Radiation Protection training

ANALYTICAL X-RAY EQUIPMENT XRD / XRF

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X-rays

- Discovered in 1895 by Wilhelm Conrad Röntgen
  - screen with barium salt lit up in presence of cathode ray tube
- Caused by accelerated or decelerated electrons
- Generated on purpose by X-ray tubes
- Are a form of electromagnetic radiation (photons)
- Are a form of ionizing radiation
  - potentially harmful in case of misuse
- Being used for:
  - material research (science and technology)
  - inspection, nondestructive testing (industry, customs, …)
  - medical diagnosis

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Principle of X-ray production

- Electrons are accelerated by an electric potential (~10's of kilovolt)
- These fast electrons are being slowed down in a target material
  - produce bremsstrahlung = X-rays ("bremsen" is German for to brake)
- The electric potential determines X-ray energy
  - the higher the electric potential, the higher the X-ray energy
- Only about 1% of electrical energy is converted to X-rays
  - rest is converted to heat, therefore cooling is important

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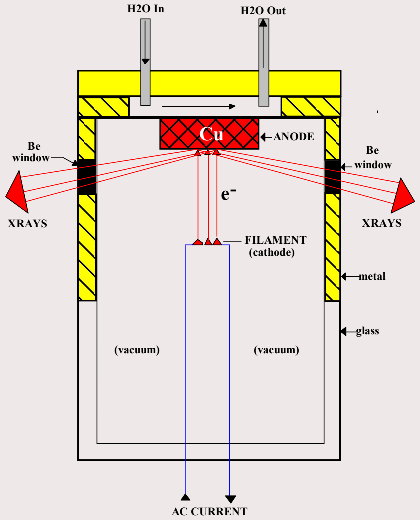
Design of an analytical X-ray tube

- Tube generates X-rays by striking the anode target with an electron beam from a tungsten filament
  - The target must be water-cooled
  - The target and filament must be contained in a vacuum
- Tube housing is lead shielded
- Anode can be fixed or rotating
  - Rotating anode enables much higher X-ray output



Source: MIT

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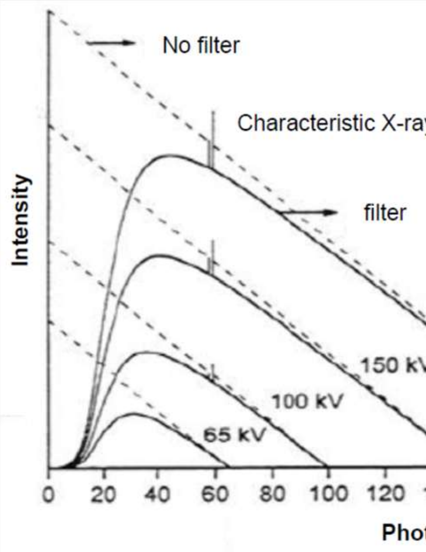
What determines X-ray tube output?

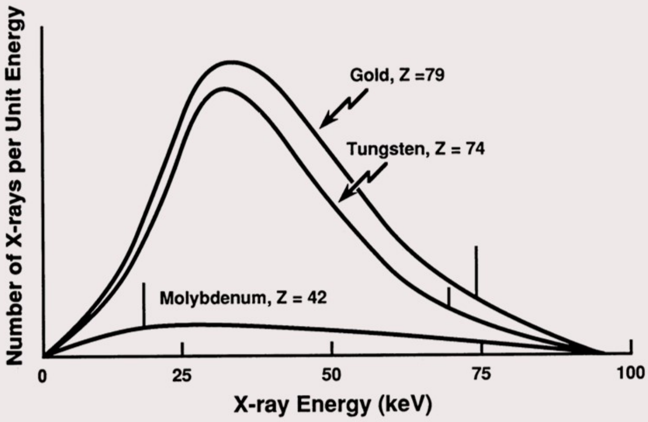
- Tube voltage (kV)
  - determines maximum energy and intensity of output
- Tube current (mA)
  - output proportional to number of electrons
- Beam time on
  - output proportional to time
- Anode material
  - higher atomic number (Z), higher output intensity
- Filtering
  - modification of output by use of filter material

Typical X-ray spectra



practical X-ray spectra
continuous bremsstrahlung
characteristic X-rays
filtering

Influence of anode material



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Main analytical use of X-rays

- X-ray diffraction (XRD)
  - X-ray scattering from crystalline materials
  - “fingerprint” of crystalline atomic structure
  - identification of known material
  - characterization of unknown material
  - used in chemistry and biology

