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Imaging and Radiation Protection

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# *Radiation Protection and Quality Control in Nuclear Medicine*

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Nuclear medicine uses small quantitites of radioistopes in diagnostic procedures which are now very widely applied. Benefits to the patient are remarkable, the status and functions of organs deep into the body can be investigated. With in-vitro radioactive techniques, information can be obtained for the analysis of hormones, vitamins, drugs, etc. etc.

Because of the low levels of radioactivity the radiological hazard is very limited, provided simple but important measures and "good sense" in handling the radioisotopes are applied. The radioactive materials used in nuclear medicine are usually short-lived, and there are well established procedures for transporting, storing and using them. In this field "protective clothing" means no more than an ordinary laboratory coat and the use of disposable gloves. In-vivo nuclear medicine radioisotopes have to be stored in shielded places and some shielded tools must be used. The radioactive wastes are of low level and when necessary may be stored at the hospital until their activity is negligible.

Risk for the patient lies either in "interpretation" errors, or in measurements made with defective or poorly functioning equipment. Faulty diagnosis may then lead to ineffective or damaging treatment. Even in advanced countries this is a difficult problem, requiring sophisticated and well-dsiciplined procedures for quality control. In developing countries, where working conditions are less favourable, the difficulties are much greater. Just providing equipment is not enough, training and quality control programmes are very important. The checking procedures of the images and of the equipment are in a way a "self learning" process; the users will get to know the equipment better and will use it in a proper way.

One of the essential differences between X-ray and nuclear medicine diagnostic investigations is that the X-rays are more or less limited to the irradiated area, while with in-vivo techniques the administered radioisotope spreads in the body acccording to its biochemical characteristics, and later on in the environment.

Consequently, evaluation of the internal dose in nuclear medicine is more complex and requires the help of sophisiticated analysis. Considering the major possible damage which ionizing radiation causes to children and pregnant women, nuclear medicine investigations have to be carried out only when no alternative investigation is available and only in case of absolute need. Therefore, it is advisable to evaluate the dose and the risk in advance.

It is very important to avoid a repetition of the investigation for erroneous interpretation, because of the repeated dose to the patients and the waste of resources.

Attention has to be given to the selection of robust and proven equipment, and to factors contributing to early breakdowns, such as unstable electrical supply or bad climatic conditions. Devices to protect against these have to be supplied with critical pieces of equipment.

Quality assurance procedures developed by the Agency for checking analysis in radioimmunoassay have been demonstrated in training courses and are in widespread use. Training is also given in the use of phantoms and other testing devices for checking the quality of images generated by gamma cameras and other diagnostic devices.

In case of treatment with radioisotopes the problem of radiation safety is different, according to the different administered activity. The problem of handling radiopharmaceuticals and wastes is, of course, heavier but always at a "reasonable" level. Depending on the total activity of the waste, deposit tanks may be required.

When NM techniques are used the influence of radioisotope wastes in the surrounding environment is to be considered according to the national and international rules.

On the whole the rules for safe use of radioisotopes in medicine can be summarized as follows:

- appropriate radiation protection infrastructures
- appropriate tests to check the equipment performance
- appropriate instrument, compatible with the conditions
- appropriate radiopharmaceuticals in order to keep the amount of radioactivity as low as possible.
- correct interpretation of the examinations.

The IAEA TEC-DOC 602 is a very comprehensive guide for performing all the calibration tests.

