## Routine Analytical Chemistry Sub-Group

# Technical Report

# Collaborative Study on the Suitability of Certain Substrates for the Ignition Propensity Test According to ISO12863:2010

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# 1. Introduction

## 1.1 Purpose and Scope

For testing the ignition propensity of cigarettes ISO 12863:2010 describes a method which requires placing lit cigarettes on a defined substrate and counting the number of cigarettes which burn to or past the front plane of the tipping paper (filter tip cigarettes) or past the tips of the metal pins for non-filter tip cigarettes (Full Length Burn, FLB) without extinguishing by themselves. The substrate on which the cigarettes are to be placed consists of 3, 10 or 15 layers of filter paper with a diameter of 150 mm. The filter paper is described in section 7.3.2 of ISO 12863 by specifying the mean and standard deviation of the mass of 15 sheets of the filter paper in a conditioned and a dried state. More particularly Whatman No.2 cellulosic filter paper is given as an example of a suitable filter paper.

For other types of filter paper, the properties of the paper that need to be controlled can be different from those for the Whatman No. 2 paper, and the mass requirements of section 7.3.2 of ISO 12863 can also be different from those for the Whatman No. 2 paper. Therefore, CORESTA was asked by ISO/TC92/SC1/WG15 to evaluate paper substrates for their suitability in the ignition propensity test.

Thus the RAC Sub-Group conducted a large international collaborative study to evaluate the efficacy, stability and reliability of four paper substrates in the ignition propensity test according to ISO 12863. The results of this study may also be used as a basis to optimise standard specifications for paper substrates used in this test. Laboratories of members in ISO/TC92/SC1/WG15 were invited and participated in the study.

All results regarding laboratories and paper substrates will be presented in anonymized form.

## 1.2 Study Protocol

The test protocol used for this collaborative study is given in Appendix A and will be briefly summarized below.

The participants were asked to measure the ignition propensity of three different test pieces on four different paper substrates in accordance with ISO 12863:2010. Each replicate consisted of testing 40 test pieces on 10 layers of the paper substrate and five replicates were to be made, each on a different day, for each combination of test piece and substrate, resulting in a total of 12 different test piece/substrate combinations and thus 60 tests of ignition propensity in total.

The laboratories had to report, on a per replicate base, the number of tested pieces, the number of test pieces which self-extinguished in the holder, the number of test pieces which self-extinguished on the substrate, and the number of test pieces which exhibited full length burn, i.e. which did not self-extinguish on the substrate.

The protocol and the testing materials were distributed in May and June 2018 and the measurements were to be completed until August 31$^{st}$, 2018. All data sets that were received were used for the statistical evaluation, which was done in two ways. First the data were evaluated to compare the different paper substrates and second the repeatability and reproducibility were calculated for each test piece/substrate combination.

## 1.3 Materials

For this collaborative study three different test pieces were used as given in Table 1. In addition to two standard test pieces, CORESTA Monitor IP 2 and the NIST Standard, a third test piece, Test Product 1.0, was used. Test Product 1.0 was specifically developed for this study to achieve a comparably high rate of FLB to be able to cover the relevant range of FLB and to increase the sensitivity of the comparison of the substrates.

The data on lengths and band geometry in Table 1 are not actually measured values but represent typical or specified product properties. The rates of FLB were taken from collaborative studies of the RAC Sub-Group on the stability of the CORESTA Ignition Propensity Monitor and the NIST Standard. For the test Product 1.0 the data were taken from preliminary laboratory trials as shown in Table 1.

**Table 1. Coding of test pieces and their main specifications**.

| **Test Piece** | | | | | | **Code** |
|---|---|---|---|---|---|---|
| CORESTA Ignition Propensity Approved Monitor No. 2 | | | | | | CM IP2 |
| NIST® SRM® 1082 Cigarette ignition strength standard | | | | | | NIST |
| Test Product 1.0 | | | | | | TP1.0 |
| **Test piece Data** | | | | | | |
| | Length | | | Bands | | |
| Code | Test Piece | Tipping | Diameter | Width | Spacing | Full Length Burn |
| | mm | mm | mm | mm | mm | % |
| CM IP2 | 83 | 25 | 7,9 | 3/1/3 | 20 | 3,2 |
| NIST | 98 | 32 | 7,9 | None | | 12,6 |
| TP1.0 | 83 | 26 | 7,7 | 6 | 18 | 57,5 |

The CORESTA Monitor IP 2 test piece had 7 mm wide bands with a specific design consisting of two narrow 3 mm bands separated by a gap of 1 mm. The spacing between bands given in Table 1 is the distance from the trailing edge of one band to the leading edge of the next band.

The test piece TP 1.0 was distributed by the study coordinator, while laboratories had to use the CORESTA IP Monitor No. 2 and the NIST Standards from their own stock. Each laboratory thus received at least 4 (papers) × 5 (replicates) × 40 (test pieces per replicate) = 800 test pieces TP 1.0.

Four paper substrates were used in this study. They were manufactured by GE Healthcare, USA, delfortgroup AG, Austria, Macherey-Nagel GmbH & Co KG, Germany and Hahnemühle FineArt GmbH, Germany. The paper substrates were randomly assigned the codes P1, P2, P3 and P4. The properties of the paper substrates were not measured as the only criterion for their suitability in the ignition propensity test according to ISO 12863:2010 is that

*they can be shown to lead to the same test results,*

and as ISO 12863 explicitly allows that they can deviate in their properties from the Whatman No. 2 filter paper. Detailed information on the alternative paper substrates can be obtained from CORESTA.

## 1.4 Study Participants

In total 18 laboratories took part in the study as listed in Table 3 in alphabetical order. Each laboratory was assigned a unique code from A to R, thus the order of laboratories in other tables does not match the order given in Table 2.

**Table 2. List of Participants**

| Participant Name | Country |
|---|---|
| Altria Client Services | USA |
| British American Tobacco | Brazil |
| British American Tobacco | Germany |
| British American Tobacco | Indonesia |
| British American Tobacco | Korea |
| British American Tobacco | Poland |
| delfort | Austria |
| Global Laboratory Services, Inc. | USA |
| Imperial Tobacco / Reemtsma | Germany |
| ITG Brands | USA |
| Japan Tobacco Inc. | Japan |
| Japan Tobacco International | Germany |
| KT&G Corp. | Korea |
| Landewyck Tobacco S.A. | Luxembourg |
| Monte Paz S.A. | Uruguay |
| Philip Morris International | Germany |
| Philip Morris International | Poland |
| R.J. Reynolds Tobacco Company | USA |

# 2. Comparison of Substrates

## 2.1 Introduction and Raw Data

For the comparison of substrates an important difference to the normal reporting of the ignition propensity as described in ISO 12863:2010 has to be noted. The ignition propensity as reported according to ISO 12863 is the fraction of cigarettes that exhibited FLB to the number of cigarettes, normally 40, that have been tested. The number of tested cigarettes includes those that have been placed on the substrate and those that self-extinguished in the holder before being placed on a substrate. However, when one wants to investigate the effect of different substrates, the test pieces that self-extinguished in the holder never came into contact with the substrate and thus do not contain any information about it. Thus in order to avoid introducing additional variability in the data, for the comparison of substrates only those test pieces were considered which actually came into contact with the substrate. This number of test pieces is abbreviated as $N_{ToS}$ (Tested on Substrate) to differentiate it from the total number of tested pieces ($N_{Tot}$). The number of test pieces that burnt to their full length will be designated as $N_{FLB}$.

Not all laboratories reported the full data set. Laboratory B did not test CM IP 2, laboratories K and R did not test NIST Standards and laboratory M made only two instead of five replicates for all test piece/substrate combinations.

The full data set is shown graphically in Appendix B.

Tables 3a-c show, for all laboratories and all test piece/substrate combinations the mean value and the standard deviation of the ratio $N_{FLB}/N_{ToS}$ expressed as a percentage and the number of replicates, nominally 5, from which mean value and standard deviation were calculated.

**Table 3a. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{ToS}$ in percent for the CORESTA Monitor IP 2 and the four substrates.**

| | CORESTA Monitor IP 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 2,0 | 3,1 | 5 | 5,2 | 4,4 | 5 | 2,5 | 1,4 | 5 | 3,4 | 3,5 | 5 |
| B | | | | | | | | | | | | |
| C | 2,1 | 2,3 | 5 | 3,7 | 2,4 | 5 | 4,1 | 2,2 | 5 | 5,0 | 2,3 | 5 |
| D | 17,9 | 3,5 | 5 | 17,8 | 6,0 | 5 | 22,5 | 5,5 | 5 | 19,2 | 9,0 | 5 |
| E | 3,7 | 3,0 | 5 | 4,0 | 1,4 | 5 | 2,6 | 3,2 | 5 | 4,2 | 4,0 | 5 |
| F | 4,6 | 2,1 | 5 | 5,2 | 3,7 | 5 | 3,5 | 2,9 | 5 | 2,5 | 4,3 | 5 |
| G | 2,0 | 2,1 | 5 | 8,2 | 3,8 | 5 | 4,2 | 3,5 | 5 | 2,1 | 2,2 | 5 |
| H | 12,0 | 7,6 | 5 | 2,0 | 2,1 | 5 | 2,5 | 2,5 | 5 | 0,0 | 0,0 | 5 |
| I | 1,7 | 2,6 | 5 | 1,1 | 1,5 | 5 | 2,7 | 1,9 | 5 | 1,6 | 1,4 | 5 |
| J | 2,6 | 2,6 | 5 | 1,6 | 2,5 | 5 | 3,1 | 2,1 | 5 | 2,7 | 2,7 | 5 |
| K | 6,8 | 3,2 | 5 | 3,9 | 3,2 | 5 | 3,4 | 2,8 | 5 | 4,5 | 2,5 | 5 |
| L | 1,5 | 2,2 | 5 | 1,5 | 1,4 | 5 | 3,0 | 3,3 | 5 | 3,0 | 2,7 | 5 |
| M | 4,1 | 2,0 | 2 | 8,3 | 0,3 | 2 | 7,8 | 3,4 | 2 | 4,1 | 1,9 | 2 |
| N | 6,1 | 5,8 | 5 | 4,1 | 3,4 | 5 | 2,6 | 1,8 | 5 | 5,1 | 3,2 | 5 |
| O | 3,2 | 3,3 | 5 | 2,6 | 3,8 | 5 | 4,3 | 1,4 | 5 | 3,6 | 3,0 | 5 |
| P | 6,7 | 1,4 | 5 | 5,1 | 0,1 | 5 | 9,9 | 2,2 | 5 | 8,2 | 4,5 | 5 |
| Q | 5,2 | 4,2 | 5 | 4,8 | 2,2 | 5 | 3,1 | 1,1 | 5 | 1,5 | 1,4 | 5 |
| R | 8,5 | 5,2 | 5 | 8,1 | 6,9 | 5 | 6,5 | 3,8 | 5 | 4,1 | 2,9 | 5 |

**Table 3b. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{ToS}$ in percent for the NIST Standard and the four substrates.**

| | NIST Cigarette Ignition Strength Standard | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 4,5 | 7,2 | 5 | 4,0 | 5,7 | 5 | 3,8 | 2,5 | 5 | 2,5 | 4,2 | 5 |
| B | 9,0 | 4,2 | 5 | 8,5 | 4,2 | 5 | 9,0 | 3,4 | 5 | 5,5 | 2,7 | 5 |
| C | 1,5 | 2,3 | 5 | 6,5 | 3,8 | 5 | 5,5 | 5,1 | 5 | 3,5 | 3,8 | 5 |
| D | 1,2 | 1,7 | 5 | 10,6 | 2,3 | 5 | 10,9 | 4,9 | 5 | 4,9 | 3,7 | 5 |

| | NIST Cigarette Ignition Strength Standard | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| E | 11,0 | 3,4 | 5 | 15,5 | 5,4 | 5 | 14,5 | 7,2 | 5 | 8,5 | 5,7 | 5 |
| F | 19,1 | 5,9 | 5 | 38,5 | 2,9 | 5 | 31,5 | 7,4 | 5 | 19,5 | 8,2 | 5 |
| G | 3,1 | 3,3 | 5 | 4,1 | 2,9 | 5 | 6,1 | 5,2 | 5 | 3,1 | 3,2 | 5 |
| H | 6,0 | 3,8 | 5 | 6,0 | 2,9 | 5 | 11,0 | 3,8 | 5 | 7,0 | 2,1 | 5 |
| I | 17,5 | 2,5 | 5 | 15,3 | 4,5 | 5 | 12,0 | 10,2 | 5 | 15,5 | 5,4 | 5 |
| J | 3,5 | 2,8 | 5 | 0,0 | 0,0 | 5 | 2,5 | 3,6 | 5 | 4,0 | 3,8 | 5 |
| K | | | | | | | | | | | | |
| L | 4,0 | 2,9 | 5 | 3,5 | 2,9 | 5 | 9,0 | 7,2 | 5 | 4,0 | 2,9 | 5 |
| M | 8,8 | 5,3 | 2 | 11,3 | 5,3 | 2 | 13,8 | 1,8 | 2 | 10,0 | 3,5 | 2 |
| N | 7,5 | 4,0 | 5 | 15,5 | 7,4 | 5 | 14,5 | 6,0 | 5 | 8,0 | 3,7 | 5 |
| O | 1,5 | 2,2 | 5 | 6,0 | 4,5 | 5 | 3,5 | 5,2 | 5 | 3,0 | 3,3 | 5 |
| P | 6,0 | 1,4 | 5 | 8,0 | 7,6 | 5 | 6,0 | 1,4 | 5 | 10,0 | 5,6 | 5 |
| Q | 8,1 | 2,2 | 5 | 7,0 | 3,3 | 5 | 5,0 | 1,8 | 5 | 5,5 | 2,1 | 5 |
| R | | | | | | | | | | | | |

**Table 3c. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{ToS}$ in percent for the Test Product 1.0 and the four substrates.**

| | Test Product 1.0 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 38,0 | 10,8 | 5 | 40,8 | 10,1 | 5 | 47,2 | 8,9 | 5 | 47,0 | 4,1 | 5 |
| B | 67,5 | 4,3 | 5 | 66,5 | 5,5 | 5 | 68,5 | 4,2 | 5 | 55,5 | 10,1 | 5 |
| C | 73,9 | 8,6 | 5 | 83,9 | 6,2 | 5 | 83,0 | 5,4 | 5 | 67,0 | 11,4 | 5 |
| D | 77,0 | 1,1 | 5 | 74,4 | 9,3 | 5 | 83,5 | 9,1 | 5 | 80,5 | 3,3 | 5 |
| E | 62,0 | 14,7 | 5 | 61,0 | 2,9 | 5 | 68,5 | 7,6 | 5 | 60,8 | 5,2 | 5 |
| F | 69,5 | 6,7 | 5 | 81,5 | 4,5 | 5 | 72,0 | 10,8 | 5 | 64,0 | 5,8 | 5 |
| G | 65,5 | 6,5 | 5 | 62,0 | 8,2 | 5 | 57,5 | 14,6 | 5 | 59,3 | 9,0 | 5 |
| H | 65,2 | 9,1 | 5 | 55,8 | 7,6 | 5 | 69,0 | 5,8 | 5 | 61,5 | 8,9 | 5 |
| I | 64,5 | 12,7 | 5 | 72,5 | 6,4 | 5 | 70,0 | 8,8 | 5 | 56,5 | 9,1 | 5 |
| J | 64,0 | 11,9 | 5 | 66,5 | 5,8 | 5 | 62,0 | 10,8 | 5 | 59,5 | 12,7 | 5 |
| K | 57,5 | 9,3 | 5 | 65,6 | 6,1 | 5 | 56,0 | 6,8 | 5 | 61,0 | 11,3 | 5 |
| L | 59,5 | 8,4 | 5 | 57,0 | 5,1 | 5 | 68,5 | 5,2 | 5 | 66,5 | 5,5 | 5 |
| M | 58,8 | 5,3 | 2 | 57,5 | 3,5 | 2 | 68,8 | 1,8 | 2 | 60,0 | 3,5 | 2 |
| N | 63,0 | 2,7 | 5 | 64,0 | 7,4 | 5 | 57,5 | 9,2 | 5 | 55,8 | 11,5 | 5 |
| O | 55,0 | 5,3 | 5 | 61,0 | 11,9 | 5 | 60,0 | 12,7 | 5 | 62,0 | 7,4 | 5 |
| P | 66,0 | 4,9 | 5 | 69,0 | 8,0 | 5 | 71,5 | 4,2 | 5 | 67,5 | 9,8 | 5 |
| Q | 57,0 | 8,9 | 5 | 61,5 | 4,9 | 5 | 66,0 | 4,5 | 5 | 56,5 | 7,8 | 5 |
| R | 56,0 | 8,2 | 5 | 58,0 | 6,2 | 5 | 62,0 | 11,2 | 5 | 60,0 | 10,8 | 5 |

## 2.2 Outlier Analysis and Removal

When $N_{ToS}$ test pieces are tested on the substrate and we assume that the probability for a full length burn, $p_{FLB}$, is the same for each test piece, the number of test pieces that exhibit FLB, $N_{FLB}$, is binomially distributed according to $B_{pFLB,NToS}$. Often the binomial distribution can be approximated by a normal distribution $N_{\mu,\sigma^2}$, with $\mu = N_{ToS} \cdot p_{FLB}$ and $\sigma^2 = N_{ToS} \cdot p_{FLB} \cdot (1-p_{FLB})$. However on a replicate basis with $N_{ToS} \approx 40$ and small $p_{FLB}$ the use of a normal distribution introduces substantial errors. Thus on a replicate basis a binomial distribution will be used, while for the data aggregated over all laboratories with $N_{ToS} \approx 3000$ the normal distribution provides a very good approximation.

As Cochran's test and Grubb's test, which are frequently used for outlier testing, for example in ISO 5725-2, rely on normally distributed data, they will not be used for outlier testing in this study. Rather the following approach is adopted.

By aggregating the data over all laboratories for a specific test piece/substrate combination the rate of FLB, $r_{FLB,}$ can be estimated by

$$r_{FLB} = \frac{\sum N_{FLB}}{\sum N_{ToS}}$$

wherein the sum is to be understood over all laboratories and all replicates for a specific test piece/substrate combination and with

$N_{FLB}$ the number of test pieces that burnt their full length in a replicate test,

$N_{ToS}$ the number of test pieces that were in contact with the substrate in this replicate test.

Thus the expected number of FLB for each replicate is $r_{FLB} \cdot N_{ToS}$ and if, based on the binomial distribution, the deviation of the observed value $N_{FLB}$ from the expected value is so large that the probability for obtaining this or a larger deviation is less than 1 % the replicate is considered an outlier and is removed.

Once this is done the rate of FLB is again estimated by

$$r'_{FLB} = \frac{\sum' N_{FLB}}{\sum' N_{ToS}}$$

wherein by ' it is indicated that the sum is now to be understood over all laboratories and all replicates for a specific test piece/substrate combination that have not been identified as outliers. Again outlier testing is done according to the above procedure and r'$_{FLB}$ is updated. After this second round of outlier elimination no further outliers were detected.

Table 4 shows which replicates were eliminated as outliers and Tables 5a-c show - after elimination of outliers -, for all laboratories and all test piece/substrate combinations the mean value and the standard deviation of the ratio $N_{FLB}/N_{ToS}$ expressed as a percentage and the number of remaining replicates, nominally 5, from which mean value and standard deviation were calculated.

