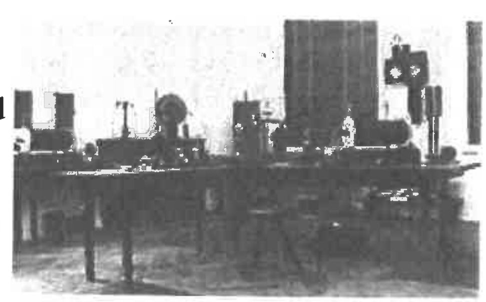
History of Radiography

X-rays were discovered in 1895 by Wilhelm Conrad Roentgen (1845-1923) who was a Professor at Wuerzburg University in Germany. Working with a cathode-ray tube in his laboratory, Roentgen observed a fluorescent glow of crystals on a table near his tube. The tube that Roentgen was working with consisted of a glass envelope (bulb) with positive and negative electrodes encapsulated in it. The air in the tube was evacuated, and when a high voltage was applied, the tube produced a fluorescent glow. Roentgen shielded the tube with heavy black paper, and discovered a green colored fluorescent light generated by a material located a few feet away from the tube.

He concluded that a new type of ray was being emitted from the tube. This ray was capable of passing through the heavy paper covering and exciting the phosphorescent materials in the room. He found that the new ray could pass through most substances casting shadows of solid objects. Roentgen also discovered that the ray could pass through the tissue of humans, but not bones and metal objects. One of Roentgen's first experiments late in 1895 was a film of the hand of his wife, Bertha. It is interesting that the first use of X-rays were for an industrial (not medical) application, as Roentgen produced a radiograph of a set of weights in a box to show his colleagues.

Roentgen's discovery was a scientific bombshell, and was received with extraordinary interest by both scientist and laymen. Scientists everywhere could duplicate his experiment because the cathode tube was very well known during this period. Many scientists dropped other lines of research to pursue the mysterious rays. Newspapers and magazines of the day provided the public with numerous stories, some true, others fanciful, about the properties of the newly discovered rays.

Public fancy was caught by this invisible ray with the ability to pass through solid matter, and, in conjunction with a photographic plate, provide a picture of bones and interior body parts. Scientific fancy was captured by the demonstration of a wavelength shorter than light. This generated new possibilities in physics, and for investigating the structure of matter. Much enthusiasm was generated about potential applications of rays as an aid in medicine and surgery. Within a month after the announcement of the discovery, several medical radiographs had been made in Europe and the United States, which were used by surgeons to guide them in their work. In June 1896, only 6 months after Roentgen announced his discovery, X-rays were being used by battlefield physicians to locate bullets in wounded soldiers.



Prior to 1912, X-rays were used little outside the realms of medicine and dentistry, though some X-ray pictures of metals were produced. The reason that X-rays were not used in industrial application before this date was because the X-ray tubes (the source of the X-rays) broke down under the voltages required to produce rays of satisfactory penetrating power for industrial purposes. However, that changed in

1913 when the high vacuum X-ray tubes designed by Coolidge became available. The high vacuum tubes were an intense and reliable X-ray source, operating at energies up to 100,000 volts.

In 1922, industrial radiography took another step forward with the advent of the 200,000-volt X-ray tube that allowed radiographs of thick steel parts to be produced in a reasonable amount of time. In 1931, General Electric Company developed 1,000,000 volt X-ray generators, providing an effective tool for industrial radiography. That same year, the American Society of Mechanical Engineers (ASME) permitted X-ray approval of fusion welded pressure vessels that further opened the door to industrial acceptance and use.

A Second Source of Radiation

Shortly after the discovery of X-rays, another form of penetrating rays was discovered. In 1896, French scientist Henri Becquerel discovered natural radioactivity. Many scientists of the period were working with cathode rays, and other scientists were gathering evidence on the theory that the atom could be subdivided. Some of the new research showed that certain types of atoms disintegrate by themselves. It was Henri Becquerel who discovered this phenomenon while investigating the properties of fluorescent minerals. Becquerel was researching the principles of fluorescence, wherein certain minerals glow (fluoresce) when exposed to sunlight. He utilized photographic plates to record this fluorescence.

One of the minerals Becquerel worked with was a uranium compound. On a day when it was too cloudy to expose his samples to direct sunlight, Becquerel stored some of the compound in a drawer with his photographic plates. Later when he developed these plates, he discovered that they were fogged (exhibited exposure to light). Becquerel questioned what would have caused this fogging. He knew he had wrapped the plates tightly before using them, so the fogging was not due to stray light. In addition, he noticed that only the plates that were in the drawer with the uranium compound were fogged. Becquerel concluded that the uranium compound gave off a type of radiation that could penetrate heavy paper and expose photographic film. Becquerel continued to test samples of uranium compounds and determined that the source of radiation was the element uranium. Bacquerel's discovery was, unlike that of the X-rays, virtually unnoticed by laymen and scientists alike. Relatively few scientists were interested in Becquerel's findings. It was not until the discovery of radium by the Curies two years later that interest in radioactivity became widespread.

While working in France at the time of Becquerel's discovery, Polish scientist Marie Curie became very interested in his work. She suspected that a uranium ore known as pitchblende contained other radioactive elements. Marie and her husband, French scientist Pierre Curie, started looking for these other elements. In 1898, the Curies discovered another radioactive element in pitchblende, and named it 'polonium' in honor of Marie Curie's native homeland. Later that year, the Curies discovered another radioactive element which they named radium, or shining element. Both polonium and radium were more radioactive than uranium. Since these discoveries, many other radioactive elements have been discovered or produced.

Radium became the initial industrial gamma ray source. The material allowed castings up to 10 to 12 inches thick to be radiographed. During World War II, industrial radiography grew tremendously as part of the Navy's shipbuilding program. In 1946, man-made gamma ray sources such as cobalt and iridium became available. These new sources were far stronger than radium and were much less expensive. The manmade sources rapidly replaced radium, and use of gamma rays grew quickly in industrial radiography.

Health Concerns

The science of radiation protection, or "health physics" as it is more properly called, grew out of the parallel discoveries of X-rays and radioactivity in the closing years of the 19th century. Experimenters, physicians, laymen, and physicists alike set up X-ray generating apparatuses and proceeded about their labors with a lack of concern regarding potential dangers. Such a lack of concern is quite understandable, for there was nothing in previous experience to suggest that X-rays would in any way be hazardous. Indeed, the opposite was the case, for who would suspect that a ray similar to light but unseen, unfelt, or otherwise undetectable by the senses would be damaging to a person? More likely, or so it seemed to some, X-rays could be beneficial for the body.

Inevitably, the widespread and unrestrained use of X-rays led to serious injuries. Often injuries were not attributed to X-ray exposure, in part because of the slow onset of symptoms, and because there was simply no reason to suspect X-rays as the cause. Some early experimenters did tie X-ray exposure and skin burns together. The first warning of possible adverse effects of X-rays came from Thomas Edison, William J. Morton, and Nikola Tesla who each reported eye irritations from experimentation with X-rays and fluorescent substances.

Today, it can be said that radiation ranks among the most thoroughly investigated causes of disease. Although much still remains to be learned, more is known about the mechanisms of radiation damage on the molecular, cellular, and organ system than is known for most other health stressing agents. Indeed, it is precisely this vast accumulation of quantitative dose-response data that enables health physicists to specify radiation levels so that medical, scientific, and industrial uses of radiation may continue at levels of risk no greater than, and frequently less than, the levels of risk associated with any other technology.

X-rays and Gamma rays are electromagnetic radiation of exactly the same nature as light, but of much shorter wavelength. Wavelength of visible light is on the order of 6000 angstroms while the wavelength of x-rays is in the range of one angstrom and that of gamma rays is 0.0001 angstrom. This very short wavelength is what gives x-rays and gamma rays their power to penetrate materials that light cannot. These electromagnetic waves are of a high energy level and can break chemical bonds in materials they penetrate. If the irradiated matter is living tissue, the breaking of chemical bonds may result in altered structure or a change in the function of cells. Early exposures to radiation resulted in the loss of limbs and even lives. Men and women researchers collected and documented information on the interaction of radiation and the human body. This early information helped science understand how electromagnetic radiation interacts with living tissue. Unfortunately, much of this information was collected at great personal expense.

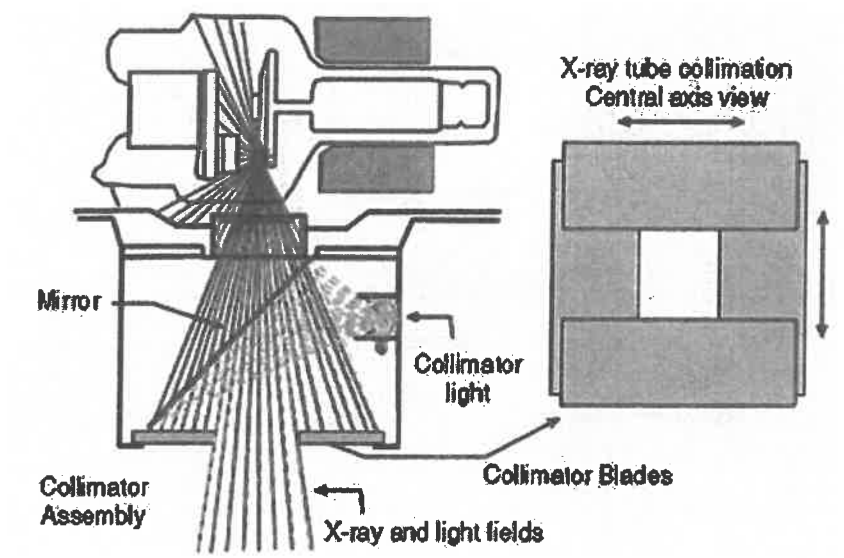
Radiation Equivalents

Unit	Measured Quantity
Rad, Grey (Gy)	Absorbed Dose
Rem, Sievert (Sv)	Biologically Equivalent Dose

Unit Equivalents	
100 Rem	1 Sv
1 Rem	10 mSv (millisievert)
1 mrem (millirem)	10 µSv (microsievert)
1 µrem (microrem)	0.01 µSv

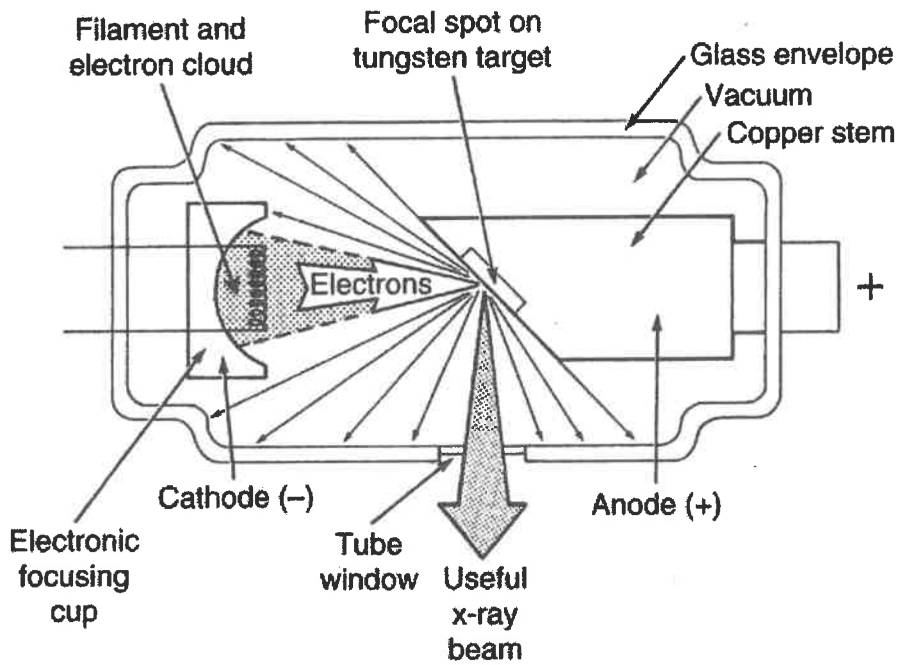
RAE SYSTEMS

PROTECTION THROUGH DETECTION



X-ray tube collimation
Central axis view
Mirror
Collimator
light
Collimator Blades
Collimator
Assembly
X-ray and light fields

Dental x-ray tube



Radiation exposure How does it compare?

