WhitePaper

ROD SOURCE / POINT DETECTOR ARRANGEMENT

Long-lasting process quality due to advantageous measuring arrangement

BERTHOLD

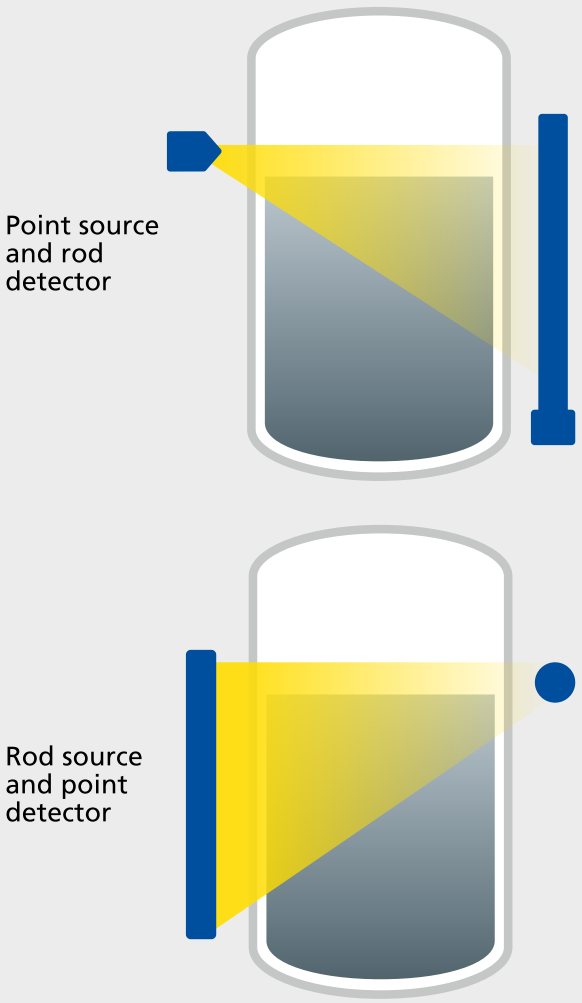
Introduction

When planning a radiometric measurement, the technical design is fundamental. It is created and developed based on process conditions, process geometry, customer input as well as local background radiation, site conditions, and mounting space limitations.

For the design of radiometric level or bulk flow measurements, a choice must be made between two arrangements: a point source with a rod detector (Fig. 1 top), or a rod source and a point detector (Fig. 1 bottom).

Due to the slightly lower purchase price, the arrangement with a point source and rod detector is frequently selected. However, the rod source (especially using Cobalt-60 (Co-60)) and point detector arrangement offers decisive advantages in measurement quality during operation, which will be addressed in this whitepaper.

Fig. 1 Arrangement examples for radiometric level measurements



Calibration and accuracy

The advantages in calibration and measurement accuracy are explained here using the example of level measurements. Since the product attenuates the gamma radiation coming from the source, the measured count rate at the detector decreases as the level in the vessel increases. In an ideal case, the relationship between the measured count rate and the level in the vessel is inversely linear (see dashed blue line in Fig. 2). During calibration when the measurement is commissioned, typically only a two-point calibration is performed, measuring the amount of gamma radiation seen by the detector while the vessel is empty and full. To calculate level in between any calibration points, the software assumes a linear relationship of count rate at the detector to process level. This results in a linear calibration curve.

In the case of the point source/rod detector arrangement, this assumption is erroneous, as the actual relationship is nonlinear, and the actual characteristic curve is arched (solid red line in Fig. 2). This is due to the geometry of this measurement arrangement. Point sources are usually mounted at the height of the 100% level, and the gamma radiation is collimated by the shield to come out at a 45° angle (see Fig. 1 top). Consequently, the path of the gamma radiation to the lower portion of the vessel, respectively of the rod detector, is longer than that to the upper part. In addition, due to the oblique radiation in the lower portion of the vessel, the vessel wall thickness effectively increases. As shown in Fig. 2, this results in a low sensitivity at 0%, which increases towards 100%. As a result, the actual characteristic curve for this arrangement is arched, and accuracy in the middle level range suffers with a standard two-point calibration and assumed linearity. Frequently, the desired control range of the process is located in this middle section.