**Table 4. Replicates (1, 2, …, 5) that were eliminated as outliers.**

| | CM IP 2 | | | | NIST | | | | TP1.0 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | P1 | P2 | P3 | P4 | P1 | P2 | P3 | P4 | P1 | P2 | P3 | P4 |
| A | | | | | 1 | | | | 3,4 | 2-4 | 2 | |
| B | | | | | | | | | | | | |
| C | | | | | | | | | 1 | 1,2,4 | 1,2 | 4 |
| D | 1-5 | 1,3-5 | 1-5 | 1,3,5 | | | | | | 1 | 1,3-5 | 1-3,5 |
| E | | | | | | 2,4 | 2,4 | 3 | | | | |
| F | | | | | 1,2,4 | 1-5 | 1-5 | 1,2,4,5 | | 1,3 | 5 | |
| G | | 3 | | | | | | | | | 1,4 | |
| H | 1,3,5 | | | | | | | | | | | |
| I | | | | | 1,3,5 | 2 | 4,5 | 1,4,5 | 1 | 5 | | |
| J | | | | | | | | | 5 | | 2 | |
| K | | | | | | | | | | | 1 | |
| L | | | | | | | 5 | | | | | |
| M | | | | | | | | | | | | |
| N | 3 | | | | | 4 | | | | | 4 | |
| O | | | | | | | | | | | | |
| P | | | 5 | 2 | | 4 | | 5 | | | | 2 |
| Q | | | | | | | | | | | | |
| R | | 1 | 1 | | | | | | | | | |

**Table 5a. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{ToS}$ in percent for the CORESTA Monitor IP 2, after elimination of outliers.**

| | CORESTA Monitor IP 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 2,0 | 3,1 | 5 | 5,2 | 4,4 | 5 | 2,5 | 1,4 | 5 | 3,4 | 3,5 | 5 |
| B | | | | | | | | | | | | |
| C | 2,1 | 2,3 | 5 | 3,7 | 2,4 | 5 | 4,1 | 2,2 | 5 | 5,0 | 2,3 | 5 |
| D | | | 0 | 10,8 | | 1 | | | 0 | 10,4 | 0,2 | 2 |
| E | 3,7 | 3,0 | 5 | 4,0 | 1,4 | 5 | 2,6 | 3,2 | 5 | 4,2 | 4,0 | 5 |
| F | 4,6 | 2,1 | 5 | 5,2 | 3,7 | 5 | 3,5 | 2,9 | 5 | 2,5 | 4,3 | 5 |
| G | 2,0 | 2,1 | 5 | 7,1 | 3,2 | 4 | 4,2 | 3,5 | 5 | 2,1 | 2,2 | 5 |
| H | 5,0 | 7,1 | 2 | 2,0 | 2,1 | 5 | 2,5 | 2,5 | 5 | 0,0 | 0,0 | 5 |
| I | 1,7 | 2,6 | 5 | 1,1 | 1,5 | 5 | 2,7 | 1,9 | 5 | 1,6 | 1,4 | 5 |
| J | 2,6 | 2,6 | 5 | 1,6 | 2,5 | 5 | 3,1 | 2,1 | 5 | 2,7 | 2,7 | 5 |
| K | 6,8 | 3,2 | 5 | 3,9 | 3,2 | 5 | 3,4 | 2,8 | 5 | 4,5 | 2,5 | 5 |

| | CORESTA Monitor IP 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| L | 1,5 | 2,2 | 5 | 1,5 | 1,4 | 5 | 3,0 | 3,3 | 5 | 3,0 | 2,7 | 5 |
| M | 4,1 | 2,0 | 2 | 8,3 | 0,3 | 2 | 7,8 | 3,4 | 2 | 4,1 | 1,9 | 2 |
| N | 3,8 | 3,3 | 4 | 4,1 | 3,4 | 5 | 2,6 | 1,8 | 5 | 5,1 | 3,2 | 5 |
| O | 3,2 | 3,3 | 5 | 2,6 | 3,8 | 5 | 4,3 | 1,4 | 5 | 3,6 | 3,0 | 5 |
| P | 6,7 | 1,4 | 5 | 5,1 | 0,1 | 5 | 9,1 | 1,6 | 4 | 6,5 | 2,7 | 4 |
| Q | 5,2 | 4,2 | 5 | 4,8 | 2,2 | 5 | 3,1 | 1,1 | 5 | 1,5 | 1,4 | 5 |
| R | 8,5 | 5,2 | 5 | 5,1 | 2,1 | 4 | 5,0 | 2,0 | 4 | 4,1 | 2,9 | 5 |

**Table 5b. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{ToS}$ in percent for the NIST Standard, after elimination of outliers.**

| | NIST Cigarette Ignition Strength Standard | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 1,4 | 1,6 | 4 | 4,0 | 5,7 | 5 | 3,8 | 2,5 | 5 | 2,5 | 4,2 | 5 |
| B | 9,0 | 4,2 | 5 | 8,5 | 4,2 | 5 | 9,0 | 3,4 | 5 | 5,5 | 2,7 | 5 |
| C | 1,5 | 2,3 | 5 | 6,5 | 3,8 | 5 | 5,5 | 5,1 | 5 | 3,5 | 3,8 | 5 |
| D | 1,2 | 1,7 | 5 | 10,6 | 2,3 | 5 | 10,9 | 4,9 | 5 | 4,9 | 3,7 | 5 |
| E | 11,0 | 3,4 | 5 | 11,7 | 1,4 | 3 | 10,0 | 5,0 | 3 | 6,3 | 3,3 | 4 |
| F | 12,7 | 0,2 | 2 | | | 0 | | | 0 | 7,5 | | 1 |
| G | 3,1 | 3,3 | 5 | 4,1 | 2,9 | 5 | 6,1 | 5,2 | 5 | 3,1 | 3,2 | 5 |
| H | 6,0 | 3,8 | 5 | 6,0 | 2,9 | 5 | 11,0 | 3,8 | 5 | 7,0 | 2,1 | 5 |
| I | 15,0 | 0,0 | 2 | 13,5 | 2,4 | 4 | 5,0 | 4,3 | 3 | 10,0 | 3,5 | 2 |
| J | 3,5 | 2,8 | 5 | 0,0 | 0,0 | 5 | 2,5 | 3,6 | 5 | 4,0 | 3,8 | 5 |
| K | | | | | | | | | | | | |
| L | 4,0 | 2,9 | 5 | 3,5 | 2,9 | 5 | 6,3 | 4,3 | 4 | 4,0 | 2,9 | 5 |
| M | 8,8 | 5,3 | 2 | 11,3 | 5,3 | 2 | 13,8 | 1,8 | 2 | 10,0 | 3,5 | 2 |
| N | 7,5 | 4,0 | 5 | 10,8 | 5,2 | 3 | 13,1 | 5,9 | 4 | 8,0 | 3,7 | 5 |
| O | 1,5 | 2,2 | 5 | 6,0 | 4,5 | 5 | 3,5 | 5,2 | 5 | 3,0 | 3,3 | 5 |
| P | 6,0 | 1,4 | 5 | 5,0 | 4,1 | 4 | 6,0 | 1,4 | 5 | 8,1 | 4,3 | 4 |
| Q | 8,1 | 2,2 | 5 | 7,0 | 3,3 | 5 | 5,0 | 1,8 | 5 | 5,5 | 2,1 | 5 |
| R | | | | | | | | | | | | |

**Table 5c. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{ToS}$ in percent for the Test Product 1.0, after elimination of outliers.**

| | Test Product 1.0 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 45,4 | 4,1 | 3 | 48,7 | 7,3 | 2 | 50,9 | 3,8 | 4 | 47,0 | 4,1 | 5 |
| B | 67,5 | 4,3 | 5 | 66,5 | 5,5 | 5 | 68,5 | 4,2 | 5 | 55,5 | 10,1 | 5 |
| C | 71,1 | 6,8 | 4 | 77,5 | 3,5 | 2 | 80,0 | 4,3 | 3 | 63,8 | 10,1 | 4 |
| D | 77,0 | 1,1 | 5 | 71,9 | 8,5 | 4 | 67,5 | | 1 | 75,0 | | 1 |
| E | 62,0 | 14,7 | 5 | 61,0 | 2,9 | 5 | 68,5 | 7,6 | 5 | 60,8 | 5,2 | 5 |
| F | 69,5 | 6,7 | 5 | 78,3 | 1,4 | 3 | 68,8 | 9,2 | 4 | 64,0 | 5,8 | 5 |
| G | 65,5 | 6,5 | 5 | 62,0 | 8,2 | 5 | 60,6 | 14,8 | 4 | 59,3 | 9,0 | 5 |
| H | 65,2 | 9,1 | 5 | 55,8 | 7,6 | 5 | 69,0 | 5,8 | 5 | 61,5 | 8,9 | 5 |
| I | 60,0 | 8,9 | 4 | 70,0 | 3,5 | 4 | 70,0 | 8,8 | 5 | 56,5 | 9,1 | 5 |
| J | 60,0 | 9,1 | 4 | 66,5 | 5,8 | 5 | 66,3 | 6,0 | 4 | 59,5 | 12,7 | 5 |
| K | 57,5 | 9,3 | 5 | 65,6 | 6,1 | 5 | 58,8 | 3,2 | 4 | 61,0 | 11,3 | 5 |
| L | 59,5 | 8,4 | 5 | 57,0 | 5,1 | 5 | 68,5 | 5,2 | 5 | 66,5 | 5,5 | 5 |
| M | 58,8 | 5,3 | 2 | 57,5 | 3,5 | 2 | 68,8 | 1,8 | 2 | 60,0 | 3,5 | 2 |
| N | 63,0 | 2,7 | 5 | 64,0 | 7,4 | 5 | 60,6 | 6,9 | 4 | 55,8 | 11,5 | 5 |
| O | 55,0 | 5,3 | 5 | 61,0 | 11,9 | 5 | 60,0 | 12,7 | 5 | 62,0 | 7,4 | 5 |
| P | 66,0 | 4,9 | 5 | 69,0 | 8,0 | 5 | 71,5 | 4,2 | 5 | 64,4 | 8,0 | 4 |
| Q | 57,0 | 8,9 | 5 | 61,5 | 4,9 | 5 | 66,0 | 4,5 | 5 | 56,5 | 7,8 | 5 |
| R | 56,0 | 8,2 | 5 | 58,0 | 6,2 | 5 | 62,0 | 11,2 | 5 | 60,0 | 10,8 | 5 |

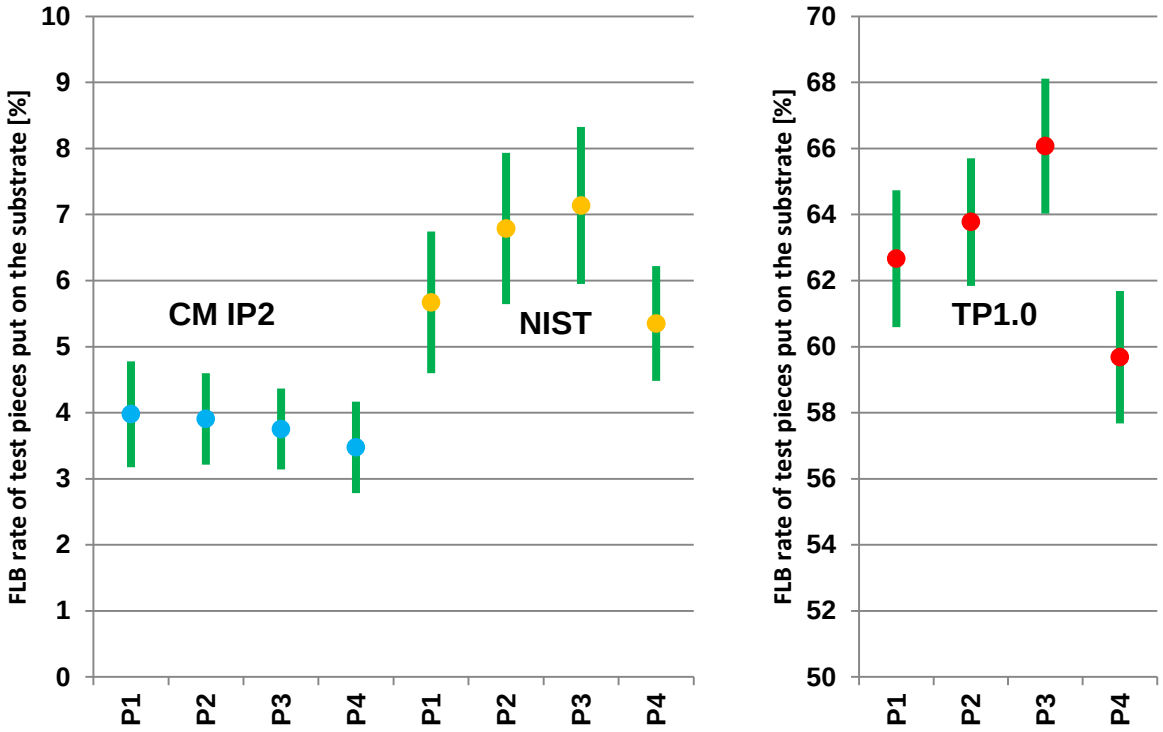
To better observe the effect of outlier elimination, the data aggregated over all laboratories are shown in Table 6.

**Table 6. Aggregated data on the number of test pieces with FLB ($N_{FLB}$), the total number of test pieces tested on the substrate ($N_{ToS}$) and the rate of FLB (rFLB), with and without outliers.**

| | | With outliers | | | Without outliers | | |
|---|---|---|---|---|---|---|---|
| | | $N_{FLB}$ | $N_{ToS}$ | $r_{FLB}$ | $N'_{FLB}$ | $N'_{ToS}$ | $r'_{FLB}$ |
| CM IP2 | P1 | 170 | 3097 | 0,055 | 109 | 2741 | 0,040 |
| | P2 | 155 | 3101 | 0,050 | 112 | 2868 | 0,039 |
| | P3 | 158 | 3113 | 0,051 | 107 | 2852 | 0,038 |
| | P4 | 134 | 3078 | 0,044 | 102 | 2936 | 0,035 |
| NIST | P1 | 212 | 3008 | 0,070 | 155 | 2733 | 0,057 |
| | P2 | 305 | 3032 | 0,101 | 176 | 2592 | 0,068 |
| | P3 | 298 | 3018 | 0,099 | 184 | 2578 | 0,071 |
| | P4 | 214 | 2995 | 0,071 | 141 | 2635 | 0,054 |
| TP1.0 | P1 | 2164 | 3471 | 0,623 | 2076 | 3313 | 0,627 |
| | P2 | 2243 | 3471 | 0,646 | 1961 | 3075 | 0,638 |
| | P3 | 2300 | 3479 | 0,661 | 1955 | 2959 | 0,661 |
| | P4 | 2112 | 3452 | 0,612 | 1917 | 3212 | 0,597 |

Figure 1 shows the 95 % confidence intervals for the rates of FLB of test pieces placed on the substrate aggregated over all laboratories without outliers.

**Figure 1. Mean value and 95 % confidence intervals of the rate of FLB ($N_{FLB}/N_{ToS}$).**




After outlier elimination the remaining data sets were used for testing the difference between the substrates.

## 2.3 Analysis of Differences between Substrates

Due to the high number of tested pieces we can assume in a very good approximation that the estimated rate of FLB, $r'_{FLB}$, is normally distributed $N_{\mu,\sigma^2}$ with mean value

$$\mu = \frac{N'_{FLB}}{N'_{ToS}} = r'_{FLB}$$

wherein the variables refer to the aggregated data without outliers taken from Table 7.

The standard deviation σ was calculated from the average standard deviation over all replicates after elimination of outliers and was in reasonable agreement with the theoretical standard deviation $\sigma_B$ based on the binomial distribution.

$$\sigma_B = \sqrt{\frac{1}{N'_{ToS}} r'_{FLB}(1 - r'_{FLB})}.$$

The difference between two such estimated rates of FLB with mean values $\mu_1$ and $\mu_2$ and standard deviations $\sigma_1$ and $\sigma_2$ is likewise approximately normally distributed with mean value $\mu_{1,2} = \mu_1 - \mu_2$ and standard deviation.

$$\sigma_{1,2} = \sqrt{\sigma_1^2 + \sigma_2^2}.$$

Based on these considerations we can test whether the substrates lead to the same results from two perspectives.

In a first perspective, we will give the alternative substrates the benefit of doubt and assume that they lead to the same test results, i.e. the difference between the rates of FLB on both substrates is assumed to be zero. We will only reject this hypothesis, if the data that were observed are so incompatible with our hypothesis that the likelihood of obtaining this data set is less than 1 % (or 5 %) and we are forced to accept the alternative hypothesis, namely that the difference is non-zero. Table 8 shows the p-values for all test pieces and substrates for this test, where, for example, p = 0,01 means that the difference $\mu_{1,2}$ is non-zero with a likelihood of error of 1 %.

From the above evaluation also 95 % and 99 % confidence intervals for the difference between the substrates can be calculated which are shown graphically in Appendix C.

The above perspective is appropriate, if we have evidence from the past that the difference is indeed zero and the different substrates lead to the same test results. We will only discard this evidence, if we have obtained new data that convincingly contradicts our past experience. Consequently, there is a certain tendency to maintain our hypothesis, even if the difference between the substrates is in fact non-zero.

However, for the present case there is on the one hand little such past experience and on the other hand any undetected differences between the substrates may have substantial implications, as the ignition propensity of cigarettes is subject to regulations in a number of countries. Therefore, in a second perspective, we do not give the substrates the benefit of doubt, but rather assume that there is a difference in the rates of FLB between the substrates. So our hypothesis is that the difference $\mu_{1,2}$ of the rates of FLB on two different substrates exceeds a certain value $\Delta > 0$. Then we search for the smallest $\Delta$, for which we have to reject the hypothesis that $\mu_{1,2} \geq \Delta$ with a likelihood of error of 1 %. In other, more colloquial words, someone, who based on the data states that the difference between the substrates exceeds $\Delta$ has a 99 % chance of being wrong. Similar reasoning applies to the case $\Delta < 0$.

The value of $\Delta$ obtained by this analysis is also given in Table 7 for each pair of substrates and each test piece.

**Table 7. Estimated mean $\mu_{1,2}$ in percent and standard deviation $\sigma_{1,2}$ in percent of the difference between the rates of FLB for all pairs of substrates; the p-value for testing, if the difference is zero; and the minimum value $\Delta$ in percent for which the hypothesis $\mu_{1,2} \geq \Delta$ (or $\mu_{1,2} \leq \Delta$ for $\Delta<0$) has to be rejected at 1 % likelihood of error.**

| | CM IP 2 | | | | NIST | | | | TP1.0 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\mu_{1,2}$ | $\sigma_{1,2}$ | p | $\Delta$ | $\mu_{1,2}$ | $\sigma_{1,2}$ | p | $\Delta$ | $\mu_{1,2}$ | $\sigma_{1,2}$ | p | $\Delta$ |
| | % | % | | % | % | % | | % | % | % | | % |
| P1 – P2 | 0,07 | 0,540 | 0,447 | 1,33 | -1,12 | 0,800 | 0,081 | -2,98 | -1,11 | 1,445 | 0,221 | -4,47 |
| P1 – P3 | 0,22 | 0,514 | 0,331 | 1,42 | -1,47 | 0,817 | 0,036 | -3,37 | -3,41 | 1,485 | 0,011 | -6,86 |
| P1 – P4 | 0,50 | 0,540 | 0,176 | 1,76 | 0,32 | 0,704 | 0,325 | 1,96 | 2,98 | 1,470 | 0,021 | 6,40 |
| P2 – P3 | 0,15 | 0,471 | 0,372 | 1,25 | -0,35 | 0,842 | 0,340 | -2,31 | -2,30 | 1,436 | 0,055 | -5,64 |
| P2 – P4 | 0,43 | 0,499 | 0,194 | 1,59 | 1,44 | 0,732 | 0,025 | 3,14 | 4,09 | 1,421 | 0,002 | 7,39 |
| P3 – P4 | 0,28 | 0,471 | 0,278 | 1,37 | 1,79 | 0,751 | 0,009 | 3,53 | 6,39 | 1,461 | 0,000 | 9,79 |

For sake of completeness and to check the effect of outlier elimination the same analysis was repeated for the data set with all outliers included and the results are shown in Table 8.

**Table 8. Estimated mean $\mu_{1,2}$ in percent and standard deviation $\sigma_{1,2}$ in percent of the difference between the rates of FLB for all pairs of substrates; the p-value for testing, if the difference is zero; and the minimum value $\Delta$ in percent for which the hypothesis $\mu_{1,2} \geq \Delta$ (or $\mu_{1,2} \leq \Delta$ for $\Delta<0$) has to be rejected at 1 % likelihood of error. Outliers are included.**

| | CM IP 2 | | | | NIST | | | | TP1.0 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\mu_{1,2}$ | $\sigma_{1,2}$ | p | $\Delta$ | $\mu_{1,2}$ | $\sigma_{1,2}$ | p | $\Delta$ | $\mu_{1,2}$ | $\sigma_{1,2}$ | p | $\Delta$ |
| | % | % | | % | % | % | | % | % | % | | % |
| P1 – P2 | 0,49 | 0,810 | 0,272 | 2,38 | -3,01 | 1,309 | 0,011 | -6,06 | -2,28 | 1,751 | 0,097 | -6,35 |
| P1 – P3 | 0,41 | 0,849 | 0,313 | 2,39 | -2,83 | 1,198 | 0,009 | -5,61 | -3,77 | 1,764 | 0,016 | -7,87 |
| P1 – P4 | 1,14 | 0,835 | 0,087 | 3,08 | -0,10 | 0,991 | 0,461 | -2,40 | 1,16 | 1,657 | 0,241 | 5,02 |
| P2 – P3 | -0,08 | 0,817 | 0,462 | -1,98 | 0,19 | 1,463 | 0,450 | 3,59 | -1,49 | 1,786 | 0,202 | -5,64 |
| P2 – P4 | 0,64 | 0,803 | 0,211 | 2,51 | 2,91 | 1,300 | 0,012 | 5,94 | 3,44 | 1,681 | 0,020 | 7,35 |
| P3 – P4 | 0,72 | 0,842 | 0,196 | 2,68 | 2,73 | 1,188 | 0,011 | 5,49 | 4,93 | 1,694 | 0,002 | 8,87 |

## 2.5 Conclusions from the Analysis

Regarding outlier testing the outliers, Table 4, seem to be concentrated in a few test piece/laboratory combinations. A higher number of outliers was observed for laboratory D testing CM IP 2, laboratories F and I testing NIST Standards and laboratories A, C and D testing TP 1.0. Consequently it seems that some laboratories showed significant deviations when testing certain test pieces rather than when testing on specific substrates. The remaining outliers are irregularly distributed and do not show any pattern, which would require specific attention.