Exposure measured in mSv

10,000	Fatal within weeks
6,000	Typical dosage recorded in those Chernobyl workers who died within a month
5,000	Single dose which would kill half of those exposed to it within a month
1,000	Single dose which could cause radiation sickness, nausea, but not death
400	Max radiation levels recorded at Fukushima plant 14 March, per hour
350	Exposure of Chernobyl residents who were relocated
100	Recommended limit for radiation workers every five years
10	Dose in full-body CT scan
9	Airline crew NYC -Tokyo polar route, annual
2	Natural radiation we're all exposed to, per year
1.02	Radiation per hour detected Fukushimia site, 12 March
0.4	Mammogram breast x-ray
0.1	Chest x-ray
0.01	Dental x-ray

SOURCE: WNA, RADIOLOGYINFO.ORG, REUTERS

Personal radiation dosimeters

Main article: Dosimeter

The radiation dosimeter is an important personal dose measuring instrument. It is worn by the person being monitored and is used to estimate the external radiation dose deposited in the individual wearing the device. They are used for Gamma, X-ray, beta and other strongly penetrating radiation, but not for weakly penetrating radiation such as alpha particles. Traditionally film badges were used for long term monitoring, and quartz fibre dosimeters for short term monitoring. However, these are mostly superseded by such as thermoluminescent dosimetry (TLD) badges and electronic dosimeters. Electronic dosimeters can give an alarm warning if a preset dose threshold has been reached, enabling safer working in potentially higher radiation levels, where the received dose must be continually monitored.

Workers exposed to radiation, such as radiographers, nuclear power plant workers, doctors using radiotherapy, those in laboratories using radionuclides, and HAZMAT teams are required to wear dosimeters so a record of occupational exposure can be made. Such devices are generally termed "legal dosimeters" if they have been approved for use in recording personnel dose for regulatory purposes.

Dosimeters can be worn to obtain a whole body dose and there are also specialist types that can be worn on the fingers or clipped to headgear, to measure the localised body irradiation for specific activities.

Common types of wearable dosimeters for ionizing radiation include:[15][16]

- Film badge dosimeter
- Quartz fiber dosimeter
- Electronic personal dosimeter
- Thermoluminescent dosimeter

X-Ray Facility Plan Review

To ensure that adequate lead is installed in the walls, floor, ceiling and/or operator's booth, Chapter 246-225 WAC requires that new, remodeled or re-located medical X-ray facilities submit shielding calculations before construction begins, or before the X-ray machine is moved.

Look up these requirements in your copy of the WAC or call 1-800-299-XRAY for a copy.

The following sequence of events should take place:

1 - Plan Review

- Qualified Experts List
- X-Ray Shielding Plan Review:
- Information for Registrants
- Information for Qualified Experts

Work with your architect, contractor, or X-ray installer to hire a qualified expert to perform the shielding calculations. You will need to provide information on projected workload, techniques to be used, exam types to be done, layout of room, occupancy of adjacent space, etc. A Qualified Experts List is provided. You should contact several experts on the list to see how much they charge and when they can do the calculations for you. When complete, the floor plan and shielding calculations are sent to us for review: X-Ray Shielding Plan Review Procedure (Word), packet for registrants.

Send the documents by e-mail or mail them to

X-Ray Program

Washington State Department of Health

P.O. Box 47827

Olympia WA 98504-7827

Personal Radiation Protection

Measuring radiation dosage

When radiation passes through the body, some of it gets absorbed. The x-rays that are not absorbed are used to create the image. The amount that is absorbed contributes to the patient's radiation dose. The radiation that passes through the body does not. The scientific unit of measurement for whole body radiation dose, called "effective dose," is the millisievert (mSv). Other radiation dose measurement units include rad, rem, roentgen, sievert, and gray.

Doctors use "effective dose" when they talk about the risk of radiation to the entire body. Risk refers to possible side effects, such as the chance of developing a cancer later in life. Effective dose takes into account how sensitive different tissues are to radiation. If you have an x-ray exam that includes tissues or organs that are more sensitive to radiation, your effective dose will be higher. Effective dose allows your doctor to evaluate your risk and compare it to common, everyday sources of exposure, such as natural background radiation.

Naturally-occurring "background" radiation

We are exposed to natural sources of radiation all the time. According to recent estimates, the average person in the U.S. receives an effective dose of about 3 mSv per year from natural radiation, which includes cosmic radiation from outer space. These natural "background doses" vary according to where you live.

People living at high altitudes such as Colorado or New Mexico receive about 1.5 mSv more per year than those living near sea level. A coast-to-coast round trip airline flight is about 0.03 mSv due to exposure to cosmic rays. The largest source of background radiation comes from radon gas in our homes (about 2 mSv per year). Like other sources of background radiation, the amount of radon exposure varies widely depending on where you live.

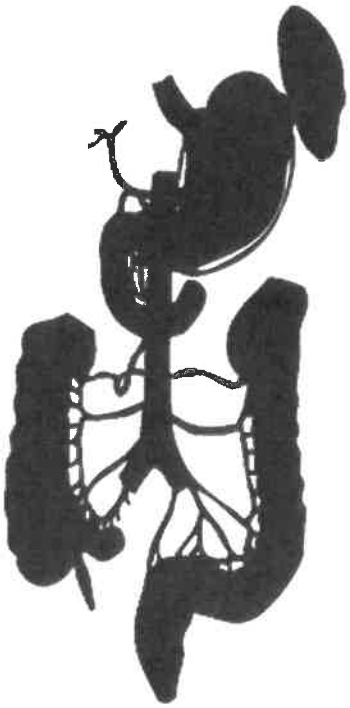
To put it simply, the amount of radiation from one adult chest x-ray (0.1 mSv) is about the same as 10 days of natural background radiation that we are all exposed to as part of our daily living.

Effective radiation dose in adults

Here are some approximate comparisons of background radiation and effective radiation dose in adults for several radiology procedures described on this website.

Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
Computed Tomography (CT)–Abdomen and Pelvis	10 mSv	3 years

ABDOMINAL REGION



Computed Tomography (CT)–Abdomen and Pelvis, repeated with and without contrast material	20 mSv	7 years
Computed Tomography (CT)–Colonography	6 mSv	2 years
Intravenous Pyelogram (IVP)	3 mSv	1 year
Barium Enema (Lower GI X-ray)	8 mSv	3 years
Upper GI Study with Barium	6 mSv	2 years

BONE

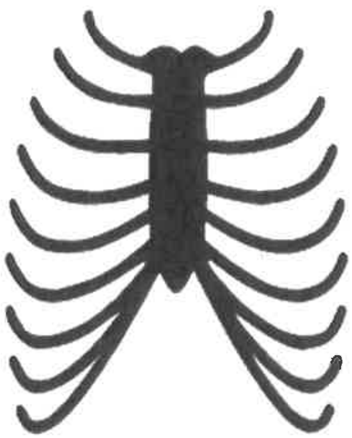
Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
Spine X-ray	1.5 mSv	6 months
Extremity (hand, foot, etc.) X-ray	0.001 mSv	3 hours

Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
Computed Tomography (CT)–Head	2 mSv	8 months
Computed Tomography (CT)–Head, repeated with and without contrast material	4 mSv	16 months

CENTRAL NERVOUS SYSTEM

Computed Tomography (CT)–Spine	6 mSv	2 years

CHEST



Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
Computed Tomography (CT)–Chest	7 mSv	2 years
Computed Tomography (CT)–Lung Cancer Screening	1.5 mSv	6 months
Chest X-ray	0.1 mSv	10 days

DENTAL

Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
Dental X-ray	0.005 mSv	1 day

Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:

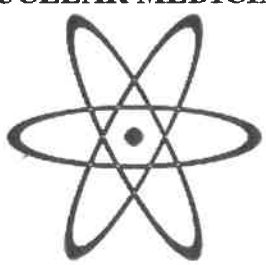
HEART

Coronary Computed Tomography Angiography (CTA)	12 mSv	4 years
Cardiac CT for Calcium Scoring	3 mSv	1 year

MEN'S IMAGING

Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
Bone Densitometry (DEXA)	0.001 mSv	3 hours

NUCLEAR MEDICINE

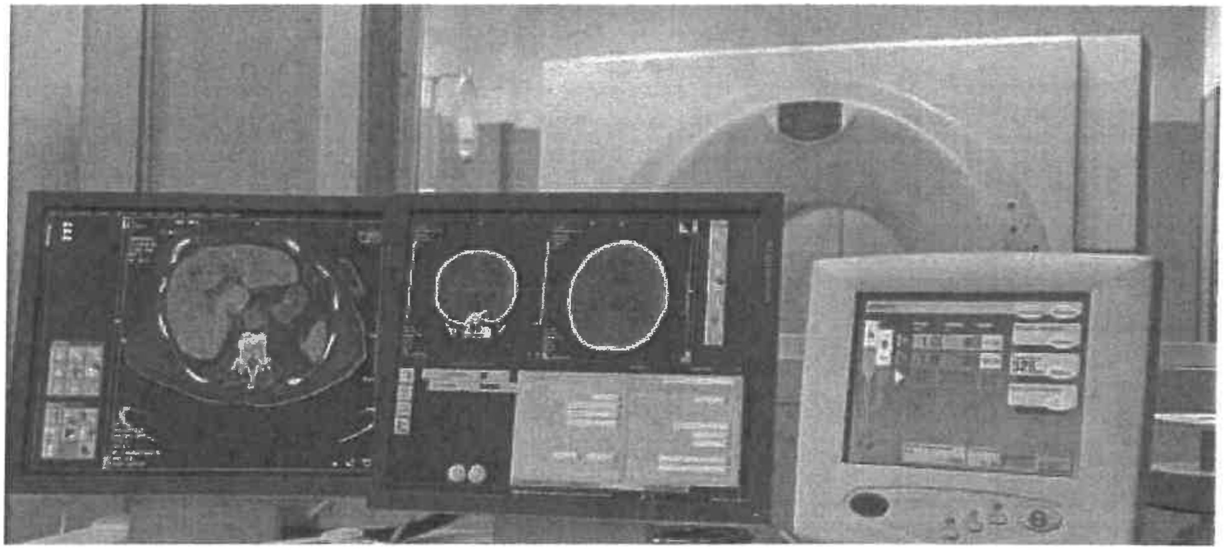


Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
Positron Emission Tomography–Computed Tomography (PET/CT)	25 mSv	8 years

