Met One Technical Bulletin

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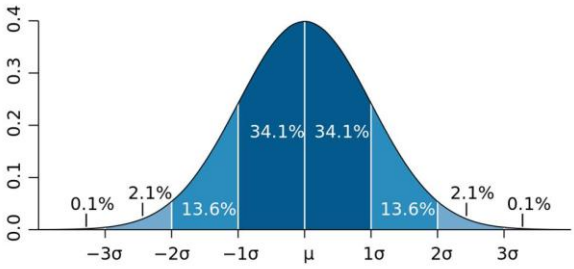
BAM-1020 Detection Limit

Advanced zero performance analysis, and understanding the statistical noise band and detection limit specifications for the BAM-1020 concentration measurement

A thorough understanding of the following fundamental principles and specifications will assist the user in obtaining high quality data from the BAM-1020 particulate monitor, especially in low concentration areas.

The beta attenuation mass measurement method inherently contains a small amount of noise due to natural random variations in the beta decay output rate of the source. Each beta source has a different emission rate, and therefore each BAM instrument has a slightly different natural noise band and resulting detection limit. Each BAM-1020 is run at the factory for 48 to 72 hours under laboratory conditions with a BX-302 HEPA zero filter installed on the inlet to prevent any particulate from entering the sample air. The average of this hourly zero data is used to determine the background correction for the BAM, and the noise characteristics are evaluated to establish the sensitivity and detection limit of the measurement.

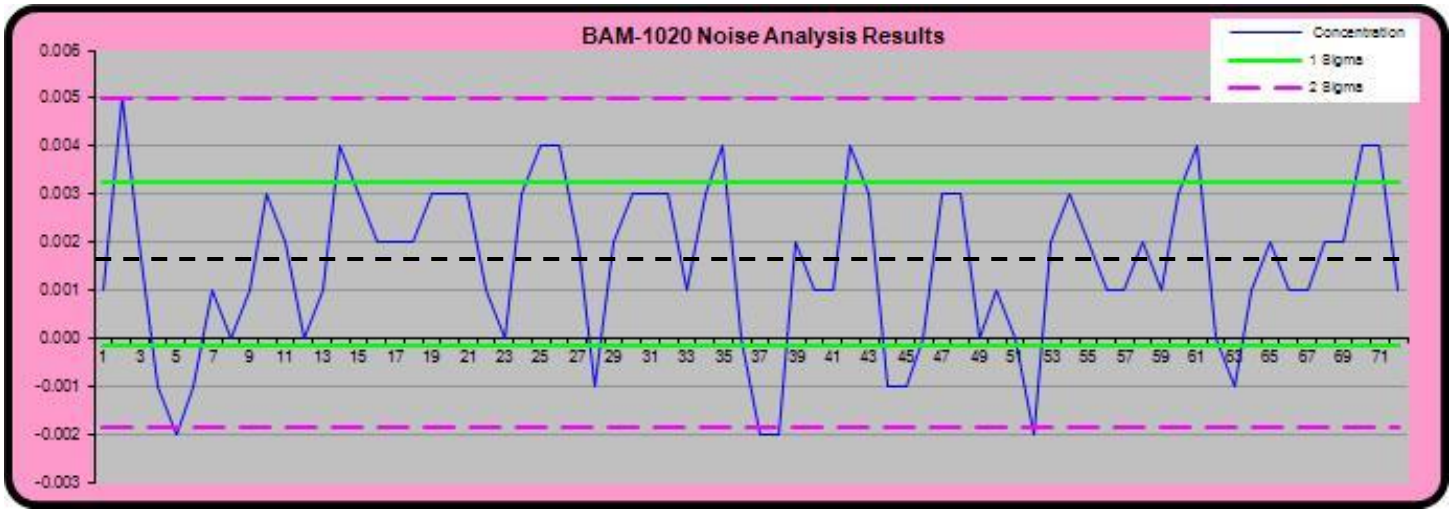
The noise is quantified by taking the statistical standard deviation 1σ (sigma) of the 72 hour zero concentration data set. The BAM-1020 is specified for an hourly standard deviation of noise of less than 2.4µg, and Met One does not ship a unit if the measured value is higher. The median hourly standard deviation over thousands of BAMs tested using this method is about 1.8 micrograms. Some units have a standard deviation as low as 1.2µg.



Normal Poisson distribution around the mean, where each band has a width of one standard deviation

The data sample below shows an actual, typical BAM-1020 with a calculated standard deviation of 1.7µg. This means that 68.2% of the hourly points in the zero dataset fall within ±1.7µg (1σ) of the average, and 95.4% of the points fall within ±3.4µg (2σ) of the average. You would statistically expect no more than 2 or 3 of the 72 points to be more than two standard deviations from the average, and it would be very rare for any one point to be more than three standard deviations from the average. This statistical method for noise analysis is more appropriate that assigning an arbitrary min/max criteria.

Because the beta decay noise is statistically random, and the zero filter test average of the BAM is always close to zero, negative hourly concentration values included in the zero test dataset are just a valid as positive concentration values. Removing negative values from the dataset would result in an artificial positive bias in the average used to establish the background correction, and in an artificially low standard deviation.



BAM-1020 Zero Test Analysis With 1.6µg Average, 1.7µg Hourly Standard Deviation, 3.4µg Hourly Detection Limit

The hourly detection limit of the BAM-1020 is defined as two standard deviations (2σ) of the hourly noise, so in the data sample above, the hourly detection limit is 3.4µg, which is fairly typical. If a BAM-1020 had a maximum allowable standard deviation of 2.4µg, then the maximum hourly detection limit would be 4.8µg.