Accordingly, a multi-point calibration is recommended for this arrangement to compensate for the measurement deviations shown in the middle level range. Very often, however, this measurement deviation is accepted and ignored since the repeatability of the results is not affected by it.

In contrast, with an arrangement of a Co-60 rod source and a point detector, a linear relationship between count rate and level and thus a constant measurement sensitivity can be achieved over the complete measurement range. This makes a two-point calibration accurate across the entire measuring range. To achieve this linear relationship, Berthold manufactures Co-60 rod sources with activity distributions specifically designed for the measurement task and vessel geometry specified by the customer. During source manufacturing, the winding of an activated Co-60 wire is distributed either more widely or more tightly along an internal guide rod (see Fig. 4) to compensate for a shorter or longer path of gamma radiation, respectively, through the vessel and vessel walls to the detector. The resulting characteristic curve shows a strictly linear progression and thus corresponds to the optimal characteristic curve (see Fig. 3).

From this strictly linear characteristic curve, clear advantages can be gained in terms of calibration and measuring accuracy. On the one hand, a two-point calibration (empty and full state) is sufficient during commissioning, which considerably reduces the time and effort required. On the other hand, with a linear characteristic curve, measured value deviations in the medium level range are eliminated, resulting in a more accurate and reliable measurement.

Fig. 4 Rod source casing with internal guide rod coiled with activated Co-60 wire. For illustrative purposes, the casing has been cut open in the detail image.

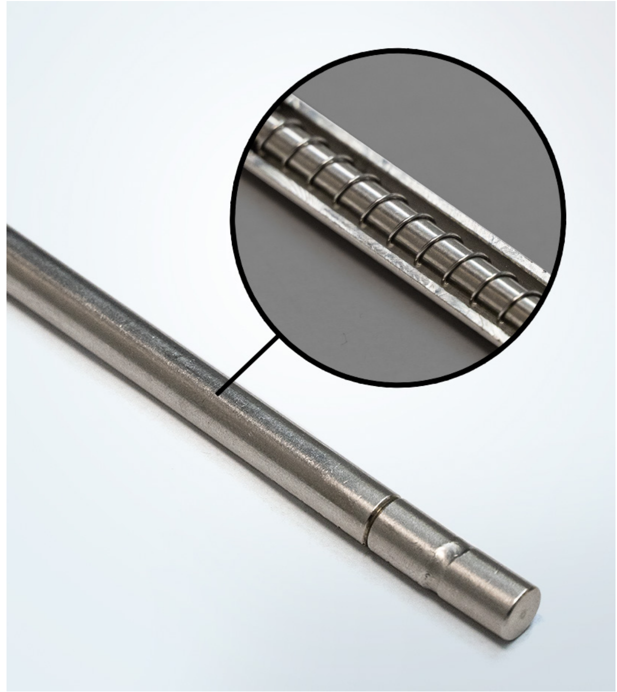


Fig. 2 Optimal characteristic curve (dashed blue) compared to the characteristic curve using a point source and a rod detector (solid red).