WOMEN'S IMAGING

Procedure	Approximate effective radiation dose	Comparable to natural background radiation for:
Bone Densitometry (DEXA)	0.001 mSv	3 hours
Mammography	0.4 mSv	7 weeks

X-Ray modalities and Test equipment

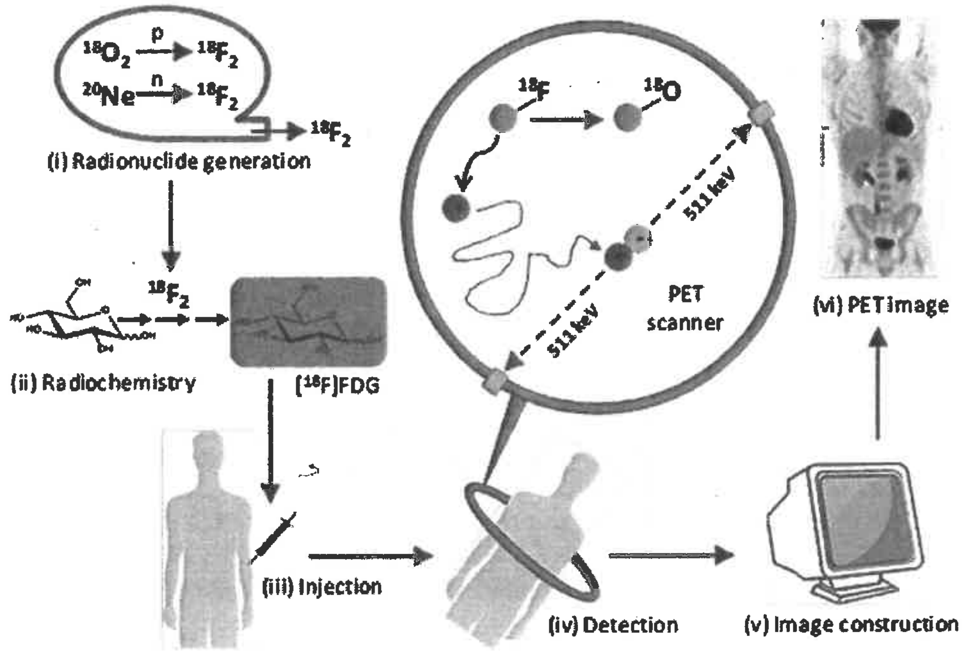


Medical Imaging Modalities involving X-rays and Medical Radiation

Medical imaging modalities, for example, includes magnetic resonance imaging (MRI), ultrasound, medical radiation, angiography and computed tomography (CT) scanners. In addition, to several scanning techniques to visualise the human body for diagnostic and treatment purposes. Also, these modalities are very useful for patient follow-up, with regards to the progress of the disease state, which has already been diagnosed, and/or is undergoing a treatment plan. The vast majority of imaging is based on the application of x-rays and ultrasound (US). These **medical imaging modalities** are involved in all levels of hospital care. In addition, they are instrumental in the public health and preventive medicine settings as well as in the curative and further extending to palliative care. The main objective is to establish the correct diagnoses.

Medical Radiation

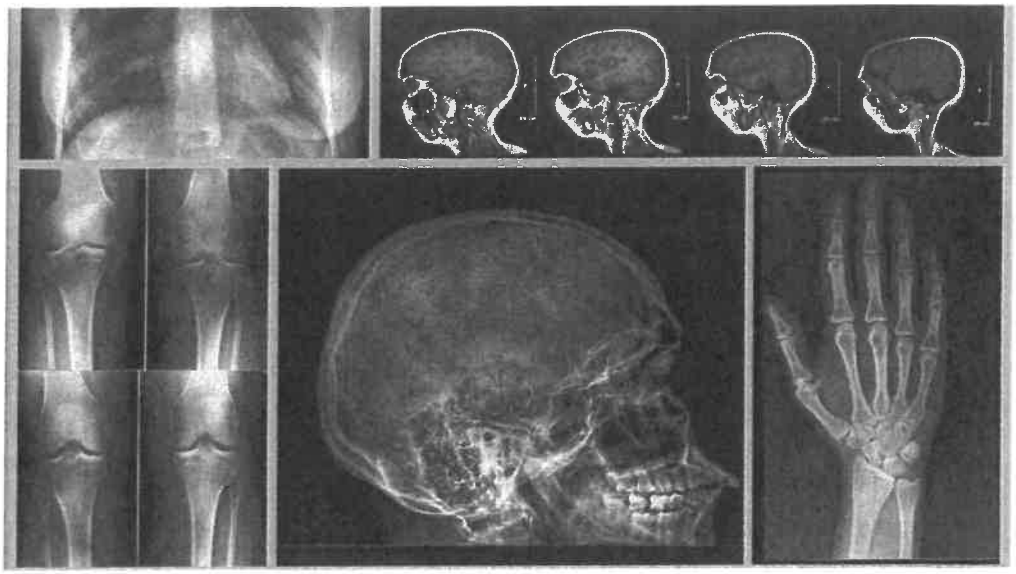
Medical imaging modalities in a clinical setting is a vital contribution to the overall diagnosis of the patient and help in the decision of an overall treatment plan. The utilisation of imaging techniques in *medical radiation* is increasing with new technological advances in medical sciences. Therefore, in the spectrum of a broad range of imaging modalities are the specialities of nuclear medicine, positron emission tomography (PET), magnetic resonance imaging (MRI) and ultrasound. Overall, imaging for medical radiation purposes involves a team of radiologists, radiographers and medical physicists.



Stages of PET Scanning

(Patching SG. Journal of Diagnostic Imaging in Therapy. 2015; 2(1): 30-102. CrossRef)

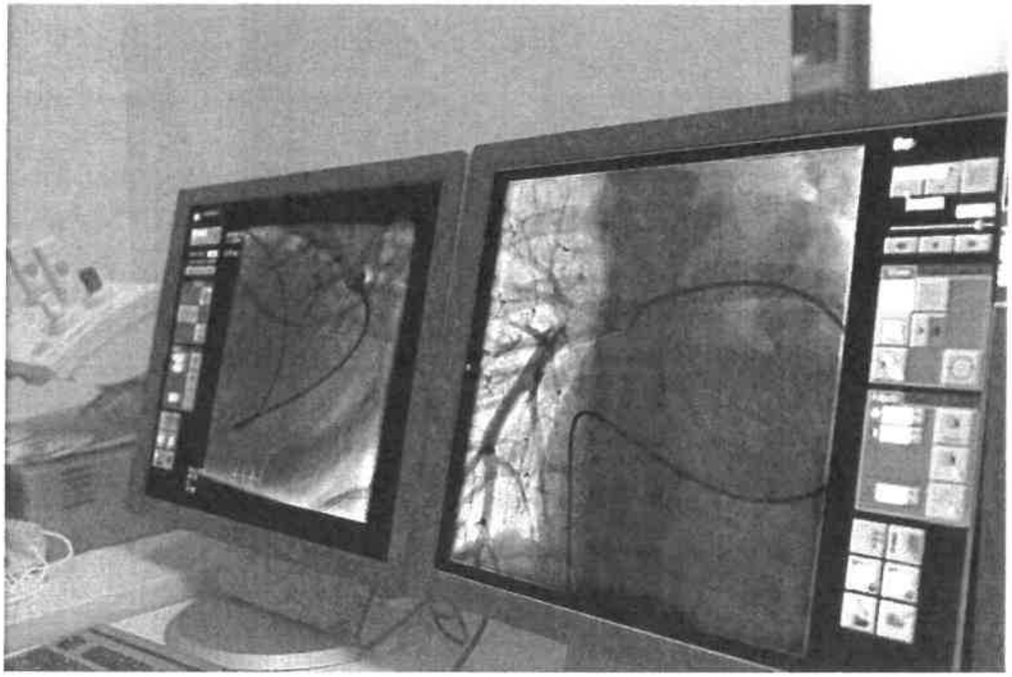
Medical imaging modalities involve a multidisciplinary approach to obtain a correct diagnosis for the individual patient with the aim of providing a personalised approach to patient care. These imaging techniques can be applied as non-invasive methods to view inside the human body, without any surgical intervention. They can be used to assist diagnosis or treat a variety of medical conditions. Medical imaging techniques utilise radiation that is part of the electromagnetic spectrum. These include imaging x-rays which are the conventional X-ray, computed tomography (CT) and mammography. To improve x-ray image quality, a contrast agent can be used, for example, in angiography examinations.



Radiography

Medical Imaging Modalities

Furthermore, imaging utilised in nuclear medicine and angiography can be attributed to several techniques to visualise biological processes. The radiopharmaceuticals used are usually small amounts of radioactive markers: these are used in molecular imaging. Other non-radioactive types of imaging include magnetic resonance imaging (MRI) and ultrasound (US) imaging. MRI uses strong magnetic fields, which do not produce any known irreversible biological effects in humans. Diagnostic ultrasound (US) systems use high-frequency sound waves to produce images of internal body organs and soft tissue. Several medical imaging modalities use radiation uses x-ray beams that are projected onto the body. When these x-ray beams pass through the human body some are absorbed, and the resultant image is detected on the other side of the body.



Angiography

Some types of medical imaging function without using ionising radiation; for example, magnetic resonance imaging (MRI), angiography, ultrasound imaging and these have significant applications in the diagnosis of disease. Medical imaging modalities include positron emission tomography (PET), single photon emission computed tomography (SPECT) and hybrid imaging systems. Alternatively, other systems use the application of radio-guided surgery (RGS) and this extends to positron emission mammography (PEM). In addition, there is the application of short and long-lived radioisotopes for research and development of new imaging agents and associated targeted therapies. Other techniques include magnetic resonance imaging (MRI), computed tomography (CT), ultrasound (US) imaging and planar x-ray (digital, analogue and portable) systems.

