The 4:1 Rule in ASME NQA-1: History, Meaning, and Modern Implementation

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CONTENTS

< 요건 12. '측정 및 시험장비 관리' 중 302 참조표준) >

기술기준	내 용
ASME NQA-1-2017 Requirement 12 302 Reference Standards	Reference standards shall have a minimum accuracy four times greater than that of the measuring and test equipment being calibrated to ensure that the reference standards contribute no more than one-fourth of the allowable calibration tolerance. Where this 4:1 ratio cannot be maintained, the basis for selection of the standard in question shall be technically justified.
ASME NQA-1-2008 Requirement 12 302 Reference Standards	Reference standards shall have a minimum accuracy four times greater than that of the measuring and test equipment being calibrated to ensure that the reference standards contribute no more than one-fourth of the allowable calibration tolerance. Where this 4:1 ratio cannot be maintained, the basis for selection of the standard in question shall be technically justified.
KEPIC QAP-1 2010년 발행판(2011년 추록) 요건 12 - 302 참조표준	참조표준의 허용 교정오차가 1/4 이내임을 확인하기 위하여, 참조표준은 교정대상 측정 및 시험장비보다 최소 4배 이상의 정확도를 가져야 한다. 만약 4:1 비율이 유지되지 않으면 의문시 되는 표준 선정 근거는 기술적으로 정당화 되어야 한다.

01 서론(2)

< 4대 1 요건(The 4:1 Rule) >

- Reference standards shall have a minimum accuracy four times greater than that of the measuring and test equipment being calibrated to ensure that the reference standards contribute no more than one-fourth of the allowable calibration tolerance.
- 참조표준의 허용 교정오차가 ¼ 이내임을 확인하기 위하여, 참조표준은 교정대상 측정 및 시험장비 보다 최소 4배 이상의 정확도를 가져야 한다.

- 1955년, 미 해군은 유도 미사일 프로그램과 관련하여 측정 신뢰성을 제고할 필요성을 인식
- 공장에서 제조되어 시험 합격 판정을 받은 미사일이, 해군 군수 창고에 입고된 후의 시험에서는 불합격 판정을 받는 문제가 발생. 이유를 확인한 결과, 시험에 사용한 시험장비들의 교정 주기에 문제가 있었고 공장과 군수창고에서 수행한 측정을 일치시키려는 노력이 없어 측정값이 불일치하였기 때문
- 이 때, 담당자였던 Jerry Hayes는 소비자 리스크(Consumer Risk) 이론을 미 해군의 교정 프로그램에 적용하여 측정 신뢰성을 확보하는 방안 연구
- 다만, 1950년 중반에는 계산 능력의 부족으로 복잡한 소비자 리스크를 계산하기 어려웠기 때문에 소비자 리스크와 정확도비(Accuracy ratio)를 연계하는 방법을 개발하여 미 해군 용역계약자들에게 정확도비를 요구하기 시작
- 최초에 Jerry Hayes는 소비자 리스크 1% 이하를 요구하기로 하였는데, 이는 정확도비로는 3대 1 이었고, 후에 정확도의 여분을 확보하기 위해 정확도비 4대 1을 요구하는 것으로 귀결됨.
- 미 해군은 이를 군수 물자 조달 요건으로 적용하였으며, 이후 전 미군으로 확대됨.

02 4대 1 요건의 역사: 미국

미 해군 군수요건(1950년 대)

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미군 군수요건
(Calibration Systems Requirement)
(MIL STD-45662A,1988)

↓

참여기관: NCSLi, NIST, DOD, NRC, DOE, FAA 등.

