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Road vehicles — Analysis of technical changes of ISO 5011:2020

Véhicules routiers — Analyse des changements techniques de l'ISO 5011:2020

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Foreword

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This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 34, *Propulsion, powertrain and powertrain fluids*.

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Introduction

This document describes the major changes made to ISO 5011:2014 with the ISO 5011:2020 revision.

Road vehicles — Analysis of technical changes of ISO 5011:2020

1 Scope

This document analyses the impact of changes to ISO 5011:2020 as regards to the following:

— precleaner efficiency;

— elimination of two secondary element tests (collapse and blocking);

— revisions to the recommended ISO dust injector (Table 1);

— validation of the absolute filter weighing method; and

— inclusion of Annex H, "Penetration sensitivity".

These changes refine the precleaner efficiency calculation, eliminate seldom used tests, which were lengthy or costly, further clarify dust injector use, the validation of the absolute material, and the precision of the efficiency measurement.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5011:2020, *Inlet air cleaning equipment for internal combustion engines and compressors — Performance testing*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5011:2020 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Precleaner efficiency calculation

Background:

In ISO 5011:2014 it was possible, using just the gain on the primary, secondary, and absolute filters alone, to calculate the precleaner efficiency. This approach was logical, in so far as the measure of the precleaner efficiency was defined by that which actually loaded on the primary, regardless of whether it was removed entirely from the system.

This can occur:

— due to the casual removal of the elements (causing dust to fall off in the air cleaner and lowering the primary gain);

— due to dust trapped within the precleaner housing itself, which commonly occurs during the initial feed to a system.

It was felt that even if the dust did not reach the primary, and thus cause an increase in restriction, that it might potentially re-entrain at some point if dislodged and could thus reach the primary.

The new change to ISO 5011:2020, 7.8.2 makes this impossible, as it now includes specifically the gain in the air cleaner in the calculation (Figure 1).

ISO 5011:2020, 7.8.2 Precleaner efficiency

> The precleaner efficiency is defined by the dust removed from the air stream prior to the primary filter housing. Precleaner efficiency (E_{p1}) shall be determined during the dust capacity test, based on the total mass of dust fed to the air cleaner and the sum of the gain in mass of the primary, secondary elements, housing and the absolute filter. Calculate the precleaner full life efficiency, E_{p1} (expressed as a percentage), as follows:
>
> $$E_{p1} = \frac{m_D - (\Delta m_P + \Delta m_S + \Delta m_F)}{m_D} 100 \tag{1}$$
>
> where
>
> m_D is the total mass of dust fed;
>
> Δm_P is the increase in mass of the, primary element and primary housing, if present;
>
> Δm_S is the increase in mass of the secondary element, if present;
>
> Δm_F is the increase in mass of the absolute filter.

Initial Primary Wt. (g.):	885.45	Final Wt. (g.):	1917.11	Total Wt. Gain (g.):	1031.66	Dust Jar Wt. (g.):	9993.6
Initial Safety Wt. (g.):	200.04	Final Wt. (g.):	200.47	Total Wt. Gain (g.):	0.43	Dust in A/C. (g.):	79.9
Capacity Absolute #:	0	Gain (g.):	0.19	Cumulative Efficiency:	100.00%	Material Balance:	100.00%
Initial Absolute #	1	Gain (g.):	0.01	Initial Efficiency:	99.99%	Additional Mass Fed (g.):	0.00
				Separator Efficiency (2020):	**89.99%**	Based on Dust Downstream (penetration beyond PC)	
Test Time:	15:34:48	Total Dust Fed (g.):	11105.80	Separator Efficiency (2014):	**90.70%**	Based on Dust on Old method with just the pirmary/secondary/absolute and NOT the AC	
				Separator Efficiency:	**89.99%**	Based on Dust Jar Gain (removal)	
		Initial Eff. Dust Fed (g.)	71.28	Element Efficiency:	**99.94%**		

Figure 1 — Examples of using the older ISO 5011:2014 calculation versus ISO 5011:2020, and how this compares with the 'dust ejected' method

Impact:

1) If prior to this, only the gain on the primary, secondary, and absolute were used – then this changes the results of the precleaner efficiency.

2) With a 100 % material balance (all masses were measured and collected), the new method eliminates the difference between calculating using amount removed versus that which passes into the primary air cleaner housing.

3) It is anticipated to be easier, under some circumstances where the method of removal makes it difficult to measure the mass removed (dust ejected into the air for example), to calculate the efficiency.

NOTE A future standard for precleaner efficiency testing is under development.

5 Collapse and blocking tests

The elimination of: ISO 5011:2014, 7.9.2.2.7

ISO 5011:2014, 7.9.2.2.7 “At the end of the test, after measuring the efficiency, the flow rate shall be increased to produce a differential pressure across the housing of 12,5 kPa (125 mbar). The secondary element shall not rupture under these conditions.”

Background: ISO 5011:2014, 7.9.2.2.7 was a test designed to challenge the secondary element at the end of a loading test, i.e. once the secondary had been subjected to the inefficiency of the primary loading.

This was done through increasing the airflow up to a preset differential pressure. The test required that the airflow be increased after the efficiency masses were taken (i.e. resulting in the removal and reinstallation of the primary). This is difficult to do without causing a change due to the loss of dust cake, and it could be messy. This test was eliminated from ISO 5011:2020.

Impact:

1) If the customer requests, then the test can be tested per ISO 5011:2014.

2) The lab can use ISO 5011:2020, 6.6 "Filter element pressure collapse test" as a substitute collapse challenge.

The elimination of: ISO 5011:2014, 7.9.4 "Secondary element blocking test"

Background: ISO 5011:2014, 7.9.4 was a method of measuring the effects of the gain on a secondary element which resulted from its repeated use with replacement/new primaries in a series of loadings. Since it was the inefficiency of the primary which determined the loading of the secondary, this reflected the ‘real world’ loading of a secondary element. However, due to the cost and time involved in the procedure, and lack of customer interest, it was eliminated from ISO 5011:2020.

Elements eliminated from ISO 5011:2014:

ISO 5011:2014, 7.9.4 "Secondary element blocking test"

7.9.4.1 General

The test determines the increase in restriction/differential pressure and mass of a secondary element, caused by the dust that has passed through the primary element.

