<u>תדריך מעבדה – בדיקות לא הורסות</u>

<u>בדיקת רדיוגרפיה</u>

1. תקציר:

1. הכרות עם שיטת הרדיוגרפיה בקרני x כבדיקה ללא הרס ולימוד המשתנים החשובים ביישומה.
2. ביצוע צילום ופיתוח של תמונה בשיטת הרדיוגרפיה.
3. פענוח תמונה שצולמה בשיטת הרדיוגרפיה תוך שימוש בדגמי סטנדרט והמרת נתונים לדגמי הניסוי.

*נלקח מאתר האינטרנט
http://www.ndt-ed.org/EducationResources/CommunityCollege/communitycollege.htm

2. רקע תיאורטי

2.1. Present State of Radiography*

In many ways, radiography has changed little from the early days of its use. We still capture a shadow image on film using similar procedures and processes technicians were using in the late 1800's. Today, however, we are able to generate images of higher quality and greater sensitivity through the use of higher quality films with a larger variety of film grain sizes. Film processing has evolved to an automated state, producing more consistent film quality by removing manual processing variables. Electronics and computers allow technicians to now capture images digitally. The use of "filmless radiography" provides a means of capturing an image, digitally enhancing, sending the image anywhere in the world, and archiving an image that will not deteriorate with time. Technological advances have provided industry with smaller, lighter, and very portable equipment that produce high quality X-rays. The use of linear accelerators provide a means of generating extremely short wavelength, highly penetrating radiation, a concept dreamed of only a few short years ago.

While the process has changed little, technology has evolved allowing radiography to be widely used in numerous areas of inspection. Radiography has seen expanded usage in industry to inspect not only welds and castings, but to radiographically inspect items such as airbags and canned food products. Radiography has found use in metallurgical material identification and security systems at airports and other facilities. Gamma ray inspection has also changed considerably since the Curies' discovery of radium. Man-made isotopes of today are far stronger and offer the technician a wide range of energy levels and half-lives. The technician can select Co-60 which will effectively penetrate very thick materials, or select a lower energy isotope, such as Tm-170, which can be used to inspect plastics and very thin or low density materials. Today gamma rays find wide application in industries such as petrochemical, casting, welding, and aerospace.

2.2. Future Direction of Radiographic Education*

Although many of the methods and techniques developed over a century ago remain in use, computers are slowly becoming a part of radiographic inspection. The future of radiography will likely see many changes. As noted earlier, companies are performing many inspections without the aid of film. Radiographers of the future will capture images in digitized form and e-mail them to the customer when the inspection has been completed. Film evaluation will likely be left to computers. Inspectors may capture a digitized image, feed them into a computer and wait for a printout of the image with an accept/reject report. Systems will be able to scan a part and present a three-dimensional image to the radiographer, helping him or her to locate the defect within the part. Inspectors in the future will be able to peal away layer after layer of a part to evaluate the material in much greater detail. Color images, much like computer generated ultrasonic C-scans of today, will make interpretation of indications much more reliable and less time consuming.

Educational techniques and materials will need to be revised and updated to keep pace with technology and meet the requirements of industry. These needs may well be met with computers. Computer programs can simulate radiographic inspections using a computer aided design (CAD) model of a part to produce physically accurate simulated x-ray radiographic images. Programs allow the operator to select different parts to inspect, adjust the placement and orientation of the part to obtain the proper equipment/part relationships, and adjust all the usual x-ray generator settings to arrive at the desired radiographic film exposure.

Computer simulation will likely have its greatest impact in the classroom, allowing the student to see results in almost real-time. Simulators and computers may well become **the** primary tool for instructors as well as students in the technical classroom.

2.3. Nature of Penetrating Radiation*

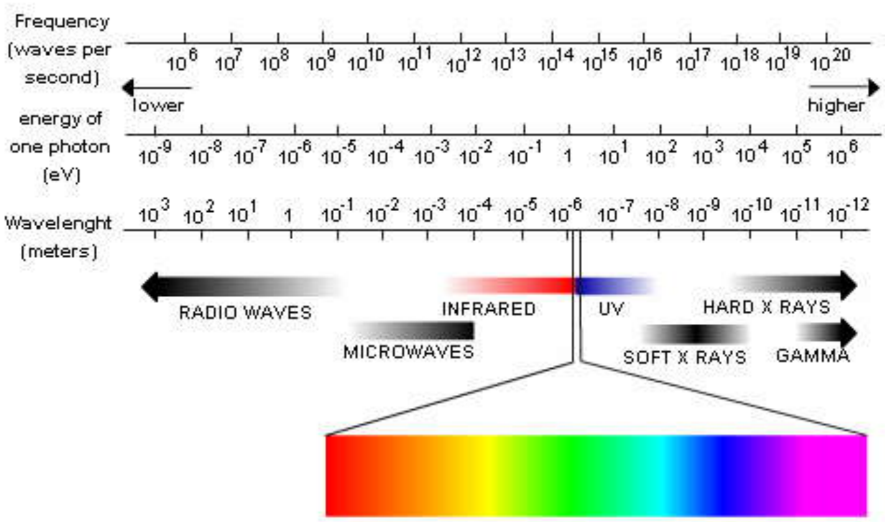

Figure 1: The electromagnetic spectrum

X-rays and gamma rays differ only in their source of origin. X-rays are produced by an x-ray generator and gamma radiation is the product of radioactive atoms. They are both part of the **electromagnetic spectrum** (Figure 1**).** They are waveforms, as are light rays, microwaves, and radio waves. X-rays and gamma rays cannot been seen, felt, or heard. They possess no charge and no mass and, therefore, are not influenced by electrical and magnetic fields and will generally travel in straight lines. However, they can be diffracted (bent) in a manner similar to light. Both X-rays and gamma rays can be characterized by frequency, wavelength, and velocity. However, they act somewhat like a particle at times in that they occur as small "packets" of energy and are referred to as "**photons."** Due to their short wavelength they have more energy to pass through matter than do the other forms of energy in the electromagnetic spectrum. As they pass through matter, they are scattered and absorbed and the degree of penetration depends on the kind of matter and the energy of the rays.

2.3.1. Properties of X-Rays and Gamma Rays

- They are not detected by human senses (cannot be seen, heard, felt, etc.).
- They travel in straight lines at the speed of light.
- Their paths cannot be changed by electrical or magnetic fields.
- They can be diffracted to a small degree at interfaces between two different materials.
- They pass through matter until they have a chance encounter with an atomic particle.
- Their degree of penetration depends on their energy and the matter they are traveling through.
- They have enough energy to ionize matter and can damage or destroy living cells.

2.4. X-Radiation*

X-rays are just like any other kind of electromagnetic radiation. They can be produced in parcels of energy called photons, just like light. There are two different atomic processes that can produce X-ray photons. One is called Bremsstrahlung and is a German term meaning "braking radiation." The other is called K-shell emission. They can both occur in the heavy atoms of tungsten. Tungsten is often the material chosen for the target or anode of the x-ray tube. Both ways of making X-rays involve a change in the state of electrons. However, Bremsstrahlung is easier to understand using the classical idea that radiation is emitted when the velocity of the electron shot at the tungsten changes. The negatively charged electron slows down after swinging around the nucleus of a positively charged tungsten atom. This energy loss produces X-radiation. Electrons are scattered elastically and inelastically by the positively charged nucleus. The inelastically scattered electron loses energy, which appears as Bremsstrahlung. Elastically scattered electrons (which include backscattered electrons) are generally scattered through larger angles. In the interaction, many photons of different wavelengths are produced, but none of the photons have more energy than the electron had to begin with. After emitting the spectrum of X-ray radiation, the original electron is slowed down or stopped.

2.4.1. Bremsstrahlung Radiation

X-ray tubes produce x-ray photons by accelerating a stream of electrons to energies of several hundred kilovolts with velocities of several hundred kilometers per hour and colliding them into a heavy target material. The abrupt acceleration of the charged particles (electrons) produces Bremsstrahlung photons (Figure 2). X-ray radiation with a continuous spectrum of energies is produced with a range from a few keV to a maximum of the energy of the electron beam. Target materials for industrial tubes are typically tungsten, which means that the wave functions of the bound tungsten electrons are required. The inherent filtration of an X-ray tube must be computed, which is controlled by the amount that the electron penetrates into the surface of the target and by the type of vacuum window present.

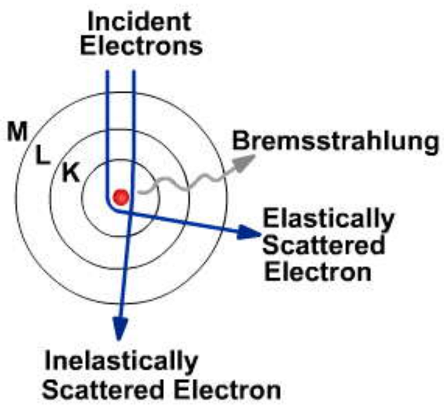

Figure 2: The Bremsstrahlung photons emission

The bremsstrahlung photons generated within the target material are attenuated as they pass through typically 50 microns of target material. The beam is further attenuated by the aluminum or beryllium vacuum window. The results are an elimination of the low energy photons, 1 keV through 15 keV, and a significant reduction in the portion of the spectrum from 15 keV through 50 keV. The spectrum from an x-ray tube is further modified by the filtration caused by the selection of filters used in the setup.

2.4.2. K-shell Emission Radiation

Remember that atoms have their electrons arranged in closed "shells" of different energies. The K-shell is the lowest energy state of an atom. An incoming electron can give a K-shell electron enough energy to knock it out of its energy state. About 0.1% of the electrons produce K-shell vacancies; most produce heat. Then, a tungsten electron of higher energy (from an outer shell) can fall into the K-shell. The energy lost by the falling electron shows up in an emitted x-ray photon. Meanwhile, higher energy electrons fall into the vacated energy state in the outer shell, and so on (Figure 3). K-shell emission produces higher-intensity x-rays than Bremsstrahlung, and the x-ray photon comes out at a single wavelength.

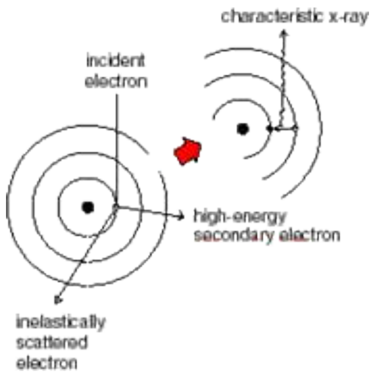

Figure 3: The K-shell emission

When outer-shell electrons drop into inner shells, they emit a **quantized** photon "characteristic" of the element. The energies of the characteristic X-rays produced are only very weakly dependent on the chemical structure in which the atom is bound, indicating that the non-bonding shells of atoms are the X-ray source. The resulting characteristic spectrum is superimposed on the continuum as shown in the graphs below (Figure 4). An atom remains ionized for a very short time (about 10^{14} second) and thus an atom can be repeatedly ionized by the incident electrons which arrive about every 10^{12} second.

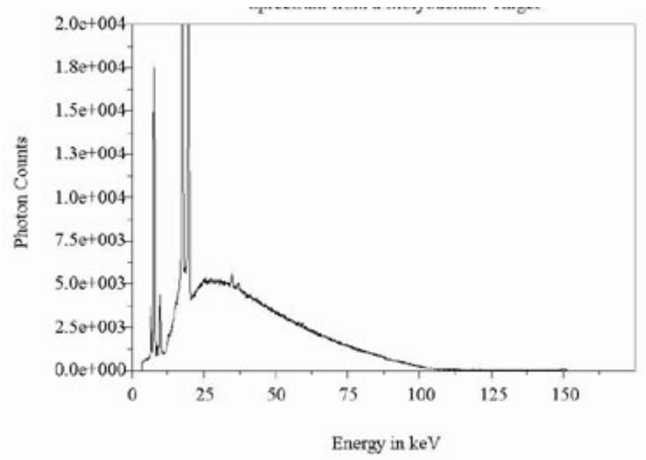

Figure 4: Characteristic spectrum from a Molybdenum target

2.5. Gamma Radiation*

Gamma radiation is one of the three types of natural radioactivity. Gamma rays are electromagnetic radiation, like X-rays. The other two types of natural radioactivity are alpha and beta radiation, which are in the form of particles. Gamma rays are the most energetic form of electromagnetic radiation, with a very short wavelength of less than one-tenth of a nanometer. Gamma radiation is the product of radioactive atoms. Depending upon the ratio of neutrons to protons within its nucleus, an isotope of a particular element may be stable or unstable. When the binding energy is not strong enough to hold the nucleus of an atom together, the atom is said to be unstable. Atoms with unstable nuclei are constantly changing as a result of the imbalance of energy within the nucleus. Over time, the nuclei of unstable isotopes spontaneously disintegrate, or transform, in a process known as radioactive decay. Various types of penetrating radiation may be emitted from the nucleus and/or its surrounding electrons. Nuclides which undergo radioactive decay are called radionuclides. Any material which contains measurable amounts of one or more radionuclides is a radioactive material.

