APPLICATION NOTE

Keysight Pass/Fail Decision Rules

Determine your application's decision rule and calibration service

KEYSIGHT

Measurement Decision Risk Overview

In a pass/fail test application, the test system makes a measurement and then compares the result to a published specification. This repeated process ensures the device under test (DUT) conforms to its specified requirements. As much as we would like to trust the accuracy of the pass/fail measurement result, there are always two possible outcomes:

1. A correct pass/fail decision
2. An incorrect pass/fail decision
   a. Called “false accept”, or “false reject”

This is because all measurements contain errors. The “uncertainty of measurement” includes errors expressed as a standard deviation of all error contributions [1]. Figure 1 shows two identical measurement results but with different measurement uncertainties. The expanded uncertainty[1] in the case “A” measurement result occurs within the tolerance limit. The case “B” measurement result has a significantly larger measurement uncertainty. There is a higher risk of falsely accepting a result in case B, because of the larger measurement uncertainty as indicated by “What is the level of risk?” in Figure 1.

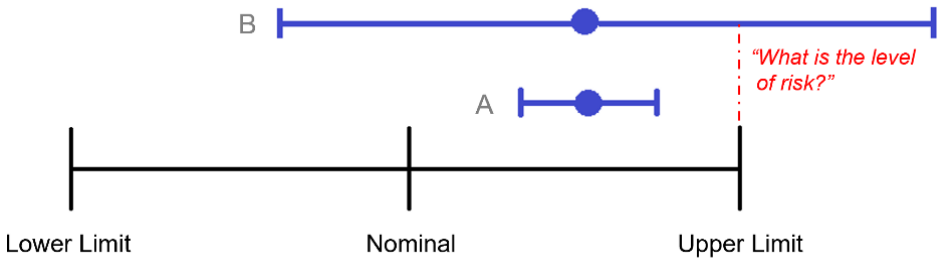


Figure 1. Illustration of measurement decision risk

Keysight Calibration Services Provide:

- Measurement results that indicate a correct pass/fail decision.
- Minimized measurement uncertainties during performance test development with Keysight’s high-quality lab standards and calibration procedures.

1. Expanded uncertainty refers to a 95% coverage interval generally equivalent to two standard deviations of the standard measurement uncertainty. See [1] for more information.

Measurement Decision Rules and Why You Should Care

A measurement decision rule “describes how measurement uncertainty is accounted for when stating conformity with a specified requirement” (clause 3.7 of [3] in the ISO/IEC standard).

Different decision rules result in different levels of false-accept or false-reject risk. As a result, the revised ISO/IEC 17025:2017 [3] includes a requirement to provide end calibration customers with the details of the decision rule used. “*When the customer requests a statement of conformity to a specification or standard for the test or calibration (e.g., pass/fail, in tolerance / out of tolerance) the specification or standard, and the decision rule shall be clearly defined. Unless inherent in the requested specification or standard, the decision rule selected shall be communicated to, and agreed with, the customer*” (clause 7.1.3 of [3]).

Decision rules of third-party calibration services

Often, a shortcoming of third-party calibration services is the use of performance measurements for only a subset of published specifications. Also, these services may make calibration measurements in reference to out-of-date lab standards which can lead to incorrect pass/fail decisions when the instrument is used in test applications. Additionally, when a third party observes a parameter out of specification, the risk of a false reject is significant. This means that the “true result” may be within specification. Likewise, a parameter that appears within specification, a false-accept, may actually be out of specification. In any case, the third party is not able to perform the proprietary instrument adjustments needed to return an instrument to specification.

Decision rules of Keysight Calibration Services

Keysight’s clear definitions of the decision rules used for each calibration service appear in both text and figures in this document. The following section provides an overview of each service.

Calibration Services

Keysight Calibration Services help you to make measurements with confidence by minimizing measurement uncertainties during test development, both in the selection of lab standards and in the calibration procedures.

