# TOTAL BODY IRRADIATION

**Dr. Rossella Vidimari**

**Department of Medical Physics**
**Ospedale Maggiore**
**A.S.U.I.T.S Ospedali Riuniti di Trieste**

School on Medical Physics for Radiation Therapy
**27 March– 7 April 2017**

# Topics

- *Clinical indications*
- *Irradiation techniques*
- *Basic dosimetry*
- *In vivo dosimetry*
- *Trieste experience*

# *Clinical indications*

## The scope of the haematopoietic stem cells transplant

- The transplant replaces the patient's diseased bone marrow with stem cells from a healthy donor (***allogenic transplant***) or from the patient himself (***autologous transplant***);
- Donor stem cells reconstitute the recipient's haematopoietic and immune systems ;
- The ***pre-transplant protocol*** or ***conditioning regimen*** aims at eradicating the patient's hematopoietic pluripotent stem cells by combining different chemotherapy agents or chemo and radio-therapy in a regimen that includes Total Body Irradiation (TBI).

# *Clinical indications*

## The role of TBI in the pre-transplant protocol :

- ***Cyto-ablative scope***: residual neoplastic eradication;

- ***Immunosuppressive scope***: induction of immuno-suppression to reduce the GVDH (Graft-versus-host disease), a complication that can occur after a stem cell or bone marrow transplant in which the newly transplanted donor cells attack the transplant recipient's body;

- ***Myelo-ablative scope:*** eradicate the patient’s hematopoietic system to allow repopulation.

# *Clinical indications*

***Certain indications:*** ***Leukaemias in adults and childhood***

- ✓ Acute lymphoblastic leukaemia (ALL),
- ✓ Acute myeloid leukaemia (AML),
- ✓ Chronic myeloid leukaemia (CML),
- ✓ Myelodysplastic syndrom (MDS).

***Optional indications:*** ***Solid tumors in childhood***

- ✓ Neuroblastomas,
- ✓ Ewing sarcomas,
- ✓ Plasmocytomas / multiple myelomas.

***In clinical test:***

- ✓ Morbus Hodgkin's disease (MHD)
- ✓ Non-Hodgkin's lymphomas (NHL).

# Clinical indications

## TBI applications in haematology and oncology :

### a) myeloablative TBI :

**supra-lethal doses of RT** (7-15.75 Gy) is administered in association with one or more chemotherapy drugs to condition patients with haematological malignancies to autologous or allogeneic bone marrow or peripheral blood stem cell transplant ;

### b) non-myeloablative TBI:

**low-dose TBI** (≤2 Gy) is administered in one session, in conditioning regimens for allogeneic transplants in elderly patients (> 55 yrs) or in patients who had already received transplants without supra-lethal radiotherapy in the conditioning regimen ;

### c) low dose cytoablative TBI:

low-dose (1-1.5 Gy) TBI, fractionated into 10-15 cGy/day, is administered 2-3 times weekly to control low-grade non-Hodgkin's lymphoma or chronic lymphoid leukemia

# *Clinical indications*

## ***Scheduling*:**

### *One fraction*

- *Non - myeloablative TBI*
- **Myeloablative TBI ( 8Gy) for allogenic HCT**

### *More fractions:*

- *2Gy x 2/die x 3 days (Seattle protocol)*
- *3.3 Gy x 3 days*
- *3.8 Gy x 3 days*
- *others*

# *Clinical indications*

## Dosimetric chart

***Type of treatment Unit:***

- beam energy
- nominal dose rate
- source-skin distance or source-axis distance

***Patient's position:***

- supports for supine, prone, seated, half seated, standing positions
- limb positions (raised, flexed, etc.)
- position in relation to beam incidence (antero-posterior; postero-anterio; latero-lateral)

***Patient's data (thickness):***

- head
- neck
- chest
- abdomen

# *Clinical indications*

## Dosimetric chart

***Dose:***

- Dose point prescrition and Total Dose
- Fractionation; Dose per fraction
- Actual Dose Rate in TBI position

***Dose Homogeneity at:***

- chest
- abdomen
- lower limbs

***Dose to organs at risk (OAR):***

- lungs
- lens of the eyes (recommended)
- kidneys (recommended)
- gonads (recommended)

***In vivo dosimetry:***

- systems and uncertainty.

# *Clinical indications*

## *Final consideration:*

- Experience over the last twenty years has demonstrated that ***fractionated and hyperfractioned TBI*** are associated with a lower incidence of side effects than TBI (8-10 Gy) at a high dose rate.
- The ***probability of severe radiotherapy-induced toxicity and fatality*** is reduced after TBI fractioned into one or more sessions a day.
- ***The use of compensators*** for the lung, brain, and eyeballs is also a parameter to control the apparition of some collateral effects like interstitial pneumonia, cognitive functions deterioration and cataract.
- ***A total dose of TBI above 10 Gy*** has been correlated with a higher incidence of secondary tumors (*relative risk of second tumors*: 0.9 with dose <10 Gy *vs* 1.9 with dose >12 Gy and 4.1 with dose >13 Gy)

# Clinical indications

## Bibliography

*The British Journal of Radiology, 70* (1997), 1204–1207 

Review article

**The radiobiological basis of total body irradiation**

T E WHELDON

*Departments of Radiation Oncology and Clinical Physics, CRC Beatson Laboratories and Beatson Oncology Centre, Glasgow G61 1BD, UK*

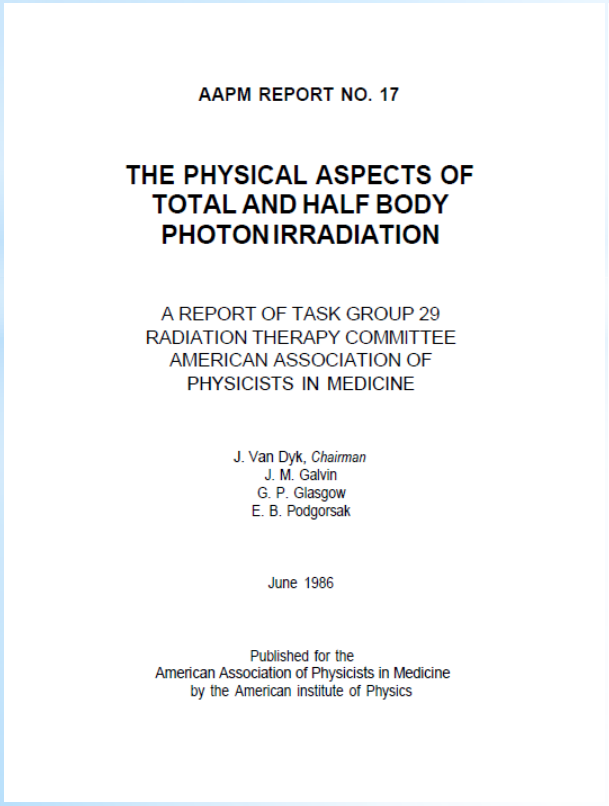
StrahlentherOnkol. 2006 Nov;182(11):672-9.

**Biologically effective dose in total-body irradiation and hematopoietic stem cell transplantation.**

Kal HB, Loes van Kempen-HarteveldM, Heijenbrok-Kal MH, Struikmans H.

# Irradiation techniques

## Bibliography



AAPM REPORT NO. 17

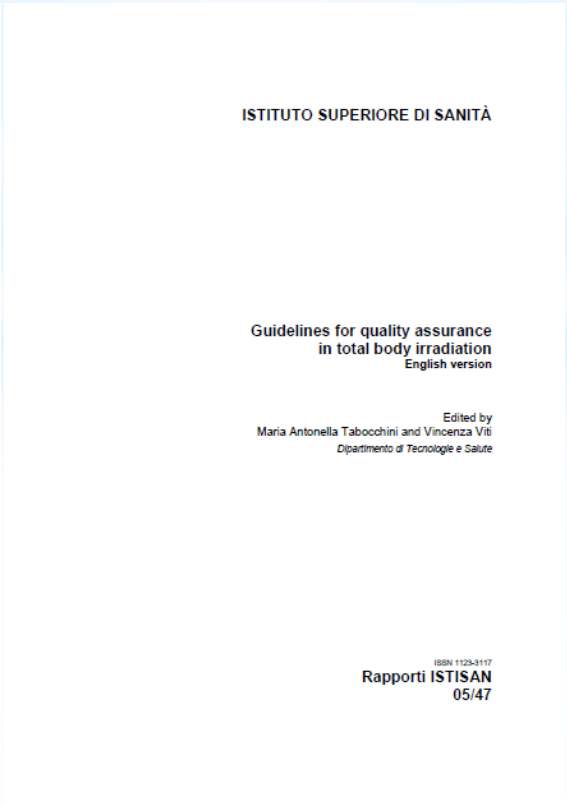
THE PHYSICAL ASPECTS OF TOTAL AND HALF BODY PHOTON IRRADIATION

A REPORT OF TASK GROUP 29
RADIATION THERAPY COMMITTEE
AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE

J. Van Dyk, *Chairman*
J. M. Galvin
G. P. Glasgow
E. B. Podgorsak

June 1986

Published for the
American Association of Physicists in Medicine
by the American institute of Physics

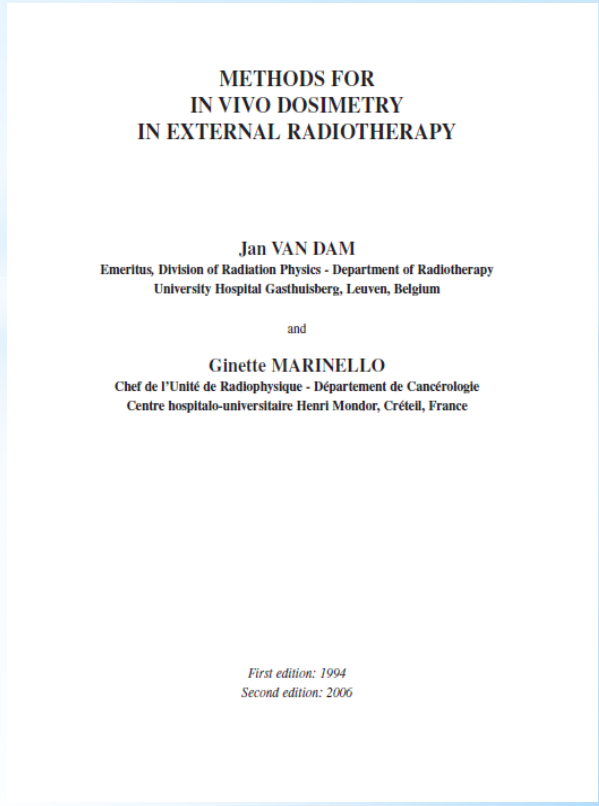


ISTITUTO SUPERIORE DI SANITÀ

Guidelines for quality assurance in total body irradiation
English version

Edited by
Maria Antonella Tabocchini and Vincenza Viti
*Dipartimento di Tecnologie e Salute*

ISBN 1125-3117
Rapporti ISTISAN
05/47



METHODS FOR
IN VIVO DOSIMETRY
IN EXTERNAL RADIOTHERAPY

Jan VAN DAM
Emeritus, Division of Radiation Physics - Department of Radiotherapy
University Hospital Gasthuisberg, Leuven, Belgium

and

Ginette MARINELLO
Chef de l'Unité de Radiophysique - Département de Cancérologie
Centre hospitalo-universitaire Henri Mondor, Créteil, France

*First edition: 1994*
*Second edition: 2006*

# *Irradiation techniques*

***Technical aspects:*** **Set - Up**

It should be as simple, reproducible and comfortable for the patient as possible in order to:

- ***guarantee delivery*** of every single fraction of treatment without interruption;
- ***reduce the time*** for patient positioning particularly when TBI is part of the daily routine work;
- ***standardize procedures*** of medical, physical, technical and nursing staff;
- ***guarantee accuracy of dose distribution***.

