## LINAC and MLC QA for IMRT

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## Acknowledgments

Cynthia Chuang, Ph.D.
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Ying Xiao, Ph.D.

## Outline

- Characteristics of three major MLC systems
- Linac specific QA for IMRT
- MLC specific QA for IMRT
- Self Assessment modules - Questions and Answers

# Characteristics of Three Major MLC Systems

## Multi-leaf Collimator Designs

- Each manufacturer has a different design of MLC
  - Location, leaf width, and leaf end design
  - Single focused or double focused
  - Restrictions on motion (path, over-travel, interleaf)
  - Field size
- These factors have an impact on IMRT delivery and must be considered in treatment planning

## Static vs Dynamic MLC

- Static MLC

  Leaves cannot be moved when the beam is on. Leaf motion and the radiation are executed sequentially.

- Dynamic MLC

  Leaves can be moved when the beam is on. Leaf motion and the radiation are executed simultaneously.

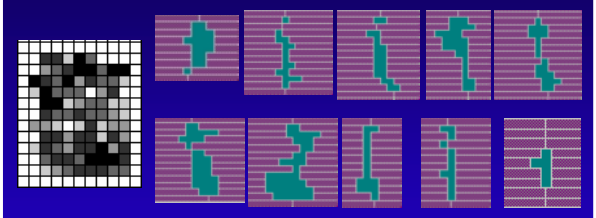
## Segmental vs. Sliding Window IMRT Delivery

- An intensity modulated field is delivered by multiple segments. MLC leaves remain stationary while the radiation is on -- Segmental method
- An intensity modulated field is delivered by continuously moving MLC leaves from one side of the field to the other side of the field while the radiation beam in on -- Sliding window method.

## Delivery Methods and MLCs

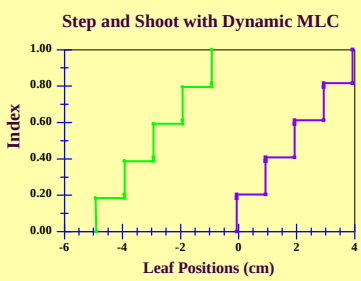
- Segmental IMRT delivery method can be used in static and dynamic MLCs
- Sliding window method can only be used in dynamic MLC.

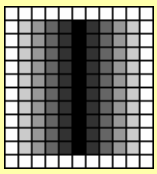
## Step and Shoot (Segmental) for SMLC



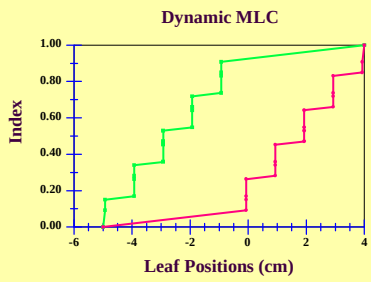
**Similar to conventional treatment, and each segment is considered as a single field.**

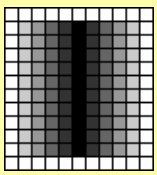
## Step and Shoot Using DMLC



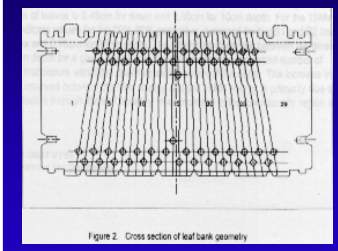



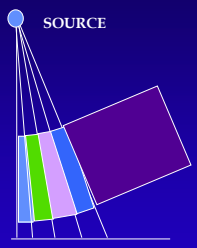
## Sliding Window Using DMLC



## Double Focused MLC

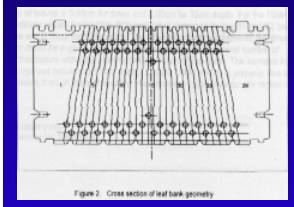


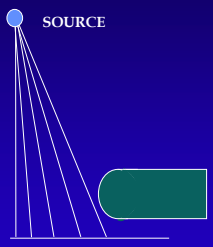




Focused in in-plane (Y)

Focused in cross plane (X)