With rather low rates of FLB for the CM IP 2 and NIST Standards, it is no surprise that outliers mainly showed high rates of FLB and thus after their elimination the mean rate of FLB, Table 7, was lower than before outlier elimination. In comparison for TP 1.0 outlier elimination had hardly any effect on the mean rate of FLB.

The fact that the standard deviation of the mean rate of FLB as estimated from the data is in reasonable agreement with the theoretical standard deviation calculated from a binomial distribution at least indicates that the data set overall is rather consistent.

After outlier removal the mean and standard deviation of the differences in the rate of FLB for each pair of substrates were calculated and the differences were tested for their statistical significance.

At a likelihood of error of 1 % the hypothesis that the difference between certain substrate pairs is zero had to be rejected for the substrate pair P3 – P4 when testing the NIST Standard and for the substrate pairs P2 – P4 and P3 – P4 when used with TP1.0. At a higher likelihood of error of 5 % additionally the substrate pairs P1 – P3 and P2 – P4 testing the NIST Standard and the substrate pairs P1 – P3 and P1 – P4 testing TP1.0 showed a statistically significant non-zero difference.

However, given the high number of tested pieces, it is no surprise that significant differences are detected, the more important question is, whether these differences are of practical relevance.

To assess the magnitude of the difference for each pair of paper substrates, the minimum difference was calculated, for which the hypothesis that the difference is larger than this value can be rejected at a likelihood of error of 1 %. In other words in 99 % of the tests a difference smaller than this value can be obtained.

For CM IP 2 all differences are positive, which means that the rates of FLB as measured on the substrates are in the order P1 > P2 > P3 > P4, which is also visible from Figure 1. These differences are not statistically significant and they are always less than 1,76 %, which means they are less than 1 in 40 tested pieces. This difference is within the reproducibility limits given in ISO 12863.

For the NIST Standard the order of the rates of FLB for the substrates is P4 > P1 > P2 > P3 and the difference is always less than 3,53 % (P3 – P4) which corresponds to differences between 1 and 2 of 40 test pieces.

Finally for TP 1.0 the order of the rates of FLB for the substrates is with P4 > P1 > P2 > P3 the same as for the NIST Standard and the differences are less than 9,79 % (P3 – P4).

Overall for all three test pieces substrate P4 provided the lowest rates of FLB, substrate P3 provided the highest rates of FLB for two of the three test pieces (NIST and TP1.0) and substrate P1 provided the highest rate of FLB for CM IP 2. Substrate P2 provided neither the highest nor the lowest result for any of the three test pieces.

# 3. Repeatability and Reproducibility

## 3.1 Introduction and Raw Data

The analysis of repeatability and reproducibility follows ISO 5725-2, with modifications that were needed to account for the binomial distribution of the data. In contrast to the comparison of the substrates, the rate of FLB will now be determined as described in ISO 12863:2010, by determining the fraction $N_{FLB}/N_{Tot}$ of test pieces that burnt to their full length ($N_{FLB}$) with respect to the total number of tested pieces ($N_{Tot}$), that is, the number of test pieces which self-extinguished in the holder and the number of test pieces that were placed on the substrate.

The full data set is shown in Appendix D.

Tables 9a-c show, for all laboratories and all test piece/substrate combinations the mean value and the standard deviation of the ratio $N_{FLB}/N_{Tot}$ expressed as a percentage and the number of replicates, nominally 5, from which mean value and standard deviation were calculated.

**Table 9a. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{Tot}$ in percent for the CORESTA Monitor IP 2 and the four substrates.**

| | CORESTA Monitor IP 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 1,5 | 2,2 | 5 | 3,5 | 2,9 | 5 | 2,0 | 1,1 | 5 | 2,5 | 2,5 | 5 |
| B | | | | | | | | | | | | |
| C | 2,0 | 2,1 | 5 | 3,5 | 2,2 | 5 | 4,0 | 2,2 | 5 | 4,5 | 2,1 | 5 |
| D | 17,5 | 3,5 | 5 | 17,0 | 5,7 | 5 | 20,5 | 5,4 | 5 | 17,0 | 8,2 | 5 |
| E | 3,5 | 2,9 | 5 | 4,0 | 1,4 | 5 | 2,5 | 3,1 | 5 | 4,1 | 3,9 | 5 |
| F | 4,5 | 2,1 | 5 | 5,0 | 3,5 | 5 | 3,5 | 2,9 | 5 | 2,5 | 4,3 | 5 |

| | CORESTA Monitor IP 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| G | 2,0 | 2,1 | 5 | 8,0 | 3,7 | 5 | 4,0 | 3,4 | 5 | 2,0 | 2,1 | 5 |
| H | 12,0 | 7,6 | 5 | 2,0 | 2,1 | 5 | 2,5 | 2,5 | 5 | 0,0 | 0,0 | 5 |
| I | 1,5 | 2,2 | 5 | 1,0 | 1,4 | 5 | 2,5 | 1,8 | 5 | 1,5 | 1,4 | 5 |
| J | 2,5 | 2,5 | 5 | 1,5 | 2,2 | 5 | 3,0 | 2,1 | 5 | 2,5 | 2,5 | 5 |
| K | 6,0 | 2,9 | 5 | 3,5 | 2,9 | 5 | 3,0 | 2,7 | 5 | 4,0 | 2,2 | 5 |
| L | 1,5 | 2,2 | 5 | 1,5 | 1,4 | 5 | 3,0 | 3,3 | 5 | 3,0 | 2,7 | 5 |
| M | 3,8 | 1,8 | 2 | 7,5 | 0,0 | 2 | 7,5 | 3,5 | 2 | 3,8 | 1,8 | 2 |
| N | 6,0 | 5,8 | 5 | 4,0 | 3,4 | 5 | 2,5 | 1,8 | 5 | 5,0 | 3,1 | 5 |
| O | 3,0 | 3,3 | 5 | 2,5 | 3,5 | 5 | 4,0 | 1,4 | 5 | 3,5 | 2,9 | 5 |
| P | 6,5 | 1,4 | 5 | 5,0 | 0,0 | 5 | 9,5 | 2,1 | 5 | 8,0 | 4,5 | 5 |
| Q | 5,0 | 4,0 | 5 | 4,5 | 2,1 | 5 | 3,0 | 1,1 | 5 | 1,5 | 1,4 | 5 |
| R | 8,5 | 5,2 | 5 | 8,0 | 6,9 | 5 | 6,5 | 3,8 | 5 | 4,0 | 2,9 | 5 |

**Table 9b. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{ToT}$ in percent for the NIST Standard and the four substrates.**

| | NIST Cigarette Ignition Strength Standard | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 4,0 | 6,3 | 5 | 3,5 | 4,9 | 5 | 3,0 | 2,1 | 5 | 2,0 | 3,3 | 5 |
| B | 9,0 | 4,2 | 5 | 8,5 | 4,2 | 5 | 9,0 | 3,4 | 5 | 5,5 | 2,7 | 5 |
| C | 1,5 | 2,2 | 5 | 6,5 | 3,8 | 5 | 5,5 | 5,1 | 5 | 3,5 | 3,8 | 5 |
| D | 1,0 | 1,4 | 5 | 10,4 | 2,1 | 5 | 10,5 | 5,4 | 5 | 4,0 | 2,9 | 5 |
| E | 11,0 | 3,4 | 5 | 15,5 | 5,4 | 5 | 14,5 | 7,2 | 5 | 8,5 | 5,8 | 5 |
| F | 19,0 | 6,0 | 5 | 38,5 | 2,9 | 5 | 31,5 | 7,4 | 5 | 19,5 | 8,2 | 5 |
| G | 3,0 | 3,3 | 5 | 4,0 | 2,9 | 5 | 6,0 | 5,2 | 5 | 3,0 | 3,1 | 5 |
| H | 6,0 | 3,8 | 5 | 6,0 | 2,9 | 5 | 11,0 | 3,8 | 5 | 7,0 | 2,1 | 5 |
| I | 17,5 | 2,5 | 5 | 15,0 | 4,7 | 5 | 12,0 | 10,2 | 5 | 15,5 | 5,4 | 5 |
| J | 3,5 | 2,8 | 5 | 0,0 | 0,0 | 5 | 2,5 | 3,5 | 5 | 4,0 | 3,8 | 5 |
| K | | | | | | | | | | | | |
| L | 4,0 | 2,9 | 5 | 3,5 | 2,9 | 5 | 9,0 | 7,2 | 5 | 4,0 | 2,9 | 5 |
| M | 8,8 | 5,3 | 2 | 11,3 | 5,3 | 2 | 13,8 | 1,8 | 2 | 10,0 | 3,5 | 2 |
| N | 7,5 | 4,0 | 5 | 15,5 | 7,4 | 5 | 14,5 | 6,0 | 5 | 8,0 | 3,7 | 5 |
| O | 1,5 | 2,2 | 5 | 6,0 | 4,5 | 5 | 3,5 | 5,2 | 5 | 3,0 | 3,3 | 5 |
| P | 6,0 | 1,4 | 5 | 8,0 | 7,6 | 5 | 6,0 | 1,4 | 5 | 10,0 | 5,6 | 5 |
| Q | 8,0 | 2,1 | 5 | 7,0 | 3,3 | 5 | 5,0 | 1,8 | 5 | 5,5 | 2,1 | 5 |
| R | | | | | | | | | | | | |

**Table 9c. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{ToT}$ in percent for the Test Product 1.0 and the four substrates.**

| | Test Product 1.0 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 37,5 | 11,0 | 5 | 40,0 | 9,8 | 5 | 47,0 | 8,9 | 5 | 46,5 | 4,2 | 5 |
| B | 67,5 | 4,3 | 5 | 66,5 | 5,5 | 5 | 68,5 | 4,2 | 5 | 55,5 | 10,1 | 5 |
| C | 72,5 | 9,4 | 5 | 83,5 | 6,0 | 5 | 83,0 | 5,4 | 5 | 66,0 | 11,3 | 5 |
| D | 77,0 | 1,1 | 5 | 74,4 | 9,3 | 5 | 83,5 | 9,1 | 5 | 80,5 | 3,3 | 5 |
| E | 62,0 | 14,7 | 5 | 61,0 | 2,9 | 5 | 68,5 | 7,6 | 5 | 60,8 | 5,2 | 5 |
| F | 69,5 | 6,7 | 5 | 81,5 | 4,5 | 5 | 72,0 | 10,8 | 5 | 64,0 | 5,8 | 5 |
| G | 65,5 | 6,5 | 5 | 62,0 | 8,2 | 5 | 57,5 | 14,6 | 5 | 59,0 | 9,1 | 5 |
| H | 65,2 | 9,1 | 5 | 55,8 | 7,6 | 5 | 69,0 | 5,8 | 5 | 61,5 | 8,9 | 5 |
| I | 64,5 | 12,7 | 5 | 72,5 | 6,4 | 5 | 70,0 | 8,8 | 5 | 56,5 | 9,1 | 5 |
| J | 64,0 | 11,9 | 5 | 66,5 | 5,8 | 5 | 62,0 | 10,8 | 5 | 59,5 | 12,7 | 5 |
| K | 56,5 | 8,0 | 5 | 65,0 | 6,6 | 5 | 56,0 | 6,8 | 5 | 61,0 | 11,3 | 5 |
| L | 59,5 | 8,4 | 5 | 57,0 | 5,1 | 5 | 68,5 | 5,2 | 5 | 66,5 | 5,5 | 5 |
| M | 58,8 | 5,3 | 2 | 57,5 | 3,5 | 2 | 68,8 | 1,8 | 2 | 60,0 | 3,5 | 2 |
| N | 63,0 | 2,7 | 5 | 64,0 | 7,4 | 5 | 57,5 | 9,2 | 5 | 55,5 | 11,5 | 5 |
| O | 55,0 | 5,3 | 5 | 61,0 | 11,9 | 5 | 60,0 | 12,7 | 5 | 62,0 | 7,4 | 5 |
| P | 66,0 | 4,9 | 5 | 69,0 | 8,0 | 5 | 71,5 | 4,2 | 5 | 67,5 | 9,8 | 5 |
| Q | 57,0 | 8,9 | 5 | 61,5 | 4,9 | 5 | 66,0 | 4,5 | 5 | 56,5 | 7,8 | 5 |
| R | 56,0 | 8,2 | 5 | 58,0 | 6,2 | 5 | 62,0 | 11,2 | 5 | 60,0 | 10,8 | 5 |

## 3.2 Outlier Analysis and Removal

For reasons already explained in section 2.2 the distribution of the number of test pieces which exhibited FLB for one replicate test of 40 test pieces cannot be approximated well by a normal distribution, but needs to be considered as binomially distributed. Thus the procedure for elimination of outliers is the same as described in section 2.2, with $N_{ToS}$ replaced by $N_{Tot}$. First a 'true' rate of FLB is estimated by aggregating all laboratory data for each test piece/substrate combination. Then all replicates which had a probability of occurrence of less than 1 % based on a binomial distribution with the 'true' rate of FLB were eliminated as outliers. The 'true' rate of FLB was then updated and the procedure repeated until no more outliers were found. Also here two rounds of outlier elimination were sufficient.

Table 10 shows which replicates were eliminated as outliers and Tables 11a-c show - after elimination of outliers -, for all laboratories and all test piece/substrate combinations the mean value and the standard deviation of the ratio $N_{FLB}/N_{Tot}$ expressed as a percentage and the number of replicates, nominally 5, from which mean value and standard deviation were calculated.

**Table 10. Replicates (1, 2, …, 5) that were eliminated as outliers.**

| | CM IP 2 | | | | NIST | | | | TP1.0 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | P1 | P2 | P3 | P4 | P1 | P2 | P3 | P4 | P1 | P2 | P3 | P4 |
| A | | | | | | | | | 3,4 | 1-4 | 1,2 | |
| B | | | | | | | | | | | | |
| C | | | | | | | | | 1 | 1,2,4 | 1,2 | 4 |
| D | 1-5 | 1,3-5 | 1-5 | 1,3,5 | | | | | | 1 | 1,3-5 | 1-3,5 |
| E | | | | | | 2,4 | 2,4 | 3 | | | | |
| F | | | | | 1,2,4 | 1-5 | 1-5 | 1,2,4,5 | | 1,3 | 5 | |
| G | | 3 | | | | | | | | | 1,4 | |
| H | 1,3,5 | | | | | | | | | | | |
| I | | | | | 1,3,5 | 2 | 4,5 | 1,4,5 | 1 | 5 | | |
| J | | | | | | | | | 5 | | 2 | |
| K | | | | | | | | | | | 1 | |
| L | | | | | | | 5 | | | | | |
| M | | | | | | | | | | | | |
| N | 3 | | | | | 1,4 | 1 | | | | 4 | |
| O | | | | | | | | | | | | |
| P | | | 5 | 2 | | 4 | | 5 | | | | 2 |
| Q | | | | | | | | | | | | |
| R | 3,5 | 1 | 1 | | | | | | | | | |

**Table 11a. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{ToT}$ in percent for the CORESTA Monitor IP 2, after elimination of outliers.**

| | CORESTA Monitor IP 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 1,5 | 2,2 | 5 | 3,5 | 2,9 | 5 | 2,0 | 1,1 | 5 | 2,5 | 2,5 | 5 |
| B | | | | | | | | | | | | |
| C | 2,0 | 2,1 | 5 | 3,5 | 2,2 | 5 | 4,0 | 2,2 | 5 | 4,5 | 2,1 | 5 |
| D | | | 0 | 10,0 | | 1 | | | 0 | 10,0 | 0,0 | 2 |
| E | 3,5 | 2,9 | 5 | 4,0 | 1,4 | 5 | 2,5 | 3,1 | 5 | 4,1 | 3,9 | 5 |
| F | 4,5 | 2,1 | 5 | 5,0 | 3,5 | 5 | 3,5 | 2,9 | 5 | 2,5 | 4,3 | 5 |
| G | 2,0 | 2,1 | 5 | 6,9 | 3,1 | 4 | 4,0 | 3,4 | 5 | 2,0 | 2,1 | 5 |
| H | 5,0 | 7,1 | 2 | 2,0 | 2,1 | 5 | 2,5 | 2,5 | 5 | 0,0 | 0,0 | 5 |
| I | 1,5 | 2,2 | 5 | 1,0 | 1,4 | 5 | 2,5 | 1,8 | 5 | 1,5 | 1,4 | 5 |
| J | 2,5 | 2,5 | 5 | 1,5 | 2,2 | 5 | 3,0 | 2,1 | 5 | 2,5 | 2,5 | 5 |
| K | 6,0 | 2,9 | 5 | 3,5 | 2,9 | 5 | 3,0 | 2,7 | 5 | 4,0 | 2,2 | 5 |
| L | 1,5 | 2,2 | 5 | 1,5 | 1,4 | 5 | 3,0 | 3,3 | 5 | 3,0 | 2,7 | 5 |

| | CORESTA Monitor IP 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| M | 3,8 | 1,8 | 2 | 7,5 | 0,0 | 2 | 7,5 | 3,5 | 2 | 3,8 | 1,8 | 2 |
| N | 3,8 | 3,2 | 4 | 4,0 | 3,4 | 5 | 2,5 | 1,8 | 5 | 5,0 | 3,1 | 5 |
| O | 3,0 | 3,3 | 5 | 2,5 | 3,5 | 5 | 4,0 | 1,4 | 5 | 3,5 | 2,9 | 5 |
| P | 6,5 | 1,4 | 5 | 5,0 | 0,0 | 5 | 8,8 | 1,4 | 4 | 6,3 | 2,5 | 4 |
| Q | 5,0 | 4,0 | 5 | 4,5 | 2,1 | 5 | 3,0 | 1,1 | 5 | 1,5 | 1,4 | 5 |
| R | 5,8 | 5,2 | 3 | 5,0 | 2,0 | 4 | 5,0 | 2,0 | 4 | 4,0 | 2,9 | 5 |

**Table 11b. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{ToT}$ in percent for the NIST Standard, after elimination of outliers.**

| | NIST Cigarette Ignition Strength Standard | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 4,0 | 6,3 | 5 | 3,5 | 4,9 | 5 | 3,0 | 2,1 | 5 | 2,0 | 3,3 | 5 |
| B | 9,0 | 4,2 | 5 | 8,5 | 4,2 | 5 | 9,0 | 3,4 | 5 | 5,5 | 2,7 | 5 |
| C | 1,5 | 2,2 | 5 | 6,5 | 3,8 | 5 | 5,5 | 5,1 | 5 | 3,5 | 3,8 | 5 |
| D | 1,0 | 1,4 | 5 | 10,4 | 2,1 | 5 | 10,5 | 5,4 | 5 | 4,0 | 2,9 | 5 |
| E | 11,0 | 3,4 | 5 | 11,7 | 1,4 | 3 | 10,0 | 5,0 | 3 | 6,3 | 3,2 | 4 |
| F | 12,5 | 0,0 | 2 | | | 0 | | | 0 | 7,5 | | 1 |
| G | 3,0 | 3,3 | 5 | 4,0 | 2,9 | 5 | 6,0 | 5,2 | 5 | 3,0 | 3,1 | 5 |
| H | 6,0 | 3,8 | 5 | 6,0 | 2,9 | 5 | 11,0 | 3,8 | 5 | 7,0 | 2,1 | 5 |
| I | 15,0 | 0,0 | 2 | 13,1 | 2,4 | 4 | 5,0 | 4,3 | 3 | 10,0 | 3,5 | 2 |
| J | 3,5 | 2,8 | 5 | 0,0 | 0,0 | 5 | 2,5 | 3,5 | 5 | 4,0 | 3,8 | 5 |
| K | | | | | | | | | | | | |
| L | 4,0 | 2,9 | 5 | 3,5 | 2,9 | 5 | 6,3 | 4,3 | 4 | 4,0 | 2,9 | 5 |
| M | 8,8 | 5,3 | 2 | 11,3 | 5,3 | 2 | 13,8 | 1,8 | 2 | 10,0 | 3,5 | 2 |
| N | 7,5 | 4,0 | 5 | 10,8 | 5,2 | 3 | 13,1 | 5,9 | 4 | 8,0 | 3,7 | 5 |
| O | 1,5 | 2,2 | 5 | 6,0 | 4,5 | 5 | 3,5 | 5,2 | 5 | 3,0 | 3,3 | 5 |
| P | 6,0 | 1,4 | 5 | 5,0 | 4,1 | 4 | 6,0 | 1,4 | 5 | 8,1 | 4,3 | 4 |
| Q | 8,0 | 2,1 | 5 | 7,0 | 3,3 | 5 | 5,0 | 1,8 | 5 | 5,5 | 2,1 | 5 |
| R | | | | | | | | | | | | |