# *Irradiation techniques*

***Technical aspects:***

- Radiotherapy Unit and Bunker size
- Beam incidence
- Patient supports
- Partial transmission shield placement
- Check system for shield placement
- *In vivo* dosimetry
- Check system for *In vivo* dosimetry

J Med Phys. 2006 Jan;31(1):5-12.

**Whole body radiotherapy: A TBI-guideline.** Quast U.

# *Irradiation techniques*

## ***Technical aspects:*** ***Radiotherapy Unit and Bunker size***

**General considerations (AAPM REPORT NO. 17)**

1) the higher the energy, the lower the dose variation (excluding the the effects of the build-up region and tissue inhomogeneities).

2) the larger the treatment distance, the lower the dose variation.

3) the larger the patient diameter, the larger the dose variation.

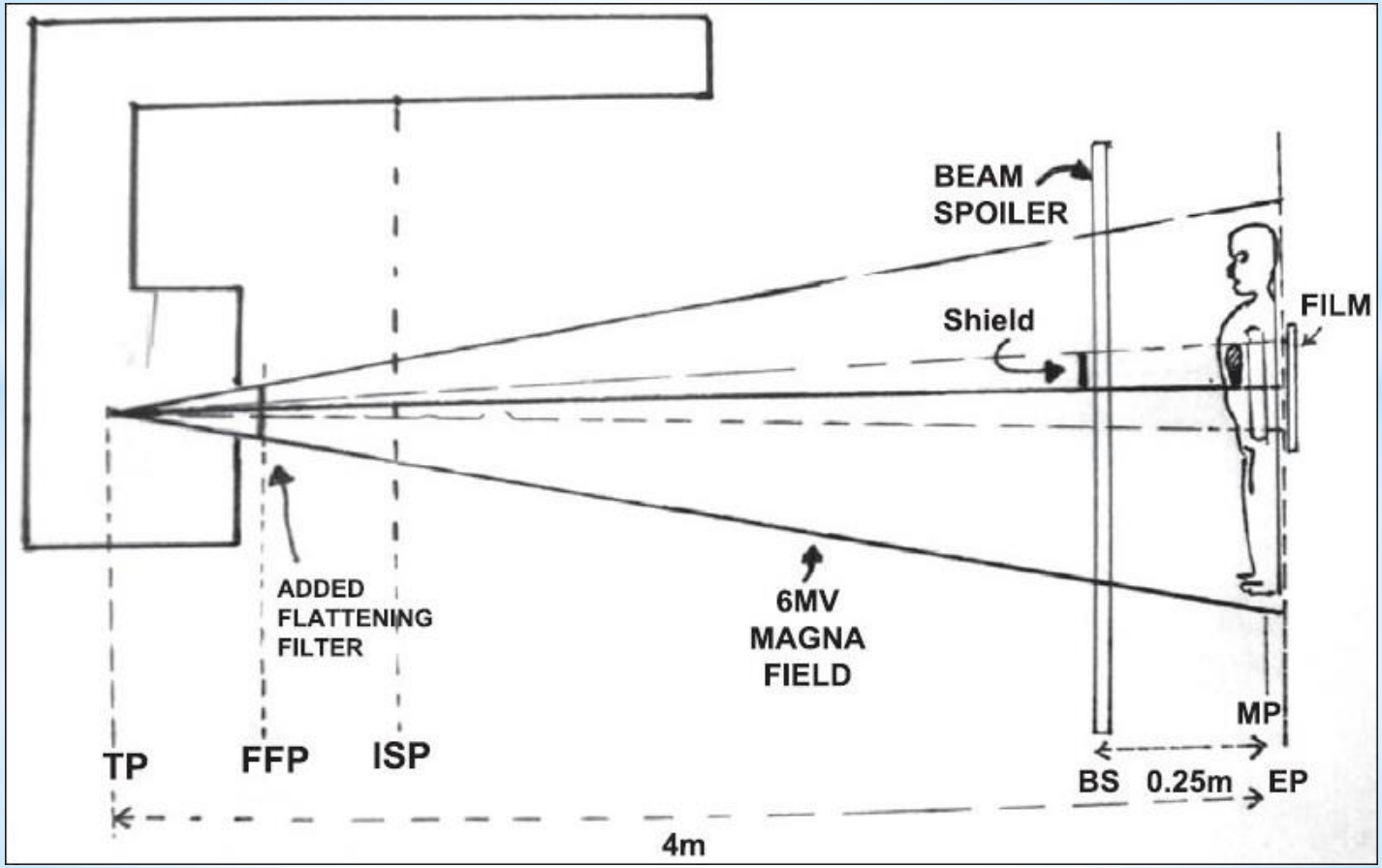
4) AP/PA treatments will yield a variation not larger than 15% for most megavoltage energies and distances.

5) Lateral opposed beams will usually give a greater dose variation compared to AP/PA treatments especially for adult patients.

*For pediatric cases or higher energy x-ray beams, a ±15% uniformity might be achievable with bilateral fields.*

# Irradiation techniques

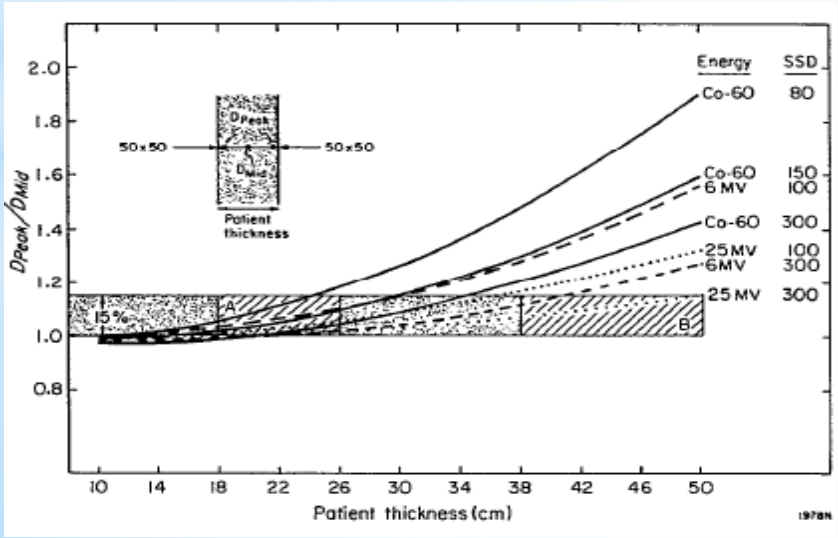
***Technical aspects:*** ***Radiotherapy Unit and Bunker size***



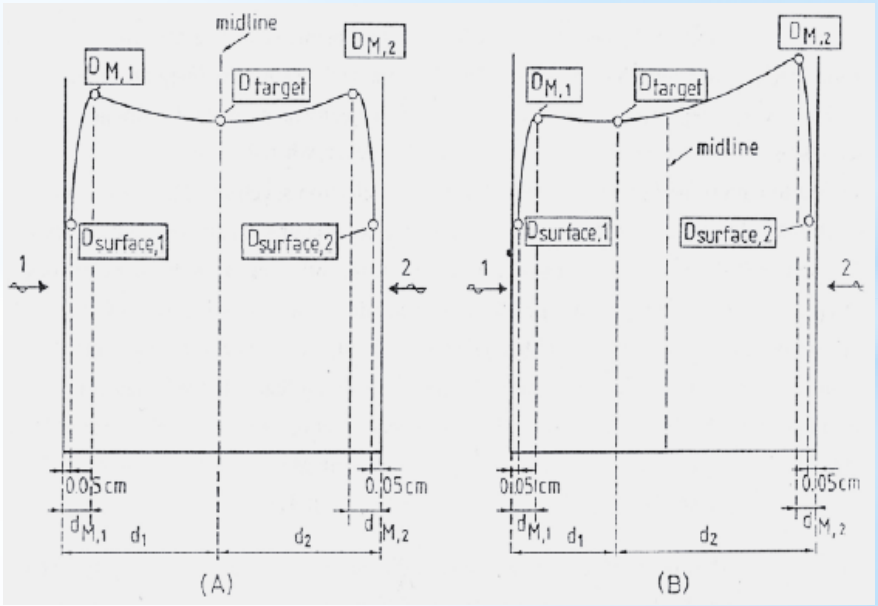
# Irradiation techniques

## Technical aspects: Radiotherapy Unit and Bunker size

- 4-15 MV photon beams is recommended: *good homogeneity in the absorbed dose distribution for the different geometries of radiation*




*Ratio of peak dose to midplane dose on the central ray versus patient thickness. AAPM REPORT NO. 17*

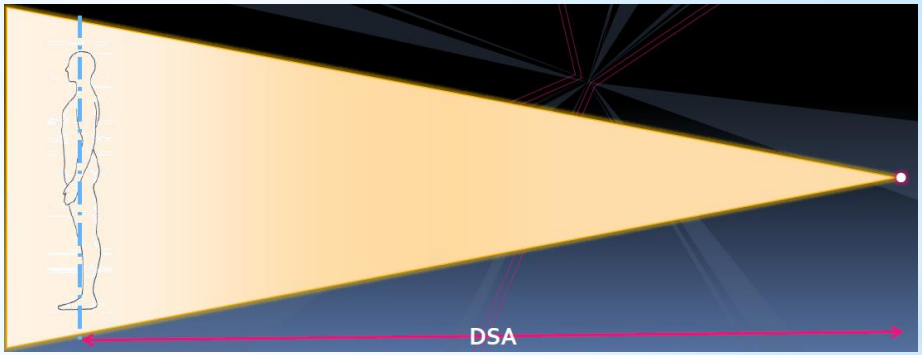



*Schematic representation of the different doses involved in in vivo dosimetry for 2 parallel opposed photon beams.* **METHODS FOR IN VIVO DOSIMETRY IN EXTERNAL RADIOTHERAPY, booklet 1 ESTRO 2006**