For details of Keysight calibration services, please visit www.keysight.com/find/calibration.

Keysight offers a choice of these calibration services:

- Keysight Calibration (Keysight Cal)
- Keysight Cal + Uncertainties
- Keysight Cal + Uncertainties + Guardbanding

Keysight Calibration

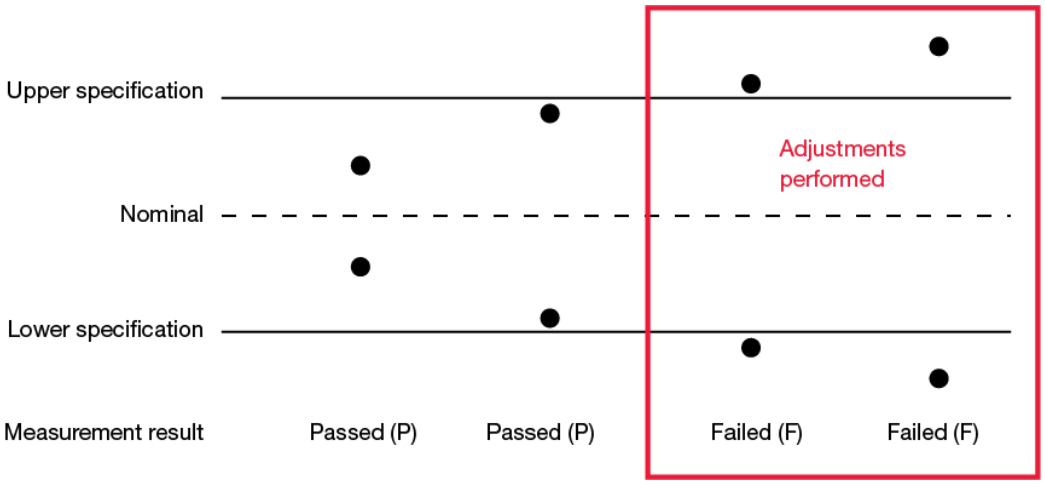


Figure 2. Decision rule for Keysight Calibration

The Keysight Cal service is the most economical service and provides the following:

1. Accurate measurements of current performance corresponding to *all* specifications (Case A, Figure 1).
2. Adjustments for any parameter observed out of specification.
3. A measurement report of all measurements performed.

Keysight Calibration uses a binary decision rule:

- Passed – The equipment's measured values are observed within specification at the points tested.
- Failed – One or more of the equipment's measured values are observed out of specification at the points tested.

Note: Keysight Cal reports do not include the measurement uncertainty associated with each measured value; therefore, this calibration service is not considered compliant with *all* requirements of ISO/IEC 17025:2017.

Benefits of Keysight Calibration Service

Keysight's instrument production process includes a complete series of adjustments to ensure optimal performance just prior to final test. In general, instruments tend to drift over time. A Periodic instrument calibration, including a measurement comparison with the published specifications, will ensure continued accurate measurements for all specified parameters.