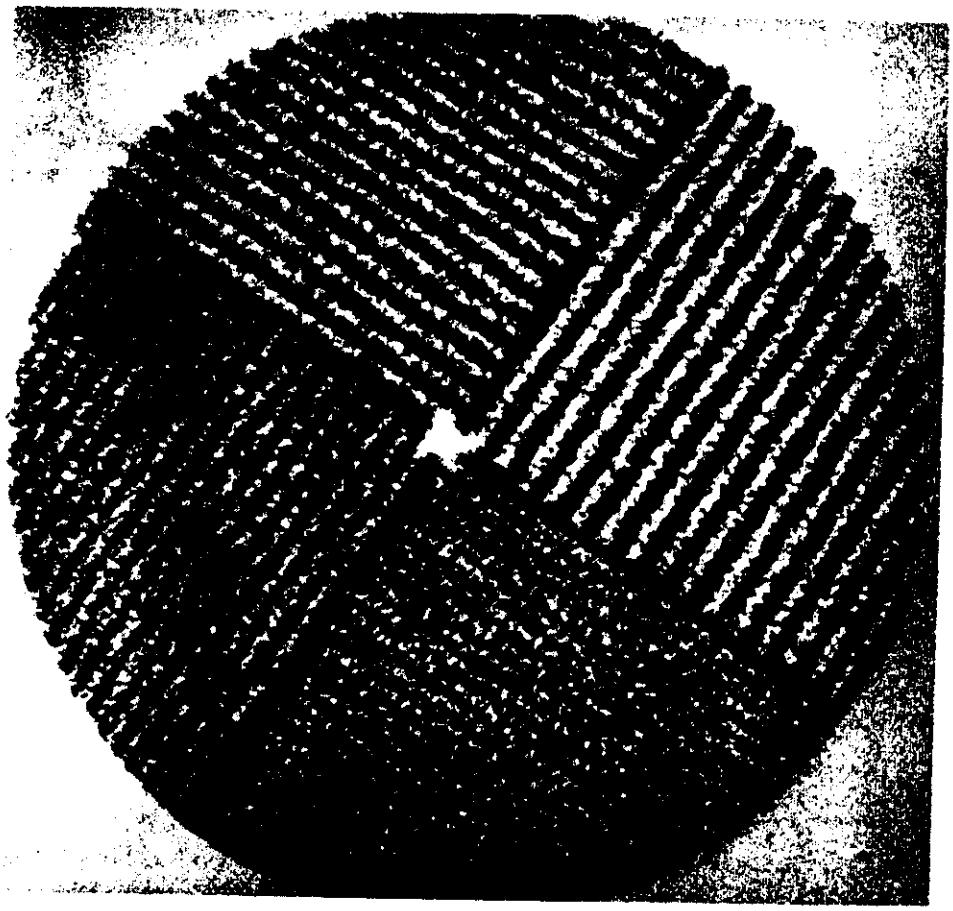

**Figure 30-6** Image of a Test Object Used to Measure the Resolving Ability (Amount of Blur) of a Gamma Camera

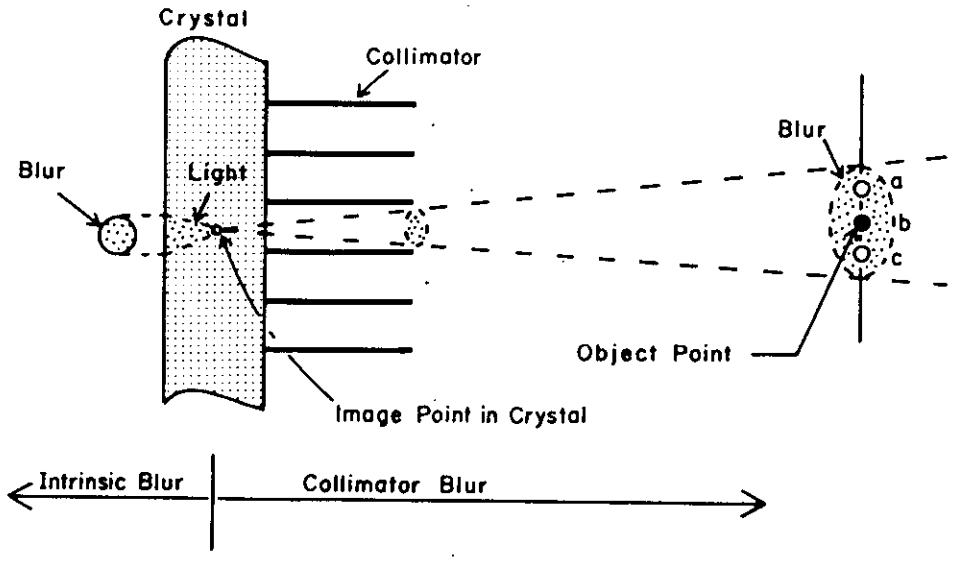


**Figure 30-7** The Two Basic Components of Gamma Camera Blur: Intrinsic Blur and Collimator Blur

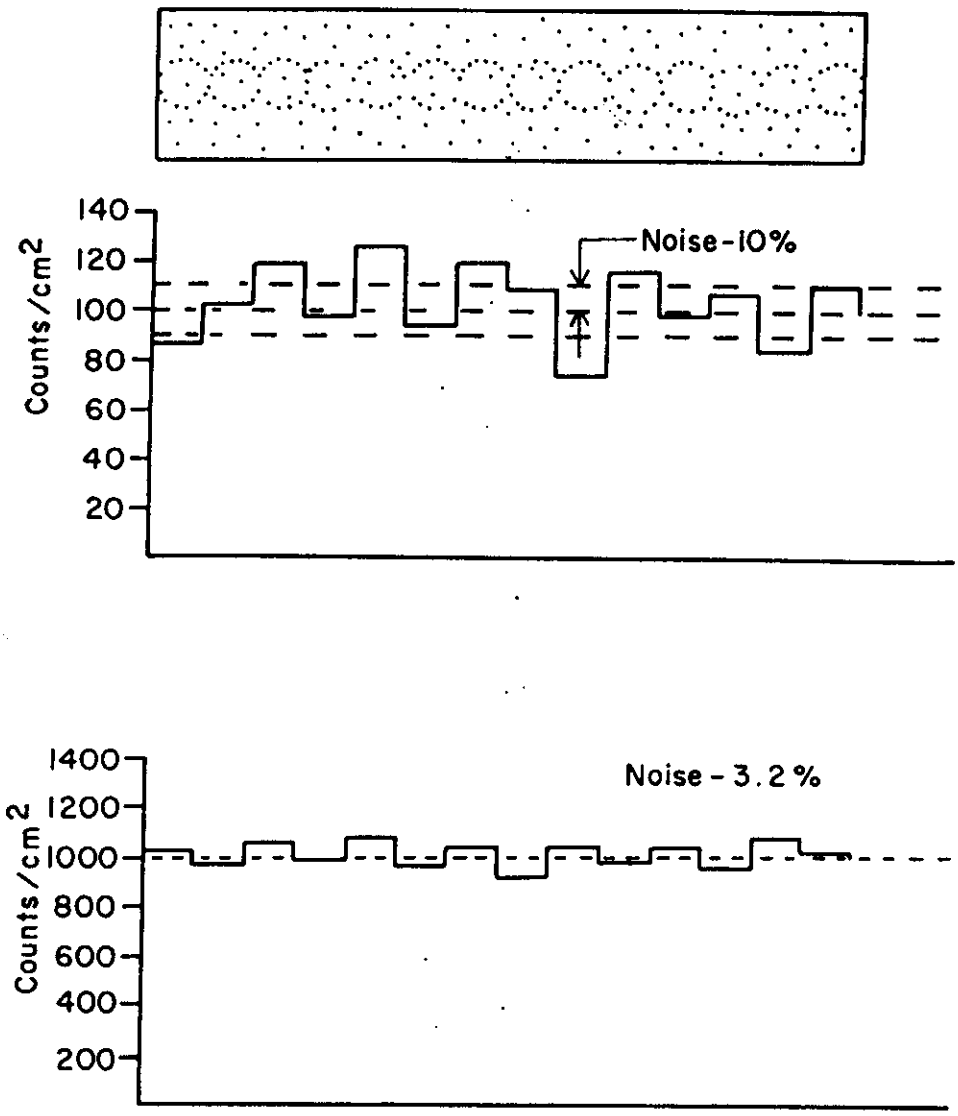


**Figure 30-12** Area-to-Area Variation in Photon Concentration for Two Average Count Densities

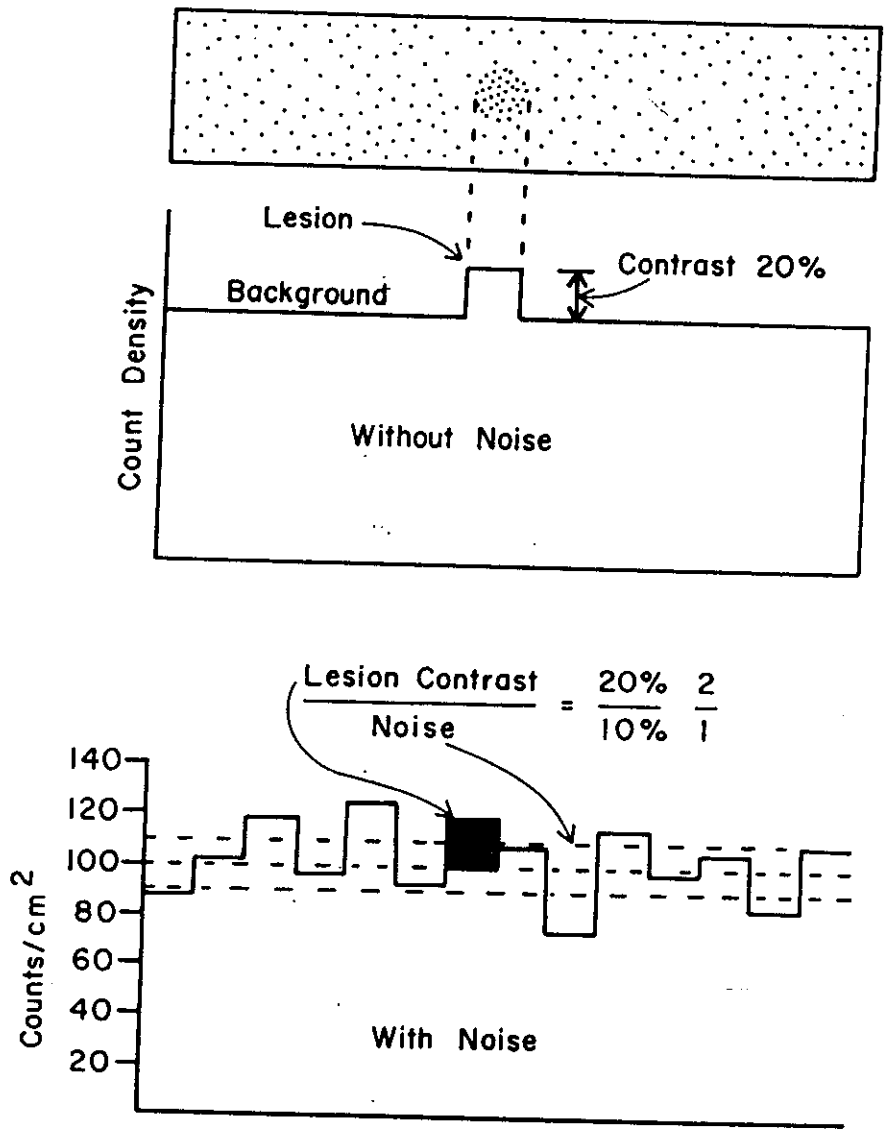


**Figure 30-13** Relationship of Lesion Contrast to Background, Both with and without Noise

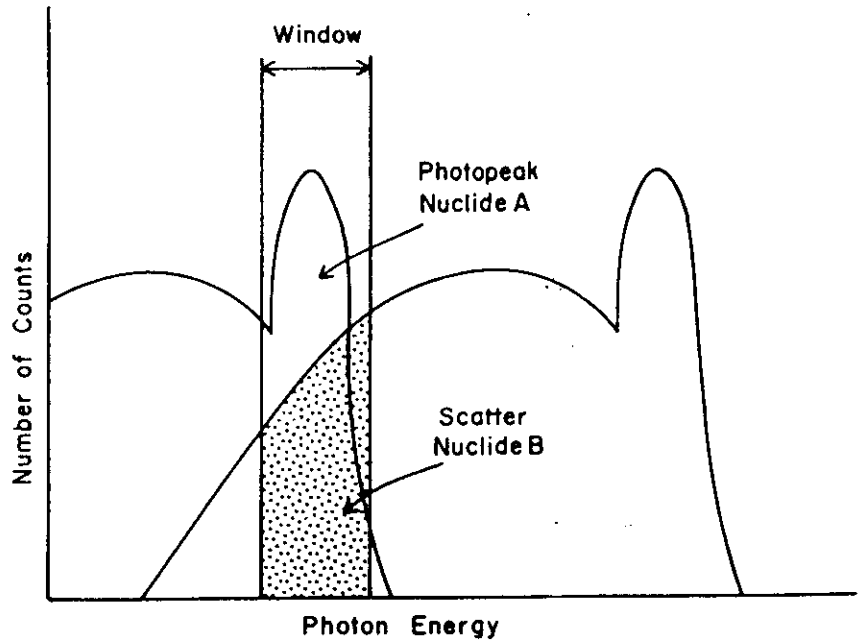


**Figure 30-4** Overlapping of the Energy Spectra of Two Nuclides



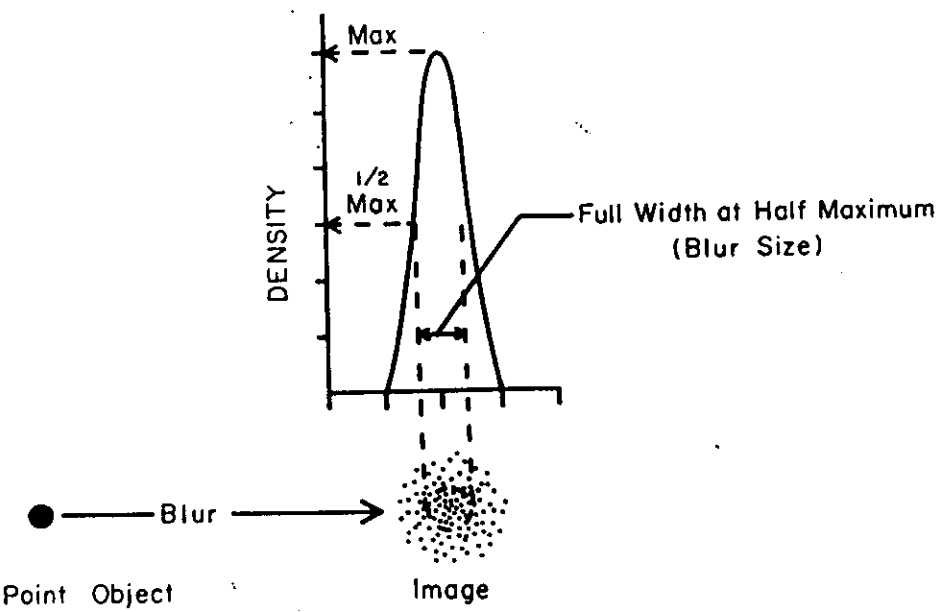


**Figure 30-5** Profile of the Blurred Image of a Small Object (Radioactive Source)

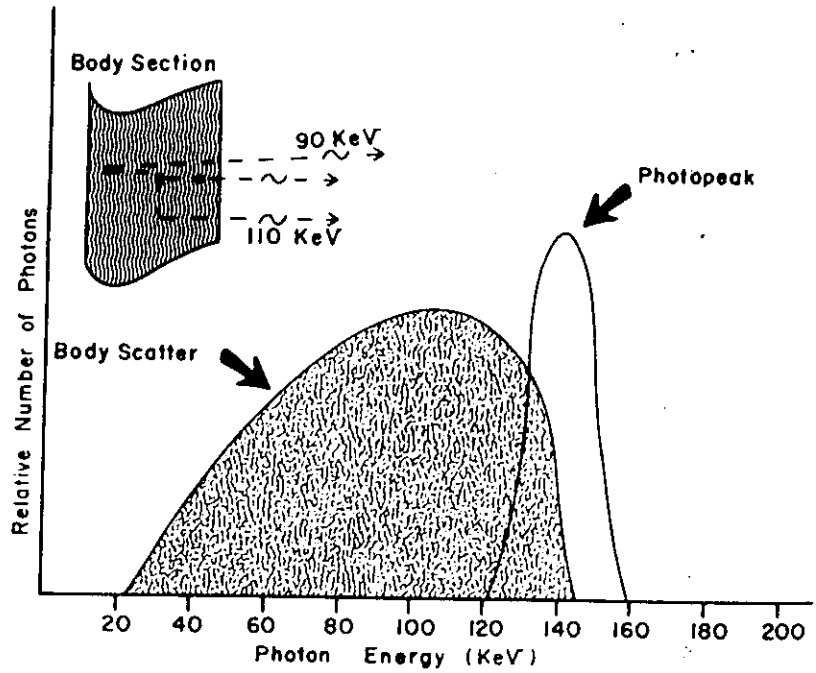


**Figure 29-14** Spectrum Component Produced by Compton Interactions within the Body



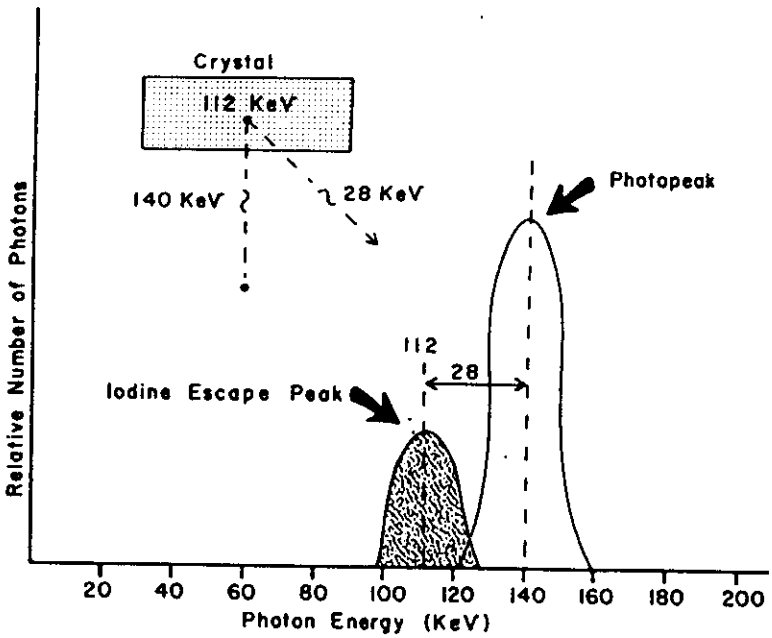


**Figure 29-15** Spectrum Component (Escape Peak) Produced by X-Ray Photons Leaving the Crystal

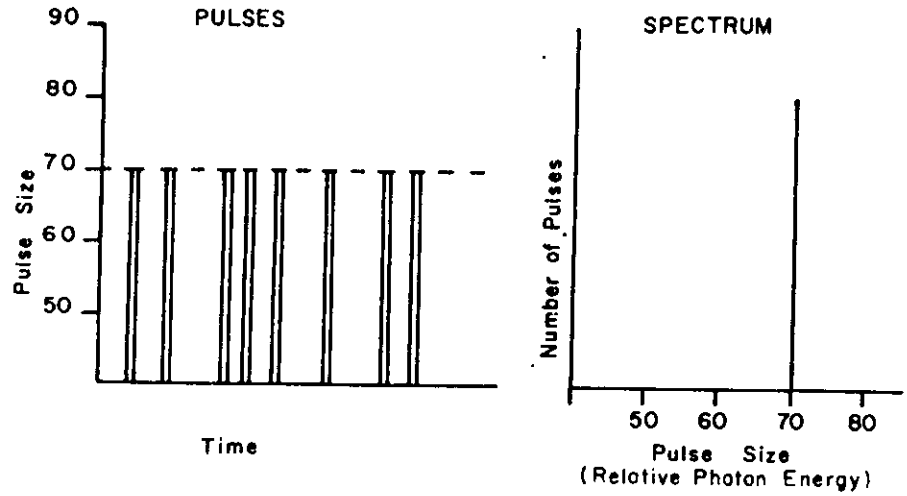


**Figure 29-11** The Pulse Spectrum That Would Be Produced by a Monoenergetic Radiation Source and an Ideal Detector



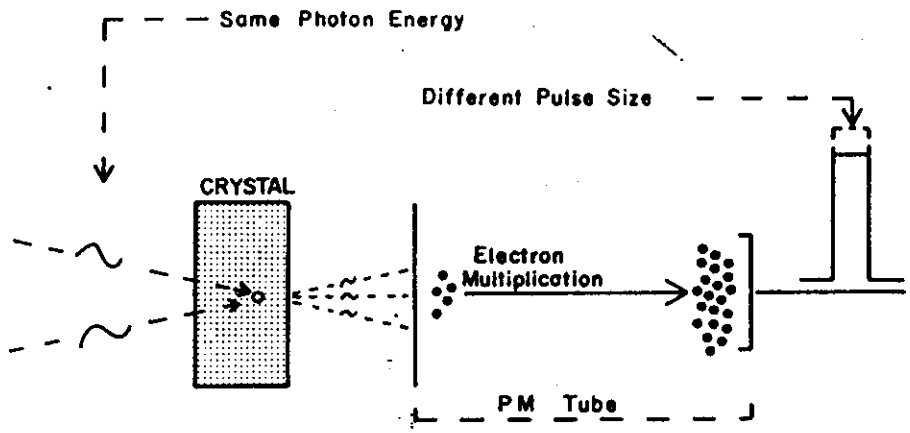