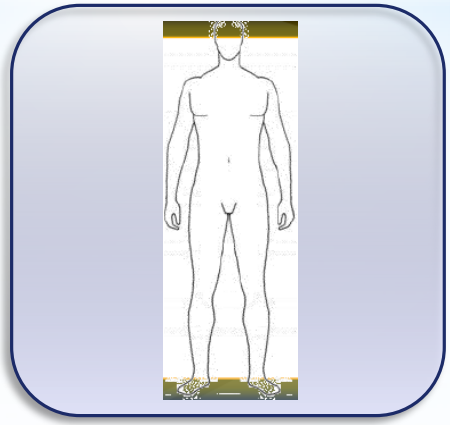
# *Irradiation techniques*

***Technical aspects:*** ***Radiotherapy Unit and Bunker size***

- **Large distance:**
  *more then 3 - 4 m*

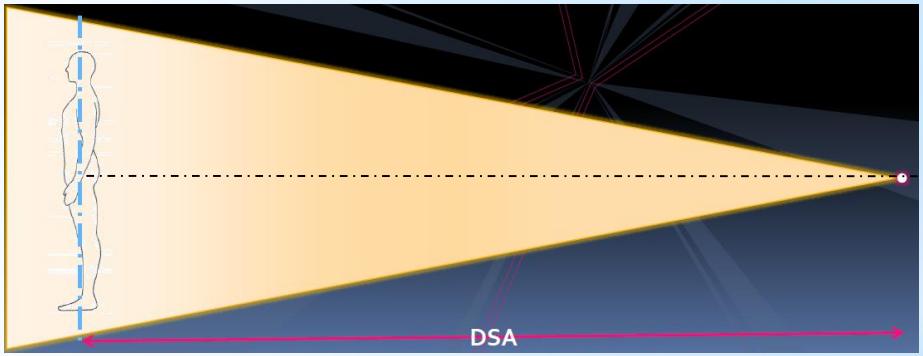


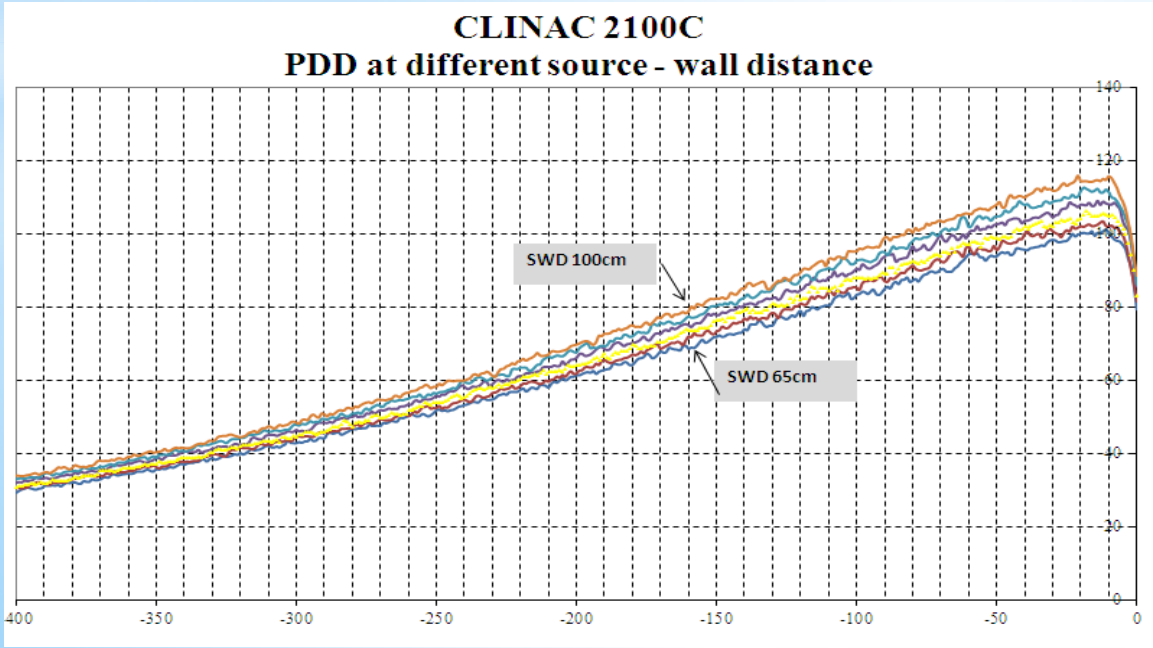

- **Large field :**
  *40x40 cm²at 0° or 45° collimator angle*



# Irradiation techniques

## Technical aspects: Radiotherapy Unit and Bunker size



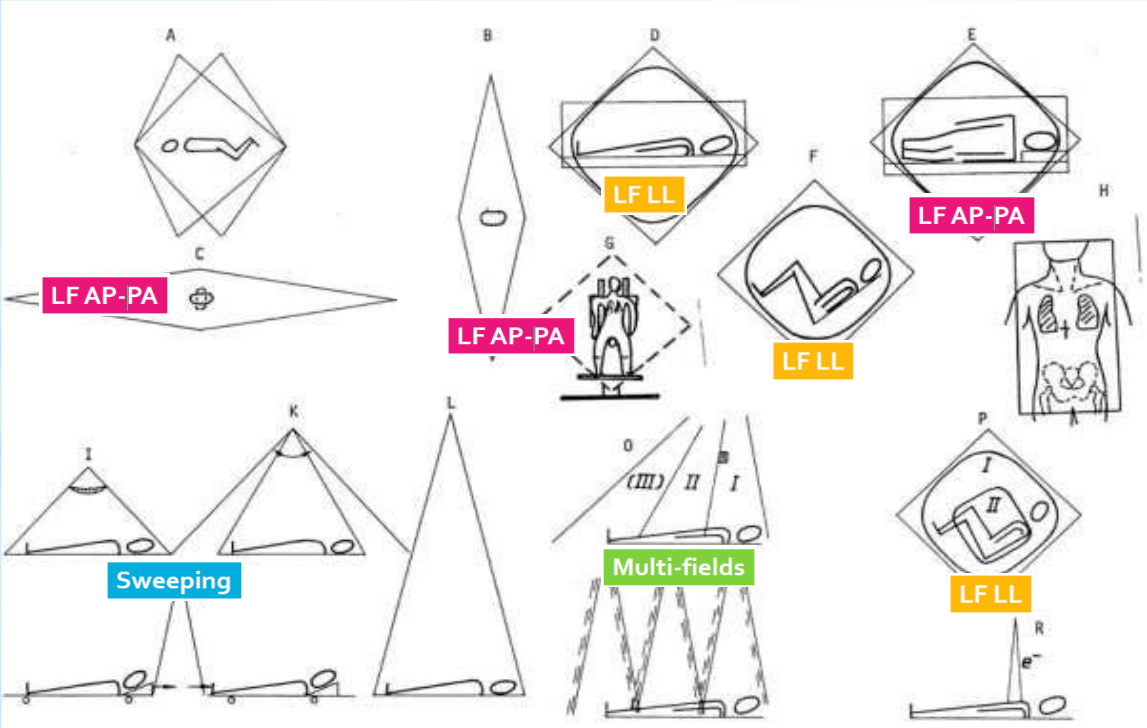




### Measurements:

need to measure the PDD curve and profile curves for TBI special conditions: large field, large SSD, etc…

# Irradiation techniques

## Technical aspects: Beam Incidence




**LF AP-PA**

antero-posterior (AP) and postero-anterior (PA)

**LF LL**

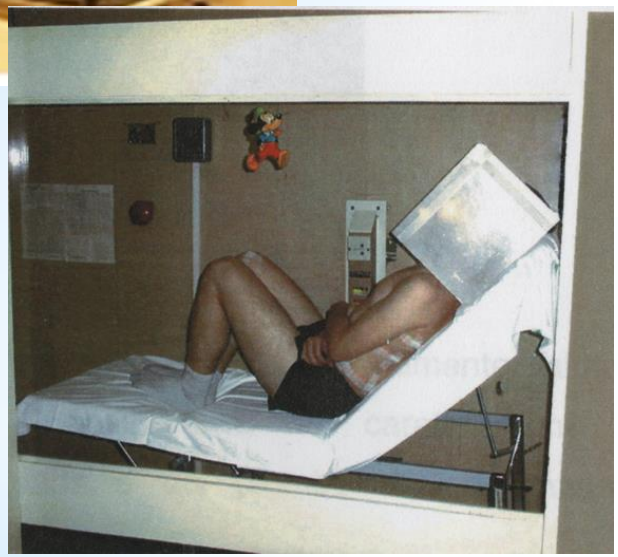
Latero-lateral (LL)

**Multi-fields**

**Sweeping**

# *Irradiation techniques*

***Technical aspects:*** ***supports*** **(bed, support for irradiation while standing);**



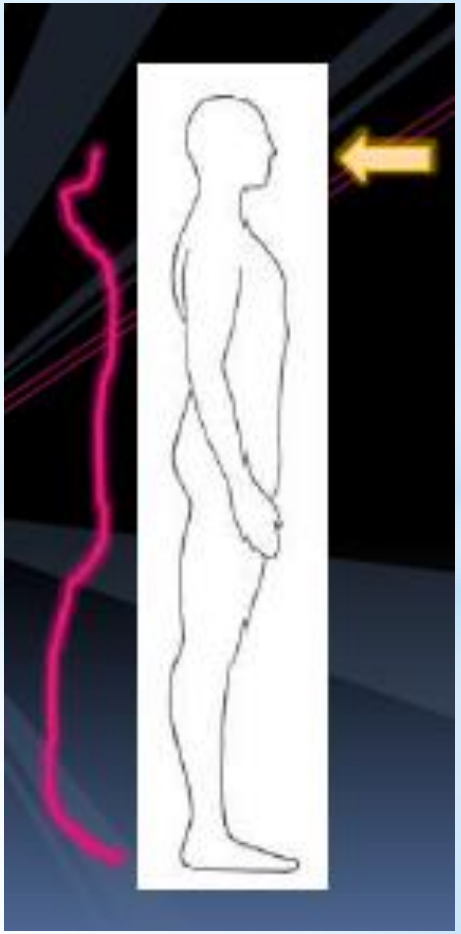
# Irradiation techniques

**Table 1. The commonest TBI techniques**

| Patient's Position | Beam alignment | Advantages and Indications | Disadvantages |
|---|---|---|---|
| Supine/fetal | Horizontal | Comfortable and reproducibile. Indicated for pediatric patients | Lateral incidence; difficulty in shield and compensator placement |
| Supine/Prone | Vertical | Indicated for children under 1 metre in height who require sedation | Height limit |
| Standing | Horizontal | Anterior and posterior incidence; easy shield and compensator placement; indicated in fractionated dose schedules. | Position cannot be maintained for long |
| Lateral decubitus | Horizontal | Anterior and posterior incidence; shields and compensators can be used; indicated in single dose therapy schedules because the position can be maintained for a long time. | Accurate shield placement verification is essential |

# *Irradiation techniques*

## *AP-PA irradiation*



***Advantages:***

- *Opposing horizontal beams 40x40 cm*
- *DSA ≥ 4m*
- *body* thickness less and more homogeneous in various districts (head, neck, thorax, abdomen, ..)
- Simple set-up and easy shielding (good lung shielding)