미국 국가 교정 기술기준 수립
(ANSI/NCSLi Z540-1, 1994)

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미국 국가 교정 기술기준 개정
(ANSI/NCSLi Z540.3, 2006)

↓

ISO 17025: 2017(현재)

NRC SRP 17.1 Quality Assurance During the Design and Construction Phases, Rev.2 (1981)
(대상: ANSI N45.2 적용)

↓

NRC SRP 17.3 Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, Rev.0 (1990)
(대상: ASME NQA-1 or NQA-2 적용)

ANSI N45.2-1971
(Reg. Guide 1.28, Rev.0, 1972)

↓

ANSI N45.2-1977
(Reg. Guide 1.28, Rev.1, 1978)

↓

ANSI/ASME NQA-1-1983, 1a-1983
(Reg. Guide 1.28, Rev.3, 1985

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ANSI/ASME NQA-1-1994

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ANSI/ASME NQA-1-2008, 1a-2009, Addenda(Part I & II)
(Reg. Guide 1.28, Rev.4, 2010)

범례

4대 1 요건 (T.A.R) 포함

4대 1 요건 (T.U.R) 포함

KEPIC QAP-1 (2005)

↓

KEPIC QAP-1 (2011 추록)

02 4대 1 요건의 역사: MIL-STD 45662A(1988)

< 4대 1 요건 관련 MIL-STD 45662A >

문서명	내 용
MIL-STD 45662A(1988), Calibration Systems Requirement	5 Detailed Requirement 5.2 Adequacy of measurement standards Measurement standards used by the contractor for calibrating M&TE and other measurement standards shall be traceable and shall have the accuracy, stability, range and resolution required for the intended use. Unless otherwise specified in the contract requirements, the collective uncertainty of the measurement standards shall not exceed 25% of the acceptable tolerance for each characteristic being calibrated. The contractor's calibration system description may include provisions for deviating from the uncertainty requirements, provided the adequacy of the calibration is not degraded. All deviations shall be documented.

NEQ NUCLEAR EQUIPMENT QUALIFICATION

< 4대 1 요건 관련 미국의 교정 기술기준 >

미국의 교정 기술기준	내 용
ANSI/NCSL Z540.1-1994	10 Calibration methods 10.2 b) The laboratory shall ensure that the calibration uncertainties are sufficiently small so that the adequacy of the measurement is not affected. Well defined and documented measurement assurance techniques or uncertainty analyses may be used to verify the adequacy of a measurement process. If such techniques or analyses are not used, then the collective uncertainty of the measurement standards shall not exceed 25% of the acceptable tolerance (e.g., manufacturer's specification) for each characteristic of the measuring and test equipment being calibrated or verified.
ANSI/NCSL Z540.3-2006	5.3 Calibration of measuring and test equipment b) Where calibrations provide for verification that measurement quantities are with in specified tolerances, the probability that incorrect acceptance decisions (false accept) will result from calibration tests shall not exceed 2% and shall be documented. Where it is not practicable to estimate this probability, the test uncertainty ratio shall be equal to or greater than 4:1.

< 미국 NRC의 SRP 중 4대 1 요건 포함 부분 >

NRC, Standard Review Plan(NUREG-0800)	내 용
17.1 Quality Assurance During the Design and Construction Phases (Rev.2, 1981)	12.6 Calibration of this equipment should be against standards that have an accuracy of at least four times the required accuracy of the equipment being calibrated or, when this is not possible, have an accuracy that assures the equipment being calibrated will be within required tolerance and that the basis of acceptance is documented and authorized by responsible management. The management authorized to perform this function is identified.
17.3 Quality Assurance Program Description (Rev.0, 1990)	9. Measuring and Test Equipment Control e. Measuring and test equipment is to be calibrated against standards that have an accuracy of at least four times the required accuracy of the equipment being calibrated or, when this is not possible, have an accuracy that ensures the equipment being calibrated will be within the required tolerance.