2.5.1. Types Radiation Produced by Radioactive Decay

When an atom undergoes radioactive decay, it emits one or more forms of radiation with sufficient energy to ionize the atoms with which it interacts. Ionizing radiation can consist of high speed subatomic particles ejected from the nucleus or electromagnetic radiation (gamma-rays) emitted by either the nucleus or orbital electrons.

2.5.1.1. Alpha Particles

Certain radionuclides of high atomic mass (Ra226, U238, Pu239) decay by the emission of alpha particles. These alpha particles are tightly bound units of two neutrons and two protons each (He4 nucleus) and have a positive charge. Emission of an alpha particle from the nucleus results in a decrease of two units of atomic number (Z) and four units of mass number (A). Alpha particles are emitted with discrete energies characteristic of the particular transformation from which they originate. All alpha particles from a particular radionuclide transformation will have identical energies.

2.5.1.2. Beta Particles

A nucleus with an unstable ratio of neutrons to protons may decay through the emission of a high speed electron called a beta particle. This results in a net change of one unit of atomic number (Z). Beta particles have a negative charge and the beta particles emitted by a specific radionuclide will range in energy from near zero up to a maximum value, which is characteristic of the particular transformation.

2.5.1.3. Gamma-rays

A nucleus which is in an excited state may emit one or more photons (packets of electromagnetic radiation) of discrete energies. The emission of gamma rays does not alter the number of protons or neutrons in the nucleus but instead has the effect of moving the nucleus from a higher to a lower energy state (unstable to stable). Gamma ray emission frequently follows beta decay, alpha decay, and other nuclear decay processes.

2.6. Activity (of Radionuclides)*

The quantity which expresses the degree of radioactivity or the radiation producing potential of a given amount of radioactive material is activity. The curie was originally defined as that amount of any radioactive material that disintegrates at the same rate as one gram of pure radium. The curie has since been defined more precisely as a quantity of radioactive material in which 3.7×10^{10} atoms disintegrate per second. The International System (SI) unit for activity is the Becquerel (Bq), which is that quantity of radioactive material in which one atom is transformed per second. The radioactivity of a given amount of radioactive material does not depend upon the mass of material present. For example, two one-curie sources of Cs-137 might have very different masses depending upon the relative proportion of non-radioactive atoms present in each source. Radioactivity is expressed as the number of curies or becquerels per unit mass or volume (Figure 5).

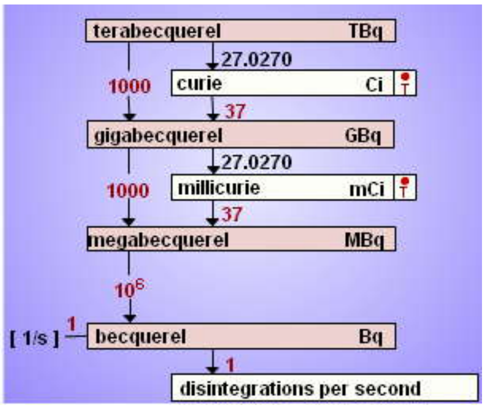

Figure 5: Activity (of radionuclides) (A)

The concentration of radioactivity, or the relationship between the mass of radioactive material and the activity, is called "specific activity." Specific activity is expressed as the number of curies or becquerels per unit mass or volume. Each gram of Cobalt-60 will contain approximately 50 curies. Iridium-192 will contain 350 curies for every gram of material. The shorter half-life, the less amount of material that will be required to produce a given activity or curies. The higher specific activity of Iridium results in physically smaller sources. This allows technicians to place the source in closer proximity to the film while maintaining geometric unsharpness requirements on the radiograph. These unsharpness requirements may not be met if a source with a low specific activity were used at similar source to film distances.

2.7. Isotope Decay Rate (Half-Life)*

Each radionuclide decays at its own unique rate which cannot be altered by any chemical or physical process. A useful measure of this rate is the half-life of the radionuclide. Half-life is defined as the time required for the activity of any particular radionuclide to decrease to one-half of its initial value. In other words one-half of the atoms have reverted to a more stable state material. Half-lives of radionuclides range from microseconds to billions of years. Half-life of two widely used industrial isotopes are 74 days for Iridium-192, and 5.3 years for Cobalt-60. More exacting calculations can be made for the half-life of these materials, however, these times are commonly used.

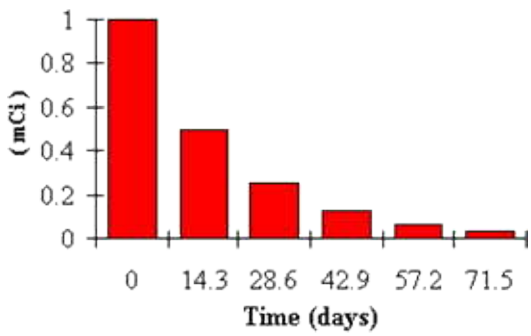

Figure 6: Radionuclide decay

** נלקח מקובץ ניסיונות מעבדות שנה ג׳, הנדסת חומרים, 2007-2008.

2.8. Radiation detection and measurement instruments**

Since **our senses cannot detect radiation**, several devices are commonly used in the field of radiography.

These devices are classified according to use and are called "**Survey Meters**" and "**Personnel Monitoring Devices**".

Survey meters are portable instruments used to monitor radiation areas.

The survey meter is designed **to give radiation exposure rate**.

Personnel monitoring devices as shown below (Figure 7) are attached to the clothing of the radiation worker.

These devices are designed **to give *cumulative* readings of exposure**.

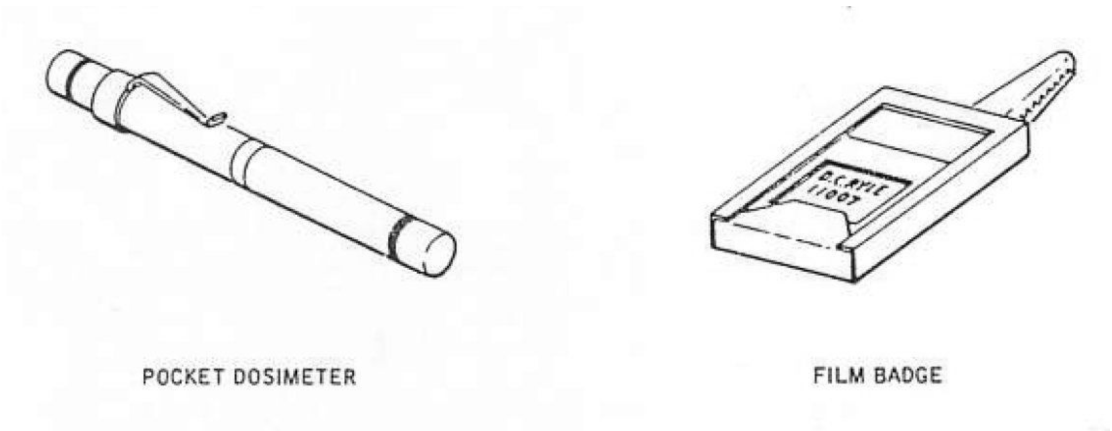

Figure 7:Personnel Monitoring Devices

All of the above devices are designed to **measure X and Gamma** radiation exposure **in Roentgens**.

All of the above devices work on the principle of "**Ionization**".

Half-Value Layer – (HVL) is a **thickness** of material **that will reduce radiation to one-half** the original intensity.

For each isotope or each X-ray a given energy, there is a characteristic half-value layer of any material.

The **Tenth-Value Layer** is another standard that will **reduce the radiation** passing through that material **to one-tenth** the original intensity.

As shown below (Table 1), **half- and tenth-value layers vary in thickness depending upon** the type of **isotope** or the **energy of X-ray** and also on the type of **shielding material**.

Table 1: Half- and tenth-value layers

SHIELDING MATERIAL IN INCHES	RADIOISOTOPE SOURCE					
	COBALT-60		IRIDIUM-192		CESIUM-137	
	1/10	1/2	1/10	1/2	1/10	1/2
LEAD	1.62	0.49	0.64	0.19	0.84	0.25
STEEL	2.90	0.87	2.0	0.61	2.25	0.68
CONCRETE OR ALUMINUM	8.6	2.6	6.2	1.9	7.1	2.1

SHIELDING MATERIAL	HALF-VALUE LAYER FOR TUBE POTENTIAL OF							
	50 kvp	70 kvp	100 kvp	125 kvp	150 kvp	200 kvp	250 kvp	300 kvp
LEAD (mm)	0.05	0.18	0.24	0.27	0.3	0.5	0.8	1.5
CONCRETE (In.)	0.2	0.5	0.7	0.8	0.9	1.0	1.1	1.2

The problems on the next page will provide a better understanding of the half- and tenth-value layer concept.

The *table below* (Table 2) shows several **isotopes commonly used** in industrial radiography.

Table 2: Commonly used isotopes

RADIOISOTOPE	R/HR/CURIE AT 1 FOOT
COBALT-60 (Co-60)	14.5
IRIDIUM-192 (Ir-192)	5.9
CESIUM-137 (Cs-137)	4.2
THULIUM-170 (Tm-170)	.03

What would be the intensity of an Ir-192 source with an activity of 10 curies?

(Answer: 59 R/hr/1 foot)

2.9. Protection from radiation**

There are **three basic means of providing protection** from radiation:

1. **Time** – Controlling the length of time a person is exposed to radiation.
2. **Distance** – Controlling the distance between personnel and the source.
3. **Shielding** – Placing absorbing materials between personnel and source.

The above three factors must always be remembered when working in radiography and will be discussed in this lesson.

Time

refers to the duration of **radiation exposure**.

The relationship of time to exposure is **directly proportional**. **The longer you stay** in a radiation area, **the more** radiation exposure **you receive**.

(A person receiving 10mR in one hour would receive 80mR in 8 hours).

Distance

Radiation **exposure decreases** drastically **as the distance** from the source **increases**.

The **mathematical law** known as the "**Inverse Square Law**" states the relationship of distance to varying radiation intensity.

The law states that **radiation intensity varies inversely as the square of the distance from the source**.

The inverse square relationship means that **if you double the distance**, you will **receive only ¼ the amount** of radiation.