7.9.4.2 Preparation

Use a clean primary element and secondary element in the housing normally employed. Determine the mass of the secondary element after conditioning in accordance with 7.5.2.1.

7.9.4.3 Test procedure

7.9.4.3.1 Set up the air cleaner as in 6.3 (restriction and differential pressure test). Measure and record the restriction/differential pressure of the unit at the rated flow only. Replace the later reference primary element by a new primary element.

7.9.4.3.2 Conduct a full life efficiency and capacity test as specified in 7.5.

7.9.4.3.3 Replace the primary element with the reference one used at the start of the test. Repeat the restriction and differential pressure test of 7.9.4.3.1. Note the result.

7.9.4.3.4 Remove the secondary element and reweigh.

Impact:

1) If the customer requests, then the test can be tested per ISO 5011:2014.

2) The lab can run ISO 5011:2020, 7.9.2 instead of ISO 5011:2014, 7.9.4. as a substitute method to challenge the secondary.

6 Revised recommended ISO dust injector table

The revision of: ISO 5011:2020, 6.2.3

The text in ISO 5011:2014, 6.2.3 reads as follows:

Use the dust injector described in Table 1 and shown in Figures B.2 and B.3.

Table 1 — Table 1 of ISO 5011:2014 "Recommended ISO dust injectors (see Figures B.2 and B.3)"

Dust feed rate (g/min)	0 to 26	26 to 45	>45
Injector type	ISO injector	ISO injector or ISO heavy-duty injector	ISO Heavy-duty injector

The specified ISO injector has been shown to feed dust satisfactorily at rates up to 45 g/min. Where dust feed rates greater than this are required, more than one injector will have to be used. It should be noted that the design of the system feeding test dust to the injector may affect this maximum rate of dust feed. The maximum attainable dust feed rate should therefore be determined prior to the dust feed/injector system being used for tests.

Injector nozzles are subject to natural erosion. Erosion may affect the distribution and delivery of test contaminant. Therefore, it is recommended to use a design with replaceable parts."

The text in ISO 5011:2020, 6.2.3 reads as follows:

Use the dust injector described in Table 1 and shown in Figures B.2, B.3 and B.18.

Table 2 — Table 1 of ISO 5011:2020 "Recommended ISO dust injectors (see Figures B.2 B.3 and B.18)"

Dust feed rate per injector (g/min)	0 to 5	5 to 26	>26
Injector type	Light-duty injector	Light-duty injector or heavy-duty injectors (A or B)	Heavy-duty injectors (A or B)

If an array of injectors is used, special care shall be taken to make sure the dust fed is distributed evenly between each injector for two reasons: First, to get homogeneous dust distribution in the airstream and second, to make sure the maximum or minimum feed rate for the injectors being used is not exceeded.

Where dust feed rates greater than this are required, more than one injector will have to be used. It should be noted that the design of the system feeding test dust to the injector may affect this maximum rate of dust feed. The maximum attainable dust feed rate should therefore be determined prior to the dust feed/injector system being used for tests.

Injector nozzles are subject to natural erosion. Erosion may affect the distribution and delivery of test contaminant. Therefore, it is recommended to use a design with replaceable parts.

Background:

The recommended ISO dust injector table provides guidance on the amount of dust to be fed through the differing sized injectors. In the past, it was possible to use a light-duty injector (Figures B.2) in order to feed up to 45 g/min.

The table has been revised and it is now recommended that if the dust feed rate is > 26 g/min, that either a second light-duty injector is to be used, or one of the heavy-duty injectors A or B (see Figures B.2, B.3 and B.18).

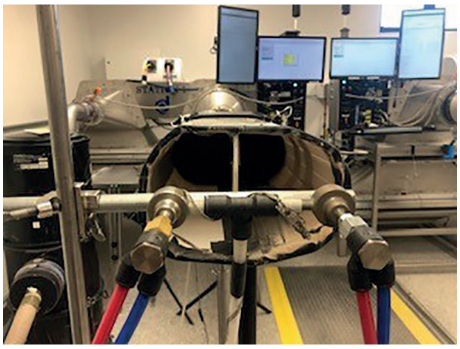


Figure 2 — A two-injector array

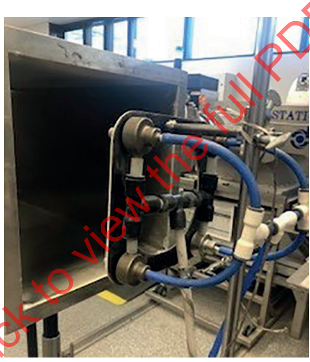


Figure 3 — A four-injector array

It is common in many labs to use and array (more than one) of light-duty dust injectors (see Figure 2 or 3d). These allow higher feed rates without going to a single heavy-duty injector and can be arranged in such a way that the dust is distributed evenly across the inlet, which is typically large due to airflow rate. When feeding >26 g/min, the principal issue becomes the problem of clogging. It is felt that this change helps eliminate that issue and that the expansion of the text clarifies the use of the table and important considerations in test setup.