02 4대 1 요건의 역사: 우리나라

< KINS 경수로형 원전 안전심사 지침(개정 6판)과 미국 NRC의 SRP 중 4대 1 요건 관련 내용의 비교 >

비교	내용
KINS 경수로형 원전 안전심사 지침(개정 6판) 제17.1절 설계 및 건설단계 품질 보증(개정번호 4, 2014. 12.)	12.바) 측정 및 시험장비는 요구되는 정확도, 목적, 사용 정도, 안정성 및 기타 측정에 영향을 주는 조건에 근거하여 규정된 시간간격으로 교정 된다. 이들 장비의 교정은 교정대상 장비에 요구되는 것보다 4배 이상의 정확도를 갖는 표준장비와 대비하여 수행되어야 하며, 이것이 불가능할 경우에는 허용공차 범위 내에서 장비가 교정됨을 보증할 수 있는 정확도를 갖는 표준장비로 교정되며, 수락근거가 문서화되고 책임 관리자에 의해 인가된다. 이러한 역할을 수행할 책임을 가지는 관리자가 지정되었다.
NRC, Standard Review Plan(NUREG-0800, 1981) 17.1 Quality Assurance During the Design and Construction Phases(Rev.2)	12.6 Calibration of this equipment should be against standards that have an accuracy of at least four times the required accuracy of the equipment being calibrated or, when this is not possible, have an accuracy that assures the equipment being calibrated will be within required tolerance and that the basis of acceptance is documented and authorized by responsible management. The management authorized to perform this function is identified.

02 4대 1 요건의 역사: 우리나라(계속)

< 국내 원전 건설 품질보증계획서 중 4대 1 요건 관련 내용 >

비교	내용
신한울 1,2 호기 건설에 관한 품질보증계획서 (한수원, 개정번호 9-2, 2018. 10.)	12.3 계약자의 측정 및 시험장비 관리에 관한 요건 12.3.2 검교정 기준 2. 검교정 표준장비는 검교정 대상장비보다 최소 4배이상의 높은 정확도를 갖거나, 혹은 이의 불가시에는 검교정 대상장비의 허용오차 범위 내에서 검교정이 가능한 표준장비를 사용하며, 그 근거가 책임조직에 의해 평가되어 서류화하여야 한다.
새울 3,4호기(신고리 5,6호기) 건설에 관한 품질보증계획서 (한수원, 개정번호 8-1, 2020. 11. 18.)	12.3 계약자의 측정 및 시험장비 관리에 관한 요건 12.3.2 검교정 기준 2. 검교정 표준장비는 검교정 대상장비보다 최소 4배이상의 높은 정확도를 갖거나, 혹은 이의 불가시에는 검교정 대상장비의 허용오차 범위 내에서 검교정이 가능한 표준장비를 사용하며, 그 근거가 책임조직에 의해 평가되어 서류화하여야 한다.

03 이론적 배경: 교정(Calibration) vs. 검증(Verification)

- 교정(Calibration): 명시된 조건 하에서 첫 번째 단계로 측정표준에 의해 제공된 양의 값(측정불확도 포함)과 대응되는 지시값(연관된 측정불확도 포함) 사이의 관계를 확립하고, 두 번째 단계로 지시값에서 측정결과를 얻는 관계를 확립하기 위해 첫 번째 단계의 정보를 이용하는 작업
(국제 측정학 용어집 제3판, 2.39)
(operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication)(JCGM 200:2012, 2.39)
* 교정(較正): 측정표준과 지시값을 비교 → 결과물: 보정값, 측정불확도

- 검증(Verification): 주어진 품목이 명시된 요건을 충족한다는 객관적인 증거의 제공
(국제 측정학 용어집 제3판, 2.44)
(provision of objective evidence that a given item fulfils specified requirements)
(JCGM 200:2012, 2.44)
* 검증: 측정 및 시험기기가 '정해진 기준 ' 을 충족하는지를 판단하는 것
* KOLAS 17025:2017 교정기관은 '검증'을 '적합성 진술'(Statements of Conformity)이라 표현

<용어 정의>

- Tolerance Interval(허용구간) = a Span of Tolerance
- Tolerance Limit (T.L., 허용 한계) = Specification Limit (S. L., 규격 한계)
  = Maximum Permissible Error (MPE, 최대허용오차)
- Acceptance Limit(A.L, 채택 한계)
- Guard Band(보호대역): 허용 한계와 채택 한계 사이의 구간
- 허용 교정 오차 (KEPIC QAP-1) = 허용 공차 (KINS 경수로형 원전 안전심사 지침)
  = 허용 한계 (KOLAS-G-002, 의사결정 규칙 및 적합성 진술에 관한 지침)
  = 규격 한계 (KOLAS-G-002, 의사결정 규칙 및 적합성 진술에 관한 지침)
  = 최대허용오차 (국제 측정학 용어집-기본 및 일반 개념과 관련 용어(VIM) 제3판)
- 측정불확도(Uncertainty of Measurement)
  parameter, associated with the result of a measurement, that characterized the dispersion of the values that could reasonably be attributed to the measurand (ISO/IEC Guide 98-3, Uncertainty of measurement – Part 3: Guide to the expression of uncertainty)
- 오차 vs. 불확도