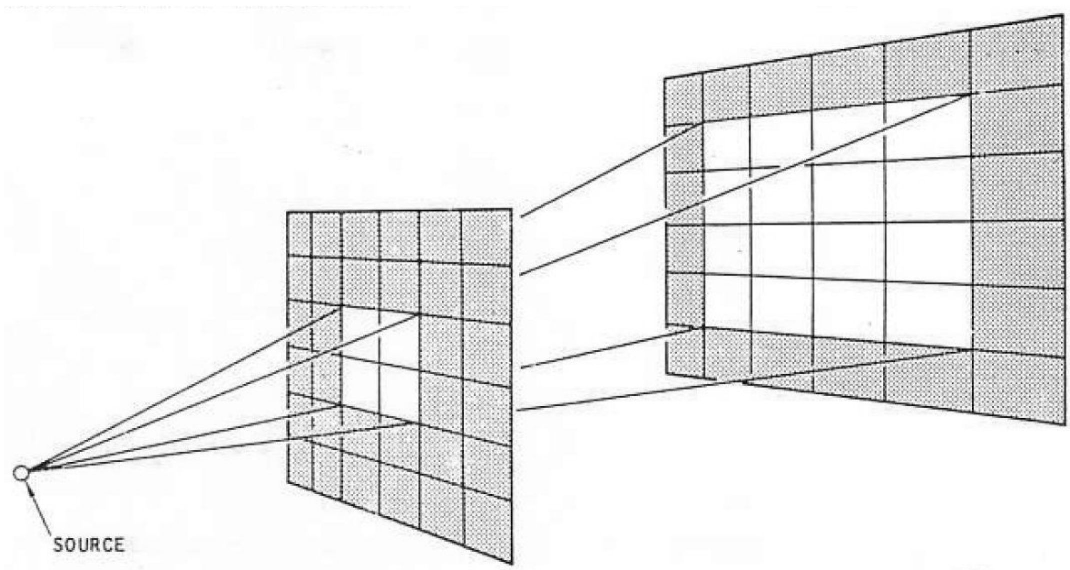

Figure 8: Inverse Square Law

In the diagram above (Figure 8), assume that the second series of squares is twice the distance from the source as the first series.

This demonstrates that each of the 16 squares in the second series is receiving ¼ of the amount as each of the four squares in the first series.

The diagram below (Figure 9) further illustrates the important effect of distance on safety.

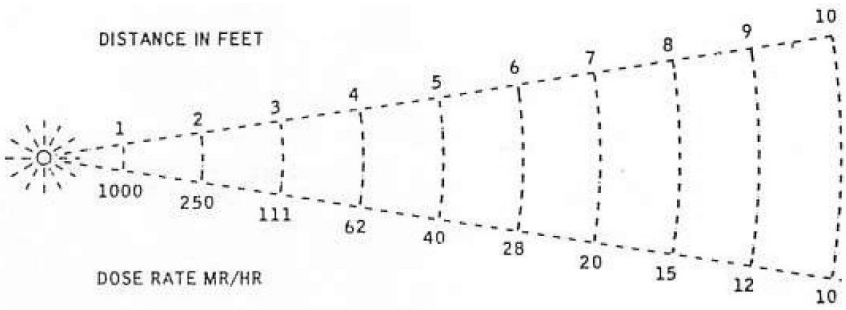

Figure 9: Effect of distance on safety

Of course, the same considerations apply if you are getting nearer the source instead of further away.

The **inverse square formula** is shown below:

$$\frac{I_1}{I_2} = \frac{(D_2)^2}{(D_1)^2}$$

I_1 = The **known** intensity at a known distance (D_1).

D_1 = The distance from a source where intensity is **known** (I_1).

I_2 = The **unknown** intensity at a second known distance.

D_2 = The distance from a source at which you want to find the **unknown** intensity.

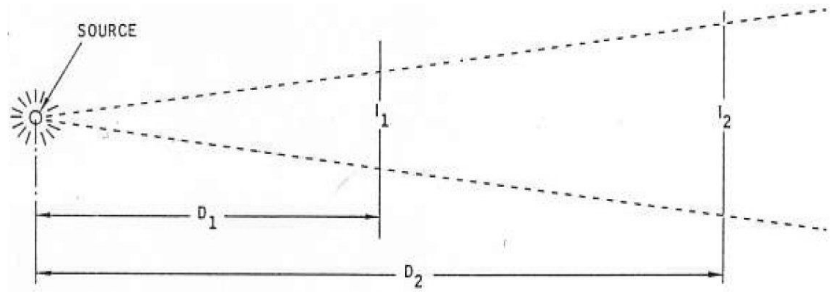

Figure 10: Inverse square formula

Table 3: Approximate radiographic equivalence factors

Material	X-rays								Gamma Rays			
	50 Kv	100 Kv	150 Kv	220 Kv	400 Kv	1000 Kv	2000 Kv	4 to 25 Mev	Ir 192	Cs 137	Co 60	Radium
Magnesium	0.6	0.6	0.5	0.08								
Aluminum	1.0	1.0	0.12	0.18					0.35	0.35	0.35	0.40
2024 (aluminum) alloy	2.2	1.6	0.16	0.22					0.35	0.35	0.35	
Titanium			0.45	0.35								
Steel		12.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
18-8 (steel) alloy		12.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Copper		18.	1.6	1.4	1.4			1.3	1.1	1.1	1.1	1.1
Zinc			1.4	1.3	1.3			1.2	1.1	1.0	1.0	1.0
Brass*			1.4*	1.3*	1.3*	1.2*	1.2*	1.2*	1.1*	1.1*	1.1*	1.1*
Inconel X alloy		16.	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Zirconium			2.3	2.0		1.0						
Lead			14.	12.		5.0	2.5	3.0	4.0	3.2	2.3	2.0
Uranium				25.				3.9	12.6	5.6	3.4	

Aluminum is taken as the standard metal at 50Kv and 100Kv, and steel at the higher voltages and gamma rays. The thickness of another metal is multiplied by the corresponding factor to obtain the approximate equivalent thickness of the standard metal. The exposure applying to this thickness of the standard metal is used.
Example: To radiograph 0.5 inch of copper at 220Kv, multiply 0.5 inch by the factor 1.4, obtaining an equivalent thickness of 0.7 inch of steel. Therefore, give the exposure required for 0.7 inch of steel.
*Tin or lead alloyed in the brass will increase these factors.

2.10. Penumbra**

Can be reduced when the **source-to-specimen distance is increased**.

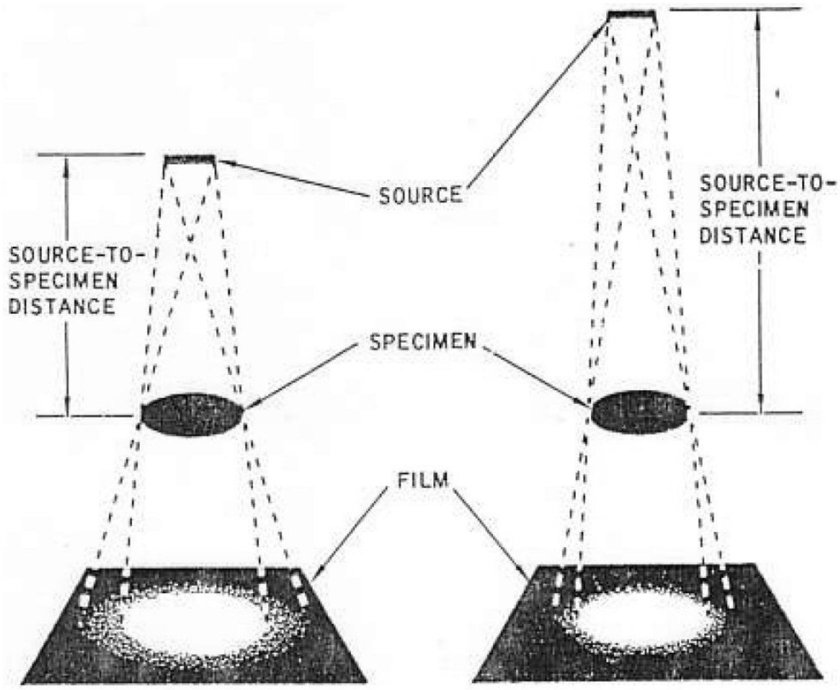

Figure 11: Penumbra reduction by increasing source-to-specimen distance

Another very important technique to **reduce penumbra** is to keep the **film as close to the specimen as possible**.

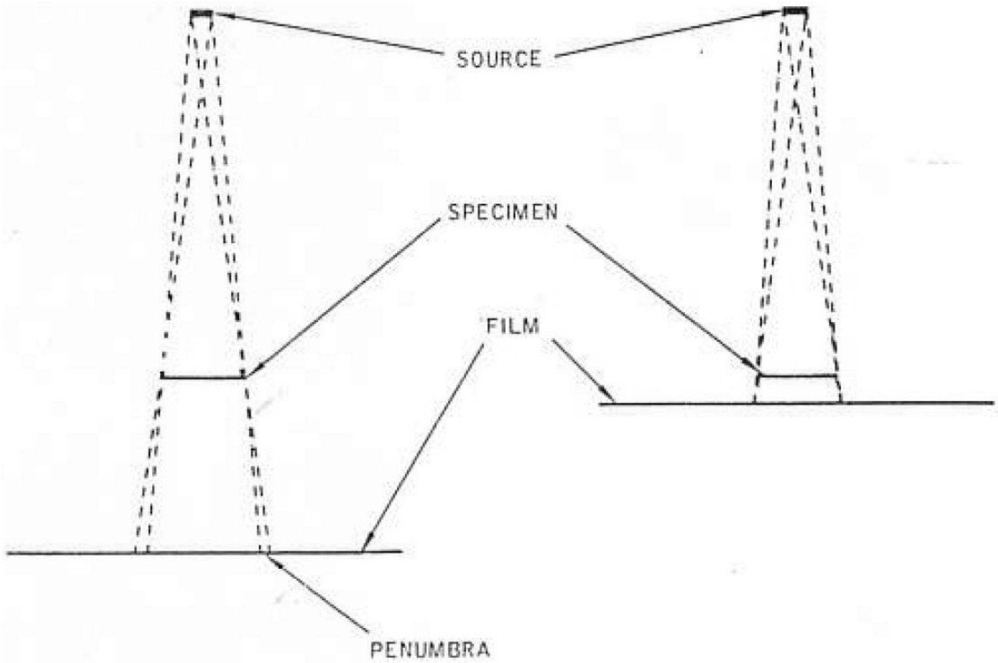

Figure 12: Penumbra reduction by decreasing film-to-specimen distance

Whenever penumbra can be reduced it will **also improve the definition** of the radiographic image.

Optimum geometrical sharpness is obtained when:

1. The radiation source is small.
2. The distance from the source to specimen is relatively great.
3. The distance from the specimen to film is small.

Whenever possible, the **rays** from the source should be directed **perpendicularly to the film to prevent a distorted image**.

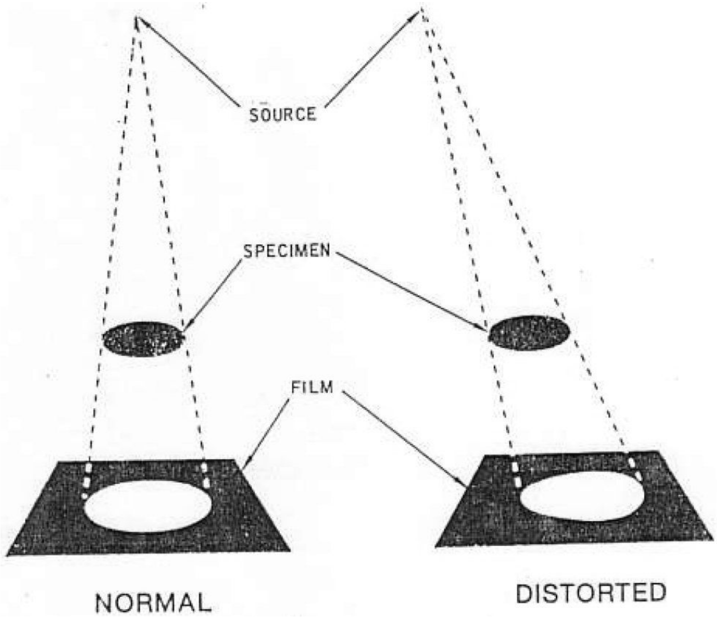

Figure 13: Keep rays perpendicular to the film to prevent image distortion

2.11. X-ray exposure charts**

These charts show the **relationship between** material **thickness**, **kilovoltage**, and **exposure**.

Each chart applies **only to a specific set of conditions**:

1. A certain X-ray machine.
2. A certain target-to-film distance (TFD).
3. A certain type of film.
4. Certain processing conditions.
5. Density upon which the chart is based.

