
  - The treatment plan now contains (1) actual fluence data; (2) not the full DRR; (3) no MLC control point data

**Ctrl-Alt-Del**

# What happened?

- March 14, 2005, 11.a.m.
  - Within 12 s, another workstation, WS1, is used to open the patients plan. The planner would have seen this:

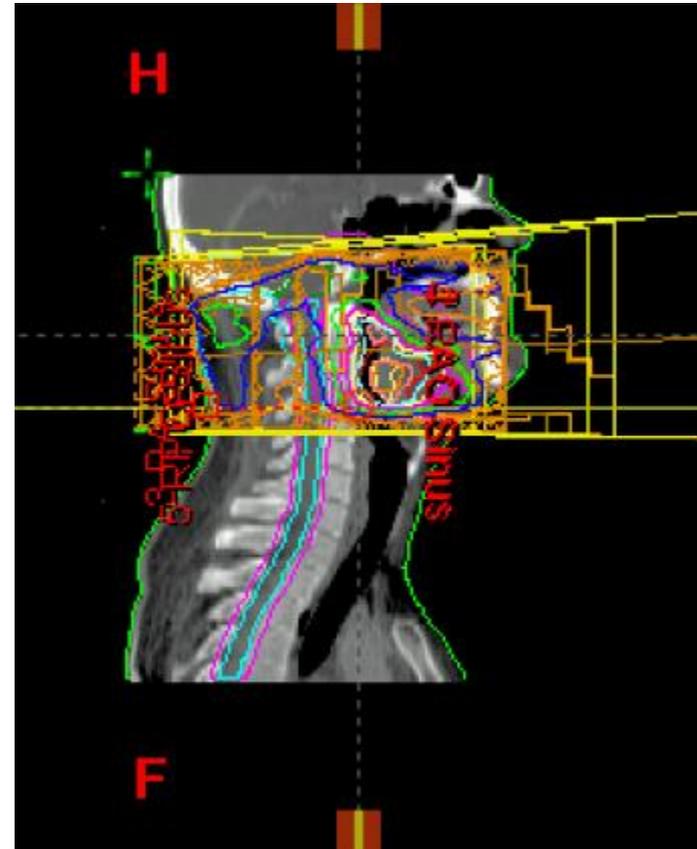
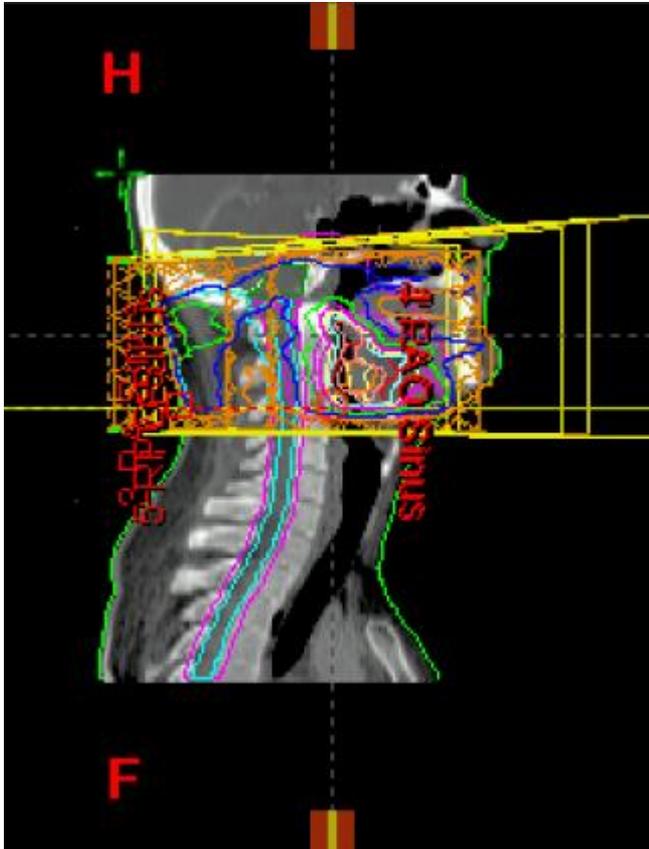


Valid fluences were already saved. Calculations of dose distribution is now done by the planner and saved. MLC control point is not required for calculation of dose distribution.