< 소비자 리스크(Consumer Risk) 계산식 및 정확도비(r), Mimbs., S(2007) >

$$\text{Consumer Risk} = \frac{1}{\pi}\int_{k_x}^{\infty}\int_{-r(k_x+t)}^{r(k_x-t)} e^{\frac{-(t^2+s^2)}{2}}\, dsdt$$

$$\text{TUR} = \frac{Upper-Lower}{2U_{95}} = \frac{Upper-Lower}{2k_e u_e} = \frac{2k_x\sigma_x}{2k_e u_e} = \frac{k_x\sigma_x}{k_e u_e}$$

Where:
- $r = \frac{\sigma_x}{\sigma_e} = \frac{\sigma_x}{u_e}$: accuracy ratio
- σ_x: the standard deviation of the product distribution
- σ_e: the standard deviation of the errors of measurement
- u_e: the standard uncertainty of the measurement
- $S\sim N(0,1) \because Y\sim N(x,\sigma_e),\ S = \frac{Y-X}{\sigma_e}$, the distribution of the errors of measurement
- $T\sim N(0,1) \because X\sim N(0,\sigma_x),\ T = \frac{X}{\sigma_x}$, the product distribution
- Tolerance Limit = k_x x σ_x k_x: Coverage Factor

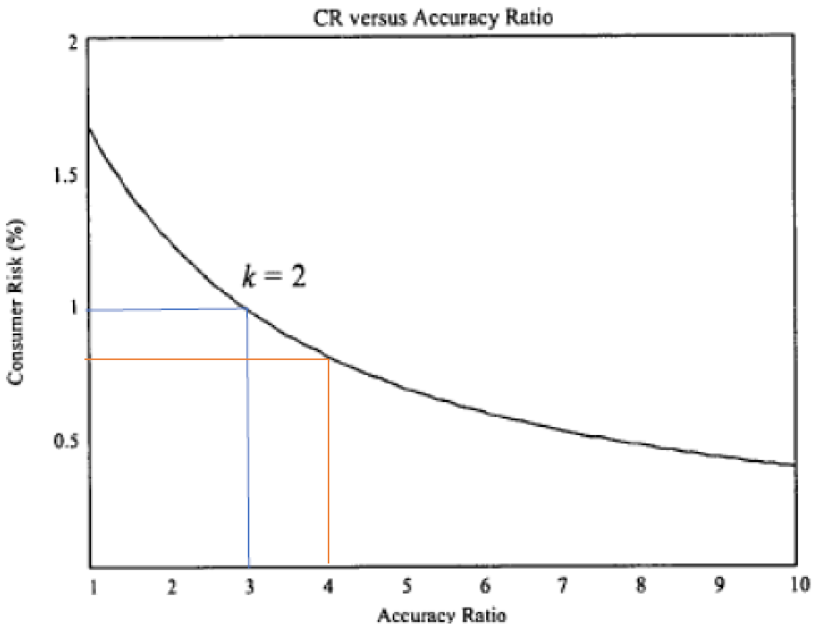
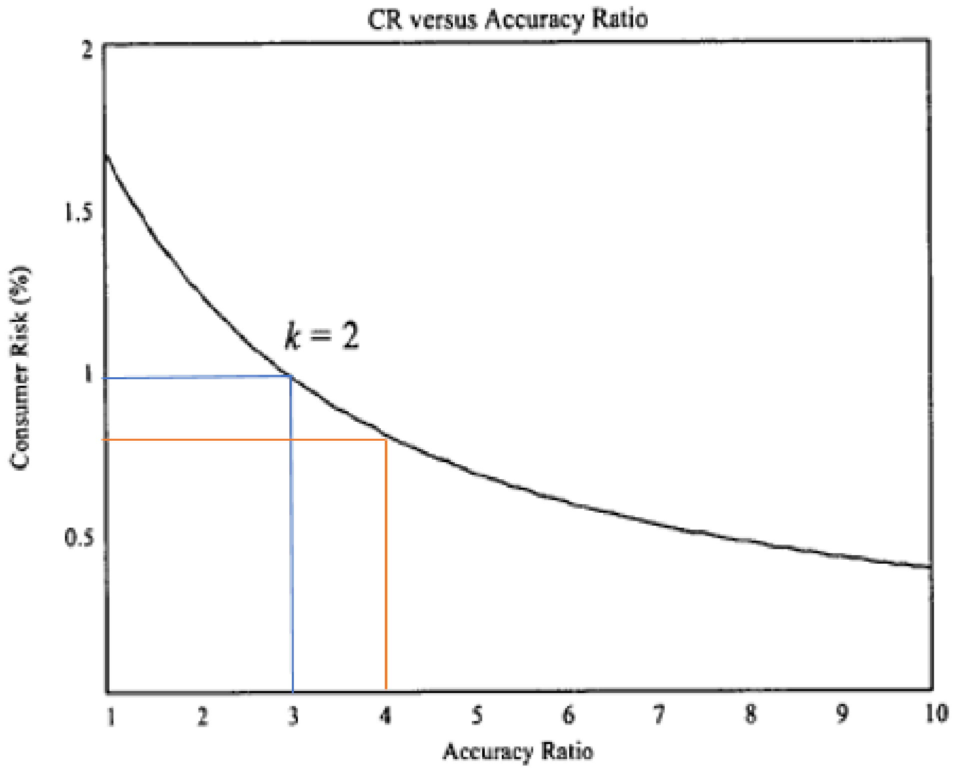


