Automation und Messtechnik GmbH | November 25, 2004

Probes 6150AD-17, 6150AD-k, and 6150AD-19

Operating Manual

for the Contamination Probes

6150AD-17, 6150AD-k, 6150AD-19

Probe 6150AD-19,
protective cover screwed off

Probe cable 1.25 m
for 6150AD-19
and 6150AD-17

Probe 6150AD-k

Probe 6150AD-17,
protective cap removed

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1. Application

The probes are to be used with the Dose Rate Meter 6150AD to detect surface contamination (6150AD-17, 6150AD-k) or volume contamination (6150AD-19). The 6150AD-17 and the 6150AD-19 use GM counting tubes as detectors, and the 6150AD-k uses a sealed proportional counter.

CAUTION! The counting tubes are operated from high voltages (approximately 500 V in case of the 6150AD-17 and the 6150AD-19, and 1500 V in case of the 6150AD-k)! Touching that high voltage may be hazardous to your health, so never try to open or repair a probe!

This manual only refers to the probes, not to the 6150AD meter the probes are used with. It is assumed throughout this manual that the reader is familiar with operation and use of the 6150AD.

NOTE! This manual is only to be used in conjunction with and as a supplement to the »Operating Manual for the Dose Rate Meter 6150AD«, issue June 2001 or later!

The probes are »pulse probes« which means that the 6150AD will represent them using the unit S^{-1} (pulses per second, counts per second). For more information see the 6150AD's Operating Manual, chapter 6, »Display Ranges and Display Formats«. You need a calibration factor to convert the reading into activity (in Bq) or surface related activity (Bq/cm^2) or volume related activity (Bq/cm^3, Bq/l). That calibration factor depends on the radionuclide which causes the count rate. You have to know about the radionuclide involved, or you have to make an assumption about the radionuclide. The probes cannot serve to determine the type of radionuclide.

2. General Information on Contamination

This chapter contains some basic information on the »contamination« subject. It addresses primarily users who are not very familiar with this subject. Experienced users may skip this chapter.

2.1 Definitions and Technical Terms

Generally speaking, contamination means the presence of undesirable or even hazardous substances. For example, food may be »contaminated« with microbes. In the present case, contamination always means the presence of radioactive substances. The risk of contamination is generally found where unsealed radioactive substances exist. As opposed to sealed sources, unsealed radioactive substances involve the danger that some fraction may arrive at or in the human body. Radioactive substances on the skin or in the body constitute a substantially higher radiation hazard than they do by external exposure from a certain distance. The most striking example is an alpha emitter. In air, alpha particles have a range of only a few centimetres, because even a light material such as air can easily stop alpha particles. Therefore, alpha radiation does not constitute any danger as long as you keep sufficiently away from its source. However, once the alpha source (the contamination) gets onto the skin or into the body, the alpha particles will no longer be stopped by air, but by cell tissue, and may damage the cells.

Contamination spreads like ordinary dirt or dust. Touching a contaminated object will transfer a fraction of the contamination onto the skin. From there another fraction may arrive in the body (washing hands before eating or drinking is not only a good general recommendation, it also reduces the risk of internal contamination). If present in gaseous or vaporous form, contamination may also be inhaled. Furthermore, contamination may enter blood circulation through an injury (even a small skin lesion may be sufficient).

The quantity of a radioactive substance is called »activity« and measured in Bq (Becquerel). One Bq is that amount of a radioactive substance in which one atomic nucleus decays per second[A]. It depends on the half-life of the radionuclide which physical amount (measured in, for example, grams) one Becquerel corresponds to[B].

Depending on which type of radioactive substance (which radionuclide) is involved, the decaying atomic nuclei emit alpha, beta or gamma radiation, in most cases even several of those radiation types.

If the surface of some object is contaminated, this is called surface contamination, and measured in Bq/cm^2 (Becquerel per square centimetre, that is activity per areal unit). The probes 6150AD-17 and 6150AD-k serve to detect surface contamination. For this purpose they need to be able to detect all types of radiation. Instruments designed to measure gamma dose rate, such as the 6150AD itself, are not suited to detect surface contamination, even if the surface contamination should also emit gamma radiation. This is because gamma radiation is less efficient to detect since it has a relatively high penetration ability; it may even cross the detector without triggering a signal. On the other hand, alpha and beta particles will always trigger a signal once they enter the detector. However, since alpha and beta particles have only a short range (are easily stopped), the detector needs to have a very thin wall so that those particles can actually enter the detector. The range of alpha and beta particles plays an important part both in designing instruments and using them. We shall later discuss the matter of »range« in more detail.

Contamination may also occur inside some substance or object rather than on its surface. During their growth, plants may absorb and accumulate radioactive substances from soil, air, or water. If during steel production some radioactive scrap metal was accidentally molten down, the resulting steel will be contaminated homogeneously. Such substances are said to have a »specific activity« measured in Bq/g (Bq per gram). In case of liquids the activity content is often specified in relation to volume, that is in Bq/cm^3 (Bq per cubic centimetre) or Bq/l (Bq per litre). Analogously to surface contamination this can be called volume contamination. Although »volume contamination« may not be a generally adopted term, we shall use that term hereafter. The probe 6150AD-19 serves to detect volume contamination of liquids. Detecting volume contamination is more difficult than detecting surface contamination because a great part of the radiation will be absorbed by the liquid without reaching the detector. Because of the high self-absorption of a thick liquid layer it makes no sense to equip the adjacent detector with a thin vulnerable wall.

[A] Formerly the unit Ci (Curie) was used for activity. One Curie is defined as the activity of one gram of Radium (Ra-226, half-life 1620 years). Conversion is as follows:

1 Ci (Curie)	= 37 GBq (Giga-Becquerel)	= $37 \cdot 10^9$ Becquerel
1 mCi (milli-Curie)	= 37 MBq (Mega-Becquerel)	= $37 \cdot 10^6$ Becquerel
1 µCi (micro-Curie)	= 37 kBq (kilo-Becquerel)	= $37 \cdot 10^3$ Becquerel

[B] If $T_{1/2}$ is the half-life, then you can calculate the number N of atoms corresponding to the activity of one Bq according to this formula:

$$N = T_{1/2} / \ln 2 = 1.44 \cdot T_{1/2}$$

where $T_{1/2}$ has to be expressed in seconds. Example: for Cs-137, $T_{1/2}$ = 30 years = $9.5 \cdot 10^8$ seconds, which means that N = $1.4 \cdot 10^9$. In other words, 1.4 billions of Cs-137 atoms represent an activity of 1 Bq; one atomic nucleus out of those 1.4 billions decays per second. 1.4 billions of Cs-137 atoms have a mass of $3.1 \cdot 10^{-13}$ grams, which is a really tiny »physical« amount. One single gram of pure Cs-137 has an activity of $3.2 \cdot 10^{12}$ Bq, that is 3.2 TBq (Tera-Becquerel).

2.2 Absorption of Radiation in Various Materials

In connection with the measurement of contamination the question frequently arises whether the particles emitted from some radioactive substance will be able to go through some layer of some material. This section contains some information on this subject.

In this context the thickness of some layer is not specified in terms of a length unit such as cm, but as the so-called »areal density« in mg/cm^2 (milligrams per square centimetre). The reason is that layers of different materials with equal areal density have similar absorption ability, because the absorption of a particle primarily depends on the amount of mass (of any material) the particle has to go through. The heavier a material, the thinner its layer representing the same areal density. Areal density and thickness of the layer are connected through the material's density as follows:

$$\text{areal density} = \text{density} \bullet \text{thickness}$$

By the way, ordinary paper is an example from everyday life where the thickness of a layer is specified by its areal density. Common printer or copier paper has a »thickness« of 80 g/m^2, that is 8 mg/cm^2.

The table below shows some examples how thin a layer of a material must be if it shall have an areal density of 1 mg/cm^2:

	density	thickness of a layer with an areal density of 1 mg/cm^2 (= 1 mg/cm^2 / density)
air	~ 0.0012 g/cm^3 at 20°C	~ 0.83 cm = 8300 µm
water	1.0 g/cm^3	0.001 cm = 10 µm
aluminium	2.7 g/cm^3	0.00037 cm = 3.7 µm
mica	~ 2.8 g/cm^3	~ 0.00036 cm = 3.6 µm

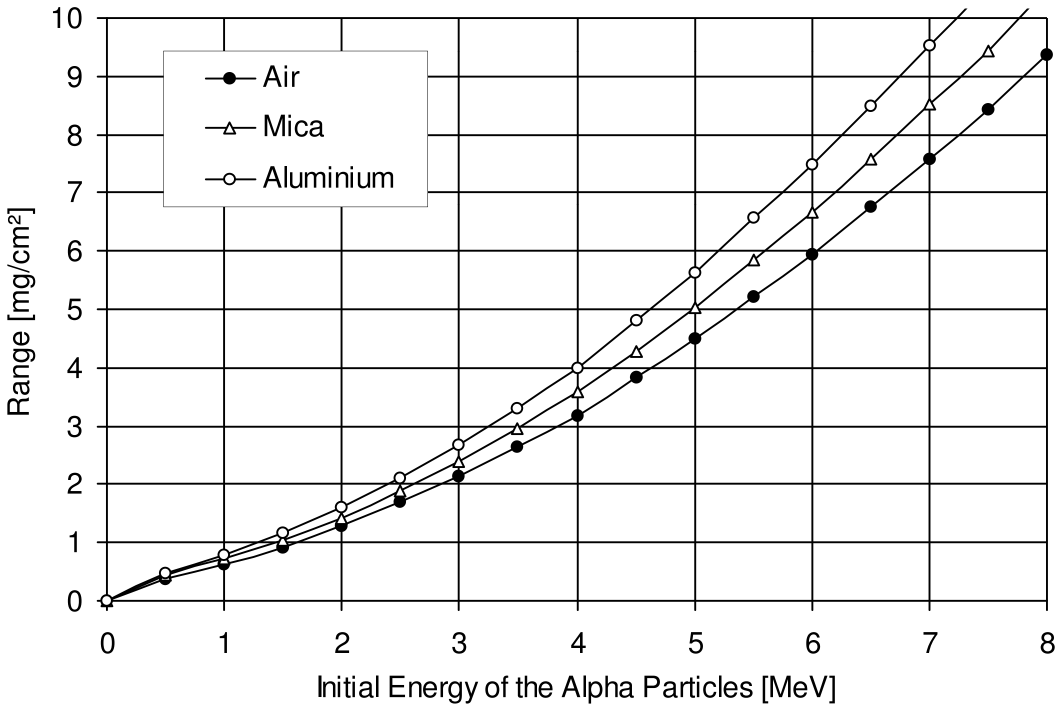
Aluminium and mica are materials that are frequently used for manufacturing thin windows for counting tubes. »Mica« denotes a group of minerals (for example, muscovite) that can be perfectly cleaved into thin sheets or flakes. Since the areal density of thin windows made from these materials is typically 1.5 to 3 mg/cm^2, the thickness of such windows is only 5 to 10 µm (1 µm = 10^{-6} m = one thousandth of a mm). This is why such windows are very vulnerable and need to be protected against touch by protection grilles or similar measures.

The »range« of a particle is the length of the path the particle travels until it is completely stopped. A particle with a particular initial energy can traverse a particular amount of mass, that is a layer with a particular areal density. Therefore the range of particles is usually specified in mg/cm^2, just like thickness of layers is. The higher the initial energy of a particle, the greater its range. If a particle shall be recognized by some detector, it has to be able to enter that detector. This means that its range must be greater than the thickness of the detector's window.

2.2.1 Range of Alpha Particles

Alpha particles are relatively heavy and travel relatively slowly through matter. They leave a dense track of ionization along their path and are easily stopped. Therefore they have only a very short range. All alpha particles emitted from a particular radionuclide have the same initial energy which is characteristic for the radionuclide (for example, approximately 5.5 MeV in the case of Am-241). The diagram below shows the range of alpha particles in various materials as a function of the initial energy of the alpha particles.

Range of Alpha Particles in Air, Mica, and Aluminium

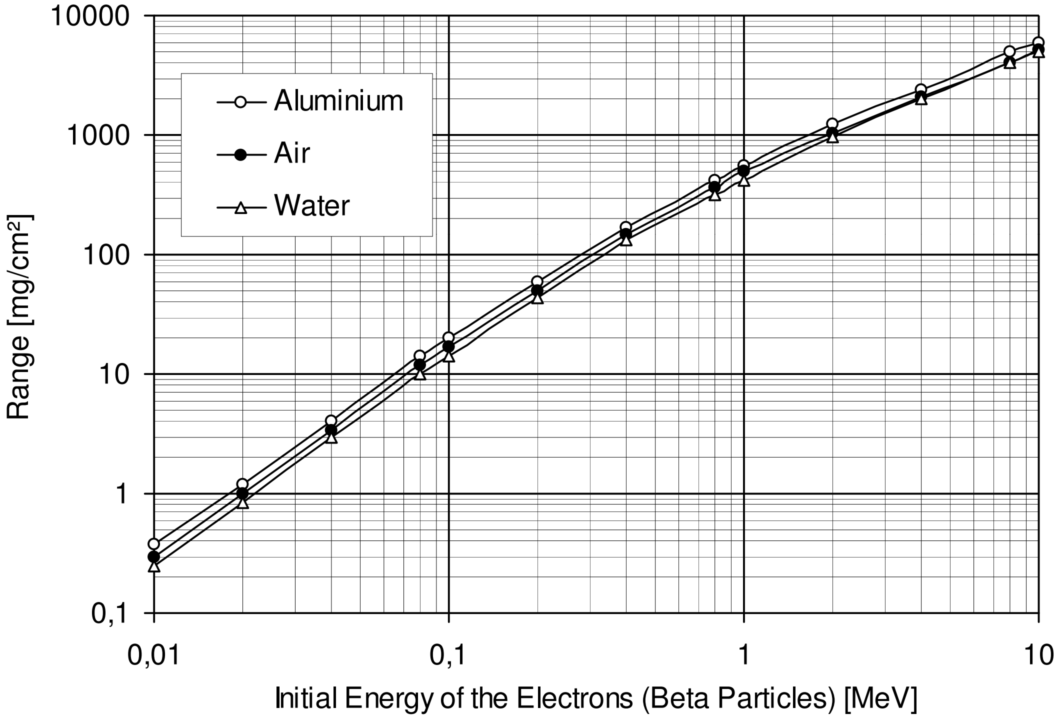


The diagram shows that the range measured in mg/cm^2 is quite similar in different materials. Note that an alpha particle has to traverse both the air gap between the source and the measuring instrument, and the window of the instrument if it shall be detected. Most alpha emitters emit alpha particles with initial energies of 4 to 6 MeV. Therefore a measuring instrument should be able to detect alpha particles with initial energies from 4 MeV on. Reading the diagram at 4 MeV shows that this can only be achieved if the sum of air gap and window thickness does not exceed approximately 3 mg/cm^2. If the window's thickness is already 2 mg/cm^2, the air gap must not amount to more than approximately 1 mg/cm^2 (= 0.8 cm of air). In practice, conditions will be even less favourable because many of the alpha particles will already have lost some of their energy in the source. This demonstrates how important it is to keep the distance from the source to the instrument to a minimum. Each millimetre may be significant.

2.2.2 Range of Beta Particles

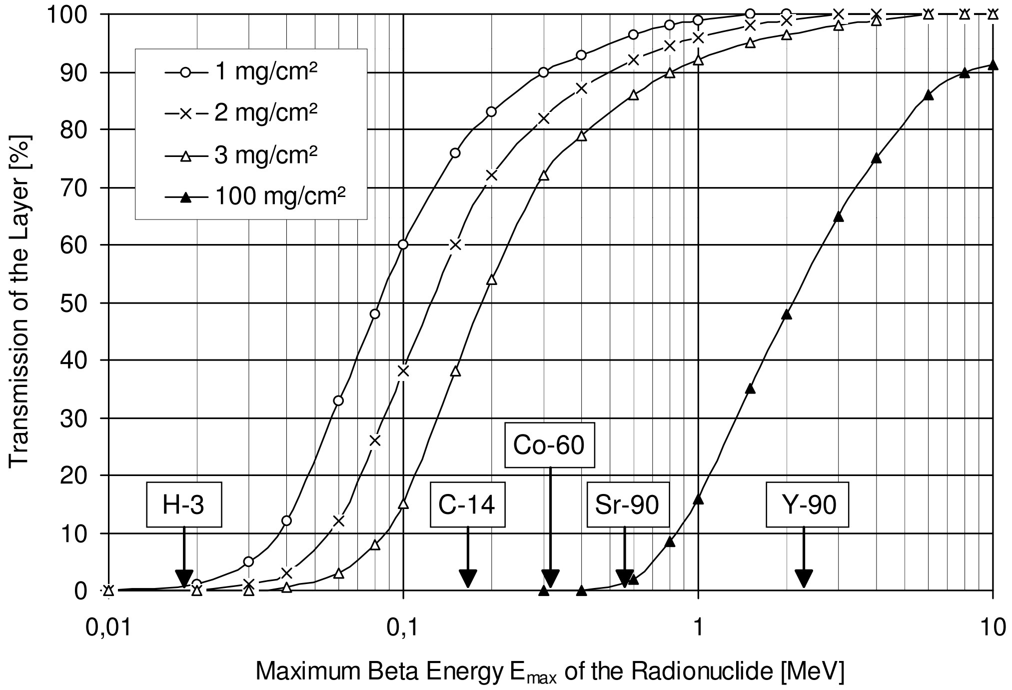
Beta particles are fast electrons. Electrons have a considerably greater range than alpha particles. However, their range is not as well-defined as the range of alpha particles, because electrons frequently change their direction when colliding with the atoms of the absorber. The diagram below shows the range of beta particles in various materials as a function of the initial energy of the beta particles.

