ELECTRON TUBE ENERGY AND ELECTRON EMISSION SPECTRUM

Dr. Mahmoud S Dahoud

Fundamental of Radio Physics

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Outline

* Electron tube energy

* Factors affecting x-ray emission spectrum

  - mA and mAs

  - kVp

  - Voltage Waveforms

  - Target Material

  - Added Filtration

Objectives

The student should be able to do the followings;

* Describe the electron tube energy

* Mention the factors affecting electron emission spectrum

* Explain how mAs, kVp, added filtration, target material, and voltage Waveforms

Electron Emission Spectrum

- It refers to the kinetic, potential, and electromagnetic energy associated with the movement of electrons within a tube. Electrons carry both kinetic energy and potential energy.
- Thermionic emission: To initiate electron flow from cathode.
- Acceleration: due to electric fields between cathode and anode.
- Electron tube energy can be converted to x- rays, in x-ray tubes, electrons are accelerated to high kinetic energy by high voltage and then slam into a metal target, converting their energy into x-ray photons.
- Electron emission from surfaces is a phenomenon where certain solid materials release electrons when exposed to various stimuli, including heat (thermionic emission), light (photoemission), or strong electric fields (field emission). This process is critical in the operation of numerous electronic devices, such as vacuum tubes, cathode-ray tubes, and electron microscopes, which rely on the manipulation of emitted electrons to perform specific functions. .At the atomic level, electrons within a metal can be thought of as an "electron gas," where they move freely but face a potential barrier at the surface that must be overcome for emission to occur

X-ray Emission Spectrum

Thermionic emission occurs when a metal is heated, allowing electrons to gain enough energy to escape the surface. In contrast, photoemission takes place when photons provide sufficient energy to electrons, enabling them to overcome the potential barrier. Field emission is characterized by a strong electric field that deforms the barrier, allowing electrons to "tunnel" through without needing to gain sufficient energy traditionally
Characteristic X-ray Spectrum: The discrete energies of characteristic x-rays are characteristic of the differences between electron binding energies in a particular element. A characteristic x-ray. from tungsten, for example, can have 1 of 15 different energies (see Table 7-1) and no others. A plot of the frequency with which characteristic x-rays are emitted as a function of their energy would look similar to that shown for tungsten in Figure 7-9.
Such a plot is called the *characteristic x-ray emission spectrum*. Five vertical lines representing K x-rays and four vertical lines representing L x-rays are included. The lower energy lines represent characteristic emissions from the outer electron shells.

TABLE 7-1 Characteristic X-rays of Tungsten and Their Effective Energies (keV)

	ELECTRON TRANSITION FROM SHELL					
Characteristic	L Shell	M Shell	N Shell	O Shell	P Shell	Effective Energy of X-ray
K	57.4	66.7	68.9	69.4	69.5	69
L		9.3	11.5	12.0	12.1	12
M			2.2	2.7	2.8	3
N				0.52	0.6	0.6
O					0.08	0.1

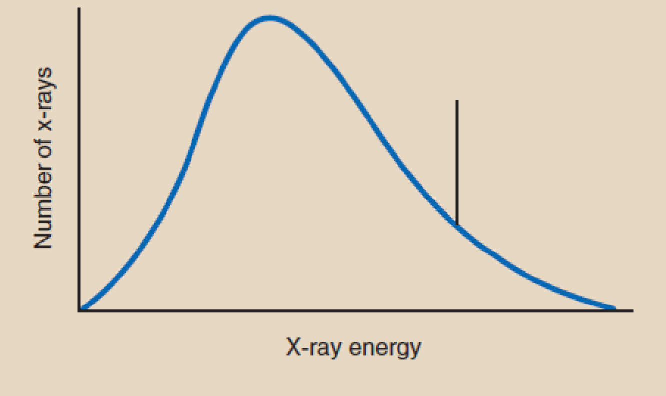

FIGURE 7-8 General form of an x-ray emission spectrum.

X-ray Emission Spectrum

Characteristic x-rays have precisely fixed (discrete) energies and form a discrete emission spectrum. The relative intensity of the K x-rays is greater than that of the lower energy characteristic x-rays because of the nature of the interaction process. K x-rays are the only characteristic x-rays of tungsten with sufficient energy to be of value in diagnostic radiology. Although there are five K x-rays, it is customary to represent them as one, as has been done in Figure 7-10 with a single vertical line, at 69 keV. Only this line will be shown in later graphs.