- X-ray fluorescence (XRF)
  - material exposed to X-rays emits characteristic fluorescent X-rays
  - secondary X-rays characteristic for element
  - X-rays can be measured in two ways:
    - wavelength dispersive mode (diffraction of waves, WDX)
    - energy dispersive mode (energy absorption in detector, EDX)

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Ionizing radiation

- X-rays are a form of ionizing radiation
  - ionizing means ability to release electron from atom
  - molecular structure damaged
- Other forms of ionizing radiation are
  - gamma radiation (from atomic nucleus)
  - alpha and beta radiation, neutrons (also from atomic nucleus)
- Ionizing radiation can be harmful
  - tissue damage in case of very high intensity exposure
  - possibly enhanced cancer probability in case of low intensity exposure
- Principles of radiation protection
  - high intensity exposure must be **prevented** at all cost
  - **reduce** low intensity exposure as much as is reasonable (ALARA)
  - maintain individual exposure **limit**

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Sources of radiation

- Primary beam (coming from X-ray tube, shutter open)
  - very intense X-ray beam, very small size
  - harmful to human tissue
  - contact with primary beam absolutely forbidden
- Diffracted rays
  - small size beams, possibly intense
  - all directions possible with respect to primary beam
- Leakage or scatter of primary beam outside detector area
  - intense X-ray fields
  - may be caused by defective equipment
- Leakage of primary beam through shutter or tube housing
  - usually low intensity fields

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Common causes of X-ray exposure

1. Changing samples with beam on / shutter open
2. Visually aligning X-ray beam (open machines*)
3. Modification of shielding
4. Misplacement of shielding after machine service
5. Failure to realize X-rays are emitted from several ports
6. Failure to read & follow manufacturers X-ray operating instructions

1-2: may only be done by application specialist, with permission
discouraged by modern machine design (interlocks)
3-4: mandatory radiation safety check after every modification
5-6: mandatory safety training and machine specific training

*An open machine is a free-exit X-ray machine without permanent enclosure of the primary beam.

Safety measures

- Interlock safety on doors (closed systems)
  - prevents exposure by primary beam and diffracted beams
  - machine shuts down or spring-loaded fail-safe shutter closes when safety is broken
- Metal housing surrounding beam lines (open systems)
  - prevents direct exposure to x-ray beam
- Shielding of machine enclosure
  - usually 0.1-1 mm lead
  - necessary shielding depends on voltage and current
- If necessary: availability of radiation measuring equipment
- Organizational measures
  - periodic radiation safety checks
  - mandatory training of users
  - only permission 'special jobs' for application specialist
  - warning signs on machines

Radiation dosimetry

- Human tissue absorbs radiation energy
  - absorbed dose expressed in energy per unit mass
  - unit is joule per kilogram, or gray (Gy)
- Possible health hazard depends on
  - absorbed dose
  - radiation type
  - exposed organs

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Human dosimetry

- In case of high intensity exposure of people we use (local) absorbed dose
  - short-term effects, dependent on exposed organ/tissue and dose level
  - unit is gray (Gy)
- In case of low intensity exposure of people we prefer the concept of effective dose
  - considers radiation type and exposed organs
  - only applicable for low exposure intensities, possible long-term effects
  - unit is sievert (Sv) or rather millisievert = 1/1000 sievert
- Whole body exposure to X-rays of 1 milligray => 1 millisievert

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Meaning of effective dose

What does 1 mSv effective dose correspond to?

- 1 year of external exposure to natural radiation sources
- 1 year of internal exposure due to natural radiation sources
- 50 transatlantic flights
- 10 radiographs of the chest
- at least 50 dental radiographs

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Dosimetry of X-ray machines

Typical dose rates inside and outside X-ray machines:

- Primary beam: Very local: 10 Gy/min up to 10 Gy/s !!
- Diffracted rays: Very local: up to 1 Gy/min
- Scattered radiation: up to 1 mGy/min
- Leakage from X-ray tube: up to 1 µGy/min
- Outside machine housing
  - TU/e constrained value < 1 µGy/h @ 10 cm distance
  - usually < 0.1 µGy/h

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Biological effects of ionizing radiation (1/1)

Tissue effects (formerly referred to as deterministic effects)

short-term effects (hours to weeks) after high intensity exposure

- directly relatable to ionizing radiation exposure
- minimum exposure needed for effects (threshold dose)
- severity increases with exposure level
- should be prevented at all cost
- very rare in the world, never seen at TU/e