Range of Electrons in Air, Water and Aluminium



Like for alpha particles, the range measured in mg/cm^2 is quite similar in different materials. Unfortunately, the diagram is not suited to read the range of beta particles of a particular radionuclide because beta particles do not have uniform energy, but cover a whole spectrum up to a maximum energy E_{max} which is characteristic for the radionuclide. The average energy of the beta particles amounts to approximately $E_{max}/3$. Since beta particles with different energy have different ranges, there is no uniform range for the beta radiation of a particular radionuclide. Therefore it makes more sense to consider the transmission ability of a particular layer for beta radiation with a particular maximum energy. The transmission specifies the percentage of beta particles that manage to traverse the layer. The transmission of an instrument's window must not be too low if the instrument shall be able to detect the beta radiation. The diagram on the next page shows the transmission of various layers as a function of the maximum beta energy E_{max}.

Transmission (Percentage) of Various Layers for Beta Radiation as a Function of the Maximum Beta Energy



The data presented in this diagram are coarse values only. For the present purpose these data may be used for all types of materials that are candidates for thin windows. The four curves representing four different amounts of thickness were chosen according to these reasons:

The first three curves represent properties of mica windows that are frequently used with counting tubes. The areal density of such end windows typically amounts to 1 to 3 mg/cm^2.

The fourth curve for 100 mg/cm^2 stands for the metallic wall of a windowless counting tube which is suited to detect gamma and high energy beta radiation. Such counting tubes have an especially thin metallic wall, the areal density of which typically amounts to 40 to 100 mg/cm^2. Such counting tubes are more rugged and less expensive to manufacture than tubes with an end window. They are suited to detect beta radiation with a maximum energy from approximately 1 MeV on.

Pure gamma counting tubes have wall densities of 500 mg/cm^2 and more, which means that they cannot be used for direct beta detection. However, they will to some extent indirectly respond to high energy beta radiation through Bremsstrahlung which is produced during the stopping process of the beta particles.

The maximum beta energy of most radionuclides is some value within 0.15 MeV to 2.5 MeV. These nuclides can be quite well detected with counting tubes if the areal density of the tube's window does not exceed approximately 3 mg/cm^2 (for beta radiation with a maximum energy of 0.15 MeV a mica window with an areal density of 3 mg/cm^2 still has a transmission of approximately 40%, see the diagram above). Radionuclides with maximum beta energies far below 0.15 MeV require different measuring techniques. A well-known example for such a radionuclide is Tritium (H-3) with its maximum beta energy of only 0.0186 MeV. That particular feature of Tritium is also reflected in international standards. There are particular standards for radionuclides with a maximum beta energy below 0.15 MeV which are intended mainly for Tritium. However, in the following we shall only consider beta radiation with a maximum beta energy above 0.15 MeV, like the later to be discussed DIN ISO 7503-1 does.

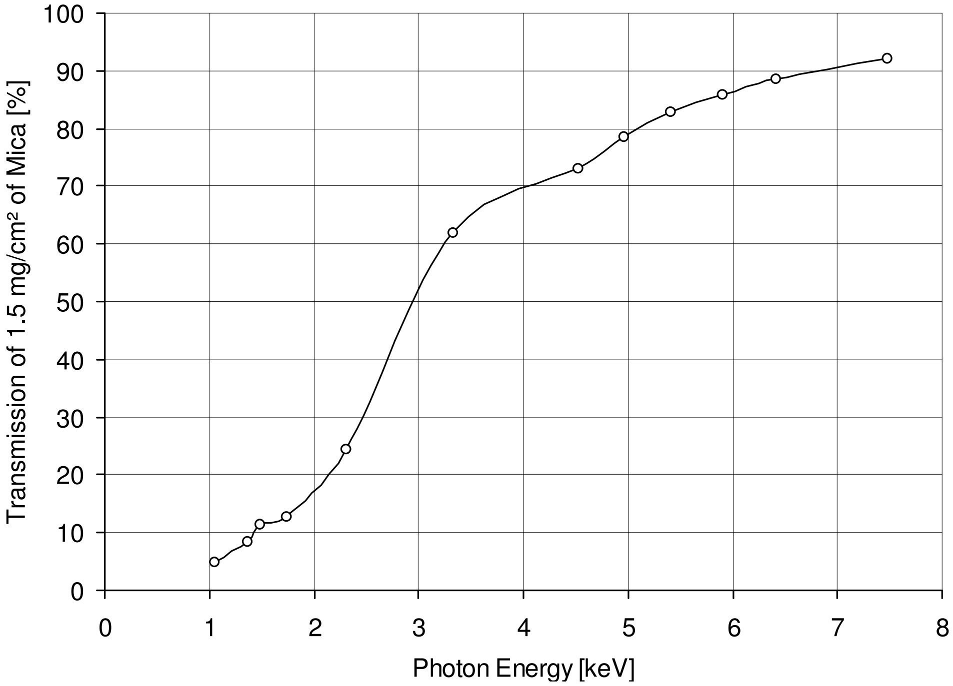
2.2.3 Range of Photons

Electromagnetic radiation is one of the most manifold phenomena in nature. Radio waves and visible light are the most popular examples of electromagnetic radiation that everyone knows from everyday life. Both X and gamma radiation are also »light«, although with much shorter wavelengths. X and gamma radiation were given different names not because of their nature, which is the same, but because of their different origin (X-radiation is generated when fast electrons hit some target, like the electron beam in an X-ray tube does, whereas gamma radiation comes from the decay of instable atomic nuclei). This is why the generic term »photon radiation« was introduced. »Bremsstrahlung« produced during the stopping process of beta particles is also photon radiation.

Conventionally photon radiation is not characterized by its frequency (as with radio waves) or by its wavelength (as with light), but by its energy[A]. Photons have a much longer range than beta particles of the same energy. For example, it takes 21 mm of lead (23700 mg/cm^2) to attenuate the photon radiation of Cs-137 (0.662 MeV) to one tenth of its initial intensity. Therefore, X and gamma radiation can easily penetrate a thin-walled detector. In many cases they may even cross the detector without triggering a signal, which makes them less efficient to detect.

Absorption by thin windows is only important for very low photon energies. The diagram below shows the transmission of a mica window with an areal density of 1.5 mg/cm^2 as an example. Transmission will not fall considerably below 100% until photon energy is lower than approximately 8 keV:

Transmission (Percentage) of a 1.5 mg/cm^2 Mica Layer for Photon Radiation as a Function of Photon Energy



[A] The wavelength λ and the frequency ν of any electromagnetic radiation are linked to each other by the velocity of light, c, as follows:

$c = \lambda \cdot \nu$

The energy of an electromagnetic radiation field is not distributed totally evenly, but is composed of small »packages« called photons (»light particles«). The energy E of a photon is calculated from the frequency ν by the aid of Planck's constant *h* as follows:

$E = h \cdot \nu.$

In practice, such low energies only occur with very »soft« X-radiation, or with only a few radionuclides. The best known example for such a radionuclide is Fe-55 (Iron 55), which emits 5.9 keV photon radiation.

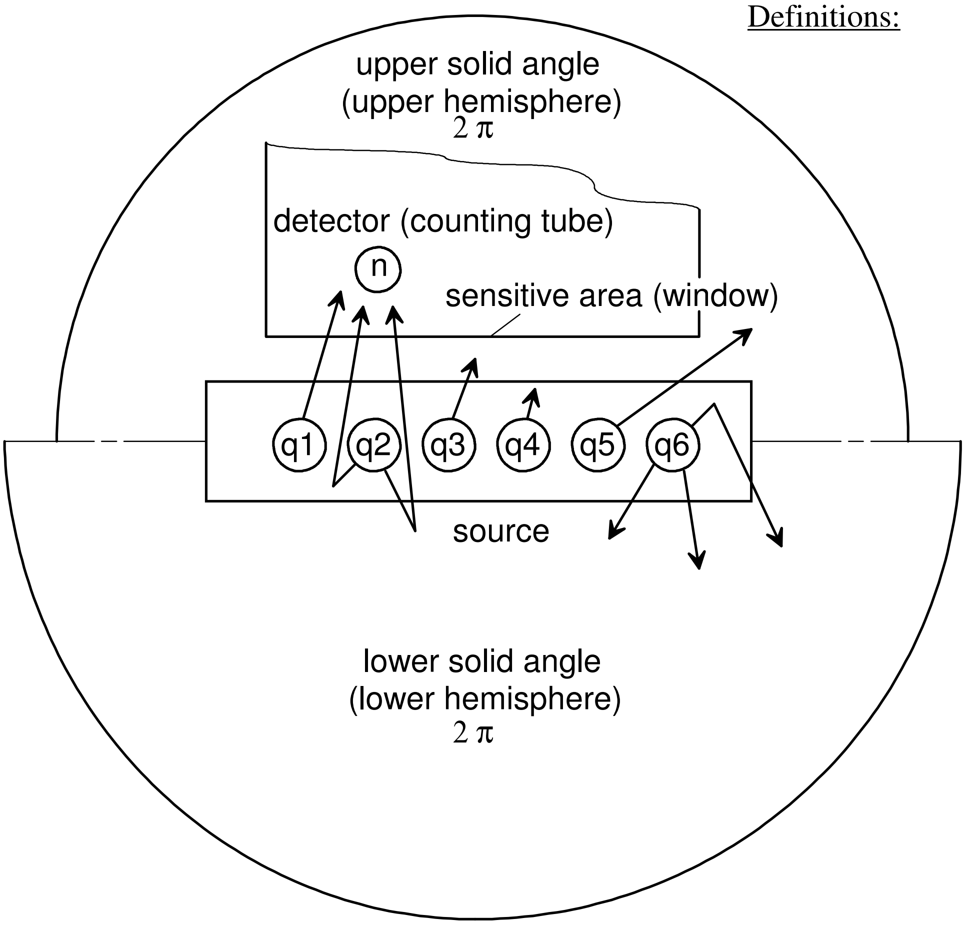
2.3 Measuring Surface Contamination

In a radioactive substance containing an activity of, for example, 100 Bq, 100 atomic nuclei decay per second. If each of those atomic nuclei emits one particle, and if each of those particles triggers a signal in the measuring instrument, the instrument must indicate 100 pulses per second. Unfortunately, in practice this is not the case. The instrument will indicate much less for two obvious reasons:

1. The particles will fly randomly in all directions in space. In the case of a contaminated surface such as, for example, a tabletop, one half of the particles will fly upwards into free space, whereas the other half will fly downwards into the tabletop. This means that only half of the particles can reach the detector, even if the instrument is brought close to the tabletop.
2. Only some fraction of the particles flying to the detector will be detected. The other fraction will not get to the sensitive part of the detector, because it will be absorbed either by the source itself or by mechanical elements of the instrument (window, protective grille). It depends on type and energy of the particles, and also on the characteristics of the source, how great the fraction of undetected particles will be.

However, this is still a simplified description of what happens. There are additional effects that affect indication of an instrument. We shall now discuss these effects in more detail.

Following DIN ISO 7503-1 we divide the particles emitted from the source into six groups according to their destiny (see the figure below). The source may be real surface contamination, but it may also be a check source to check or calibrate an instrument.



Definitions:

activity of the source:
$A = q1+q2+q3+q4+q5+q6$

W = sensitive area of the detector in cm^2

surface related activity:
$A_S = A/W$ in Bq/cm^2

surface emission rate:
$q_{2\pi} = q1+q2+q3+q5$

surface efficiency:
$\varepsilon_s = q_{2\pi} / A$

n = count rate generated in the instrument

instrument efficiency according to DIN ISO 7503-1:
$\varepsilon_i = n / q_{2\pi}$

instrument efficiency according to DIN 44801-1 / IEC 325:
$\varepsilon_{4\pi} = n / A$

The total activity A of the source is the sum of the groups q1 to q6. Only groups q1 and q2 get to the detector. However, this does not mean that the instrument will detect groups q1 and q2 completely. The detector is the counting tube including its mechanical wall (window, protective grille). Since that wall, particularly the protective grille, will absorb a fraction of the particles, the count rate n is lower than the sum of q1 and q2.

IMPORTANT: In this view A is always only the activity underneath the sensitive area of the detector, even if the source should be larger than that area. An instrument can only detect alpha or beta activity underneath its sensitive area. It will indicate activity as the total activity underneath that area, and it will indicate surface contamination as a value averaged across that area in case the activity is not distributed uniformly.

The groups q1 to q6 have the following meaning:

q1: Particles that reach the detector directly.

q2: Particles that reach the detector indirectly by backscatter from the source or the source’s ground. Considerable backscatter mainly appears with high energy beta emitters and may result in a situation where more than half of the particles leave the source upwards. However, this situation is not very likely in practice, because in many cases self-absorption (q4) is stronger than backscatter.

q3: Particles that leave the source upwards in the direction of the detector, but do not reach the detector because of absorption in air. This effect becomes more important as the gap between source and instrument grows. It is particularly important for alpha emitters.

q4: Particles that are emitted upwards in the direction of the detector, but do not leave the source because of self-absorption inside the source. This effect may result in a situation where less than half of the particles leave the source upwards. The shorter the range of the particles, and the thicker the source, the more important this effect will be. In case of alpha emitters it may be so dominant that almost all of the radiation will be absorbed inside the source itself, which will lead to a pronounced underestimate of the activity (contamination).

q5: Particles that leave the source upwards in the direction of the detector, but miss the detector for geometrical reasons (edge losses).

q6: Particles that leave the source downwards or are scattered downwards.

As manifold as these effects are, as complicated practical determination of surface contamination will be. The various effects also emphasize what has to be observed in practice. For example, the instrument has to be brought to the surface in question as close as possible to keep absorption in air and geometrical loss to a minimum (but, on the other hand, not so close that contamination may be transferred to the instrument). Moreover, indication of an instrument also depends on the characteristics of the source itself. Sources with equal activity, but different self-absorption, have different surface efficiencies. For example, humidity may strongly hide alpha contamination; once the surface has dried and the measurement is repeated, indication will be considerably higher. Even check sources of equal activity may have different surface efficiencies if one manufacturer managed better than the other to produce the source as »thin« as possible, that is with as few self-absorption as possible.

We shall now have a closer look at the response of an instrument. Response is important because it is needed to convert reading into contamination. Response strongly depends on type and energy of the radiation, that is on the radionuclide concerned. Usually manufacturers of instruments specify response for various radionuclides. Additionally it may become necessary that the user himself determines the response to a particular radionuclide by the aid of a reference source.

The response of an instrument is its reading divided by the true value of the quantity the instrument is exposed to. In case of contamination meters, reading is (for example) counts per second, and the true value is some activity in Bq, that is decays per second. Therefore the response of a contamination meter is also called »efficiency« (symbol ε), because it tells how efficient the instrument converts decays per second into counts per second. For the current purpose, the terms »response« and »efficiency« can be regarded as more or less equivalent.

Even experts may not agree how to define response and efficiency, as can be seen from the standards DIN ISO 7503-1 and DIN 44801-1 (DIN 44801-1 is basically the international standard IEC 325). We shall therefore discuss both standards.

	DIN ISO 7503-1		DIN 44801-1 / IEC 325	
	definition	unit	definition	unit
surface (or source) efficiency	$\varepsilon_s = q_{2\pi} / A$	-	term not defined	
(2π) instrument efficiency	$\varepsilon_i = n / q_{2\pi}$	-	term not defined	
activity response, also known as »4π efficiency«	$R_i = \varepsilon_i \cdot \varepsilon_s = n / A$	-	$\varepsilon_{4\pi} = n / A$	s^{-1} / Bq
	Once efficiencies ε and the sensitive area W of the instrument are known, the readout n converts into A and A_S as follows:			
activity A (underneath the sensitive area W)	$A = n / (\varepsilon_i \cdot \varepsilon_s)$	Bq	$A = n / \varepsilon_{4\pi}$	Bq
surface related activity A_S (averaged across the sensitive area W)	$A_S = A / W$ $= n / (\varepsilon_i \cdot \varepsilon_s \cdot W)$	Bq / cm^2	$A_S = A / W$ $= n / (\varepsilon_{4\pi} \cdot W)$	Bq / cm^2

Some remarks on the symbols appearing in the table:

1. n is the indication of the instrument caused by the source. Note that any instrument will also have a non-zero indication in the absence of the source, the so-called instrumental background or background count rate. That background count rate must be subtracted from the observed count rate. In other words, n is not just the indication of the instrument, but the indication in presence of the source reduced by the indication in absence of the source.

2. The sensitive area W is the total geometrical area including mechanical elements such as protective grilles. Since the protective grille hides a fraction of W, the »truly« sensitive area, also known as »effective window area« or »usable window area«, is smaller than W. However, the user does not need to take further care of that fact because responses or efficiencies specified for an instrument already include the absorbing effect of protective elements.

3. $\varepsilon_{4\pi}$ is a symbol we chose as a symbol for 4π response. DIN 44801-1 / IEC 325 does not use this symbol.