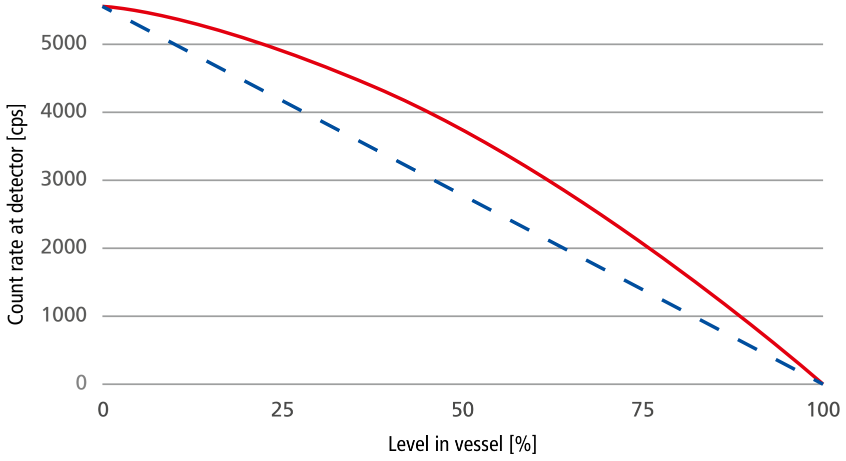
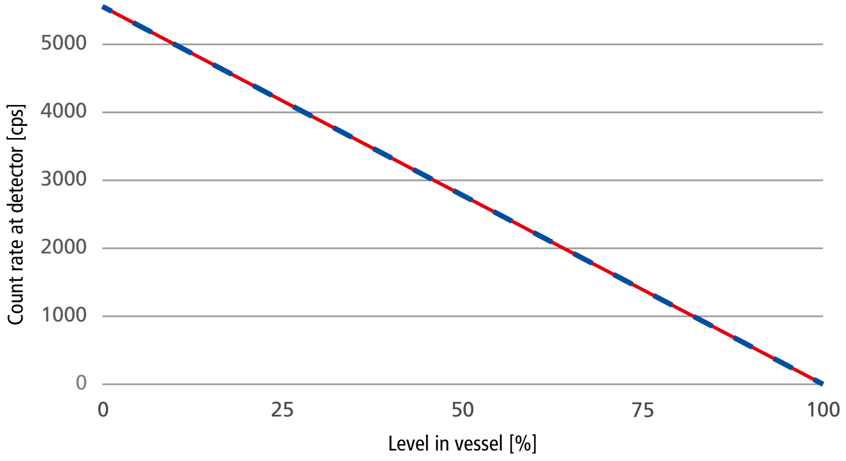


Fig. 3 Optimal characteristic curve (dashed blue) congruent with characteristic curve using a rod source and a point detector (solid red).



Long-term stability

Point detectors, typically used in arrangements with rod sources, offer a significantly better long-term and temperature stability than rod detectors, which will be discussed in this section.

Both point detectors and rod detectors use scintillators, the part of the detector sensitive to gamma radiation. In the scintillator, several light flashes (photons) are indirectly generated by the incoming ionizing radiation of the radioactive source. At the adjacent photomultiplier, the incoming photons knock electrons out of the photocathode, which are then multiplied in the photomultiplier. Subsequently, a measurable current pulse can be recorded at the anode.

In point detectors, with a few exceptions, a sodium iodide crystal doped with thallium is used as the scintillation material. These crystals have a maximum length of 125 mm. Rod detectors, on the other hand, require significantly longer scintillators (500 mm to 3000 mm), which is why a special polymer material is used instead. With increasing age of the detector or due to extreme environmental influences (high temperatures, impacts, water ingress, etc.), the scintillation material ages. In the case of polymer scintillators, the ageing of the material becomes visible in the form of fogging, yellowing and altered reflection properties at the surface (Fig. 5). These ageing effects cause decreased light transmission to the photomultiplier tube in rod detectors. Furthermore, due to the long scintillator, there is a sensitivity gradient along the length of the detector, with higher sensitivity closer to the photomultiplier tube. Due to the scintillator ageing, this sensitivity gradient is also intensified over time. As a result, the resulting characteristic curve changes, and recalibration may become necessary.