**Table 11c. Mean value (MV) and standard deviation (StD) of the replicates (N) for the ratio $N_{FLB}/N_{Tot}$ in percent for the TP1.0, after elimination of outliers.**

| | Test Product 1.0 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P1 | | | P2 | | | P3 | | | P4 | | |
| ID | MV | StD | N | MV | StD | N | MV | StD | N | MV | StD | N |
| A | 45,0 | 4,3 | 3 | 52,5 | | 1 | 52,5 | 2,5 | 3 | 46,5 | 4,2 | 5 |
| B | 67,5 | 4,3 | 5 | 66,5 | 5,5 | 5 | 68,5 | 4,2 | 5 | 55,5 | 10,1 | 5 |
| C | 69,4 | 7,2 | 4 | 77,5 | 3,5 | 2 | 80,0 | 4,3 | 3 | 62,5 | 9,4 | 4 |
| D | 77,0 | 1,1 | 5 | 71,9 | 8,5 | 4 | 76,3 | 12,4 | 2 | 75,0 | | 1 |
| E | 62,0 | 14,7 | 5 | 61,0 | 2,9 | 5 | 68,5 | 7,6 | 5 | 60,8 | 5,2 | 5 |
| F | 69,5 | 6,7 | 5 | 78,3 | 1,4 | 3 | 68,8 | 9,2 | 4 | 64,0 | 5,8 | 5 |
| G | 65,5 | 6,5 | 5 | 62,0 | 8,2 | 5 | 67,5 | 6,6 | 3 | 59,0 | 9,1 | 5 |
| H | 65,2 | 9,1 | 5 | 55,8 | 7,6 | 5 | 69,0 | 5,8 | 5 | 61,5 | 8,9 | 5 |
| I | 60,0 | 8,9 | 4 | 70,0 | 3,5 | 4 | 70,0 | 8,8 | 5 | 56,5 | 9,1 | 5 |
| J | 60,0 | 9,1 | 4 | 66,5 | 5,8 | 5 | 66,3 | 6,0 | 4 | 59,5 | 12,7 | 5 |
| K | 56,5 | 8,0 | 5 | 65,0 | 6,6 | 5 | 58,8 | 3,2 | 4 | 61,0 | 11,3 | 5 |
| L | 59,5 | 8,4 | 5 | 57,0 | 5,1 | 5 | 68,5 | 5,2 | 5 | 66,5 | 5,5 | 5 |
| M | 58,8 | 5,3 | 2 | 57,5 | 3,5 | 2 | 68,8 | 1,8 | 2 | 60,0 | 3,5 | 2 |
| N | 63,0 | 2,7 | 5 | 64,0 | 7,4 | 5 | 60,6 | 6,9 | 4 | 55,5 | 11,5 | 5 |
| O | 55,0 | 5,3 | 5 | 61,0 | 11,9 | 5 | 60,0 | 12,7 | 5 | 62,0 | 7,4 | 5 |
| P | 66,0 | 4,9 | 5 | 69,0 | 8,0 | 5 | 71,5 | 4,2 | 5 | 64,4 | 8,0 | 4 |
| Q | 57,0 | 8,9 | 5 | 61,5 | 4,9 | 5 | 66,0 | 4,5 | 5 | 56,5 | 7,8 | 5 |
| R | 56,0 | 8,2 | 5 | 58,0 | 6,2 | 5 | 62,0 | 11,2 | 5 | 60,0 | 10,8 | 5 |

To better observe the effect of outlier elimination the data aggregated over all laboratories are shown in Table 12.

**Table 12. Aggregated data on the number of test pieces with FLB ($N_{FLB}$), the total number of tested pieces ($N_{ToT}$) and the rate of FLB ($r_{FLB}$), with and without outliers.**

| | | With outliers | | | Without outliers | | |
|---|---|---|---|---|---|---|---|
| | | $N_{FLB}$ | $N_{Tot}$ | $r_{FLB}$ | $N'_{FLB}$ | $N'_{Tot}$ | $r'_{FLB}$ |
| CM IP2 | P1 | 170 | 3276 | 0,052 | 99 | 2836 | 0,035 |
| | P2 | 155 | 3275 | 0,047 | 112 | 3035 | 0,037 |
| | P3 | 158 | 3280 | 0,048 | 107 | 3000 | 0,036 |
| | P4 | 134 | 3278 | 0,041 | 102 | 3118 | 0,033 |
| NIST | P1 | 212 | 3079 | 0,069 | 161 | 2839 | 0,057 |
| | P2 | 305 | 3082 | 0,099 | 176 | 2642 | 0,067 |
| | P3 | 298 | 3080 | 0,097 | 184 | 2640 | 0,070 |
| | P4 | 214 | 3075 | 0,070 | 141 | 2715 | 0,052 |
| TP1.0 | P1 | 2164 | 3481 | 0,622 | 2044 | 3281 | 0,623 |
| | P2 | 2243 | 3478 | 0,645 | 1944 | 3039 | 0,640 |
| | P3 | 2300 | 3480 | 0,661 | 1937 | 2920 | 0,663 |
| | P4 | 2112 | 3459 | 0,611 | 1917 | 3219 | 0,596 |

The data set without outliers was then used for the determination of repeatability and reproducibility.

## 3.3 Repeatability and Reproducibility Results

The repeatability and reproducibility statistics were calculated according to ISO 5725-2. The results are given for each test piece/substrate combination in Table 13.

**Table 13. Repeatability and reproducibility statistics for all test pieces and substrates. Global mean, standard deviations (StD) and limits are in percent FLB. The coefficient of variation (CoV) is given also as a percentage of the mean rate of FLB.**

| | | | Repeatability | | | Reproducibility | | |
|---|---|---|---|---|---|---|---|---|
| | | Global Mean in % | StD | Limit | CoV | StD | Limit | CoV |
| CM IP2 | P1 | 3,49 | 3,25 | 9,20 | 90,01 | 5,02 | 14,20 | 138,90 |
| | P2 | 3,69 | 2,38 | 6,74 | 57,18 | 5,75 | 16,28 | 138,03 |
| | P3 | 3,57 | 2,40 | 6,78 | 63,11 | 4,82 | 13,63 | 126,88 |
| | P4 | 3,27 | 2,50 | 7,07 | 70,19 | 5,58 | 15,78 | 156,61 |
| NIST | P1 | 5,67 | 3,27 | 9,25 | 51,18 | 9,82 | 27,78 | 153,67 |
| | P2 | 6,66 | 3,61 | 10,21 | 50,47 | 9,08 | 25,68 | 126,94 |
| | P3 | 6,97 | 4,14 | 11,72 | 56,42 | 9,10 | 25,74 | 123,97 |
| | P4 | 5,19 | 3,26 | 9,23 | 57,11 | 6,51 | 18,40 | 113,88 |
| TP1.0 | P1 | 62,30 | 7,49 | 21,17 | 12,11 | 17,57 | 49,69 | 28,42 |
| | P2 | 63,97 | 6,43 | 18,18 | 10,01 | 17,32 | 48,98 | 26,99 |
| | P3 | 66,34 | 7,24 | 20,49 | 10,83 | 16,03 | 45,33 | 23,97 |
| | P4 | 59,55 | 8,65 | 24,46 | 14,32 | 15,50 | 43,84 | 25,67 |

## 3.4 Comparison with Other Studies

The RAC Sub-Group has repeatedly tested CM IP 2 and NIST Standards for their performance in the ignition propensity test over the years 2014 to 2016. The results from these collaborative studies can be compared with the present study to evaluate the suitability of CM IP 2 or NIST Standards as a monitor test piece. The results of the past and present studies are summarized in Table 14 giving the global mean value, the repeatability limit and the reproducibility limit of ignition propensity for 2014 to 2016 and as an average over all paper substrates P1 to P4 for this study.

**Table 14. Mean value, repeatability and reproducibility limits of CM IP 2 and NIST Standards from previous studies and this study.**

| | | Global Mean in % | Repeatability Limit | Reproducibility Limit |
|---|---|---|---|---|
| CM IP2 | 2014 | 3,24 | 7,86 | 9,29 |
| | 2015 | 4,10 | 8,83 | 9,66 |
| | 2016 | 3,96 | 8,65 | 11,66 |
| | this study | 3,50 | 7,45 | 14,97 |
| NIST | 2014 | 8,73 | 12,55 | 14,51 |
| | 2015 | 10,34 | 13,41 | 19,61 |
| | 2016 | 9,83 | 13,04 | 23,36 |
| | this study | 6,11 | 10,10 | 24,40 |

## 3.5 Conclusions from the r&R Data

The outliers found in the analysis for repeatability and reproducibility show the same pattern as for the comparison of the substrates. Again the outliers concentrate in certain laboratory/test piece combinations and were found particularly for laboratory D when testing CM IP 2, laboratories F and I when testing NIST Standards and laboratories A, C and D when testing TP 1.0. Also here outliers are more likely to occur when testing certain test pieces than when testing on certain substrates. All other outliers are evenly distributed over the data set.

As before, outlier elimination led to a decrease in the mean rate of FLB for the CM IP 2 and the NIST Standard, as both have low rates of FLB in the 3 % to 7 % range while there was little change in the mean rate of FLB for the TP 1.0 having a rate of FLB of about 60 % to 65 %.

Regarding repeatability all paper substrates appear to behave similarly. The highest repeatability standard deviations were found for substrate P1 used with CM IP 2, for substrate P3 used with NIST and substrate P4 used with TP1.0. The lowest repeatability standard deviations were found for substrate P2 used with CM IP 2, for substrate P4 used with NIST and substrate P2 used with TP 1.0.

The reproducibility limits are generally a factor of two higher than the repeatability limits and again there are no specific trends or patterns. Only substrate P4 when tested with the NIST Standard showed a particularly low reproducibility limit of 18,40 % while for all other paper substrates this value is above 25 %.

For rates of FLB of about 5 % ISO 12863:2010 lists in Table D.1 a repeatability limit of 10 % (4 of 40 cigarettes) which is very well in line with the values of about 7 % to 12 % observed in this study. The reproducibility limit of 11 %, however, is below the 13 % to 28 % obtained in this study.

The repeatability for cigarettes with a rate of FLB of about 60 % is given as 22 % in Table D.1 of ISO 12863:2010 and agrees very well with the values found for TP 1.0 (18 % - 25 %). Again the reproducibility limit for TP 1.0 is with about 45 % to about 50 % substantially higher than the value of 26 % reported in ISO 12863:2010.

From the comparison with previous studies it can be seen that the results of this study for CM IP 2 are well in line with the results obtained in studies from 2014 to 2016 and are stable over the years. However, there may be a slight trend that the reproducibility limit increases over the years. This should be monitored in future studies.

Nevertheless CM IP 2 is a suitable monitor test piece. If used as a test piece and considering that a range of twice the reproducibility standard deviation is acceptable, one can expect to obtain values between 0 % and 13,5 % when testing 40 pieces, i.e. between 0 and 5 test pieces will burn their full length.

For the NIST Standard a comparably low rate of FLB has been observed in this study. However, the standard deviation of the results is also higher than for CM IP 2, so that it cannot be concluded that the difference is of statistical significance. If used as a test piece, rates of FLB between 0 % and 19,6 %, i.e. between 0 and 8 test pieces showing FLB, can be expected, when 40 pieces are tested.

# 4. Summary

In this collaborative study three test pieces were tested on four different paper substrates for their ignition propensity according to ISO 12863:2010. The purpose of the study was to check if the substrates differ in their performance. In total 18 laboratories tested the different test piece/substrate combinations with five replicates of forty test pieces per combination.

After elimination of outliers, the statistical analysis showed the following results:

- None of the pairs of paper substrates showed a statistically significant difference when testing CM IP 2 at a likelihood of error 1 % and even at a likelihood of error of 5 %.
- For the NIST Standard the substrate pair P3 – P4 showed a statistically significant difference at a likelihood of error of 1 % and the substrate pairs P1 – P3 and P2 – P4 were statistically significantly different at a likelihood of error of 5 %.
- For the test product TP 1.0 the substrate pairs P2 – P4 and P3 – P4 were statistically significantly different at a likelihood of error of 1 % and further the pairs P1 – P3 and P1 – P4 showed statistically significant differences at a likelihood of error of 5 %.

The minimum difference in the rate of FLB between all pairs of substrates that is to be exceeded with a likelihood of less than 1 % was generally less than 1 in 40 test pieces for CM IP2 and less than 2 in 40 test pieces for the NIST Standard.

For all three test pieces substrate P4 provided the lowest rates of FLB and substrate P3 provided the highest rates of FLB for two of the three test pieces. Substrate P1 provided the highest rate of FLB for CM IP 2 and substrate P2 provided neither the highest nor the lowest rates of FLB for any of the three test pieces.

Repeatability and reproducibility were also determined. No substrate-specific effects were observed. The repeatability data are in good agreement with the data reported in ISO 12863:2010.

The reproducibility limits are a factor two higher than the repeatability limits and likewise do not show substantial substrate-specific effects. The reproducibility limits obtained in this study are higher than those reported in ISO 12863:2010.

The comparison with past data has shown that CM IP 2 is stable and suitable as a monitor test piece on all of the substrates covered in this study.

# 5. References


- ISO 12863:2010, Standard test method for assessing the ignition propensity of cigarettes
- ISO 5725-2:1994, Accuracy (trueness and precision) of measurement methods and results - Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method
- CORESTA Routine Analytical Chemistry Sub-Group (RAC-113), Technical Report – 2016 Collaborative Study of CORESTA Ignition Propensity Monitor Test Piece CM IP 2 for the Determination of Ignition Propensity, March 2017
- CORESTA Routine Analytical Chemistry Sub-Group (RAC-028), Technical Report – 2015 Collaborative Study of CORESTA Ignition Propensity Monitor Test Piece CM IP 2 for the Determination of Ignition Propensity, April 2016
- CORESTA Routine Analytical Chemistry Sub-Group, Technical Report – 2014 Collaborative Study of CORESTA Ignition Propensity Monitor Test Piece CM IP 2 for the Determination of Ignition Propensity, March 2015

# APPENDIX A - Protocol

## Collaborative Test
## Ignition Propensity – Different Substrates
## Protocol

### 1. Objective

To assess the variability (inter and intra-laboratory) for the analysis of CORESTA IP Monitor No 2, NIST Standard and TP1.0 on different substrates, which are [redacted], [redacted], [redacted] and [redacted], according to ISO method 12863.

### 2. Test coordinator

Huub Vizée

Head of Regulatory Affairs

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Austria

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### 3. Parameters to be measured

The parameter to be measured is the ignition propensity, according to the ISO method 12863, with the modification that also the number of cigarettes, which extinguished in the holder, i.e. before being placed on the substrate, has to be reported.

**Table 1. Parameter to be measured**

| | **Parameter** |
|---|---|
| 1 | **Ignition propensity**<br>Number of tested cigarettes<br>Number of cigarettes, extinguished in the holder<br>Number of cigarettes with full length burn |

### 4. Test methods

The testing of cigarettes has to be carried out in strict compliance with ISO 12863:2010.

### 5. Test samples

**a) Test cigarettes**

Test samples consist of 1 machine-made CORESTA Monitor IP No 2, the NIST standard and TP1.0. Cigarette sample TP 1.0 is provided by Papierfabrik Wattens GmbH & Co KG and for CORESTA Monitor IP No 2 and the NIST standard, each laboratory shall use its own stock. Please inspect samples upon arrival and contact the test coordinator in case of problems.

**Table 2. Test cigarettes for the Collaborative Study**

| Test cigarette |
|---|
| MONITOR IP NO.2 |
| NIST STANDARD |
| TP1.0 |

**b) Substrates**

Test samples consist of [redacted], [redacted], [redacted] and [redacted]. Substrate samples are provided by Papierfabrik Wattens GmbH & Co KG, [redacted]. Please inspect samples upon arrival and contact the test coordinator in case of problems.

**Table 3. Test substrates for the Collaborative Study**

| Test substrate |
|---|
| [redacted] |
| [redacted] |
| [redacted] |
| [redacted] |

## 6. Schedule

For a given brand and given substrate, 1 replicate of 40 cigarettes should be measured in a single test day, for a total of 5 replicates over 5 independent days. There are no constraints concerning the spacing between the days of experiment, however please keep them as close as possible. Each cigarette must be measured on each substrate for a total of 5 replicates over 5 independent days, giving a total of 60 tests of 40 cigarettes each.

The study starts second half of June 2018. Each laboratory is free to organize at its will the timeframe during which it performs the study. However, the test results should be sent to Papierfabrik Wattens GmbH & Co KG no later than **August 31st, 2018**.

## 7. Reporting of test results

The test results should be reported using the Excel file *Template for coll. study on ignition propensity_substrates 2018.xls.*

The data are to be reported in the Excel template. In addition to IP test specific results, the temperature and relative humidity during the testing shall be reported as well.