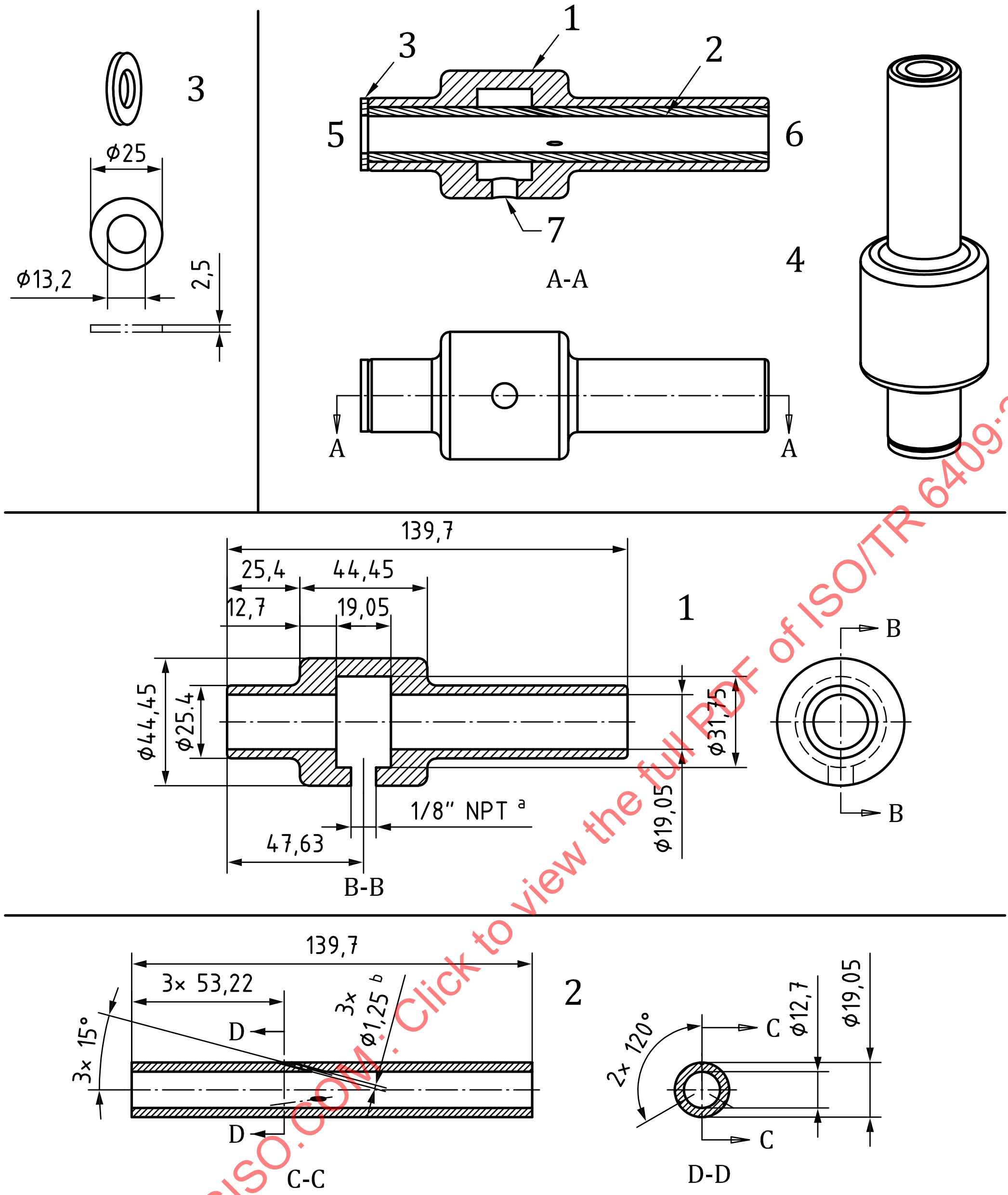
Impact:

1) If labs use a single light-duty dust injector to feed between 26 g/min and 45 g/min, then this change recommends the use of either a heavy-duty injector, or an array of multiple light-duty injectors.

2) The change was implemented to reduce the chance of clogging. This change most likely will help to distribute the dust more evenly across a larger inlet.

7 Dust injector (ISO 5011:2020, Figure B.18)

Figure 4 shows a schematic of a new dust injector design.



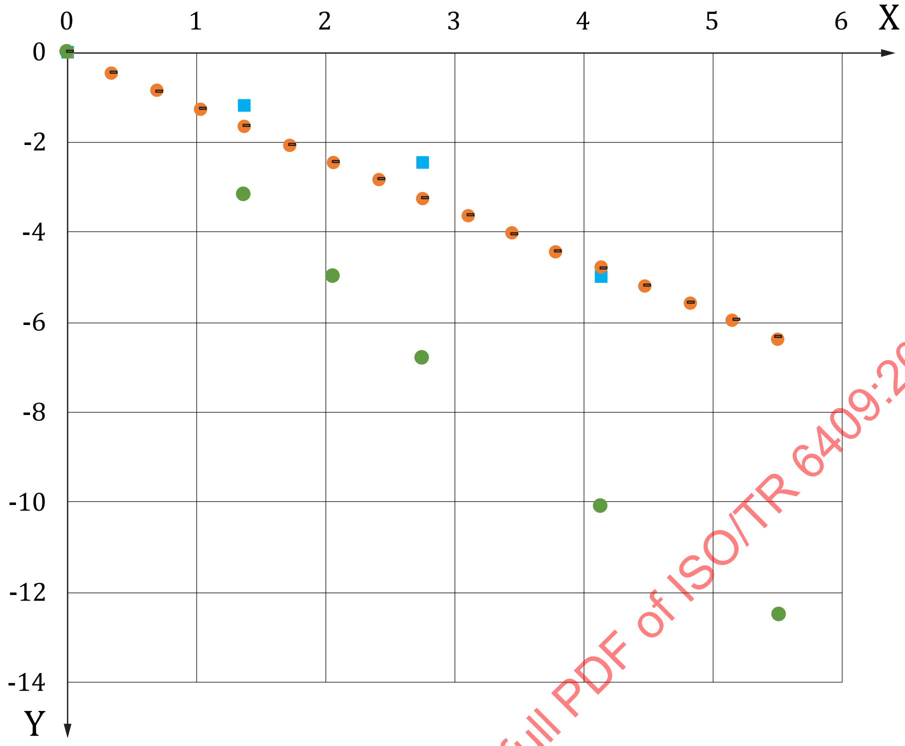
Key

1 injector outer body
2 ceramic insert
3 steel erosion shield
4 assembled part
5 dust entry
6 air/dust exit
7 air entry
a Or equivalent threads.
b Thru hole.

Figure 4 — Drawing of the dust injector from ISO 5011:2020, Figure B.18

In the graph below (Figure 5) it is shown the dP versus flow results of the new dust injector design versus the standard ejector shown in ISO 5011:2020, Figure B.3.