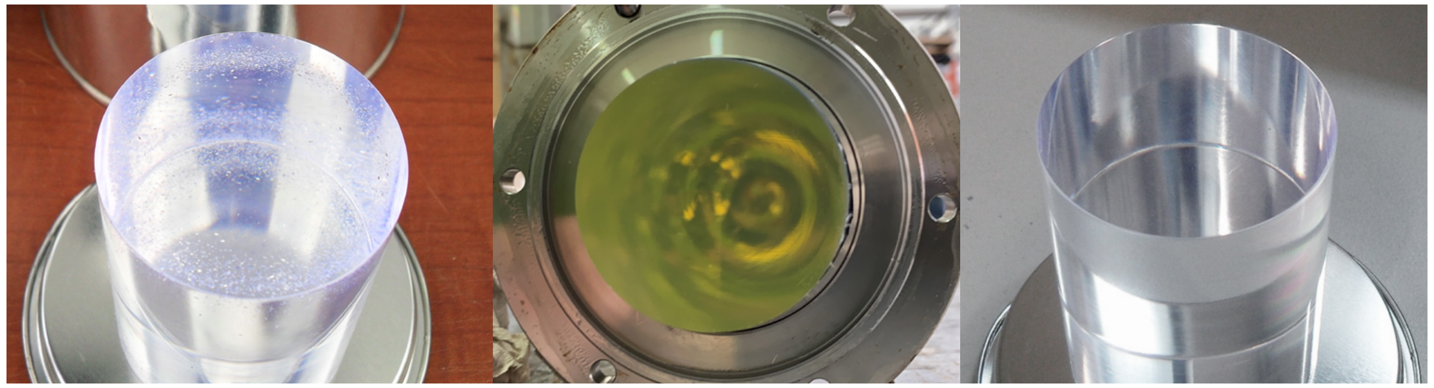
To counteract the decreasing light transmission due to material ageing, the manufacturers of rod detectors have developed special solutions, e.g., a special reflector foil. This foil is fitted around the scintillator in rod detectors, which increases the reflection but ultimately cannot completely compensate for the ageing effect. In addition to this reflector foil, the specially developed and patented cosmic gain control operates continuously in the background of Berthold's rod detector measurements. The cosmic gain control monitors the measurement and by readjusting the high voltage in the photomultiplier, ageing and temperature effects are significantly reduced.

In the case of sodium iodide crystals, due to the crystalline structure, the smaller size and since the material is fully encapsulated, ageing takes significantly longer and requires more extreme conditions. Due to the small scintillator size, there is, in comparison, no such sensitivity gradient in point detectors. Here, it is not the detector but the source that covers the length of the measuring range. Likewise, the inorganic crystal structure of the sodium iodide scintillators achieves a higher level of stability, which cannot be achieved with polymer scintillators. Thus, using the point detector and rod source arrangement, the customer has a more reliable and repeatable measurement for a longer period of time without the need for recalibration.

Suppression of process influences

In the operating process, there are often influences that can contribute to a falsification of the measured value, e.g., product build-ups and gas pressure fluctuations in level measurements and process deposits in bulk flow measurements. These variables influence the absorption of the gamma radiation emitted by the source. Especially in the case of gamma radiation from cesium-137 (Cs-137), which has half the energy of gamma radiation from Co-60, this effect is quickly evident in the displayed measured value. A radiometric measurement with Co-60 reacts far less sensitively to the above-mentioned influences due to the higher gamma energy. For point sources, the isotope Cs-137 is often used, which is why stronger influences can be expected in these cases. In comparison, the isotope Co-60 is usually used for rod sources, which means that the measurement will be influenced to a significantly lesser extent and the measured value represents the actual level or the actual load.

Fig. 5 Fogging (left) and yellowing (middle) of polymer scintillators compared to an unaltered polymer scintillator (right)



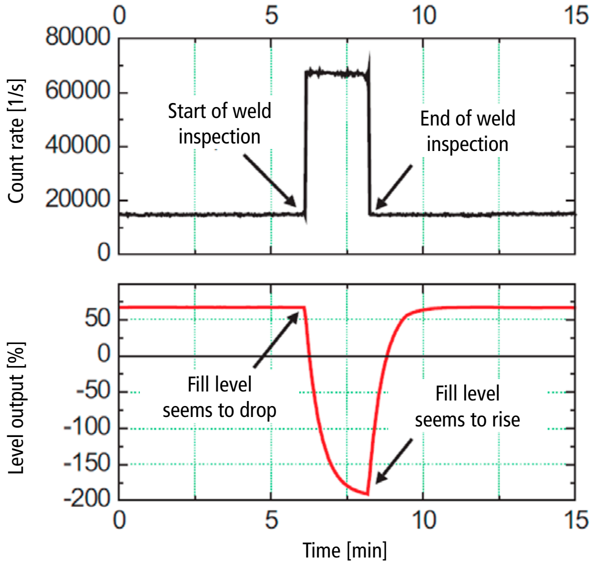
Susceptibility to errors due to NDT

In many cases, the non-destructive testing (NDT) of welds is carried out with high gamma radiation (mainly iridium-192 or selenium-75), which can also influence radiometric measurements over hundreds of metres by greatly increasing the count rate at the detector and thus falsifying the measured value. This influence leads to the fact that e.g., for level measurements the measured value runs towards 0% or even below 0% (see Fig. 6) and for bulk flow measurements the load is indicated as being too low. How severe the influence is, depends on the measurement arrangement, the detector used, and the distance from the weld test.