Bremsstrahlung X-ray Spectrum If it were possible to measure the energy contained in each bremsstrahlung x-ray emitted from an x-ray tube, one would find that these energies range from the peak electron energy all the way down to zero. In other words, when an x-ray tube is operated at 90 kVp, bremsstrahlung x-rays with energies up to 90 keV are emitted. A typical bremsstrahlung x-ray emission spectrum is shown in Figure 7-10.

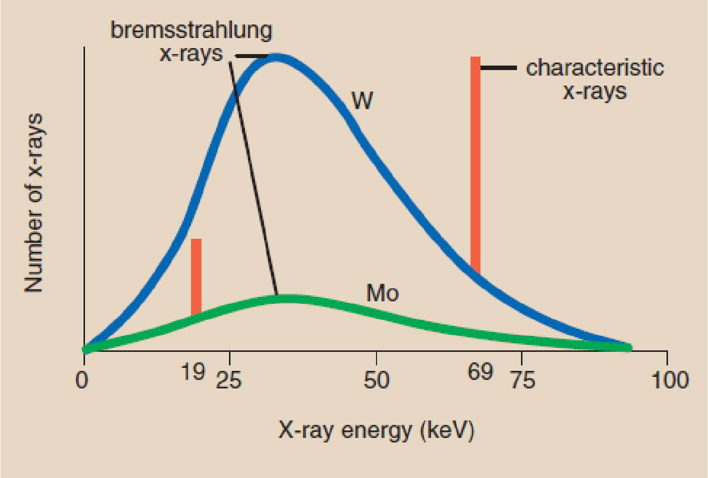

FIGURE 7-10 The bremsstrahlung x-ray emission spectrum extends from zero to maximum projectile electron energy, with the highest number of x-rays having approximately one third the maximum energy. The characteristic x-ray emission spectrum is represented by a line at 69 keV.

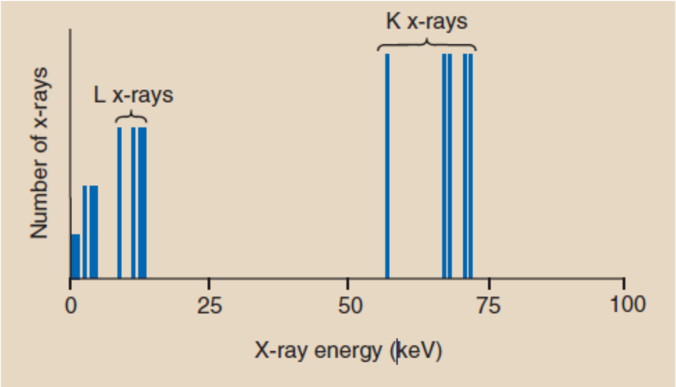

FIGURE 7-9 Characteristic x-ray emission spectrum for tungsten contains 15 different x-ray energies.

Factors Affecting X-Ray Emission Spectrum

The total number of x-rays emitted from an x-ray tube could be determined by adding together the number of x-rays emitted at each energy over the entire spectrum, a process called **integration.**
Graphically, the total number of x-rays emitted is equivalent to the area under the curve of the x-ray emission spectrum.
The general shape of an emission spectrum is always the same, but its relative position along the energy axis can change.
* The farther to the right a spectrum is, the higher the effective energy or **quality** of the x-ray beam.
* The larger the area under the curve, the higher is the x-ray intensity or **quantity**.

The Effect Of Ma And Mas On Electron Emission Spectrum

If one changes the current from 200 to 400 mA while all other conditions remain constant, twice as many electrons will flow from the cathode to the anode, and the mAs will be doubled. This operating change will produce twice as many x-rays at every energy. In other words the x-ray emission spectrum will be changed in amplitude but not in shape (Figure 7-11). A change in mA or mAs results in a proportional change in the amplitude of the x-ray emission spectrum at all energies.

Each point on the curve labeled 400 mA or 400 mAs is precisely two times higher than the associated point on the 200 mA or 200 mAs curve. Thus the area under the x-ray emission spectrum varies in proportion to changes in mA or mAs, as does the x-ray quantity.