Sagittal view of patient, with fields and dose distribution

# What happened?

- March 14, 2005, 11.a.m.
  - No control point data is included in the plan.



The sagittal view should have looked like the one to the right, with MLCs

# What happened?

- Would have been seen on verification:

The screenshot displays a medical treatment planning software interface. The main window is titled "1 LPO-DRR1 - 3/14/2005 11:37 AM". The interface includes a menu bar (File, Edit, View, Insert, Task, Workspace, Parameters, Tools, Window, Help), a toolbar, and a left-hand tree view showing a treatment plan for "1B Oropharyn".

The central panel shows the "Information" tab with the following details:

- Course: 1 - Curative w/chemo
- Volume: BODY
- Plan: 1B Oropharyn
- Machine: Clinac\_1

Below this is a table of treatment parameters:

Field Order/type	5 / Treat	6 / Treat	7 / Treat	8 / Treat	9 / Treat
Field ID	3B PA Sinus	1B LPO	2B LAO Sinus	4B RAO Sinus	5B RPO Sinus
Field Name	AP Sinus	LPO	LPO Sinus	RAO Sinus	RPO Sinus
Technique	STATIC	STATIC	STATIC	STATIC	STATIC
Energy / Mode	6X	6X	6X	6X	6X
Dose Rate [MU / min]	300	300	300	300	300
MU	309	281	334	258	282
Time [min]	1.44	1.31	1.56	1.21	1.32
Tot. Table	IMRT_HN	IMRT_HN	IMRT_HN	IMRT_HN	IMRT_HN
SSD [cm]	91.2	90.7	94.2	94.4	90.7
Gantry/Source Rtn [Deg]	150.0	150.0	60.0	300.0	210.0
Coll Rtn [Deg]	90.0	90.0	90.0	90.0	90.0
Field X [cm]	11.0	11.3	11.3	11.3	10.9
X1 [cm]	+1.5	+1.5	+1.5	+1.5	+1.4
X2 [cm]	+9.5	+9.8	+9.8	+9.8	+9.5
Field Y [cm]	14.3	15.0	15.0	15.0	15.0
Y1 [cm]	+7.0	+6.5	+8.0	+6.5	+6.0
Y2 [cm]	+7.3	+6.5	+6.0	+8.5	+9.0
MLC	NONE	NONE	NONE	NONE	NONE
Dynamic Wedge					
Int Mount					
Acc Mount					
Comp Mount					
e-Aperture					
Coach Vrt [cm]					
Coach Lng [cm]					
Coach Lat [cm]					
Coach Rtn [Deg]	0.0	0.0	0.0	0.0	0.0
Imager Vrt [cm]					
Imager Lng [cm]					
Imager Lat [cm]					
Setup Note					

The table shows that the MLC (Multi-Leaf Collimator) is set to "NONE" for all five treatment fields. A red circle highlights this row. In the 3D anatomical model on the right, a yellow box highlights a region in the neck area, which is also circled in red.

# What happened?

- Should have been seen on verification:

The screenshot displays a medical treatment planning software interface. The main window is titled "1B Oropharyn" and shows a table of field parameters for five different treatment fields. The table is as follows:

Field Order/Type	5 / Treat	6 / Treat	7 / Treat	8 / Treat	9 / Treat
Field ID	3B PA Sinus	1B LPO	2B LAO Sinus	4B RAO Sinus	5B RPO Sinus
Field Name	AP Sinus	LPO	LPO Sinus	RAO Sinus	RPO Sinus
Technique	STATIC	STATIC	STATIC	STATIC	STATIC
Energy / Mode	6X	6X	6X	6X	6X
Dose Rate [MU / min]	300	300	300	300	300
MU	279	254	303	233	255
Time [min]	1.44	1.31	1.58	1.21	1.32
ToI Table	IMRT_HN	IMRT_HN	IMRT_HN	IMRT_HN	IMRT_HN
SSD [cm]	91.2	90.7	94.2	94.4	90.7
Gantry/Source Rtn [Deg]	190.0	150.0	60.0	300.0	210.0
Coll Rtn [Deg]	90.0	90.0	90.0	90.0	90.0
Field X [cm]	11.0	11.3	11.3	11.3	10.9
X1 [cm]	+1.5	+1.5	+1.5	+1.5	+1.4
X2 [cm]	+9.5	+9.8	+9.8	+9.8	+9.5
Field Y [cm]	14.3	15.0	15.0	15.0	15.0
Y1 [cm]	+7.0	+8.5	+9.0	+9.5	+6.0
Y2 [cm]	+7.3	+8.5	+6.0	+9.5	+9.0
MLC	Dose Dynamic				
Dynamic Wedge					
Inf Mount					
Acc Mount					
Comp Mount					
e-Aperture					
Coach Vrt [cm]					
Coach Lng [cm]					
Coach Lat [cm]					
Coach Rtn [Deg]	0.0	0.0	0.0	0.0	0.0
Imager Vrt [cm]					
Imager Lng [cm]					
Imager Lat [cm]					
Setup Note					