Point detectors are typically used in combination with rod sources. As already described, these detectors have a very small scintillator volume. The gamma radiation from weld tests must therefore hit this small volume to influence the measurement. Rod detectors, on the other hand, have a very large volume, making them far more sensitive on all sides if heavy rod detector shields are not used. This makes them very sensitive to gamma radiation from weld tests. In addition, point detectors can be very easily and effectively shielded by small detector shields (so-called collimators) that only allow radiation coming from the product side. This leads to an additional immunisation of the point detectors against weld tests.

In addition, the manufacturer Berthold, for example, offers the function of radiation interference discrimination (RID) when using Co-60 sources in combination with RID-capable transmitters (e.g., LB 470RID). RID makes it possible to continue to measure level undisturbed even during NDT events, as long as the NDT gamma radiation is dissimilar in energy to that of Co-60. If the NDT gamma radiation is similar in energy or if Cs-137 sources are used for level measurement, Berthold offers the interference radiation protection function (X-Ray Interference Protection - XIP). With XIP, an alarm is triggered when interference radiation is detected, and the output is frozen, and thus falsified outputs are prevented. After the interfering radiation event has ended, the output resumes automatically. During the event, however, the output is not live, and the level cannot be monitored radiometrically.

Fig. 6 The influence of weld testing with strong gamma radiation on level measurements with rod detectors



Background radiation influence

Depending on the geographical location and the local conditions, background radiation is permanently present in addition with the above-described temporary interference radiation, e.g., from NDT. A distinction must be made here between natural and artificial background radiation.

Natural background radiation is mainly caused by cosmic or terrestrial radiation. While the effect of cosmic radiation is constant, terrestrial background radiation can vary greatly depending on the geographical location and weather conditions. Radionuclides of the thorium and uranium decay series as well as potassium-40 are natural components of the Earth's crust, which is why the radiation dose varies greatly worldwide, depending on the bedrock composition. The noble gas radon contributes significantly to terrestrial background radiation with its radioisotopes. The most stable one of these radioisotopes is radon-222, with a half-life of 3.82 days, which occurs as a daughter nuclide and as the only gaseous element in the uranium decay series. Radon is a very mobile gas that can diffuse freely through soils and is thus released into the atmosphere. Moreover, radon is additionally washed out of the atmosphere by precipitation, causing it to accumulate near the ground. Rn-222 is a pure alpha emitter. The daughter and grandchild nuclides of Rn-222 decay further by emitting gamma radiation. Consequently, during rainfall, the background radiation can almost double for a short time.

Artificial background radiation can originate, for example, from other radiometric measurements in the direct vicinity, but also from radioactive material that is used in neighbouring processes. This increases the measured background radiation.

Depending on the measuring arrangement and activity, this additional radiation, which is independent of the process, influences the radiometric measurement to a greater or lesser extent, especially when the activity of the source used decreases.

Due to the large scintillator length of rod detectors, they are more strongly influenced by an increased or fluctuating background value, especially when the source becomes weaker, than point detectors, with smaller sensitive areas and ease of shielding with a collimator.

Spare parts inventory

In case of failure, it is the best to have a spare detector on site in order to resume measurement as quickly as possible. If many processes are monitored by rod detectors, stocking spare parts can become more difficult because the detector length is adapted to the measuring range. This can result in multiple rod detectors of different lengths being used and stored at one plant. In such a case, many different replacement detectors would be needed. This can be avoided by using rod sources in combination with point detectors, because the rod source, which remains at the measurement location and does not require a spare, is adapted to the measurement range. The point detector, on the other hand, is always of the same size. Hence, it is only necessary to stock one type of detector, which can be used for all measurements with rod sources. The compact design of point detectors also has the advantage that they require little storage space and can be replaced with minimal effort in the event of a failure.