Fig 1. Consumer Risk vs Accuracy Ratio, quoted from Mimbs(2007) & added by author

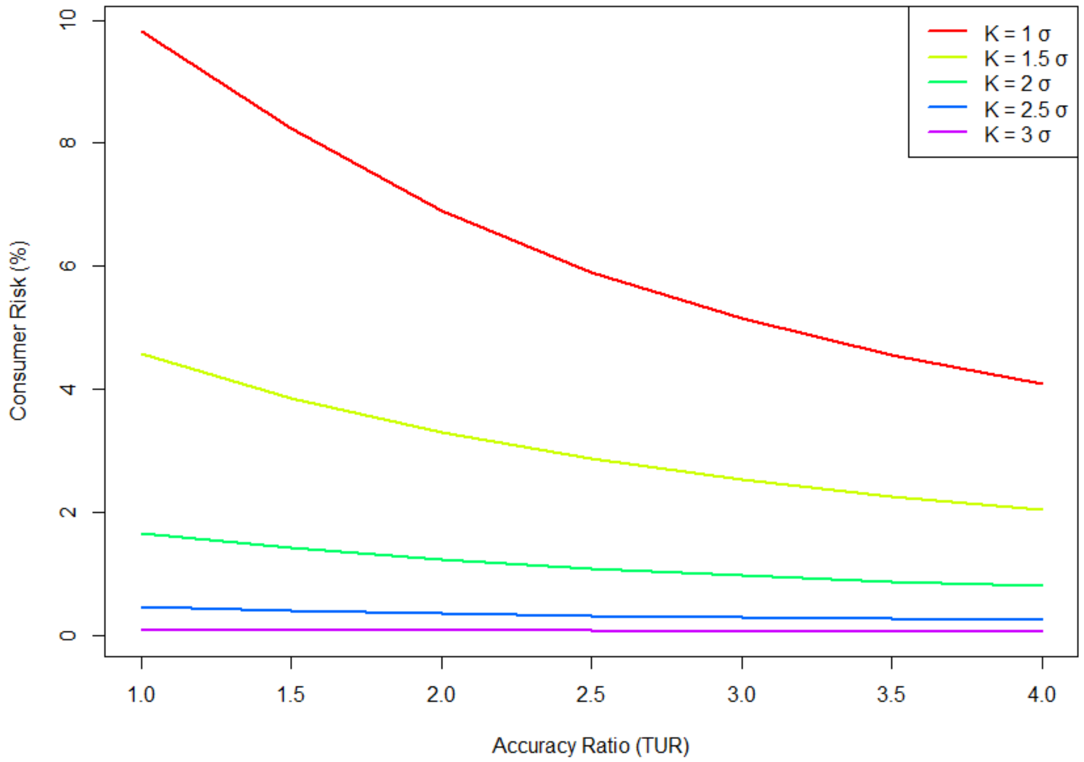
Jerry L. Hayes
- 미 해군 무기 연구소(the U.S. Naval Ordnance Laboratory) 근무
- 미 해군 계량 공학 센터(the Navy Metrology Engineering Center) 기술 이사(Technical director)
- 미 해군의 공식 측정 및 시험장비 교정 프로그램 개발
- 미 과학 아카데미 회원(교정 및 표준 분야)
- 측정과학 학회(Measurement Science Conference) 및 미국 표준학회 (National Conference of Standards Laboratories) 설립자
- The Jerry L. Hayes Award: 미 해군의 주요 연구기관인 NSWC(Naval Surface Warfare Center)가 시험 및 측정 분야에서 과학적인 업적을 이룩한 사람에게 수여하는 상