**Figure 29-12** Factors That Produce a Variation in Detector Pulse Size

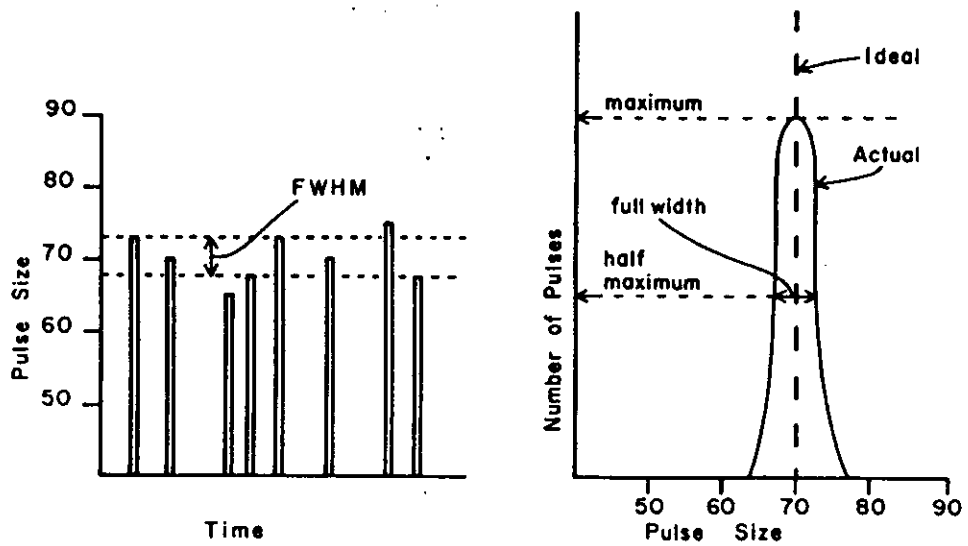


**Figure 29-13** Pulse Spectrum Produced by a Monoenergetic Radiation Source and a Typical Detector

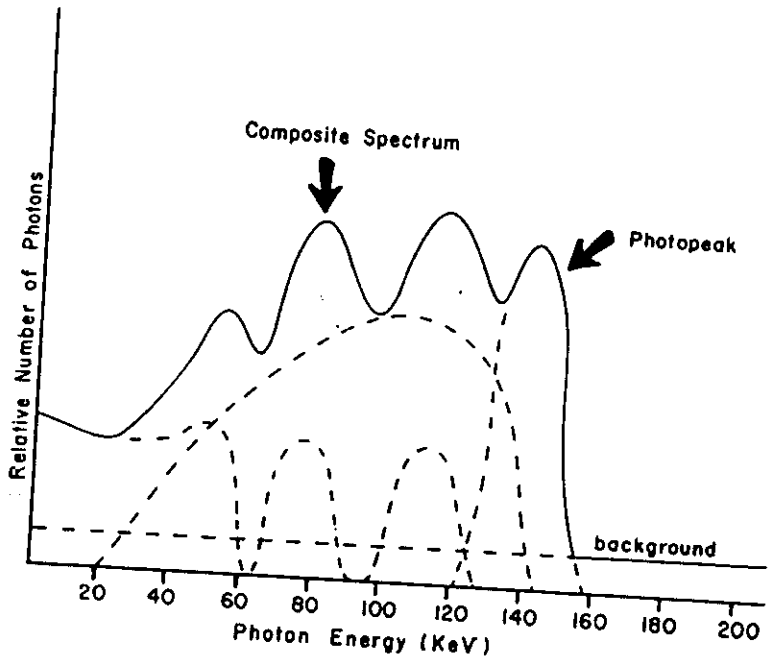


**Figure 29-16** Composite Spectrum Produced by Adding the Different Spectral Components

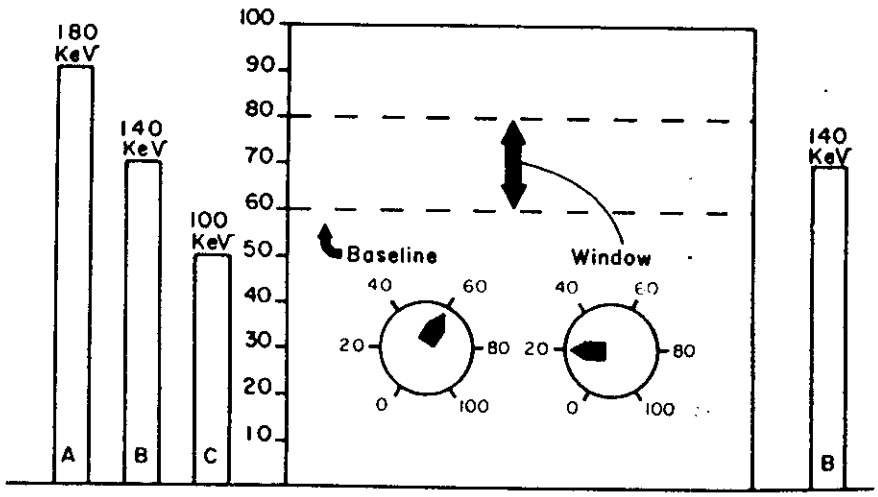


**Figure 29-17** Basic Function of a Pulse Height Analyzer

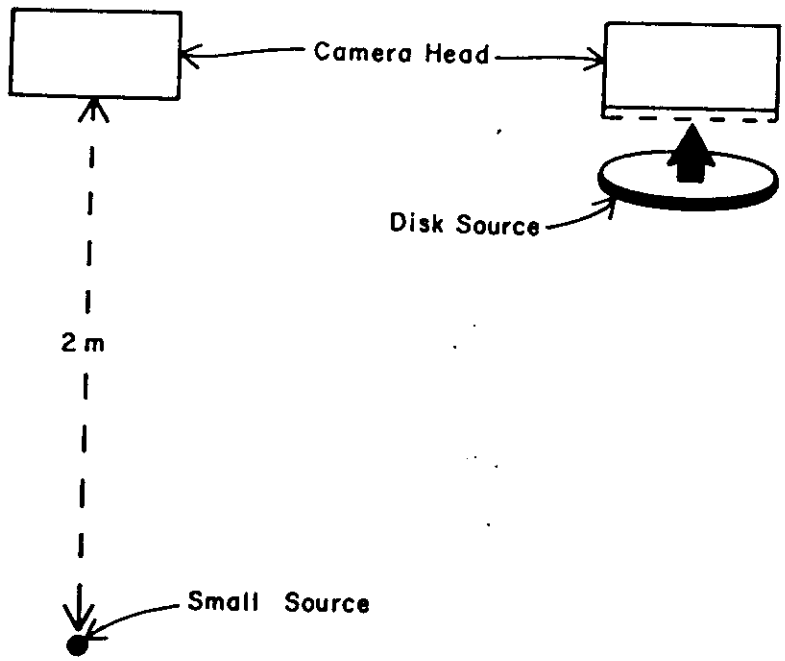


**Figure 30-14** Radioactive Sources Used to Test a Gamma Camera for Uniformity Over the Image Area

# RADIATION PROTECTION FOR DIAGNOSTIC USE OF RADIOISOTOPES

## I-REGULATIONS

Any use of radionuclides is fraught with the danger of inedvertently exposing an individual to radiation and, therefore, to its attendent hazards. This is especially true in the nuclear medicine laboratory where large amounts of unsealed radioactive sources are routinely handled. Each time a generator is milked, a radiopharmaceutical dose is drawn or injected, or a scan is performed on a patient. There is the possibility of exposure and contamination to the user as well as to the environment. To