OPERATING INSTRUCTIONS
for Counter Tube Type B

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1. Dose rate measurement with counter tube type B

Counter tube type B is a combination counter tube, i.e. it can be used in many different applications. When using counter tube type B for dose rate measurements, the protective cover of the counter tube (which is removed for contamination measurements) must remain in position on the counter tube, in order to shield the BETA radiation. Dose rate measurements are measurements of GAMMA radiation (high energy electromagnetic waves), and it is necessary to shield the ALPHA + BETA radiation (particle radiation), which often occurs simultaneously.

The radiation dose is given in Rem, and more recently in Sievert (Sv), whereby
100 rem = 1 Sv or 1 rem = 0.01 Sv

For counter tube type B
8 impulses per minute (Ipm) = 120 mrem/a (millirem per year)
This means : 120 mrem/a : 8 = 15

i.e. 1 Ipm for counter tube B corresponds to 15 mrem/a

In order to calculate the radiation dose in millirem per year the counted impulses per minute must be multiplied by the factor 15. To calculate the dose for 1 hour the yearly dose value must be divided by 8500. In radiation measuring technique the yearly hour basis is taken as 8500 and not 8640 or 8760 hours, which is found by more exact calculation.

EXAMPLE:

During a 10 minute measurement 800 impulses are counted. This corresponds to 80 impulses for 1 minute.

80 Ipm x factor 15 = 1200 mrem/a or 12 mSv/a
1200 mrem : 8500 = 0.142 mrem/hr or 0.00142 mSv/hr

Since 120 mrem corresponds to the normal background radiation (Federal Republic of Germany) the radiation contamination is thus 10 times higher than the normal value. If the radioactive radiation is more than 40 times higher, protective clothing is normally recommended.

2. Statistical error of measurement

120 mrem/a or 1.2 mSv/a is the normal background radiation (solar and earth radiation), although this can vary considerably in different regions. The normal background radiation of a particular region or measuring place can be determined by allowing the radiation measuring device to run for 2 hours with no radioactive emitters in the vicinity. The registered impulse count is converted to a basis of 1 minute. This value (Ipm) is then the so called zero (background) rate. When taking measurements, only measured values which are above the zero rate give an indication that there may be radioactive contamination in the area.

All measurements are subject to a statistical measurement error. This is due to the fact that radioactive radiation is not constant with respect to time and space, but occurs at different intervals.

The measurement error can be calculated from the root of the counted impulses

$$\text{Error of measurement in \%} = \frac{100}{\sqrt{N}}$$

(N = total counted impulses)

This means the error of measurement reduces with an increasing number of impulses. In other words, the longer the measurement, the more accurate the measurement. A series of measurements of, for example, 100 impulses has an error of measurement of 10 %, at 1.000 impulses only 3.2 % and at 10,000 impulses 1 %.

When testing food a minimum measuring period of 10 minutes is always to be recommended. Experience has shown that for 10 minute measurements and a zero rate of 8 Ipm, the tolerance value is 11 Ipm (8 + 3), i.e. only the impulses above 11 per minute result from additional radiation contamination. If the determined zero rate is not 8 but, for example, 10, the tolerance value is then 13 (10 + 3) - see section on detection limit.