Keysight Calibration + Uncertainties

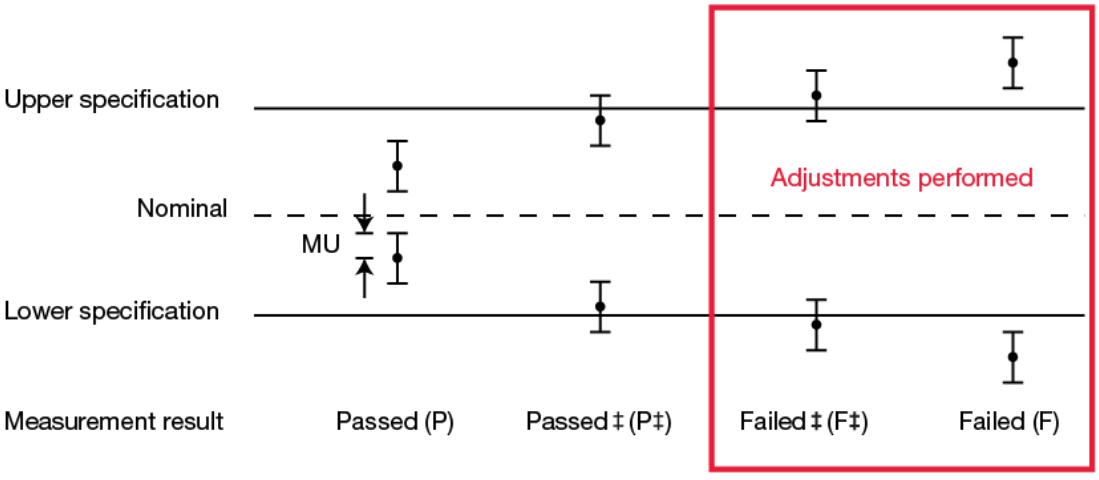


Figure 3. Decision rule for Keysight Calibration + Uncertainties

The Keysight Cal + Uncertainties service is the main calibration offering and provides the following:

1. Accurate measurements of current performance corresponding to all specifications (see case A of Figure 1).
2. Adjustments for any parameter observed out of specification.
3. A report of all measurements performed, including point-by-point measurement uncertainty.
4. Results based on a nonbinary decision rule featuring four statements of conformity to give customers more insight.
5. Compliance with ISO/IEC 17025:2017.

The Keysight Cal + Uncertainties service is fully compliant with ISO/IEC 17025:2017. For reporting, this service employs a nonbinary decision rule resulting in four statements of conformity, as illustrated.

Customers can confidently rely on very low decision risk with either **Passed** or **Failed**.

Passed ǂ results are observed as in-specification. However, there is an increased risk of false acceptance compared with Passed. Customers receiving an instrument with Passed ǂ may see their production specification performance margin eroding. We provide tools to estimate this risk below and reference [4].

Failed ǂ results are observed as out-of-specification. There is an increased risk of false rejection compared to Failed. Customers receiving an instrument with Failed ǂ may be falsely rejecting their products in final test because the instrument is operating out of specification. Below we provide tools to estimate this false-reject risk and reference [4].

Note: Keysight performs adjustments for any results marked Failed ǂ or Failed.

Benefits of Keysight Cal + Uncertainties Service

Keysight Cal + Uncertainties service is fully compliant with ISO/IEC 17025:2017 and ANSI Z540-1. In addition, many Keysight laboratories accredited to ISO/IEC 17025:2017 for the parameters and ranges covered in their scope of accreditation (http://www.keysight.com/find/accreditation) may include the accreditation body symbol on these reports.

The Keysight calibration report includes the measurement uncertainty and customers can use the tools included in this application note to estimate the false-accept percent risk for Passed ǂ results or the false-reject percent risk for Failed ǂ results.