***Disadvantages:***

- placement of uncomfortable treatment

# *Irradiation techniques*

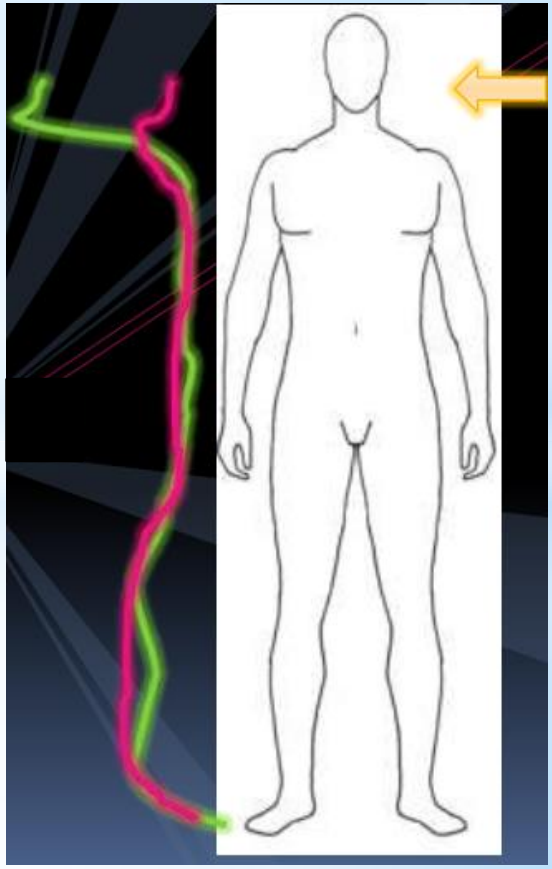
## *LL irradiation*

***Advantages:***

- *Opposing horizontal beams 40x40 cm*
- *DSA ≥ 4m*
- *Confortable displacement*

***Disadvantages:***

- Greater body thickness and less homogeneous in various districts (head and neck overdose)
- Hard shielding
- not recommended for adult treatment but possible for children



# *Irradiation techniques*

## *Dose Rate effect*

***"A higher TBI dose rate has been shown to be an adverse prognostic factor for developing IP (Interstitial pneumonia)…. The use of fractionated TBI at a dose rate of 7.5 cGy/min or less rather than 15 cGy/min is recommended…"***

Br J Cancer. 2004 Jun 1;90(11):2080-4. Carruthers SA, Wallington MM.
***Total body irradiation and pneumonitis risk: a review of outcomes.***

***"The last twenty years has demonstrated that fractionated and hyperfractioned TBI are associated with a lower incidence of side effects than STBI (8-10 Gy) at a high dose rate."***

**«Guidelines for quality assurance in total body irradiation»**
Report ISTISAN 05/47

# *Irradiation techniques*

## *Recommendations for the doserate*

- ***Fractionated Dose*** ≥10-12 Gy
  ⇒ **dose-rate < 15-16 cGy/min**

- ***Single Dose*** (10 Gy low dose-rate)
  ⇒ **dose-rate <5 cGy/min**

- ***Mini-TBI:*** 2 Gy in one fraction
  ⇒ **dose-rate < 10 cGy/min**

**«Guidelines for quality assurance in total body irradiation» Report ISTISAN 05/47**

# *Irradiation techniques*

## *Dose Rate effect*

The actual dose-rate in patient is determined by:

- ***SAD***
- ***Repetion Rate (MU/min) or Doserate (Gy/min)***
- ***Presence of attenuators/compensators***
- ***Patient size***

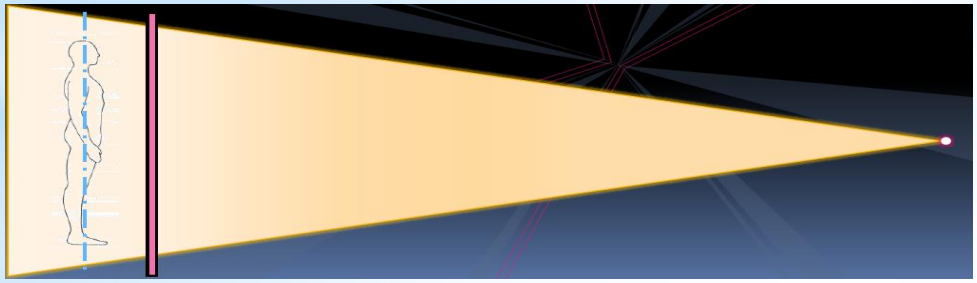
The reduction of dose rate can be obtained by increasing the treatment distance or lowering the dose-rate of the accelerator.

# Irradiation techniques

## Technical aspects: Beam Spoiler Effect

**"In TBI it's desiderable to ensure that the *skin surface receives close to the fully prescribed dose*."**

High energy beams needs the use of a ***PMMA plate*** of such a thickness as to absorb the build-up region of the depth dose curve.
The PMMA spoiler must be placed close to the patient (10-30 cm)



The build-up region is minimized, infact additional scatter component increases the input dose.

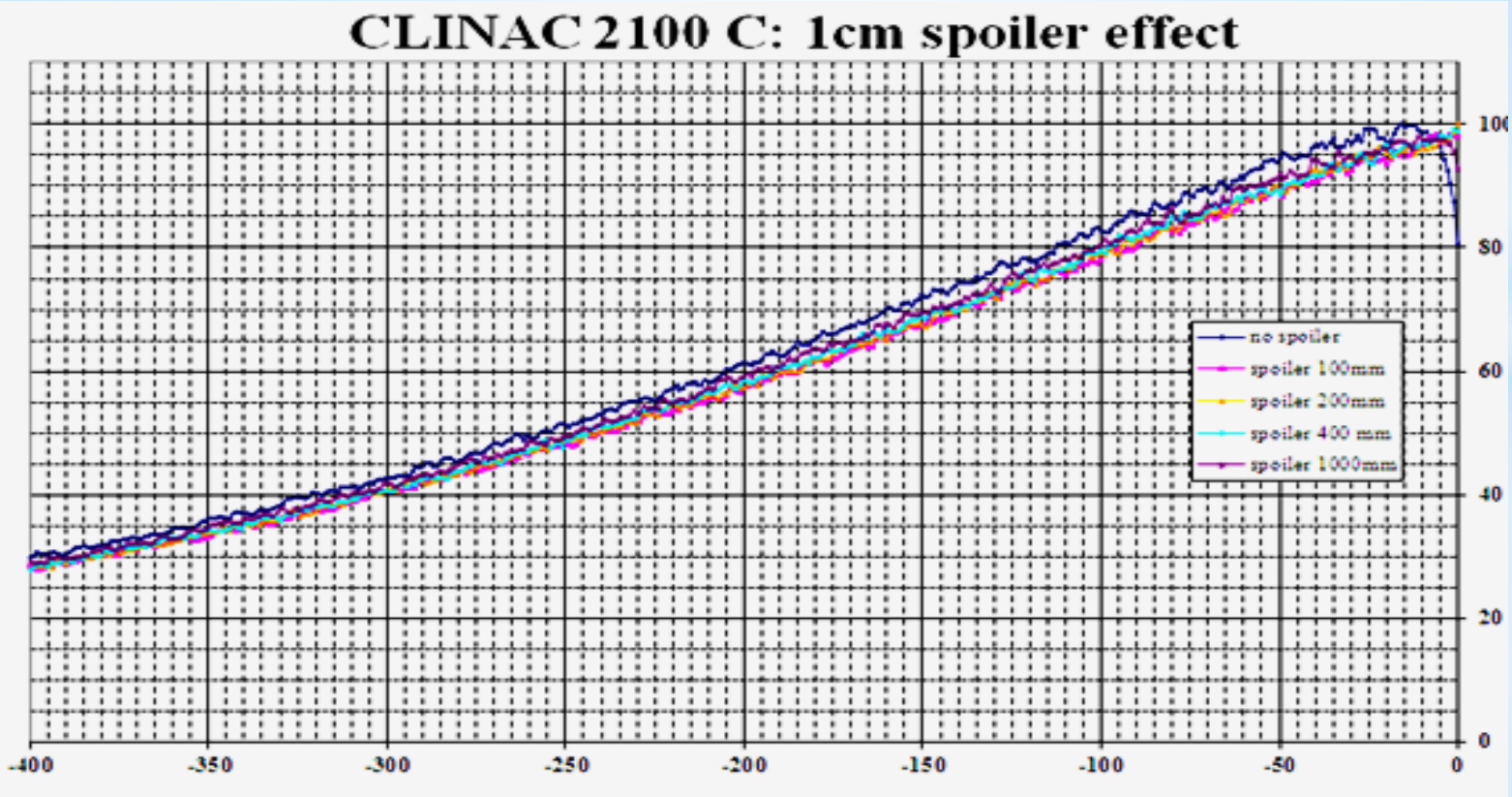
**Table 3** Beam quality variations with treatment distance.

| No. | Source axis Distance(SAD) d (cm) | Intensity ratios 20/15 | Intensity ratios 25/15 |
|---|---|---|---|
| 1 | 200.0 | 0.8495 | 0.7160 |
| 2 | 227.5 | 0.8484 | 0.7148 |
| 3 | 259.4 | 0.8478 | 0.7133 |
| 4 | 300.0 | 0.8471 | 0.7122 |
| 5 | 350.0 | 0.8472 | 0.7112 |
| 6 | 400.0 | 0.8467 | 0.7110 |
| 7 | 400.0(1.0BS) | 0.8544 | 0.7591 |
| 8 | 400.0(1.5BS) | 0.8491 | 0.7150 |

You must evaluate the attenuation (typically on the order of 5%) and the influence on beam quality

# Irradiation techniques

## Technical aspects: Beam Spoiler Effect




Trieste Measurements

# *Irradiation techniques*

## ***Technical aspects:*** ***Target Volume***

The ***target volume*** of myeloablative TBI is all malignant cells including those circulating as well as the whole cellular immune system

**It means that the Whole Body including the Skin**

Organs with a high risk of recurrence (“homing phenomenon”) and meninges, testes, may required additional local radiotherapy

# *Irradiation techniques*

## ***Technical aspects:*** ***Organ at risks***

*The dose of TBI can exceed the tolerance of organs at risk, particularly for the lung or the lens of the eyes.*

***Lungs*** are at particularly high risk

***Interstitial pneumonia*** has been one of the main fatal complications of TBI in conditioning regimens for allogeneic transplant.