3. Contamination Measurements

For contamination measurements counter tubes must be able to detect BETA radiation. In order to guarantee the necessary detection sensitivity, counter tube B should be used without the protective cover for contamination measurements. Furthermore, the contamination is measured in Becquerel (activity) and not in Rem or Sievert (energy of the radiation).
For surface measurements counter tubes with a sensitive end window are preferred. However, if measurement of the ALPHA radiation is not essential, immersion counter tubes should be used, since these are more robust, easier to handle and better results with respect to sensitivity can be achieved.
For food controls we recommend, in addition to 10 minute measurements, that counter tube B is used as an immersion counter tube, since this enables a higher counting yield to be achieved through the geometry factor (all round pick up of radiation). The sample to be tested should be ground and dried to give 100 grams of dry material. Drying can be carried out in a baking oven or microwave oven. Before drying, the sample should be weighed, since the measured radiation should be related to the normal weight.
As already mentioned, the tolerance value for a 10 minute measurement is 11 Ipm. This means that if a maximum of 110 impulses is indicated during a 10 minute measurement, the value is still within the permissible tolerance. If the number of impulses measured is above 110 impulses after 10 minutes, then every additional impulse corresponds to 20 Bq/kg
(* taking into consideration the next paragraph)
This calculation is a rule of thumb, which can vary by max ± 30 %, depending on the nuclide.

The determined value is based on the normal weight of the sample if the sample has been artificially dried. If the food is dry bulk material, e.g. coffee, tea, cocoa, drugs of any kind, milk powder etc., the measured value is always related to 1 kg. The counter tube only detects radiation at a distance of max. 1 - 2 cm anyway, no matter whether it is placed in a 100 liter drum or in a 100 gram container.

EXAMPLE:

For a 10 minute measurement 150 impulses are counted. The zero (background) rate is 8 Ipm, so that, for a 10 minute measurement 110 impulses are still within the tolerance. Every impulse above this value represents 20 Bq of unnatural radiation contamination.

150 impulses - 110 tolerance value = 40 impulses

40 impulses x 20 Bq = 800 Bq/kg

These 800 Bq should be considered as the minimum value of radiation contamination, since the tolerance range (80 - 110 impulses for a 10 minute measurement) also includes a proportion of radiation contamination which cannot be determined accurately, however, since it is outside the detection limit. Therefore the radiation contamination is really between 800 and 1400 Bq/kg.

4. Detection Limit (DL)

The detection limit (DL) of an instrument is calculated as follows:

$$DL = 3 \times \sqrt{\text{zero rate}}$$

For counter tube B the detection limit for a measurement of 1 minute is 8.5 impulses, so that the tolerance value would be 16.5 impulses:

$$3 \times \sqrt{8} = 2.828 \times 3 = 8.48 \text{ impulses per minute (DL)}$$

$$8 + 8.5 = 16.5 \text{ impulses per minute tolerance value}$$

For a 10 minute measurement the detection limit decreases:

$$8 \text{ impulses zero rate} \times 10 \text{ minutes} = 80 \text{ impulses}$$

$$3 \times \sqrt{80} = 8.94 \times 3 = 26.8 \text{ impulses per minute}$$

$$26.8 : 10 \text{ minutes} = 2.68 \text{ Ipm} = DL$$

$$80 + 27 = 107 \text{ impulses or } 8 + 2.7 = 10.7 \text{ Ipm}$$

As can be seen from these examples the measuring accuracy increases with measuring time. The measuring time may have to be increased if the result after a 10 minute measurement is not satisfactory.

Using the measuring table in the APPENDIX the following calculations are obtained for Cs-137, after correcting the impulse values (multiplication by factor 10), when using immersion counter tubes:

273 Ipm (27.3 x 10) correspond to 100 Bq Cs-137

Therefore 8.5 Ipm correspond to 100 Bq : 273 x 8.5 = 3.1 Bq Cs-137

For a 10 minute measurement the DL is 2.7 Ipm. Using the measuring table (Cs-137) this gives

100 Bq : 273 x 2.7 = 0.99 Bq Cs-137

In other words, when used as an immersion counter tube and with a measuring time of 1 minute, counter tube B can detect contamination values from 3 Bq Cs-137. For a measuring time of 10 minutes this is possible from the even lower value of 1 Bq. In order to estimate the result for 1 kg, these values must be multiplied by the factor 40, since the immersion counter tube only detects radiation at a distance of 1 - 2 cm, which generally corresponds to 20 - 30 grams.