Safety and sustainability

The Co-60 alloy used for rod sources is safely encapsulated in a tightly closed stainless steel housing. The ISO 2919 standard qualifies the sources according to their safety characteristics. Co-60 rod sources achieve the highest achievable safety classification C-66646.

With regard to the disposal of radiometric sources after their period of use, Co-60 is more economical because of its shorter half-life of 5 years. Within 50 years, Co-60 will have decayed to about 1/1000 of its original activity. For Cs-137, on the other hand, it takes 300 years to reach this point.

Arguments against Co-60 sources

For competitive reasons, arguments against Co-60 rod sources are often used to promote the more widespread Cs-137 point sources. These arguments are presented in the following section and their flaws are identified.

Rod sources are very expensive in comparison

Measurements with rod sources are somewhat more expensive. As a rule, the price difference between a rod source/point detector and a point source/rod detector arrangement is between 15-30% depending on the measuring range. For short measuring ranges, the price difference is higher, whereas for longer measuring ranges, the difference decreases, since a comparable arrangement with rod detectors would then also require the use of several point sources.

In addition, the somewhat higher acquisition costs may be mitigated quite quickly if, for example, an improvement in the production process or a reduction in downtime can be achieved through the advantages mentioned above.

Very short working lifetime due to short half-life

When specifying the working lifetime, two aspects are considered: the working lifetime from the radiation protection point of view and the working lifetime from the technical point of view. For reasons of radiation protection, there is a requirement that a source enclosure must be leak-proof over its lifespan. Considering the relevant standard ISO 2919, sources from Berthold, for example, have a recommended working lifetime of 15 years. From a technical point of view, a source can be operated until the statistical fluctuation is too high due to radioactive decay and a further increase in the time constant is no longer possible, as the reaction of the measurement to process changes would otherwise become too slow.

However, the half-life of the Co-60 nuclide is often mistakenly equated with the working lifetime of a radiometric Co-60 source. The half-life of about 5 years does not mean that the source can no longer be used after one half-life has elapsed, but it means that the source has lost merely half of its original activity. This misunderstanding is often used as a common argument that the working lifetime of Co-60 rod sources is too short. It is also necessary to consider that Co-60, compared to Cs-137, has a specific gamma energy about a factor of 2 higher and, in addition, two gamma quanta are emitted per decay (gamma energy Co-60: 1173/1332 keV; Cs-137: 660 keV). With Co-60, therefore, significantly less radiation is attenuated by the measured material. To achieve the same measured count rate at the detector, Co-60 requires less activity and therefore a lower amount of radioactive material than Cs-137.

All known manufacturers of radiometric gamma sources recommend a working lifetime of 15 years, which applies to both Co-60 and Cs-137 sources. With optimal design of the radiometric measurement, three half-lives can therefore elapse when using Co-60 sources before the source would need to be replaced. Consequently, it should be noted that regardless of the nuclide used, the initial activity of each measurement can be designed in such a way that it will reach the required designed lifetime of typically 10-15 years.

Rod source shields are very difficult to install

Furthermore, the argument is made that shields for rod sources are very difficult to install due to their heavy weight. In principle, the installation of rod source shields is more demanding than that of point source shields, but it is only a one-time undertaking that is disproportionate to the benefits that an operator will subsequently derive over many years.

As already described above, due to the large scintillator volume rod detectors react more sensitively to interfering radiation, e.g., from NDT, compared to point detectors. In addition to the interference radiation protection described above, the operator also has the option of protecting rod detectors from interference radiation by using rod detector shields. Thus, even when using Cs-137 point sources, the process could still be monitored during interference radiation events. These shields are comparably difficult to install as the shields of the rod sources. This weakens the argument that rod source shields are very difficult to install.

Conclusion

Based on the points presented, it can be concluded that a rod source/point detector arrangement offers numerous advantages that cannot be achieved with a point source/rod detector arrangement. Due to less frequent production downtimes, simpler and thus more economical spare parts inventory, increased long-term and temperature stability and consistent process quality, the higher acquisition costs are mitigated within a short period of time.

Before choosing a radiometric measurement, it is therefore advisable that the operator weighs up the advantages and disadvantages of the measuring arrangements, obtains comparative offers for both measuring arrangements and contemplates possible secondary costs in order to find the best measuring arrangement for the process.

References

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