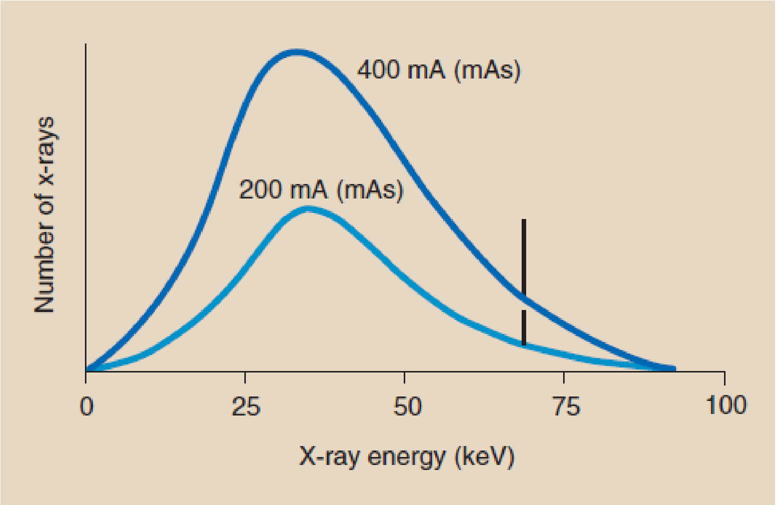

FIGURE 7-11 Change in mA or mAs results in a proportionate change in the amplitude of the x-ray emission spectrum at all energies.

Four Principal Factors Influencing The Shape Of An X-Ray Emission Spectrum

1. The projectile electrons accelerated from cathode to anode do not all have peak kinetic energy. Depending on the types of rectification and high-voltage generation, many of these electrons may have very low energies when they strike the target. Such electrons can produce only heat and low-energy x-rays.

2. The target of a diagnostic x-ray tube is relatively thick. Consequently, many of the bremsstrahlung x-rays emitted result from multiple interactions of the projectile electrons, and for each successive interaction, a projectile electron has less energy.

3. Low-energy x-rays are more likely to be absorbed in the target.

4. External filtration is always added to the x-ray tube assembly. This added filtration serves selectively to remove low-energy x-rays from the beam.

Kvp Affect Electron Emission Spectrum

As the kVp is raised, the area under the curve increases to an area approximating the square of the factor by which kVp was increased. Accordingly, the x-ray quantity increases with the square of this factor. When kVp is increased, the relative distribution of emitted x-ray energy shifts to the right to a higher average x-ray energy. The maximum energy of x-ray emission always remains numerically equal to the kVp. A change in kVp affects both the amplitude and the position of the x-ray emission spectrum..

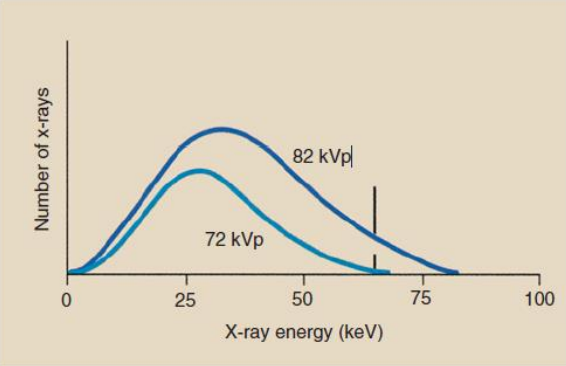

FIGURE 7-12 Change in kVp results in an increase in the amplitude of the emission spectrum at all energies but a greater increase at high energies than at low energies. Therefore the spectrum is shifted to the right, or high-energy, side.

Figure 7-12 demonstrates the effect of increasing the kVp while other factors remain constant. The lower spectrum represents x-ray operation at 72 kVp, and the upper spectrum represents operation at 82 kVp (10-kVp (or 15%) increase). The area under the curve has approximately doubled, while the relative position of the curve has shifted to the right, the high-energy side. More x-rays are emitted at all energies during operation at 82 kVp than during operation at 72 kVp. The increase, however, is relatively greater for high-energy x-rays than for low-energy x-rays.