5. Measurements in liquids

For measurements in liquids other laws apply, since liquids (or the water contained to a more or less extent in the sample) shield (absorb) the radiation. The counter tube can therefore only partially detect this radiation (if this is possible at all).

By highly concentrating the samples (evaporation of the water) the measured results are improved. Basically it should be assumed that in water, or similar liquids, only 10 % of the actual radiation can be detected.

Counter tube B can be used for liquid measurements. The tip of the counter tube and the plastic handle are waterproof and washable, the immersion depth being approximately 8 cm.

For the combination counter tube type B, the detection limit in 100 ml of unconcentrated liquid with caesium-137

for a measuring time of 10 minutes is 93 Bq caesium-137
and
for a measuring time of 20 minutes is 65 Bq caesium-137.

This corresponds to 930 and 650 Bq respectively for 1 liter! Better results can be achieved either by using a longer measuring time, or a more sensitive counter tube (FSZ)

6. Measurement of potassium-40 in coffee, tea, cocoa etc.

When carrying out measurements on coffee, tea, cocoa, tobacco (i.e. mainly with all industrially cultivated products) using counter tube B as an immersion counter tube, an increase in radiation will be found. This radiation is due to the natural radionuclide, potassium-40.
32.5 Bq are emitted per gram of potassium, as follows:

BETA radiation at max. 1.312 keV amounting to 89.3 %
and
GAMMA radiation at 1.461 keV amounting to 10.7 %

Caesium-137 releases, for example, BETA and GAMMA radiation at 662 keV.

Potassium is contained in fertilizers up to about 20 %, and it is therefore also stored in the plants to a corresponding extent. According to medical opinion and the responsible authorities this is not dangerous, since excess potassium in the body is broken down again and excreted within a short period.

Counter tube B used as an immersion counter tube indicates the radiation to be 0.8 Ipm per 100 Bq (10 minute measurement)

If coffee powder is measured, for example, and 140 impulses are found after 10 minutes, with a zero rate of 8 Ipm (x 10 minutes = 80), then 60 impulses are too high, and are also significantly above the tolerance threshold of 11 and 110 impulses respectively.

If 0.8 Ipm or 8 impulses in 10 minutes = 100 Bq K-40
then 60 impulses correspond to (60 : 8 = 7.5 x 100) = 750 Bq K-40.

In freeze-dried coffee extract the radiation contamination found is about double this value.

The stored potassium is water soluble. If you are in doubt as to whether the existing radiation actually comes from K-40 or not, then boil the coffee powder (or tea) and measure the residue of coffee, tea or whatever else it might be. This must, of course, first be dried, so that it has about the same consistency as the coffee powder or tea before boiling. You will find that no more radiation is registered in the coffee or tea residue. If there is any radiation then this is not from K-40!

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Measuring Table

In this measuring table standard emitters are prepared for 6 different nuclides which can be released in any failures in nuclear power stations; these are standard emitters with 100 Bq and 1,000 Bq. The impulses per minute during the measuring time of 10 minutes were recorded with the calculated background count of the radiation detection tubes deducted. These are therefore the net impulse frequencies (without background radiation).
A distance of 30 mm was chosen for this measurement. Smaller distances give higher impulse frequencies and larger distances correspondingly lower counting efficiencies.

NUCLIDE	END WINDOW COUNTER TUBES		IMMERSION COUNTER TUBES	
		- Ipm -		
100 Bq	Type A	Type G	Type B	Type FSZ
J-131	26.2	63	13.5	27.5
Cs -137	35.6	143	27.3	52.3
Sr-90	36.0	155	29.1	59.0
Sr-90 + Y -90	84.6	363	100.3	203.4
Uranium	15.9	64	28.9	57.0
Thorium	19.3	74	31.2	62.1

1000 Bq	Type A	Type G	Type B	Type FSZ
J-131	262	626	135	275
Cs -137	356	1431	273	523
Sr-90	360	1550	291	590
Sr-90 + Y -90	846	3630	1003	2034
Uranium	159	638	289	570
Thorium	193	744	312	621

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Using the Measuring Table

As can be seen, the relationship between the impulses of the radiation detection tubes is proportional to the becquerel values, in other words the higher impulse rates mean correspondingly higher becquerel values. So conclusions for other measurements are possible.