The table shows that the MLC (Multi-Leaf Collimator) is set to "Dose Dynamic" for all five fields. A red circle highlights this row in the original image. To the right of the table, there is a 3D visualization of a patient's head and neck, with a red circle highlighting a specific area of the neck. The software interface also shows a tree view on the left with various treatment plans and fields, and a status bar at the bottom indicating "Ready".

# What happened?

- March 14, 2005, 1 p.m.
  - The patient is treated. The console screen would have indicated that MLC is not being used during treatment:

The screenshot displays the Varian Medical Systems 4D Console interface. The top window shows a patient photo and a grid of treatment fields labeled X1, X2, Y1, and Y2. A red circle highlights the MLC status in the table below, which is currently set to 'Off'. The table also shows various treatment parameters such as Technique, Energy, Dose Rate, MU, Time, and Gantry Rtn.

	Plan	Actual	Plan	Actual	Plan	Actual	
Technique	Static	Static	Coll Rtn	90.0	90.0	MLC	Off
Energy	6X	6X	Field Y			Couch W	44444
Dose Rate	300	300	Field X			Couch Lng	44444
MU	281	281	Gantry Rtn	150.0	150.0	Couch Lat	44444
Time	1:31	1:31				Couch Rtn	0.0
Tol. Table	DMRT_HN					SSD	90.7
EDW			Y1	8.5	8.5		
Accessory	NoAccy	NoAccy	Y2	6.5	6.5		
			X1	1.5	1.5		
			X2	9.8	9.8		

# What happened?

- March 14, 2005, 1 p.m.
  - Expected display:

The screenshot shows a medical treatment planning software interface. The left sidebar lists treatment plans for a patient, including '1B Oropharynx' and '2A LAN'. The main area displays a treatment plan table with columns for 'Plan' and 'Actual' values. The table includes parameters such as Technique, Energy, Desc Rate, MU, Time, Tol. Table, EDW, Accessory, Coll Rtn, Field Y, Field X, Gantry Rtn, Y1, Y2, X1, X2, MLC, Couch Rot, Couch Ling, Couch Lat, Couch Rtn, and SSD. The MLC setting is highlighted with a red circle, showing a change from 'Static' to 'Dynamic'. The beam arrangement diagram in the top right is also highlighted with a red circle, showing a cross-section of the patient's head and neck with a central beam and two side beams.

	Plan	Actual		Plan	Actual
Technique	Static	Static	Coll Rtn	90.0	90.0
Energy	6X	6X	Field Y		
Desc Rate	300	300	Field X		
MU	254	254	Gantry Rtn	150.0	150.0
Time	1.31	1.31			
Tol. Table	DMRT_HN		Y1	8.5	8.5
EDW			Y2	6.5	6.5
Accessory	NoAccy	NoAccy	X1	1.5	1.5
			X2	9.8	9.8
			MLC	Static	Dynamic
			Couch Rot		0.0
			Couch Ling		0.0
			Couch Lat		0.0
			Couch Rtn	0.0	0.0
			SSD		90.7

# Lessons Learned

- Do what you should be doing according to a QA program
  - Never cut corners
- Comply with standard operating procedures
  - Do not rush
- Work with awareness
  - Do not assume anything
- Be alert when computer crashes
  - Always try to find out why a computer crash occurred

} Human focus

} Tech focus

**Unambiguous and intuitive computer messages**

# Summary

1. Radiation Oncology is IT intense and it has substantial unmet need for IT integration and security in radiation oncology
2. Some progress has been made in ensuring interconnectivity and interoperability in radiation oncology but more work is needed.
3. There is an increasing need for reducing computer errors, fault management, and to prevent “message fatigue” in the design of software for radiotherapy applications.