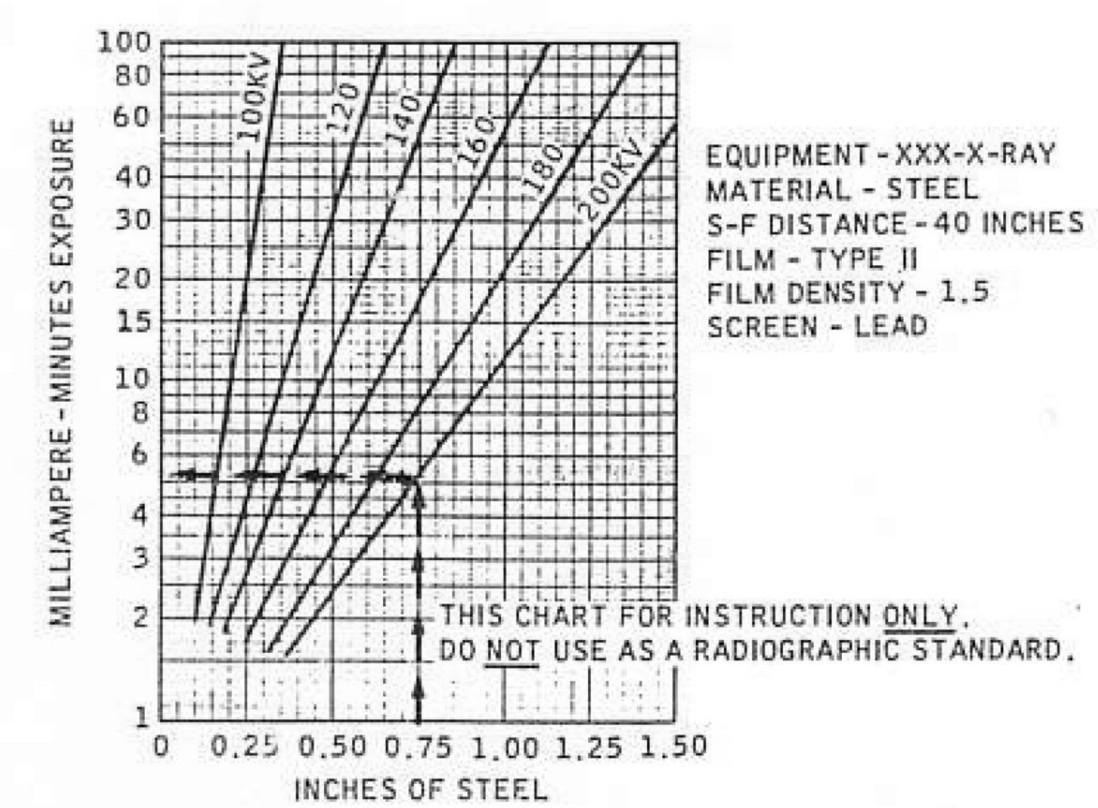

Figure 14: X-ray exposure chart

As shown above (Figure 14) the exposure is **plotted** on a **logarithmic scale** to shorten the chart in the vertical direction.

The **left side of the chart shows exposure** in milliampere-minutes (MAM) and **thickness of the material at the bottom**.

To use this type of chart you enter the chart at the thickness of the specimen, follow the chart vertically to the selected KV and then horizontally to find the correct exposure.

Example: ¾″ of steel at 200KV would require about 5.3 MAM.

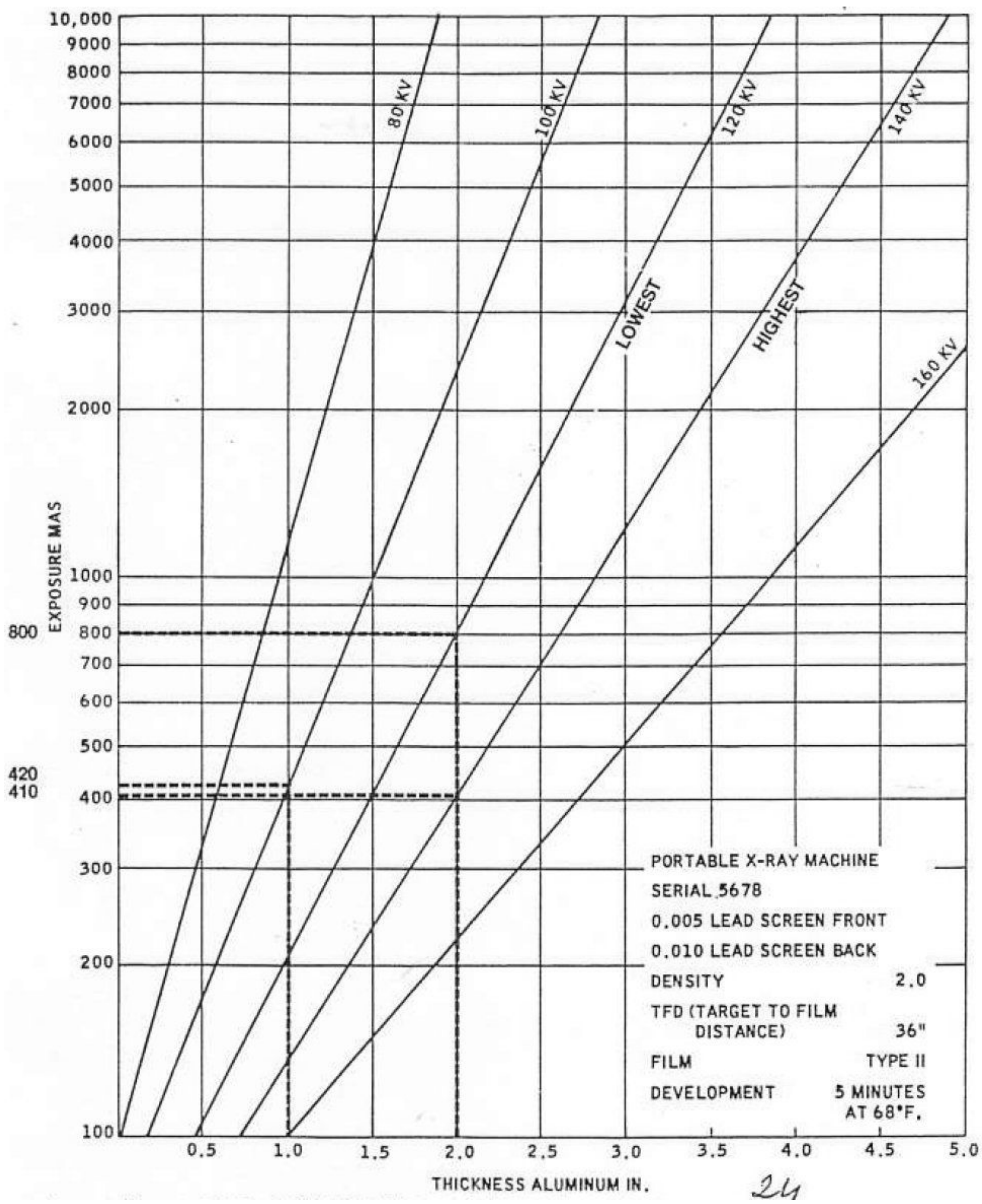

Figure 15: Another X-ray exposure chart

2.12. Equivalence charts**

Generally, exposure charts are made for either aluminum or steel. This could create a problem when you wish to radiograph a specimen of some other material.

The **following chart** (Table 4) shows a **radiographic equivalence chart** which relates other materials to aluminum and steel.

The **figures** given in the chart **are multiplication factors** and are used to convert a particular thickness of the selected material to the equivalent thickness of the standard material.

Note that the **standard material for 50-100 KV** exposures is **aluminum** (factor 1.0).

Also note that for **higher voltages and isotopes**, the **standard material is steel** (factor 1.0).

Table 4: Radiographic equivalence chart

	X-RAYS KV							GAMMA RAYS		
	50	100	150	220	400	1000	2000	Ir 192	CE-137	CO-60
MAGNESIUM	0.6	0.6	0.05	0.08				0.22	0.22	0.22
ALUMINUM	1.0	1.0	0.12	0.18				0.34	0.34	0.34
TITANIUM		8.0	0.63	0.71	0.71	0.9	0.9	0.9	0.9	0.9
STEEL		12.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
COPPER		18.0	1.6	1.4	1.4	1.1	1.1	1.1	1.1	1.1
ZINC			1.4	1.3	1.3	1.1	1.0	1.1	1.0	1.0
BRASS			1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0
LEAD			14.0	12.0		5.0	2.5	4.0	3.2	2.3

If you wanted to X-ray 0.5 inches of copper at 220 KV using an exposure chart for steel, what would be the equivalent thickness in steel?

Answer: 0.7″ steel (multiplication factor 1.4 times 0.5″ copper = 0.7″).

2.13. Radiographic Sensitivity**

Before a radiograph can be of any use as a nondestructive testing tool, we must have some idea how accurate the tool is.

This **measure of accuracy is called the "Sensitivity"** of the radiograph.

Sensitivity in a radiograph is **a function of** the "**Contrast**" and the "**Definition**" of the radiograph.

Contrast is the **comparison between film densities** for different areas of the radiograph as shown below (Figure 16).

Film "A" shows **higher contrast** than film "B".

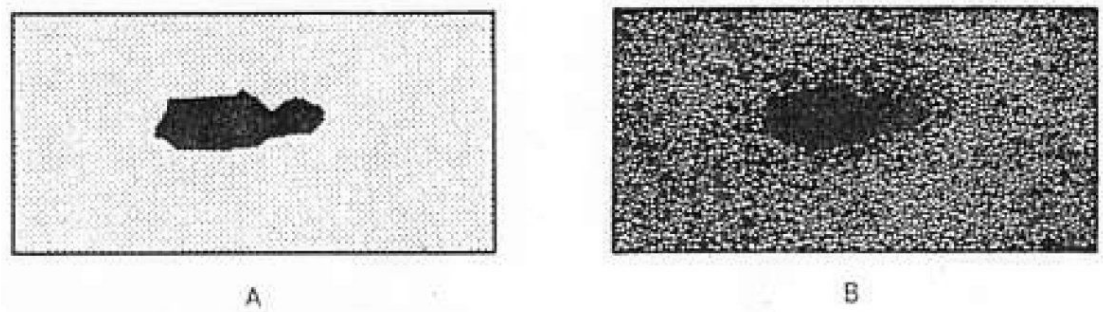

Figure 16: Contrast

Definition is the **line of demarcation between areas of different densities**.
If the image is **clear and sharp** the radiograph is said to have **good definition** as shown below (Figure 17).
Film "B" shows **better definition** then film "A".

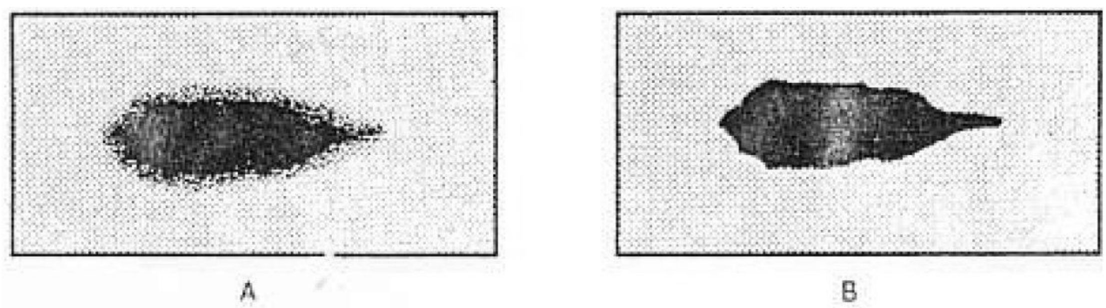

Figure 17: Definition

2.14. Inherent Unsharpness**

Inherent Unsharpness is **caused by free electrons** that are generated by the radiographic ray as it passes through the film.
This **scattering of free electrons** (shown below, Figure 18) through the film causes the film to be exposed wherever the electrons travel.
The scattering causes some degree of **"fuzzy" edges** on the image that **cannot be avoided**.