If, for example, a specific object contaminated by caesium-137*** must be investigated, a 10 minute measurement at a distance of 30 mm from the sample should be carried out. The result reduced to 1 minute must then be used for the table.

EXAMPLE

> A 10 minute measurement on a sample with caesium-137 using a type B Geiger counter shows after the measuring time a measured value of 500 impulses.
> After reduction to 1 minute (500 : 10 = 50 Ipm) and after deduction of the background frequency (8 Ipm) a net impulse rate of 42 Ipm is left.
> The column in the measuring table for a type B Geiger counter shows under 100 Bq Cs-137: 27,3 Ipm. Consequently, 42 Ipm corresponds to

100 Bq : 27,3 x 42 = 153,8 Bq

If the sample weight is, for example, 5 gram this value must be extrapolated to 1 kg

(153,8 Bq x 200 = 30.760 Bq/kg)

Experience has shown that the measurement conditions often do not agree with those assumed in the measuring table. For surface measurements with the end window counter tubes, type B or G, a smaller distance is frequently selected, usually 5 mm. At a distance of 5 mm the number of impulses is 5 times higher than that given in the measuring table, i.e. before conversion the corresponding value in the measuring table must be multiplied by the factor 5.

Thus 136,5 Ipm (27,3 x 5) would correspond to 100 Bq. Calculated on the basis of the above 30 Ipm, this would then only be (100 : 136,5 x 47) = 30,7 Bq Cs-137.

Immersion counter tubes are not generally used for surface measurements. These are much more efficient as immersion devices. In order to obtain comparable results, in this case the value in the measuring table has to be multiplied by the higher factor 10, i.e. the 100 Bq Cs-137 would correspond to 273 Ipm (27.3 x 10) for counter tube B.

*** It can be assumed that existing contamination in Europe as a result of the Tschernobyl catastrophe is due almost entirely to the nuclide caesium-137.

Instructions for Handling the Measuring Probes B and FSZ for Environmental/Mobile Measurements

The measurement table (p. 8) was drawn up to determine whether the counter tubes can be gauged/calibrated. In mobile applications outside of the laboratory, such pure nuclides are hardly ever encountered. The measurement table is intended more for teaching purposes at secondary school or university, where these kinds of nuclide are used. Unmixed or shielded nuclides are in fact very rare in nature (the environment).

For this reason we have commissioned studies in which measurements were conducted which better equate with the reality of mobile applications. A test arrangement was set up in which the submersible counter tube types B and FSZ were used as area counter tubes (surface measurements) and as submersible probes.

1. The test object was tea that had been contaminated with caesium 137 and caesium 134. First, it was determined what quantity of tea could be measured via the submersible probe, e.g. to which a contamination could be attributed.
It was shown that **35.5 g** tea was the optimum amount. With larger quantities of tea, radiation measurements using the submersible probe were no longer possible. That is important for extrapolation up to 1 kg. This means that the measured value of radiation must be multiplied by **28** to obtain the result for 1 kg.
This extrapolation is normal and necessary for all commercial devices for making mobile radiation measurements, because the reference values refer to activity relating to **mass per kg**. The 35.5 g tea sample was contaminated with 749.9 becquerels Cs 137 and with 87.4 becquerels Cs 134; giving a total activity of 837.3 becquerels.
Whilst using counter tubes B and FSZ as submersible probes the following net pulse rates (**without null rate**) were measured in the contaminated tea with counter tubes B and FSZ:

Type B = 92.2 ppm +/- 2.5 **Type FSZ = 176.2 ppm +/- 3.4**

ppm = pulse per minute:
For counter tube B this came to 1 ppm (837.3 **:** 92.2) **9 becquerels**
Extrapolated to 1 kg that equals (9 x 28) **252 becquerels**

For the FSZ counter tube this came to 1 ppm (837. **:** 176.2) **4.75 becquerels**
Extrapolated to 1 kg that equals (4.75 x 28) **133 becquerels**

This is also the measuring limit for this measuring probe when used as a submersible probe!