## Single Focused MLC

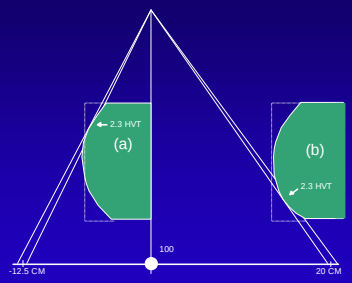


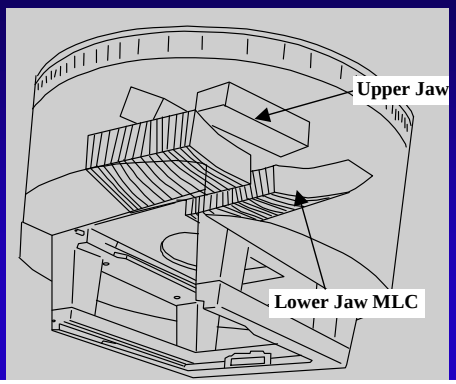

Focused in in-plane ( Y )

Focused in cross-plane ( X )

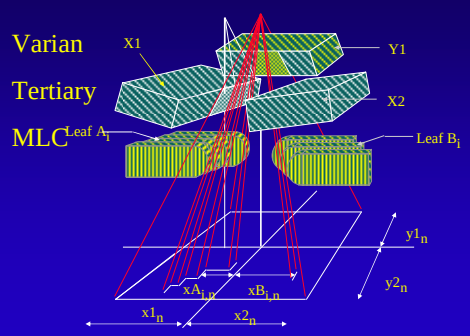
## Rounded Leaf End vs Penumbra



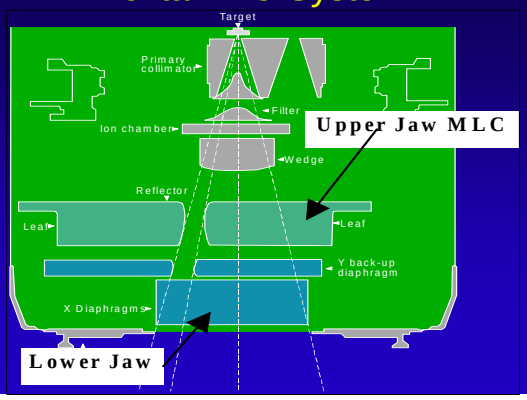

## Siemens MLC



## Varian MLC System




## Elekta MLC System

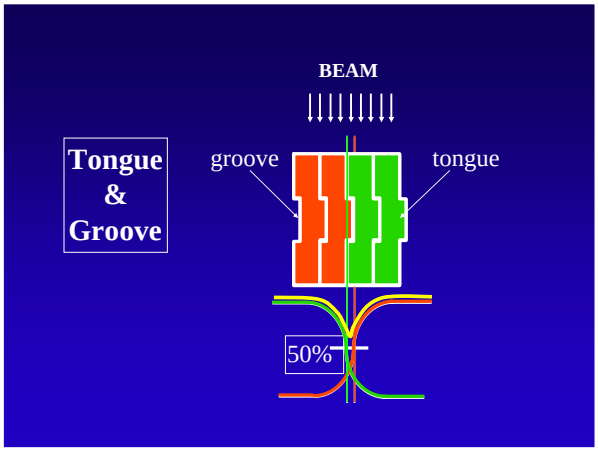


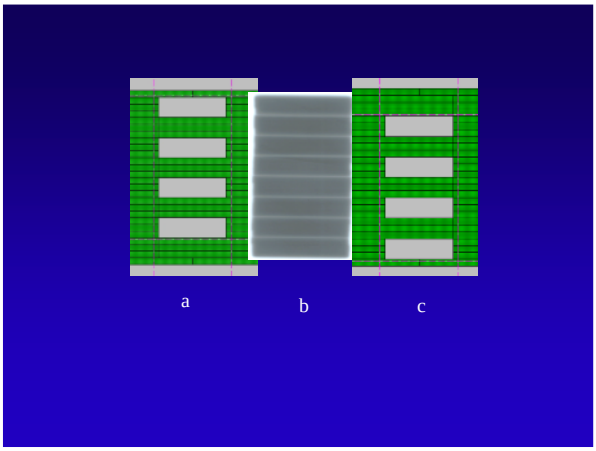

## Physical Leaf Length vs. Over-travel Distance

- The MLC physics leaf length (project to iso-center) is 16 cm, 30 cm, 32.5 cm for Varian, Siemens, and Elekta Accelerators, respectively.
- The distance that each individual leaf passes over iso-center is called over-travel distance, without leaving a uncovered region behind the leaf.