ensure proper and safe use of radionuclides govermental agencies regulate production, transportation, possession, use and disposal of radionuclides. Local regulations for each country are based primarily on the recommendations of two advisory bodies, the ICRP-International Commission on Radiation Protection and the NCRP-National Council on Radiation Protection. Recommendations from these groups do not carry the force of law.

### I-1) Restricted and Unrestricted Areas

Regulations prescribe different maximum radiation limits for restricted and unrestricted areas. Normally, restricted areas are not accessible to the general public, and they are occupied only by individuals whose employment responsibilities require them to work with radioactive materials. Such individuals are said to be occupationally exposed -e.g., nuclear medicine physicians, technicians, pharmacists etc.

### I-2) Maximum Permissible Doses

Maximum permissible dose limits recommended by NCRP are given in Table-1. An individual's life time cumulative occupational dose should not exceed (N-18)*5 rems, where N is the individual's age in years.

These dose limits, which apply to occupationally exposed personnel, are called occupational dose limits, but not include radiation dose received by medical examination.

Maximum permissible doses for persons under age 18, and for persons in unrestricted areas, are reduced by a factor of 10 from those for restricted areas Figure 1.

I-4) The regulations also specify maximum permissible concentrations for radionuclides disposed of into the sewage water. An anual limit of one curie for the total amount of radioactivity disposed is specified.

## II) SAFE HANDLING OF RADIOACTIVE MATERIALS

### II-1) The ALARA Consept

Radiaton dose limits, maximum permissible values are legal limits that must not be exceeded at any time. However they should not be considered as thresholds below which the hazards may be assumed to be "zero".

Although the limits in the regulations are very small, they are not assumed to be totally risk free, and any reasonable technique for reducing radiation dose may have potential benefits in the long run.

The guiding principle in the radiation protection is that radiation doses should be "as low as reasonably achievable" (ALARA). The philosopy is to reduce radiation levels in work places to as low a level as is economically and technologically feasible, even the levels are well below the legal limits.