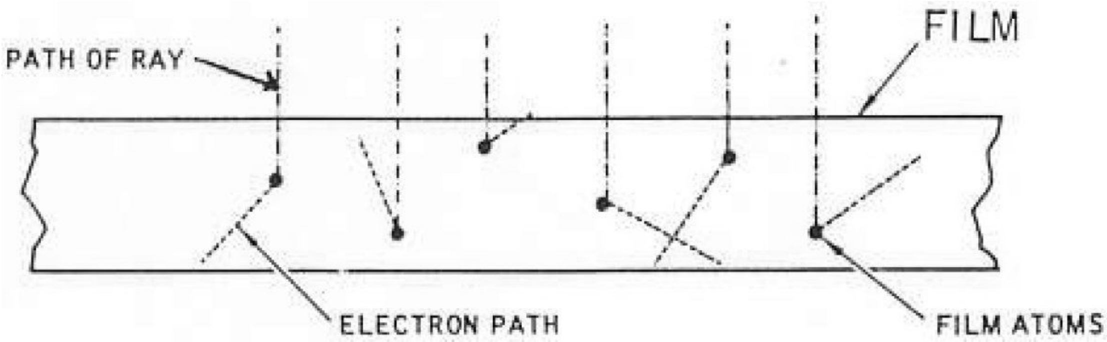

Figure 18: Inherent unsharpness

2.15. Scattered Radiation**

Scattered Radiation adversely **affects** both the **contrast and** the **definition** of the radiograph.

Scattered radiation is usually **described with reference to its origin**.

1. **Internal Scatter** originates within the specimen (Figure 19). **On the left** is a radiograph that would be obtained if there was ***no* internal scatter**.
   On the right is shown a **loss of definition** caused by the internal scatter.

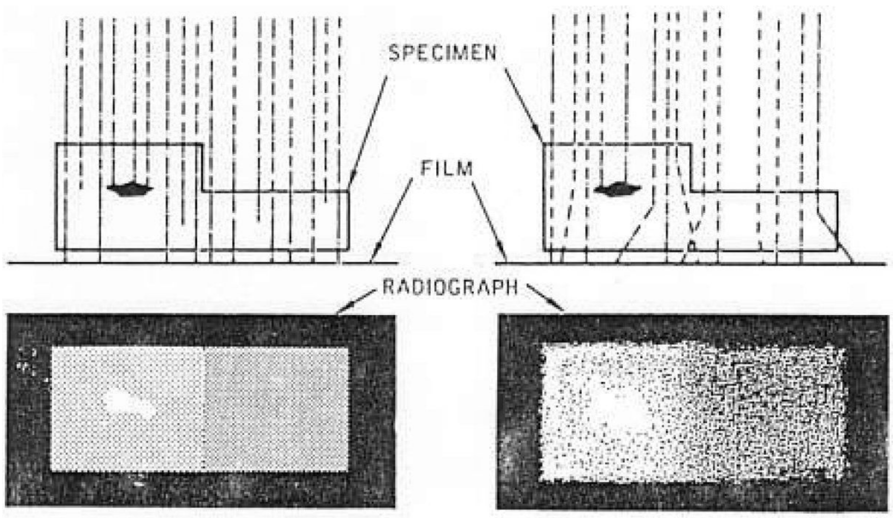

Figure 19: Internal Scatter

2. **Side Scatter** originates from walls, or any other **objects** nearby that are **in the path of the primary ray** (Figure 20).

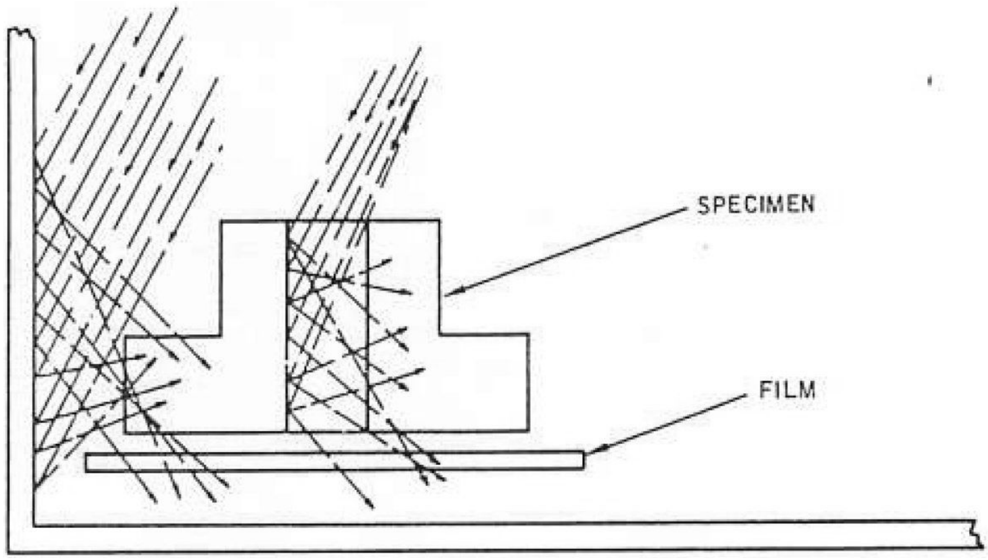

Figure 20: Side scatter

3. **Back Scatter** originates from **any material** (wall, floor, table top, or cassette) that is located **in back of the film** (Figure 21).

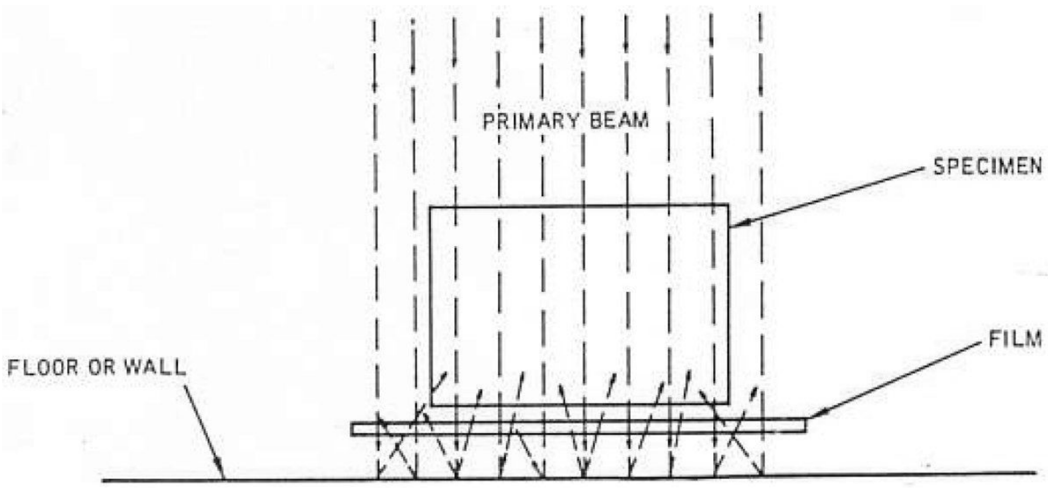

Figure 21: Back scatter

Back scatter is often identified by placing a lead letter **"B" on the back side of the cassette**. If the letter image appears on the film, this would indicate scatter radiation.

2.16. H & D Curves**

It is difficult for the human eye to readily distinguish between small density differences in a radiographic film.

The **H & D Curves** make it apparent that **as exposure and density increase**, **film contrast also increases**.

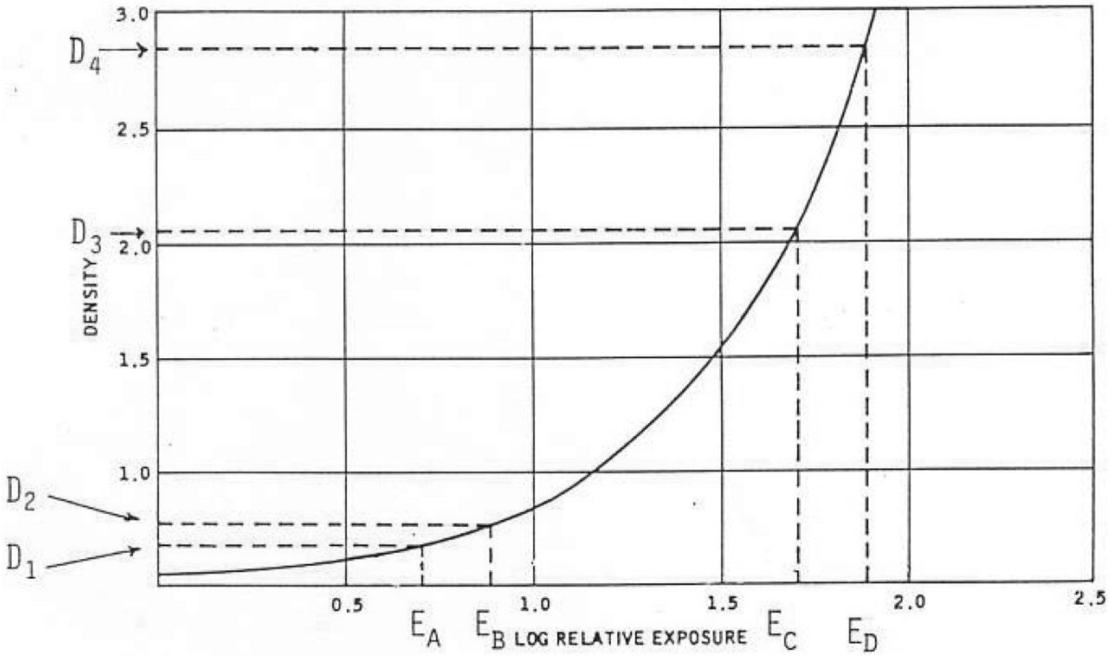

Figure 22: H & D curve

On the above H & D curve (Figure 22), suppose that the **exposure** of the film **varies** from E_A to E_B **due to a change in thickness** of the specimen.

Note that the resulting contrast is the difference between D_1 and D_2.

However, **if a higher radiation level was used** so that the thickness difference had caused a difference in exposure E_C to E_D (equal to E_A to E_B), the difference in **density would increase** as shown by D_3 to D_4.

The H & D curve clearly shows that the **density** differences **between thicknesses** D_3 and D_4 **is considerably greater** than the density between D_1 and D_2.

As shown below (Figure 23), a **distorted image** could **affect the film interpretation**.

The **angled leg** of the specimen **has been shortened** on the radiographic image.

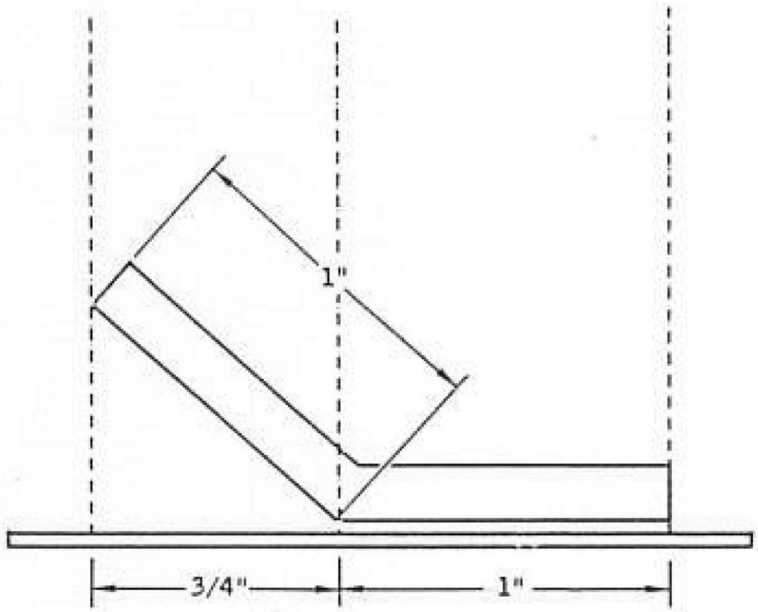

Figure 23: Distorted image of an angled leg

Specimen shape is another geometrical factor that **affects the definition** seen on the radiograph.

The **image of an inclusion** could be **almost invisible** because of a very gradual change in photographic density.

Specimen "A" below (Figure 24) will have the **best definition** because of the abrupt thickness change.