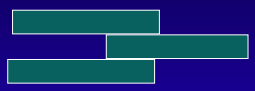
## Over-travel Distances

- For Siemens and Elekta machines, the over-travel distances are 10cm and 12.5 cm, respectively, without leaving a uncovered region behind the leaf.
- For Varian MLC, X jaw is used to cover the uncovered region of MLCs. The over-travel distance = 2 cm (x jaw over-travel distance) + 15 cm = 17 cm.
- The maximum differences between the leading leaf and the trailing leaf $\leq$15 cm

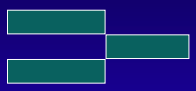


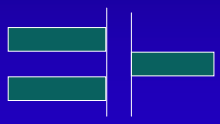

## Leaf Motion Constraints



Interleaf motion (Varian)



No Interleaf motion (Siemens)



Minimum Gap (Elekta)

Segmentation is affected by these constraints

## MLC Leakages

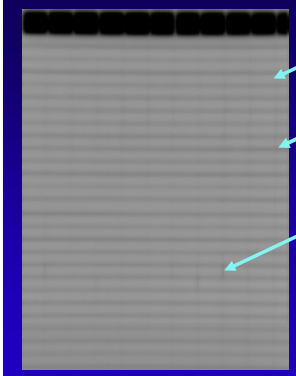
- Intra-leaf leakage
  - Thickness

- Inter-leaf leakage
  - Tongue & groove

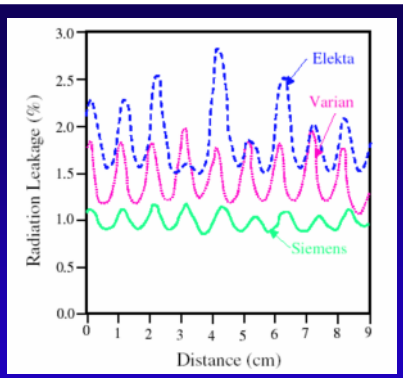
- Leaf-end leakage
  - Rounded leaf end
  - Flat leaf end

## MLC Leakage and Backup Jaws

- MLC leakage can be minimized by letting backup jaws following each IMRT segment.
  - Varian: Backup jaws do not follow each MLC segment.
  - Siemens: Backup jaws follow each segment.
  - Elekta: Backup Jaws follow each segment.




Siemens Primus
6MV




Huq, MS, et.al. *Phys Med Biol* 2002; 47: N159-70.

## Machine Specific QA

## Why A Special Machine QA is Needed for IMRT ?

- IMRT plans deliver a large fraction of total MUs with field segments that have very small MUs.
- IMRT plans often produce small, irregular, and off-center fields when compared to the conventional fields.

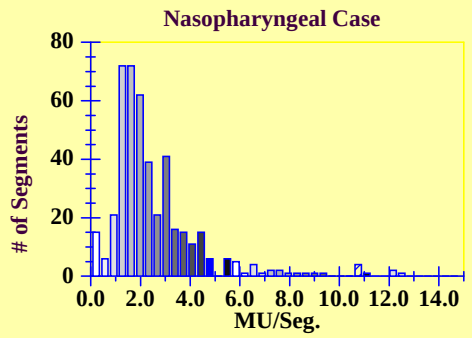
## Machine Specific QA

- **Machine QA**
  - **Beam characteristic**
    - **Output for small field size**
    - **Linearity for small MU (1-10)**
    - **Flatness & Symmetry**
    - **MLC defined penumbra**
  - **Multi-leaf Collimator (MLC)**
    - **Position, Speed**

## Linearity, Flatness, and Symmetry for Small MU Fields

## Small MU Fields

- Dose linearity, field flatness, and symmetry are often verified under stable beam condition and large MUs.
- IMRT delivery introduces many small MU segments, which could be delivered under unstable beam condition.
- Dose linearity, field flatness, and symmetry need to be verified under IMRT delivery with small MUs.




Treatment technique: 15 gantry angles, 10 intensity levels, total # of segments = 491, 400MU/min.

## Dose Linearity Check

- Using an ion chamber to measure the output of an IM square field.

  20 segments, 1 MU/segment, 10x10 $cm^2$
  10 segments, 2 MU/segment, 10x10 $cm^2$
  5 segments, 4 MU/segment, 10x10 $cm^2$

  ….depending on the smallest allowed MU

- Compared with that of a regular 10x10 $cm^2$ field delivered with 20 MU.