Voltage Waveforms Affect Electron Emission Spectrum

There are five voltage waveforms: half-wave–rectified, full-wave–rectified, three-phase/six-pulse, three-phase/12-pulse, and high-frequency waveforms. Half-wave–rectified and full-wave–rectified voltage waveforms are the same except for the frequency of x-ray pulse repetition. There are twice as many x-ray pulses per cycle with full-wave rectification as with halfwave rectification. The difference between three-phase/six-pulse and three-phase/12-pulse power is simply the reduced ripple obtained with 12-pulse generation compared with sixpulse generation. High-frequency generators are based on fundamentally different electrical engineering principles. They produce the lowest voltage ripple of all high-voltage generators.

Voltage Waveforms Affect Electron Emission Spectrum

Figure 7-15 shows an exploded view of a full-wave–rectified voltage waveform for an x-ray imaging system operated at 100 kVp. Recall that the amplitude of the waveform corresponds to the applied voltage and that the horizontal axis represents time.

At t = 0, the voltage across the x-ray tube is zero, indicating that at this instant, no electrons are flowing and no x-rays are being produced. At t = 1 ms, the voltage across the x-ray tube has increased from 0 to approximately 60,000 V. The x-rays produced at this instant are of relatively low intensity and energy; none exceeds 60 keV.

At t = 2 ms, the tube voltage has increased to approximately 80,000 V and is rapidly approaching its peak value.

At t = 4 ms, the maximum tube voltage is obtained, and the maximum energy and intensity of x-ray emission are produced. For the following one quarter cycle between 4 and 8 ms, the x-ray quantity and quality decrease again to zero.

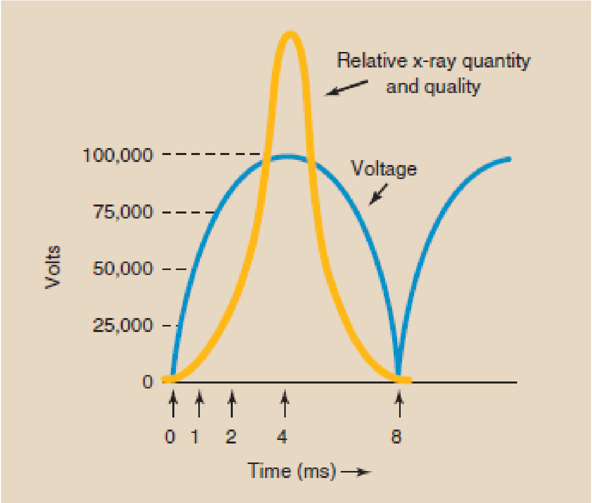

FIGURE 7-15 As the voltage across the x-ray tube increases from zero to its peak value, x-ray intensity and energy increase slowly at first and then rapidly as peak voltage is obtained.

Voltage Waveforms Affect Electron Emission Spectrum

The number of x-rays emitted at each instant through a cycle is not proportional to the voltage. The number is low at lower voltages and increases at higher voltages. The quantity of x-rays is much greater at peak voltages than at lower voltages. Consequently, voltage waveforms of three-phase or high-frequency operation result in considerably more intense x-ray emission than those of single-phase operation. The relationship between x-ray quantity and type of high-voltage generator provides the basis for another rule of thumb used by radiologic technologists. If a radiographic technique calls for 72 kVp on single-phase equipment, then on three-phase equipment, approximately 64 kVp—a 12% reduction—will produce similar results. High-frequency generators produce approximately the equivalent of a 16% increase in kVp, or slightly more than a doubling of mAs over single-phase power.

Because of reduced ripple, operation with three-phase power or high frequency is equivalent to an approximate 12% increase in kVp, or almost a doubling of mAs over single-phase power.

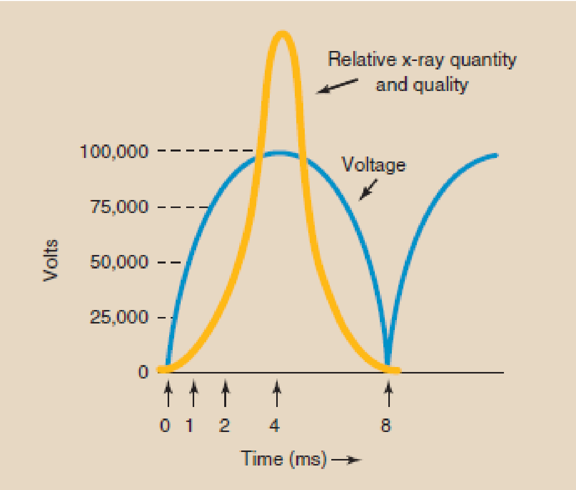

FIGURE 7-15 As the voltage across the x-ray tube increases from zero to its peak value, x-ray intensity and energy increase slowly at first and then rapidly as peak voltage is obtained.