# *Irradiation techniques*

## ***Technical aspects: Dose Prescription***

The TBI dose is normally prescribed at the ***abdominal and lung midplanes***

In order to take account of the density and geometry of the beam central section and to at least three pulmonary sections (upper, middle and lower parenchyma), **CT scan is recommended for treatment planning.**

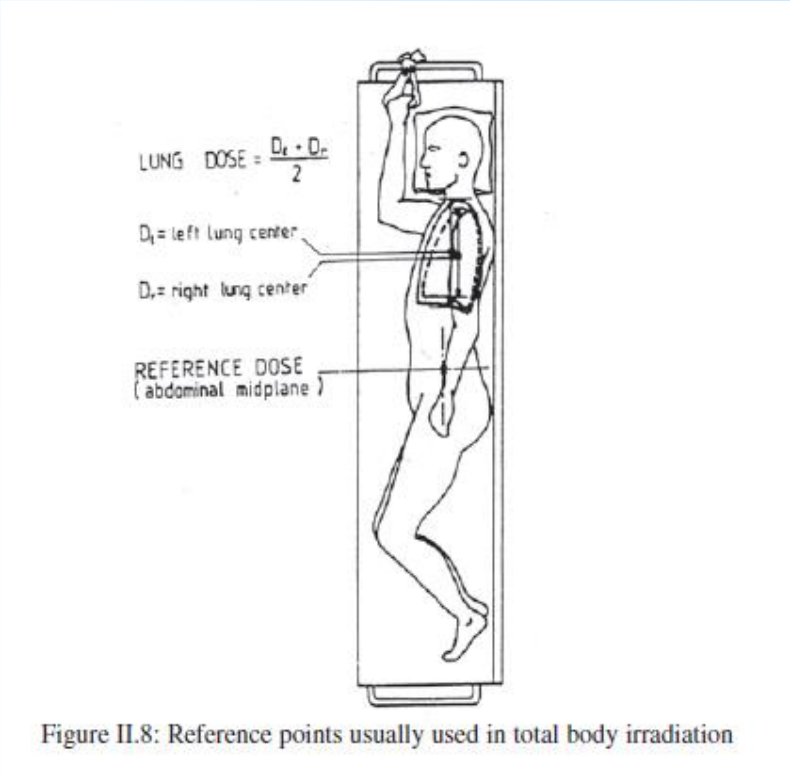



Figure II.8: Reference points usually used in total body irradiation

# *Irradiation techniques*

## ***Technical aspects: Dose Prescription***

The dose delivered to other critical organs such us **gonads, lens of the eyes**, or **kidneys** must be recorded in the reporting, together with longitudinal and cross-section irregularities at different reference points (**head, neck, mediastinum, pelvis, lower limbs**).

**The dose variation at the different reference points should be between ± 10%.**

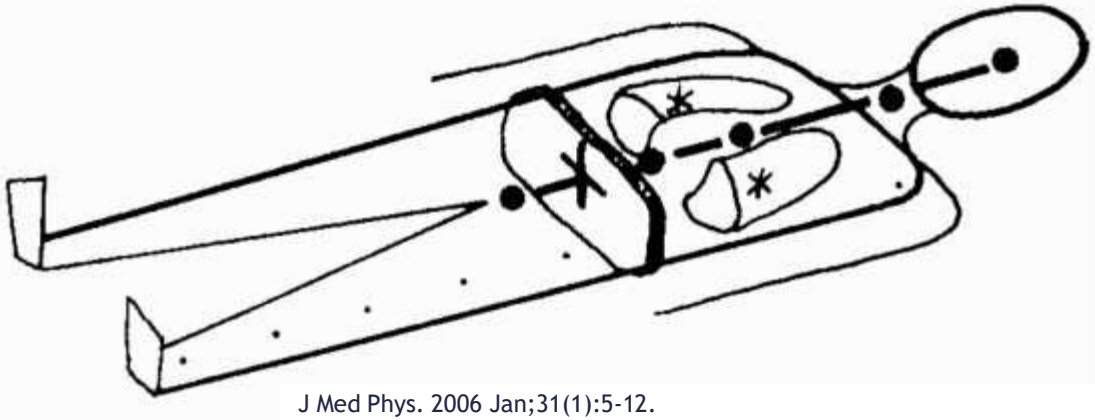
If, because of irregular thickness, the dose is not within this range, **compensators** may need to be applied around areas of lesser thickness.

# *Irradiation techniques*

## ***Technical aspects: Dose Prescrition***

*The dose reference point (+) **for dose specification to the target is defined** at **mid abdomen at the height of the umbilicus**.*

***The dose reference points** (∗) for lung dose specification are defined as mid points of both lungs…*



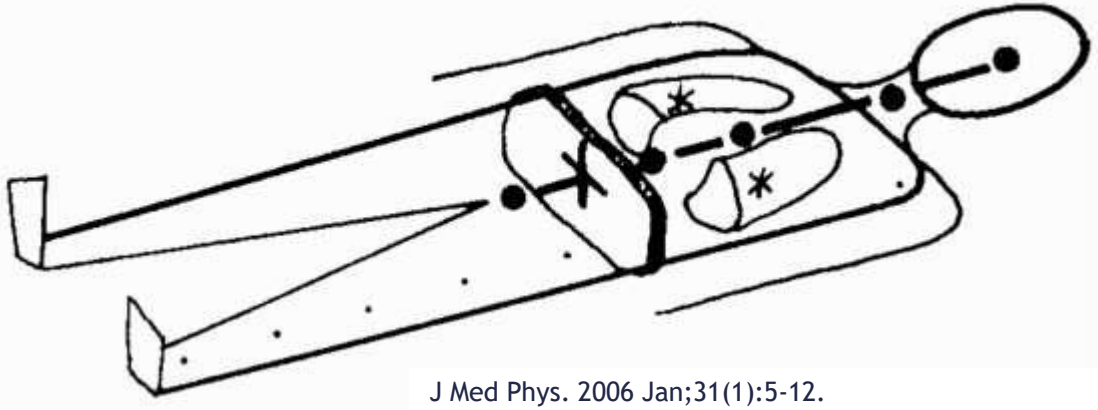
J Med Phys. 2006 Jan;31(1):5-12.
**Whole body radiotherapy: A TBI-guideline.** Quast U.

# *Irradiation techniques*

## ***Technical aspects: Spatial Dose Distribution***

*The spatial distribution of dose in the target can be characterized by the DVH or…by determining the dose at the specification point and the dose variation in the target ($D_{Ref}$, $D_{min}$, $D_{max}$).*

*This triplet of values can be derived from the longitudinal homogeneity of dose (at **selected points (•) along the midline**)*



J Med Phys. 2006 Jan;31(1):5-12.
**Whole body radiotherapy: A TBI-guideline.** Quast U.

# Irradiation techniques

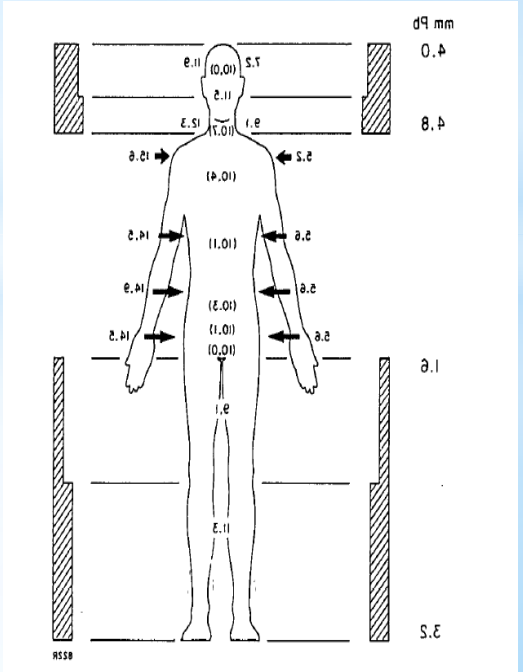
## Technical aspects: Shielding critical structures

The **lungs** are an example of an organ system that is particularly sensitive to radiation, easily effected by other therapy regimes.

**Two methods for reducing the dose to critical structures**:

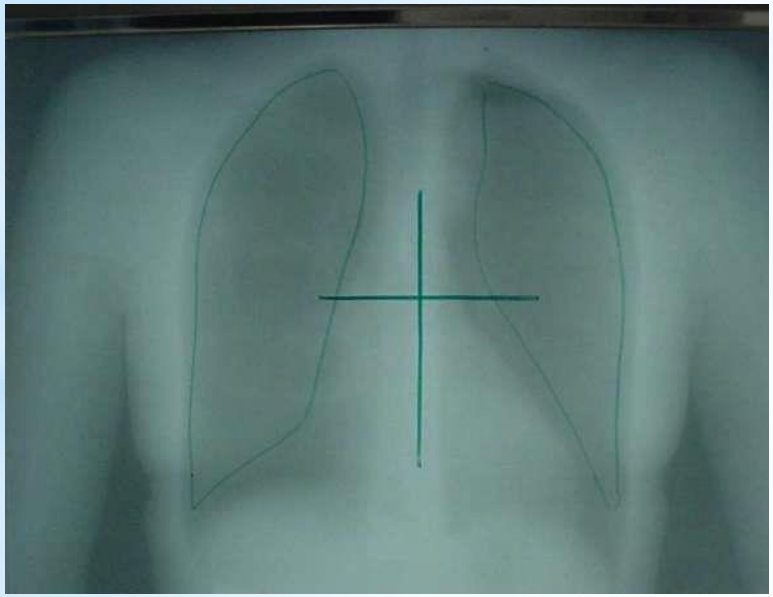
1) it is possible to place strips of absorbing material completely across the patient to shield these regions. The compensator can be placed on the treatment unit head using the block tray.
   Port film is used to check the positioning of the compensator.

2) more shielding for the lungs by placing ***cerrobend blocks*** between the source of radiation and the patient.
   These alloy blocks conforms more tightly to the lung shadow as seen on a radiograph.

