IAEA Standard syllabus course on Radiation Protection in diagnostic and interventional radiology

# RADIATION PROTECTION IN DIAGNOSTIC RADIOLOGY

Part 7: X-ray beam

IAEA Post Graduate Educational Course Radiation Protection and Safe Use of Radiation Sources

## Introduction

A review is made of:

- The system for x-ray beam production : generator, rating chart, automatic exposure control system
- The mode of operation of X-ray equipment

Part 7 X-ray tube and generator 2

## Contents

- Rating chart
- X-ray generator
- Automatic Exposure Control (AEC)
- X-ray equipment operation and mode

Part 7 : X-ray tube and generator 3

## Overview

- To become familiar with the technological principles of the X-ray production.

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Part 7: X-ray beam

Topic 1 : X-ray generator

## X-ray generator (I)

It supplies the X-ray tube with :

- → Current to heat the cathode filament
- → Potential to accelerate electrons
- → Automatic control of exposure (power application time)
- → Energy supply ≈ 1000 x X-ray beam energy (of which 99.9% is dissipated as thermal energy)

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0,1 % → X Zahl

## X-ray generator (II)

- Generator characteristics have a strong influence on the contrast and sharpness of the radiographic image
- The motion unsharpness can be greatly reduced by a generator allowing an exposure time as short as achievable
- Since the dose at the image plane can be expressed as :

$$D = k_0 . U^n . I . T$$

  - **U** : peak voltage (kV)
  - **I** : mean current (mA)
  - **T** : exposure time (ms)
  - **n** : ranging from about 3 at 150 kV to 5 at 50 kV

## X-ray generator (III)

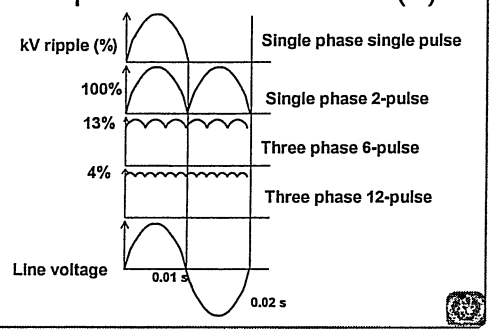
- Peak voltage value has an influence on the beam hardness
- It has to be related to medical question
  - **What is the anatomical structure to investigate ?**
  - **What is the contrast level needed ?**
  - For a thorax examination : 140 - 150 kV is suitable to visualize the lung structure
  - While only 65 kV is necessary to see bone structure
- The ripple "r" of a generator has to be as low as possible

$$r = [(U - U_{min})/U] \times 100\%$$

## Tube potential wave form (I)

- Conventional generators
  - single ϕ 1-pulse (dental and some mobile systems)
  - single ϕ 2-pulse (double rectification)
  - three ϕ 6-pulse
  - three ϕ 12-pulse
- Constant potential generators (CP)
- HF generators (use of DC choppers to convert 50Hz mains into voltages with frequencies in the kHz range) ➔ "Inverter technology"

## Tube potential wave form (II)




## The choice of the number of pulses (I)

- Single pulse : low power (<2 kW)
- 2-pulse : low and medium power
- 6-pulse : uses 3-phase mains, medium and high power (manual or automatic compensation for voltage drop)
- 12-pulse : uses two shifted 3-phase system, high power up to 150 kW

## The choice of the number of pulses (II)

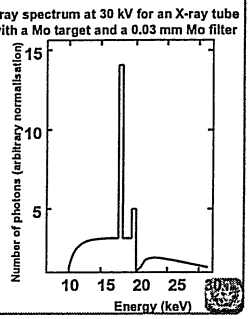
- CP : eliminates any changes of voltage or tube current
  - high voltage regulators can control the voltage AND switch on and off the exposure
  - voltage can be switched on at any moment (temporal resolution)
  - kV ripple <2% thus providing low patient exposure
- HF : combines the advantages of constant potential and conventional generator
  - reproducibility and consistency of tube voltage
  - high frame rate possible

## Radiation emitted by the x-ray tube

- Primary radiation : before interacting photons
- Scattered radiation : after at least one interaction
- Leakage radiation : not absorbed by the x-ray tube housing shielding
- Transmitted radiation : emerging after passage through matter → Antiscatter grid

## Factors influencing the x-ray spectrum

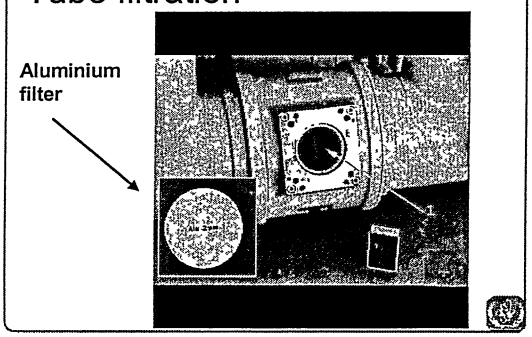
- tube potential
  - kVp value
- wave shape of tube potential
- anode track material
  - W, Mo, Rh etc.
- X-ray beam filtration
  - inherent + additional