4. The other symbols A, A_S, $q_{2\pi}$, ε_s, and ε_i are defined next to the figure on page 9.

Let us first take a look at DIN 44801-1 / IEC 325. The key parameter to determine activity is the »activity response« $\varepsilon_{4\pi}$. The name »efficiency« for that parameter is a little bit unfavourable, because according to the definition of $\varepsilon_{4\pi}$ even an ideal instrument can hardly achieve an efficiency of more than 50% due to group q6 particles. However, engineering usually defines an efficiency in such a way that an ideal device - that is a device without any loss - will have an efficiency of 100%. This is why DIN 44801-1 / IEC 325 avoid the name »efficiency« and use »response« instead, where response is measured in »s^{-1}/Bq« (which is actually dimensionless). We shall be less strict than international standards and shall also use the name »efficiency«, while bearing in mind that this efficiency can never reach 100%. This efficiency is also called »4π efficiency« because it refers to all particles that are emitted into the total solid angle of 4π. The advantage of 4π efficiency is that the user only requires one parameter per radionuclide to determine activity. The disadvantage is that the characteristics of the source are included in that efficiency. This means that DIN 44801-1 / IEC 325 assume that all sources of a particular radionuclide will have equal self-absorption and backscatter characteristics. Since this is not the case in practice, corresponding inaccuracies have to be expected.

DIN ISO 7503-1 solves this problem by dividing $\varepsilon_{4\pi}$ into ε_s and ε_i ($\varepsilon_{4\pi} = \varepsilon_s \cdot \varepsilon_i$). ε_s is surface or source efficiency and accounts for self-absorption and backscatter. ε_i is instrument or detector efficiency. For the instrument, the efficiency ε_i is a fair definition because it refers to only those particles that are emitted into the upper 2π solid angle towards the instrument. That efficiency is therefore also called »2π efficiency«. With this definition, an ideal instrument may achieve an efficiency close to 100% (only group q5 particles will not be recognized because even an ideal instrument always has an edge). The advantage of DIN ISO 7503-1 is that it better takes into account what really happens. The disadvantage is that the user now has to deal with two parameters per radionuclide. Whereas instrument efficiency ε_i can in principle be determined extremely accurately, surface efficiency ε_s is initially unknown. DIN ISO 7503-1 recommends these nominal values:

$\varepsilon_s = 0.5$ for beta emitters with a maximum beta energy greater than 0.4 MeV,
$\varepsilon_s = 0.25$ for alpha emitters and beta emitters with a maximum beta energy from 0.15 MeV to 0.4 MeV (DIN ISO 7503-1 does not apply for beta emitters with a maximum beta energy lower than 0.15 MeV).

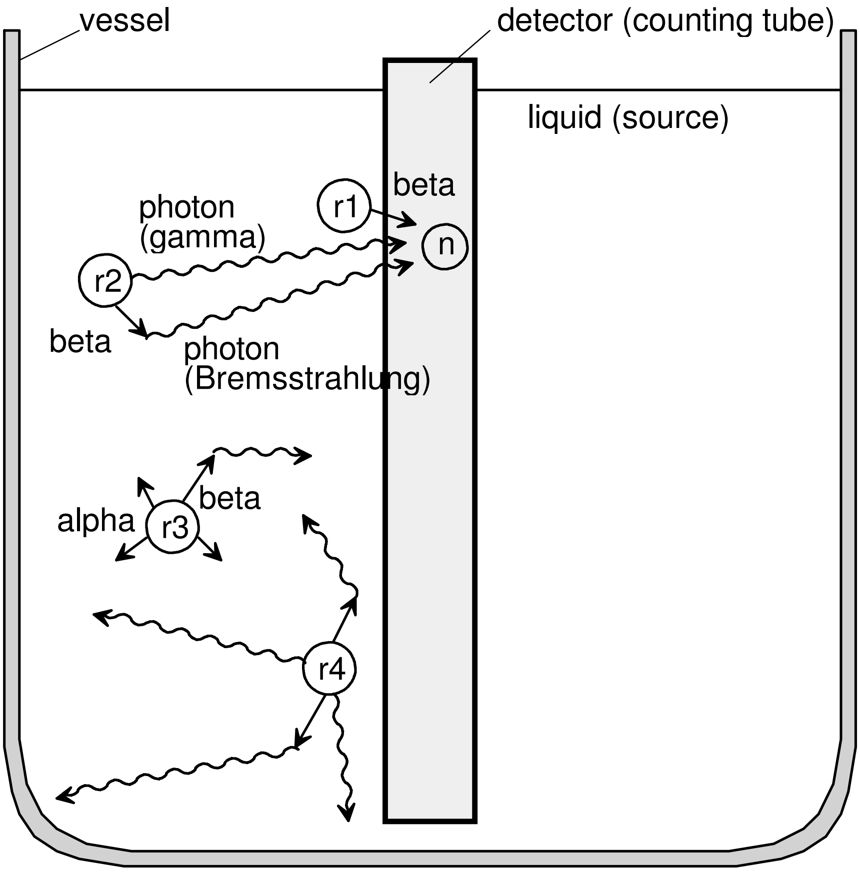
This is a rather coarse division into two categories. It reflects that the poor knowledge about the source's true characteristics will always lead to considerable uncertainties of contamination measurements. Even the most sophisticated definitions cannot rule out such uncertainties.

The question arises which approach to use. We decided in favour of the classical 4π efficiency because this seems easier in practice. There will be only one conversion factor for each radionuclide ($\varepsilon_{4\pi}$). It has to be accepted that this factor involves the source's characteristics as an uncertainty. DIN ISO 7503-1 basically involves the same uncertainty hidden in the uncertainty of ε_s. In terms of DIN ISO 7503-1, we use only the factor R_i ($= \varepsilon_s \cdot \varepsilon_i = \varepsilon_{4\pi}$) which we determine by the aid of reference sources.

2.4 Measuring Volume Contamination

Self-absorption inside the source plays a dominant part when measuring volume contamination. Alpha radiation and a great part of beta radiation will be absorbed before it can get to the detector. Detection of beta radiation (not alpha radiation) is made a little easier by indirect detection through Bremsstrahlung[A]. Photon radiation has high penetration ability and thus a good chance to get to the detector, but may for the same reason cross the detector without triggering a signal.

Suppose some radioactive substance is evenly dissolved in some liquid. Imagine that the liquid is in some cup-like vessel with a detector dipped into the centre of that cup. That arrangement corresponds to the probe 6150AD-19. As with surface contamination, we divide the particles emitted from the source into groups according to their destiny:



Definitions:

activity of the source:
$A = r1 + r2 + r3 + r4$

V = volume of the liquid in l (litres)

M = mass of the liquid in g (grams)

specific activity:
$A_S = A/M$ in Bq/g

volume contamination:
$A_V = A/V$ in Bq/l

n = count rate generated in the instrument

instrument efficiency:
$\varepsilon = n / A$

The division into groups r1 to r4 and the definitions were not taken from some national or international standard, but are our own definitions. The groups r1 to r4 have the following meaning:

r1, r2: Particles and their secondary products that get to the detector. Because of their low range, beta particles will only arrive at the detector if they originate from the immediate vicinity of the detector (r1). Photon radiation (gamma radiation and Bremsstrahlung, r2) is able to traverse thicker liquid barriers, but may also traverse the detector without triggering a signal. This is why the count rate n is rather low.

r3: Particles and their secondary products that will not arrive at the detector because they are absorbed totally by the liquid.

r4: Particles and their secondary products that miss the detector for geometrical reasons.

Compared to surface contamination it is obvious that volume contamination is much more difficult to detect because self-absorption is high and geometry is unfavourable. Volume contamination meters

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[A] Bremsstrahlung is photon radiation generated during the stopping process of electrons (beta particles).

arranged as shown above will not achieve efficiencies of more than a few percent, even under favourable circumstances. The reasons are:

1. The low detection probability for photon radiation (group r2), even if the radiation should arrive at the detector,
2. the inevitably high self-absorption (group r3),
3. the unfavourable geometry (group r4).

The range of alpha particles in liquids is so short that they will be absorbed completely inside the liquid. Therefore it makes no sense to put high effort into designing a detector that would be able to detect alphas, because even then the fraction r1 would be infinitely small for alphas. It is impossible to detect a pure alpha contamination with this method. The same is true for Tritium, the radiation of which also has an extremely short range (beta radiation with a maximum energy of only 18.6 keV). Detecting such types of contamination requires other methods such as mixing the liquid in question with a liquid scintillator. In some cases one might consider to transform volume contamination into better detectable surface contamination by filtering or evaporating the liquid.

Detection of beta radiation is made a little easier by indirect detection through Bremsstrahlung. Maybe you wonder why Bremsstrahlung was not mentioned when discussing surface contamination, although it obviously must appear there as well. The reason is that in case of surface contamination, that is in case of relatively weak self-absorption, the number of events triggered in the detector by Bremsstrahlung is small compared to the number of events triggered directly by the beta particles. In case of volume contamination, however, Bremsstrahlung is an important or even the dominant effect to detect beta contamination.

If the contaminated volume is a solid object (for example, steel where radioactive scrap metal was accidentally molten down), one has to approach the problem in a totally different manner. Since alpha and beta radiation will be absorbed inside that object almost completely, such an object will only radiate outwards noticeably if the contamination is (partly) a gamma source. In such a case it is not very meaningful to check the surface for alpha or beta radiation. One would rather try to determine the radionuclide and then conclude the activity from gamma dose rate. Besides that, the hazard emerging from such an object is more external exposure rather than potential incorporation in the human body. The hazard is then the gamma dose rate in the vicinity of the object rather than the activity contained in it (at least as long as the object will not be processed mechanically producing dust or similar which could arrive at or in the human body).

2.5 Differentiation between Surface and Volume Contamination

In practice the question may arise whether a contamination is surface or volume contamination, and which method that contamination should be measured with.

In order to detect a surface contamination *quantitatively*, self-absorption must not be too pronounced. This means the following conditions have to be fulfilled:

1. The surface must be so hard that no essential part of the contamination has got into the surface. Materials such as metal, plastic, and also lacquered wood will usually meet this condition, and so will objects like tools, work surfaces, and similar. If, on the other hand, the surface is porous and has already absorbed a considerable part of the contamination, this may be more volume than surface contamination.
2. The surface must be dry because humidity may lead to considerable self-absorption, particularly in the case of alpha emitters.
3. The surface must be smooth so that it is safe to assume that there will be only few self-absorption. This is generally the case if the surface seems clean or only slightly dusty. If, on the other hand, the surface is covered with a heavy layer of dirt, or is heavily rusty in case of metals, this may be more a volume contamination of the layer of dirt.

All these conditions have to be met if surface contamination shall be measured correctly. Otherwise surface contamination will be underestimated or will even pass unnoticed.

However, this does not mean that one should immediately try to measure volume contamination if one of the conditions is not fulfilled. It would not be very meaningful to scratch off the contaminated layer of dirt or rust, transform it into liquid form, and then measure the activity contained in that liquid. This method would not only take much effort, but it would also be quite inaccurate because measuring volume contamination is rather difficult as mentioned earlier. In practice, one will measure volume contamination mostly on objects that are originally »voluminous« and do not have limiting surfaces, such as liquids.

Once a surface contamination is discovered, the goal is mostly not to measure that surface contamination accurately, but to decontaminate the object by cleaning it as often as necessary until no or only fixed contamination is left (wear gloves!). After that thorough cleaning the surface will automatically be so clean and smooth that 2. and 3. of the above conditions are met and the remaining surface contamination can be determined with reasonable accuracy.

2.6 Wipe Survey

Part of a contamination may be fixed at the surface, and another part may be removable. Removable contamination represents a greater hazard. Wipe survey is a method to test whether part of the contamination is removable: Firmly smear the surface in question with a clean piece of paper (for example, a filter paper or a paper towel) and then test the paper for contamination. If the surface carries removable contamination, part of that contamination must have been transferred to the paper and can be detected on that paper. Furthermore, wipe survey is a method to test for removable contamination if the surface in question is so difficult to access that you cannot bring the instrument directly to that surface.

Under certain conditions the contamination on the paper can be converted into the surface contamination of the surface in question. Firstly, observe to smear in such a way that the contaminated area of the paper will not be larger than the area of the detector that is used afterwards to examine the paper. Secondly, the area that was wiped must be known. It is recommended to wipe an area of 10 cm x 10 cm = 100 cm^2. Then bring the (potentially) contaminated part of the wipe to the window of the detector and determine the total amount of activity that was removed. Then you can calculate the surface contamination of the surface wiped as follows:

$$\text{Surface contamination} = \frac{\text{activity removed [Bq]}}{\text{area wiped [cm}^2\text{]}} \;/\; \text{removal factor}$$

The removal factor takes into account that the wipe will only remove a fraction of the surface contamination. DIN ISO 7503-1 recommends a removal factor of 0.1 as a (conservative) estimate, which means it is assumed that only 10% of the contamination were removed. Since such assumptions are always accompanied by considerable uncertainties, any surface contamination determined with this method can only be a coarse estimate.

Note: Instinctively one might suppose that smearing with a damp paper will result in better removal, and thus in better detection sensitivity. As to better removal, this is surely correct. However, contamination may much more easily get into the porous structure of paper if the paper is damp, which may lead to considerable self-absorption inside the paper. Although the damp paper will have removed more activity, that gain may be over-compensated by increased self-absorption, which will finally lead to an underestimate of the contamination. Therefore paper used for wipe surveys should always be dry.

2.7 Condensation Water on the Detector Window

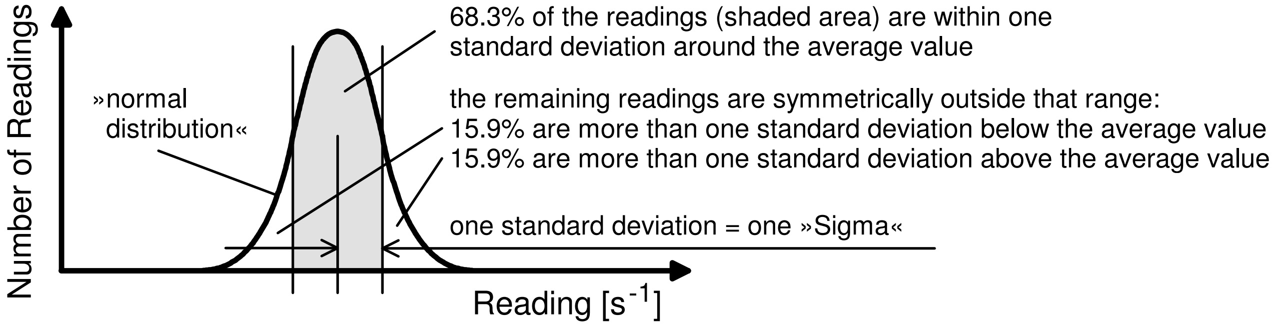
As already pointed out repeatedly, contamination will be underestimated if part of the radiation is absorbed before entering the detector. Condensation water on the detector window, even in form of a thin film only, is another potential source for such an error. If climatic conditions support the formation of condensation water, for example when bringing the instrument from a cool atmosphere into a warm and humid one, you have to wait for that humidity to dry before starting a survey.

3. Statistical Fluctuations and Accuracy of Reading

The previous chapter showed that it is anything but simple to convert the indication of an instrument into contamination, even if the instrument can be considered as calibrated perfectly. But this is not yet enough: It is even not so easy to read the instrument correctly, because statistical fluctuations of the instrument's indication make reading it more difficult. We shall now discuss this problem in more detail. Like the previous one, this chapter primarily addresses users who are not very familiar with this subject.

3.1 The Standard Deviation »Sigma«

Imagine to watch an instrument indicating a count rate in s^{-1} (counts per second) under constant conditions. Although conditions are constant, indication will fluctuate statistically. If you register the indicated values and how frequently they appear, you will obtain a symmetrical bell-shaped distribution around the average value as shown in the graph below (provided that the count rate is not too low). That distribution is what the theory of statistics calls a »normal distribution« (you can find an experimental example in section 3.3).



The width of this distribution, that is the amount of fluctuation, is measured by the so-called standard deviation. The longer the counting period (respectively: the longer the instrument's time constant), the smaller the standard deviation will be. Hereafter we shall call the standard deviation »Sigma«, because this is the name of the Greek letter σ, which theory of probabilities uses as a symbol for the standard deviation. Sigma is measured in the same unit as the reading itself, that is s^{-1} in the example above. Furthermore there is the relative standard deviation, hereafter called »Sigma-rel«. Sigma-rel is the standard deviation divided by the average value, and is specified in percent (and is also known as »coefficient of variation«).

The drawing above specifies how many of the readings are within or out of one Sigma. The question arises, how many Sigmas are required so that the shaded area in the drawing will cover, for example, 90% of the readings. This is not easy to compute; the table below shows some selected values, some of which we shall require later:

number of Sigmas	portion of the shaded area (»confidence level«)
1.000	68.3 %
1.645	90.0 %
1.960	95.0 %
2.000	95.5 %
2.576	99.0 %
3.000	99.7 %

We shall turn to the question how to determine Sigma later in sections 3.4.1 and 3.4.3.

3.2 Confidence Level and Error Probability

The confidence level is the probability that some statement is true. Such a statement may for example be: »The count rate is (6 ± 1) s^{-1}«. A confidence level of 95% is generally recommended, which corresponds to approximately two Sigmas (precisely: 1.96 Sigmas), see the table in the previous section. Then only 5% of all statements are false, which is considered as tolerable (the desirable confidence level of 100%, that is absolute certainty, can never be achieved according to the laws of probability).

Example: A 6150AD6 with an external probe in mode »average value« indicates a count rate of 30 s^{-1} and a Sigma-rel of 10%. Then, and at a confidence level of 95% (two Sigmas), the following statement is true: »The count rate is 30 s^{-1} ± 20%, that is (30 ± 6) s^{-1}«. The probability that this statement will be false, the »error probability«, is then 5%.