ISO 5011:2020, Figures B.3 and B.18 dust injector performance map



Key

X pressure [bar]

Y suction pressure [kPa]

■ ISO B.3 data set 3

- ISO B.3 data set 1

● ISO B.3 data set 2

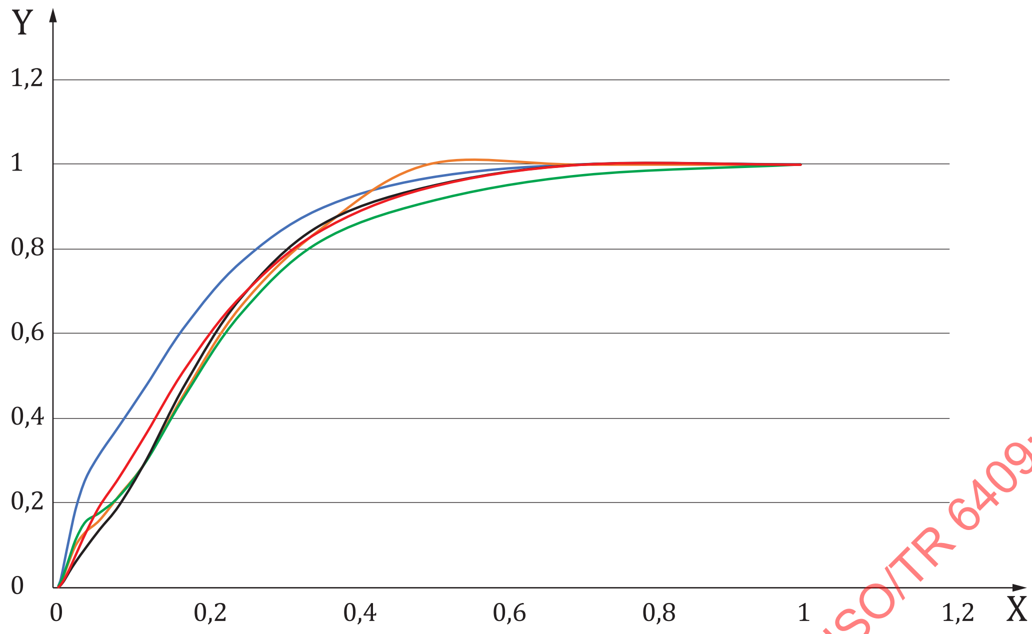
● ISO 5011:2020 injector B.18

ISO B.3 injector data is from two different sources.

Figure 5 — Comparison of the dust injectors from ISO 5011:2020, Figures B.3 and B.18

Shadowgraphy results of dust injectors

The next two graphs (Figure 6 and 7) show the shadowgraphy results for this new dust injector versus standard types.



Key

X particle size (micron)

Y cumulative volume fraction (-)

(blue line) ISO heavy 40 psi 200 g/hr

(orange line) ISO heavy 80 psi 200 g/hr

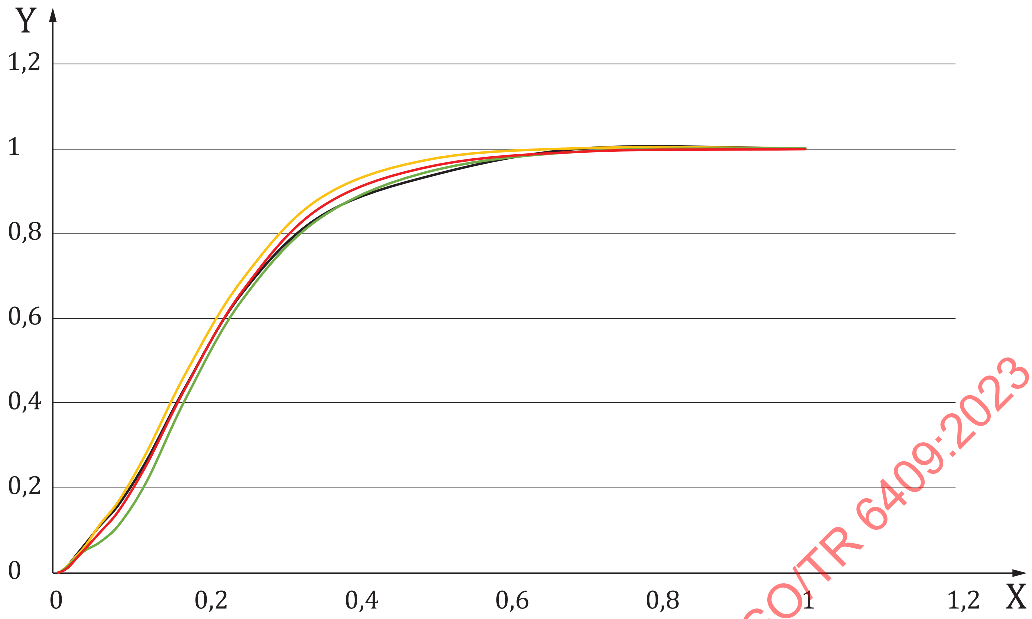
(green line) custom large 50 psi 200 g/hr

(black line) custom large 30 psi 200 g/hr

(red line) ISO light 14,5 psi 200 g/hr

Evaluation was completed on three different injectors with ISO 12103-1 A2 dust.

Figure 6 — Shadowgraphy results of three different injectors



Key

X particle size (micron)

Y cumulative volume fraction (-)

— ISO heavy 40 psi 3 000 g/hr

— ISO heavy 80 psi 3 000 g/hr

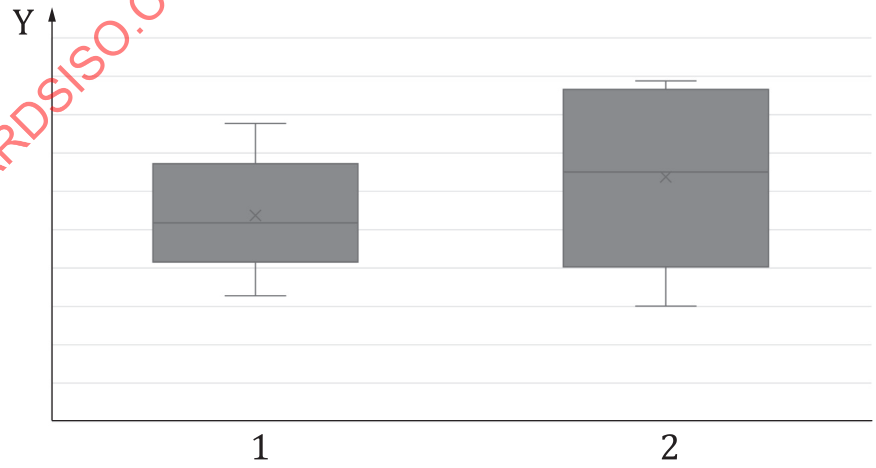
— custom large 50 psi 3 000 g/hr

— custom large 30 psi 3 000 g/hr

Evaluation was completed on two different injectors with ISO 12103-1 A2 dust.