KeysightCal + Uncertainties + Guardbanding

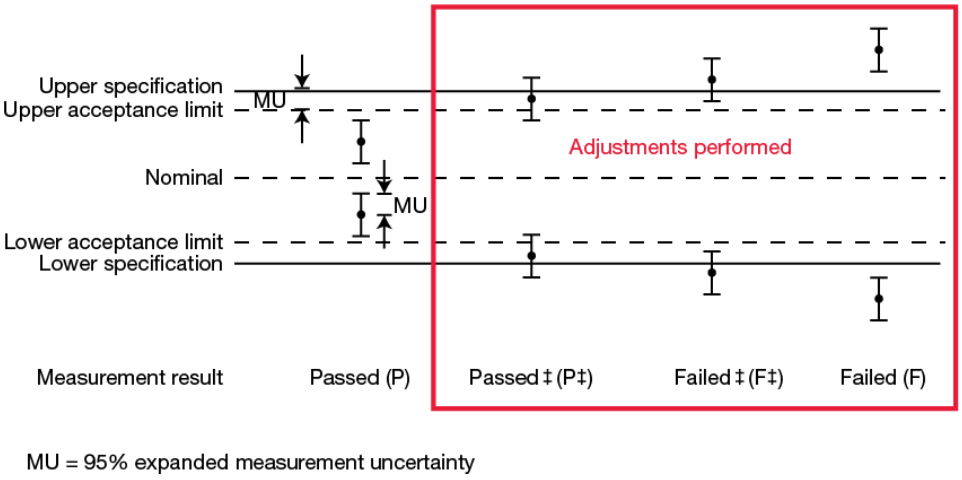


Figure 4**.** Decision rule for Keysight Cal + Uncertainties + Guardbanding

The Keysight Cal + Uncertainties + Guardbanding service is a premium offering and provides the following:

1. Accurate measurements of current performance corresponding to all specifications (see case A of Figure 1).
2. Adjustments for any parameters observed Passed ǂ (or any Undetermined results) and out of specification.
3. A report of all measurements performed, including point-by-point measurement uncertainty.
4. Results based on a nonbinary decision rule featuring four statements of conformity to give customers more insight.
5. Compliance with ISO/IEC 17025:2017 and ANSI Z540.3:2006.

The Keysight Cal + Uncertainties + Guardbanding service uses a nonbinary decision rule that uses a guardband with a 95% expanded measurement uncertainty for reporting results and triggering adjustments. This results in four statements of conformity, as illustrated.

Keysight developed this service to ensure strict compliance with ISO/IEC 17025:2005 and ILAC-G8:03/2009. Accordingly, two of the statements-of-conformity labels are Undetermined which indicates that a portion of the 95% expanded uncertainty crosses the specification limit. However, the Undetermined statement of conformity provides no information whether the observed measurement is in or out of specification. Based on changes in ISO/IEC 17025:2017 [3] and ILAC-G8:09/2019 [5], Keysight will transition to using the same Passed ǂ and Failed ǂ statements of conformity as used for the Keysight Cal + Uncertainties service.[1]

The only difference between the two services is that the Keysight Cal + Uncertainties + Guardbanding service includes additional adjustments for Passed ǂ results (or any Undetermined results).

Benefits of Keysight Cal + Uncertainties + Guardbanding

The Keysight Cal + Uncertainties + Guardbanding service offers a premium calibration with the lowest false-accept risk of any of Keysight's calibration service alternatives. It ensures a probability of false acceptance of 2% or less and a probability of false rejections of 15% or less. Customers who want to maximize production margins to their specifications rely on this cal service.

This calibration service is fully compliant with ISO/IEC 17025:2017, ANSI Z540.3, and ILAC-G8:2019. In addition, many Keysight laboratories accredited to ISO/IEC 17025:2017 for the parameters and ranges covered in their scope of accreditation (http://www.keysight.com/find/accreditation) may include the accreditation body symbol on these reports.

You can use the tools included in this application note to estimate the false-accept percent risk for any Passed ǂ results or the false-reject percent risk for Failed ǂ results. However, you can count on your instrument once again meeting all published specifications with a 95% measurement uncertainty guardband.

KEYSIGHTCARE

Proper equipment calibration is important to achieve and maintain confidence in your measurement results. Keysight provides these different levels of periodic high-quality instrument calibration and recommends KeysightCare Enhanced, which includes calibration to ensure your instruments are always accurate, operate within specifications, and have compliance backed by calibration certificates.

Experience the Enhanced level of service, including technical support, and committed repair and calibration turnaround times, to help you stay on schedule, accelerate test, ensure precision, and optimize uptime. KeysightCare Enhanced provides 2-, 3-, and 5-year plans that include a calibration service of choice with a 5-day committed turnaround time and additional benefits of technical support response in 2 business hours, and repair coverage, if needed, with a 7-day instrument repair turnaround time. Our calibration services ensure your test system performs to specification and meets local and global standards.