Voltage Waveforms Affect Electron Emission Spectrum

This discussion is summarized in Figure 7-16, where an x-ray emission spectrum from a full-wave–rectified unit is compared with that from a three-phase, 12-pulse generator and a high-frequency generator, all operated at 92 kVp and at the same mAs. The x-ray emission spectrum that results from high-frequency operation is more efficient than that produced with a single-phase or a three-phase generator. The area under the curve is considerably greater, and the x-ray emission spectrum is shifted to the high-energy side.

The characteristic x-ray emission spectrum remains fixed in its position on the energy axis but increases slightly in magnitude as a result of the increased number of projectile electrons available for K-shell electron interactions.

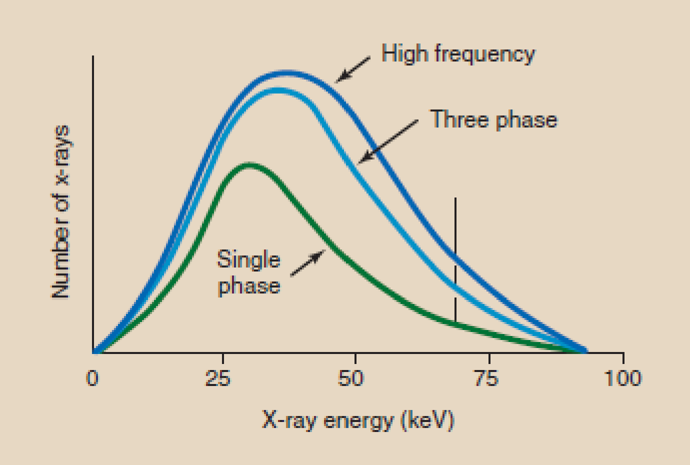

FIGURE 7-16 Three-phase and high-frequency operations are considerably more efficient than single-phase operation. Both the x-ray intensity (area under the curve) and the effective energy (relative shift to the right) are increased. Shown are representative spectra for 92-kVp operation at constant mAs.

Question: What would be the difference in the x-ray emission spectra between a full-wave– rectified operation and a half-wave–rectified operation if the kVp and the mAs are held constant? Answer p133

Target Material Affects Electron Emission Spectrum

The atomic number of the target affects both the number (quantity) and the effective energy (quality) of x-rays. As the atomic number of the target material increases, the efficiency of the production of bremsstrahlung radiation increases, and high-energy x-rays increase in number to a greater extent than low-energy x-rays. The change in the bremsstrahlung x-ray spectrum is not nearly as pronounced as the change in the characteristic spectrum. After an increase in the atomic number of the target material, the characteristic spectrum is shifted to the right, representing the higher energy characteristic radiation. This phenomenon is a direct result of the higher electron binding energies associated with increasing atomic number.

Increasing target atomic number enhances the efficiency of x-ray production and the energy of characteristic and bremsstrahlung x-rays.

Target Material Affects Electron Emission Spectrum

These changes are shown schematically in Figure 7-14. Tungsten is the primary component of x-ray tube targets, but some specialty x-ray tubes use gold as target material. The atomic numbers for tungsten and gold are 74 and 79, respectively. Molybdenum (Z = 42) and rhodium (Z = 45) are target elements used for mammography. In many dedicated mammography imaging systems, these elements are incorporated separately into the target. The x-ray quantity from such mammography target material is low owing to the inefficiency of x-ray production. This occurs because of the low atomic number of these target elements. Elements of low atomic number also produce low-energy characteristic x-rays.