Figure 7 — Shadowgraphy results of two different injectors

The below graph (Figure 8) shows the results of a loading test on a filter using either the new injector or the one described in Figure B.3 (ISO 5011:2014 and ISO 5011:2020).



Key

Y capacity (grams)

1 ISO 5011 injector B.18

2 ISO injector B.3

Figure 8 — ISO 5011:2020 lab testing comparisons

8 Validation of the absolute filter weighing method (ISO 5011:2020, 5.4.1)

Figure 9 explains how to validate the absolute weighing method. Table 3 shows the results of that validation at one particular lab.

— Multiple methods are possible in ISO 5011:2020, 5.4

— Using the method of choice:

 — Complete the entire absolute method (ISO 5011:2020, 5.4) each day for three days on the same pad.

 — Compare the results from each day and use the delta from the three results for use in Annex H. An example can be seen in Table 3.

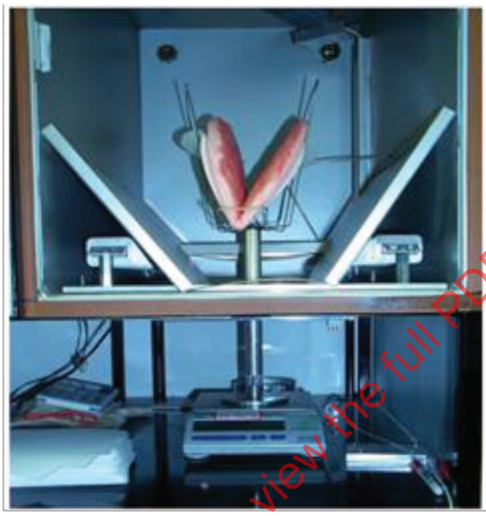


Figure 9 — Example of ISO 5011:2020, 5.4 method

Table 3 — Validation of the absolute filter weighing method

Sample	Day 1 measurement	Day 2 measurement	Day 3 measurement	Greatest difference	Abs. filter instrument sigma (Table H.1)
1	25,37	25,39	25,37	0,02	0,018
2	25,37	25,39	25,42	0,04	0,036

9 ISO 5011:2020, Annex H – Examples on how to implement it

The following are three examples of how Annex H can be used to determine uncertainty in efficiency.

1) Initial efficiency of a heavy-duty engine air element using the absolute filter method (ISO 5011:2020, 7.4)

 A technician is asked to test an element with 1 m^2 of media. The technician reviews ISO 5011:2020, 7.4.3 and determines that 11 g of fed dust is required to determine initial efficiency.

 The technician then calculates the efficiency to be 99,99 % as 0,001 1 g of dust had been collected on the absolute filter. If it was possible to have 100 % certainty that the dust captured on the element and the absolute filter was correct, this would be the end. But during the validation of the absolute filter weighing procedure the lab has found that the technician, after weighing an absolute filter pad three times over three days, found that the same pad had a maximum weight difference of 0,03 g. ISO 5011:2020, Annex H requires that this variation in the absolute filter media is accounted for in the efficiency measurement.

Because the technician measured an efficiency above 95 % and is using the absolute filter method, ISO 5011:2020, Table H.1 can be used to determine the uncertainty in the efficiency using the following procedure.

Figure 10 shows how the technician went down the first column until he/she found a value equal to or larger than 0,03 g (the maximum difference during the absolute filter pad weighing procedure validation).

Then he/she moved right along that row until he/she found the largest weight in the horizontal header row that is less than the total dust fed during the test.

Abs, Filter Measurement criteria (+/-)	Abs, Filter Instrument sigma (δ)	10 g	20 g	30 g	40 g	50 g	100 g
0,01	0,006	0,084 9 %	0,042 4 %	0,028 3 %	0,021 2 %	0,017 %	0,008 5 %
0,02	**0,01**	0,141 4 %	0,070 7 %	0,047 1 %	0,035 4 %	0,028 3 %	0,014 1 %
0,03	**0,018**	0,254 6 %	0,127 3 %	0,084 9 %	0,063 6 %	0,050 9 %	0,025 5 %
0,03	**0,02**	0,282 8 %	0,141 4 %	0,094 3 %	0,070 7 %	0,056 6 %	0,028 3 %
0,05	**0,03**	0,424 3 %	0,212 1 %	0,141 4 %	0,106 1 %	0,084 9 %	0,042 4 %
0,07	**0,04**	0,565 7 %	0,282 8 %	0,188 6 %	0,141 4 %	0,113 1 %	0,056 6 %
0,08	**0,05**	0,707 1 %	0,353 6 %	0,235 7 %	0,176 8 %	0,141 4 %	0,070 7 %
0,1	**0,06**	0,848 5 %	0,424 3 %	0,282 8 %	0,212 1 %	0,169 7 %	0,084 9 %
0,12	**0,07**	0,989 9 %	0,495 %	0,33 %	0,247 5 %	0,198 %	0,099 %
0,13	**0,08**	1,131 4 %	0,565 7 %	0,377 1 %	0,282 8 %	0,226 3 %	0,113 1 %
0,15	**0,09**	1,272 8 %	0,636 4 %	0,424 3 %	0,318 2 %	0,254 6 %	0,127 3 %
0,17	**0,1**	1,414 2 %	0,707 1 %	0,471 4 %	0,353 6 %	0,282 8 %	0,141 4 %
		confidence can be measured only to 99 %					
		Uncertainty in the pene					

Figure 10 — Using ISO 5011:2020, Table H.1 to determine measurement uncertainty

NOTE The table above is not used for an efficiency below 95 %, in that case the technician would need to use Formula H.3 and input δ_a from Table H.1 for the lab's particular absolute filter measurement criteria. δ_D (the uncertainty in the weight of the UUT) is also evaluated in a manner similar to what was used for the absolute (see Figure H.1 on how to do this using a Monte Carlo simulation).

Based on the weights measured, an efficiency of 99,99 % and an uncertainty of ±0,254 6 % is calculated. ISO 5011:2020, Annex H requires that the stated penetration (in this case 0,01 %) is at least twice the value of the uncertainty. The technician realizes that an efficiency of 99,99 % cannot be measured and revises the initial efficiency to be 99 % ± 0,254 6 % which meets the criteria.