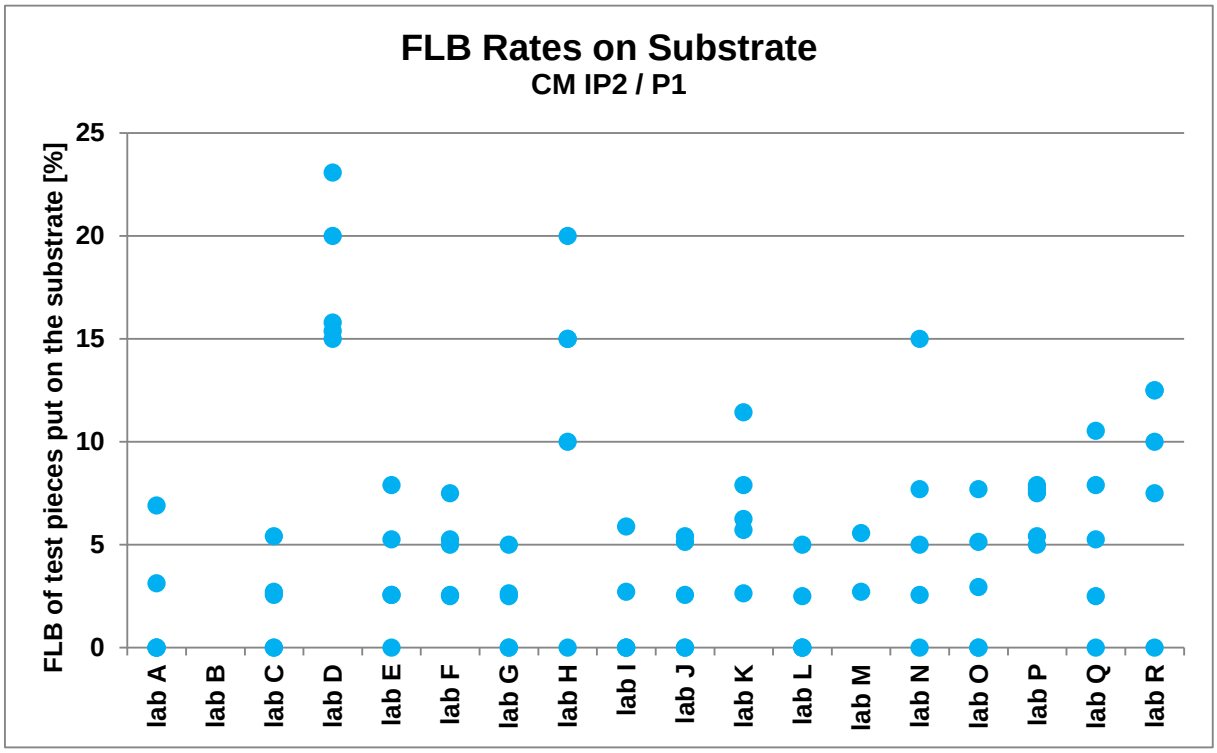
Results should be sent electronically:

To: Maria Gleinser

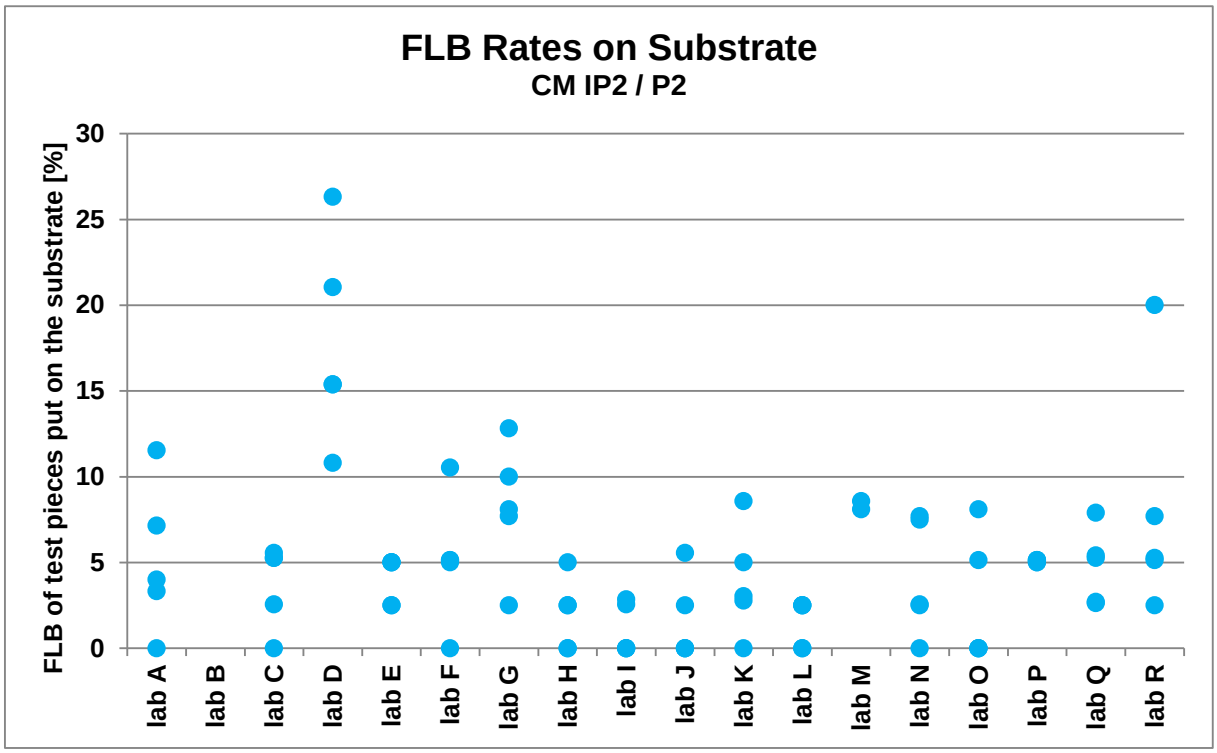
Cc: Huub Vizée

# APPENDIX B - Raw Data for Substrate Comparison

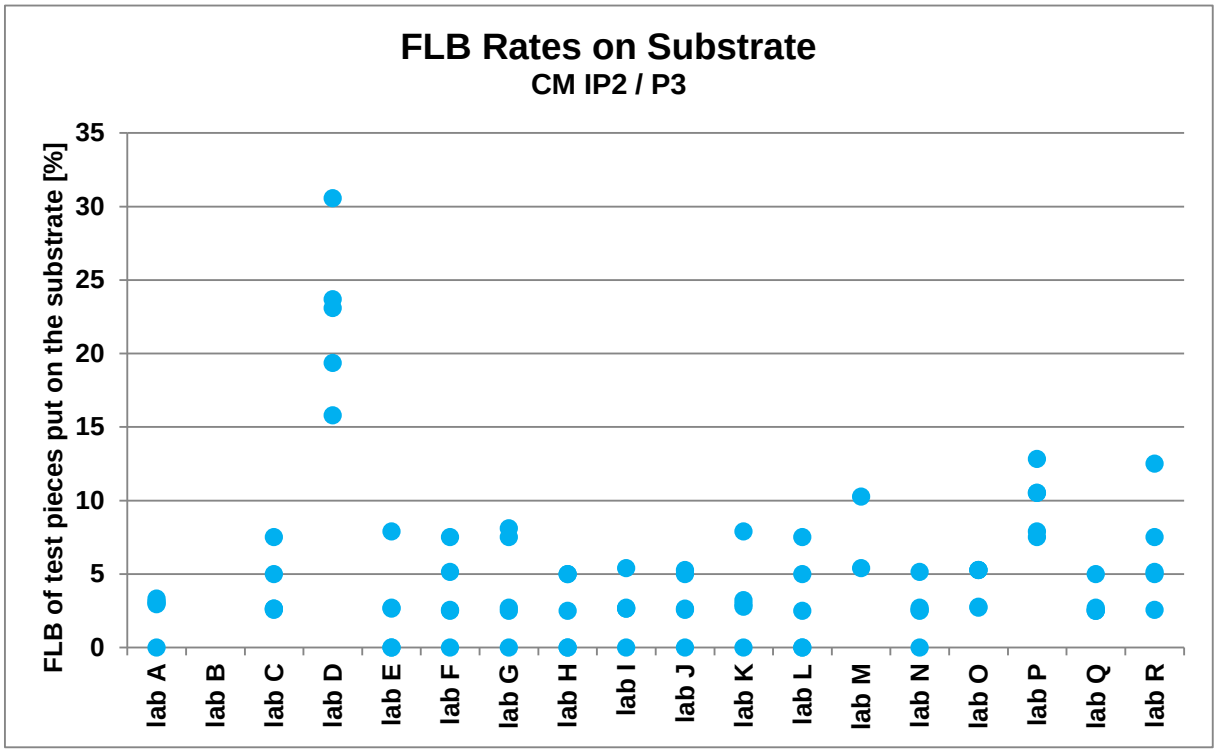
**Appendix B.1. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for CORESTA Monitor IP 2 on substrate P1.**



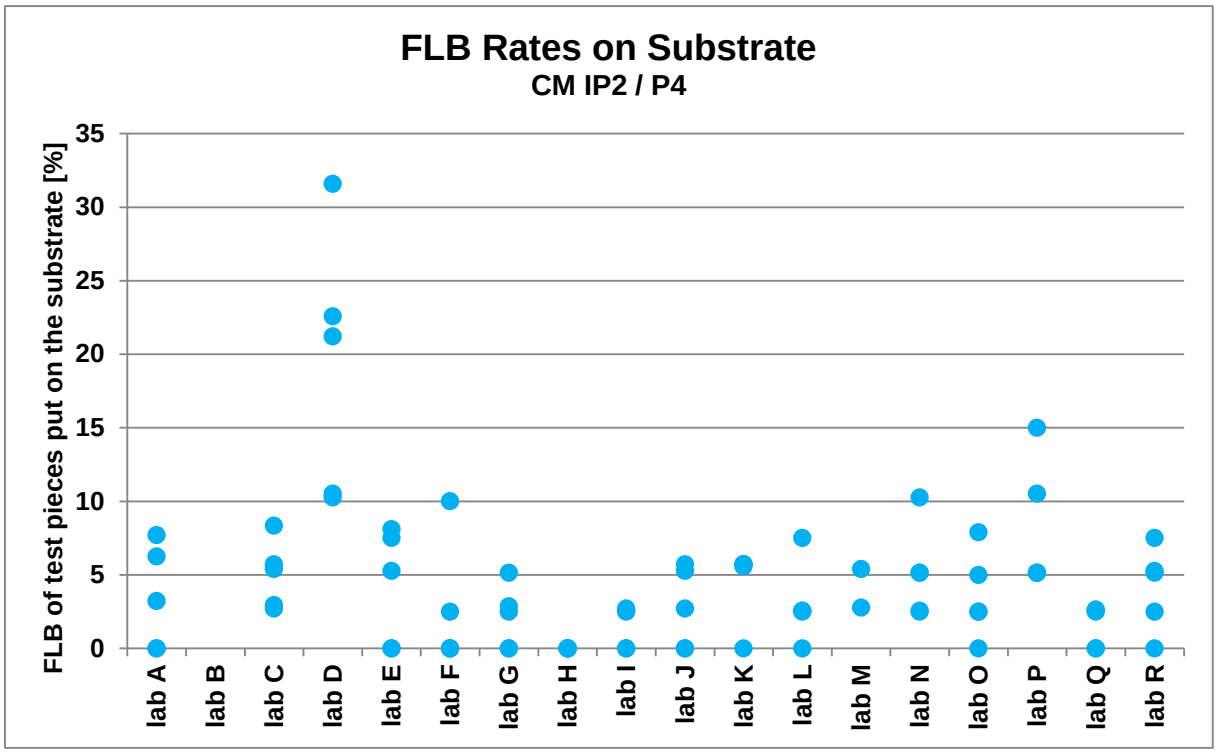

**Appendix B.2. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for CORESTA Monitor IP 2 on substrate P2.**



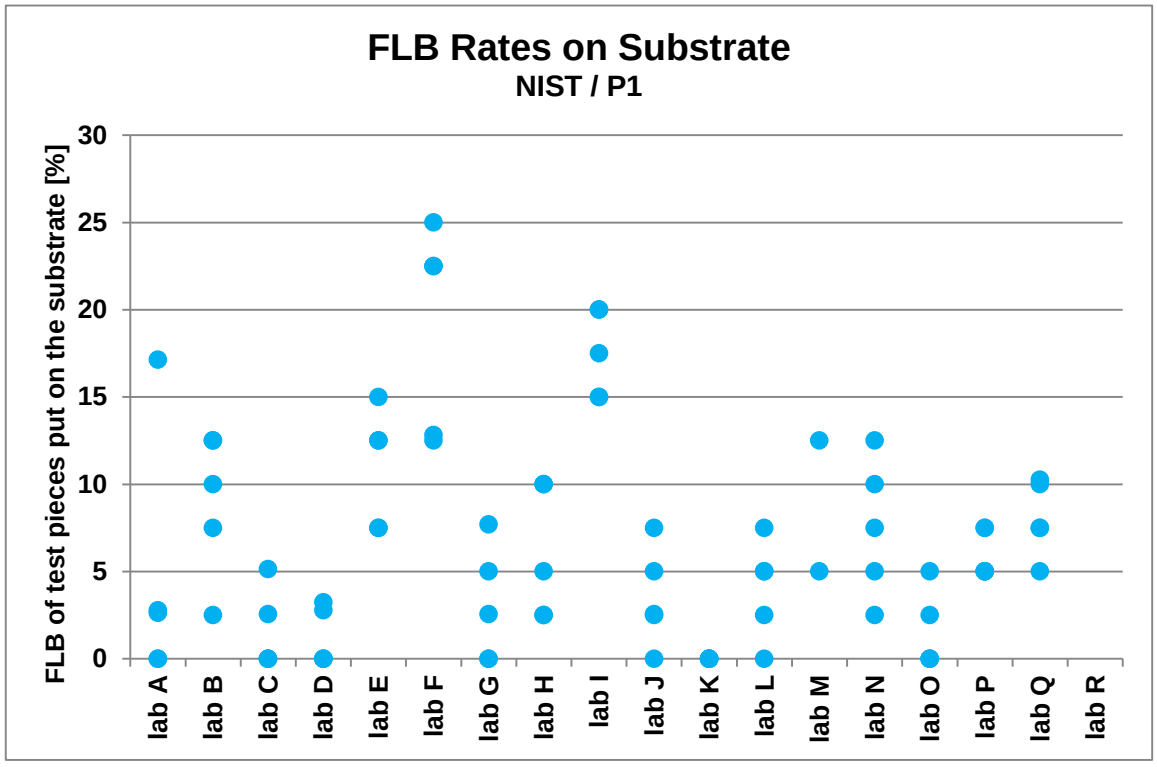
**Appendix B.3. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for CORESTA Monitor IP 2 on substrate P3.**



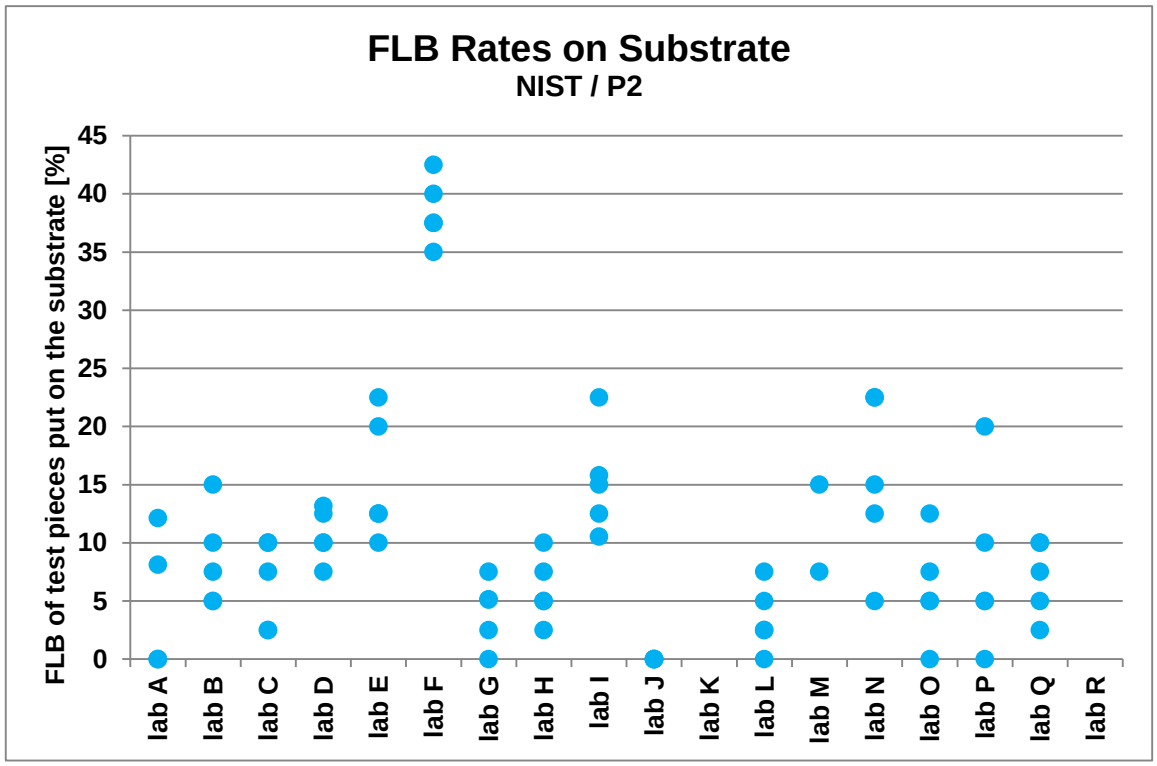

**Appendix B.4. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for CORESTA Monitor IP 2 on substrate P4.**



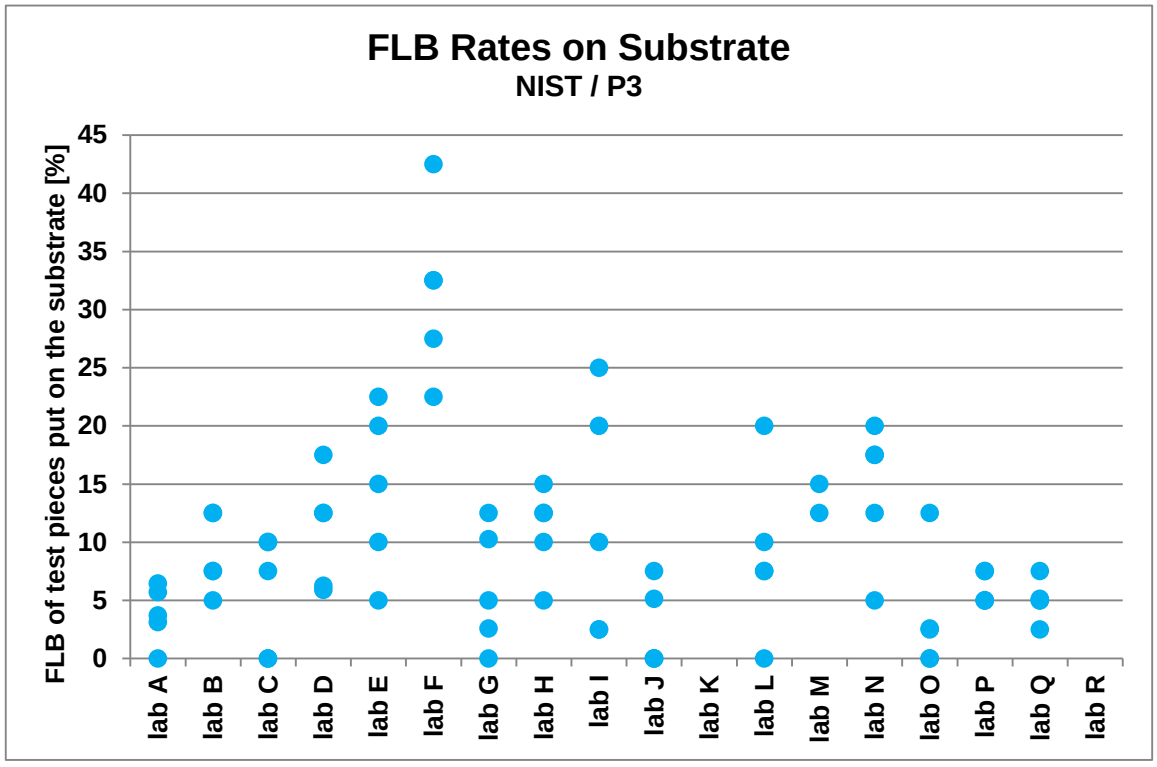
**Appendix B.5. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for the NIST Standard on substrate P1.**