### II-2) Reduction of Radiation Doses From External Sources

i) Type of sources

External sources are those that deliver a radiation dose from outside the body. The principle sources are gamma and X-ray emitting radionuclides in patients, syringes, vials, waste disposal areas, etc. Unshielded beta emitters with sufficient energy to travel some distance in air (P-32) also constitute an external hazard.

ii) Exposure rate constant

Several factors affect the exposure produced by an external radioactive source, as illustrated in Figure 2. At this point, it is important to remember the difference between exposure (milli roentgens) and exposure rate (milli roentgens per hour). The exposure produced by a radioactive source is related to the accumulated activity (micro curie-hours), whereas exposure rate is related to the activity, A (micro curies), at a particular time.

The number of photon per transition and photon energy have characteristic values for each radionuclide. When this factors are known, it is possible to determine the exposure rate at a standart distance, such as 1 m. from a radioactive source. This exposure value is generally designated the gamma constant ($\Gamma$). The value of gamma constant is the

The effect of distance can have a marked effect on radiation levels. Increasing distance always has a dose reduction effect. Direct contact with radiation sources should be avoided by any available means, e.g., by using tongs to handle vials. Patient study areas (e.g., imaging rooms) should be arranged to permit the technician to operate instrumentation at reasonable distance (e.g., 2 meters) from patient. Separate waiting areas should be provided for patient who have been injected with radioactivity and for relatives, orderlies, and patients not requiring radioactive injections. Table-3. Reception areas should not be used as waiting areas for radioactive patients.

Examples of effective use of shielding are lead pigs for storage of vials and generators, lead-lined syringe holders, lead aprons, lead bricks for lining storage areas, and lead-lined drawing sations Figure 4. Leaded glass provides comfortable viewing and radiations protection simultaneously, especially for low-energy gamma and x-ray emitters (<200 keV). Dose calibrators should be enclosed in a shielded area, using lead sheet or bricks, to avoid unnecessary exposure during measurement of radio-pharmaceutical activity.

Skin doses to fingers in contact with syringes containing radionuclides. (Radiation doses-maximum estimates-when unshielded syringes are used) Figure 5.

TABLE-3

| Nuclide | Dose (mrad 100 $\mu$Ci$^{-1}$ .min$^{-1}$ ) |
|---|---|
| Tc-99m | 1-5 |
| In-113 | 10-15 |
| I-131 | 14-70 |
| Au-198 | 8-20 |

## II-3) Reduction of Radiation Doses from Internal Sources

Type of sources:

Nearly all nuclear medicine personnel are required at one time or another to work with radioactive sources in open or poorly sealed containers. There is always the possibility that in these operations some of the radioactive material will find its way into the body, where it delivers a radiation dose as an internal radiation source. The cardinal rule for keeping radiation doses from internal sources "ALARA" is to prevent the entry of the radioactive material into the body in the first place. To a certain extent, this is a matter of careful design of laboratory facilities, but

4. Wash basins and sinks should be conveniently available where unsealed radioactive materials are handled. It is desirable that sinks in hot labs have foot- or elbow-operated controls.
5. The laboratory design should permit separate storage of glassware and work tools (e.g., tongs, stirring devices, etc.) not used with radioactive materials to prevent needless contamination or mixture with similar items used with radioactive preparations.

## II-5) Procedure For Handling Spills

Accidental spills of radioactive materials are infrequent occurrences in well-run nuclear medicine laboratories. Also, the quantities of radioactivity used in nuclear medicine do not create "life threatening" hazards. Nevertheless, radioactive spills should not be treated as events completely without hazard, the laboratory personnel should be aware of the appropriate procedures to follow when spills do occur.

The steps to follow in dealing with a radioactive spill are (1) to inform, (2) to control, and (3) to decontaminate.

1. Individuals in the immediate work area should be informed that a spill has occurred so they can avoid contamination if possible. Individuals outside the immediate area should be warned so they do not enter it. The radiation officer should be informed so that he/she may begin supervising further action as soon as possible.
2. By whatever means are reasonably possible, without risking further hazards to themselves, laboratory personnel should attempt to control the spill to prevent further spread of contamination. A flask that has been tipped over should be uprighted. Absorbent pads should be thrown over a liquid spill. Doors should be closed to prevent the escape of airborne radioactivity (gases, powders, etc.). The spill area should closed off to prevent entry, especially by persons who might not be aware of the spill. Personnel monitoring for contamination should be started as soon as possible, so that contaminated and uncontaminated persons can be segregated. To prevent the further spread of radioactivity, contaminated individuals should be not allowed to leave the area until they are decontaminated, and uncontaminated individuals should not be allowed to enter the spill area. Contamination monitoring should be done using a sensitive radiation monitoring instrument appropriate for the type of radioactivity involved. It is advisable that each laboratory have on hand a thin-window GM counter survey meter for handling such situations.

TLD, film badges are the dosimeters for personnel monitoring. Pocket dosimeters that provide an immediate readout of radiation doses one especially useful for measuring over short periods of time or when a rapid indication of results is needed.

Well counter (for gamma emitting nuclides) or a liquid scintilation counter (for emitters) can be used for wipe test.

## IV. INSTRUMENTATION IN NUCLEAR MEDICINE

### IV-1) Counting System

Radiation counting system are used for a variety of purposes in nuclear medicine. In vitro (in glass) counting systems are employed to measure radioactivity in tissue, blood and urine sample for radioimmunoassay. In vivo (in living subject) counting systems are employed for measuring radioactivity in humun subjects.

At present, the most efficient and economical detector for counting gamma ray emission is NaI(Tl). Most of the systems are comprised of the detector and high voltage supply, preamplifier, amplifier, one or more single channel analyzer (or a multichannel analyzer), scaler-timer, ratemeter or other data readout device.

A) NaI(Tl) Well Counter

The detector for a NaI(Tl) well counter is single crystal of NaI(Tl) with a hole in one end for the insertion of sample (Figure 6). The 4.5 cm diameter x 5 cm long crystal with 1.6 cm diam x 3.8 cm deep well is the standard detector and is the most frequently used in nuclear medicine. Gamma rays absorbed in the crystal cause light scintilations where in turn; give rise to electrial pulses at the anode of the photomultiplier tube. After the further amplification and shaping, they are directed to puls height analyzer and finally to readout device.

In this type of detector, only a small fraction (<5 %) of the radiations emitted by the sample escapes from the sensitive volume of the crystal and, therefore geometric efficiency approaches 95 %. The intrinsic efficiency of the crystal depends on the size of the crystal- the larger the crystal the higher the intrinsic efficiency of a given energy gamma ray.

The fraction of gamma rays escaping through the hole at the end of the well depends on the position of the source in the well. The fraction is only about 5 percent near the bottom of the well but increases to 50 percent the top and is even larger for sources outside the well Figure 7.