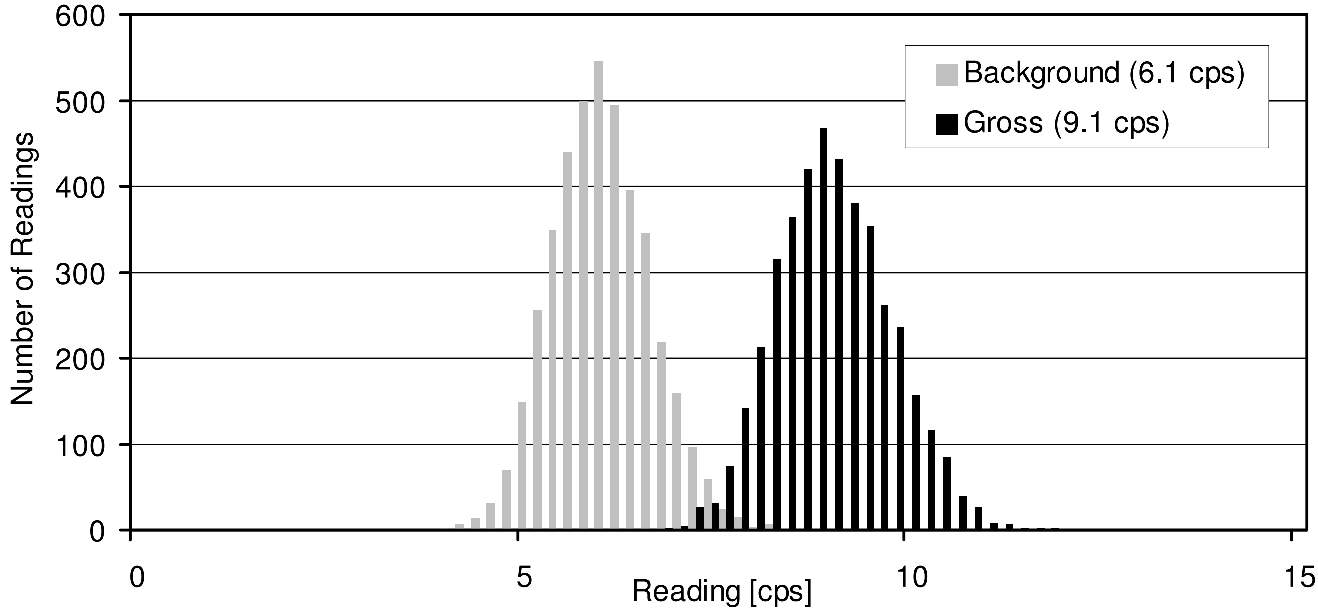
3.3 Background Count Rate, Gross Count Rate, and Net Count Rate

Even if there is no radioactive sample close to the instrument, the instrument will indicate non-zero values. This so-called background count rate is caused by one or more of the following:

1. Natural or artificial background radiation,
2. natural radioactivity incorporated in materials the instrument or detector is made of,
3. contamination of the instrument itself,
4. inherent electronic noise effects.

When a radioactive sample is brought to the instrument, indication will increase. Only that increase comes from the sample, and only that increase must be taken to determine contamination of the sample.

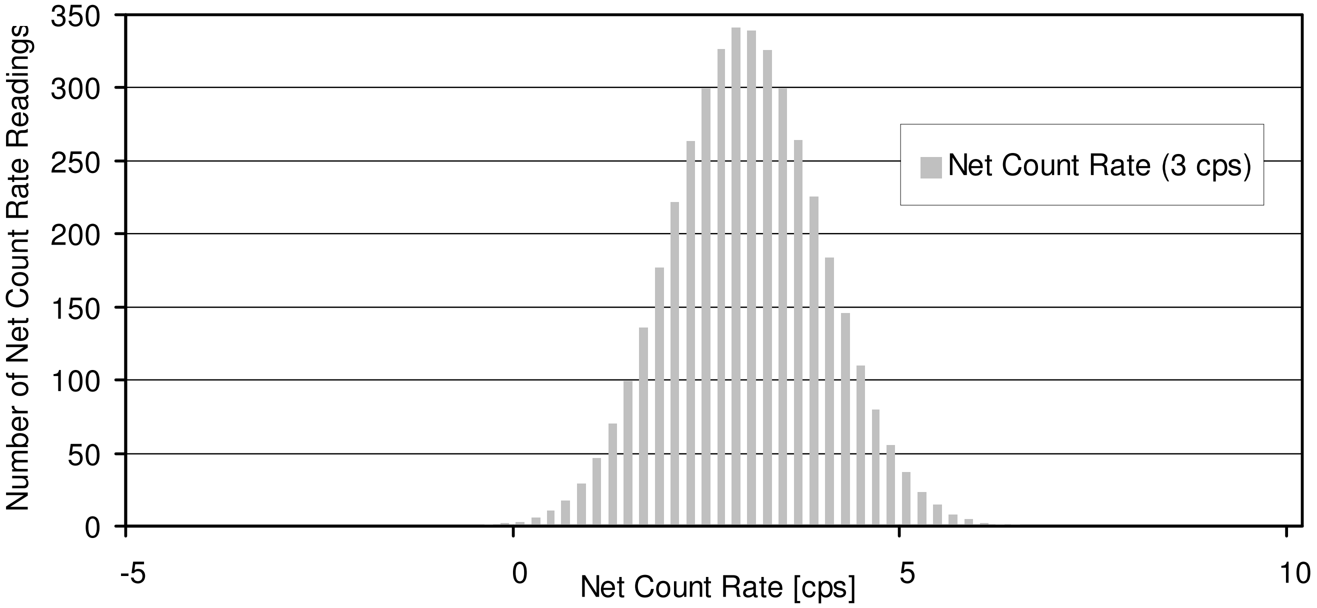
At first sight this seems reasonable and easy. First measure the background count rate (indication without sample), then the gross count rate (indication with sample), and finally subtract the background count rate from the gross count rate to obtain the net count rate. However, statistical fluctuations may lead to considerable reading errors. The graph below shows an example obtained from a field test:



The data in this graph were obtained experimentally with a 6150AD6 and a contamination probe 6150AD-k in mode »alpha-beta-gamma« as follows:

- Grey bars: Background count rate, that is indication while there was no radioactive sample close to the instrument. The 6150AD6 was operated in mode »dose rate indication« (which is »count rate indication« in the present case) and was read at one second intervals for a little more than one hour. That makes about 4000 readings. The grey bars represent how frequent the readings (divided into intervals of 0.2 s^{-1}) were. The average of the readings is 6.1 s^{-1}. Sigma calculated from the 4000 readings according to formula (2d) from section 3.4.3 is 0.62 s^{-1}.
- Black bars: Gross count rate, that is indication with a radioactive sample brought to the instrument. Again 4000 readings were taken at one second intervals. The average of the readings is 9.1 s^{-1}, and their Sigma is 0.74 s^{-1}. Consequently, the net count rate is 9.1 s^{-1} - 6.1 s^{-1} = 3.0 s^{-1}.

The effect of the radioactive sample is obvious because, on an average, the gross count rate is clearly greater than the background count rate. But it is also obvious that both distributions overlap. What does this mean in practice? Suppose you read the instrument only twice, that is firstly the background count rate (distribution of probabilities according to grey bars), and secondly the gross count rate (probabilities according to black bars). The difference of those two readings is the net count rate. Further suppose to repeat this procedure many times. The net count rate determined with this procedure will be subject to even heavier fluctuations, see the graph below (note the origin of the x-axis!):



The average of the net count rate readings is 3.0 s^{-1}. Sigma calculated according to formula (2d) from section 3.4.3 is 0.97 s^{-1}. This was also to be expected theoretically from the Sigmas of gross and background count rates, see section 3.5.

The graph shows: In many cases you will be »lucky« and read a reasonable net count rate not far from the true value of 3 s^{-1}. However, there will also be results considerably larger (5 s^{-1} and more) or close to zero. You may even be »very unlucky« and obtain a negative net count rate, which means you will not even notice the radioactive sample! We shall now have a closer look at this problem.

3.4 Decision Threshold and Detection Limit

In context with contamination measurements the technical terms »decision threshold« and »detection limit« appear. These meaning of those two terms is:

- Decision Threshold: A measurement shall decide whether there is contamination or not. Contamination is considered to be existing if the reading exceeds the so-called decision threshold. The decision threshold is suited as an alarm threshold for instruments with adjustable thresholds.
- Detection Limit: From the decision threshold follows the minimum contamination that can be detected at a particular confidence level. That minimum contamination is the so-called detection limit. It is always greater than the decision threshold. The detection limit of an instrument specifies whether that instrument is suited for a particular purpose. For example, if some regulation requires a contamination not to exceed a particular limit, the detection limit of the instrument must not be greater than that limit if the instrument shall be suited to prove that the limit is not exceeded.

Understanding decision thresholds and detection limits requires understanding things like counting (or measuring) period, time constant of a ratemeter, and calculation of Sigma. We shall shortly discuss these items and then define decision threshold and detection limit. In that discussion we follow DIN 25482-1, which corresponds to the international standard ISO 11929-1 (and which may use a slightly different notation than DIN 25482-1). However, we shall focus on those parts of the standards that apply to our contamination probes, and we shall keep the discussion as simple as possible. Should you require more detailed information, you will have to consult the standards mentioned.

3.4.1 Calculating Sigma for a Fixed Counting Period

If there is a count rate R (in s^{-1}), and pulses are counted for a fixed counting period T (in s), the total number of counts will be $N = R \cdot T$. Then you can calculate Sigma from the count number N as follows:

$$\text{Sigma} = \sqrt{N} \qquad (1a)$$

i.e.

$$\text{Sigma-rel} = \frac{\text{Sigma}}{N} = \frac{1}{\sqrt{N}} \qquad (1b)$$

These formulas are only valid if you can assume a normal distribution, which is the case from approximately N = 10 on.

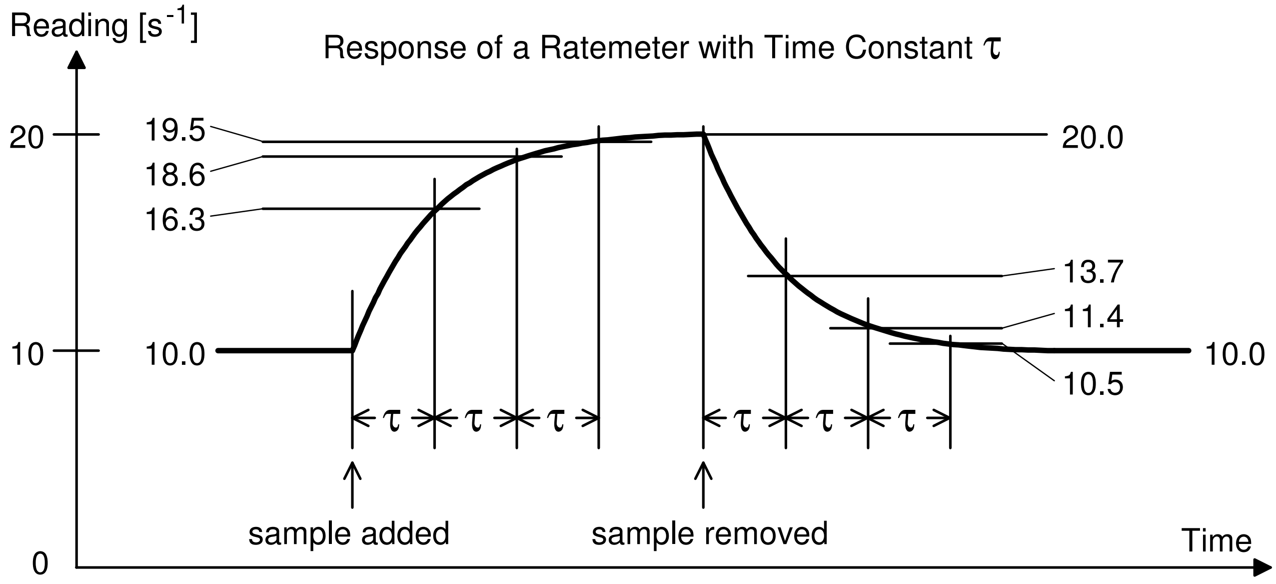
3.4.2 Counting Period in Case of a Ratemeter

A ratemeter is an instrument indicating count rate (possibly with some calibration factor applied). The 6150AD in mode »dose rate indication« (respectively: »count rate indication«) is an example for a ratemeter. A ratemeter uses a time constant to reduce the statistical fluctuations of its indication. The time constant acts like a counting period. The longer the time constant, the smaller the fluctuations (and the longer it takes for the ratemeter to respond to changes in count rate). It may happen that you come across some formula requiring a counting period to be inserted. The question arises what the counting period of a ratemeter will be. The answer is: The »effective« counting period of a ratemeter with a time constant τ is just twice the time constant:

$$\text{Effective counting period of a ratemeter} = 2 \cdot \tau.$$

IMPORTANT: Before reading the ratemeter you have wait some time so that the ratemeter’s indication has approached the (new) value. It is recommended to wait at least three time constants because after that the ratemeter will have responded by 95% to a sudden change of the true value.

Example: Due to a radioactive sample the reading of a ratemeter increases from 10 s^{-1} to 20 s^{-1}. The drawing below illustrates how the reading will develop in time (statistical fluctuations not shown):



Of course it may be annoying to wait »long« before reading the instrument. However, note that waiting for 3 • τ is equivalent to an effective counting period of 2 • τ. The waiting is not at all in vain, but serves for a more precise reading.

3.4.3 Calculating Sigma for a Ratemeter

A ratemeter with a time constant τ at a count rate R has an effective N = 2 • τ • R. Then formula (1b) from section 3.4.1 applied to the ratemeter looks as follows:

$$\text{Sigma-rel} = \frac{1}{\sqrt{N}} = \frac{1}{\sqrt{2\tau R}} \qquad (2a)$$

However, not each ratemeter will necessarily directly indicate the count rate of its detector. Some ratemeters may multiply the count rate R by a conversion factor F (for example, a calibration factor) before displaying it as the value D:

$$D = F \cdot R \qquad \text{respectively, at background:} \quad D_B = F \cdot R_B$$

The factor F does not affect the relative standard deviation Sigma-rel, but the absolute standard deviation Sigma. From Sigma = Sigma-rel • D follows:

$$\boxed{\text{Sigma} = D\sqrt{\frac{F}{2\tau \times D}} = \sqrt{\frac{F \times D}{2\tau}}} \qquad (2b)$$

The standard deviation Sigma_B of the background indication D_B is particularly important:

$$\text{Sigma}_B = \sqrt{\frac{F \times D_B}{2\tau}}$$

Sigma_B is the key parameter for decision threshold and detection limit, because both are multiples of Sigma_B. In the following we shall meet Sigma_B frequently again.

Applying formula (2b) requires information on F and τ. In case of the 6150AD you can avoid this formula by consulting the chapter »Time Constant and Standard Deviation« in the 6150AD's Operating

Manual. In that chapter you find a diagram specifying Sigma-rel as a function of 6150AD indication D for all detectors. That diagram is nothing but a graphical representation of formula (2b), where the various scales of the x-axis account for the conversion factors F of the various detectors. With Sigma-rel taken from that diagram you may easily compute Sigma as follows:

$$\boxed{\text{Sigma} = \text{Sigma-rel(from Operating Manual)} \cdot D} \qquad (2c)$$

If you do not know anything about time constant and factor F, because the ratemeter in question is an »unknown« one, you have to determine Sigma experimentally. Watch the ratemeter for a prolonged period and read it at regular intervals. 100 readings at intervals of 10 seconds will yield good results in the very most cases. Then Sigma is:

$$\boxed{\text{Sigma} = \sqrt{\frac{n\sum x^2 - (\sum x)^2}{n(n-1)}}} \qquad (2d)$$

where:

n is the number of readings,

$\sum x^2$ is the sum of the squares of the values read,

$(\sum x)^2$ is the square of the sum of the values read.

This formula is integrated in some scientific pocket calculators. This formula is also valid if the instrument uses a conversion factor F.

Conclusion: There are several ways how to determine Sigma. Using the practical example of the background count rate D_B of the probe 6150AD-k, we summarize three equivalent methods how to determine Sigma_B:

1. Applying formula (2b) with $D_B = 6\ s^{-1}$, $\tau = 8$ s and F = 1:

   $$\text{Sigma}_B = \sqrt{\frac{6\ s^{-1}}{2 \times 8s}} = 0.61\ s^{-1} \qquad \text{(6150AD-k in mode } \alpha\beta\gamma)$$

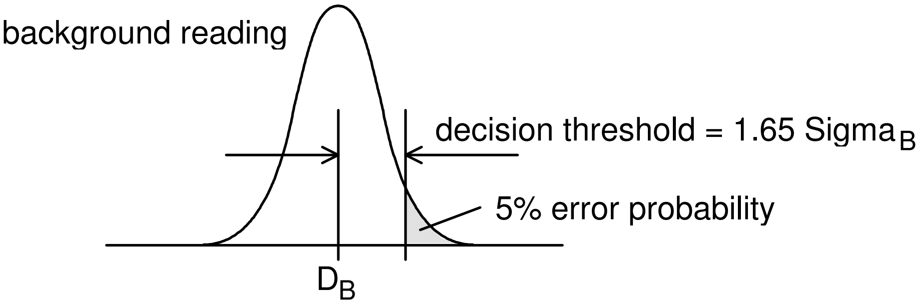
   The specification $\tau = 8$ s was taken from the 6150AD's Operating Manual. The specification F = 1 comes from the technical data of the 6150AD-k.