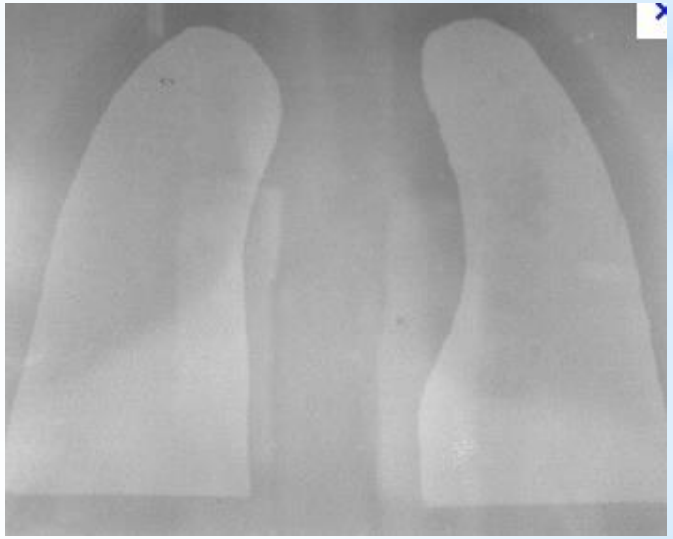


# Irradiation techniques

## Lungs Lead Shielding



- *X-Ray film and shielding design*
- *Portal film Verification*



# Irradiation techniques

## Lung and kidney Lead Shielding

- *X-Ray film and shielding design and Portal film Verification*

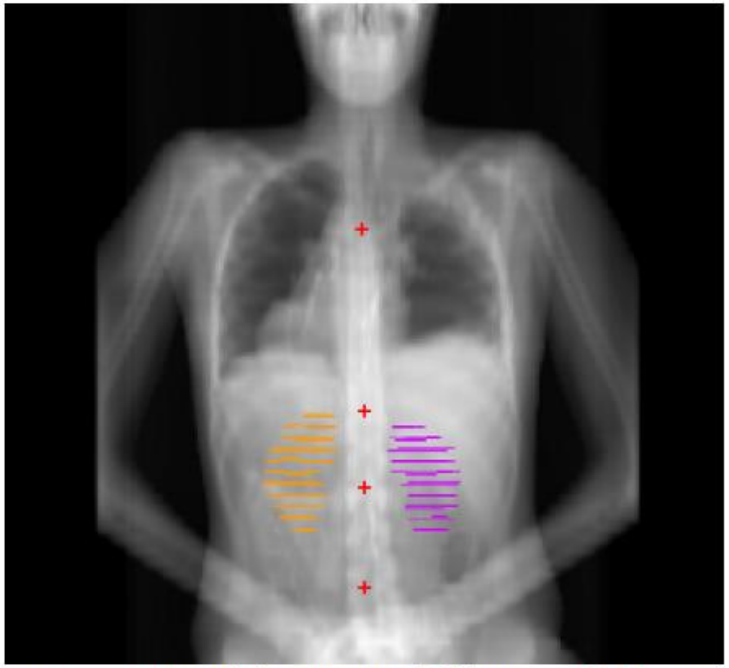


Figure1: DRR with segmented kidneys and external markers

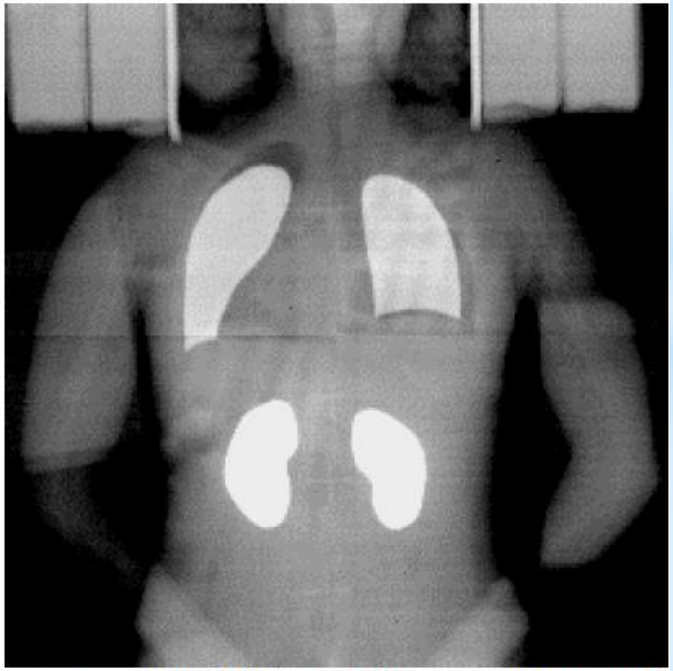


Figure 2: PortalVision XL image with lung and kidney shielding blocks

# Irradiation techniques

## Lungs Shielding / Compensation

**LL : lungs "compensated" by arms**

**AP-PA : Shaped Lead shielding**

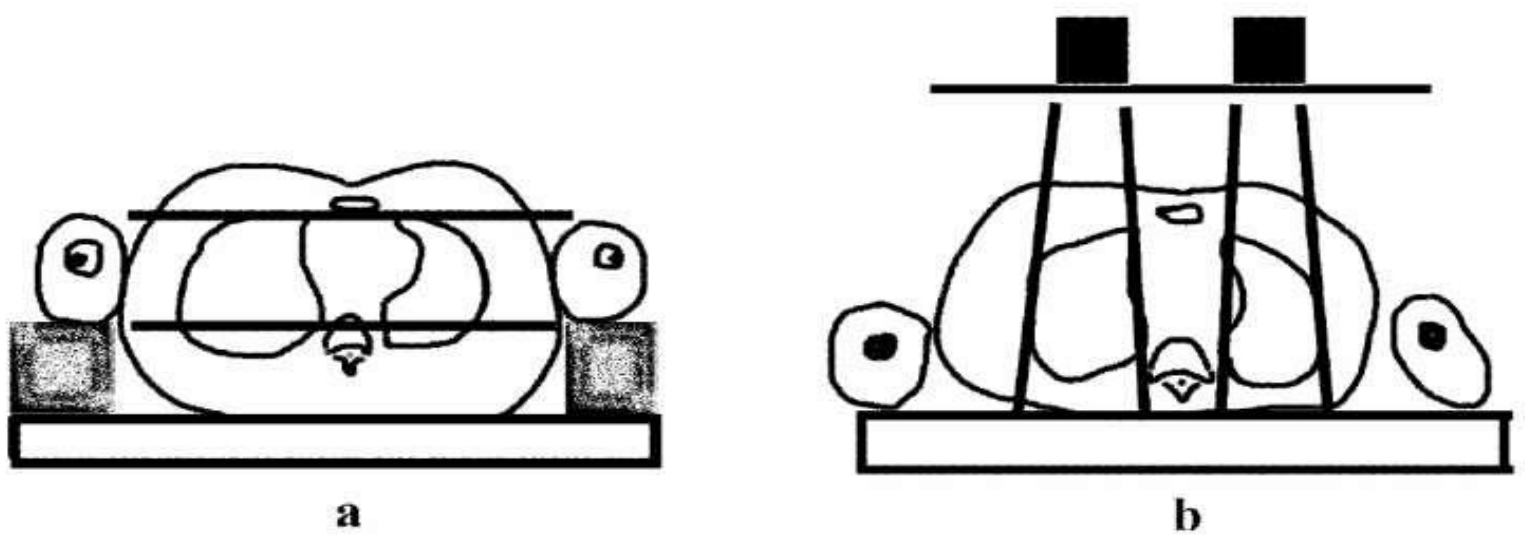



Fig. 5. Shielding of the lungs. a: Bilateral TBI. b: Anterior-posterior TBI.

# Basic Dosimetry

## New approach at TBI SAD

***Step 1.*** Determine an absolute calibration of the radiation beam using the large field geometry and the largest phantom available.

***Step 2.*** Correct this dose such that it represents both:

(a) the dose that would be obtained for a phantom that covers the entire beam

(b) the dose that would be obtained for a deep phantom i.e. full scattering conditions.

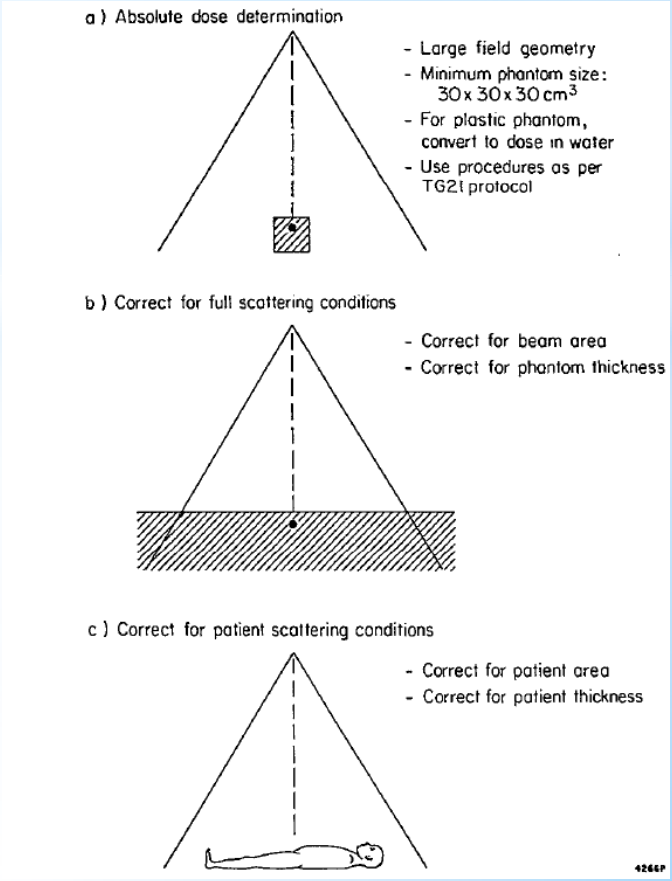
***Step 3:*** For patient treatments, corrections should be made for patient dimensions both in terms of the area of the patient intersecting the radiation beam as well as patient thickness.

# Basic Dosimetry

## New measurements at TBI SAD

## (IAEA protocol for non reference conditions)

- Beam calibration
- Depth dose curves
- Beam profiles
- Scatter factor
- Wall and floor scatter factor
- Beam spoiler attenuation



# Basic Dosimetry

## Measurements of PDD /TMR at large SAD, Profiles at TBI set-up

Table 2 Measured tissue maximum ratios (6 MV).

| No. | Depth 'd' cm | TMR 1.0m SAD (40 × 40 cm) | | TMR 3.5m SAD (140 × 140 cm) | TMR 4.0mSAD 160 × 160 cm | |
|---|---|---|---|---|---|---|
| | | RH | BJR 25 Ref [13] | | Open | 1.5 cm BS |
| 1 | 1.5 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2 | 3.0 | 0.983 | 0.983 | 0.975 | 0.976 | 0.973 |
| 3 | 5.0 | 0.948 | 0.949 | 0.934 | 0.937 | 0.932 |
| 4 | 10.0 | 0.844 | 0.848 | 0.819 | 0.828 | 0.819 |
| 5 | 15.0 | 0.740 | 0.741 | 0.703 | 0.714 | 0.704 |
| 6 | 20.0 | 0.633 | 0.638 | 0.595 | 0.610 | 0.601 |
| 7 | 25.0 | 0.525 | 0.528 | 0.496 | 0.518 | 0.510 |

Ravichandran R, et al., ***Beam configuration and physical parameters of clinical high energy photon beam for total body irradiation (TBI)***, Physica Medica (2010)

- *Water phantoms dedicated to horizontal beams*
- *As an alternative large sized plastic phantom or placing near diffusor bodies*
- *Films? Diode Array? Others?*

# Basic Dosimetry

## *Measurements of scatter factors* at *TBI Set-up*

The scatter is not dependent on field size (normally 40x40 $cm^2$) but the patient's sizes (district):

$$S_{cp} = S_c(40) \times S_p(pz)$$

$S_p$ depends only by the energy of the beam for which should be approximately the same as in SAD, otherwise measures with phantoms of various sizes

Ravichandran R, et al., *Beam configuration and physical parameters of clinical high energy photon beam for total body irradiation (TBI)*, Physica Medica (2010)

# *In vivo Dosimetry*

## *Target volume of high dose TBI*

- **Whole body,** including the skin, as the *target cells* are widely disseminated, all manifest or occult clones of malignant cells, including those circulating and the whole cellular immune system.

- ***Organs with a high risk of recurrence*** ("homing phenomenon") and ***primary extended*** ("bulky") ***tumour regions*** like meninges, testes, or abdominal lymph nodes may require additional concurrent local radiotherapy.