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Biological effects of ionizing radiation (1/2)

Stochastic effects

possible long-term effects (many years) after low intensity exposure

- cannot be directly related to ionizing radiation exposure due to natural occurrence of effect
- current assumption: no minimum exposure needed for effects (cancer)
- probability of effect is related to magnitude of exposure
- probability (so also dose) should be reduced to reasonable levels

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Summary

Tissue effects

- Short-term (> weeks)
- High doses (> 1 Gy)
- Severity of effect
- Threshold
- Prevention at all cost

Stochastic effects

- Long-term (> years)
- Low doses (> 0 mSv)
- Probability of effect
- No threshold
- Reduction of doses/probability to reasonable levels

Effects of very high radiation exposure

- High radiation dose only possible in case of very bad practice
- Only hand/fingers could be exposed to high dose levels
- A few seconds in primary beam could lead to very high exposure!
  - effect varies from skin redness to (in extreme cases) amputation
  - effects of radiation exposure appear only after days or weeks
- Exposure to scattered radiation or leakage radiation can not lead to such serious effects

Skin effect	Absorbed dose (Gy)
Perceptible reddening of skin (Erythema)	3
Dry desquamation of skin	10
Wet desquamation and blistering	15
Ulceration and necrosis of skin or flesh	30

Principles of radiation protection

- Justification of radiological practice: useful and necessary
- ALARA (As Low As Reasonably Achievable)
- Dose limits: (legal) limit of acceptability
  - **Radiological exposed workers**
    Effective dose **20 mSv** per year

    Equivalent dose: eye lens 20 mSv per year
    skin / hand / foot 500 mSv per year
  - **Members of the public**
    Effective dose **1 mSv** per year
  - **No dose limits for patient (why?)**

Dose limits for workers at TU/e

Workers (radiological classified and non-classified workers)

- Exposed workers
  - cat. A 20 mSv
  - cat. B* 6 mSv
- Unexposed workers**
  - Other radiological workers (cat. C) 1 mSv
  - Other unclassified workers 1 mSv
  - Unborn child, during pregnancy*** 1 mSv

* Formally this is not a dose limit but a dose constraint. In case a person may exceed this exposure level he/she should be in category A.
** Unexposed workers include those working with X-ray diffraction, X-ray fluorescence and microCT machines.
*** Pregnancy must be reported as soon as possible, directly to SBD, or through local supervisor or physician. Confidentiality is guaranteed.

TU/e regulations at workplace (1/2)

- General rules for radiological areas
  - access restricted to classified personnel
  - warning signs outside area
  - mandatory personal dosimetry, and sometimes special clothing
- Area with analytical X-ray machines
  - not classified as a radiological area
  - no access restrictions
  - no ambient or personal dosimetry needed
  - dose rate outside machine < 1 µSv/h @ 10cm
  - additional (temporary) measures in case of use of open machines

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TU/e regulations at workplace (2/2)

- Machine specific radiation protection
  - warning signs on X-ray machine
  - operation of machines only with proper instruction and authorization
  - special jobs only by specialists and with permission
  - interlock override key must be kept in a safe place by local Radiation Protection Officer (TMS)
  - regular safety inspection (at least once a year) by Radiation Protection Unit (SBD)

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Warning sign X-ray machines

- Presence of X-ray machine
  - warning sign on machine or machine enclosure
- Warning sign on machine that shows beam on
  - e.g. yellow or red lamp

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Summary

- Working with modern (closed) X-ray machines is very safe, provided
  - operation and safety instructions are followed
  - special jobs, like visual alignment, are reserved to specialists
  - machines are regularly checked by Radiation Protection Unit
- In normal circumstances radiation exposure is extremely low
  - well below natural radiation background levels
- In case of severe breach of safety rules
  - exposure can be high (especially to hands/fingers)
  - health damage can be the result

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Finally …

- In case of any questions regarding safe operation of X-ray machines
  - consult your local Radiation Protection Officer (RPO = TMS or Toezichthoudend Medewerker Stralingsbescherming)
  - or, consult Radiation Protection Unit (RPU = SBE, Stralingsbeschermingseenheid SBD), T: 3355
  - refer to our intranet site Occupational Health, Safety, Environment & Radiation Protection or SBD internet site www.tue.nl/sbd

- To take the test make an appointment with our Radiation Protection Unit (SBD)