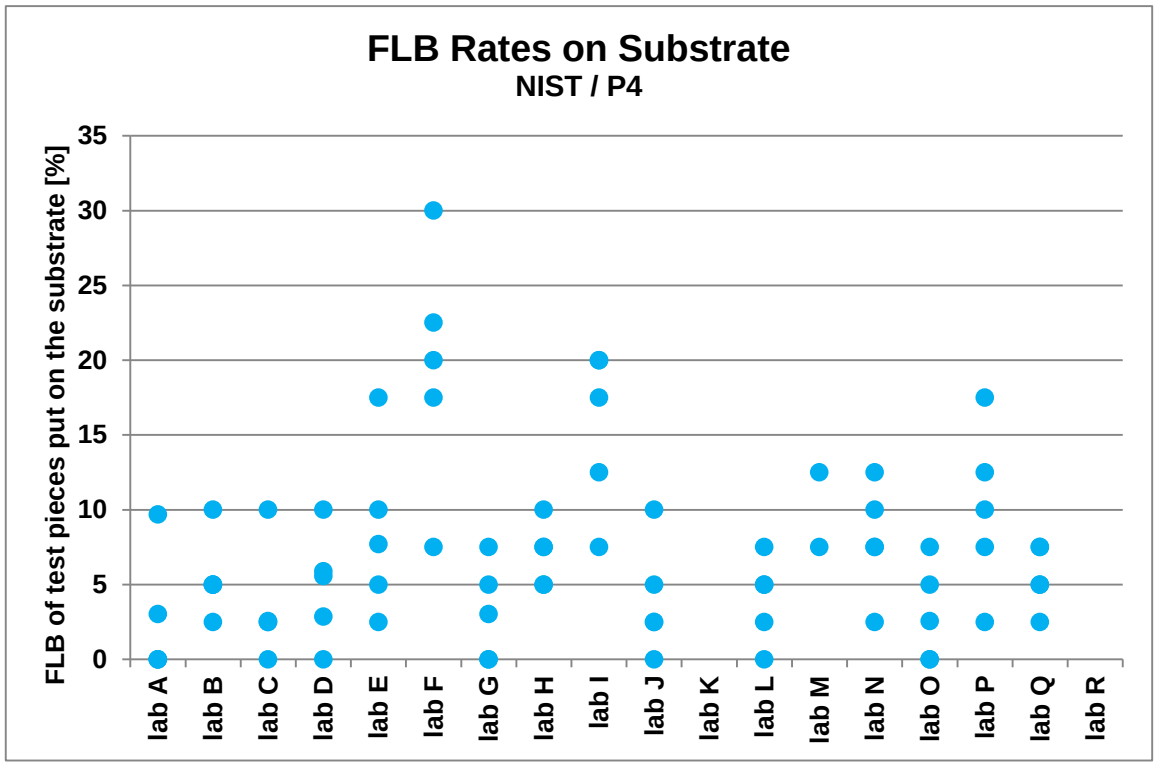

**Appendix B.6. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for the NIST Standard on substrate P2.**



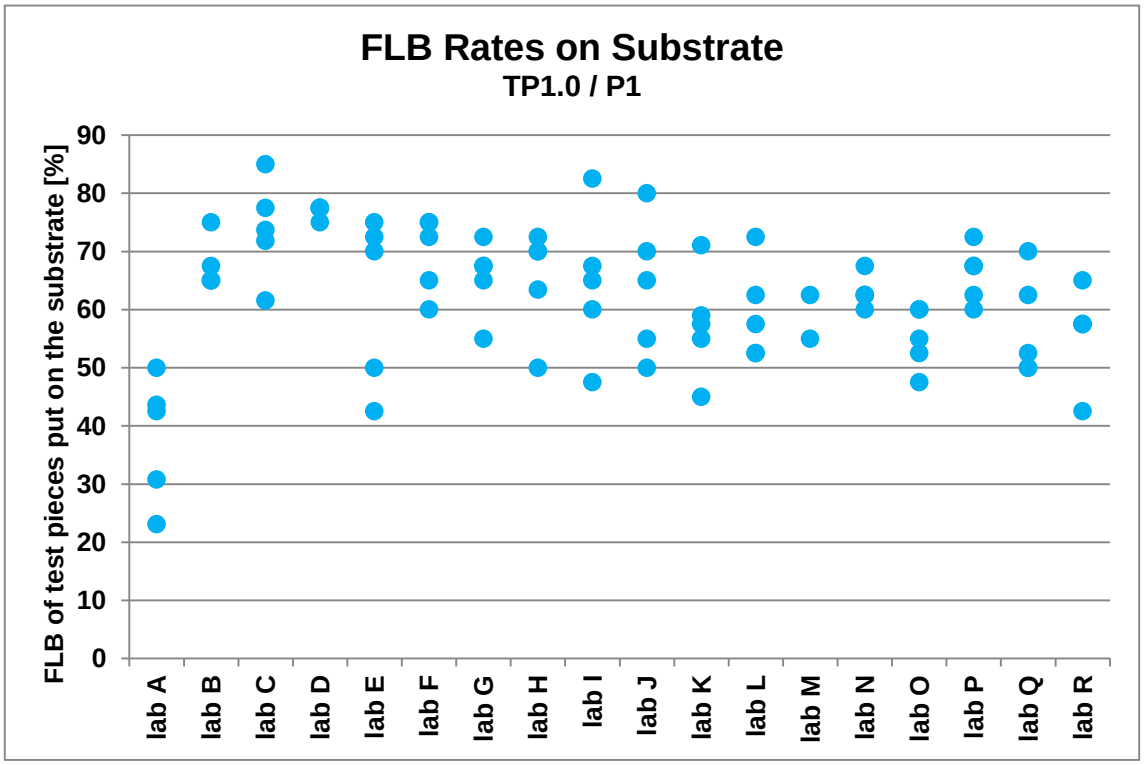
**Appendix B.7. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for the NIST Standard on substrate P3.**



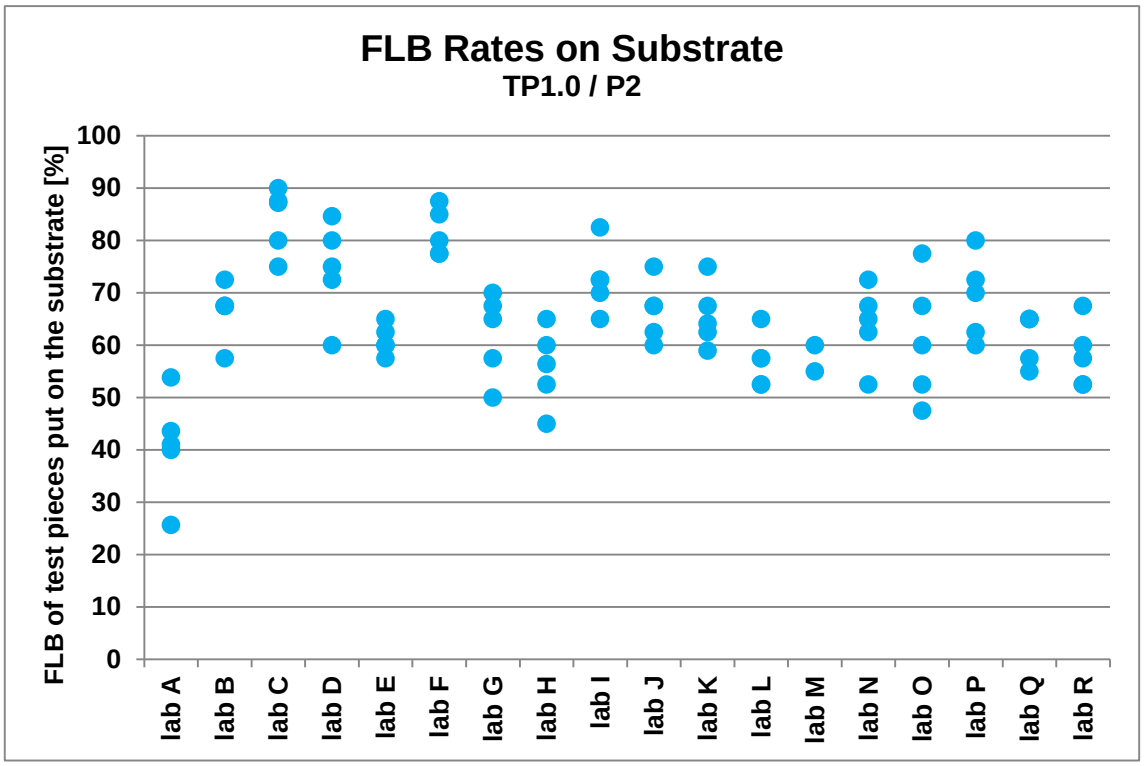

**Appendix B.8. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for the NIST Standard on substrate P4.**



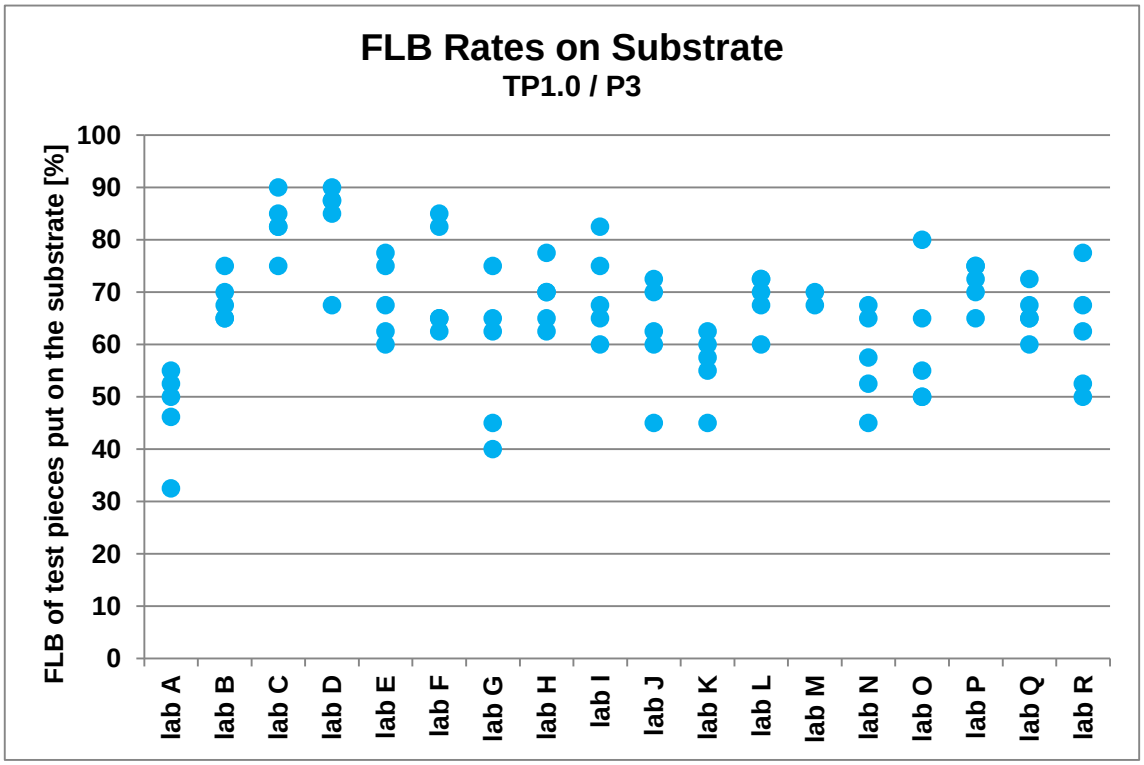
**Appendix B.9. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for Test Product TP 1.0 on substrate P1.**



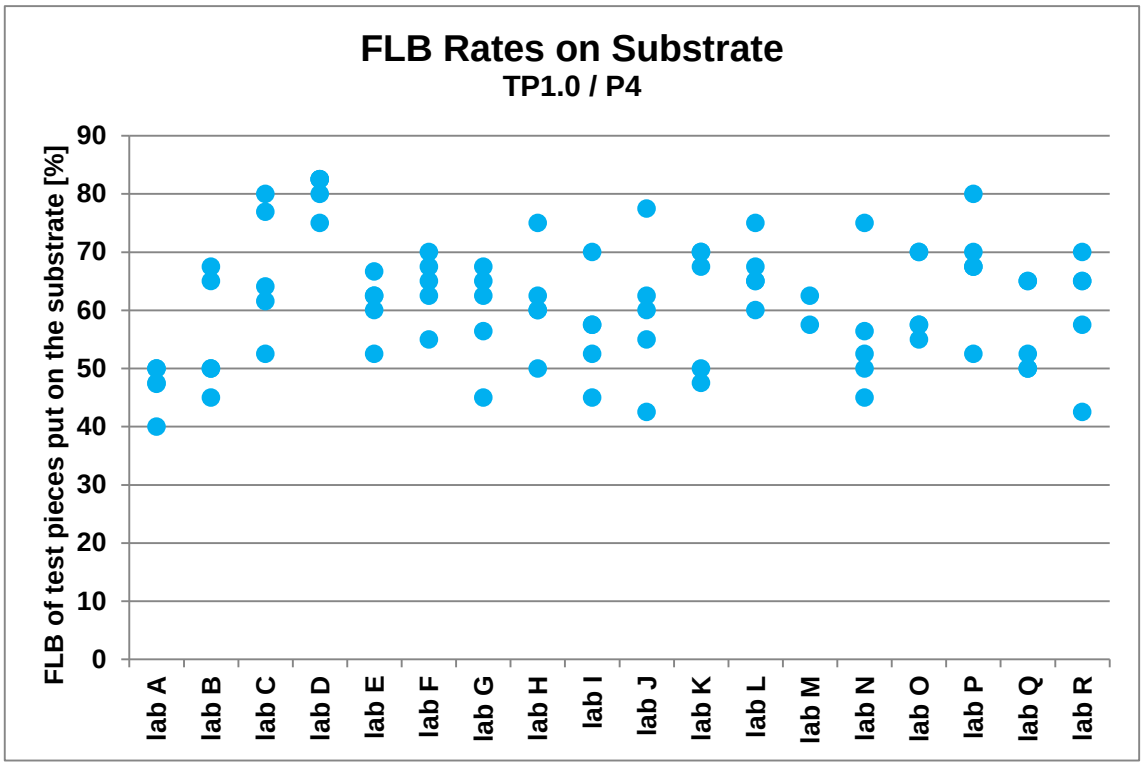

**Appendix B.10. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for Test Product TP 1.0 on substrate P2.**



**Appendix B.11. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for Test Product TP 1.0 on substrate P3.**

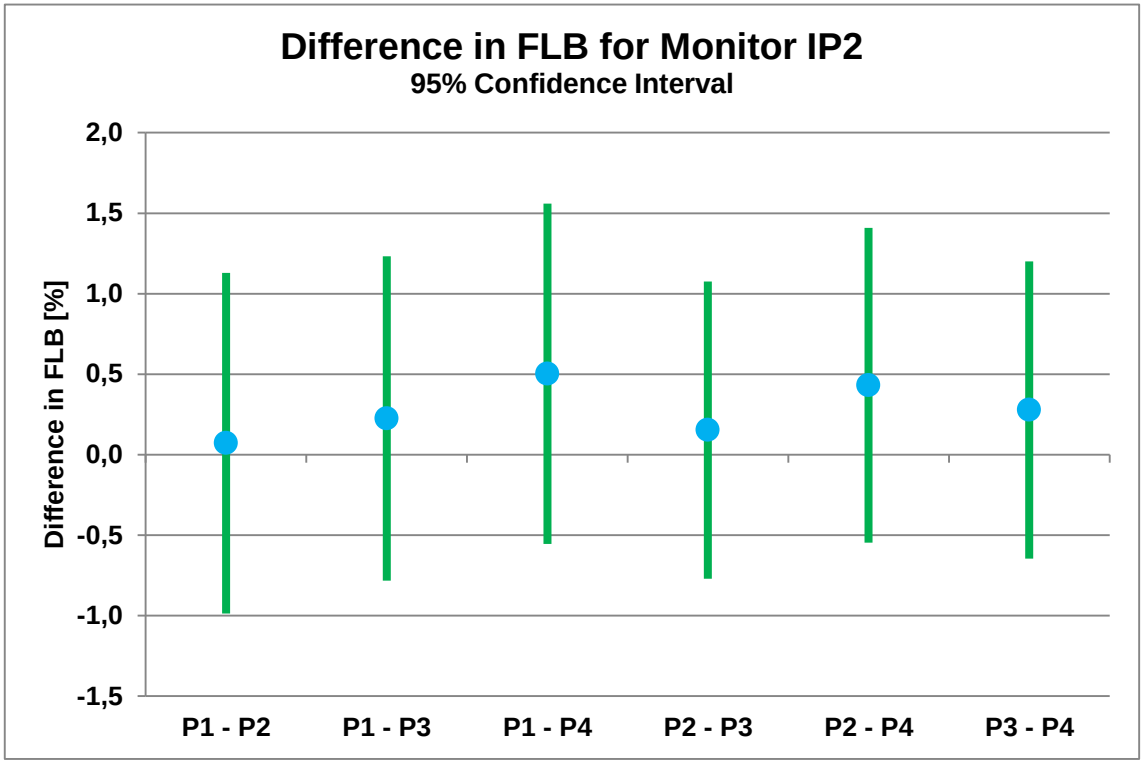



**Appendix B.12. Rate of FLB of test pieces placed on the substrate ($N_{FLB}/N_{ToS}$) for Test Product TP 1.0 on substrate P4.**

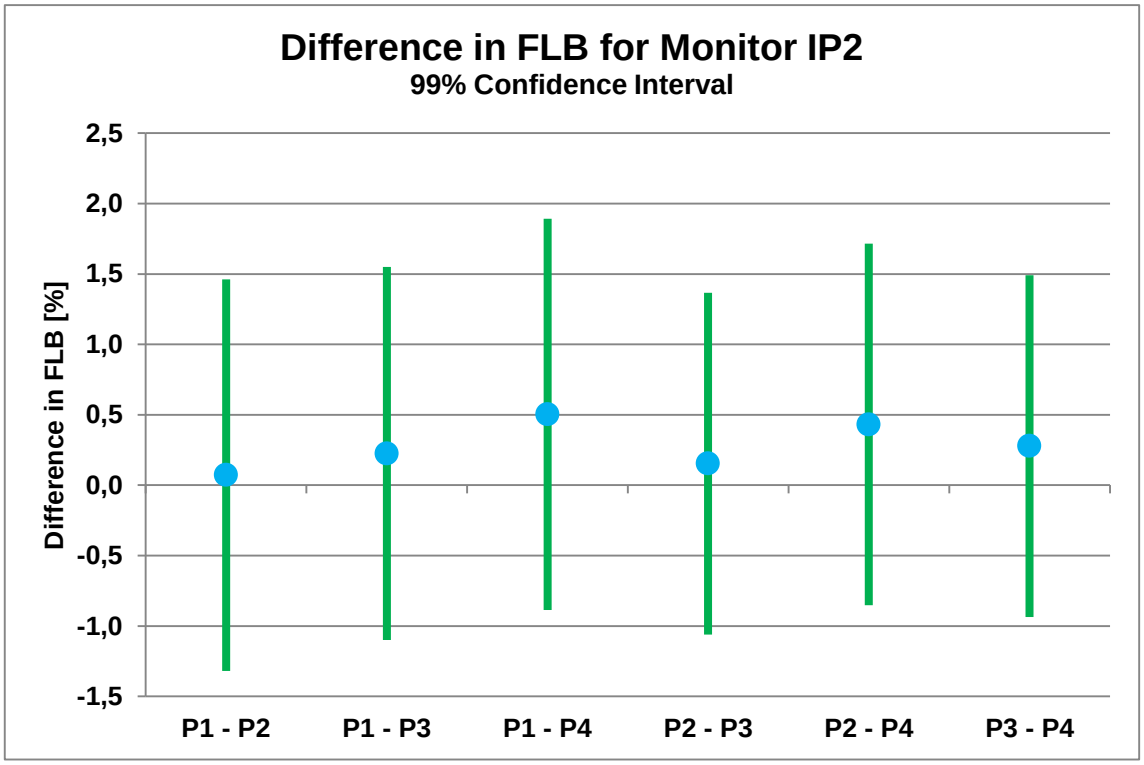


# APPENDIX C - Confidence Intervals for Differences

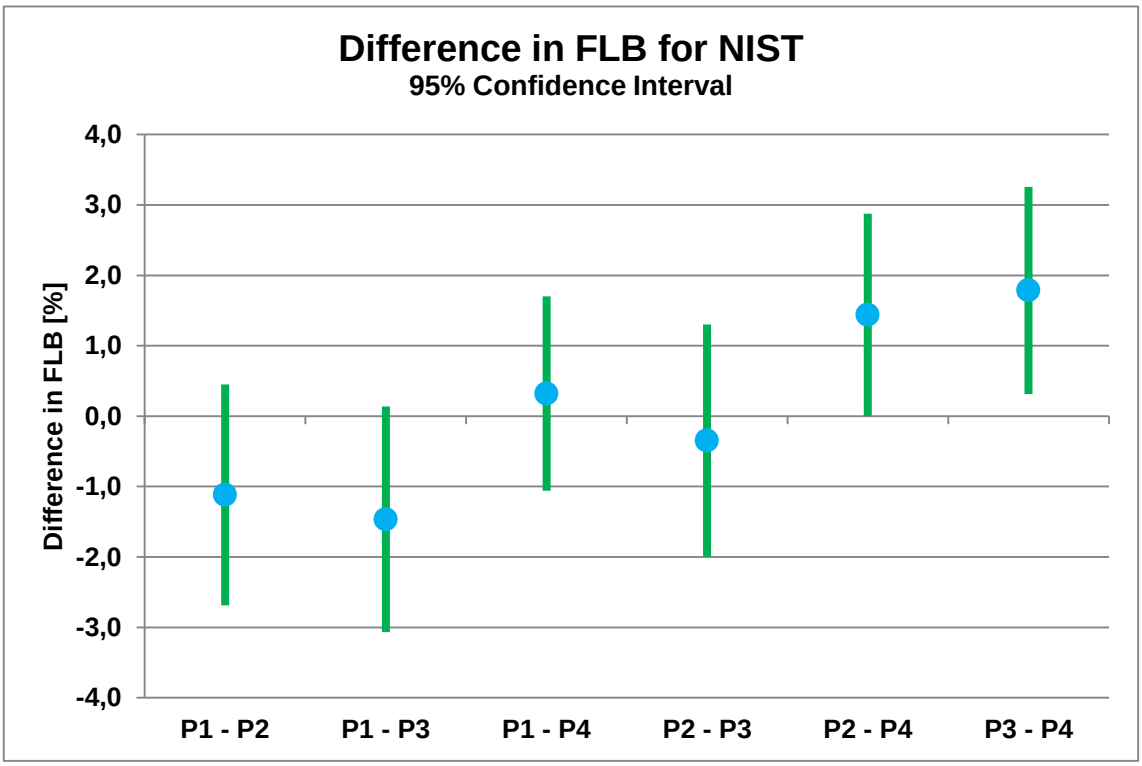
**Appendix C.1. 95 % Confidence interval for the difference in the rate of FLB between substrates for CORESTA Monitor IP 2.**