Because the noise band is statistically random, the detection limit of multi-hour concentration averages is reduced by dividing by the square root of the number of values included in the average. This means that the daily detection limit of the BAM-1020 is the hourly detection limit divided by the square root of 24 (4.899). So in the sample above, the daily detection limit is ((2*1.7µg)/ 4.899) = 0.69µg. A unit with a maximum allowable hourly standard deviation of 2.4µg would have a daily detection limit if 0.98µg.

This is why the BAM-1020 daily average measurement usually matches a manual 24-hour gravimetric sample within a fraction of a microgram (as long as other factors such as sample flow, sample RH, and filter tape movement are properly controlled), even though any individual hourly BAM concentration value could have a couple of micrograms of positive or negative noise associated with it.

Noise and Detection Limit Characteristics During Normal Ambient PM Sampling

In the data sample above, the zero average of the zero filter test data is +1.6µg, so the background correction (BKGD) will be set to -0.0016 mg (-1.6µg) This corrects all subsequent data so that the noise band would be perfectly centered around zero. This is the primary purpose of the required field zero filter test for $PM_{2.5}$ units. The BAM-1020 noise band and detection limits quantified during the zero filter test apply to normal ambient sampling as well. In very clean ambient air where the true particulate mass concentration is below the detection limit of the instrument, it is statistically possible to occasionally see the BAM-1020 generate a negative hourly concentration value, even if the background correction is set correctly. These negative hourly values are not removed from the daily average simply because they are negative, unless there is another data validation reason for doing so. Similar noise excursions in the positive direction are also present in the dataset, you just cannot identify them. Removing negative hourly BAM concentrations from data artificially biases the daily average in the positive direction. This is usually not desirable.

For data validation purposes, the magnitude of the statistically possible noise spikes will be determined by the exact detection limit of the BAM, as determined during the field zero. For the data sample above, assume that the BKGD value is correctly set to -1.6µg so that the noise band is perfectly centered around zero, then the zero filter is removed and the instrument is set to measure normal ambient $PM_{2.5}$ concentrations. Assume that the true ambient dust levels drop to near zero, and a couple of occasional negative concentration values appear in the BAM data. Since this particular BAM-1020 has a standard deviation of 1.7µg and an hourly detection limit of 3.4µg, it would be statistically possible to see an occasional negative concentration value as low as -3.4µg

(2σ) or even -5.1µg (3σ). However, if this unit exhibited multiple concentration values of -7µg or -8µg for example, then this would be beyond statistical likelihood based on the known noise band, and the unit should be investigated for operational or maintenance problems.

It is not uncommon for a field zero filter test on a BAM-1020 to show a slightly higher standard deviation that the factory value which was established under lab conditions. This can sometimes be attributed to minor variations in factors such as grounding, shelter temperature stability, inlet heater operation, or electromagnetic interference. However, the noise band should at least be close to the 2.4µg factory spec, and it should be consistent during subsequent zero test performed seasonally or annually. For example, if the BAM-1020 above was initially field tested with a standard deviation of 1.7µg, and a subsequent zero filter test a year later shows a standard deviation of 3µg, then the unit should probably be investigated for operational or maintenance problems such as nozzle leaks, flow stability, moisture in the zero filter, etc.

The subject of detection limits is even more complicated when PM_{10} and $PM_{2.5}$ concentrations are measured simultaneously using two BAM-1020s. At times when the true PM_{10} concentration is low, it is statistically possible to get an occasional hourly $PM_{2.5}$ data point which is higher than the corresponding PM_{10} value for the same hour, which is of course impossible. This may also occasionally occur even at higher concentrations if the particle spectra in that area is such that the PM_{10} consists mostly of 2.5 micron particulate.

Additional Considerations:

- You should generally not see negative hourly BAM concentrations which are considerably more negative than the instrument's hourly 2σ detection limit. In most 8-minute count units, hourly concentration values below about -5 µg are statistically unlikely if the BKGD correction is set correctly.
- You should not see negative 24-hour daily average concentrations from the BAM. Because the daily detection limit is a fraction of a microgram, negative daily averages from the BAM are very unlikely, even in very clean air, if the BKGD correction is set correctly in the unit.
- It is not uncommon for the first field zero test to result in a BKGD value which is several micrograms different than the factory-set BKGD value. This is because the factory zero test is run without an inlet heater. You should not see large changes in the field zero average or standard deviation over time.
- You should not see a clear diurnal pattern in a graph of the zero test data. The normal noise band should appear to be random.
- A large noise spike at the same time every day is sometimes an indication of some external influence such as RF interference or large shelter temperature changes.
- You should not see multi-hour periods of continuing negative concentrations, or concentration data clipped at the lower range limit of -15µg.
- Data with multiple points of -15µg should not be used to set the BKGD average, even if the standard deviation is low. The sigma is only low in this case because the bottom part of the noise is clipped.
- A high standard deviation in the zero test data usually means that the data set is not appropriate to use to set the background correction in the BAM. Units sold only for PM_{10} use usually have a larger noise band because they are limited to 4-minute beta counts instead of 8 minutes.
- The 72-hour zero filter test must be correctly performed under field conditions on all $PM_{2.5}$ or $PM_{10-2.5}$ coarse units, and is recommended for all PM_{10} units. Complete instructions are included with the BX-302 zero filter and in the BAM-1020 manual rev H or later. Zero test records for each unit should be retained with your other calibration and data validation records.