## Results of Linearity Check

| Total MU | MU/Seg | Energy | Reading | Δ (%) |
|---|---|---|---|---|
| 99 | 99 | 6MV | 0.4705 | |
| 99 | 1 | 6MV | 0.4750 | 1.0 |
| 99 | 99 | 18MV | 0.4780 | |
| 99 | 1 | 18MV | 0.4844 | 1.3 |

KD-2, Dmax, 100 cm SSD, 15x15 $cm^2$

**After adjusting a special soft pot**

## Field Symmetry and Flatness Check

- Conventional water tank profile measurement can not be used because of insufficient MUs.
- Ion chamber, diode array, film, or EPID can be used to measure IMRT field flatness and symmetry.

## Results of Symmetry and Flatness

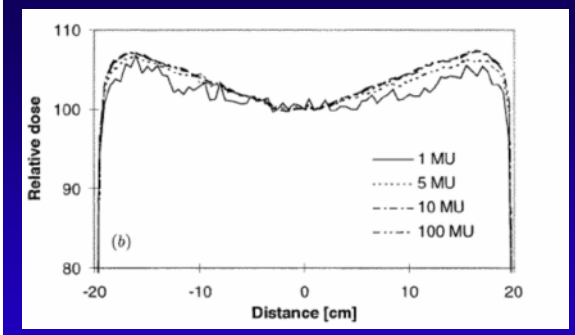
| Location | Total MU | MU/seg | Readings | Δ (%) |
|---|---|---|---|---|
| (0,0) | 99 | 99 | 0.4705 | 0 |
| (0,0) | 99 | 1 | 0.4750 | 0.96 |
| (-5, 5) | 99 | 1 | 0.4853 | 3.15 |
| (-5, -5) | 99 | 1 | 0.4889 | 3.91 |
| (5, 5) | 99 | 1 | 0.4801 | 2.04 |
| (5, -5) | 99 | 1 | 0.4836 | 2.78 |

KD2, 6MV, 1.5 cm depth, 100 cm SSD, 15x15 $cm^2$

## Results of Symmetry and Flatness

| Location | Total MU | MU/seg | Readings | Δ (%) |
|---|---|---|---|---|
| (0,0) | 19 | 19 | 0.0934 | 0.0 |
| (0,0) | 19 | 0.1 | 0.0933 | 0.11 |
| (-5, 5) | 19 | 0.1 | 0.0920 | 1.52 |
| (-5, -5) | 19 | 0.1 | 0.0915 | 2.03 |
| (5, 5) | 19 | 0.1 | 0.0913 | 2.25 |
| (5, -5) | 19 | 0.1 | 0.0920 | 1.50 |

CL_2300, 18MV, 3.2 cm depth, 100 cm SSD, 15x15 $cm^2$




V. N. Hanseny, et.al, Phys. Med. Biol. 43 (1998) 2665–2675.

## Beam Stabilities

- The dose linearity per MU was found to be within ±2% for exposures larger than 4 MU.
- Beam flatness and symmetry also met accepted quality assurance standards for a minimum exposure of 4 MU.
- For the non-slitted flight tube the field flatness is stable after 0.6 s, which corresponds to an exposure of approximately 4 MU at a dose rate of 400 MU per minute.
- The slitted flight tube took just over 1 s to stabilize, or approximately 7 MU.

**M. B. Sharpe, et. al, Med. Phys. 27, 2719-2725 (2000).**

## Beam "Pausing" Status

- With a Siemens Primus accelerator, during a step and shoot delivery, the radiation beam is turned off by desynchronizing the injector while the field parameters are being changed.
- When the machine is ready again a trigger pulse is sent to the injector to start the beam instantaneously.

C. W. Cheng, and I. J. Das, **Med. Phys. 29,** 226-230 (**2002).**

## Suppress Dark Current Radiation

- With the Initial Pulse Forming Network (IPFN) at >80% of the PFN value, a spurious radiation associated with dark current at about 0.7% of the dose at isocenter for a 10x10 $cm^2$ field is detected during the ''PAUSE'' state of the accelerator for 15 MV x rays.
- When the IPFN is lowered to 80% of the PFN value, no dark current radiation (DCR) is detected.
- For 6 MV x rays, no measurable DCR was detected regardless of the IPFN setting.