1. Keysight Technologies employs multiple software platforms. It will take some time before Keysight converts all current measurement reports to the new statements of conformity.

Estimating the level of false-accept or false-reject risk

ISO/IEC 17025:2017 clause 7.8.6.1 states, *"When a statement of conformity to a specification or standard is provided, the laboratory shall document the decision rule employed, taking into account the level of risk (such as false accept and false reject and statistical assumptions) associated with the decision rule employed, and apply the decision rule."*

Before introducing the estimation tools, it is important to understand the two types of risk:

1. *Specific risk* is the probability that an accepted item is nonconforming or that a rejected item does conform. This risk is based on measurements of a single item. [2]
2. *Average risk*[2] is the average probability that an accepted item is nonconforming or that a rejected item does conform. It does not directly address the probability of false acceptance to any single item, discrete measurement result, or individual workpiece. [2]

For more information on the statistical theory regarding specific and average risk, please see references [2], [4], and [7]. Specific risk is most appropriate for singular reference standards such as a precision mass or measuring instruments that have not been calibrated for a number of years.

As part of internal quality policies, many measurement instrument owners submit their instruments for regular calibration and track the percent of similar instruments (by manufacturer model) that pass-all-specifications. This is true for those who comply with the ANSI Z650-1:2002 or ANSI Z540.3-2006 user requirements. Average risk is more appropriate[3] for these users.

As you work to determine and better understand the level of false-accept or false-reject risk of your test system, here are some things to consider. Terms such as high, medium, and low risk mean something different to everyone, so these are not useful. Most people understand and make decisions based on percent risk. One example is when an auto service technician tells you, "Based on the rate of wear of your car's brake pads, the current thickness, and the time until the next scheduled service, there is a 65% probability that your brake pads will score the rotor drum. Would you like to replace them now?" A percent risk estimation allows you to make decisions about things such as your brake pads and your measuring instruments.

The tools that follow allow you to estimate percent risk based on readily available information from your calibration report. Keysight Cal customers that want more information regarding false-accept risk can choose Keysight Cal + Uncertainties. If you require the lowest false-accept risk, select the Keysight Cal + Uncertainties + Guardbanding[4] service.

2. Some references use the term "global risk" rather than average risk.
3. The ≤ 2% probability of false-accept risk of ANSI Z540.3 refers to average risk.
4. An instrument returned to you with a Passed determination of Keysight Cal + Uncertainties + Guardbanding has < 0.15% average false-accept risk. [4]

Estimation of specific false-accept risk

To estimate specific false-accept risk, you need the measured result, the tolerance[5], and the 95% expanded uncertainty from your measurement report. To use Figure 5, do the following:

1. Divide the measured result by the tolerance to determine the point on the X-axis.
2. Divide the tolerance by the 95% expanded uncertainty to determine the test uncertainty ratio (TUR).
    a. Locate the appropriate curve line per the color coding; use linear interpolation for TURs in between the integer value curves.