2. Applying formula (2c): The 6150AD-k is a member of the probe family 6150AD-0. Reading the diagram in the 6150AD's Operating Manual for the 6150AD-0 at an indication of $D_B = 6\ s^{-1}$ shows a Sigma-rel of 10%. Therefore: $\text{Sigma}_B = 10\% \cdot 6\ s^{-1} = 0.6\ s^{-1}$.

3. Experimentally (see section 3.3) by the aid of formula (2d). The result was $\text{Sigma}_B = 0.62\ s^{-1}$. This method may be troublesome, but it is straightforward and the most secure method in case you are not sure which formula to apply correctly. It is the only method if specifications for F and τ are missing.

3.4.4 Definition of the Decision Threshold

The decision threshold is defined as the limiting value exceeding which leads (with a certain error probability) to the conclusion that a contamination exists. The decision threshold only depends on background, counting period, and the error probability conceded. A value of 5% is generally recommended as an error probability. That error would be to detect a contamination although there is none[A]. That error always occurs when the background reading is accidentally so high that the reading exceeds the decision threshold. This means that the decision threshold has to be chosen such that 5% of the background readings will be above the decision threshold:



If 5% of the readings are too high, then another 5% are too low, which is insignificant in the present case. Consequently, we are looking for a confidence level of 90% (*not* 95%) when reading the background. According to the table in section 3.1 this corresponds to 1.65 Sigma$_B$. This means that the decision threshold[B] for the net count rate will be (symbol R_n^* according to DIN 25482-1):

$$R_n^* = 1.65 \sqrt{\frac{F \times D_B}{2\tau}} = 1.65 \text{ Sigma}_B \quad (D_B \text{ measured precisely}) \qquad (3a)$$

This formula is only valid if D_B and therefore Sigma$_B$ were measured sufficiently precisely. »Sufficiently precisely« means that the counting period for the background D_B must have been at least ten times as long as the routine counting period for the gross count rate will be. This requires to average the reading of the ratemeter at background conditions for at least $20 \cdot \tau$. D_B obtained as that average has to be inserted into formula (3a). The 6150AD makes this troublesome job much easier. It allows to read D_B precisely from the average value indication (counting period at least $20 \cdot \tau$).

If D_B is not measured particularly precisely, but with the same counting period as the gross count rate, the decision threshold[C] will be:

$$R_n^* = 1.65 \sqrt{\frac{F \times D_B}{\tau}} = 2.33 \text{ Sigma}_B \quad (D_B \text{ read directly}) \qquad (3b)$$

Let us apply formula (3a) to the 6150AD-k practical example presented in section 3.3. For the probe 6150AD-k, F = 1. The background measurement showed $D_B = 6.1\ s^{-1}$, $\tau = 8$ seconds, and Sigma$_B$ = 0.62 s^{-1}. Since D_B was measured sufficiently precisely, according to formula (3a) the decision threshold for the net count rate is $1.65 \cdot 0.62\ s^{-1} = 1.02\ s^{-1}$, which is approximately 1 s^{-1}. The decision threshold for the gross count rate is then $6.1\ s^{-1} + 1\ s^{-1} = 7.1\ s^{-1}$. This means that we can set the alarm threshold of the

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[A] The probability of the opposite error, that is that an existing contamination will pass unnoticed, defines the detection limit, see section 3.4.5.

[B] In DIN 25482-1 you will find much more complicated formulas for the decision threshold. Formula (3a) is equivalent to the approximation formula from DIN 25482-1 if it is assumed that: $k_{1-\alpha} = 1.65$, $t_B >> t_G$, and $t_G = 2\tau$, where t_B and t_G are background and gross counting periods. Furthermore DIN 25482-1 generally assumes F = 1 ($D_B = R_B$).

[C] Formula (3b) is equivalent to the approximation formula from DIN 25482-1 if it is assumed that: $k_{1-\alpha} = 1.65$, and $t_B = t_G = 2\tau$, where t_B and t_G are background and gross counting periods. Furthermore DIN 25482-1 generally assumes F = 1 ($D_B = R_B$).

6150AD-k to 7.1 s^{-1} in order to notice the smallest possible contamination. However, we have to accept that false alarms caused by statistical fluctuations of the background reading will occur with a probability of 5%. The instrument will issue alarm 5% of the time although there is no contamination at all.

This example demonstrates how important it is to know the background count rate D_B exactly. Suppose due to an increase in background radiation the background count rate would only slightly increase from 6.1 s^{-1} to 6.5 s^{-1} while the alarm threshold would remain at 7.1 s^{-1}. Then the alarm threshold would no longer be 1 s^{-1} above background, but only 0.6 s^{-1}, which is one Sigma only. The probability of false alarms would then increase from 5% to 16%, which is surely too much in practice. Therefore the background must not only be known exactly, it must also be checked at reasonable intervals. Once the background D_B has changed, because environmental conditions have changed, or because the instrument itself was slightly contaminated, the decision threshold has to be re-calculated and the alarm threshold to be re-adjusted. Ideally the background is determined every time before a potentially radioactive item is surveyed.

Carefully measuring and checking the background is quite laborious and requires experienced users. It is easier and much more comfortable to read the background in the same way as the gross count rate, that is directly from the ratemeter. That gain in comfort goes at the expense of sensitivity by increasing the decision threshold. Formula (3b) now applies. According to formula (3b) the decision threshold for the net count rate of the 6150AD-k now amounts to $2.33 \cdot 0.62\ s^{-1} = 1.44\ s^{-1} \sim 1.5\ s^{-1}$. However, this value is not sufficient to define a decision threshold for the gross count rate (alarm threshold) because this would require the background also to be known accurately. The user himself has to decide that there is contamination if the instrument's indication increases by at least the decision threshold. That procedure may look as follows:

1. The decision threshold is defined to be 1.5 s^{-1} since the user is not expected to re-calculate the decision threshold from D_B every time an object shall be surveyed. This is achieved by initially measuring D_B more accurately and assuming that D_B will not change drastically. Then the user is instructed to make his decision regarding contamination following these steps:
2. Read the background directly, which means remember the instrument's indication without sample.
3. Bring the sample to the instrument, wait for at least three time constants (that is, at least 24 seconds), and then read the gross count rate directly.
4. If the gross count rate is at least 1.5 s^{-1} above the background, consider the sample as contaminated, otherwise consider the sample as clean. Before the next reading (another sample or background again), wait again for at least three time constants.

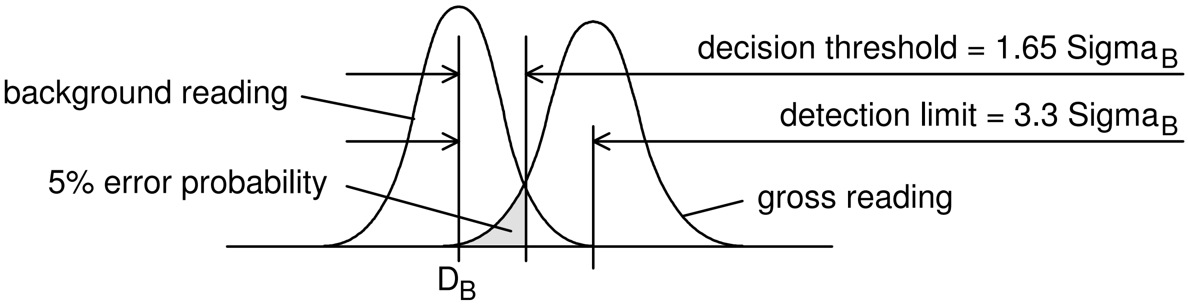
Using this procedure the user will notice heavy contaminations, and he will incorrectly declare 5% of the clean samples as contaminated. On the other hand, some of the weakly contaminated samples will pass unnoticed. The next section discussing the detection limit is dedicated to this problem.

3.4.5 Definition of the Detection Limit

We just learned how the decision threshold decides whether contamination is considered to exist:

- A reading above the decision threshold leads to the decision: »The sample is contaminated«. As explained in the previous section, 5% of the clean samples will be incorrectly declared as contaminated.
- A reading below the decision threshold leads to the decision: »The sample is not contaminated«. This statement, too, will not always be true, because a weak contamination may pass unnoticed. The question arises, how strong a contamination must be if it shall be detected with a certain probability. That minimum contamination is called detection limit, also known as MDA (minimum detectable activity).

In other words, the detection limit is the lowest net count rate that can be detected with a certain error probability. Like for the decision threshold, the same value of 5% is generally recommended as an error probability for the detection limit. That error would be to miss an existing contamination. That error always occurs when the gross count rate reading is accidentally so low that it falls below the decision threshold. This means that, for a contamination equal to the detection limit, 5% of the gross count rate readings will be below the decision threshold:



The shapes of the distributions of background and gross count rate are not identical but very similar. Therefore it is a good approximation to say: *At equal error probabilities for decision threshold and detection limit, the detection limit is twice the decision threshold of the net count rate*. We may therefore use the formulas (3a) and (3b) for the decision threshold. Consequently, the detection limit of the net count rate is (symbol ρ_n^* according to DIN 25482-1):

$$\rho_n^* = 2\ R_n^* = 3.3\ \text{Sigma}_B \qquad (D_B \text{ measured precisely}) \qquad (4a)$$

$$\rho_n^* = 2\ R_n^* = 4.7\ \text{Sigma}_B \qquad (D_B \text{ read directly}) \qquad (4b)$$

The second formula (4b) is preferred because it results in a greater detection limit. This covers the case where D_B is read directly, which will be the more frequent situation in practice.

Even experts do not always agree. You will also meet the recommendation to use generally six Sigma$_B$ as the detection limit. However, all agree that Sigma$_B$ is the measure for the detection limit. It is more a »matter of taste« how many Sigma$_B$ the detection limit will be. We shall use formula (4b) but round up the pre-factor of 4.7 to the next integer value of 5:

$$\text{Detection Limit} = 5\ \text{Sigma}_B \qquad (5)$$

where Sigma$_B$ is calculated from one of the formulas (2b), (2c), or (2d). The decision threshold should be chosen to some value between 1.65 Sigma$_B$ and half the detection limit, that is to some value between one third and one half of the detection limit, depending on the error probability you wish to allow for.

3.5 Confidence Interval of the Net Count Rate

This section discusses how much statistical confidence you may have in a measured net count rate. But first of all, remember that you will not always have to determine the actual net count rate. A practical instruction to check for contamination may read as follows:

- Use the decision threshold to decide whether there is contamination or not. If not, the sample is considered clean, and the procedure is completed. If yes, decontaminate the sample, and make the decision again. Repeat the attempt to decontaminate as often as necessary until the sample is considered clean.

This procedure does not require the amount of contamination, the net count rate, to be known as a precise reading. Nevertheless, this procedure is suited to prove that some regulatory limit is not exceeded, provided that the detection limit of the instrument used is not greater than this regulatory limit (and provided that the decision threshold was not chosen more than half of the detection limit).

But how to proceed if the amount of net count rate needs to specified, for example because part of the contamination is fixed and could not be removed? It is not very helpful to specify a single number for the net count rate without adding information on the statistical reading error. You should not specify the net count rate as a single number, but as a range or interval containing the true value with a certain probability, that is at a certain confidence level. That range is the so-called confidence interval. It is specified, for example, as »x ±Δx«. The lower boundary x-Δx and the upper boundary x+Δx are called confidence limits. Specifying a confidence interval makes only sense if the confidence level belonging to it is also specified. As already mentioned in section 3.2, a confidence level of 95% corresponding to two Sigmas is usually recommended.

The net count rate is the difference between gross and net count rate. Gross and net count rate have each their own confidence level measured by their corresponding standard deviation. We already discussed in detail the standard deviation Sigma_B of the background; we shall now call the standard deviation of the gross count rate Sigma_G. Sigma_G is calculated according to the formulas in section 3.4.3, like Sigma_B is, where now the gross count rate has to be inserted for indication D. The question arises, what the standard deviation Sigma_N of the net count rate will be if Sigma_G and Sigma_B are known. We need some mathematics to answer this question, that is the so-called error propagation law. That law says (in a simplified manner):

If x and y are independently measured values with absolute errors Δx and Δy - that is, with relative errors Δx/x and Δy/y - , then is

- the relative error Δz/z of the product z = x • y or the quotient z = x / y

  $\frac{\Delta z}{z} = \sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2}$ (quadratic addition of the *relative* errors in case of *product* or *quotient*)

- the absolute error Δz of the sum z = x + y or the difference z = x - y

  $\Delta z = \sqrt{\Delta x^2 + \Delta y^2}$ (quadratic addition of the *absolute* errors in case of *sum* or *difference*)

These formulas describe how, according to theory of probabilities, the statistical errors of the measured values x and y will propagate to the result z. The most probable error of the result is always greater than each individual error, but it is not equal to the sum of the individual errors, because the errors may partly compensate. Since the net count rate is the difference between gross and background count rate, the second formula has to be used to calculate Sigma_N:

$$\boxed{\text{Sigma}_N = \sqrt{\text{Sigma}_G^2 + \text{Sigma}_B^2}} \qquad (6)$$

Once Sigma_N is known, it is easy to specify the confidence interval of the net count rate for a particular confidence level. For example, if the usual confidence level of 95% is required (two Sigmas), and the net count rate measured is D_N, the confidence interval of the net count rate is $D_N \pm 2 \cdot \text{Sigma}_N$.

Let us verify formula (6) taking the 6150AD-k practical example presented in section 3.3. There was $\text{Sigma}_B = 0.62\ s^{-1}$ and $\text{Sigma}_G = 0.74\ s^{-1}$. Then, according to formula (6):

$$\text{Sigma}_N = \sqrt{0.74^2 + 0.62^2}\ \ s^{-1} = \sqrt{0.932}\ \ s^{-1} = 0.97\ s^{-1}$$

In fact, this is exactly the same value for Sigma_N that was obtained experimentally from the distribution of the net count rate readings, which confirms the validity of formula (6).

In practice, Sigma_B and Sigma_G will not be known as accurately as in our example, where the Sigmas were obtained from many readings. However, that does not alter the fact that formula (6) is well suited to determine Sigma_N. Suppose we would have read each the background D_B and the gross count rate D_G only once. Further suppose D_B would have been 7 s^{-1} (that is, accidentally slightly more than the average of 6.1 s^{-1}), and D_G would have been 8.5 s^{-1} (that is, accidentally slightly less than the average of 9.1 s^{-1}). This is all the information we have since we do not know the »true« values. So far we have read a net count rate of $D_N = (8.5 - 7)\ s^{-1} = 1.5\ s^{-1}$. Now Sigma_N is still missing. From the 6150AD's Operating Manual we read a Sigma-rel of about 9% for count rates in the range of 7 to 8.5 s^{-1}. Consequently, $\text{Sigma}_B = 9\% \cdot 7\ s^{-1} = 0.63\ s^{-1}$, and $\text{Sigma}_G = 9\% \cdot 8.5\ s^{-1} = 0.765\ s^{-1}$. Then, according to formula (6): $\text{Sigma}_N = \sqrt{0.765^2 + 0.63^2}\ \ s^{-1} = 0.99\ s^{-1}$. That value for Sigma_N is very close to the »true« value of 0.97 s^{-1}. The reason is that Sigma_B and Sigma_G change only slowly with count rate. At a confidence level of 95% we specify the confidence interval as: $D_N = (1.5 \pm 2)\ s^{-1}$. That specification is correct since the true value of $D_N = 3\ s^{-1}$ is inside that interval. However, $D_N = 0$ is also inside that interval. This means that, at a confidence level of 95%, we cannot even say that there is contamination at all. This demonstrates how important it is for the significance of some measured value to specify a confidence interval.

The only way to reduce Sigma_N is to increase the counting period. The counting period of a ratemeter is determined by its time constant; the user can usually not modify the time constant. Besides that, a very long time constant would make the instrument respond too slowly in practice. This is why, in addition to normal ratemeter operation, the 6150AD was given the function to indicate the average value. By the aid of that function, and by using long counting periods, the statistical error can be reduced down to almost any value. The 6150AD5/6 even calculates Sigma-rel of the average, where Sigma-rel decreases as the counting period grows, and where Sigma-rel can be displayed upon pressing a key[A].