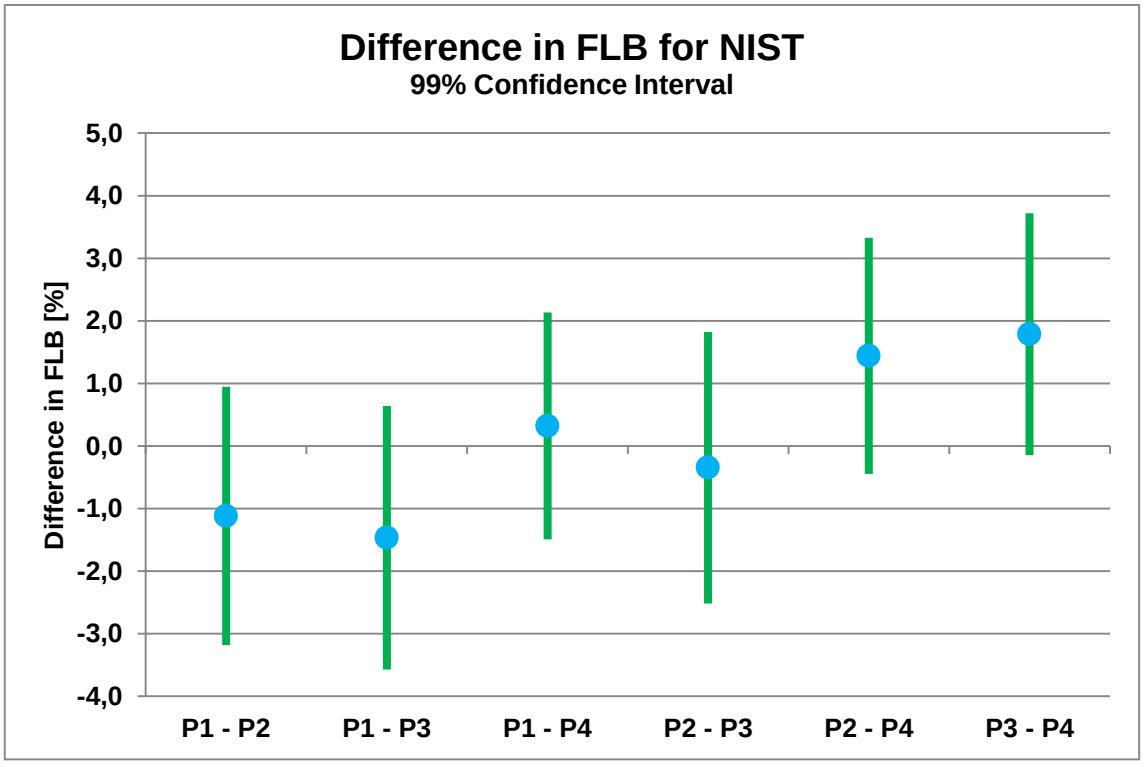

**Appendix C.2. 99 % Confidence interval for the difference in the rate of FLB between substrates for CORESTA Monitor IP 2.**



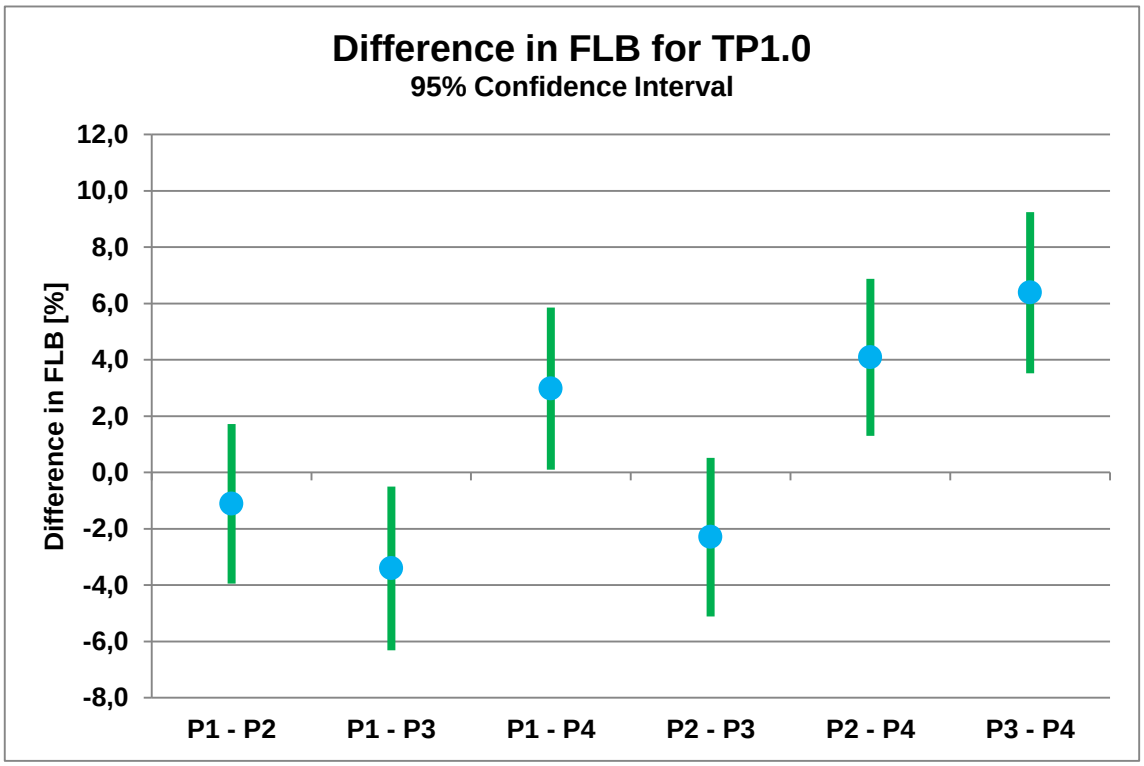
**Appendix C.3. 95 % Confidence interval for the difference in the rate of FLB between substrates for the NIST Standard.**



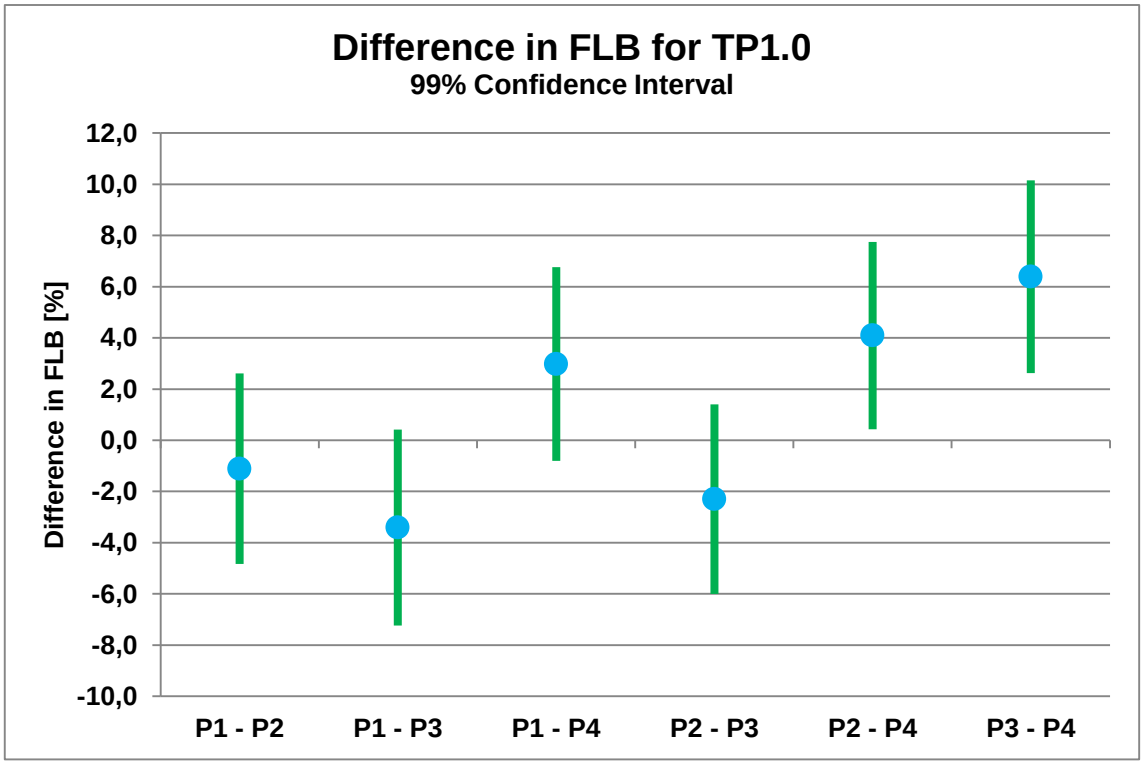

**Appendix C.4. 99 % Confidence interval for the difference in the rate of FLB between substrates for the NIST Standard.**



**Appendix C.5. 95 % Confidence interval for the difference in the rate of FLB between substrates for TP 1.0.**

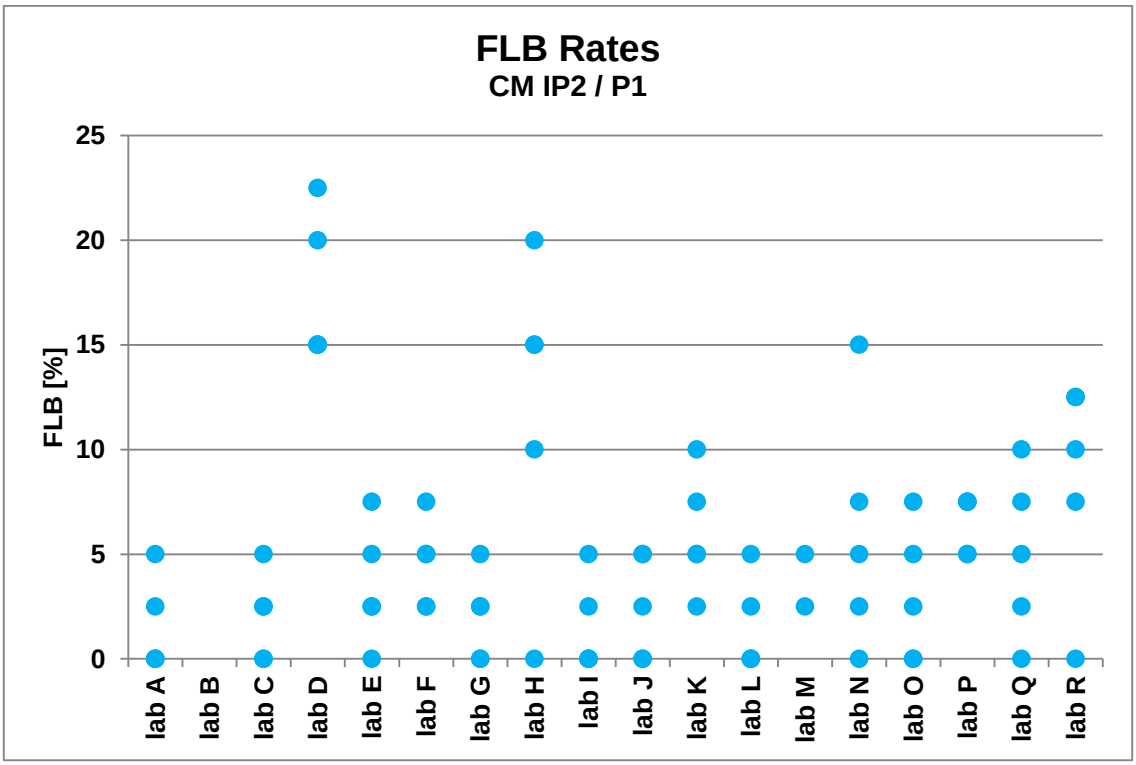



**Appendix C.6. 99 % Confidence interval for the difference in the rate of FLB between substrates for TP 1.0.**

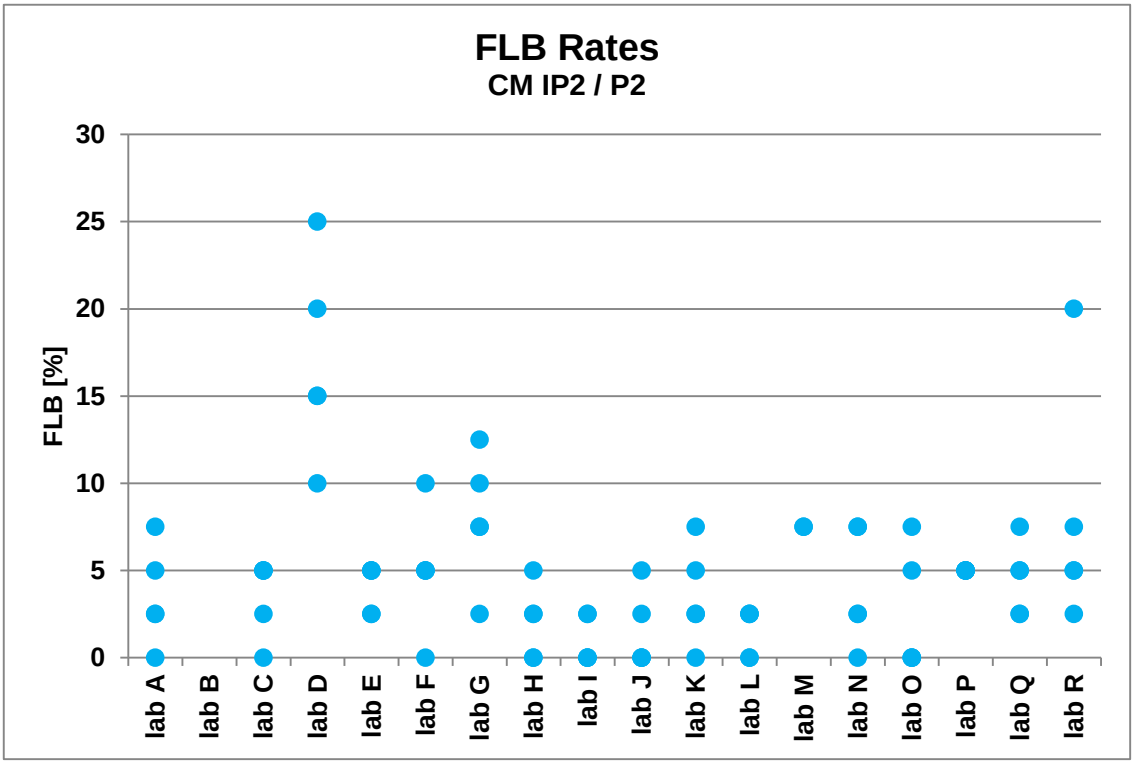


# APPENDIX D - Raw Data for r&R

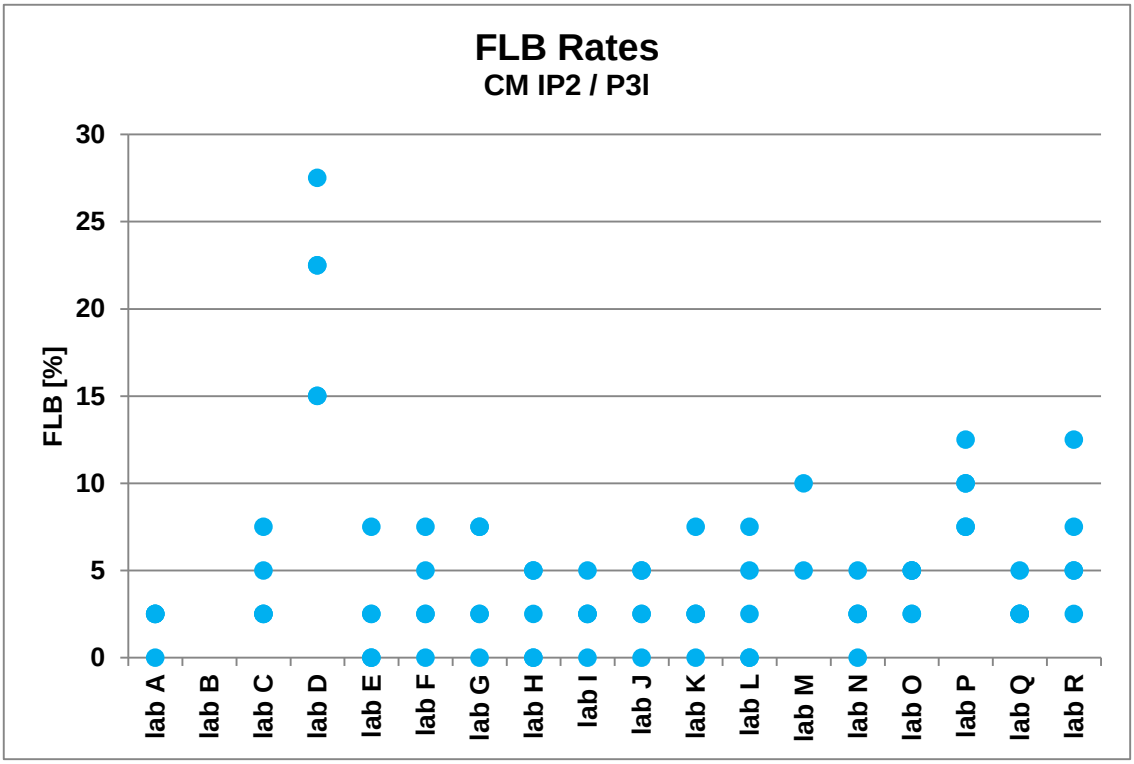
**Appendix D.1. Rate of FLB ($N_{FLB}/N_{ToT}$) for CORESTA Monitor IP 2 on substrate P1.**



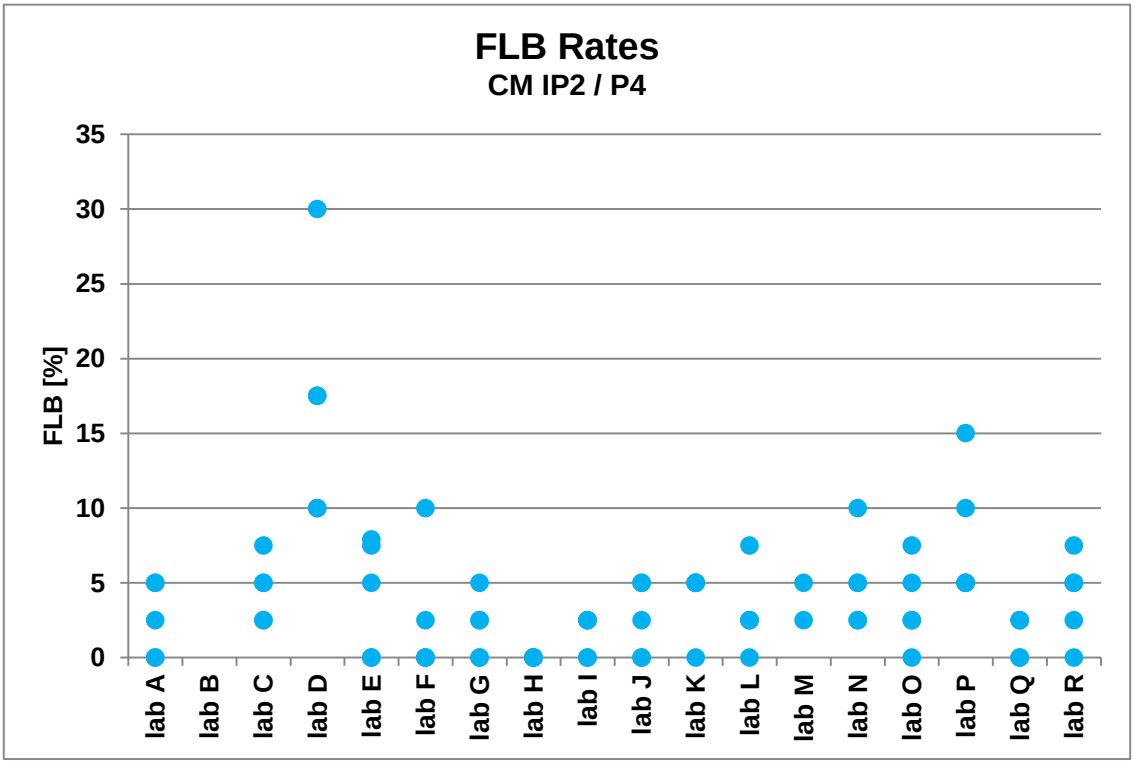

**Appendix D.2. Rate of FLB ($N_{FLB}/N_{ToT}$) for CORESTA Monitor IP 2 on substrate P2.**



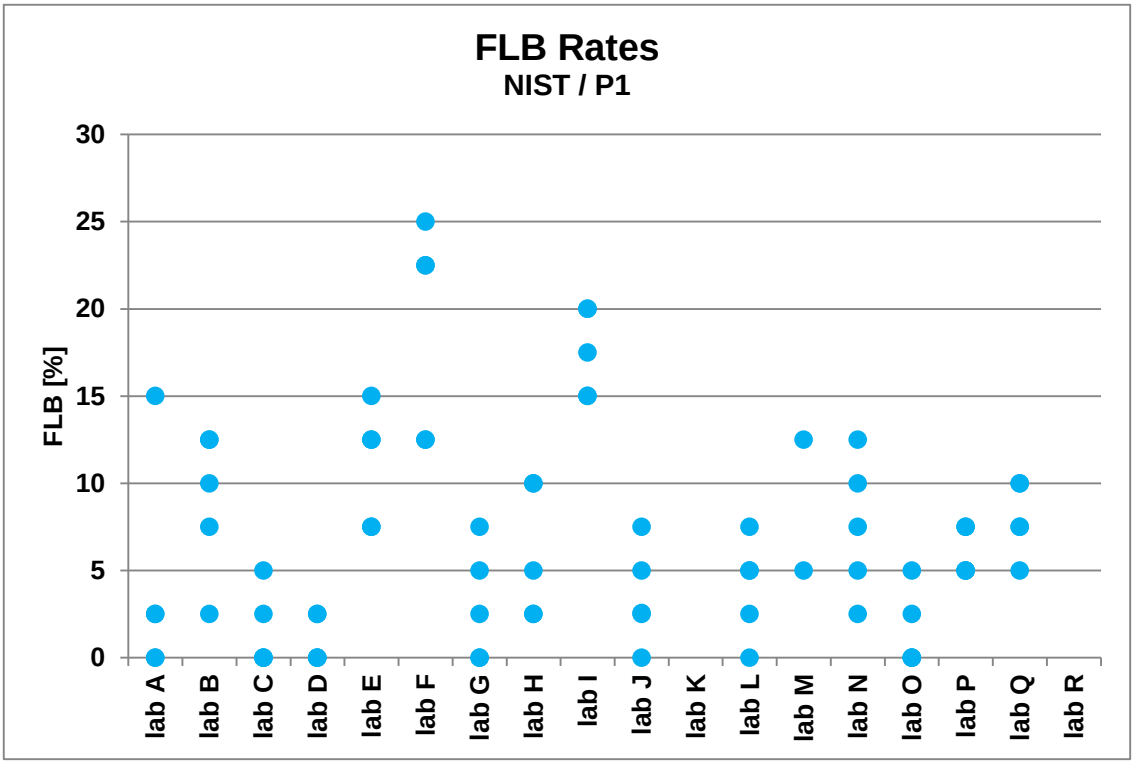
**Appendix D.3. Rate of FLB ($N_{FLB}/N_{ToT}$) for CORESTA Monitor IP 2 on substrate P3.**