The special resolution required to elucidate detailed images of various structures within the human body are the main practical limitations of current medical imaging modalities. However, the rate of image acquisitions has increased over the last decade; this does not allow for the sensitivity required in order to express anatomical structure and function which is limited by the radiation dose amongst other factors.

Spatial Resolution of Medical Imaging Modalities

Imaging Modality	Spatial Resolution (mm)	
	Animal	Clinical
PET	1-2	6-10
SPECT	0.5-2	7-15
OPTICAL	2-5 (Visible to IR)	

MRI	0.025-0.1	0.2
US	0.05-0.5	0.1-1
CT	0.03-0.4	0.5-1

Medical imaging modalities will not be dictated by the advancements in imaging quality, but more likely the objective will be to reduce the cost and scanning time including exposure to radiation. These technical innovations allow for the rational conclusion that medical radiation dose, scanning speed, image resolution and sensitivity including cost per patient will all be elements of personalised medicine in the future.

Consequently, the medical physicist will play a pivotal role to further these challenges: especially to extend knowledge and understanding of the effect of which signals used to construct 3-D time-dependent images.

In particular, it is important to account for the physical and biological factors that modulate the behaviour of different energy forms within the human body. Moreover, to understand how to interpret images and derive more crucial information regarding the patient's disease state in order to formulate a treatment plan which is personal to the patient.

As with the continual development and improvements in imaging, it is essential to understand the specific biological episode associated with each specific disease state. It would be crucial to design medical imaging modalities that can recognise a 'fingerprint' that can be attributed to an individual disease.

Furthermore, new imaging modalities would be used to evaluate changes in tissue composition resulting from a disease like fibrosis. In this case, the physiological parameter would be the reduction of blood flow in arteries according to angiography. Other techniques could evaluate the change in conductivity or magnetic susceptibility of brain tissue. All of these improvements could help in the understanding of the contrast mechanisms in several medical imaging modalities.

In essence, it is important to make use of the data within digital images to develop more quantitative tissue characterisation from these anatomical scans. For example, functional magnetic resonance imaging (fMRI) has transformed understanding the construction of the brain.

This imaging technique has provided the exact relationship between the MRI signals used to map neural activity. However, fundamental neurochemical and electrophysiological processes are not well defined.

Diagnostic imaging tools provide powerful techniques to locate biological processes within the human body. This includes spatial heterogeneity and related changes to the different regions within the fine detail surrounding the anatomical structure.

Advancements in medical imaging modalities will contribute to an overall personalised treatment plan for each patient. This can only be guaranteed by continuing translational research in the design of novel radiopharmaceuticals and biomarkers in order to increase the efforts to devise robust personalised treatment plans for individual patients.

All the above imaging modalities are discussed in the Journal of Diagnostic Imaging in Therapy according to the aims and scope.

Radiology

The Radiology product line offers a wide range of solutions for maintaining the accuracy of medical imaging equipment within the radiographic, fluoroscopic and CT modalities. The latest development is the Model 464 ACR CT Phantom that has become the new testing standard for CT scanners as defined by the ACR accreditation program.

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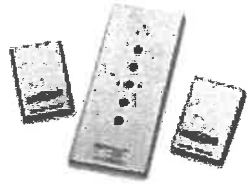

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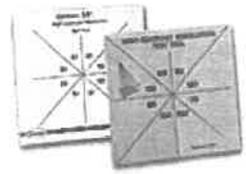

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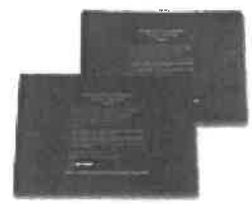

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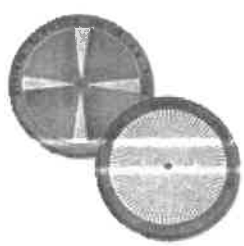

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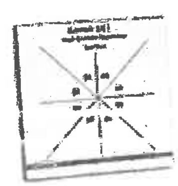

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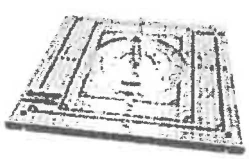

Pro-Fluo 150
Pro-Project
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Gammex
MA0438 MA0439
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Resolution Test Pattern (Call for Intl pricing)
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MA0437
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1 2 3

Half value layer

http://qcinradiography.weebly.com/half-value-layer

Laura LeBlanc, 1204502

The intensity of an x-ray beam is an important property in radiography and can be reduced as it penetrates an object by absorption or scattering. Reduction in the intensity of the beam can be affected by the atomic number of the absorbing material or beam energy. In radiography, technologists use the half value layer (HVL) to measure the quality or intensity of the beam. The HVL of an x-ray beam is defined as the amount of absorbing material that is needed to reduce the beam to half of its original potential. HVL is an indirect measure of photon energy or beam hardness. HVL is an important quality control test as it is used to measure whether or not there is sufficient filtration in the x-ray beam to remove low energy radiation, which can be damaging. It also helps to determine the type and thickness of shielding required in the facility.

In this experiment, the purpose is to measure the quality of the x-ray beam. The materials necessary and the setup are outlined below in Figure 1.

Figure 1:

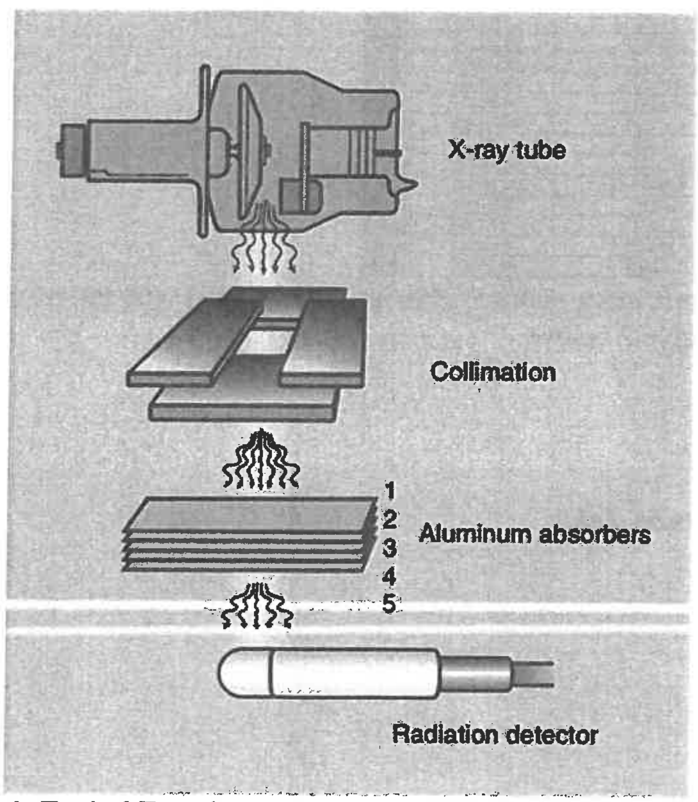


Figure 1: Typical Experiment Arrangement for Determination of HVL.

In this experiment, 1mm thick aluminum sheets were used as attenuating material. The beam energy was tested at 70 kVp, 90 kVp and 120 kVp with a range from 0-7mm of aluminum thickness. First, the exposure was measured at 70 kVp with 0mm of added filtration and with each subsequent exposure, 1mm of aluminum was added until an exposure with 7mm was achieved. This was repeated at 90 kVp and 120 kVp. The exposure was measured using the Cobia Smart X-ray Meter in milligray and microgray and the results are included in the table below (Table 1).

Table 1

Data Sheet for Half Value Layer

Added Filtration mm Al	mAs	Average Exposure (mGy)	Average Exposure converted to mR	Average Intensity mR/mAs
0	40	1.75	201.25	5.0313
1	40	1.297	149.155	3.7289
2	40	1.052	120.98	3.0245
3	40	0.8024	92.276	2.3069
4	40	0.6652	76.498	1.9125
5	40	0.55115	63.38225	1.5846
6	40	0.46245	53.18175	1.3295
7	40	0.384	44.16	1.1040
0	40	2.805	322.575	8.0644
1	40	2.1935	252.2525	6.3063
2	40	1.789	205.735	5.1434
3	40	1.475	169.625	4.2406
4	40	1.2645	145.4175	3.6354
5	40	1.0875	125.0625	3.1266
6	40	0.9429	108.4335	2.7108
7	40	0.80855	92.98325	2.3246
0	40	4.5775	526.4125	13.1603
1	40	3.82	439.3	10.9825
2	40	3.2255	370.9325	9.2733
3	40	2.7915	321.0225	8.0256
4	40	2.4615	283.0725	7.0768
5	40	2.185	251.275	6.2819
6	40	1.941	223.215	5.5804
7	40	1.7095	196.5925	4.9148

Conversion of mGy to mR:
1mGy = 115 mR

After calculating the mR/mAs, another table was constructed with the percentage transmission. This can be seen in Table 2 below.

Table 2

Percentage Transmission Table

KVp	Added Filtration	Average Intensity mR/mAs	% Transmission
70	0	5.0313	100.00%
70	1	3.7289	74.11%
70	2	3.0245	60.11%
70	3	2.3069	45.85%
70	4	1.9125	38.01%
70	5	1.5846	31.49%
70	6	1.3295	26.42%
70	7	1.1040	21.94%
90	0	8.0640	100.00%
90	1	6.3063	78.20%
90	2	5.1434	63.78%
90	3	4.2406	52.59%
90	4	3.6354	45.08%
90	5	3.1266	38.77%
90	6	2.7108	33.62%
90	7	2.3246	28.83%
120	0	13.1603	100.00%
120	1	10.9825	83.45%
120	2	9.2733	70.46%
120	3	8.0256	60.98%
120	4	7.0768	53.77%
120	5	6.2819	47.73%
120	6	5.5804	42.40%
120	7	4.9148	37.35%

A plot (Figure 2) was constructed using the percentage transmission values versus the thickness of aluminum (in mm) used for the 3 tube voltages.

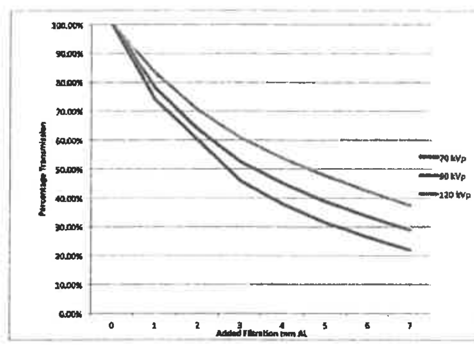


Figure 2: Percentage Transmission per Thickness Absorber for 70, 90, and 120 kVp.

Next, using the plot, the HVL for each curve was calculated. This can be seen in figures 3, 4 & 5. Using the percentage transmission that was calculated above, a straight-line was drawn from 50% transmission to the curve. This point represents the amount or thickness of aluminum required to reduce the x-ray beam to half of it's original intensity. This step was repeated for 90 & 120 kVp.