One alternative for the technician is to instead measure the initial efficiency of three primary elements while using the same absolute filter and calculate the average. This means a greater amount of dust was fed without changing the uncertainty in the absolute measurement thereby leading to a higher confidence in the results. For this case the dust fed would be 33 g and the technician could use the 30 g column in Table H.1 (Figure 11).

Abs, Filter Measurement criteria (+/-)	Abs, Filter Instrument sigma (δ)	10 g	20 g	30 g	40 g	50 g	100 g
0,01	0,006	0,084 9 %	0,042 4 %	0,028 3 %	0,021 2 %	0,017 %	0,008 5 %
0,02	**0,01**	0,141 4 %	0,070 7 %	0,047 1 %	0,035 4 %	0,028 3 %	0,014 1 %
0,03	**0,018**	0,254 6 %	0,127 3 %	0,084 9 %	0,063 6 %	0,050 9 %	0,025 5 %
0,03	**0,02**	0,282 8 %	0,141 4 %	0,094 3 %	0,070 7 %	0,056 6 %	0,028 3 %
0,05	**0,03**	0,424 3 %	0,212 1 %	0,141 4 %	0,106 1 %	0,084 9 %	0,042 4 %
0,07	**0,04**	0,565 7 %	0,282 8 %	0,188 6 %	0,141 4 %	0,113 1 %	0,056 6 %
0,08	**0,05**	0,707 1 %	0,353 6 %	0,235 7 %	0,176 8 %	0,141 4 %	0,070 7 %
0,1	**0,06**	0,848 5 %	0,424 3 %	0,282 8 %	0,212 1 %	0,169 7 %	0,084 9 %
0,12	**0,07**	0,989 9 %	0,495 %	0,33 %	0,247 5 %	0,198 %	0,099 %
0,13	**0,08**	1,131 4 %	0,565 7 %	0,377 1 %	0,282 8 %	0,226 3 %	0,113 1 %
0,15	**0,09**	1,272 8 %	0,636 4 %	0,424 3 %	0,318 2 %	0,254 6 %	0,127 3 %
0,17	**0,1**	1,414 2 %	0,707 1 %	0,471 4 %	0,353 6 %	0,282 8 %	0,141 4 %
		confidence can be measured only to 99 %					
		Uncertainty in the pene					

Figure 11 — Using ISO 5011:2020, Table H.1 to determine measurement uncertainty

Due to the extra dust fed the technician attempts to state an average initial efficiency for three elements of 99,99 % ± 0,084 9 % as the uncertainty was decreased by a factor of about 3. Unfortunately, the uncertainty is still too large and revises the efficiency once again to 99 %, but this technique could be used in a case where the lab could more precisely measure an absolute weight (within 0,01 g after three measurements), then going from 10 g to 30 g of loading would improve the confidence enough to go from 99 % to 99,9 %.

2) Final efficiency using the absolute filter method.

In this example, a larger filter is used and the technician would like to evaluate for final efficiency. In this case the dust fed is 1 000 g. But due to the large size of the absolute filter this lab can only measure to within 0,08 g difference over three days. The air cleaner system has an efficiency greater than 95 %, so ISO 5011:2020, Table H.1 can once again be used.

Using Figure 12 the technician follows the far-left column and goes down to 0,08, then he/she moves to the right along that row until the column with the header of 1 000 g is reached.

Abs, Filter Measurement criteria (+/-)	Abs, Filter Instrument sigma (δ)	Dust fed																			
		10 g	20 g	30 g	40 g	50 g	100 g	500 g	1 000 g	1 500 g	2 000 g	2 500 g	3 000 g	3 500 g	4 000 g	5 000 g	6 000 g	7 000 g	8 000 g	9 000 g	10 000 g
0,01	0,006	0,084 9 %	0,042 4 %	0,028 3 %	0,021 2 %	0,017 %	0,008 5 %	0,001 7 %	0,000 8 %	0,000 6 %	0,000 4 %	0,000 3 %	0,000 3 %	0,000 2 %	0,000 2 %	0,000 2 %	0,000 1 %	0,000 1 %	0,000 1 %	0,000 1 %	0,000 1 %
0,02	**0,01**	0,141 4 %	0,070 7 %	0,047 1 %	0,035 4 %	0,028 3 %	0,014 1 %	0,002 8 %	0,001 4 %	0,000 9 %	0,000 7 %	0,000 6 %	0,000 5 %	0,000 4 %	0,000 4 %	0,000 3 %	0,000 2 %	0,000 2 %	0,000 2 %	0,000 2 %	0,000 1 %
0,03	**0,018**	0,254 6 %	0,127 3 %	0,084 9 %	0,063 6 %	0,050 9 %	0,025 5 %	0,005 1 %	0,002 5 %	0,001 7 %	0,001 3 %	0,001 %	0,000 8 %	0,000 7 %	0,000 6 %	0,000 5 %	0,000 4 %	0,000 4 %	0,000 3 %	0,000 3 %	0,000 3 %
0,03	**0,02**	0,282 8 %	0,141 4 %	0,094 3 %	0,070 7 %	0,056 6 %	0,028 3 %	0,005 7 %	0,002 8 %	0,001 9 %	0,001 4 %	0,001 1 %	0,000 9 %	0,000 8 %	0,000 7 %	0,000 6 %	0,000 5 %	0,000 4 %	0,000 4 %	0,000 3 %	0,000 3 %
0,05	**0,03**	0,424 3 %	0,212 1 %	0,141 4 %	0,106 1 %	0,084 9 %	0,042 4 %	0,008 5 %	0,004 2 %	0,002 8 %	0,002 1 %	0,001 7 %	0,001 4 %	0,001 2 %	0,001 1 %	0,000 8 %	0,000 7 %	0,000 6 %	0,000 5 %	0,000 5 %	0,000 4 %
0,07	**0,04**	0,565 7 %	0,282 8 %	0,188 6 %	0,141 4 %	0,113 1 %	0,056 6 %	0,011 3 %	0,005 7 %	0,003 8 %	0,002 8 %	0,002 3 %	0,001 9 %	0,001 6 %	0,001 4 %	0,001 1 %	0,000 9 %	0,000 8 %	0,000 7 %	0,000 6 %	0,000 6 %
0,08	**0,05**	0,707 1 %	0,353 6 %	0,235 7 %	0,176 8 %	0,141 4 %	0,070 7 %	0,014 1 %	0,007 1 %	0,004 7 %	0,003 5 %	0,002 8 %	0,002 4 %	0,002 %	0,001 8 %	0,001 4 %	0,001 2 %	0,001 %	0,000 9 %	0,000 8 %	0,000 7 %
0,1	**0,06**	0,848 5 %	0,424 3 %	0,282 8 %	0,212 1 %	0,169 7 %	0,084 9 %	0,017 %	0,008 5 %	0,005 7 %	0,004 2 %	0,003 4 %	0,002 8 %	0,002 4 %	0,002 1 %	0,001 7 %	0,001 4 %	0,001 2 %	0,001 1 %	0,000 9 %	0,000 8 %
0,12	**0,07**	0,989 9 %	0,495 %	0,33 %	0,247 5 %	0,198 %	0,099 %	0,019 8 %	0,009 9 %	0,006 6 %	0,004 9 %	0,004 %	0,003 3 %	0,002 8 %	0,002 5 %	0,002 %	0,001 6 %	0,001 4 %	0,001 2 %	0,001 1 %	0,001 %
0,13	**0,08**	1,131 4 %	0,565 7 %	0,377 1 %	0,282 8 %	0,226 3 %	0,113 1 %	0,022 6 %	0,011 3 %	0,007 5 %	0,005 7 %	0,004 5 %	0,003 8 %	0,003 2 %	0,002 8 %	0,002 3 %	0,001 9 %	0,001 6 %	0,001 4 %	0,001 3 %	0,001 1 %
0,15	**0,09**	1,272 8 %	0,636 4 %	0,424 3 %	0,318 2 %	0,254 6 %	0,127 3 %	0,025 5 %	0,012 7 %	0,008 5 %	0,006 4 %	0,005 1 %	0,004 2 %	0,003 6 %	0,003 2 %	0,002 5 %	0,002 1 %	0,001 8 %	0,001 6 %	0,001 4 %	0,001 3 %
0,17	**0,1**	1,414 2 %	0,707 1 %	0,471 4 %	0,353 6 %	0,282 8 %	0,141 4 %	0,028 3 %	0,014 1 %	0,009 4 %	0,007 1 %	0,005 7 %	0,004 7 %	0,004 %	0,003 5 %	0,002 8 %	0,002 4 %	0,002 %	0,001 8 %	0,001 6 %	0,001 4 %
		confidence can be measured only to 99 %						confidence can be measured up to 99,9 %					confidence can be measured to four 9s efficiency (i.e. 99,99 %)								
		Uncertainty in the penetration assuming we know the dust fed exactly (uncertainty only in the absolute filter weight)																			