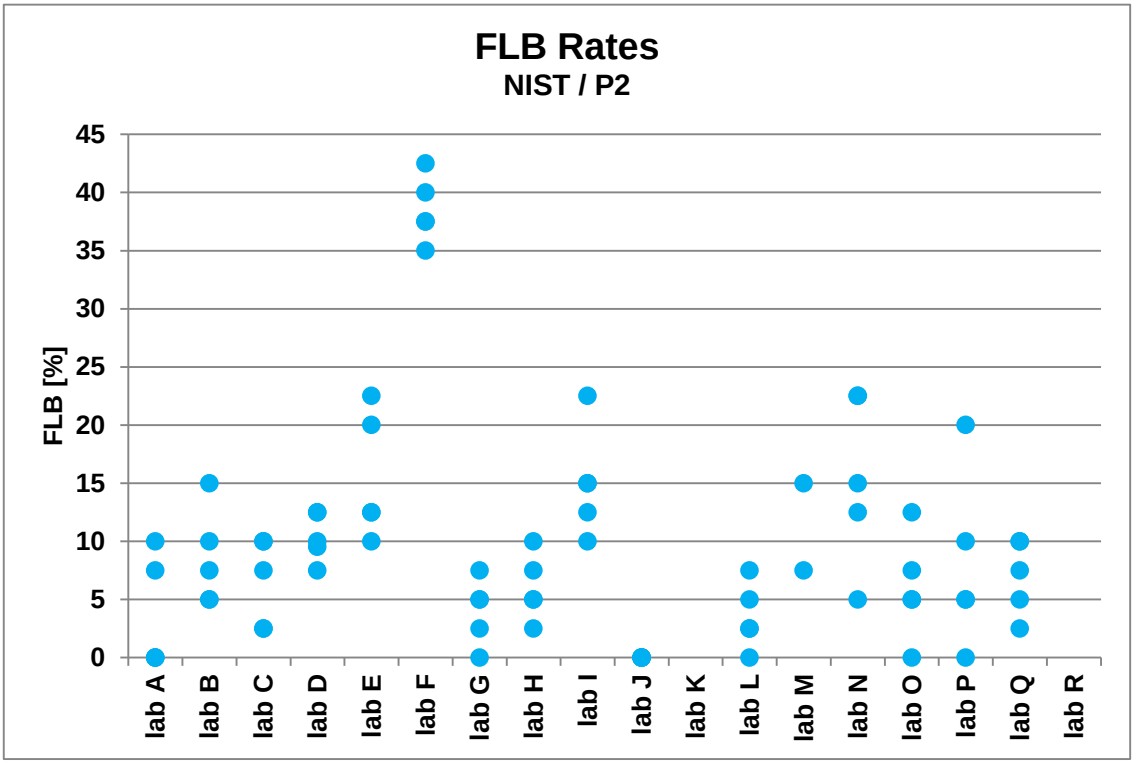

**Appendix D.4. Rate of FLB ($N_{FLB}/N_{ToT}$) for CORESTA Monitor IP 2 on substrate P4.**



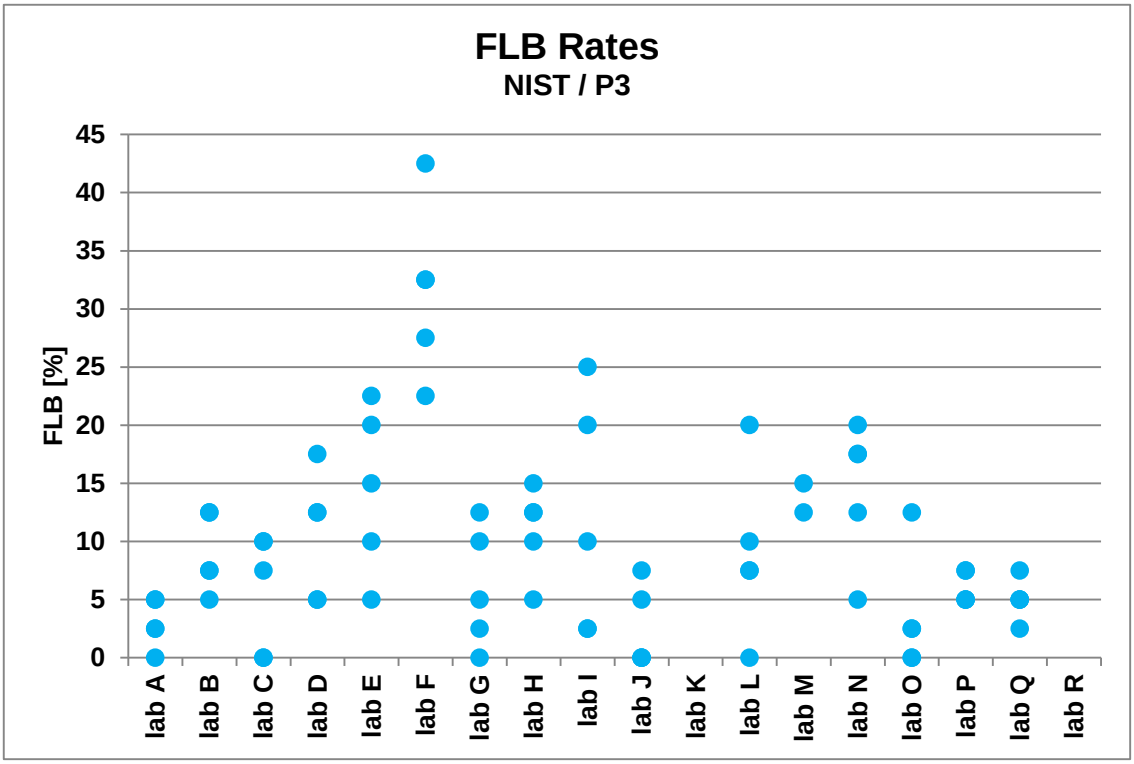
**Appendix D.5. Rate of FLB ($N_{FLB}/N_{ToT}$) for the NIST Standard on substrate P1.**



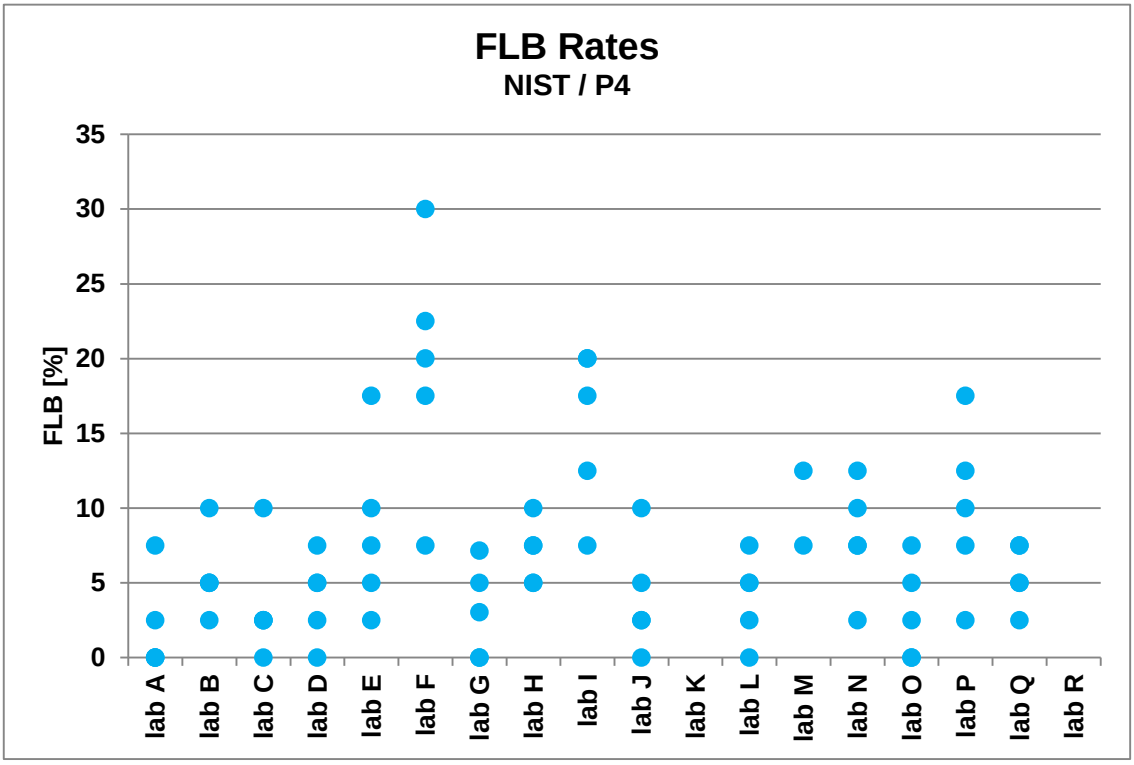

**Appendix D.6. Rate of FLB ($N_{FLB}/N_{ToT}$) for the NIST Standard on substrate P2.**



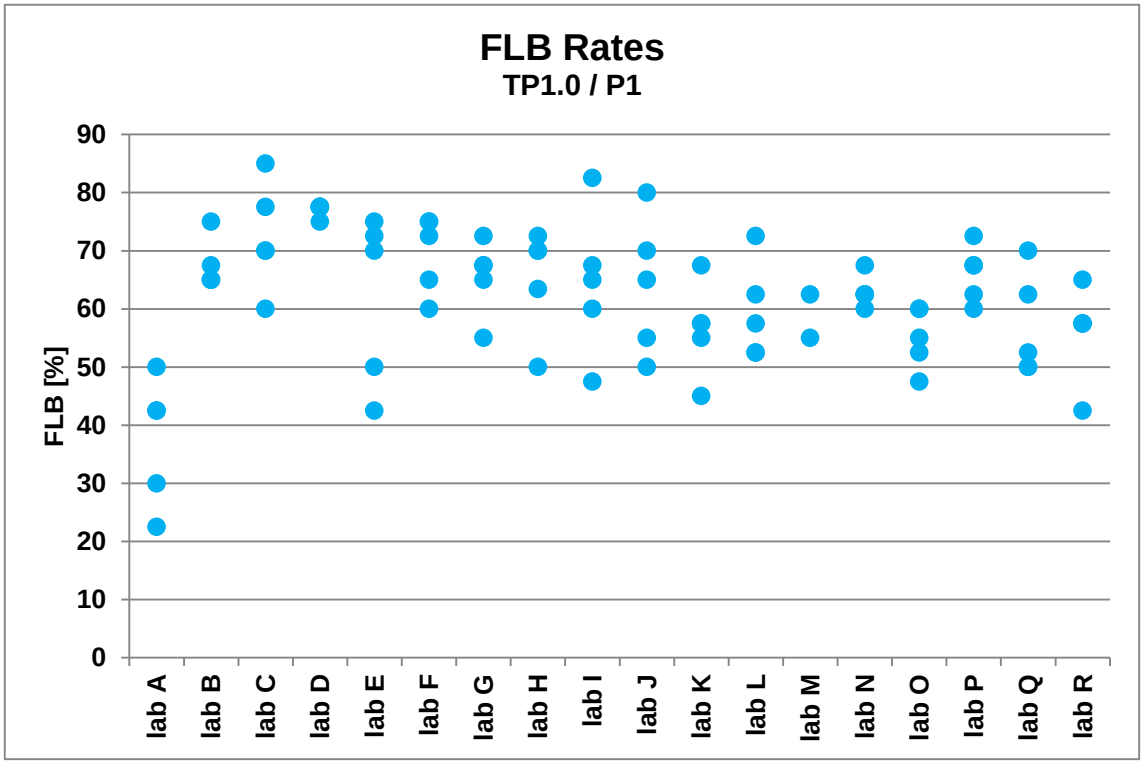
**Appendix D.7. Rate of FLB ($N_{FLB}/N_{ToT}$) for the NIST Standard on substrate P3.**



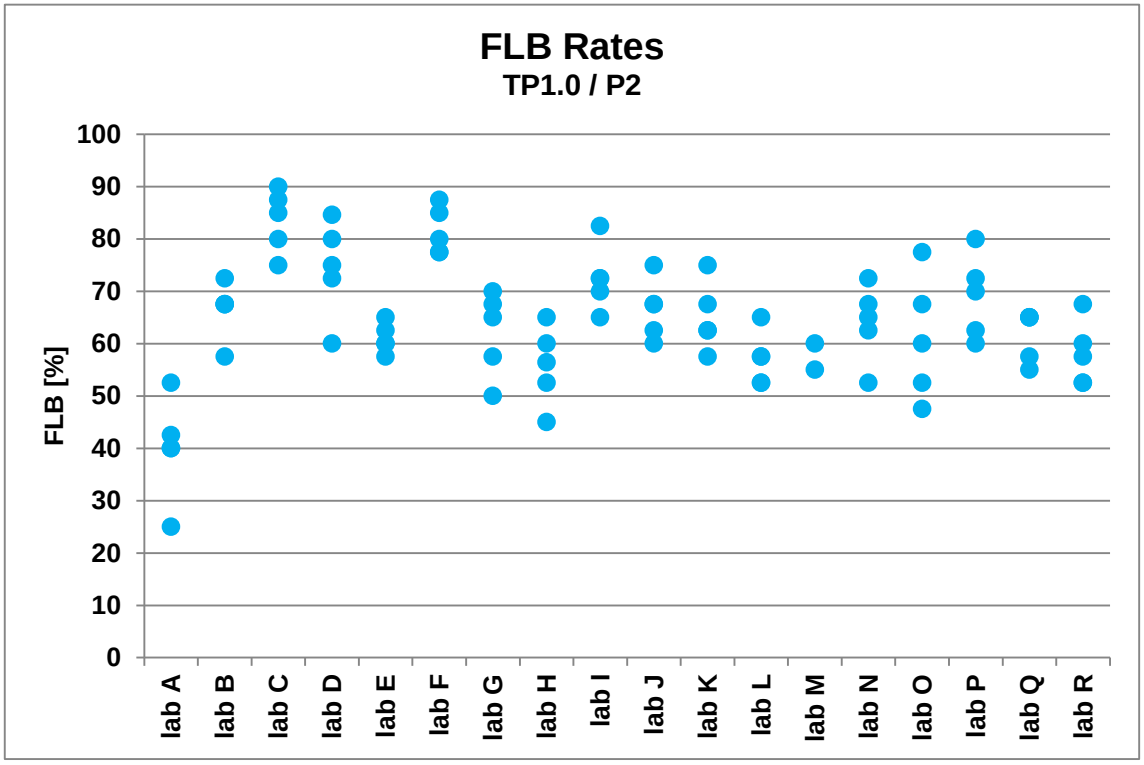

**Appendix D.8. Rate of FLB ($N_{FLB}/N_{ToT}$) for the NIST Standard on substrate P4.**



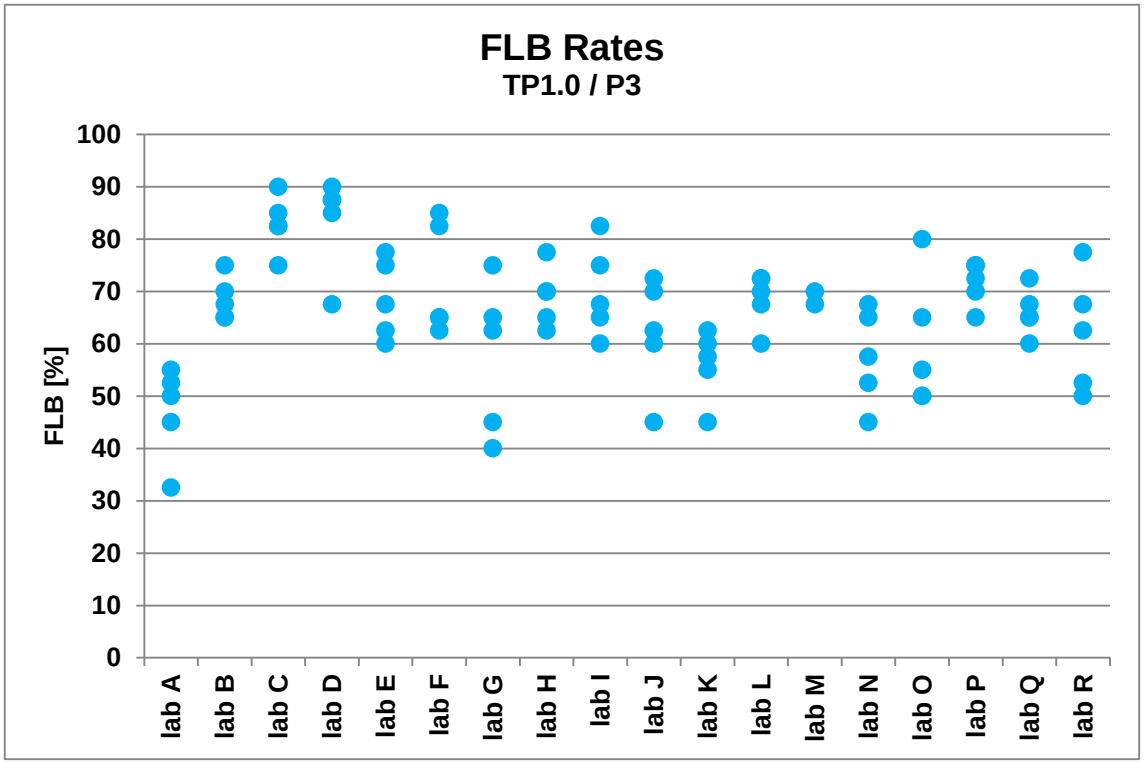
**Appendix D.9. Rate of FLB ($N_{FLB}/N_{ToT}$) for Test Product TP 1.0 on substrate P1.**




**Appendix D.10. Rate of FLB ($N_{FLB}/N_{ToT}$) for Test Product TP 1.0 on substrate P2.**



**Appendix D.11. Rate of FLB ($N_{FLB}/N_{ToT}$) for Test Product TP 1.0 on substrate P3.**




**Appendix D.12. Rate of FLB ($N_{FLB}/N_{ToT}$) for Test Product TP 1.0 on substrate P4.**