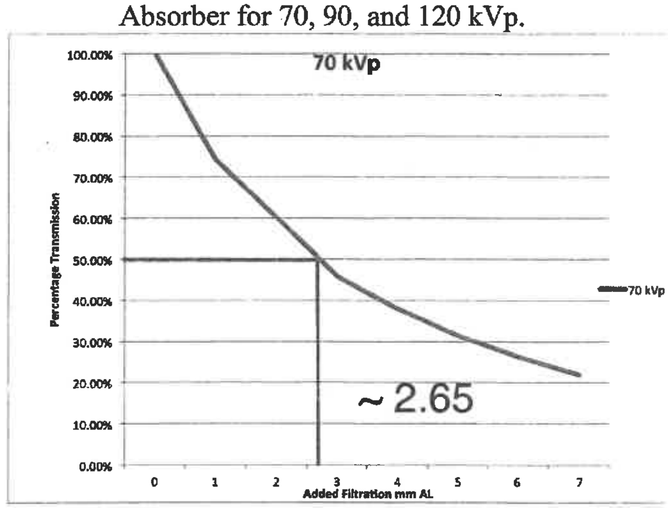


Figure 3: HVL at 70 kVp

The results are summarized in the table below (Figure 6).

RESULTS	
Tube Voltage, kVp	HVL, mm Al
70	2.65
90	3.3
120	4.7

Figure 6: HVL Results Table

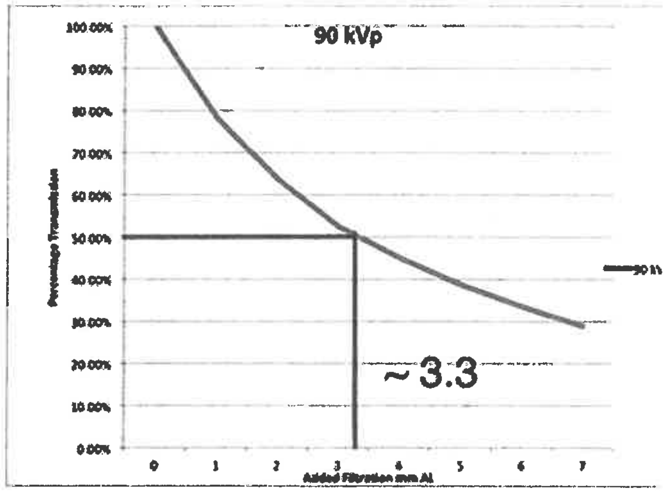


Figure 4: HVL at 90 kVp

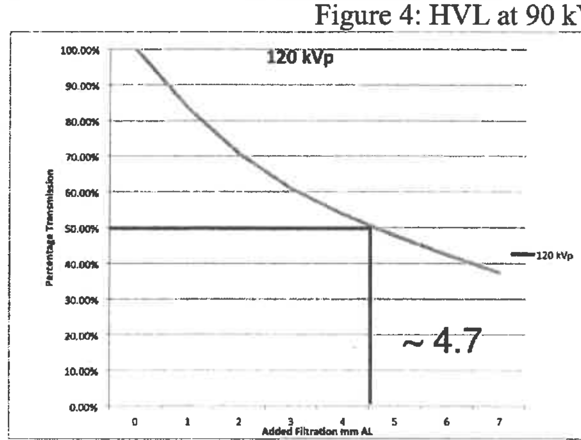


Figure 5: HVL at 120 kVp

Below is a table set out by Safety Code 35 (S.C. 35). The table shows the minimum HVL values that the safety code recommends.

Table 8: Minimum Half-Value Layers of aluminum for given X-ray tube voltages (IEC 2008)

X-ray Tube Voltage (kV)	Half-Value Layer of Aluminum (mm)
70	2.5
80	2.9
90	3.2
100	3.6
110	3.9
120	4.3
130	4.7
140	5.0
150	5.4

As outlined by Safety Code 35, there must be radiation absorbing filters in place that provide a certain degree of attenuation. This means that the HVL of aluminum must not be less than the values stated in Table 8 for a specific kVp. Comparing the values from Table 3: HVL Results table to Table 8 from Safety Code 35, it is clear that no corrective action is required. The slight differences seen between

Table 3 and Table 8 of the Safety Code could have occurred due to: too much added or inherent filtration resulting in a hardened beam that filtered more than what was necessary of the damaging low energy photons.

On the right, are the standards listed in Table 8 by H.A.R.P.. According to H.A.R.P., the HVL of aluminum must not be less than the values stated. Comparing the values from Table 3: HVL results table to Table 7 from H.A.R.P., no corrective action is required meaning the values obtained in the lab fall within specified standards.

TABLE 8

Column 1 Measured Potential (kilovolts peak)	Column 2 Minimum Half-value Layer (millimetres of aluminum)
30	0.3
40	0.4
49	0.5
50	1.2
60	1.3
70	1.5
71	2.1
80	2.3
90	2.5
100	2.7
110	3.0
120	3.2
130	3.5
140	3.8
150	4.1

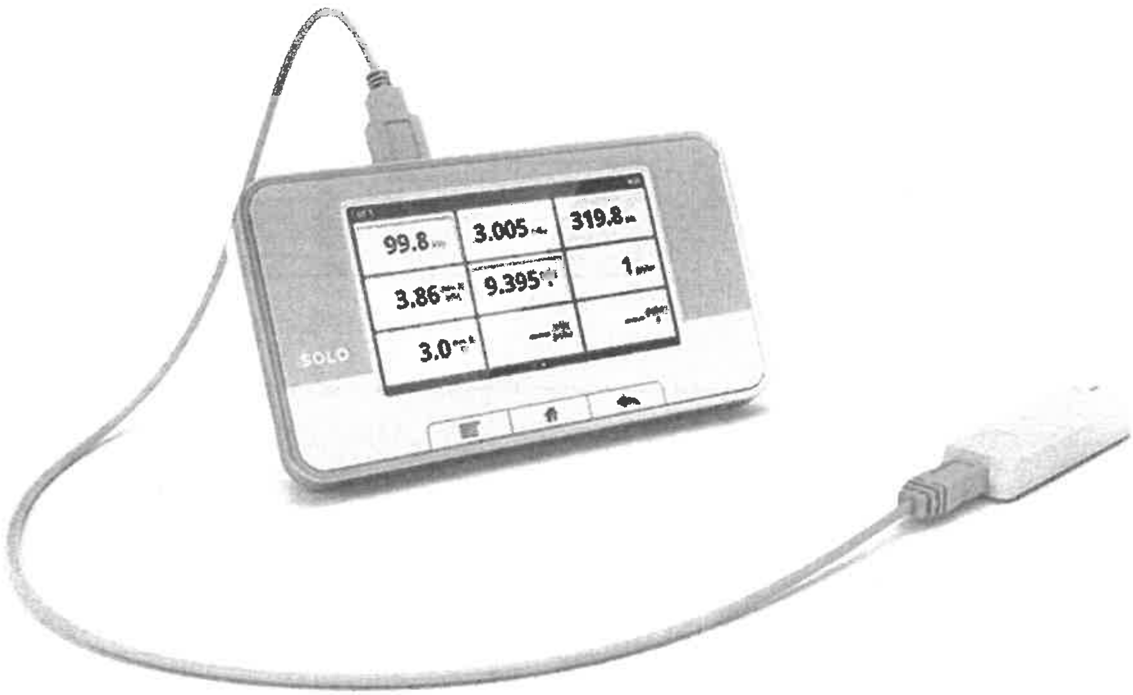
TABLE [illegible] Minimum HVL Values for Diagnostic X-Ray Units

X-Ray Tube Voltage (kilovolt peak)		Minimum HVL (mm of Al)	
Designed Operating Range	Measured Operating Potential	Specified Dental Systems	Other X-Ray Systems
Below 50	30	1.5	0.3
	40	1.5	0.4
	49	1.5	0.5
50 to 70	50	1.5	1.2
	60	1.5	1.3
	70	1.5	1.5
Above 70	71	2.1	2.1
	80	2.3	2.3
	90	2.5	2.5
	100	2.7	2.7
	110	3.0	3.0
	120	3.2	3.2
	130	3.5	3.5
	140	3.8	3.8
	150	4.1	4.1

According to Papp, a filtration check is performed before new equipment is used and then annually, unless service has been performed on the x-ray tube or collimator. The best way to determine if adequate filtration exists is to measure HVL as it is not possible to measure inherent filtration. The filament evaporates as the tube is used, adding a layer of tungsten to the inside of the x-ray tube window. So by measuring the HVL, it doesn't matter what material is in the path of the beam, as long as sufficient beam quality is obtained. Another test can be performed to determine if adequate filtration is present, if HVL cannot be determined. However, this test only determines if adequate filtration is present and doesn't account for the total amount of filtration. This test is done using a 2.3mm thick piece of aluminum and a dosimeter and should not replace the HVL measurement during quality control testing. According to Table 7-1 in Papp and Table 3: HVL results, no corrective action is required.

Determining HVL is important and failure to comply to standards defined by S.C. 35, H.A.R.P. and Papp would result in added dose to patient. The low energy photons will not be filtered out and will add entrance skin exposure to patients, increasing their overall dose.

RaySafe X2 Solo



All you need for your modalities

RaySafe X2 Solo is a new product line from RaySafe that covers the measurement needs of your specific X-ray modalities. It's based on the same technology as RaySafe X2, highly esteemed for its user-friendliness and performance, but instead of multi-modality capability, each model meets specific needs. Within your X-ray modalities the X2 Solo will meet all your QA or service measurement needs.

RaySafe X2 Solo users will enjoy a large touch screen showing all parameters simultaneously, sensors ready for measurements without special settings or modes and a base unit storing all readings and showing full waveforms. Plus, much more. It's true ease-of-use, which saves valuable time and minimizes the risk of making faulty measurements. Or as RaySafe X2 customers say: "It just works".

Less effort. More insight.

RaySafe X2 Solo removes unnecessary steps in taking a measurement – like positioning the sensor, choosing a setting, or interpreting results. The R/F and DENT sensors are both orientation independent so the only thing you need to do is to place the sensor in the X-ray beam and turn on the instrument. The rest is automatic – no menus or special settings needed.

RaySafe X2 Technology

RaySafe X2 Solo combines state-of-the-art sensor technology with an intuitive and proven user interface, making it the ultimate in user friendliness. Each X2 Solo includes a specific sensor to

Storing, Sharing and Viewing the image

About DICOM

DICOM (Digital Imaging and Communications in Medicine) is a standard for handling, storing, printing, and transmitting information in medical imaging. It includes a file format definition and a network communications protocol.

The communication protocol is an application protocol that uses TCP/IP to communicate between systems. DICOM files can be exchanged between two entities that are capable of receiving image and patient data in DICOM format.