C. W. Cheng, and I. J. Das, **Med. Phys. 29,** 226-230 (**2002).**

## MLC Calibration

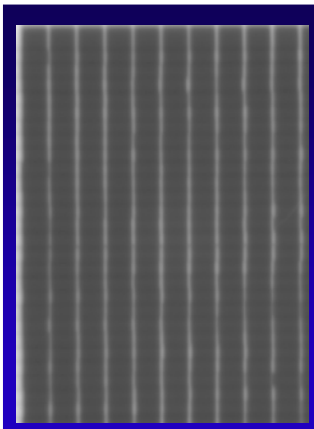
## MLC Calibration

- **Leaf position calibration**
  - **Difference radiation field vs light field**
  - **Off-set this difference in treatment planning**
  - **Gantry angle dependence and off-axis distance dependence**
  - **Closing leaf end calibration**
- **Leaf speed calibration**

## Modeling Rounded Leaf End

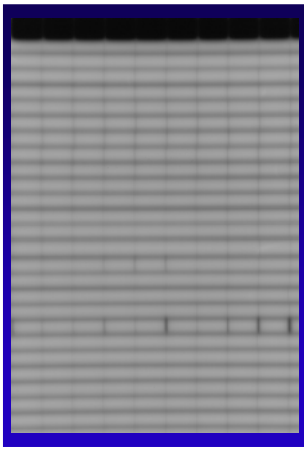
- The rounded leaf end design makes the radiation field larger than the light field.
- It is suggested that a leaf gap reduction is necessary, which is energy dependent.
- Cadman et. al found that a maximum underestimate of calculated dose of 12% with no leaf gap reduction.
- With 1.4 mm leaf gap reduction, the discrepancy between measured and calculated dose is reduced to ±5%.

Cadman P, at. al. Phys. Med. Biol. **47** (2002) 3001–3010

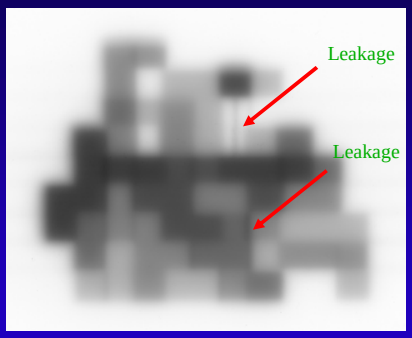


**Off-set between the light field and radiation field**

**Inspect MLC leakage at closed positions**



**Leakage without a proper calibration**



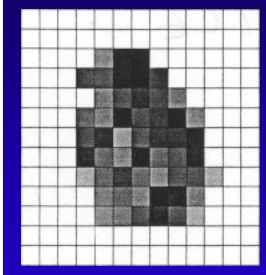

## DMLC Delivery

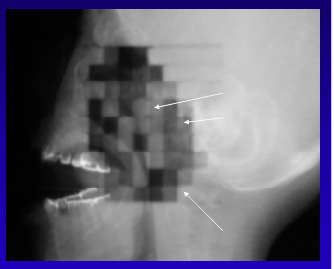
- In the sliding window technique of DMLC application, the delivered dose is directly related to the gap between opposed leaves as they sweep across the field.
- A variation of ±0.2mm in gap width for a 1.0 cm nominal gap can result in a dose variation of ±3% for each DMLC field
- The MLC position precision is better than 0.1 mm.

Thomas LoSasso,et. al. Med. Phys. 25 , 1919-1927 (1998).

## Special Issues

## Intensity Map Port Film





E.H.

Differences in intensity patterns from plan to port film

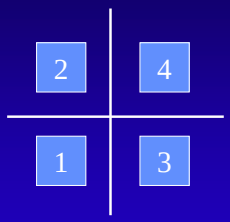
## *Step and Shoot Delivery Using DMLC*

**Every 50 ms**

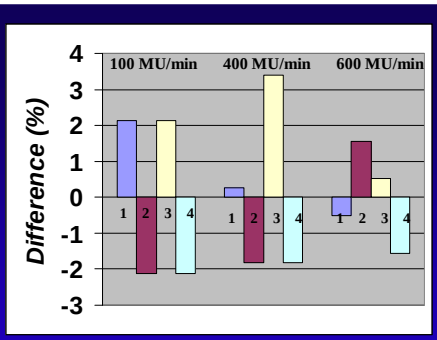
**Positions of each segment** **Control total MU**