Let us look again at the 6150AD-k practical example presented in section 3.3. After having measured background for 4000 seconds, the 6150AD6 indicated an average of 6.1 s^{-1} and a Sigma-rel of 0.6%. After having measured the gross count rate for the same period, it indicated an average of 9.1 s^{-1} and a Sigma-rel of 0.5%. Sigma_N obtained from these data is much smaller than from direct reading. The following table compares the results obtained from direct reading with those obtained from the average value:

[A] The 6150AD1-4 does not yet have this function. Although it indicates the average value, it does not indicate Sigma-rel. There are two ways to determine Sigma or Sigma-rel with a 6150AD1-4:

1. You are satisfied with Sigma-rel = 5%. Wait until the indication of the average value stops flashing, and then assume Sigma-rel = 5%.
2. Calculate Sigma or Sigma-rel according to formulas (1a) or (1b) from section 3.4.1. You can read the number of counts (pulses) as the »dose« from the 6150AD (before each measurement, switch the 6150AD off and on again to reset the probe dose). Note: The formulas (1a) and (1b) require the true pulse count N to be inserted, which means that it has to be observed that the »dose« as indicated by the 6150AD contains the conversion factor F (»dose« = F • N). Therefore, the true pulse count is: N = dose/F.

	direct reading of the 6150AD’s count rate (»Sigma-rel« taken from the diagram in the 6150AD’s Operating Manual)			average value and standard deviation of the 6150AD after a counting period of 4000 seconds each (»Sigma-rel« as indicated by the 6150AD6)		
	reading	Sigma-rel	Sigma	reading	Sigma-rel	Sigma
background	~ 6 s^{-1}	~ 10 %	Sigma_B ~ 0.6 s^{-1}	6.1 s^{-1}	0.6 %	$\text{Sigma}_B = 0.037\ s^{-1}$
gross	~ 9 s^{-1}	~ 8 %	Sigma_G ~ 0.7 s^{-1}	9.1 s^{-1}	0.5 %	$\text{Sigma}_G = 0.046\ s^{-1}$
net	~ 3 s^{-1}		Sigma_N ~ 1.0 s^{-1}	3.0 s^{-1}		$\text{Sigma}_N = 0.059\ s^{-1}$

By the aid of the average value we achieved a Sigma_N of 0.06 s^{-1}. At a confidence level of 95% we can specify the confidence interval of the net count rate to be (3.0 ± 0.12) s^{-1}. This is a very high accuracy of ±4%.

This example clearly demonstrates how strongly the counting period affects accuracy. It also demonstrates that the average value indication of the 6150AD is a powerful tool to reduce the statistical error, provided that there is sufficient time to perform the measurement.

However, keep in mind that reducing the statistical error improves reading accuracy only. Even the best reading accuracy cannot avoid systematic errors such as, for example, the unknown self-absorption of the source. It makes therefore no sense to bring the reading error down to a few percent if systematic uncertainties of 20% to 30% or more are to be expected.

4. Operation

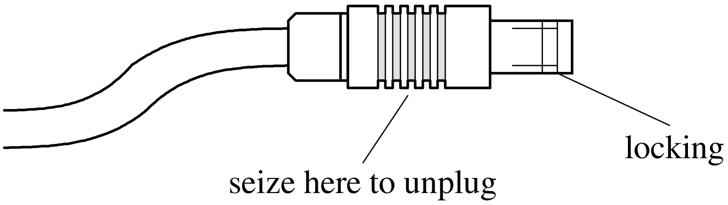
4.1 Connecting the Probes to the 6150AD

In case of the probe 6150AD-k, first place a Dose Rate Meter 6150AD on the probe and fix it at its front side using the knurled screw. Connect the 6150AD-k to the 6150AD using the short probe cable which is fixed at the 6150AD-k.

The probes 6150AD-17 and 6150AD-19 require a separate probe cable (accessory). To put the probe into operation, just connect it to the 6150AD through a standard probe cable. Both ends of the probe cable are equal, so you do not have to care which end to plug into the probe and which one into the 6150AD.

The probe cable not only serves to transfer data, but also to supply the probe with power. To put the probe out of operation, disconnect it or switch off the 6150AD. The 6150AD may be powered while connecting or disconnecting the probe; it will automatically recognize that the probe has been changed.

NOTE! When unplugging the connector, always seize the connector at the area with the grooves to release the locking! Never try to unplug the connector by seizing it at its smooth end or even at the cable! This would not release the locking and thus damage the probe cable!



The 6150AD displays the probe type in the upper left corner of its LCD as follows:

- »ext 17« for the probe 6150AD-17,
- »ext 19« for the probe 6150AD-19,
- »ext 0« for the probe 6150AD-k. The probe 6150AD-k is a member of the probe family 6150AD-0, the count rate of which is indicated without any conversion factor.

With all these probes, the unit automatically changes to S^{-1} (counts per second, pulses per second). All measurements indicated from now on are obtained with the probe (except battery voltage which always refers to the 6150AD's battery). See the 6150AD Operating Manual for a detailed discussion of the various indications.

4.2 6150AD-17

The probe 6150AD-17 uses a GM counting tube with a mica end window as a detector. That end window has a thickness of 1.5 to 2 mg/cm^2 and is located at the circular front side of the probe behind a protective grille. A removable protective cap made of rubber serves as an additional protection of the end window. Furthermore, the protective cap may serve to discriminate between alpha and beta radiation on the one hand, and gamma radiation on the other hand.

NOTE! The end window is very thin and thus very vulnerable. By all means, avoid touching the end window, because any such contact may destroy the tube!

During storage of the probe the protective cap should always remain on. During operation it depends on the circumstances whether the protective cap should be applied or removed:

- Should you wish to survey some object for surface contamination, you always have to remove the protective cap so that the probe is able to respond to alpha and beta radiation. Bring the front side with the protective grille as close as possible to the object in question. Use the audible single pulse detection of the 6150AD in order to notice a potential increase in count rate more easily. If you do not immediately notice such an increase, remember the time constant of the 6150AD, which amounts to eight seconds. If weak contaminations down to the order of the detection limit shall be detected, you have to wait for at least three time constants before reading the count rate! Once you observed contamination, carefully avoid to contaminate the probe or even yourself.
- Only if rough environmental conditions seem to make damaging the end window more likely, you should consider operating the probe with the protective cap on. However, the probe will then respond to photon radiation only. With the protective cap on, the probe is a »gamma tracing probe« which can be used to detect an increase in gamma dose rate, for example when trying to locate a gamma source.

If indication with the protective cap removed is considerably higher than with the protective cap on, this means that there is alpha or beta radiation (or very low energy photon radiation). Further information regarding the kind of radiation, particularly the radionuclide(s) involved, is not available. If you wish to convert net count rate into surface contamination, you need to know both the radionuclide and its calibration factor. Section 6.1 specifies calibration factors for a choice of radionuclides.

When using the probe as a »gamma tracing probe« please note that: We calibrate the probe 6150AD-17 at Cs-137 gamma radiation in such a way that the following conversion is valid for photon radiation (gamma or X-radiation):

$1\ \mu Sv/h = 1\ s^{-1}$ (for photon radiation in the energy range of 200 to 1300 keV)[A]

Since the probe has no energy compensation, this simple conversion is only valid in the energy range mentioned. Within that energy range, the probe is quite well suited to measure photon dose rate. The protective cap has almost no influence on response at such high energies.

At photon energies below 200 keV, indication depends more and more on the direction of radiation incidence as the energy decreases, and also the influence of the protective cap becomes more and more significant. For such low energies converting the indication from s^{-1} to µSv/h will in most cases give incorrect results. Particularly if the protective cap is removed and photon radiation enters the end window vertically, the probe will indicate much more than an energy compensated probe would do. This is even advantageous if the aim is to detect photon radiation as efficiently as possible rather than measuring it quantitatively.

[A] In order to achieve this, the 6150AD multiplies the count rate coming from the counting tube by a factor of approximately 0.65 (this is the factor F from section 3.4.3).

4.3 6150AD-k

The probe 6150AD-k uses a large area proportional counting tube as a detector. The window is made from aluminium foil. The counting tube is sealed and does not require refilling or flushing from external gas reservoirs which you may have experienced from similar instruments of other manufacturers. This makes handling much easier since the probe is immediately ready to measure. The filling is a mixture of inert gases which is not inflammable and thus does not represent any fire or explosion hazard even in case the filling should escape for some reason. The aluminium foil has a thickness of approximately 2.8 mg/cm^2 and is supported by a grille above which an additional fine etched mesh grille protects the foil.

NOTE! The aluminium foil is very thin and thus very vulnerable. By all means, avoid touching the aluminium foil, because any such contact may destroy the tube!

A stainless steel discriminator plate may serve to discriminate between beta and gamma radiation. During storage the discriminator plate additionally protects the window.

The handle of the probe has a joint which can be locked so that the orientation of the window can be adjusted to the position of the hand. Attaching the handle extension 770.1-60 (optional accessory) to the handle allows to survey the floor comfortably in an upright position. The handle extension 770.1-60 may be further extended by the tube extension 770.1-70 (optional accessory, too), see also the drawing in the technical data section.

You may also operate the probe remotely from the 6150AD. This makes the 6150AD much more easy to read in case you have to measure objects difficult to access (for example, the bottom side of a vehicle). For this purpose, the left side of the probe's housing carries a socket for an external probe cable. Connect the probe to the 6150AD through this socket using a standard probe cable (optional accessory, length up to 100 metres). The short probe cable permanently fixed at the probe is now no longer needed; you may accommodate its connector in the holder at the front side of the probe so that the short cable will not dangle around.

You may operate the probe 6150AD-k in two modes: »alpha« and »alpha-beta-gamma«. Select either mode through the switch on the probe, the two positions of which are marked »α« and »αβγ«. In mode »α« the counting tube operates at reduced high voltage and is therefore sensitive to alpha radiation only. In mode »αβγ« all three kinds of radiation will be detected. Apart from the switch position, background indication will also tell you which mode is selected. Background reading is approximately 6 s^{-1} in mode »αβγ«, and only approximately 0.05 s^{-1} in mode »α«. The reason is that natural background radiation does not comprise an alpha portion worth mentioning (the remaining indication of 0.05 s^{-1} is not caused by »residual« alpha radiation, but is the inevitable instrumental background).

When carrying out a measurement, it is usually not known which kinds of radiation may exist. If a potential contamination shall not pass unnoticed, the instrument has to be sensitive to all three kinds of radiation. This means that mode »αβγ« has to be selected, and the discriminator plate has to be removed, so that alpha and beta radiation can get to the counting tube.

NOTE! If an unknown contamination shall be detected, the discriminator plate has to be removed and mode »αβγ« selected, because these conditions are the only ones where the probe will respond to all three kinds of radiation!

Bring the window as close as possible to the object in question. Use the audible single pulse detection of the 6150AD in order to notice a potential increase in count rate more easily. If you do not immediately notice such an increase, remember the time constant of the 6150AD, which amounts to eight seconds. If weak contaminations down to the order of the detection limit shall be detected, you have to wait for at least three time constants before reading the count rate! Once you observed contamination, carefully avoid to contaminate the probe or even yourself.

Once a contamination was detected, you may conclude the kinds of radiation involved from the following procedure: Set the switch to »α« and read the portion of alpha radiation. Then set the switch to »αβγ« again, put the discriminator plate on, and read the gamma portion. The beta portion is the total reading (without discriminator plate) minus alpha portion minus gamma portion. With all readings, mind to subtract the corresponding background (approximately 6 s^{-1} in mode »αβγ«, and approximately 0.05 s^{-1} in mode »α«)! Also mind to prepare the probe for the next survey by putting it into mode »αβγ« and removing the discriminator plate!

It is not possible to identify the radionuclide(s) involved. If you wish to convert net count rate into surface contamination, you need to know both the radionuclide and its calibration factor. Section 6.1 specifies calibration factors for a choice of radionuclides.

Note: When the discriminator plate is put on and snaps in, the probe will get a brief mechanical shock, and may respond to that shock by a short increase in indication. This behaviour is normal and does not constitute an error.

Even if you did not notice contamination it may be worth switching to mode »α« and repeating the survey. In mode »α« the detection limit is much lower because the background is much lower. In other words, the probe can detect alpha radiation much better in mode »α« than in mode »αβγ«. Example: Suppose there would be an alpha contamination causing an indication of approximately 0.5 s^{-1}. In mode »αβγ«, that is at a background reading of 6 s^{-1}, the increase in indication by 0.5 s^{-1} will surely pass unnoticed, but it will not in mode »α« at a background reading of only 0.05 s^{-1}. Since alpha emitters represent the greater hazard compared to beta or gamma emitters of equal activity, regulatory limits for maximum allowed surface contaminations are lower for alpha emitters. It may happen that only in mode »α« the detection limit of the probe 6150AD-k is low enough to prove that a regulatory limit for alpha emitters is not exceeded. Then the second survey in mode »α« is even mandatory.

NOTE! For alpha emitters, the detection limit is much lower (better) in mode »α« than in mode »αβγ«! If a contamination with alpha emitters cannot be excluded, it is strongly recommended to perform a second survey in mode »α«, even if the first survey in mode »αβγ« did not reveal any contamination!

In mode »αβγ«, the probe 6150AD-k may also be used as a high sensitivity »gamma tracing probe« for photon radiation (gamma or X-radiation). Sensitivity is approximately:

1 µSv/h ~ 50 s^{-1} (for photon radiation in the energy range of 200 to 1300 keV)

This conversion is only valid in the energy range mentioned. The discriminator plate has only few influence on response at such high energies. At lower photon energies, approximately in the range of 30 to 200 keV, and with the discriminator plate removed, the probe is even much more sensitive. This is even advantageous if the aim is to detect photon radiation as efficiently as possible rather than measuring it quantitatively.

4.4 6150AD-19

The probe 6150AD-19 uses a GM counting tube as a detector which is part of a cup-like vessel made from glass. Since glass is known to be fragile, the probe must be handled with care, although it is not as vulnerable as the end window of a counting tube. A plastic cover is screwed on to the probe as a protection for the cup-type counting tube during storage. Besides that, the protective cover serves as a protection against ambient light during a measurement.

NOTE! The cup-type counting tube may respond to light to some extent. During a measurement the protective cover must always be screwed on, because otherwise ambient light may increase indication and thus falsify the result!

The cup-type counting tube has a marking indicating a filling level of 100 ml (100 millilitres, 100 cm^3). During any measurement the tube has to be filled with exactly 100 ml of liquid if the calibration factors from section 6.2 shall be valid. If the sample to be measured is less than 100 ml, it must be diluted up to a total quantity of 100 ml if the calibration factors shall apply.

In the following we assume that the probe will always be filled with a liquid essentially consisting of water (drinks like milk or fruit juice essentially consist of water, too). This is important in so far as the self-absorption inside the liquid affects response and thus the calibration factor. Should the density of the liquid be considerably different from the density of water, both self-absorption and calibration factors will change. If you need to survey such a different liquid quantitatively, you will have to get a radioactive reference liquid and determine the calibration factor on your own.

Measuring the background count rate requires closer consideration. The background includes ambient radiation. When the counting tube is filled, the filling will absorb part of the ambient radiation. Therefore the counting tube has to be filled while the background is counted.

NOTE! While measuring the background, the cup-like counting tube needs to be filled with exactly 100 ml of clean water, so that the ambient radiation is attenuated in the same way as it will be later when measuring the gross count rate!

The probe has quite a low efficiency. The reasons for that were explained in section 2.4. Therefore we recommend to take the average value of the 6150AD for reading both background and gross count rate. This takes more time but gives much more accurate results than reading the count rate directly. That additional time should be available since surveying a liquid is usually a less frequent task performed under laboratory conditions rather than a daily routine job. Furthermore we recommend to calculate the confidence interval of the net count reading according to section 3.5 to see whether the net count rate that may have been observed is really significantly greater than zero.

Finally a remark on calibration of the probe 6150AD-19. We do not calibrate the probe with radioactive reference liquids because we cannot and do not want to expect from our staff to handle such liquids just for calibration. Rather, we calibrate the probe at Cs-137 gamma radiation free in air in such a way that the following conversion is valid:

$$1\ \mu Sv/h = 5\ s^{-1} \text{ (at Cs-137 gamma radiation)}$$[A]

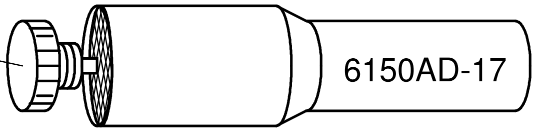
However, this does not mean that we recommend to use the probe as a gamma probe. It shall merely explain the contents of the calibration certificate. In the calibration certificate we specify indication at various dose rates of Cs-137, where the expected value of the indication (in s^{-1}) is equal to the fivefold of the true dose rate (in μSv/h).

[A] In order to achieve this, the 6150AD multiplies the count rate coming from the counting tube by a factor of approximately 0.8 (this is the factor F from section 3.4.3).

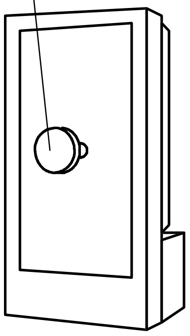
5. Radiological Check

First we describe how to perform a radiological check by the aid of the check source 6706 (nominal activity 333 kBq of Cs-137). Since that check source is a gamma source[A], it is not really the best choice for checking contamination meters. However, for other reasons, some users may already have a check source 6706, or an equivalent one according to DIN 44427. Those users may check the probes using the source 6706 as follows:

Check source 6706 on the protective grille
Indication approximately 250 s^{-1}

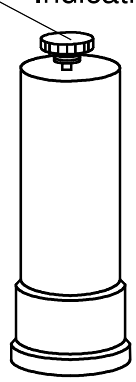


Check source 6706 on the protective grille
Indication approximately 950 s^{-1}



6150AD-k
mode »alpha-beta-gamma«
discriminator plate removed

Check source 6706 on the protective cover
Indication approximately 45 s^{-1}



6150AD-19

The check reading has to be corrected for the activity loss of the check source caused by its decay. The 6150AD Operating Manual tells you how to carry out that correction.

NOTE! The check readings just specified are typical values only. Small deviations from these coarse values are normal and must not lead you to the conclusion that the instrument would be miscalibrated!

If a check source is not available, background count rate may also serve as a quite useful tool to check whether the probe is working correctly. You will find typical values for background count rates in the technical data section.