The National Electrical Manufacturers Association (NEMA) holds the copyright to this standard. It was developed by the DICOM Standards Committee, whose members are also partly members of NEMA.

https://www.dicomlibrary.com/

Picture archiving and communication system

PACS

A **picture archiving and communication system (PACS)** is a medical imaging technology which provides economical storage and convenient access to images from multiple modalities (source machine types).[1] Electronic images and reports are transmitted digitally via PACS; this eliminates the need to manually file, retrieve, or transport film jackets, the folders used to store and protect X-ray film. The universal format for PACS image storage and transfer is DICOM (Digital Imaging and Communications in Medicine). Non-image data, such as scanned documents, may be incorporated using consumer industry standard formats like PDF (Portable Document Format), once encapsulated in DICOM. A PACS consists of four major components: The imaging modalities such as X-ray plain film (PF), computed tomography (CT) and magnetic resonance imaging (MRI), a secured network for the transmission of patient information, workstations for interpreting and reviewing images, and archives for the storage and retrieval of images and reports. Combined with available and emerging web technology, PACS has the ability to deliver timely and efficient access to images, interpretations, and related data. PACS reduces the physical and time barriers associated with traditional film-based image retrieval, distribution, and display.

Types of images

Most PACSs handle images from various medical imaging instruments, including ultrasound (US), magnetic resonance (MR), Nuclear Medicine imaging, positron emission tomography (PET), computed tomography (CT), endoscopy (ES), mammograms (MG), digital radiography (DR), phosphor plate radiography, Histopathology, ophthalmology, etc. Additional types of image formats are always being added. Clinical areas beyond radiology; cardiology, oncology, gastroenterology, and even the laboratory are creating medical images that can be incorporated into PACS. (see DICOM Application areas).

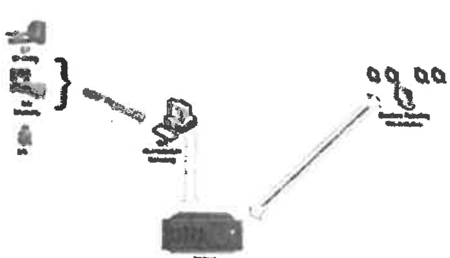
Uses

PACS has four main uses:

- Hard copy replacement: PACS replaces hard-copy based means of managing medical images, such as film archives. With the decreasing price of digital storage, PACSs provide a growing cost and space advantage over film archives in addition to the instant access to prior images at the same institution. Digital copies are referred to as Soft-copy.
- Remote access: It expands on the possibilities of conventional systems by providing capabilities of off-site viewing and reporting (distance education, telediagnosis). It enables practitioners in different physical locations to access the same information simultaneously for teleradiology.
- Electronic image integration platform: PACS provides the electronic platform for radiology images interfacing with other medical automation systems such as Hospital Information System (HIS), Electronic Medical Record (EMR), Practice Management Software, and Radiology Information System (RIS).
- Radiology Workflow Management: PACS is used by radiology personnel to manage the workflow of patient exams.

PACS is offered by virtually all the major medical imaging equipment manufacturers, medical IT companies and many independent software companies. Basic PACS software can be found free on the Internet.

Architecture



PACS workflow diagram

The architecture is the physical implementation of required functionality, or what one sees from the outside. There are different views, depending on the user. A radiologist typically sees a viewing station, a technologist a QA workstation, while a PACS administrator might spend most of their time in the climate-controlled computer room. The composite view is rather different for the various vendors.[2]

Typically a PACS consists of a multitude of devices. The first step in typical PACS systems is the modality. Modalities are typically computed tomography (CT), ultrasound, nuclear medicine, positron emission tomography (PET), and magnetic resonance imaging (MRI). Depending on the facility's workflow most modalities send to a quality assurance (QA) workstation or sometimes called a PACS gateway. The QA workstation is a checkpoint to make sure patient demographics are correct as well as other important attributes of a study. If the study information is correct the images are passed to the archive for storage. The central storage device (archive) stores images and in some cases reports, measurements and other information that resides with the images. The next step in the PACS workflow is the reading workstations. The reading workstation is where the radiologist reviews the patient's study and formulates their diagnosis. Normally tied to the reading workstation is a reporting package that assists the radiologist with dictating the final report. Reporting software is optional and there are various ways in which doctors prefer to dictate their report. Ancillary to the workflow mentioned, there is normally CD/DVD authoring software used to burn patient studies for distribution to patients or referring physicians. The diagram above shows a typical workflow in most imaging centers and hospitals. Note that this section does not cover integration to a Radiology Information System, Hospital Information System and other such front-end system that relates to the PACS workflow.

More and more PACS include web-based interfaces to utilize the internet or a Wide Area Network as their means of communication, usually via VPN (Virtual Private Network) or SSL (Secure Sockets Layer). The clients side software may use ActiveX, JavaScript and/or a Java Applet. More robust PACS clients are full applications which can utilize the full resources of the computer they are executing on and are unaffected by the frequent unattended Web Browser and Java updates. As the need for distribution of images and reports becomes more widespread there is a push for PACS systems to support DICOM part 18 of the DICOM standard. Web Access to DICOM Objects (WADO) creates the necessary standard to expose images and reports over the web through truly portable medium. Without stepping outside the focus of the PACS architecture, WADO becomes the solution to cross platform capability and can increase the distribution of images and reports to referring physicians and patients.

PACS image backup is a critical, but sometimes overlooked, part of the PACS Architecture (see below). HIPAA requires that backup copies of patient images be made in case of image loss from the PACS. There are several methods of backing up the images, but they typically involve automatically sending copies of the images to a separate computer for storage, preferably off-site.

Ultrasound

An ultrasound scan uses high-frequency sound waves to create images of the inside of the body. It is suitable for use during pregnancy.

Ultrasound scans, or sonography, are safe because they use sound waves or echoes to make an image, instead of radiation.

Ultrasound scans are used to evaluate fetal development, and they can detect problems in the liver, heart, kidney, or abdomen. They may also assist in performing certain types of biopsy.

The image produced is called a sonogram.

- Fast facts on ultrasound scans

Here are some key points about ultrasound scans. More detail is in the main article.

- Ultrasound scans are safe and widely used.
- They are often used to check the progress of a pregnancy.
- They are used for diagnosis or treatment.
- No special preparation is normally necessary before an ultrasound scan.

Concept

Ultrasound scans are carried out by a sonographer.

The person who performs an ultrasound scan is called a sonographer, but the images are interpreted by radiologists, cardiologists, or other specialists.

The sonographer usually holds a transducer, a hand-held device, like a wand, which is placed on the patient's skin.

Ultrasound is sound that travels through soft tissue and fluids, but it bounces back, or echoes, off denser surfaces. This is how it creates an image.

The term "ultrasound" refers to sound with a frequency that humans cannot hear.

For diagnostic uses, the ultrasound is usually between 2 and 18 megahertz (MHz).

Higher frequencies provide better quality images but are more readily absorbed by the skin and other tissue, so they cannot penetrate as deeply as lower frequencies.

Lower frequencies penetrate deeper, but the image quality is inferior.

How does it capture an image?

Ultrasound will travel through blood in the heart chamber, for example, but if it hits a heart valve, it will echo, or bounce back.

It will travel straight through the gallbladder if there are no gallstones, but if there are stones, it will bounce back from them.

The denser the object the ultrasound hits, the more of the ultrasound bounces back.

This bouncing back, or echo, gives the ultrasound image its features. Varying shades of gray reflect different densities.

Ultrasound transducers

The transducer, or wand, is normally placed on the surface of the patient's body, but some kinds are placed internally.

These can provide clearer, more informative images.

Examples are:

- an endovaginal transducer, for use in the vagina
- an endorectal transducer, for use in the rectum
- a transesophageal transducer, passed down the patient's throat for use in the esophagus

Some very small transducers can be placed onto the end of a catheter and inserted into blood vessels to examine the walls of blood vessels.

Uses

Ultrasound images are made from reflected sound, and a diagnosis can then be made.

Ultrasound is commonly used for diagnosis, for treatment, and for guidance during procedures such as biopsies.

It can be used to examine internal organs such as the liver and kidneys, the pancreas, the thyroid gland, the testes and the ovaries, and others.

An ultrasound scan can reveal whether a lump is a tumor. This could be cancerous, or a fluid-filled cyst.

It can help diagnose problems with soft tissues, muscles, blood vessels, tendons, and joints. It is used to investigate a frozen shoulder, tennis elbow, carpal tunnel syndrome, and others.

Circulatory problems

Doppler ultrasound can assess the flow of blood in a vessel or blood pressure. It can determine the speed of the blood flow and any obstructions.

An echocardiogram (ECG) is an example of Doppler ultrasound. It can be used to create images of the cardiovascular system and to measure blood flow and cardiac tissue movement at specific points.

A Doppler ultrasound can assess the function and state of cardiac valve areas, any abnormalities in the heart, valvular regurgitation, or blood leaking from valves, and it can show how well the heart pumps out blood.

It can also be used to:

- examine the walls of blood vessels
- check for DVT or an aneurysm
- check fetal heart and heartbeat
- evaluate for plaque buildup and clots
- assess for blockages or narrowing of arteries

A carotid duplex is a form of carotid ultrasonography that may include a Doppler ultrasound. This would reveal how blood cells move through the carotid arteries.

Ultrasound in anesthesiology

Ultrasound is often used by anesthetists to guide a needle with anesthetic solutions near nerves.

Ultrasound in emergency medicine

Ultrasound is commonly used in emergency medicine to assess various conditions, including:

- traumatic injuries
- pericardial tamponade

- fluid buildup around the heart
- hemoperitoneum, or blood leakage in the abdomen

Abdominal sonography

Gastroenterologists use ultrasound to generate images of the spleen, kidneys, bile ducts, gall bladder, liver, aorta, inferior vena cava, pancreas, and other solid organs located in the abdomen.

It can evaluate patients for suspected gallstones or inflammation of the gallbladder, known as cholecystitis.

It can detect if the appendix is swollen or inflamed, which would suggest appendicitis. Blood work would confirm an infection.

Fat and gas in the bowel can sometimes block the ultrasound waves, making diagnosis more difficult.

Newborn infants

The sonographer can perform an ultrasound scan on a newborn by placing the probe on the fontanelle, the soft spot on the top of the skull.

This can check for abnormalities in the brain, hydrocephalus, and periventricular leukomalacia, a form of white-matter brain injury.

As the fontanelle grows smaller in time, the quality of the images becomes poorer.

Obstetric ultrasonography

Ultrasound devices emit a high-frequency sound from their wand and can be used to give an image of the inside of a person's body, for example, during pregnancy.

Ultrasound is part of standard prenatal care. It gathers images of the fetus or embryo in the uterus.

Obstetric ultrasonography can reveal various aspects of both fetal and maternal health. It can also help doctors assess the progress of the pregnancy.

The probe or transducer is typically placed on the mother's abdomen, but sometimes it is placed in the vagina.

A transvaginal scan can provide a clearer picture during early pregnancy, and it may be a better option if the mother has obesity.