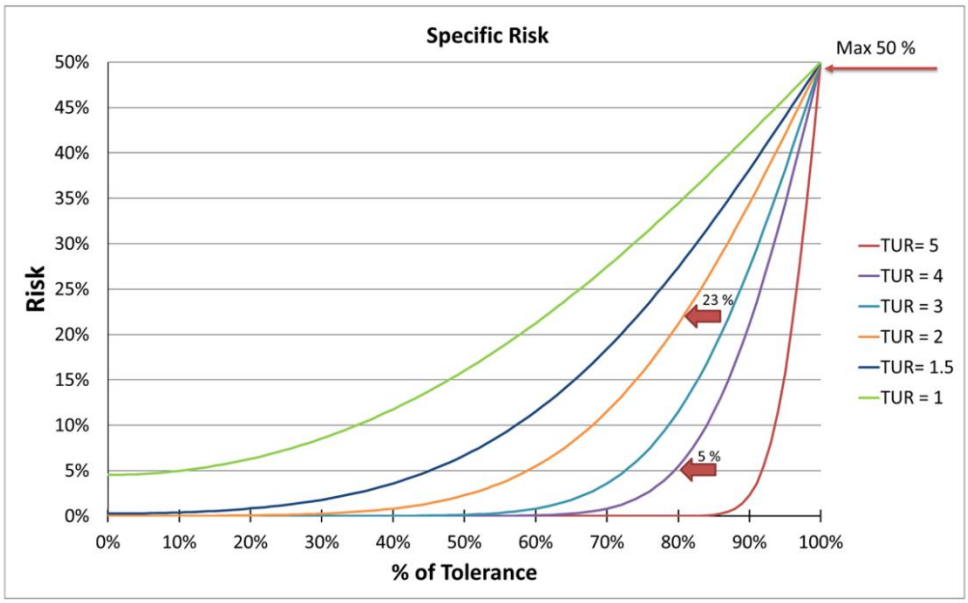


Figure 5. Estimation of the level of specific risk

Notice that as the measured result approaches the tolerance, the specific risk approaches a limit of 50% risk. This is true regardless of the value of the 95% expanded uncertainty. However, a second look at Figure 5 shows that specific risk drops as the measured result is farther below the tolerance. It drops more quickly for higher TURs (lower measurement uncertainties). For example, the red arrows illustrate how a measured result that is 80% of tolerance has a 23% false-accept risk for a TUR = 2:1, but only a 5% false-accept risk of TUR = 4:1.

5. Tolerance is *metrology speak* for published specification.

Test uncertainty ratio

TUR is the ratio of the tolerance, *TL*, of a measurement quantity divided by the 95% expanded uncertainty of the measurement process where $TUR = TL \div U$. See Figure 6.

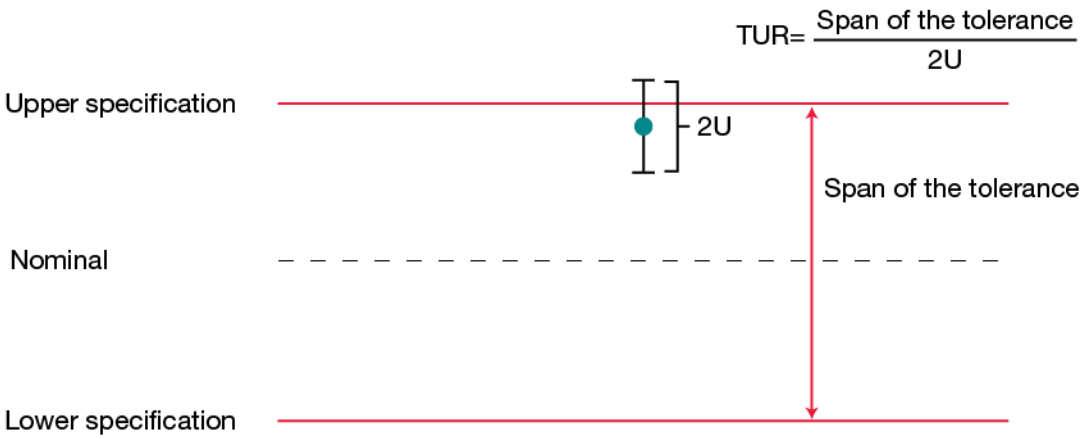


Figure 6. Test uncertainty ratio

Need to know:
- Measurement Result (pass/fail)
- TUR

Look up Max Average Risk value from chart

	Max Global Risk	
TUR	Passed PFA	Failed PFR
1	7.5%	13.8%
1.25	6.1%	10.3%
1.5	5.3%	8.1%
1.75	4.6%	6.7%
2	4.1%	5.7%
2.25	3.7%	5.0%
2.5	3.4%	4.4%
2.75	3.1%	4.0%
3	2.9%	3.6%
3.25	2.7%	3.3%
3.5	2.5%	3.0%
3.75	2.4%	2.8%
4	2.2%	2.6%
4.25	2.1%	2.4%
4.5	2.0%	2.3%
4.75	1.9%	2.2%
5	1.8%	2.1%