GM counting tubes - as used in the probes 6150AD-17 and 6150AD-19 - are known to be quite stable in time. The 6150AD processes the pulses in a purely digital way. According to our experiences, in the very most cases a GM counting tube will either work correctly, or it will not work at all, for example if it is broken (zero indication). As long as the probes 6150AD-17 and 6150AD-19 indicate reasonable values at natural background radiation, there is a good chance that they will be okay.

The same is not necessarily true for the probe 6150AD-k with its proportional counter. Here it may occur that a tiny leak will lead to a slow but continuous loss of counting gas resulting in a slow decrease in sensitivity. Although that decrease in sensitivity will also affect background count rate, it may remain unnoticed more easily. This makes checking the probe 6150AD-k with a check source more important

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[A] Cs-137 is a beta emitter with a maximum beta energy of 0.51 MeV. After that beta decay the Cs-137 atomic nucleus has turned into a Ba-137m atomic nucleus, which immediately falls into its ground state by emitting a photon of 662 keV in energy. This means that Cs-137 emits both beta and gamma radiation. If the Cs-137 source is enclosed by a material completely absorbing the beta radiation, only the gamma radiation will force its way to the outside. This is true for the check source 6706. Similarly, Co-60 emits both beta and gamma radiation, too.

than for the probes 6150AD-17 and 6150AD-19. The check source 6708 emitting both alpha and beta radiation was especially designed to check the probe 6150AD-k. You will find some specifications of the check source 6708 among the accessories for the probe 6150AD-k in the technical data section, and you will find more detailed specifications in the separate 6708 data sheet.

Although designed for the probe 6150AD-k, the check source 6708 may also serve to check the probe 6150AD-17. If you place the probe 6150AD-17 directly on the check source 6708, protective cap removed, indication must amount to approximately 300 s^{-1}.

6. Numerical Data for Calibration Factors

6.1 6150AD-17 and 6150AD-k

Calibration factors and efficiencies specified in this section serve the following purposes:

1. Efficiency $\varepsilon_{4\pi}$: converts the net count rate n into activity A underneath the detector area W:
   A [Bq] $= n / \varepsilon_{4\pi}$ (n in s^{-1} and $\varepsilon_{4\pi}$ in s^{-1}/Bq)
2. Calibration factor C_S: converts the net count rate n into surface related activity A_S averaged across the detector area W:
   A_S [Bq/cm^2] $= C_S \cdot n$ (n in s^{-1} and C_S in (Bq/cm^2)/s^{-1})

Here $\varepsilon_{4\pi}$ is defined as the 4π efficiency as explained in section 2.3. Both parameters $\varepsilon_{4\pi}$ and C_S are not independent of each other. From $A_S = A / W$ follows that $C_S = 1 / (\varepsilon_{4\pi} \cdot W)$. Nevertheless, for the sake of convenience, we shall specify both parameters C_S and $\varepsilon_{4\pi}$.

The statement that A_S is the activity »averaged across the detector area« shall remind you that the instrument can only report that average in case the activity is not distributed uniformly or even concentrated on a small spot.

The calibration factors and efficiencies specified in the tables to follow were determined by the aid of reference sources the area of which was at least as large as the detector area. This means that the factors already account for losses at the edge of the detector. If the contaminated area should be much smaller than the detector area (small spot contamination), there will be no edge losses, which will make the instrument indication slightly higher, and which will make the contamination to get slightly overestimated.

»U-nat« denotes natural uranium, 99.3% of which is U-238. All uranium isotopes and their daughter nuclides contribute to instrument indication. When calculating an activity from the data in the tables, that activity is the U-238 activity only.

The comparatively high efficiency for Sr-90/Y-90 comes from the fact that Sr-90 is in equilibrium with its daughter Y-90. Therefore each Becquerel of Sr-90 generates two beta particles per second, that is one from Sr-90 and one from Y-90. When calculating an activity from the data in the tables, that activity is the Sr-90 activity only. The total activity of both Sr-90 and Y-90 together is just twice the activity calculated for Sr-90.

NOTE! Applying a calibration factor requires to know which radionuclide is involved. The probes 6150AD-17 and 6150AD-k do not allow to identify the radionuclide!

6150AD-17

Alpha and beta measurements were performed with the protective cap removed, whereas gamma measurements were performed with the protective cap applied to suppress alpha and beta radiation. The gap between the probe and the reference source was 2 mm in all cases.

Calibration factors C_S and efficiencies $\varepsilon_{4\pi}$ for the probe 6150AD-17 (detector area W = 6.2 cm^2)

radionuclide	$T_{1/2}$ years	predominant radiation type and energy	$C_S = 1/(\varepsilon_{4\pi} \cdot W)$ (Bq/cm^2)/s^{-1}	$\varepsilon_{4\pi}$ s^{-1}/Bq	protective cap applied yes/no
Am-241	432	alpha 5.5 MeV	1.3	0.125	no
U-nat (-238)	(4.5 10^9)	alpha 4.2 - 4.8 MeV + others	0.4	0.40	no
C-14	5730	beta max. 0.15 MeV	2.5	0.065	no
Co-60	5.27	beta max. 0.32 MeV	1.6	0.10	no
Cs-137	30.2	beta max. 0.51 MeV	0.7	0.23	no
Cl-36	300 000	beta max. 0.71 MeV	0.7	0.23	no
Sr-90(/Y-90)	28.7	beta max. 0.54/2.3 MeV	0.3	0.54	no
Co-60	5.27	gamma 1.25 MeV	20	0.008	yes
Cs-137	30.2	gamma 0.66 MeV	120	0.0013	yes

Example how to use the data in the table:

Suppose the probe 6150AD-17 has indicated a gross count rate of approximately 8 s^{-1} when read directly (not through average value indication of the 6150AD). The background was approximately 0.1 s^{-1} which is negligible compared to uncertainty of the gross reading. Consequently, the net count rate is 8 s^{-1}, too.

Reading the diagram in the chapter »Time Constant and Standard Deviation« in the 6150AD's Operating Manual tells that, for the probe 6150AD-17 at an indication of 8 s^{-1}, Sigma-rel = 7%.

It is further assumed that the radionuclide involved is Am-241.

1. Question: What is the surface contamination averaged across the probe area of 6.2 cm^2?
   Answer: 8 s^{-1} • 1.3 (Bq/cm^2)/s^{-1} = 10.4 Bq/cm^2
   More detailed question: What is the confidence interval at a confidence level of 95%?
   Answer: Two Sigmas, that is 10.4 Bq/cm^2 ± 2 • 7% = 10.4 Bq/cm^2 ± 14%
2. Question: What is the total activity underneath the probe area?
   Answer: 8 s^{-1} / 0.125 s^{-1}/Bq = 64 Bq
   More detailed question: What is the confidence interval at a confidence level of 95%?
   Answer: Two Sigmas, that is 64 Bq ± 14%

NOTE! The above mentioned confidence interval only accounts for statistical reading errors, not for systematic uncertainties!

This was a particularly simple example because the background reading was negligibly small compared to the gross count rate reading. If this is not the case, calculating the confidence interval is a bit more laborious, because Sigma of the background count rate needs to be respected additionally, see the example for the 6150AD-k on the next page.

6150AD-k

Alpha and beta measurements were performed with the discriminator plate removed, whereas gamma measurements were performed with the discriminator plate applied to suppress alpha and beta radiation. The gap between the probe and the reference source was as small as the shape of the sources allowed for.

Calibration factors C_S and efficiencies $\varepsilon_{4\pi}$ for the probe 6150AD-k (detector area W = 170 cm^2)

radionuclide	predominant radiation type and energy	mode	$C_S = 1/(\varepsilon_{4\pi} \cdot W)$ (Bq/cm^2)/s^{-1}	$\varepsilon_{4\pi}$ s^{-1}/Bq	gap between probe and cont. surface
Am-241	alpha 5.5 MeV	»α«	0.074	0.08	3.4 mm of air
		»αβγ«	0.056	0.105	
U-nat (-238)	alpha 4.2 - 4.8 MeV + others	»α«	0.21	0.028	1.5 mm of air
		»αβγ«	0.015	0.40	
C-14	beta max. 0.15 MeV	»αβγ«	0.182	0.032	12 mm of air
Co-60	beta max. 0.32 MeV		0.058	0.10	
Cs-137	beta max. 0.51 MeV		0.026	0.23	
Cl-36	beta max. 0.71 MeV		0.026	0.23	
Sr-90(/Y-90)	beta max. 0.54/2.3 MeV		0.011	0.54	
Co-60	gamma 1.25 MeV		0.51	0.0115	discriminator plate plus 9 mm of air
Cs-137	gamma 0.66 MeV		2.69	0.0022	

Example how to use the data in the table:

Suppose the probe 6150AD-k in mode »αβγ« has indicated a background of 6 s^{-1}, and a gross count rate of 20 s^{-1}, both when read directly (not through average value indication of the 6150AD). Consequently, the net count rate is 14 s^{-1}.

Reading the diagram in the chapter »Time Constant and Standard Deviation« in the 6150AD's Operating Manual tells that, for the probe family 6150AD-0 at an indication of 6 s^{-1}, Sigma-rel = 10%, and at an indication of 20 s^{-1}, Sigma-rel = 5.5%. Consequently, Sigma of the background is 10% • 6 s^{-1} = 0.6 s^{-1}, and Sigma of the gross count rate is 5.5% • 20 s^{-1} = 1.1 s^{-1}. Applying formula (6) from section 3.5 provides Sigma of the net count rate: $\sqrt{0.6^2 + 1.1^2}\ \mathrm{s}^{-1} = 1.25\ \mathrm{s}^{-1}$.

It is further assumed that the radionuclide involved is Sr-90/Y-90.

1. Question: What is the confidence interval of the net count rate at a confidence level of 95%?
   Answer: Two Sigmas, that is (14 ± 2 • 1.25) s^{-1} = (14 ± 2.5) s^{-1} = 14 s^{-1} ± 18%
2. Question: What is the surface contamination averaged across the probe area of 170 cm^2?
   Answer: 14 s^{-1} • 0.011 (Bq/cm^2)/s^{-1} = 0.154 Bq/cm^2 (Sr-90 only, excluding Y-90!)
   More detailed question: What is the confidence interval at a confidence level of 95%?
   Answer: Two Sigmas, that is 0.154 Bq/cm^2 ± 18%
3. Question: What is the total activity underneath the probe area?
   Answer: 14 s^{-1} / 0.54 s^{-1}/Bq = 25.9 Bq (Sr-90 only, excluding Y-90!)
   More detailed question: What is the confidence interval at a confidence level of 95%?
   Answer: Two Sigmas, that is 25.9 Bq ± 18%

NOTE! The above mentioned confidence interval only accounts for statistical reading errors, not for systematic uncertainties!

Calibration factors for other radionuclides

Of course there are much more radionuclides than just mentioned in the tables with the calibration factors. It is known from experience that for particular types of instruments the calibration factors for particular radionuclides are similar. The tables below show various radionuclides the calibration factors of which are close to those of the reference nuclides Am-241, C-14, Co-60, and Cs-137. You may estimate calibration factors for other radionuclides by the aid of these tables.

These values were taken from literature. »Similar« calibration factors differ from the value of the reference nuclide by up to approximately 10%. »Slightly greater« and »slightly lower« calibration factors differ from the value of the reference nuclide by approximately 10% to 20%.

Surface contamination calibration factors for alpha emitters			
	calibration factor C_S		
reference nuclide	C_S slightly greater (that is, slightly poorer to detect)	C_S similar (that is, just as good to detect)	C_S slightly lower (that is, slightly better to detect)
Am-241		Th-228, Pu-238	Ra-224, Pu-236

Surface contamination calibration factors for beta emitters			
	calibration factor C_S		
reference nuclide	C_S slightly greater (that is, slightly poorer to detect)	C_S similar (that is, just as good to detect)	C_S slightly lower (that is, slightly better to detect)
C-14	Nb-95	S-35, Se-79, Ag-110m, Np-236	Ru-103, I-126, Pm-147, Eu-152
Co-60	P-33, Ca-45, Cu-64, Sb-125	Zr-95, Tc-99, Ce-144, Er-169	Cs-134
Cs-137, Cl-36		F-18, Na-22, P-32, Kr-85, Sr-89, Nb-94, Mo-99, Ag-111, Sb-124, Sb-127, I-131, Ce-141, Eu-154, Re-186, Re-188, Tl-204, Bi-210	

In case of photon radiation, the efficiencies of the probes 6150AD-17 and 6150AD-k are quite low (1% and less, see the values for the gamma radiation of Co-60 and Cs-137 on the previous pages). Therefore, nuclides emitting only photon radiation are more difficult to detect. Examples for pure photon emitters are:

- Cr-51 (320 keV photon radiation)[A],
- Tc-99m (143 keV photon radiation)[A],
- I-125 (35 keV photon radiation),
- Fe-55 (5.9 keV photon radiation).

We cannot specify calibration factors for these radionuclides because we do not have suitable reference sources. We would just like to point out that detection of photon emitters may also require to remove the protective cap of the probe 6150AD-17 or the discriminator plate of the probe 6150AD-k. Particularly the photon radiation of Fe-55 is so low in energy that part of it will be absorbed even by the thin windows of the probes.

[A] The energy of the radiation of Cr-51 and Tc-99m is high enough to be inside the energy range of the 6150AD. Therefore, in principle, that radiation can be measured as a dose rate by the 6150AD itself (without any contamination probe). However, this does not improve the poor response to photon radiation, which is even more pronounced for the 6150AD's internal energy compensated detector than for the detectors of the contamination probes. It takes quite a high activity (approximately 1 kBq or more) if the dose rate shall not be too small to be detected, even at a short distance from the source.

6.2 6150AD-19

Calibration factors and efficiencies specified in this section serve the following purposes:

1. Efficiency ε: converts the net count rate n into activity A contained in the surveyed volume V:
   $A\,[\text{Bq}] = n / \varepsilon$ (n in s^{-1} and ε in s^{-1}/Bq)
2. Calibration factor C_V: converts the net count rate n into volume related activity A_V:
   $A_V\,[\text{Bq/l}] = C_V \cdot n$ (n in s^{-1} and C_V in (Bq/l)/s^{-1})

Here »Bq/l« stands for »Becquerel per litre«. Both parameters ε and C_V are not independent of each other. From $A_V = A / V$ follows that $C_V = 1 / (\varepsilon \cdot V)$. For the probe 6150AD-19 the volume is always $V = 100$ ml = 0.1 l. Consequently, $C_V = 10 / \varepsilon$. Nevertheless, for the sake of convenience, we shall specify both parameters C_V and ε.

The calibration factors and efficiencies specified in the table below were determined by the aid of reference liquids using water as a solvent, where A_V was about 100 to 200 kBq/l. In all cases the probe was filled up to the marking corresponding to a filling of 100 ml, so that the total activity in the probe was about 10 to 20 kBq. As pointed out in section 4.4, the probe was filled with 100 ml of clean water when measuring background count rate. During all measurements the protective cover was screwed on.

Efficiencies ε are quite low. The reason was explained in detail in section 2.4. Only for Sr-90 an efficiency of slightly more than one percent is achieved. The better efficiency for Sr-90/Y-90 comes from the fact that Sr-90 is in equilibrium with its daughter Y-90. Therefore each Becquerel of Sr-90 generates two beta particles per second, that is one from Sr-90 and one from Y-90. Furthermore, Y-90 beta radiation is easier to detect because of its high energy. When calculating an activity from the data in the table, that activity is the Sr-90 activity only. The total activity of both Sr-90 and Y-90 together is just twice the activity calculated for Sr-90.

NOTE! Applying a calibration factor requires to know which radionuclide is involved. The probe 6150AD-19 does not allow to identify the radionuclide!

Calibration factors C_V and efficiencies ε for the probe 6150AD-19 (volume V = 0.1 l)

radionuclide	predominant radiation types and energies beta	 gamma	$C_V = 10/\varepsilon$ (Bq/l)/s^{-1}	ε s^{-1}/Bq
Cs-137	max. 0.51 MeV	0.66 MeV	7000	0.00143
I-131	max. 0.61 MeV	0.36 MeV	12500	0.00080
Sr-90(/Y-90)	max. 0.54/2.3 MeV	-	750	0.01333

Example how to use the data in the table:

Suppose the probe 6150AD-19 has indicated a net count rate of 4 s^{-1} at a Sigma-rel of 11% (the example for the probe 6150AD-k on the preceding page explains how to determine Sigma-rel).

It is further assumed that the radionuclide involved is Sr-90/Y-90.

- Question: What is the volume related activity at a confidence level of 95%?
  Answer: 4 $s^{-1} \cdot 750$ (Bq/l)/$s^{-1} \pm 2 \cdot 11\%$ = 3000 Bq/l ± 22%
  (Sr-90 only, excluding Y-90; volume related activity of Y-90 is 3000 Bq/l, too!)

NOTE! The above mentioned confidence interval only accounts for statistical reading errors, not for systematic uncertainties!

7. Numerical Data for Detection Limits

Detection limits result from Sigma_B, the standard deviation of the background count rate. Using formula (5) from section 3.4.5 and formula (2b) from section 3.4.3 we define the detection limit DL to be the fivefold of Sigma_B[A]:

$$DL = 5 \times \text{Sigma}_B = 5 \times \sqrt{\frac{F \times D_B}{2\tau}} \qquad \text{(background } D_B \text{ read directly from the 6150AD)}$$

or, when reading the average value of the 6150AD after a counting period T:

$$DL = 5 \times \text{Sigma}_B = 5 \times \sqrt{\frac{F \times D_B}{T}} \qquad \text{(background } D_B \text{ read as the average value of the 6150AD)}$$

This detection limit DL is specified in the same unit as instrument indication, that is s^{-1}. It is straightforward to convert this detection limit into units of contamination (Bq/cm², Bq, Bq/l) by the aid of the calibration factors and efficiencies from chapter 6. Therefore, in the following we specify the detection limit generally in s^{-1}, and additionally for some exemplary radionuclides in units of contamination.