# DOSE CALIBRATORS

A dose calibrator is essentially a well-type ionization chamber that is used for assaying relatively large quantities (i.e., mCi range) of gamma ray emitting radioactivity (Figure 14). Dose calibrators are used for measuring or verifying the activity of generator eluates, patient preparations etc., similar quantities of activity is too large for assay with NaI(Tl) detector systems. Although the ionization chamber have no inherent ability for energy discrimination, the different decay properties of radionuclides are used for the activity measurement of the different isotopes.

As it is stated earlier, if the radioactivity of the source doubled, the number of photons emitted will doubled, causing twice the ionization and twice as much electrical current to flow in the circuit.

For example, a radioactive source of 1 mCi of I-131 will generate a current of about 10 x10-12 amp in an ionization chamber. A source of 2 mCi of I-131 will generate a current of about 20 x10-12 amp. Thus the total current generated is directly proportional to the quantity of radioactivity in the chamber.

Radionuclides differ from one another in their made of decay. For example, Cr-51 emits 10 gamma ray of 320 keV each for every 100 radioactive transitions and Tc-99m emits 88 gamma rays of 140 keV for every 100 transitions. Therefore, more photons than for 1 mCi of Cr-51. Also photons of 140 keV are more likely to interact with the gas in the ion-chamber than are the more energetic 320 keV photons.

As a result of the variation of interaction probability versus photon energy and the fact that different radionuclides emit different numbers of photons per nuclear transformation, a millicurie of one radioactive subtance will not generate the same ionization current as a millicurie of different radionuclide. Figure 15 is a graph showing the relative ionization current versus milicuries of radioactivity for several radionuclides.

Different resistor values in the system electronic are calibrated at the factory in order to measure the activity of different isotopes.

Performance of a dose calibrator depends on a number of different parameters: the linearity over the activity range, sensitivity of the chamber to different source configuration, accuracy of the instrument, and precision of reproducibility.