Figure 12 — Using ISO 5011:2020, Table H.1 to determine measurement uncertainty

Even though the technician measured an efficiency of 99,99 %, including the uncertainty found in this table gives an efficiency of 99,99 % ± 0,0071 %. The uncertainty is greater than 50 % of the penetration of 0,01 % so it cannot be stated that this efficiency is met, and the efficiency value would need to be restated as 99,9% ± 0,0071 %. This case would be a perfect example of where a technician might want to run the average of 2 or 3 elements in order to reduce the uncertainty and state a higher efficiency value as an extra 500 g of dust fed would allow the efficiency to be stated to 99,99 %.

3) Final efficiency using the absolute filter method (mining element)

While measuring efficiency for a very large mining truck element for final efficiency, the final dust fed is 10,000 g and the maximum difference in the absolute filter measurement is 0,05 g.

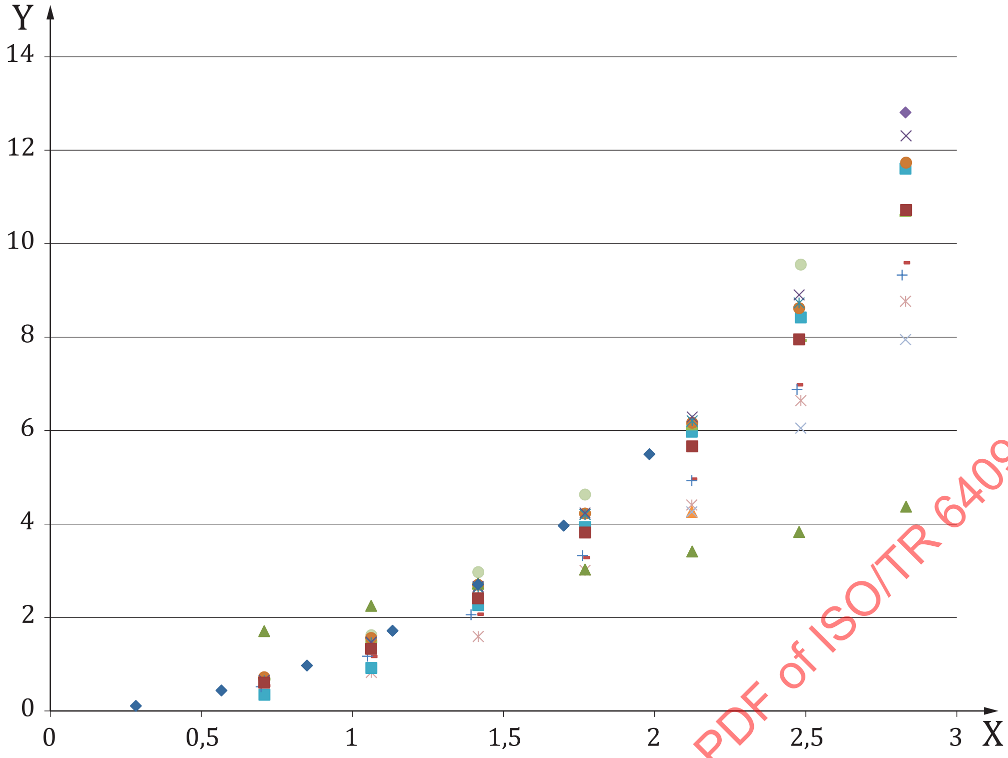
Figure 13 shows how the technician follows the first column on the left and goes down to 0,05 g, then he/she moves to the right along that row until the column with the header of 10, 000 g is reached. The highest efficiency that can be stated here is 99,999 % ± 0,0004 % based on the criteria of ISO 5011:2020, Annex H.