Doppler sonography shows the fetal heartbeat. It can help the doctor detect signs of abnormalities in the heart and blood vessels.

Ultrasound and urology

In urology, ultrasound can check:

- how much urine remains in the bladder after urinating
- the health of the organs in the pelvic region, including the uterus and testicles

In young, adult males, ultrasound can distinguish different types of swelling from testicular cancer.

Pelvic sonographies can be internal or external.

In a male, the internal sonogram may be inserted into the rectum. In a female, it might be inserted into the vagina.

This can provide information about the prostate gland, ovaries, or uterus.

Ultrasound scans of the pelvic floor can help the doctor determine the extent of, for example, a pelvic prolapse, incontinence, or obstructed defecation.

Musculoskeletal sonography

Ultrasound can be used to examine ligaments, bone surfaces, soft tissue masses, nerves, muscles, and tendons.

What to expect

An ultrasound can be done at a doctor's office, at an outpatient clinic, or in the hospital.

Most scans take between 20 and 60 minutes. It is not normally painful, and there is no noise.

In most cases, no special preparation is needed, but patients may wish to wear loose-fitting and comfortable clothing.

If the liver or gallbladder is affected, the patient may have to fast, or eat nothing, for several hours before the procedure.

For a scan during pregnancy, and especially early pregnancy, the patient should drink plenty of water and try to avoid urinating for some time before the test.

When the bladder is full, the scan produces a better image of the uterus.

The scan usually takes place in the radiology department of a hospital. A doctor or a specially-trained sonographer will carry out the test.

External ultrasound

The sonographer puts a lubricating gel onto the patient's skin and places a transducer over the lubricated skin.

The transducer is moved over the part of the body that needs to be examined. Examples include ultrasound examinations of a patient's heart or a fetus in the uterus.

The patient should not feel discomfort or pain. They will just feel the transducer over the skin.

During pregnancy, there may be slight discomfort because of the full bladder.

Internal ultrasound

If the internal reproductive organs or urinary system need to be evaluated, the transducer may be placed in the rectum for a man or in the vagina for a woman.

To evaluate some part of the digestive system, for example, the esophagus, the chest lymph nodes, or the stomach, an endoscope may be used.

A light and an ultrasound device are attached to the end of the endoscope, which inserted into the patient's body, usually through the mouth.

Before the procedure, patients are given medications to reduce any pain.

Internal ultrasound scans are less comfortable than external ones, and there is a slight risk of internal bleeding.

Safety

Most types of ultrasound are noninvasive, and they involve no ionizing radiation exposure. The procedure is believed to be very safe.

However, since the long-term risks are not established, unnecessary "keepsake" scans during pregnancy are not encouraged. Ultrasound during pregnancy is recommended only when medically needed.

Anyone who is allergic to latex should inform their doctor so that they will not use a latex-covered probe.

https://www.medicalnewstoday.com/articles/245491.php

Ultrasonic transducers

Ultrasonic transducers or **ultrasonic sensors** are a type of acoustic sensor divided into three broad categories: transmitters, receivers and transceivers. Transmitters convert electrical signals into ultrasound, receivers convert ultrasound into electrical signals, and transceivers can both transmit and receive ultrasound.

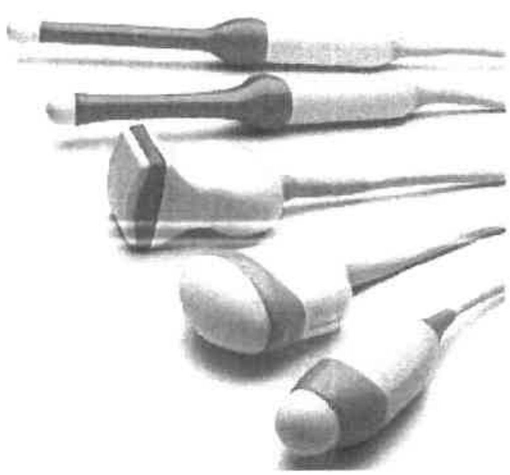
In a similar way to radar and sonar, ultrasonic transducers are used in systems which evaluate targets by interpreting the reflected signals. For example, by measuring the time between sending a signal and receiving an echo the distance of an object can be calculated. Passive ultrasonic sensors are basically microphones that detect ultrasonic noise that is present under certain conditions.

Ultrasonic probes and ultrasonic baths apply ultrasonic energy to agitate particles in a wide range of materials; See **Sonication**.

Medical ultrasonic transducers (probes) come in a variety of different shapes and sizes for use in making cross-sectional images of various parts of the body. The transducer may be passed over the surface and in contact with the body, or inserted into a body opening such as the rectum or vagina. Clinicians who perform ultrasound-guided procedures often use a probe positioning system to hold the ultrasonic transducer.

Air detection sensors are used in various roles.[*further explanation needed*] Non-invasive air detection is for the most critical situations where the safety of a patient is mandatory. Many of the variables, which can affect performance of amplitude or continuous-wave-based sensing systems, are eliminated or greatly reduced, thus yielding accurate and repeatable detection.

One key principle of in this technology is that the transmit signal consists of short bursts of ultrasonic energy. After each burst, the electronics looks for a return signal within a small window of time corresponding to the time it takes for the energy to pass through the vessel. Only signals received during this period will qualify for additional signal processing. This principle is



similar to radar range gating.

What is General Ultrasound Imaging?

Ultrasound is safe and painless, and produces pictures of the inside of the body using sound waves. Ultrasound imaging, also called ultrasound scanning or sonography, involves the use of a small transducer (probe) and ultrasound gel placed directly on the skin. High-frequency sound waves are transmitted from the probe through the gel into the body. The transducer collects the sounds that bounce back and a computer then uses those sound waves to create an image. Ultrasound examinations do not use ionizing radiation (as used in x-rays), thus there is no radiation exposure to the patient. Because ultrasound images are captured in real-time, they can show the structure and movement of the body's internal organs, as well as blood flowing through blood vessels.

Ultrasound imaging is a noninvasive medical test that helps physicians diagnose and treat medical conditions.

Conventional ultrasound displays the images in thin, flat sections of the body. Advancements in ultrasound technology include three-dimensional (3-D) ultrasound that formats the sound wave data into 3-D images.

A Doppler ultrasound study may be part of an ultrasound examination.

Doppler ultrasound, also called color Doppler ultrasonography, is a special ultrasound technique that allows the physician to see and evaluate blood flow through arteries and veins in the abdomen, arms, legs, neck and/or brain (in infants and children) or within various body organs such as the liver or kidneys.

There are three types of Doppler ultrasound:

- Color Doppler uses a computer to convert Doppler measurements into an array of colors to show the speed and direction of blood flow through a blood vessel.
- Power Doppler is a newer technique that is more sensitive than color Doppler and capable of providing greater detail of blood flow, especially when blood flow is little or minimal. Power Doppler, however, does not help the radiologist determine the direction of blood flow, which may be important in some situations.
- Spectral Doppler displays blood flow measurements graphically, in terms of the distance traveled per unit of time, rather than as a color picture. It can also convert blood flow information into a distinctive sound that can be heard with every heartbeat.

What are some common uses of the procedure?

Ultrasound examinations can help to diagnose a variety of conditions and to assess organ damage following illness.

Ultrasound is used to help physicians evaluate symptoms such as:

- pain
- swelling
- infection

Ultrasound is a useful way of examining many of the body's internal organs, including but not limited to the:

- heart and blood vessels, including the abdominal aorta and its major branches
- liver
- gallbladder
- spleen
- pancreas
- kidneys
- bladder
- uterus, ovaries, and unborn child (fetus) in pregnant patients
- eyes
- thyroid and parathyroid glands
- scrotum (testicles)
- brain in infants
- hips in infants
- spine in infants

Ultrasound is also used to:

- guide procedures such as needle biopsies, in which needles are used to sample cells from an abnormal area for laboratory testing.
- image the breasts and guide biopsy of breast cancer (*see the Ultrasound-Guided Breast Biopsy page.*
- diagnose a variety of heart conditions, including valve problems and congestive heart failure, and to assess damage after a heart attack. Ultrasound of the heart is commonly called an "echocardiogram" or "echo" for short.

Doppler ultrasound images can help the physician to see and evaluate:

- blockages to blood flow (such as clots)
- narrowing of vessels
- tumors and congenital vascular malformations
- reduced or absent blood flow to various organs
- greater than normal blood flow to different areas, which is sometimes seen in infections

With knowledge about the speed and volume of blood flow gained from a Doppler ultrasound image, the physician can often determine whether a patient is a good candidate for a procedure like angioplasty.

What does the equipment look like?

Ultrasound scanners consist of a console containing a computer and electronics, a video display screen and a transducer that is used to do the scanning. The transducer is a small hand-held device that resembles a microphone, attached to the scanner by a cord. Some exams may use different transducers (with different capabilities) during a single exam. The transducer sends out high-frequency sound waves (that the human ear cannot hear) into the body and then listens for the returning echoes from the tissues in the body. The principles are similar to sonar used by boats and submarines.

The ultrasound image is immediately visible on a video display screen that looks like a computer or television monitor. The image is created based on the amplitude (loudness), frequency (pitch) and time it takes for the ultrasound signal to return from the area within the patient that is being examined to the transducer (the device placed on the patient's skin to send and receive the returning sound waves), as well as the type of body structure and composition of body tissue through which the sound travels. A small amount of gel is put on the skin to allow the sound waves to travel from the transducer to the examined area within the body and then back again. Ultrasound is an excellent modality for some areas of the body while other areas, especially air-filled lungs, are poorly suited for ultrasound.

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How does the procedure work?

Ultrasound imaging is based on the same principles involved in the sonar used by bats, ships and fishermen. When a sound wave strikes an object, it bounces back, or echoes. By measuring these echo waves, it is possible to determine how far away the object is as well as the object's size, shape and consistency (whether the object is solid or filled with fluid).

In medicine, ultrasound is used to detect changes in appearance, size or contour of organs, tissues, and vessels or to detect abnormal masses, such as tumors.

In an ultrasound examination, a transducer both sends the sound waves into the body and receives the echoing waves. When the transducer is pressed against the skin, it directs small pulses of inaudible, high-frequency sound waves into the body. As the sound waves bounce off internal organs, fluids and tissues, the sensitive receiver in the transducer records tiny changes in the sound's pitch and direction. These signature waves are instantly measured and displayed by a computer, which in turn creates a real-time picture on the monitor. One or more frames of the moving pictures are typically captured as still images. Short video loops of the images may also be saved.

Doppler ultrasound, a special application of ultrasound, measures the direction and speed of blood cells as they move through vessels. The movement of blood cells causes a change in pitch of the reflected sound waves (called the Doppler effect). A computer collects and processes the sounds and creates graphs or color pictures that represent the flow of blood through the blood vessels.

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How is the procedure performed?

For most ultrasound exams, you will be positioned lying face-up on an examination table that can be tilted or moved. Patients may be turned to either side to improve the quality of the images.