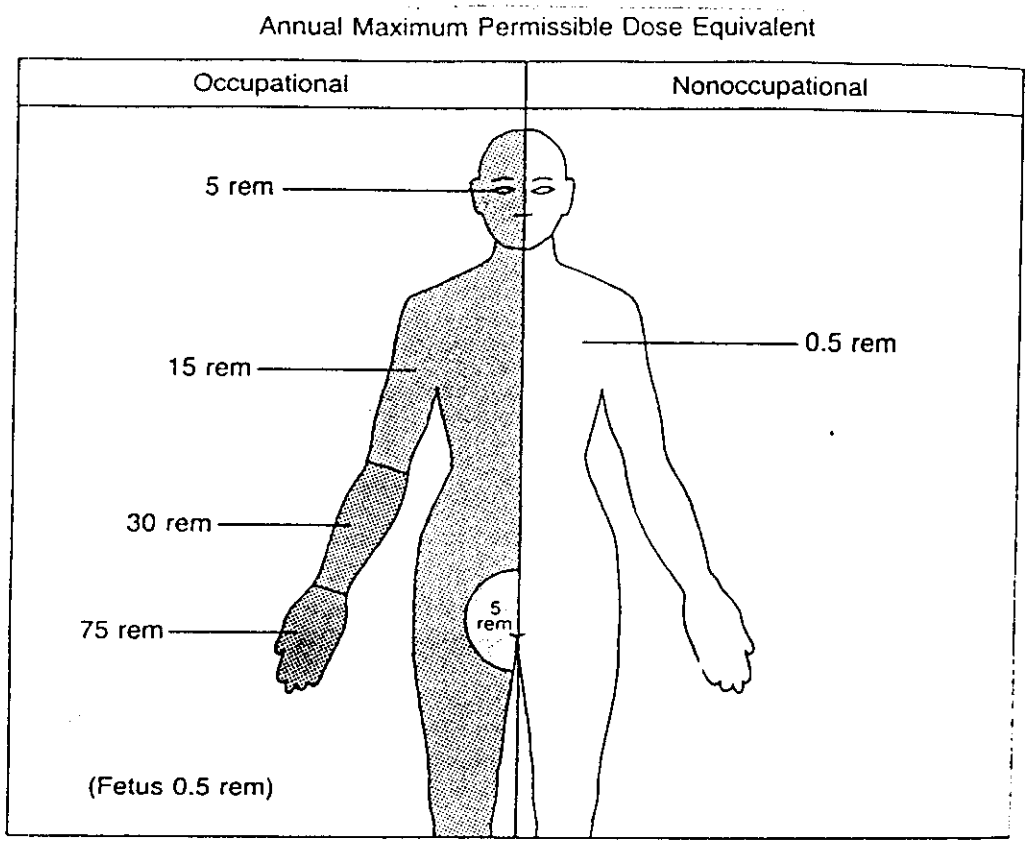


Figure-1 Maximum permissible dose equivalent (MPD) values

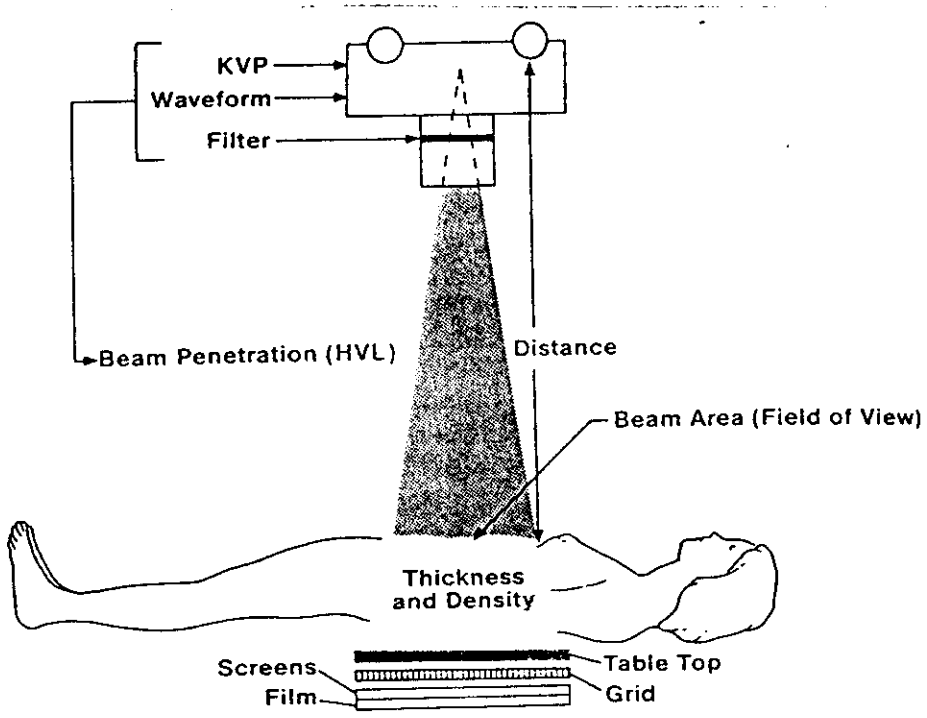


Figure-2 Factors that affect patient exposure in a radiographic procedure

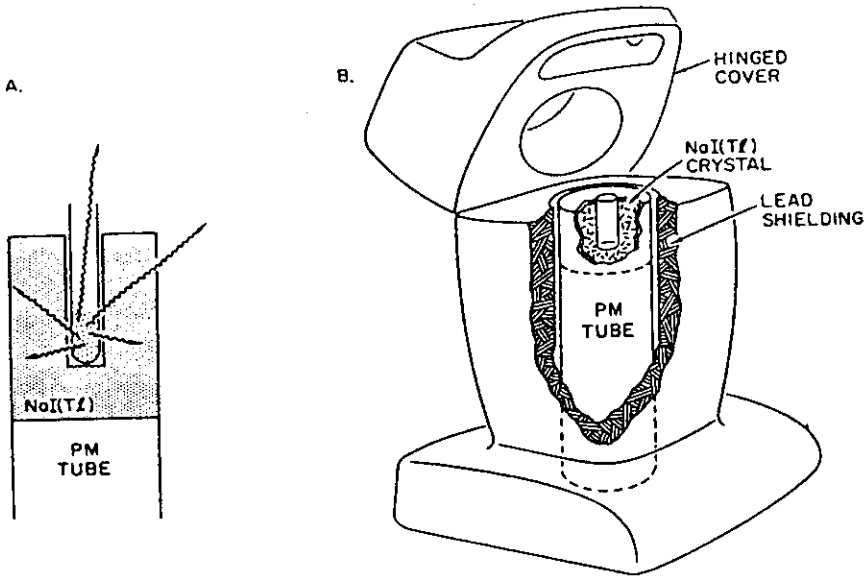


Figure-6 (A) Cross-sectional view of a well counter detector. (B) Detector and shielding

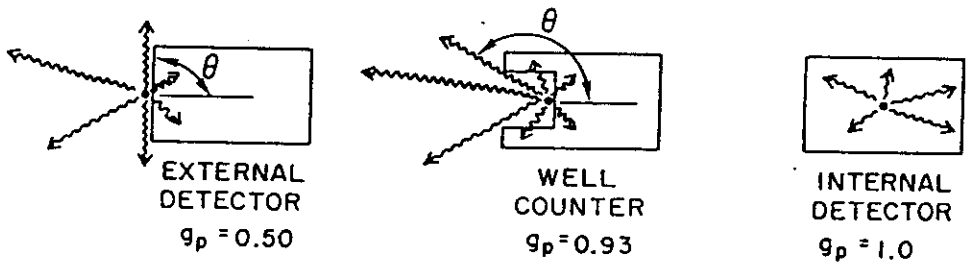


Figure-7 Examples of geometric efficiencies for different source detector geometries

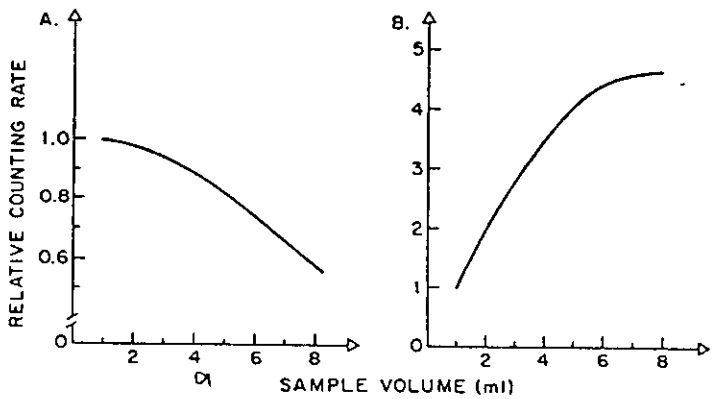


Figure-8 Change in counting rate (A)With constant activity. (B) With constant concentration.

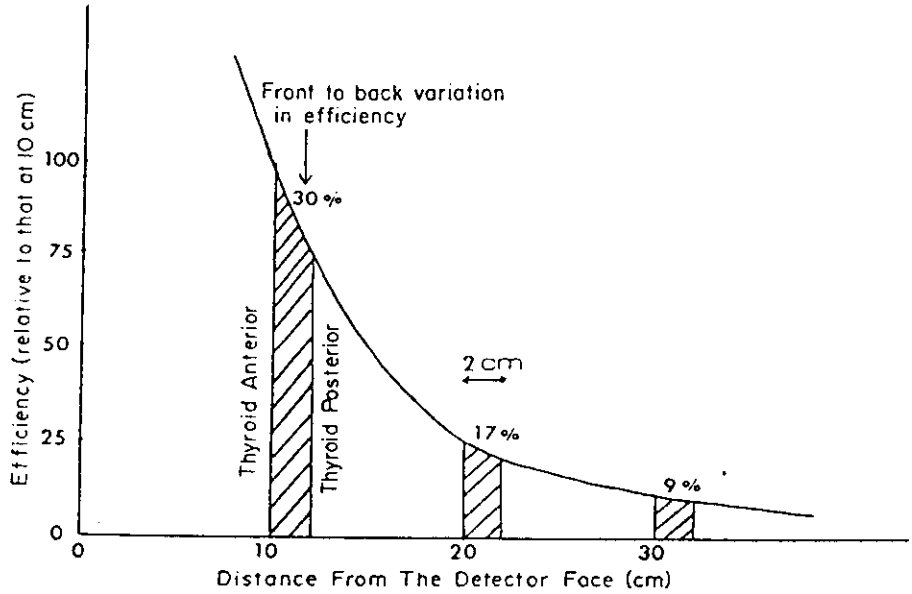


Figure-12 Variation of the efficiency of a thyroid probe as a function of the distance of the thyroid from the probe. The efficienc drops by a factor of 9 when the distance is increased from 10 to 30cm but the uniformity of response within the thyroid (2cm thick) improve

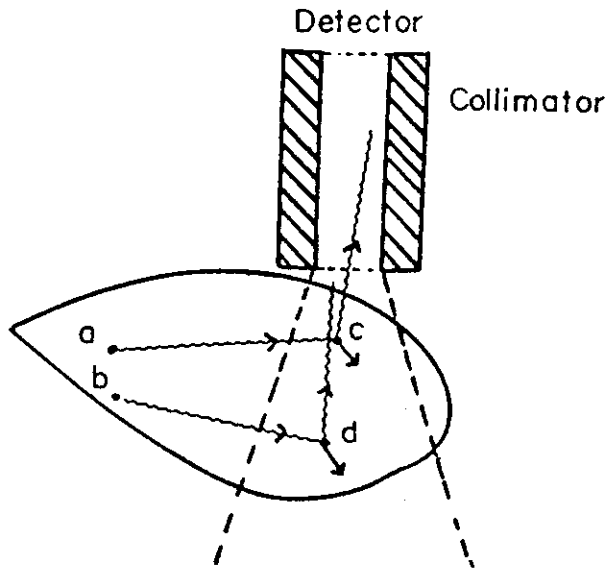


Figure-13 Compton scattering of gamma rays interferes with the function of a collimator. Gamma-rays originating outside the field of view from points a and b are able to reach the detector as a result of compton scattering at points c and d respectively.