**Communication delay ~ up to 100 ms between segments**

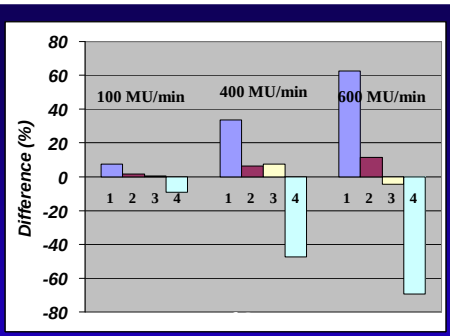
## *Experiment*



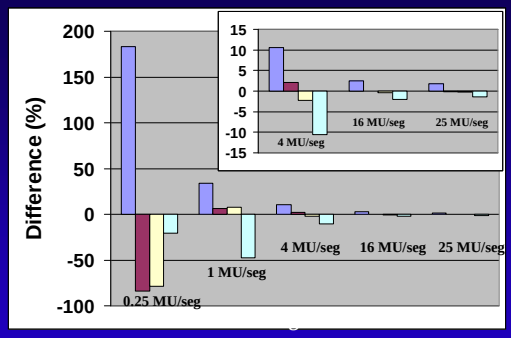

**0.25 MU/seg**
**1.0 MU/seg**
**4.0 MU/seg**
**16.0 MU/seg**
**25.0 MU/seg**
**at**
**100 MU/min**
**400 MU/min**
**600 MU/min**




**1MU/seg delivered with static mode**
**(CL2300, 6MV, 100 SSD, 1.5 cm depth)**




**1 MU /seg delivered with dose mode**
**( Cl2300, 6MV, 100 SSD, 1.5 cm depth)**




Delivered with dose mode at 400MU/min
(CL2300, 6MV, 100 SSD, 1.5 cm depth)

## Communication Delay

The dose error in each segment:

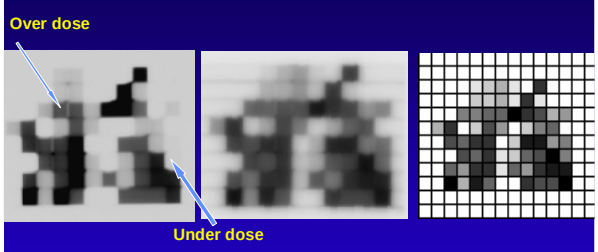
$$\Delta = RT/M$$

(R: dose rate, T: time delay, M:MU/segment)

e.g. R = 400 MU/min, T=50 ms, M=1 MU/seg

$$\Delta = 400 / 60 * 0.05 = 0.33$$

$\Delta$ can be significant if R is large and M is small.




8 MU port film | 96 MU EDR film | Fluence Map

(1) Which of the following processes best explains how a radiation beam is delivered during segmental IMRT ?

1. Only deliver radiation while the MLC is stopped.
2. Leave the radiation beam on during the entire delivery sequence.
3. Continuously move all primary collimators and MLC leaves.
4. Move all MLC leaves in one direction only.

**(1) Which of the following processes best explains how a radiation beam is delivered during segmental IMRT ?**

★ **(A) Only deliver radiation while the MLC is stopped.**

**(B) Leave the radiation beam on during the entire delivery sequence.**

**(C) Continuously move all primary collimators and MLC leaves.**

**(D) Move all MLC leaves in one direction only.**

**(2) Which of the following statements about the single focused MLC is correct?**

1. The leaf end must be designed in a flat shape to maintain similar penumbra for all field sizes.
2. It follows the beam divergence along the leaf movement direction.
3. All MLC leaves move along a straight line.
4. It is not focused in the direction perpendicular to the leaf motion.

**(2) Which of the following statements about the single focused MLC is correct?**

(A) The leaf end must be designed in a flat shape to maintain similar penumbra for all field sizes.

(B) It follows the beam divergence along the leaf movement direction.

★ (C) All MLC leaves move along a straight line.

(D) It is not focused in the direction perpendicular to the leaf motion.

**(3) Which of the following definitions of the over-travel distance of MLC leaves is correct?**

1. It is equal to the whole leaf length.
2. It is equal to half of the maximum field width.
3. It is the distance that MLC leaves travel across the iso-center.
4. It depends on the specification of the MLC.

**(3) Which of the following definitions of the over-travel distance of MLC leaves is correct?**

(1) It is equal to the whole leaf length.
(2) It is equal to half of the maximum field width.
★ (3) It is the distance that MLC leaves travel across the iso-center.
(4) It depends on the specification of the MLC.

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