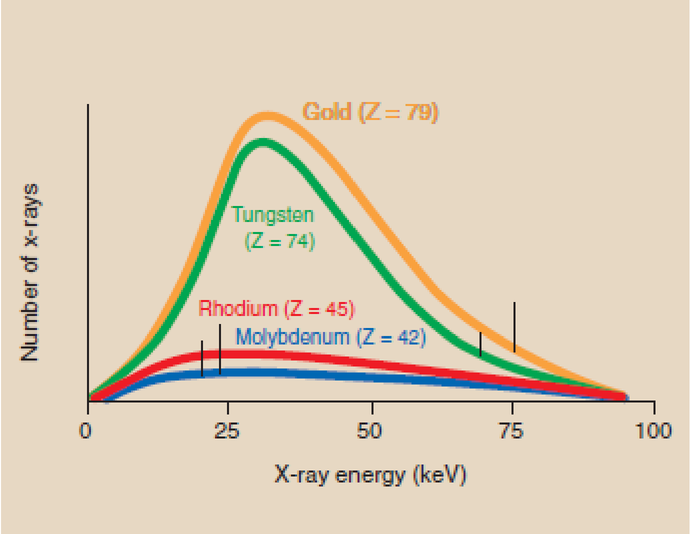

FIGURE 7-14 Discrete emission spectrum shifts to the right with an increase in the atomic number of the target material. The continuous spectrum increases slightly in amplitude, particularly to the high-energy side, with an increase in target atomic number.

Added Filtration Affects Electron Emission Spectrum

Adding filtration to the useful x-ray beam reduces x-ray beam intensity while increasing the average energy. This effect is shown in Figure 7-13, where an x-ray tube is operated at 95 kVp with 2-mm aluminum (Al) added filtration compared with the same operation with 4-mm Al added filtration. Added filtration more effectively absorbs low-energy x-rays than high-energy x-rays; therefore, the bremsstrahlung x-ray emission spectrum is reduced further on the left than on the right.

Adding filtration is sometimes called **hardening** the x-ray beam because of the relative increase in average energy. The characteristic spectrum is not affected, nor is the maximum energy of x-ray emission. There is no simple method for calculating the precise changes that occur in x-ray quality and quantity with a change in added filtration.

The result of added filtration is an increase in the average energy of the x-ray beam with an accompanying reduction in x-ray quantity.

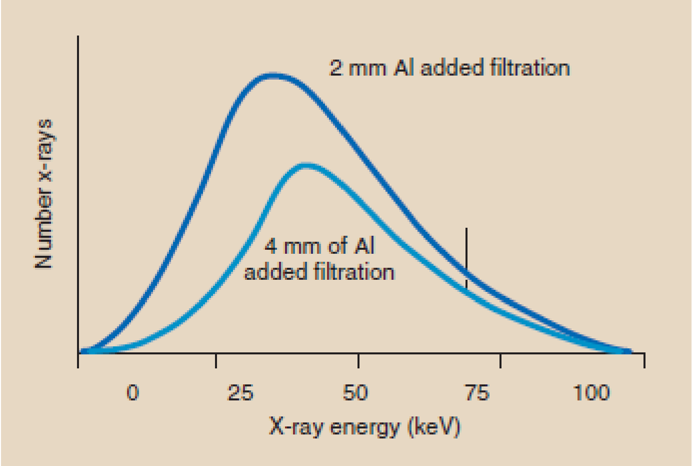

FIGURE 7-13 Adding filtration to an x-ray tube results in reduced x-ray intensity but increased effective energy. The emission spectra represented here resulted from operation at the same mA and kVp but with different filtration.

SUMMARY

- When electrons are accelerated from the cathode to the target of the anode, three effects take place: the production of heat, the formation of characteristic x-rays, and the formation of bremsstrahlung x-rays.
- Characteristic x-rays are produced when an electron ionizes an inner-shell electron of a target atom. As the inner-shell void is filled, a characteristic x-ray is emitted.
- Bremsstrahlung x-rays are produced by the slowing down of an electron by the target atom's nuclear field. Most x-rays in the diagnostic range (20–150 kVp) are bremsstrahlung x-rays.
- X-ray emission spectra can be graphed as the number of x-rays for each increment of energy in keV. Characteristic x-rays of tungsten have a discrete energy of 69 keV. Bremsstrahlung x-rays have a range of energies up to X keV, where X is the kVp.
- The following four factors influence the x-ray emission spectrum: (1) low-energy electrons interact to produce low-energy x-rays, (2) successive interactions of electrons result in the production of x-rays with lower energy, (3) low-energy x-rays are most likely to be absorbed by the target material, and (4) added filtration preferentially removes low-energy x-rays from the useful beam.

References

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