FU NDAMENTALS OF X-RAY PRODUCTION ● The production of X Rays involves the bombardment of a thick target with energetic electrons. ● Electrons undergo a complex sequence of collisions and scattering processes during the slowing down process which results in the production of ● Bremsstrahlung (continues radiation) and ● Characteristic radiation IA EA ● Energetic Electrons are mostly slowed down in matter by: ● Collisions and ● Excitation interactions ● If an electron comes close to an atomic Nucleus the attractive Coulomb forces causes a change of the electron's trajectory ● An accelerated electron or an electron changing its direction emits electromagnetic radiation and given the name Bremsstrahlung ● The energy of the emitted photon is subtracted from the kinetic energy of the electron ● The Energy of the Bremsstrahlung photon depends on the ● Attractive Coulomb forces and hence on the ● Distance of the electron from the nucleus ● The total x-ray energy emitted per second depends on the atomic number Z of the target material and on the x-ray tube current. This total x-ray intensity is given by: I cont = AiZV2 A – constant i – tube current (measure of the number of electrons per second striking the target) Z- atomic number IA EA Diagnostic Radiology Physics: a Handbook for Teachers and Students – V- voltage chapter 5, 4 FUNDAMENTALS OF X-RAY PRODUCTION ● For each element binding energies and the Monoenergetic radiation resulting from such interactions, are unique and Characteristic for that element. ● The electrons are slowed down and stopped in the Target (within a range of a few tens of μm). ● X rays are not generated at the surface but within the target resulting in attenuation of the X ray beam ● Characteristic radiation shows up if the kinetic energy of the electron exceeds the binding energies Energies of characteristic X rays, keV K-shell Ka1 Ka2 Kb1 Kb2 Element W Mo Rh IA EA to an electron which is ejected radiation from the shell (Auger Electron) production probability decreases with Z FUNDAM ENTALS OF X-RAY PRODUCTION ● L-Radiation is totally absorbed by a typical filtration of 2.5 mm Al ● The K-Edge in the photon attenuation of tungsten can be noticed as a drop of the continuum at the binding energy of 69.5 keV ● Efficiency for the conversion of electrical power to Bremsstrahlung radiation is proportional to U·Z IA EA ● At 100 kV the efficiency is as low as ~0.8% ● This is the cause for most of the technical problems in the design of XRTs as practically all electrical power applied in the acceleration of electrons is converted to Heat Components of the X Ray Tube ● The production of both Bremsstrahlung and Characteristic Radiation requires energetic electrons hitting a target ● Principle components of an X ray tube are an Electron Source from a heated tungsten filament with a focusing cup serving as the tube Cathode, an Anode or Target and a Tube Envelope to maintain an interior vacuum ● The Filament is heated by a current that controls the thermionic emission of electrons, which in turn determines the number of electrons flowing from cathode to anode (Tube or Anode Current) e.g. 1000 mA in single exposures ● The accelerating Potential Difference applied between cathode and anode controls both X ray energy and yield e.g. 40 to 150 kV for general diagnostic radiology and 25 to 40 kV in mammography ● Thus two main circuits operate within the XRT: ● Filament circuit ● Tube voltage circuit IA EA Diagnostic Radiology Physics: a Handbook for Teachers and Students – chapter 5, 7 X-RAY TUBES Cathode ● The Spiral-Wound filament is typically made from tungsten wire of 0.2 to 0.3 mm diameter and operates at around 2700oK=2426oC. ● To minimise the Evaporation of tungsten from the hot surface, the filament temperature is kept at a lower level except during exposure when it is raised to operational levels. ●

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Thermionic Emission of electrons increases with temperature (Richardson's law) and produces a cloud of electrons (Space Charge) enclosing the filament. Anode ● For such anodes X ray spectra show less contribution by Bremsstrahlung but rather dominant Characteristic X rays of the anode materials ● Allows a more satisfactory optimization of image quality and patient dose ● In Digital Mammography these advantages are less significant, and some manufacturers prefer tungsten anodes IA EA ● For common radiographic applications, a high Bremsstrahlung yield is mandatory requiring materials with high atomic numbers (Z) ● Due to the low efficiency of X ray production, it is essential that the thermal properties such as Maximum Useful Temperature determined by melting point and vapor pressure, heat conduction, specific heat and density are also considered ● Tungsten (Z=74) is the optimum choice ● For Mammography other anode materials such as molybdenum (Z=42) and rhodium (Z=45) are frequently used Line-focus principle (anode angle) ● For measurement purposes, the focal spot size is defined along the central beam projection ● For the sake of high anode currents the area of the anode hit by the electrons should be as large as possible to keep power density within acceptable limits ● The size of the focal spot of an XRT is given for the central beam in the X ray field running perpendicular to the electron beam or the tube axis ● The actual focal spot size depends on the position within the field of view increasing from the anode side of the tube to the cathode IA EA Diagnostic Radiology Physics: a Handbook for Teachers and Students – chapter 5, 9 Line-Focus Principle (Anode Angle) ● In addition to X rays produced in the primary focus, some Off- Focus Radiation results from electrons scattered from the anode which are then accelerated back and hit the anode outside of the focal area ● Extra Focal Radiation can contribute up to ~10% of the primary X ray intensity ● Since the effective focal spot size for off-focus radiation is substantially Larger than for the primary focus it has an impact on image quality such as background fog and blurring IA EA Diagnostic Radiology Physics: a Handbook for Teachers and Students – chapter 5, 10 Stationary & Rotating Anodes ● For X ray examinations that require only a low anode current or infrequent low power exposures (e.g. dental units, portable X ray units and portable fluoroscopy systems) an X ray tube with a Stationary Anode is applicable ● A small tungsten block serving as the target is Brazed to a copper block to dissipate the heat efficiently to the surrounding cooling medium ● As the focal spot is Stationary the maximum loading is determined by anode temperature and temperature gradients Stationary & Rotating Anodes ● Most X ray examinations need photon fluences which Cannot be obtained with stationary anodes as bombarding the same spot with higher anode currents leads to Melting and Destruction of the anode ● In a tube with a Rotating Anode a tungsten disk rotates during an exposure thus effectively increasing the area bombarded by the electrons to the circumference of a Focal Track ● The energy is dissipated to a much larger volume as it is Spread Over the anode disk ● The Rotational Speed of the anode is determined by the frequency of the power supply and the number of active windings in the stator ● Speed can be varied between high (9000-10000 rpm) and low speed (3000-3600 rpm) ● Rotor Bearings are critical components of a rotating anode tube and along with the whole assembly, cycling over a large temperature range results in high thermal stresses IA EA Thermal Properties ● The Limiting Factor in the use of X ray tubes is given mainly by the thermal loading capacity of the anode ● The Nominal Power is determined for an exposure time of 0.1 s ● Within the First 0.1 s, the maximum load is determined by mechanical stress in the anode material developing from temperature gradients near the surface of the focal spot (A) ● As a consequence cracks can develop leading to an increase in anode surface roughness ● Maximum Permissible Tube Load vs. time for a single exposure, constant current, 100 kV tube ● This effect can be reduced by: voltage and a 50 kW tube ● Use of a more ductile alloy as the focal track (e.g. Tungsten/Rhenium alloys) or ● An increase in the size of the focal spot or the rotational speed of the anode IA EA Diagnostic Radiology Physics: a Handbook for Teachers and Students – chapter 5, 12 Thermal Properties ● In CT and fluoroscopic procedures Longer exposure times are needed (10 s to >200 s) ● Here the dissipation of heat across the Entire anode disk becomes important ● The important physical properties are then the Heat Conduction and Heat Capacity of the anode disk. ● The Heat Capacity is the energy stored in the anode disk with the anode at its maximum permissible temperature ● It depends on the Specific Heat and Mass of the anode materials ● Molybdenum is superior to Tungsten in this respect ● Increasing the mass of the anode (diameter, thickness) has its limitations as balancing the rotating anode becomes difficult for the wide range of temperatures occurring ● Since Graphite has a higher specific heat at higher temperatures than molybdenum or tungsten the heat capacity can be increased by attaching graphite heat sinks to the back of the anode disk Graphite enhances the dissipation of heat by Black-Body Thermal Radiation IA EA Diagnostic Radiology Physics: a Handbook for Teachers and Students – chapter 5, 13 Tube Envelope ● The tube envelope maintains the required Vacuum in the XRT ● A Failing vacuum due to leakage or degassing of the materials causes increased ionization of the gas molecules which slows down the electrons ● Further, a current of Positive Ions flowing back could impair or destroy the cathode filament ● The envelope is commonly made of glass but high performance tubes increasingly have Glass/Metal or Ceramic/Metal envelopes ● The X ray beam exits the tube through a Window in the envelope Typical housing assembly for a general purpose XRT ● To reduce absorption the Thickness of the glass is reduced in this area ● If low-energy X rays are used as in mammography, the exit port is a Beryllium window which has less absorption than glass due to its low atomic number IA EA Diagnostic Radiology Physics: a Handbook for Teachers and Students – chapter 5, 14 The X Ray Generator The essential components are: ● a Filament Heating circuit to determine anode current ● a High Voltage supply ● a Motor Drive circuit for the stator windings required for a rotating anode tube ● an Exposure Control providing the image receptor dose required an Operational Control IA EA Diagnostic Radiology Physics: a Handbook for Teachers and Students – Sc hematic diagram of a basic X ray generator chapter 5, 15 ● Provides all electrical power sources and signals required for the operation of the X ray tube ● Controls the operational conditions of X ray production CO LLIMATION & FILTRATION Collimator & Light Field The limitation of the X ray field to the size required for an examination is accomplished with Collimators The benefits of collimating the beam are Twofold: § Reduction of patient dose § Improvement of image contrast due to reduced scattered radiation IA EA Diagnostic Radiology Physics: a Handbook for Teachers and Students – chapter 5, 16 Collimator & Light Field ● A Collimator Assembly is typically attached to the tube port defining the field size with adjustable parallel-opposed lead Diaphragms or blades ● Visualization of the X ray field is achieved by a mirror reflecting the light from a bulb ● The light field then mimics the actual X ray field IA EA