# *In vivo dosimetry*

***In vivo dosimetry*** is of particular relevance in case of Total Body Irradiation before bone marrow transplantation for different reasons:

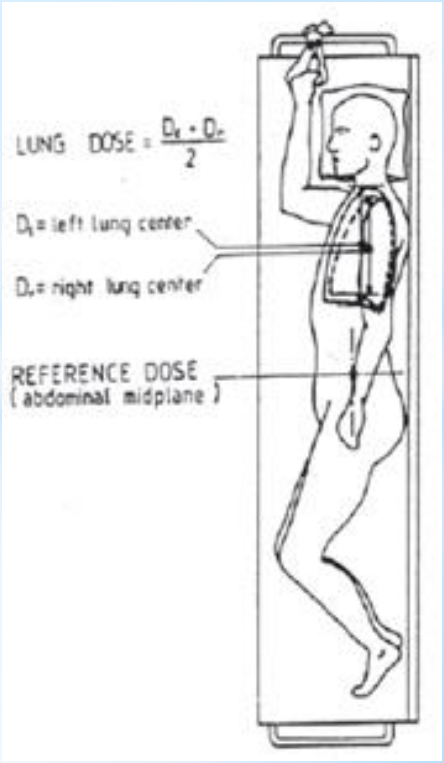
- ***difficulties in calculation of the dose at different points in the patient***
- ***increased risk of patient movements due to the long duration of the treatment***
- ***in single fraction regimen, need to correct the dose before the end of the session.***

The ***in vivo measurements*** are to be considered not only as an independent check, but rather as an integral part of the overall dosimetric approach for this particular treatment technique.

# In vivo dosimetry

## Tasks for in vivo dosimetry

- Evaluation of the dose at the dose specification point, usually taken at mid-pelvis or mid-abdomen
- to estimate the homogeneity of the midline dose distribution at different loci in cranio-caudal direction
- to monitor the dose at the level of organs at risk (lungs, liver, etc).



# *In vivo dosimetry*

## *Target dose, simplified approach* :

- symmetrical , with respect to the midline point, expansion or compression of the real patient to a thicker or thinner “water patient”
- tissue inhomogeneities should be symmetrical and equally distributed with respect to the midline

❖ **In LL direction good approximation**

❖ **In Antero- Posterior direction not realistic approximation**

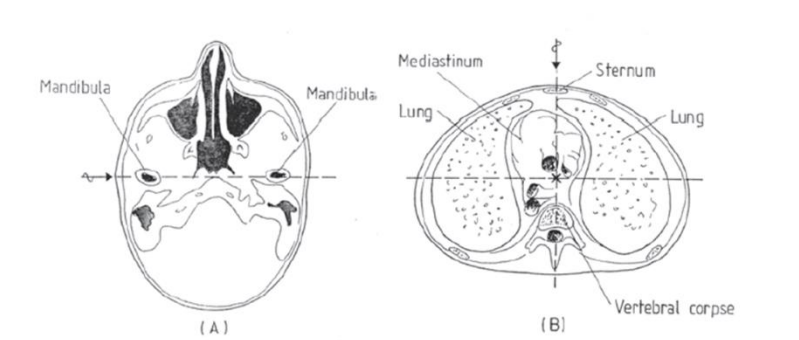



Figure II.5: Examples of symmetrical (A) and asymmetrical (B) disposition of the tissues, with respect to the midline depth. For the head-and-neck fields (A) the method of target dose determination is applicable, while it is not for the thorax fields (B).

*In most clinical cases, the arithmetic mean of entrance and exit dose may be a quite reasonable approximation for Dose at midline.*

# In vivo Dosimetry

***Dosimeters set-up***

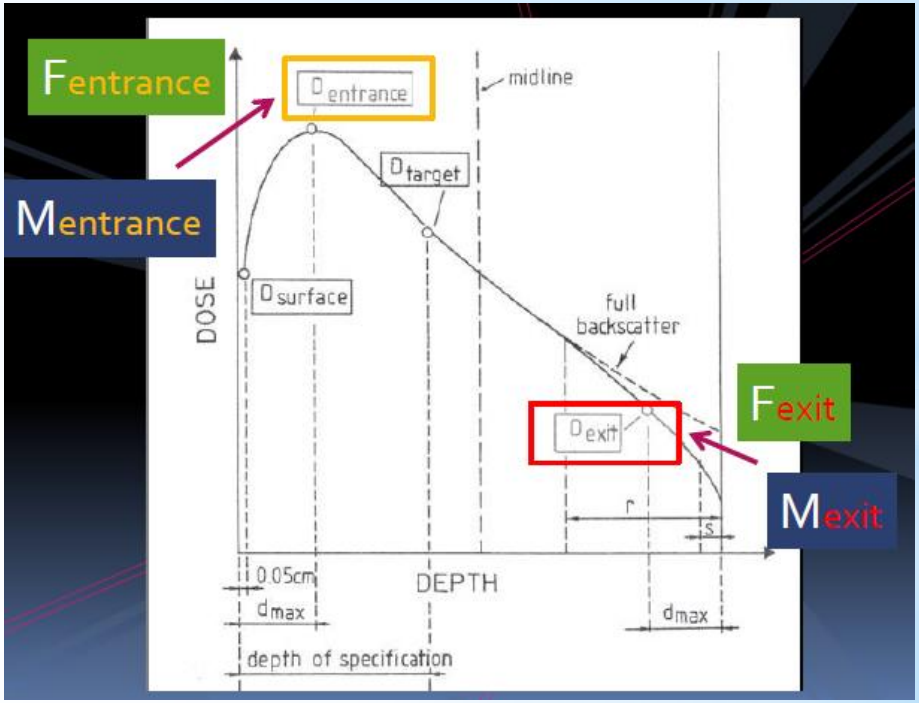
The dosimeters must be placed on the skin of the patient in pairs (one "*in entrance*" and the other "*in exit*") in the point of reference (abdomen) and in several body districts, like head, neck, mediastinum, lungs (possibly on both lungs if they are not "dosimetrically symmetrical", like the irradiation AP-PA in lateral decubitus), navel, knees and ankle.

Subsequently, for every district, the pair of measured values must be used in order to calculate the "***dose at half thickness***"

# In vivo Dosimetry

An algorithm for calculation of the **"dose at half thickness"** in TBI uses:

- the **entrance dose**, corrected by the distance from "centre field";
- the **"equivalent depth in water"**, determined on the base of its dosimetric correlation with the **"exit dose / entrance dose" ratio**;
- the correlation between the **"equivalent depth in water"** and the **data of attenuation**




*The detectors must be previously calibrated in TBI conditions, for comparison with the ionization chamber.*

# In vivo Dosimetry

## Main Detectors for *in-vivo Dosimetry*

- **TLD**
- **MOSFET**
- **DIODI**

**And in Trieste**

- **Gafchromic film**

# QA in TBI procedure

TBI demands specific additional protocols of quality control , not required for standard treatments:

## ❖ *Base controls*

Related to the dosimetric and geometric parameters of the specific treatment unit in TBI condition, to the performances of the employed treatment planning systems (verification of the algorithms for distances superior to conventional ones and fields larger than the dimensions of the patient) and to the dosimetric systems for the determination of the absolute and relative dose.

## ❖ *Pre-irradiation controls*

Related to the dosimetric systems, and to the verification of the accessories (absorber and diffusers, couch /seat, etc.) for the positioning during irradiation, to be specifically carried out for each patient.

# QA in TBI procedure

**Table 4. TBI specific base controls in addition to those prescribed for conventional radiotherapy**

| Object | Parameter to control | Modality of control |
|---|---|---|
| Basic dosimetriy | Dose in standard phantom at reference depth | Audit or external confrontation in TBIconditions; calibration according to international protocols |
| LINAC or telecobalt | OAR profiles | Dosimetric measures in standard phantom in TBI condition |
| LINAC or telecobalt | PDD or TPR | Dosimetric measures in standard phantom in TBI condition |
| Treatment planning system (TPS) | Dose in anthropomorhic phantom with lung type inhomogeneity: absolute values and dose distribution. | Dosimetric measures in TBI condition |
| *In vivo* dosimetry system | Entrance and exit dose and algorithm of calculation at half thickness | Dosimetric measures in TBI condition |
| "Standard phantom" is that recommended by the dosimetric protocol of reference | | |
| LINAC or telecobalt | Dose | Control of constancy |
| Personalize beam modifiers (protection, shields, compensators, bolus) | Attenuation of the shields Consistency of compensators and bolus | Dosimetric measures |
| Positioning devices | Geometric parameters (distance from the source, height from the pavement etc.) | Metric control |
| *In vivo* dosimetry | Sensitivity | Calibration in terms of absorbed dose or control relative to the response |

# Experience of Trieste

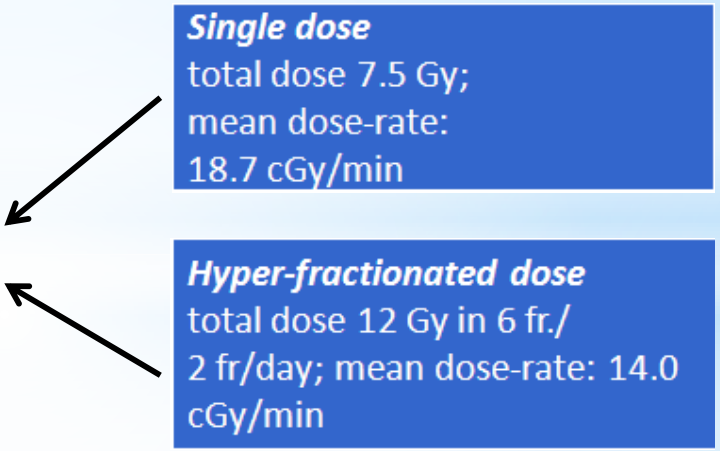
***Total body irradiation (TBI) in pediatric patients:***

*Since 1984 pediatric patients have been treated with TBI as a conditioning regimen for autologous and allogeneic BMT, at the Radiotherapy Center of Trieste*

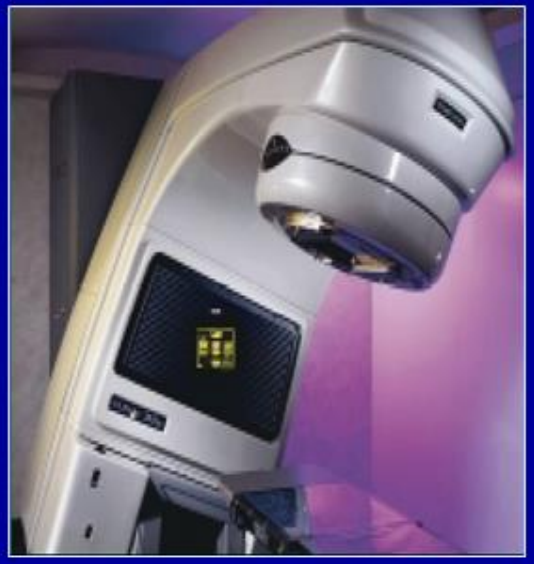
| ***Patients*** | ***36*** |
|---|---|
| *Median Age* | 12 (6-19) |
| *Female*<br>*Male* | 10<br>26 |
| ***Disease*** | |
| ALL<br>*I or II CR*<br>*> II CR*<br>*PR*<br>*relapse/refractory* | 33<br>22<br>2<br>3<br>6 |
| AML *I CR* | 1 |
| AML/ALL *I or II CR* | 2 |

# Experience of Trieste

| ***Conditioning regimen*** | ***N*** |
|---|---|
| *THIO, EDX*<br>*EDX*<br>*FLU, EDX, THIO*<br>*FLU, EDX, THIO, DAUNO*<br>*Others* | 14<br>*5*<br>*3*<br>*3*<br>11 |
| ***TBI*** | |
| Single dose | 14 |
| Hyper-fractionated dose | 22 |
| ***Type of donor*** | |
| MRD | 13 |
| MUD | 7 |
| Haploidentical | 14 |
| Autologous | 2 |