## Tube filtration

- Inherent filtration (always present)
  - ⇒ reduced entrance (skin) dose to the patient (cut off the low energy X-rays which do not contribute to the image)
- Additional filtration (removable filter)
  - further reduction of patient skin and superficial tissue dose without loss of image quality
- Total filtration (inherent + added)
- Total filtration must be > 2.5 mm Al for a > 110 kV generator
- Measurement of filtration ⇒ Half-Value Layer

## Tube filtration




## Scattered radiation

- Effect on mage quality
  - increasing of blurring
  - loss of contrast
- Effect on patient dose
  - increasing of superficial and depth dose

Possible reduction through :

⇒ use of grid

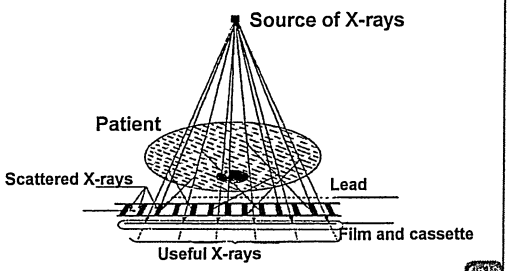
⇒ limitation of the field to the useful portion

⇒ limitation of the irradiated volume (e.g.:breast compression in mammography)

## Anti scatter grid (I)

- Radiation emerging from the patient
  - **primary beam** : contributes to the image
  - **scattered radiation** : does not reach the detector and contributes to the major part of the patient dose
- the grid (between patient and film) eliminates most of scattered radiation
- stationary grid
- moving grid (better performance)
- focused grid
- Potter-Bucky system

## Anti scatter grid (II)

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## Part 7: X-ray beam

Topic 2 : Automatic Exposure Control (AEC)

## Automatic exposure control

- Optimal choice of technical parameters in order to avoid repeated exposures (kV, mA)
- Radiation detector behind (or in front of) the film cassette (with due correction)
- Exposure is terminated when the required dose has been integrated
- Compensation for kVp at a given thickness
- Compensation for thickness at a given kVp

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## Part 7: X-ray beam

Topic 3 : X-ray equipment operation and mode

## X-ray equipment operation mode and application (I)

Mobile Radiography

- Single phase generator (inverter technology)
  - output : up to 2 kW @ 1.4 focus size with stationary anode
  - output : up to 30 kW @ 0.7 focus size with rotating anode

Mammography

- Single or 3-phase generator (inverter technology)
  - output : Mo or Rh anode 5 kW @ 0.3 focus size
  - output : 0.9 kW @ 0.15 focus size (magnification)
  - AEC with transparency compensation

## X-ray equipment operation mode and application (II)

Radiography and Tomography

- Single and 3 ϕ generators (inverter technology)
  - output : 30 kW at 0.3 focus spot size
  - output : 50 - 70 kW at 1.0 focus spot size
  - selection of kV and mAs , AEC

Radiography and Fluoroscopy

- Under couch equipment, 3 ϕ generators (inverter technology) - continuous output of 300 - 500 W
  - output : 50 kW at 1.0 focus size for spot film
  - output : 30 kW at 0.6 for fluoroscopy (high resolution)
  - priority given to contrast
  - automatic settings of kV

## X-Ray equipment operation mode and application (III)

- Radiography and Fluoroscopy
  - Over couch equipment, 3 ϕ generators (inverter technology) - continuous output of at least 500 W
    - output : 40 kW @ 0.6 focus size for spot film
    - output : 70 kW @ 1.0 for fluoroscopy (high resolution)
    - priority given to contrast
    - automatic settings of kV
- Cardiac angiography
  - 3 ϕ generators - continuous output ≥ 1kW
    - output : 30 kW @ 0.4 focus size
    - output : 80 kW @ 0.8 focus size
    - frame rate : up to 120 fr/s



## Summary

- The main parts of the system contributing to the desired X-ray production:
  - provide the required source of power
  - deliver an appropriate x-ray spectrum
  - ensure the optimum adjustment of exposure to warrant the image quality



## Where to Get More Information

- Equipment for diagnostic radiology, E. Forster, MTP Press, 1993
- IPSM Report 32, part 1, X-ray tubes and generators
- The Essential Physics of Medical Imaging, Williams and Wilkins. Baltimore:1994
- Manufacturers data sets for different x-ray tubes