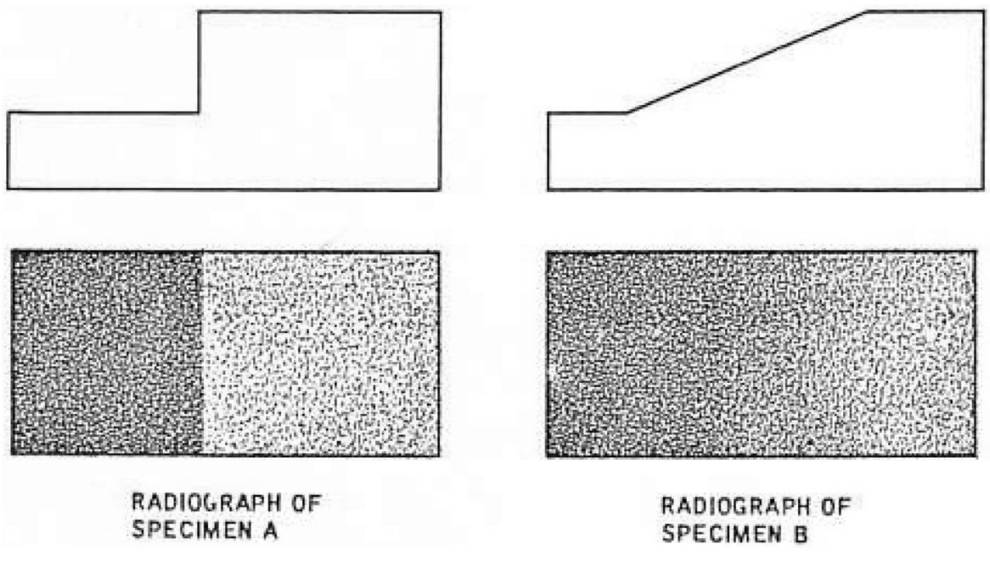

Figure 24: Specimen shape affects the definition

A **practical example** is shown below to **demonstrate** the (film characteristic curve) **H & D curve**.

Two **similar specimens** are shown (Figure 25) that **differ only in their thickness**. Note that the change in thickness (a) is the same.

If both specimens receive the **same exposure** on the **same type of film**, the one on the **right** would show the **most contrast**.

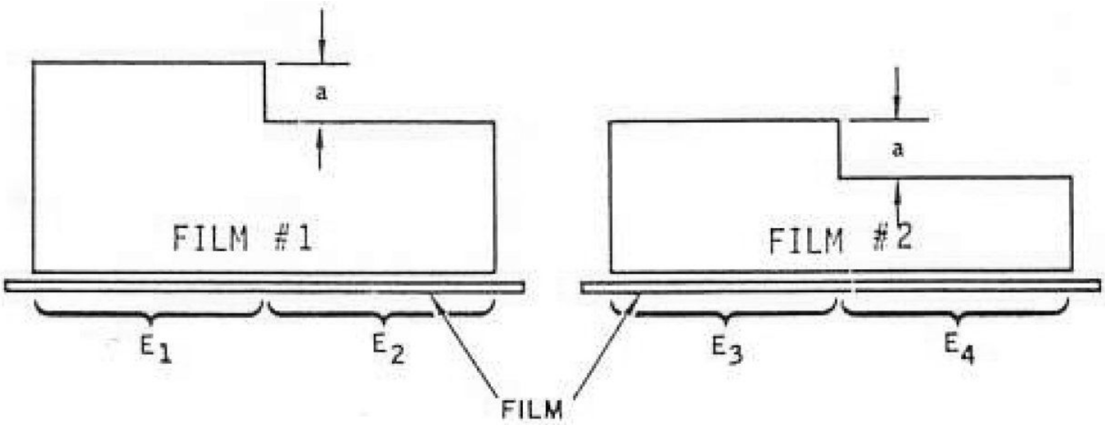

Figure 25: Specimens for H & D curve example

Obviously, **film #1** above is going to receive **less radiation** and be **less dense** and therefore have **less contrast** than film #2.

The **film characteristic curve below** (Figure 26) shows that where **film #2** received a **higher radiation** level (E_3 to E_4), it would be **more dense** and show **more contrast** (D_3 to D_4).

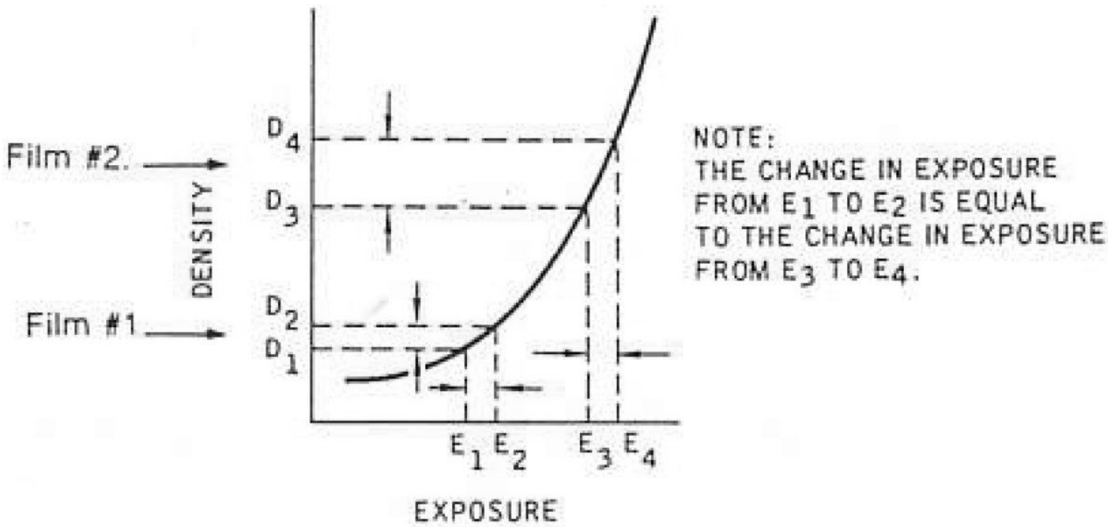

Figure 26: H & D curve example

2.17. Subject and Film Contrast**

Remember that we have said that **contrast** is a **comparison between film densities** for different areas of the radiograph (Figure 27).

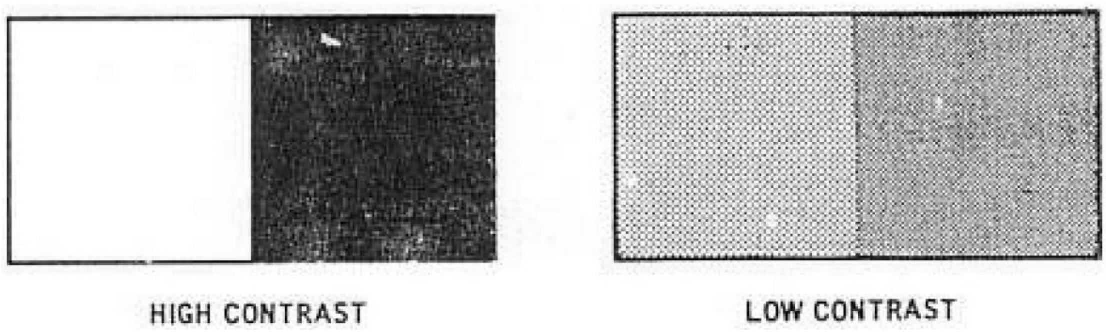

Figure 27: Contrast levels

Contrast is a **combination** of "**subject**" contrast and "**film**" contrast.

Those **factors in the specimen** that affect contrast are referred to as "**Subject Contrast**".

Those **factors in the film** that affect contrast are referred to as "**Film Contrast**".

Subject Contrast

A radiograph of a specimen of uniform thickness and density has no subject contrast as shown below (Figure 28).

By definition, **subject contrast** is the **ratio** of X or gamma ray **intensities** transmitted by **two selected portions** of the **specimen**.

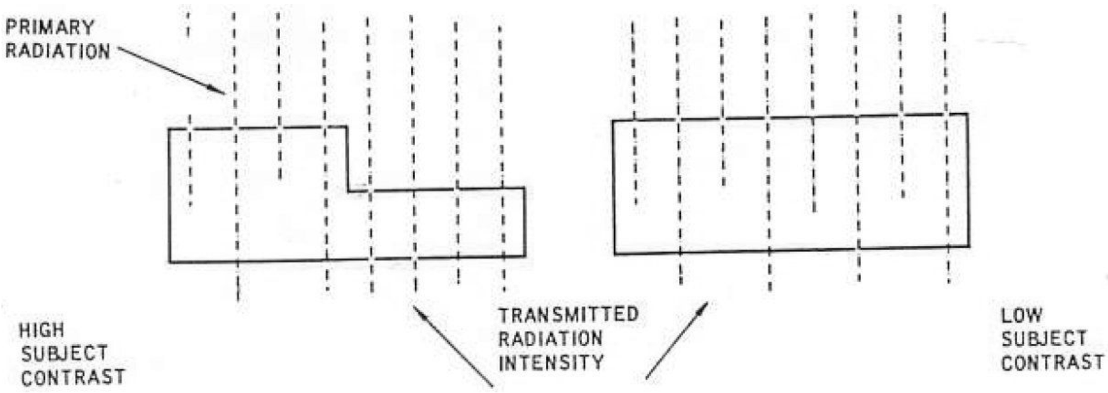

Figure 28: Subject Contrast

The **best** possible **subject contrast** is achieved by utilizing rays produced by the **lowest kilovoltage** (soft radiation) **that will penetrate** the specimen.

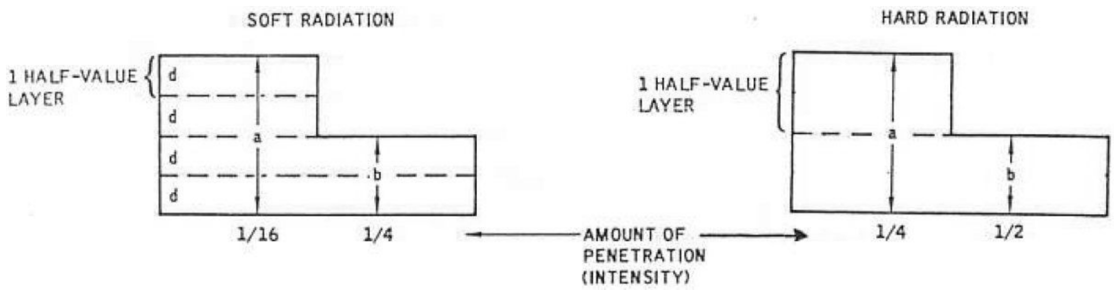

Figure 29: Kilovoltage affects subject contrast

For example, let's assume that the half-value layer of the specimen at the left is equal to "d" (Figure 29).

In the **thick section** the radiation will have to **penetrate** through **4 half-value layers** and will emerge at $^{1}/_{16}$ **the original value**.

In the **thin section** the radiation will only have to **penetrate** through **2 half-value layers** and will emerge at ¼ **the original value**.

However, in the **specimen on the right** the radiation will only have to **penetrate 2 half-value layers** in the **thick section** and will emerge at ¼ **the original value**.

In the **thin section** the ray will only have to **penetrate 1 half-value layer** and will emerge at ½ **the original value**.

The **comparison of the transmitted densities** can be shown as a "**ratio**" and will be discussed on the next page.

To take a "**ratio**" of two numbers, you compare them by **dividing the smaller number into the larger number**.