# Experience of Trieste



Linear Accelerator, 6MV X-rays
Maximum Radiation Field
Source Axis Distance ~ 4 m
Collimator rotated
Parallel opposed lateral fields

Patients were treated in the seated-supine position. The lateral position of the arms provided partial lung shielding

# *Experience of Trieste*

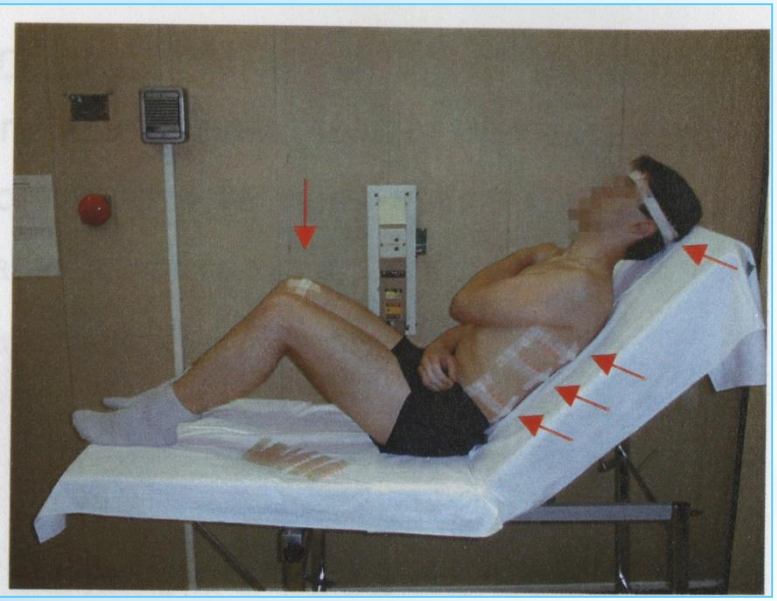
***Before treatment:*** many dosimeters measure entrance and exit dose and allow to evaluate the mean patient axis dose:

- ***until 2005*** *sets of calibrated LiF TLDs (cylindrical micro-rods of length 6 mm and with diameters of 1 mm) were applied to 9 body sites*

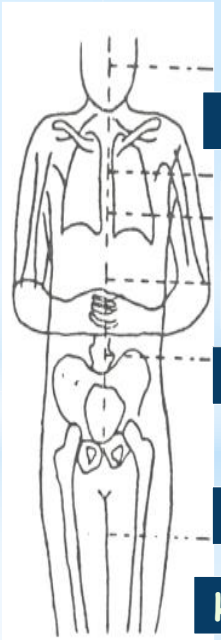
- ***since 2006*** *sets of EBT gafchromics are used at 9 body sites before treatment (STBI) or at the first fraction (HFTBI)*

***During treatment:*** *one ionization chamber is set in right armpit, and one in the axis of legs check the actual irradiation and the reproducibility of the treatment*

# Dosimeters distribution and measured dose values

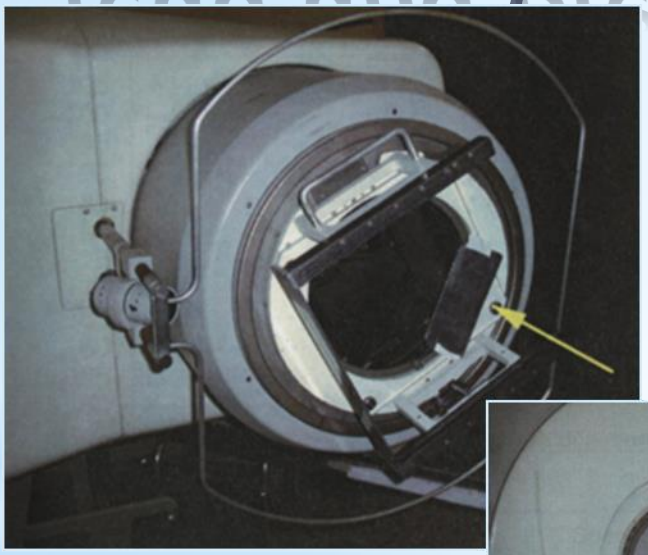


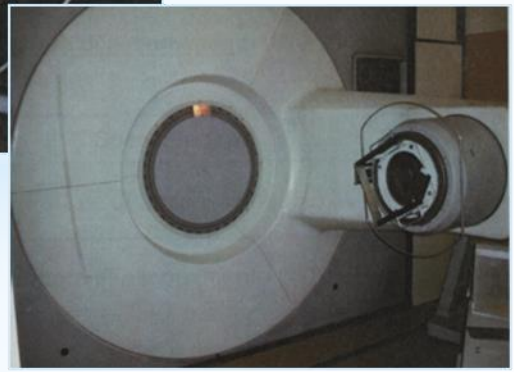
| | Medium Dose (Gy) | Min. Dose % | Max Dose % |
|---|---|---|---|
| Head | 1.98 | -6 | 5 |
| Armpit | 2.00 | -6 | 10 |
| Lung | 1.98 | -8 | 6 |
| Elbow | 2.01 | -5 | 6 |
| Abdomen | 2.07 | -6 | 13 |
| Thigh | 2.04 | -9 | 9 |
| Knee | 2.04 | -5 | 11 |
| Calf | 2.05 | -4 | 10 |
| Ankle | 2.14 | -1 | 13 |

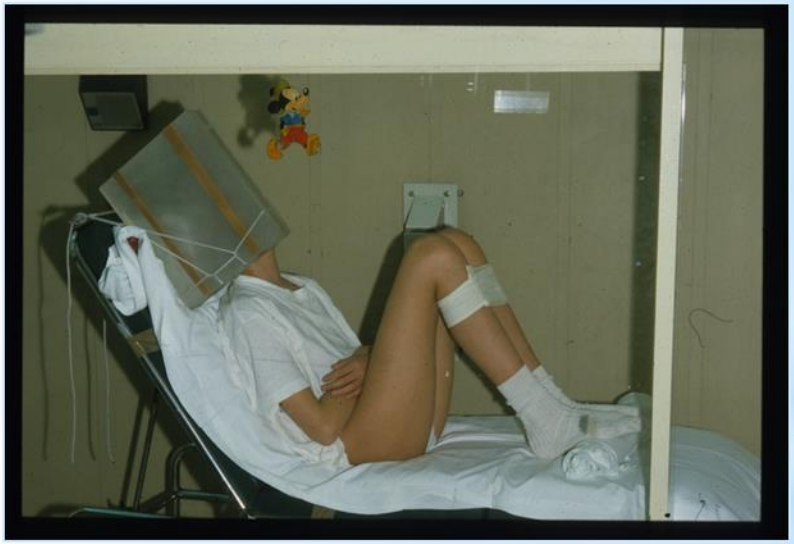



Monitor units are calculated by the mean value of three body dose points: armpit, lung and elbow

# *In vivo dosimetry: lead and plexiglass shielding*







1-2 mm lead shielding
for the leg dose homogenity

4-9 cm plexiglass slabs
to compensate thin head

# *Trieste experience: Adverse events*

| Outcomes | N |
|---|---|
| GvHD | 22 (61%) |
| VOD | 1 (2.78%) |
| Interstitial pneumonia<br>*Adenovirus*<br>*Actinomyces*<br>*CMV*<br>***Idiopathic interstitial pneumonia*** | 4 (11.1%)<br>2<br>1<br>1<br>**0** |
| Neurological toxicity | 6 (16.67%) |
| Renal failure | 2 (5.56%) |
| Cataract | 0 |
| Hypothyroidism | 0 |
| Secondary tumours | 0 |

Acute GvHD: 15 (41.6%)

Chronic GvHD: 7 (19.4%)

Lung complications were diagnosed by clinical, radiological and micro-biological examinations: IP was considered idiopathic when no infectious agent was detected

# Dosimeters distribution and measured dose values

| gaf code | pre irradiation reading | post irradiation reading | log (LG no irr/LGirr) | Calculated Dose | district | medium dose / 1200UM | Δ % | medium dose / 1330UM | shielding | Δ % per 1330 UM | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 44.356 | 31308 | 0,151297 | 172,54 | TESTA DX | 178,0 | -1,1 | 197,3 | | | |
| 2 | 44.194 | 30648 | 0,158961 | 183,47 | TESTA SN | | | | | | |
| 3 | 44.101 | 30289 | 0,163164 | 189,58 | COLLO DX | 192,7 | 7,1 | 213,6 | 200,8 | 2,4 | |
| 4 | 44.391 | 30191 | 0,167417 | 195,85 | COLLO SN | | | | | | |
| 5 | 44.103 | 30799 | 0,155932 | 179,12 | ASCELLE DX | 178,1 | -1,1 | 197,4 | | | |
| 6 | 43.938 | 30785 | 0,154501 | 177,08 | ASCELLE SN | | | | | | |
| 7 | 43982 | 30975 | 0,152264 | 173,90 | POLMONE DX | 175,3 | -2,6 | 194,3 | | | |
| 8 | 43286 | 30350 | 0,154189 | 176,63 | POLMONE SIN | | | | | | |
| 9 | 43.955 | 30494 | 0,158794 | 183,23 | ADDOME DX | 187,1 | 4,0 | 207,4 | | | |
| 10 | 43.852 | 30050 | 0,164145 | 191,02 | ADDOME SN | | | | | | |
| 11 | 43.738 | 29699 | 0,168117 | 196,89 | COSCIA DX | 198,7 | 10,4 | 220,3 | | 12,4 | 0 mm pb |
| 12 | 44.004 | 29711 | 0,170575 | 200,56 | COSCIA SN | | | | | | |
| 13 | 44.216 | 29848 | 0,170664 | 200,70 | GINOCCHIO DX | 201,5 | 11,9 | 223,3 | | 13,9 | 0 mm pb |
| 14 | 43.962 | 29605 | 0,171712 | 202,27 | GINOCCHIO SN | | | | | | |
| 15 | 43.973 | 28821 | 0,183477 | 220,31 | CAVIGLIA DX | 221,9 | 23,3 | 246,0 | 217,2 | 10,8 | 1 mm pb |
| 16 | 44.169 | 28814 | 0,185514 | 223,51 | CAVIGLIA SN | | | | | | |
| gaf measured medium dose at reference point: | | | | 176,7 | cGy per 1200UM per parte | | | | | | |
| armpit Dose (i.c.): | | | | 180,0 | cGy per 1200UM per parte | | | | | | |
| Legs Dose (i.c.): | | | | 197,1 | cGy per 1200UM per parte | | | | | | |
| gaf measured medium dose at reference point: | | | | 195,8 | cGy per 1330UM per parte | | | | | | |
| UM / 200 cGy: | | | | 2660 | | | | | | | |
| Doserate (160UM/min): | | | 11,8 | cGy/min | | | | | | | |

CASTELLO DI MIRAMARE. Veduta del porticciolo, riserva marina del WWF. © APT Trieste - ph.: Alessandro Savella.