2. A further test arrangement was set up for measurements in liquid using the two submersible probes. Caesium 137 was dissolved in a **50 ml** solution, marked with 55,500 becquerels (1.5 µCi). Measurements were made by placing the measuring probe in the contaminated liquid.

Using the **counter tube B** a net pulse rate of **1,591.7 ppm** was measured. With respect to the 55,500 total activity that equates to **34.86 Bq per ppm** (55,000 : 1,591.7). Extrapolated to one litre (x 20) that gives **697 Bq/litre.**

Using the **counter tube FSZ** a net pulse rate of **3,297.2 ppm** was measured. With respect to the 55,500 total activity that equates to **16.83 Bq per ppm** (55,000 : 1,591.7). Extrapolated to one litre (x 20) that gives **336 Bq/litre.**

Such measurements are of particular significance for food consumables containing high quantities of liquids. The values can differ depending on the consistency of the measuring sample (different liquid quantities). Lower liquid quantities lead to a lower measuring limit. Liquids have a particularly high shielding property for radiation (self-absorption). The measurement values using the FSZ counter tube could lay anywhere between 4.45 Bq per ppm (dry goods) and 16.8 Bq per ppm (pure liquid).

Anomalous measurements could also be caused by fluctuations in the background radiation, which themselves are caused by variation in the given weather conditions (wind direction). An uncertainty of ±20 % is to be expected for measurements of radiation in mobile applications, independent of type of construction of the measuring device.

We should point out that assessments of these measurement values have been conducted and documented by the Institute for Nuclear Physics at the Technical University of Darmstadt. For the measurements, preparations used to contaminate the samples were provided by the Physikalisch-Technische Bundesanstalt in Braunschweig.

3. In another test arrangement, the two measurement probes were used for making surface measurements; once at a distance of 3 cm and again in another experiment where the probes were placed directly on the contaminated tea sample. The same contaminated tea sample was used as in Point 1 as well as a further tea sample measuring 4.53 g that was spread widely. This smaller sample was contaminated with 94.4 Bq Cs 137 and 12.5 Bq Cs 134, giving a total of 106.9 Bq.

3.1 The following net pulse rates were measured using the **counter tubes**:

a) Small tea sample (4.53 g):	**Net pulse rate direct on the surface**	**18.1 ppm +/- 1.1**
Measuring probe B	**Net pulse rate at 3 cm distance**	**2.9 ppm +/- 0-6**
b) Large tea sample (35.5 g):	**Net pulse rate direct on the surface**	**39.3 ppm +/- 1.6**
Measuring probe B	**Net pulse rate at 3 cm distance**	**13.9 ppm +/- 1.5**
a) Small tea sample (4.53 g):	**Net pulse rate direct on the surface**	**31.4 ppm +/-1.4**
Measuring probe FSZ	**Net pulse rate at 3 cm distance**	**6.2 ppm +/- 0.9**
b) Large tea sample (35.5 g):	**Net pulse rate direct on the surface**	**69.5 ppm +/- 2.1**
Measuring probe FSZ	**Net pulse rate at 3 cm distance**	**28.6 ppm +/-1.6**

The significantly lower values (sensitivity) of the surface measurements demonstrate that the measuring probes B and FSZ are better suited for use as submersible probes. With increased distance from the source of radiation, the magnitude of the values measured (sensitivity) drops significantly.
Rule of thumb: with increasing distance, the amount of radiation measured drops by the square of distance from the source of radiation.