The **ratio** of intensities emerging from the specimen on the **left below** (Figure 30) is:

$$\frac{1/4}{1/16} = \frac{16}{4} = 4$$

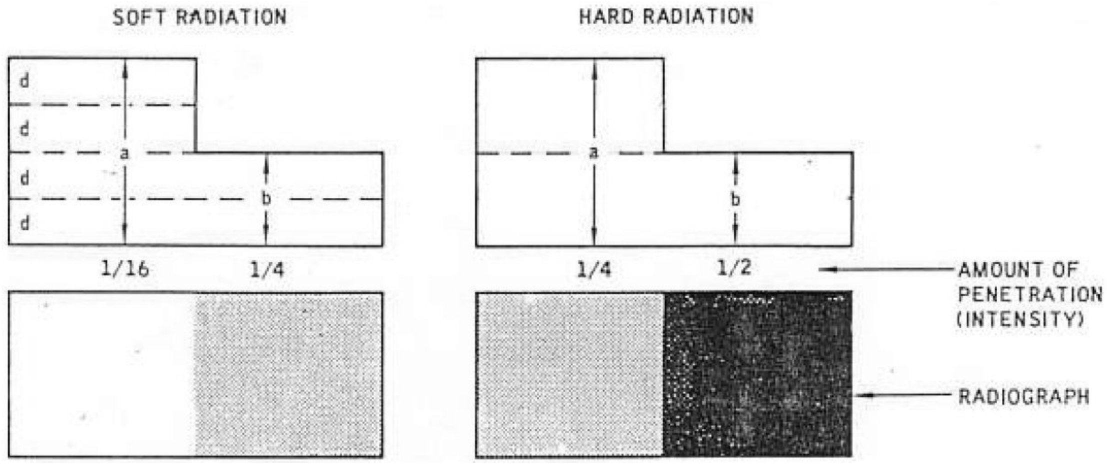

Figure 30: Comparison of subject contrast

The **ratio** of intensities emerging from the specimen on the **right above** is:

$$\frac{1/2}{1/4} = \frac{4}{2} = 2$$

Because of the larger difference between the intensities emerging from the specimen on the left (ratio = 4), it is apparent that the **subject contrast** is also **the best**.

As shown in the specimen on the right, **increasing the energy** of the ray **decreases the subject contrast**.

Increasing and decreasing **penetrating power** obviously **affects subject contrast**, **but there are limits** to how far the kilovoltage can be changed.

As shown below (Figure 31) on the **left**, a very **low KV** results in zero penetration of the thickest section and a high density in the thinnest.

> This results in a **very high contrast**, **but** may be impractical since discontinuities that might lie in the thickest section could not appear on the film.

As shown on the **right**, a **KV** is selected that is **so high** that it penetrates all sections almost equally and results in equal density with **no subject contrast**.

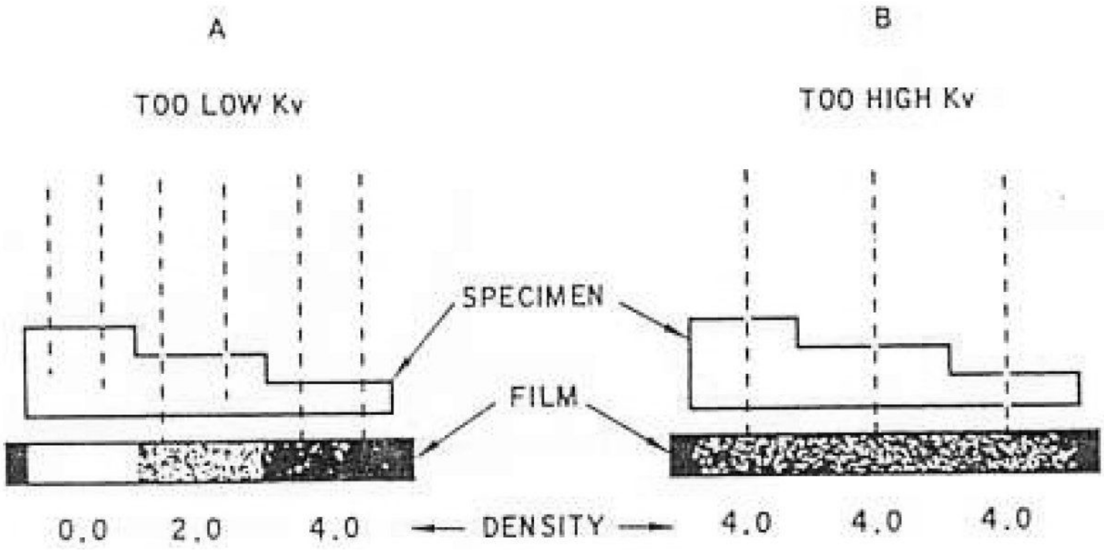

Figure 31: limits on chosen kilovoltage

The **skilled radiographer** is expected to **select a kilovoltage** that will **adequately penetrate** the specimen **and** still **give** the **necessary subject contrast**.

Film Contrast

Film contrast is **defined** as the inherent ability of a film to show a **density difference for a given change in film exposure**.

All film manufacturers produce **several different types of film** and **some** types have the ability to **show more "film contrast"** than others.

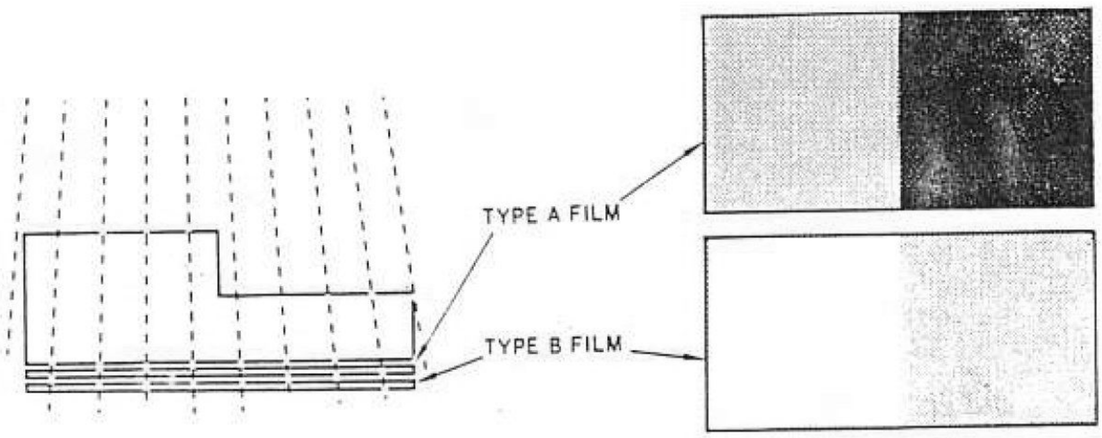

Figure 32: Film contrast

As shown above (Figure 32), **both film types** received the **same amount of radiation** in a single exposure.

However, the **film on the top** has the ability to show **better "film contrast"**. **Film contrast values of any particular film are usually expressed as a relationship between film exposure and resulting density.**

The relationship is expressed in the form of **film characteristic curves**.

Total Radiographic Contrast is defined as the combination of "**subject contrast**" and "**film contrast**" and depends upon:

Radiation applied, film type, exposure, film processing, specimen, scattered radiation, and kind of screens used.

An **important consideration** to remember is the **effect of low kilovoltage relating to increased scattered radiation**.

While it is desirable to attain **good contrast** by using a **low radiation** level, the **lower radiation** will also produce **more scatter**.

Scatter from low energy radiation **will cause "fuzziness"** in the image.

As the voltage across a X-ray tube **is increased** some **contrast is lost**, **but also less scatter is produced** to fog the film and cause fuzzy images.

Latitude is closely **related to contrast** but **in the opposite sense**. As shown below (Figure 33), the radiograph with the **highest contrast** has the **least latitude** and vice versa.

Latitude is the **range of** thicknesses that can be adequately recorded on the radiograph.

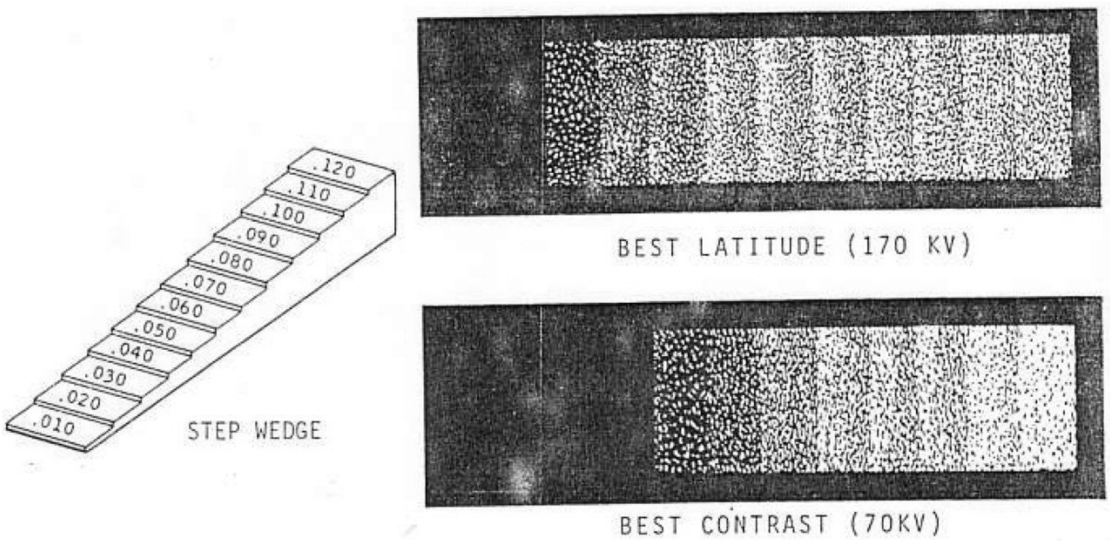

Figure 33: Latitude

2.18. Radiographic Film**

A **transparent polyester or acetate** is used as **the base** of radiographic film (Figure 34).

Most radiographic film has a **sensitive emulsion on both sides** of the acetate base.

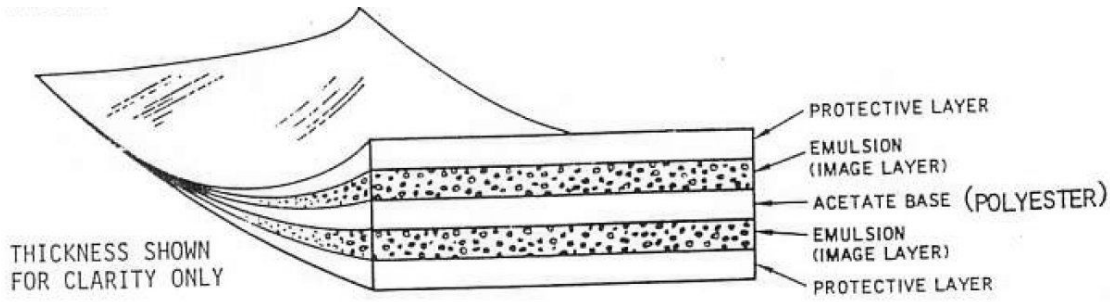

Figure 34: Radiographic film

The **outer layer** of the film is a layer of **gelatin** which protects the emulsion layer from scratches.

The soft **emulsion layer (image layer)** has suspended in it **microscopic grains of silver bromide**.

These silver bromide grains **when exposed** to light or radiation would become visible and **turn the film black**.

However, the **image is "latent"** and no visible change in film would be noticeable **until after development**.

A latent image is formed on the film **when** some of the **silver bromide grains are ionized** by the X-ray, gamma ray, or light.

The **latent image is made visible** by developing the film where the ionized **silver bromide grains** are **reduced to black metallic silver**.

Each individual grain that has been exposed then helps form the image on the film.

There is no partial exposure of a silver grain.

Areas on the film of light and dark simply represent the number of grains exposed in those areas.

More exposed grains give a **darker image**.

The **difference** in radiographic films is mainly **due to** the various **grain sizes** (even the largest of which are microscopic).

Because "**graininess**" (visible clumps of grains) is present in all film, **the larger the grain the less sharp the image**.

The **larger grained films** expose more silver to the rays per grain. Therefore, the **image is exposed more quickly**.

The fine **detail** however is **lacking** with coarse-grained film.

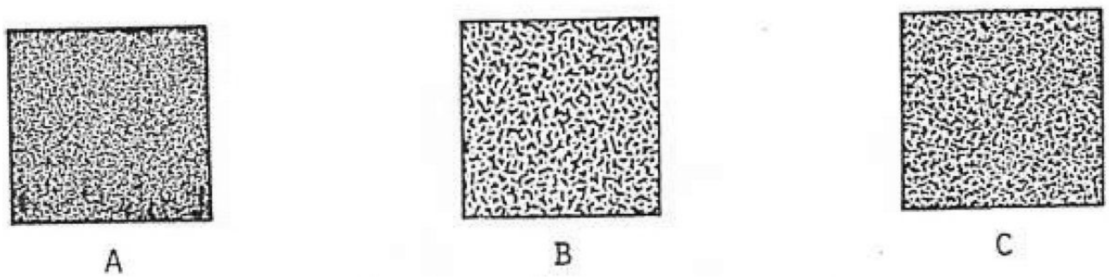

Figure 35: Film grain size

Which of the above (Figure 35) would be the **fastest film**?
(Answer: "B").