Source: Stern & Harben, NCSLI paper 2017

Figure 7**.** Test uncertainty ratio

Each entry in the table in Figure 7 represents a numerical solution of a double integral expression of average risk [2], [4]. To use Figure 7, you need the tolerance and the 95% expanded uncertainty from your measurement report. Then:

1. Divide the tolerance by the 95% expanded uncertainty to determine the TUR.
2. Read the average risk from the table. Use linear interpolation for TURs in between the table values.

Note: Figure 7 provides the maximum average percent risk. If you maintain records of the percent of instruments of a given model number that pass all specifications for a regular calibration interval (also known as in-tolerance probability [6]), you can estimate average risk more accurately using Figure 8. As before, interpolate in between the family of constant TUR curves as needed.

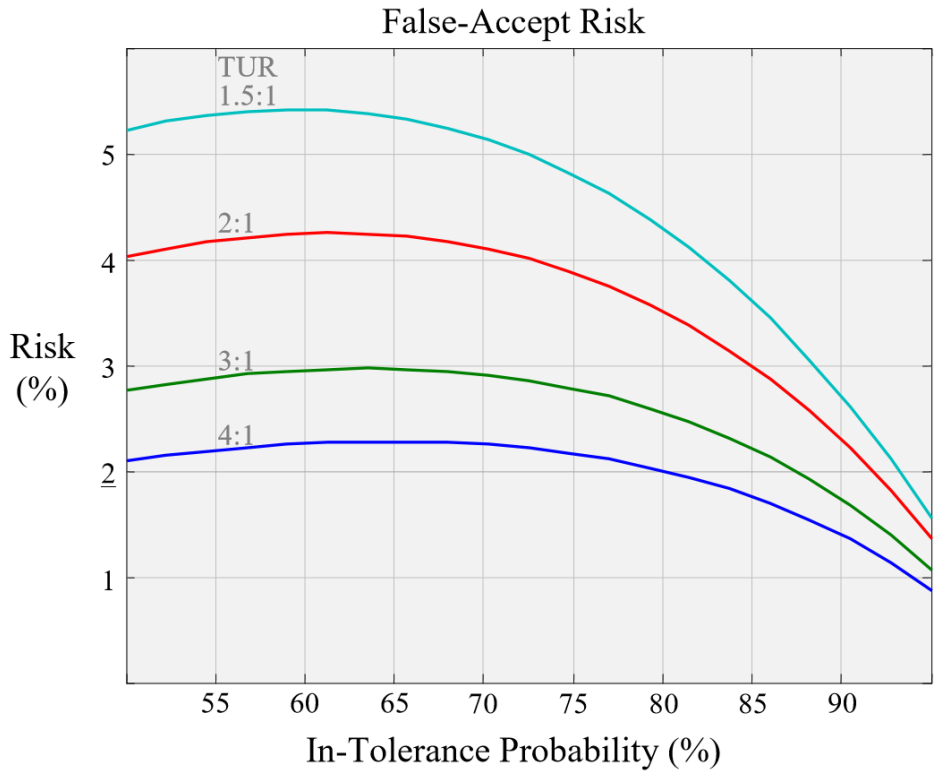


Figure 8. False-accept risk (where the acceptance limits equal the tolerance limits)

6. Some customers refer to in-tolerance probability as end-of-period reliability (EOPR).

References

1. JCGM 100:2008 (GUM). *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement.* https://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

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   Note: This document is also available as ISO/IEC Guide 98-4:2012.

3. ISO/IEC 17025:2017. *General Requirements for the Competence of Testing and Calibration Laboratories.* https://www.iso.org/ISO-IEC-17025-testing-and-calibration-laboratories.html

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