After you are positioned on the examination table, the radiologist (a physician specifically trained to supervise and interpret radiology examinations) or sonographer will apply a warm water-based gel to the area of the body being studied. The gel will help the transducer make secure contact with the body and eliminate air pockets between the transducer and the skin that can block the sound waves from passing into your body. The transducer is placed on the body and moved back and forth over the area of interest until the desired images are captured.

There is usually no discomfort from pressure as the transducer is pressed against the area being examined. However, if scanning is performed over an area of tenderness, you may feel pressure or minor pain from the transducer.

Doppler sonography is performed using the same transducer.

Rarely, young children may need to be sedated in order to hold still for the procedure. Parents should ask about this beforehand and be made aware of food and drink restrictions that may be needed prior to sedation.

Once the imaging is complete, the clear ultrasound gel will be wiped off your skin. Any portions that are not wiped off will dry quickly. The ultrasound gel does not usually stain or discolor clothing.

In some ultrasound studies, the transducer is attached to a probe and inserted into a natural opening in the body. These exams include:

- **Transesophageal echocardiogram.** The transducer is inserted into the esophagus to obtain images of the heart.
- **Transrectal ultrasound.** The transducer is inserted into a man's rectum to view the prostate.
- **Transvaginal ultrasound.** The transducer is inserted into a woman's vagina to view the uterus and ovaries.

What are the benefits vs. risks?

Benefits

- Most ultrasound scanning is noninvasive (no needles or injections).
- Occasionally, an ultrasound exam may be temporarily uncomfortable, but it should not be painful.
- Ultrasound is widely available, easy-to-use and less expensive than other imaging methods.
- Ultrasound imaging is extremely safe and does not use any ionizing radiation.
- Ultrasound scanning gives a clear picture of soft tissues that do not show up well on x-ray images.
- Ultrasound is the preferred imaging modality for the diagnosis and monitoring of pregnant women and their unborn babies.
- Ultrasound provides real-time imaging, making it a good tool for guiding minimally invasive procedures such as needle biopsies and fluid aspiration.

Risks

- For standard diagnostic ultrasound, there are no known harmful effects on humans.

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What are the limitations of General Ultrasound Imaging?

Ultrasound waves are disrupted by air or gas; therefore ultrasound is not an ideal imaging technique for air-filled bowel or organs obscured by the bowel. In most cases, barium exams, CT scanning, and MRI are the methods of choice in such a setting.

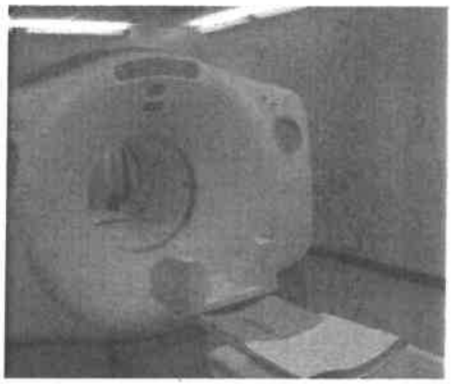
Large patients are more difficult to image by ultrasound because greater amounts of tissue attenuate (weaken) the sound waves as they pass deeper into the body and need to be returned to the transducer for analysis.

Ultrasound has difficulty penetrating bone and, therefore, can only see the outer surface of bony structures and not what lies within (except in infants who have more cartilage in their skeletons than older children or adults). For visualizing internal structure of bones or certain joints, other imaging modalities such as MRI are typically used.

Magnetic Resonance Imaging (MRI)

- What is MRI?
- How does MRI work?
- What is MRI used for?
- Are there risks?
- What are examples of NIBIB-funded projects in MRI?

What is MRI?



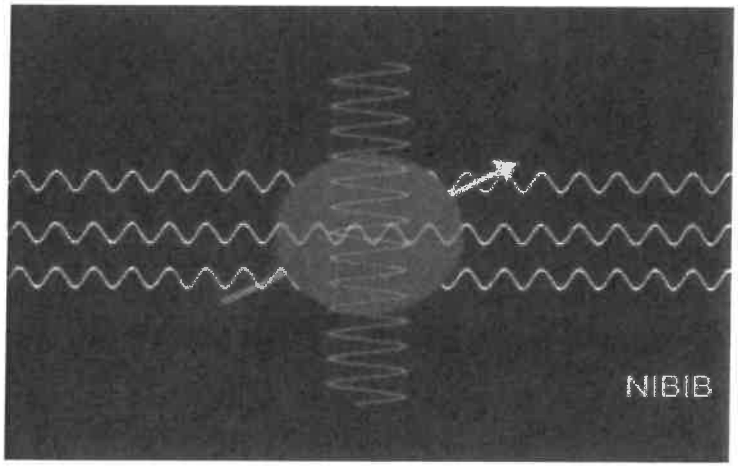
MRI is a non-invasive imaging technology that produces three dimensional detailed anatomical images. It is often used for disease detection, diagnosis, and treatment monitoring. It is based on sophisticated technology that excites and detects the change in the direction of the rotational axis of protons found in the water that makes up living tissues.

How does MRI work?

MRI of a knee

MRIs employ powerful magnets which produce a strong magnetic field that forces protons in the body to align with that field. When a radiofrequency current is then pulsed through the patient, the protons are stimulated, and spin out of equilibrium, straining against the pull of the magnetic field. When the radiofrequency field is turned off, the MRI sensors are able to detect the energy

released as the protons realign with the magnetic field. The time it takes for the protons to realign with the magnetic field, as well as the amount of energy released, changes depending on the environment and the chemical nature of the molecules. Physicians are able to tell the difference between various types of tissues based on these magnetic properties.



How Does an MRI Work?

To obtain an MRI image, a patient is placed inside a large magnet and must remain very still during the imaging process in order not to blur the image. Contrast agents (often containing the element Gadolinium) may be given to a patient intravenously before or during the MRI to increase the speed at which protons realign with the magnetic field. The faster the protons realign, the brighter the image.

What is MRI used for?

MRI scanners are particularly well suited to image the non-bony parts or soft tissues of the body. They differ from computed tomography (CT), in that they do not use the damaging ionizing radiation of x-rays. The brain, spinal cord and nerves, as well as muscles, ligaments, and tendons are seen much more clearly with MRI than with regular x-rays and CT; for this reason MRI is often used to image knee and shoulder injuries.

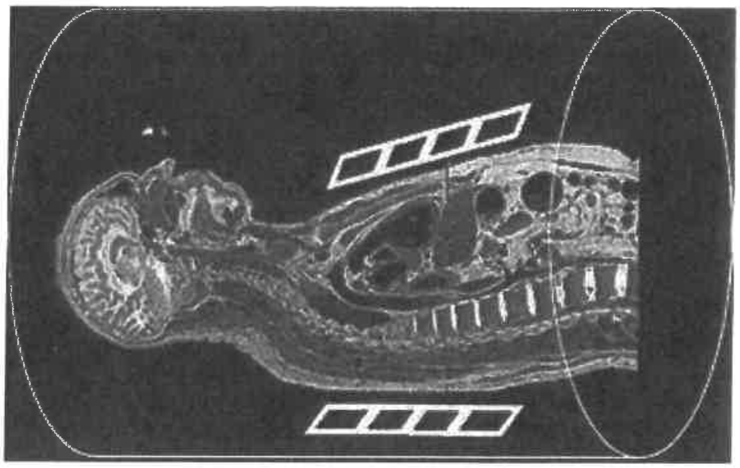
In the brain, MRI can differentiate between white matter and grey matter and can also be used to diagnose aneurysms and tumors. Because MRI does not use x-rays or other radiation, it is the imaging modality of choice when frequent imaging is required for diagnosis or therapy, especially in the brain. However, MRI is more expensive than x-ray imaging or CT scanning.

One kind of specialized MRI is functional Magnetic Resonance Imaging (fMRI.) This is used to observe brain structures and determine which areas of the brain "activate" (consume more oxygen) during various cognitive tasks. It is used to advance the understanding of brain

organization and offers a potential new standard for assessing neurological status and neurosurgical risk.

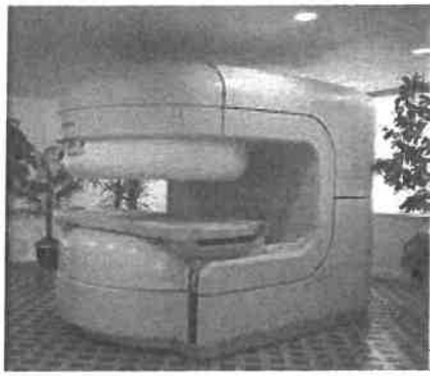
Are there risks?

Although MRI does not emit the ionizing radiation that is found in x-ray and CT imaging, it does employ a strong magnetic field. The magnetic field extends beyond the machine and exerts very powerful forces on objects of iron, some steels, and other magnetizable objects; it is strong enough to fling a wheelchair across the room. Patients should notify their physicians of any form of medical or implant prior to an MR scan.



When having an MRI scan, the following should be taken into consideration:

- People with implants, particularly those containing iron, — pacemakers, vagus nerve stimulators, implantable cardioverter- defibrillators, loop recorders, insulin pumps, cochlear implants, deep brain stimulators, and capsules from capsule endoscopy should not enter an MRI machine.
- Noise—loud noise commonly referred to as clicking and beeping, as well as sound intensity up to 120 decibels in certain MR scanners, may require special ear protection.
- Nerve Stimulation—a twitching sensation sometimes results from the rapidly switched fields in the MRI.
- Contrast agents—patients with severe renal failure who require dialysis may risk a rare but serious illness called nephrogenic systemic fibrosis that may be linked to the use of certain gadolinium-containing agents, such as gadodiamide and others. Although a causal link has not been established, current guidelines in the United States recommend that dialysis patients should only receive gadolinium agents when essential, and that dialysis should be performed as soon as possible after the scan to remove the agent from the body promptly.
- Pregnancy—while no effects have been demonstrated on the fetus, it is recommended that MRI scans be avoided as a precaution especially in the first trimester of pregnancy when the fetus' organs are being formed and contrast agents, if used, could enter the fetal bloodstream.


New open MRI machine

- Claustrophobia—people with even mild claustrophobia may find it difficult to tolerate long scan times inside the machine. Familiarization with the machine and process, as well as visualization techniques, sedation, and anesthesia provide patients with mechanisms to overcome their discomfort. Additional coping mechanisms include listening to music or watching a video or movie, closing or covering the eyes, and holding a panic button. The open MRI is a machine that is open on the sides rather than a tube closed at one end, so it does not fully surround the patient. It was developed to accommodate the needs of patients who are uncomfortable with the narrow tunnel and noises of the traditional MRI and for patients whose size or weight make the traditional MRI impractical. Newer open MRI technology provides high quality images for many but not all types of examinations.

https://www.nibib.nih.gov/science-education/science-topics/magnetic-resonance-imaging-mri

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