Abs, Filter Measurement criteria (+/-)	Abs, Filter Instrument sigma (δ)	Dust fed																			
		10 g	**20 g**	**30 g**	**40 g**	**50 g**	**100 g**	**500 g**	**1 000 g**	**1 500 g**	**2 000 g**	**2 500 g**	**3 000 g**	**3 500 g**	**4 000 g**	**5 000 g**	**6 000 g**	**7 000 g**	**8 000 g**	**9 000 g**	**10 000 g**
0,01	0,006	0,084 9 %	0,042 4 %	0,028 3 %	0,021 2 %	0,017 %	0,008 5 %	0,001 7 %	0,000 8 %	0,000 6 %	0,000 4 %	0,000 3 %	0,000 3 %	0,000 2 %	0,000 2 %	0,000 2 %	0,000 1 %	0,000 1 %	0,000 1 %	0,000 1 %	0,000 1 %
0,02	**0,01**	0,141 4 %	0,070 7 %	0,047 1 %	0,035 4 %	0,028 3 %	0,014 1 %	0,002 8 %	0,001 4 %	0,000 9 %	0,000 7 %	0,000 6 %	0,000 5 %	0,000 4 %	0,000 4 %	0,000 3 %	0,000 2 %	0,000 2 %	0,000 2 %	0,000 2 %	0,000 1 %
0,03	**0,018**	0,254 6 %	0,127 3 %	0,084 9 %	0,063 6 %	0,050 9 %	0,025 5 %	0,005 1 %	0,002 5 %	0,001 7 %	0,001 3 %	0,001 %	0,000 8 %	0,000 7 %	0,000 6 %	0,000 5 %	0,000 4 %	0,000 4 %	0,000 3 %	0,000 3 %	0,000 3 %
0,03	**0,02**	0,282 8 %	0,141 4 %	0,094 3 %	0,070 7 %	0,056 6 %	0,028 3 %	0,005 7 %	0,002 8 %	0,001 9 %	0,001 4 %	0,001 1 %	0,000 9 %	0,000 8 %	0,000 7 %	0,000 6 %	0,000 5 %	0,000 4 %	0,000 4 %	0,000 3 %	0,000 3 %
0,05	**0,03**	0,424 3 %	0,212 1 %	0,141 4 %	0,106 1 %	0,084 9 %	0,042 4 %	0,008 5 %	0,004 2 %	0,002 8 %	0,002 1 %	0,001 7 %	0,001 4 %	0,001 2 %	0,001 1 %	0,000 8 %	0,000 7 %	0,000 6 %	0,000 5 %	0,000 5 %	0,000 4 %
0,07	**0,04**	0,565 7 %	0,282 8 %	0,188 6 %	0,141 4 %	0,113 1 %	0,056 6 %	0,011 3 %	0,005 7 %	0,003 8 %	0,002 8 %	0,002 3 %	0,001 9 %	0,001 6 %	0,001 4 %	0,001 1 %	0,000 9 %	0,000 8 %	0,000 7 %	0,000 6 %	0,000 6 %
0,08	**0,05**	0,707 1 %	0,353 6 %	0,235 7 %	0,176 8 %	0,141 4 %	0,070 7 %	0,014 1 %	0,007 1 %	0,004 7 %	0,003 5 %	0,002 8 %	0,002 4 %	0,002 %	0,001 8 %	0,001 4 %	0,001 2 %	0,001 %	0,000 9 %	0,000 8 %	0,000 7 %
0,1	**0,06**	0,848 5 %	0,424 3 %	0,282 8 %	0,212 1 %	0,169 7 %	0,084 9 %	0,017 %	0,008 5 %	0,005 7 %	0,004 2 %	0,003 4 %	0,002 8 %	0,002 4 %	0,002 1 %	0,001 7 %	0,001 4 %	0,001 2 %	0,001 1 %	0,000 9 %	0,000 8 %
0,12	**0,07**	0,989 9 %	0,495 %	0,33 %	0,247 5 %	0,198 %	0,099 %	0,019 8 %	0,009 9 %	0,006 6 %	0,004 9 %	0,004 %	0,003 3 %	0,002 8 %	0,002 5 %	0,002 %	0,001 6 %	0,001 4 %	0,001 2 %	0,001 1 %	0,001 %
0,13	**0,08**	1,131 4 %	0,565 7 %	0,377 1 %	0,282 8 %	0,226 3 %	0,113 1 %	0,022 6 %	0,011 3 %	0,007 5 %	0,005 7 %	0,004 5 %	0,003 8 %	0,003 2 %	0,002 8 %	0,002 3 %	0,001 9 %	0,001 6 %	0,001 4 %	0,001 3 %	0,001 1 %
0,15	**0,09**	1,272 8 %	0,636 4 %	0,424 3 %	0,318 2 %	0,254 6 %	0,127 3 %	0,025 5 %	0,012 7 %	0,008 5 %	0,006 4 %	0,005 1 %	0,004 2 %	0,003 6 %	0,003 2 %	0,002 5 %	0,002 1 %	0,001 8 %	0,001 6 %	0,001 4 %	0,001 3 %
0,17	**0,1**	1,414 2 %	0,707 1 %	0,471 4 %	0,353 6 %	0,282 8 %	0,141 4 %	0,028 3 %	0,014 1 %	0,009 4 %	0,007 1 %	0,005 7 %	0,004 7 %	0,004 %	0,003 5 %	0,002 8 %	0,002 4 %	0,002 %	0,001 8 %	0,001 6 %	0,001 4 %
		confidence can be measured only to 99 %						confidence can be measured up to 99,9 %					confidence can be measured to four 9s efficiency (i.e. 99,99 %)								
		Uncertainty in the penetration assuming we know the dust fed exactly (uncertainty only in the absolute filter weight)																			

Figure 13 — Using ISO 5011:2020, Table H.1 to determine measurement uncertainty

10 Orifice flow test round robin results

In 2013, a round robin was completed with a variety of different test sites. The test involved four different orifices, depending on the lab/test stand capabilities. Each lab tested at the given round robin flow test points and report a restriction at each flow point. Below is a summary of the four different orifices (Figures 14, 15, 16, and 17).



Key

X air flow [m³/min]

Y restriction [kPa]

Figure 14 — 0,825" orifice – 16 laboratory test stands