Which of the above would give the **sharpest detail**?
(Answer: "A").

While it is often economically advantageous to make exposures as fast as possible, the use of fast (coarse-grained) film is limited by the graininess that can be tolerated.

During normal processing, the grains that have been exposed will turn black; and those which have received no exposure will be removed from the film base during processing.

2.19. Specialized radiographic equipment**

Screens – There are basically **three types of radiographic screens** that enable us to use the radiation beam more effectively:

1. **Lead Foil** intensifying screen.
2. **Fluorescent** intensifying screen.
3. **Fluorometallic** intensifying screen.

The **lead foil screen** consists of a **thin lead sheet (0.005″ – 0.010″)** usually mounted on a cardboard base.

The lead screens are **placed in front and in back of** the unexposed **film** as shown below (Figure 36).

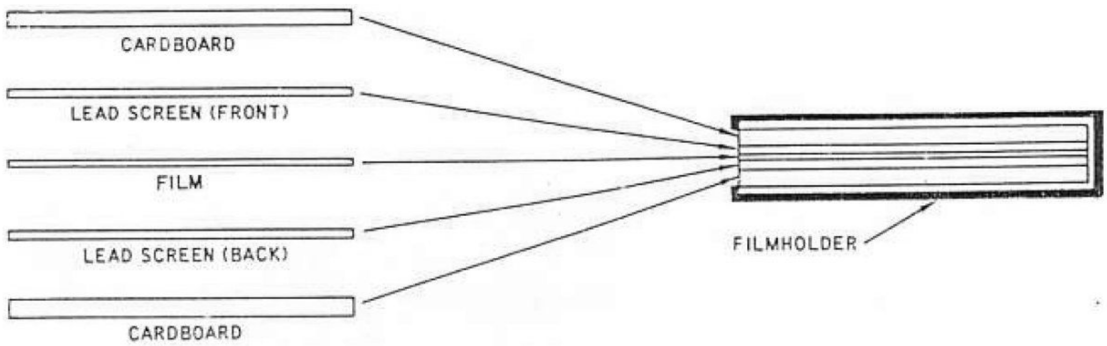

Figure 36: Lead foil screen

The **lead screen in the front** serves two important purposes:

1. **Filters** out the **low energy radiation**.
2. **Increases the photographic action** on the film (discussed on the next page).

The **lead screen in the back** of the film, often a thicker sheet (0.010″) serves to **absorb** the radiation **back scatter**.

Lead screens act as intensifiers because X- and gamma rays cause electrons to be liberated from the lead (remember the Compton effect).

If the lead screen is very close to the film, the **electrons expose the film** (ionization) and the ray is effectively intensified (Figure 37).

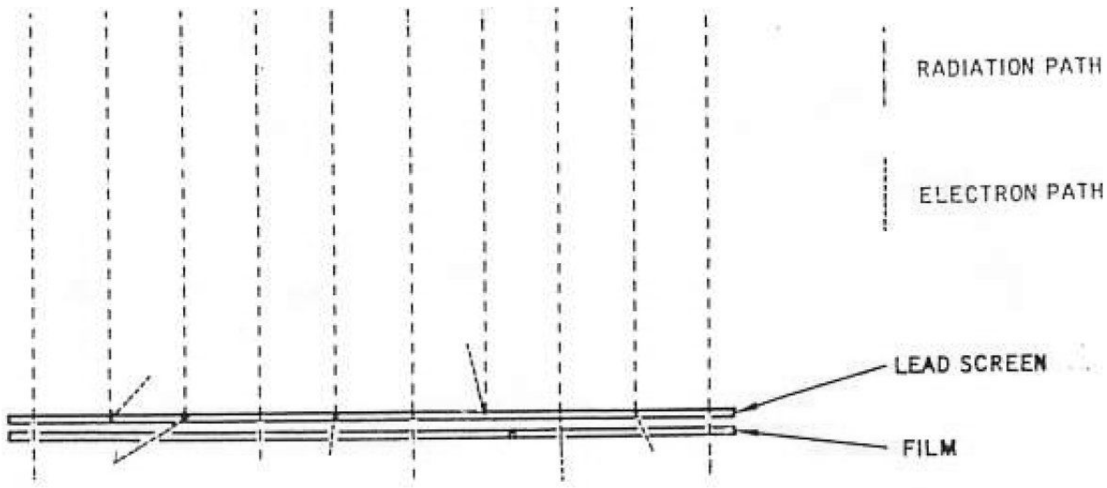

Figure 37: Intensification by lead screens

Both the **front and back** lead screen **add** to the formation of the image on the film due to the effect of the **scattered electrons**.

However, any **space between the screen and film** allows room for the electrons to spread causing **"fuzzy" images** (Figure 38).

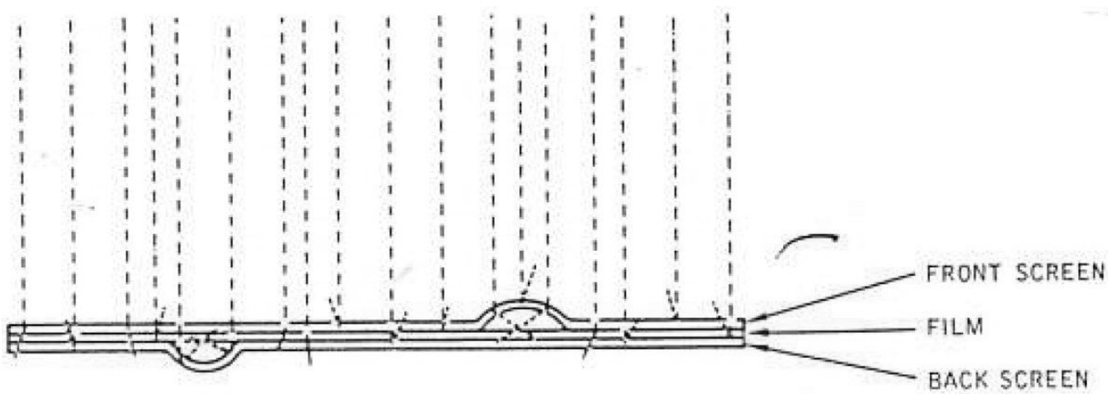

Figure 38: Scattered electrons might degrade image

Generally speaking, **lead screens** give **better definition then fluorescent screens**.

The **poorer definition** is caused by the **spreading of visible light** emitted from the fluorescent screens.

However, **fluorescent screens** are **useful** when the penetrating voltage of the X-ray unit is limited and you wish to radiograph a **relatively thick specimen**.

Fluorometallic Intensifying Screen

The fluorometallic screen **combines** the **advantages** of the lead foil and fluorescent screens.

These screens **absorb the scattered radiation** with the lead foil **and** at the same time **provide a visible light** to increase intensification (Figure 39).

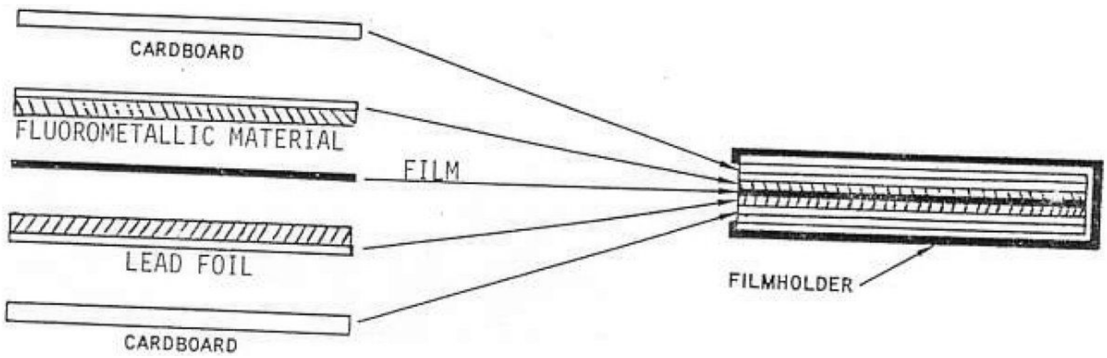

Figure 39: Fluorometallic screen

3. מכשור:

- הניסוי ייעשה במתקן תעשייתי לקרני X (אינוונטר מספר דגם 30595),

המספק מתח האצה עד 200KV והספק מותר עד 200W.

המתקן מאפשר צילום של חלקים באמצעות סרטי צילום וגם תצפית ישירה באמצעות מסך פלורסנטי הממוקם מתחת לחלקים הנבדקים.

- דנציטומטר: X-rite model 301X
- אילומינטורים

4. מהלך הניסוי.

4.1 הכרת המכשיר: הכנס למתקן קופסת מתכת סגורה ובה חפצים שונים. הדלק את השפופרת והתבונן במסך הפלורוסנטי בתוכן הקופסא המשוקף על המסך.

4.2 הכרת שיטת הצילום:

4.3 הכר את סולם צפיפות ההשחרה באמצעות סרטי דוגמא.

4.4 תרגל את הבחירה של תנאי החשיפה על פי עקומות החשיפה:

- סוג הסרט: D7 ו-D4 (D7 מהיר פי 4 מ-D4).
- השחרה רצויה: בדרך כלל 1.5-2.
- מתח האצה: מתח גבוה נחוץ לשיקוף חלקים עבים. במתח נמוך ההפרדה של פרטים טובה יותר.
- זמן וזרם: קשורים למתח ההאצה בגלל מגבלת ההספק המירבי של מכשיר.
- הוסף מסך עופרת דק בבדיקת חלקים עבים או מתכות כבדות. העופרת עוצרת קרינה מפוזרת ויוצרת תמונה חדה.

4.5 הכר את אמצעי הכיול לקביעת רגישות העבודה: דגם מדרגות ופנטרומטר חוטים. החוט הדק ביותר שניתן לאבחנה בצילום הוא גבול הגילוי של המערכת.

4.6 בצע צילומים רדיוגרפיים של פריטים שונים. במידת האפשר הוסף דגמי כיול לקביעת הרגישות (כושר ההפרדה) של כל צילום:

- **דגם מתיחה יצוק ובו נקבוביות.**
- **דגם אלומיניום יצוק בעל pipe.**
- **דגם קוביה עם חלל פנימי.**
- **חלק מלבני ארוך ועבה מאלומיניום עם חורים קדוחים בקטרים שונים ממילימטר אחד עד שמונה מילימטרים.**
- **דגמי יציקה מסוג אלומיניום, מסוגסג בעופרת.**
- **פלח סגסוגת אלומיניום-מגנזיום Al-Mg מרותך במרכזו.**
-

6.1. מהלך הצילום :

- הכנס את הדגם וקבע את תנוחת הצילום הרצויה.
- כוון כפתור penetration ל-0.
- הפעל timer לזמן בהתאם לחישובייך.
- אור אדום נדלק והשעון מתחיל לפעול.
- מעלים את המתח באמצעות כפתור penetration למתח הרצוי.
- בגמר הצילום נכבית המנורה האדומה ואפשר לפתוח את דלת תא הצילום ולהוציא את הדגם והסרט.

6.2.פיתוח :

מותר לעבוד באור אדום.

א. טבול את הסרט במפתח (rapid) x-ray או D-19 עד שרואים תמונה בעין חופשית.

ב. שטוף במים (עם מעט חומצת חומץ).

ג. העבר לקובע (x-ray fixer) לכ-10 דקות, שטוף במים 15-20 דקות. אפשר להיעזר בדטרגנט לניקוי הסרט.

5. הנחיות לדו"ח מסכם.

1. תאר את הניסויים שביצעת.
2. מהם היתרונות והמגבלות של הרדיוגרפיה בקרני x.

6. ביבליוגרפיה.

1. http://www.ndt-ed.org/EducationResources/CommunityCollege/communitycollege.htm
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