The table below shows the detection limit of the probe 6150AD-17 (F = 0.65) in case of direct reading and average value reading, and for various levels of background each. Examples added are the radionuclides Am-241 (alpha emitter) and Co-60 (beta emitter with comparatively low beta energy occurring in nuclear facilities). Since both radionuclides have quite similar calibration factors, their detection limits are quite similar, too.

6150AD-17
Direct reading, which means that the counting period is determined by the time constant τ

background D_B	τ	Sigma_B	detection limit = 5 • Sigma_B				conditions
s^{-1}	s	s^{-1}	s^{-1}	nuclide	Bq/cm²	Bq	
~ 0.07	8	0.053	0.27	Am-241	0.35	2.2	at natural background radiation
				Co-60	0.43	2.7	
~ 1.0	8	0.202	1.0	Am-241	1.3	8.1	at increased background radiation of 1 µSv/h
				Co-60	1.6	10	
~ 10.0	8	0.637	3.2	Am-241	4.2	25.6	at increased background radiation of 10 µSv/h
				Co-60	5.1	32	

6150AD-17
Reading the average value after counting periods of T = 300 s and T = 3600 s

background D_B	T	Sigma_B	detection limit = 5 • Sigma_B				conditions
s^{-1}	s	s^{-1}	s^{-1}	nuclide	Bq/cm²	Bq	
~ 0.07	300	0.0123	0.062	Co-60	0.10	0.62	at natural background radiation
	3600	0.00356	0.018		0.029	0.18	
~ 1.0	300	0.0465	0.23		0.37	2.3	at increased background radiation of 1 µSv/h
	3600	0.0134	0.067		0.11	0.67	
~ 10.0	300	0.147	0.74		1.18	7.4	at increased background radiation of 10 µSv/h
	3600	0.0425	0.21		0.34	2.1	

[A] Consequently, the specified detection limits apply to equal counting periods for background and gross count rate. If the background is measured more accurately (longer), the detection limits will be slightly lower.

The table below shows the detection limit of the probe 6150AD-k (F = 1.0) in mode »αβγ« in case of direct reading and average value reading, and for various levels of background each. Examples added are the radionuclides Am-241 (alpha emitter) and Co-60 (beta emitter with comparatively low beta energy occurring in nuclear facilities). Since both radionuclides have quite similar calibration factors, their detection limits are quite similar, too.

6150AD-k in mode »αβγ«
Direct reading, which means that the counting period is determined by the time constant τ

background D_B	τ	Sigma$_B$	detection limit = 5 • Sigma$_B$				conditions
s^{-1}	s	s^{-1}	s^{-1}	nuclide	Bq/cm^2	Bq	
~ 6	8	0.61	3.1	Am-241 Co-60	0.17 0.18	30 31	at natural background radiation
~ 50	8	1.77	8.8	Am-241 Co-60	0.49 0.51	84 88	at increased background radiation of 1 µSv/h
~ 500	8	5.59	28.0	Am-241 Co-60	1.57 1.62	270 280	at increased background radiation of 10 µSv/h

6150AD-k in mode »αβγ«
Reading the average value after counting periods of T = 300 s and T = 3600 s

background D_B	T	Sigma$_B$	detection limit = 5 • Sigma$_B$				conditions
s^{-1}	s	s^{-1}	s^{-1}	nuclide	Bq/cm^2	Bq	
~ 6	300	0.141	0.707	Co-60	0.04	7.1	at natural background radiation
	3600	0.0408	0.204		0.012	2.0	
~ 50	300	0.408	2.04		0.12	20	at increased background radiation of 1 µSv/h
	3600	0.118	0.59		0.034	5.9	
~ 500	300	1.29	6.45		0.37	65	at increased background radiation of 10 µSv/h
	3600	0.373	1.86		0.11	19	

The table below shows the detection limit of the probe 6150AD-k (F = 1.0) in mode »α« in case of direct reading and average value reading. It is not necessary to consider various levels of background since, in mode »α«, the probe is sensitive to alpha radiation only and does not respond to increased levels of background. For the same reason we add only the alpha emitter Am-241 as an example.

6150AD-k in mode »α«

background D_B	counting period	Sigma$_B$	detection limit = 5 • Sigma$_B$				conditions
s^{-1}		s^{-1}	s^{-1}	nuclide	Bq/cm^2	Bq	
~ 0.05	τ = 8 s	0.056	0.28	Am-241	0.021	3.5	direct reading
	T = 300 s	0.0129	0.065		0.0048	0.81	average value reading
	T = 3600 s	0.0037	0.019		0.0014	0.24	

Comparing the detection limits of the probe 6150AD-17 with those of the 6150AD-k in mode »αβγ« shows that the limits of the probe 6150AD-17 are about 2.5 times as large. At first sight, surprisingly enough, this looks like the probe 6150AD-17 is almost as good as the 6150AD-k, at least if the latter is operated in mode »αβγ«. However, this simple comparison is unfair because it neglects the different size of the sensitive areas. The area of the probe 6150AD-k is larger than the area of the 6150AD-17 by a factor of 170/6.2 = 27.4. If a certain area shall be surveyed, the probe 6150AD-17 requires approximately 30 times as many measurements as the probe 6150AD-k. After all, the probe 6150AD-k is still much more »sensitive« than the probe 6150AD-17.

The table below shows the detection limit of the probe 6150AD-19 (F = 0.8) in case of direct reading and average value reading, and for various levels of background each. Examples added are all the radionuclides section 6.2 specifies calibration factors for. The detection limits in Bq are necessarily one tenth of the detection limits in Bq/l because the filling volume amounts to 0.1 l, that is one tenth of a litre.

6150AD-19
Direct reading, which means that the counting period is determined by the time constant τ

background D_B	τ	Sigma$_B$	detection limit = 5 • Sigma$_B$				conditions
s^{-1}	s	s^{-1}	s^{-1}	nuclide	Bq/l	Bq	
~ 0.3	8	0.122	0.61	Cs-137 I-131 Sr-90(/Y-90)	4 300 7 700 460	430 770 46	at natural background radiation
~ 5.0	8	0.50	2.5	Cs-137 I-131 Sr-90(/Y-90)	18 000 32 000 1 900	1 800 3 200 190	at increased background radiation of 1 µSv/h

6150AD-19
Reading the average value after counting periods of T = 300 s and T = 3600 s

background D_B	T	Sigma$_B$	detection limit = 5 • Sigma$_B$				conditions
s^{-1}	s	s^{-1}	s^{-1}	nuclide	Bq/l	Bq	
~ 0.3	300	0.0283	0.14	Cs-137 I-131 Sr-90(/Y-90)	1 000 1 800 110	100 180 11	at natural background radiation
	3600	0.0082	0.041	Cs-137 I-131 Sr-90(/Y-90)	290 510 30	29 51 3	
~ 5.0	300	0.115	0.58	Cs-137 I-131 Sr-90(/Y-90)	4 100 7 300 440	410 730 44	at increased background radiation of 1 µSv/h
	3600	0.0333	0.167	Cs-137 I-131 Sr-90(/Y-90)	1 200 2 100 130	120 210 13	

8. Technical Data

8.1 6150AD-17 and Accessories

Detector	alpha beta gamma end window tube LND 7231 or equivalent, not energy compensated, gamma sensitivity at Cs-137 approximately 5600 pulses per μSv
End window of the counting tube	dimensions: diameter 2.8 cm, that is 6.2 cm^2 in area material: mica, areal density 1.5 - 2 mg/cm^2
Range and alarm thresholds	see 6150AD Operating Manual, issue June 2001 or later
Conversion of measured count rate R into indicated count rate D	$D = F \cdot R$ where $F = 0.65$; this results in: at 1 μSv/h Cs-137 gamma radiation, D = 1 s^{-1}
Indication at natural background radiation	approximately 0.07 s^{-1}
Overload: overrange will be indicated up to:	500 mSv/h of Cs-137 gamma radiation
Temperature range (tested with Cs-137 gamma radiation free in air)	-30°C to + 50°C, deviation max. ±10% referred to indication at +20°C
Humidity	nominal range 0 to 95% within specified temperature range (observe notes in section 2.7!)
Atmospheric pressure	nominal range 60 to 130 kPa (600 to 1300 mbar)
Geotropism (change of response as a result of gravitational effects)	none
Power supply	4.75 Volt out of Dose Rate Meter 6150AD
Battery life including the 6150AD (with a 6LR61 battery)	approximately 650 hours at low count rates with the 6150AD's illumination off
Housing	black anodized aluminium, protective cap made of black rubber, protection class IP 67 according to DIN 40050 (with some restrictions according to the vulnerable end window)
Dimensions	protective cap removed: diameter 40 mm, length 132 mm protective cap applied: diameter 49 mm, length 135 mm
Weight	approximately 180 g (including the protective cap)
Length of probe cable (necessary accessory)	recommended 1.25 m, maximum 5 m from S/N 117435 on: maximum 100 m

Optional accessory for the probe 6150AD-17:

Holder 817.1.1-10	
Application	holder to attach the probe 6150AD-17 to the Handle Extension 770.1-60 (see accessories for the probe 6150AD-k); for surveys at places difficult to reach
Dimensions	diameter 40 mm, length 115 mm
Material / Weight	aluminium / approximately 185 g

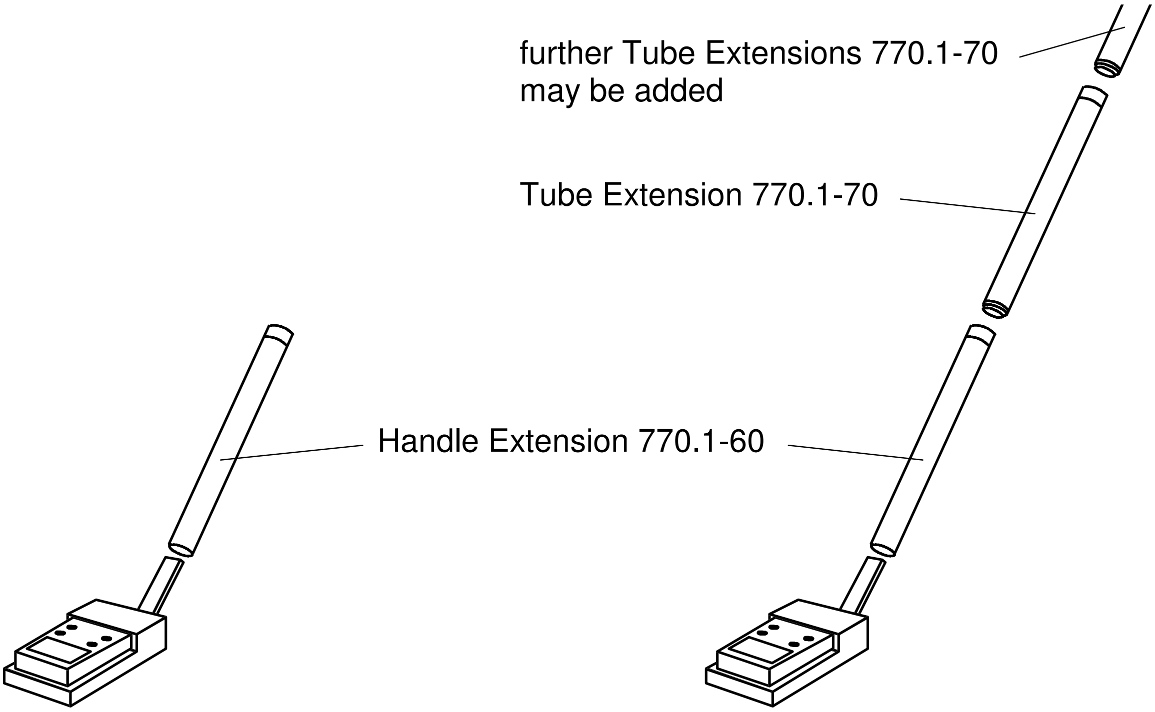
8.2 6150AD-k and Accessories

Detector	large area proportional counting tube, sealed, filled with inert gas mixture, does not require refilling or flushing from external gas reservoirs, gamma sensitivity at Cs-137 approximately 180 000 pulses per µSv
End window of the counting tube	dimensions: 17 cm x 10 cm, that is 170 cm^2 in area material: aluminium foil, areal density 2.8 mg/cm^2
Grille	supporting grille made of aluminium, above it an additional fine etched mesh grille made of stainless steel; geometrical aperture of both grilles approx. 60%, which means that approx. 60% of the window area are not covered by the grilles
Range and alarm thresholds	see specifications for the »6150AD-0« probe family in the 6150AD Operating Manual, issue June 2001 or later
Conversion of measured count rate R into indicated count rate D	D = F • R where F = 1.0 (that is, no conversion at all)
Operating modes, selectable	1) measurement of alpha radiation 2) measurement of alpha-beta-gamma radiation
Discriminator plate, attachable	stainless steel, 1 mm in thickness, to discriminate between beta and gamma radiation
Indication at natural background radiation	in mode »α«: approximately 0.05 s^{-1} in mode »αβγ«: approximately 6 s^{-1}
Linearity of indication	up to approximately 20 ks^{-1}
Rejection of gamma radiation in mode »α«	up to approximately 100 mSv/h of Cs-137 gamma radiation
Temperature range (tested with Am-241 in mode »α«, and with C-14 and Sr-90 in mode »αβγ«)	-15°C to + 50°C, deviation max. ±15% referred to indication at +20°C (observe notes in section 2.7!)
Humidity	nominal range 0 to 95% within specified temperature range (observe notes in section 2.7!)
Atmospheric pressure	nominal range 60 to 130 kPa (600 to 1300 mbar)
Geotropism (change of response as a result of gravitational effects)	none
Power supply	4.75 Volt out of Dose Rate Meter 6150AD
Battery life including the 6150AD (with a 6LR61 battery)	approximately 300 hours at low count rates with the 6150AD's illumination off
Housing	aluminium, protection class IP 67 according to DIN 40050
Dimensions	210 x 120 x 90 mm^3
Weight	approximately 1.7 kg including the 6150AD
Length of probe cable (optional accessory)	100 m maximum; an external probe cable is only required if the probe 6150AD-k shall be used remotely from the 6150AD

Optional accessories for the probe 6150AD-k:

Handle Extension 770.1-60	
Application	extends the handle of the probe 6150AD-k; for surveys at places difficult to reach
Dimensions	diameter 30 mm, length 770 mm
Material / Weight	aluminium / approximately 430 g

Tube Extension 770.1-70	
Application	further extends the Handle Extension 770.1-60
Dimensions	diameter 30 mm, length 775 mm
Material / Weight	aluminium / approximately 450 g



Wall Holder 770.1-80	
Application	stores the probe 6150AD-k at a wall (including the Dose Rate Meter 6150AD mounted on the probe).
Dimensions	height 225 mm, width 120 mm, depth 80 mm
Material / Weight	aluminium and plastic / approximately 550 g

Check Source 6708 (for details see the separate 6708 data sheet)	
Application	radiological check
Radioactive substances	1) Americium 241 in form of solid oxide, activity 1 kBq ±30% 2) Strontium 90 in form of solid oxide, activity 2 kBq ±30%
Check reading with 6150AD-k	in mode »α«: approximately 90 s^{-1} in mode »αβγ«: approximately 500 s^{-1}
Dimensions	diameter 50 mm, height 3 mm, active diameter 36 mm

8.3 6150AD-19 and Accessories

Detector	cup-type counting tube for liquids, areal density of the wall approximately 25 mg/cm^2, sensitive tube length 6 cm, gamma sensitivity for Cs-137 radiation free in air approximately 22 000 pulses per µSv
Cup volume	100 cm^3
Range and alarm thresholds	see 6150AD Operating Manual, issue June 2001 or later
Conversion of measured count rate R into indicated count rate D	D = F • R where F = 0.8; this results in: at 1 µSv/h Cs-137 gamma radiation free in air, D = 5 s^{-1}
Indication at natural background radiation	approximately 0.2 to 0.3 s^{-1}
Overload: overrange will be indicated up to:	100 mSv/h of Cs-137 gamma radiation
Temperature range (tested with Cs-137 gamma radiation free in air)	-30°C to + 50°C, deviation max. ±10% referred to indication at +20°C
Humidity	nominal range 0 to 95% within specified temperature range
Atmospheric pressure	nominal range 60 to 130 kPa (600 to 1300 mbar)
Response to ambient light	cannot be excluded completely. During any measurement, always apply the protective cover so that the counting tube will not be exposed to light!
Power supply	4.75 Volt out of Dose Rate Meter 6150AD
Battery life including the 6150AD (with a 6LR61 battery)	approximately 650 hours at low count rates with the 6150AD's illumination off
Housing	socket made of black anodized aluminium, protective cover made of plastic to be screwed on the socket
Dimensions including protective cover	diameter 70 mm, height 205 mm
Weight	approximately 550 g (including the protective cover)
Length of probe cable (necessary accessory)	recommended 1.25 m, maximum 5 m

Optional accessory for the probe 6150AD-19:

Measuring Beaker MB09-0003	
Application	Measuring beaker with scale divisions to measure the required filling volume of 100 cm^3 (100 ml)
Material	white plastic

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