이론적 배경: 소비자 리스크와 정확도비(계속)

< 소비자 리스크와 포함인자(k_x)의 관계 >
Deaver(1993), *How to Maintain Your Confidence*



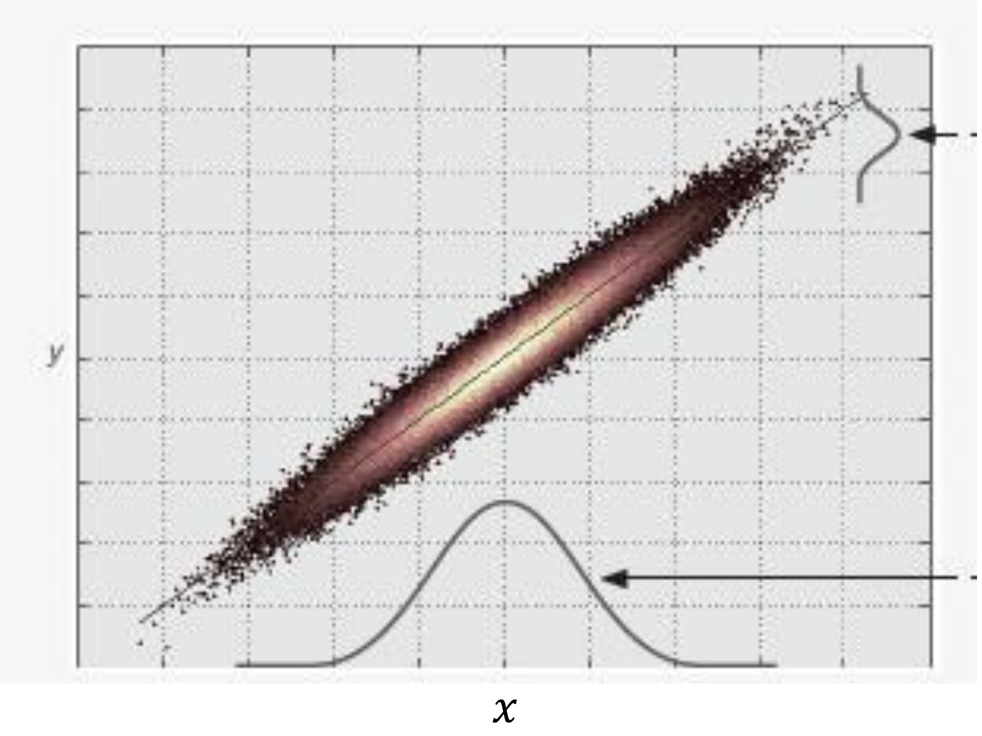
포함인자(k)별 소비자 리스크와 TUR의 관계



03 이론적 배경: 소비자 리스크의 계산 모델

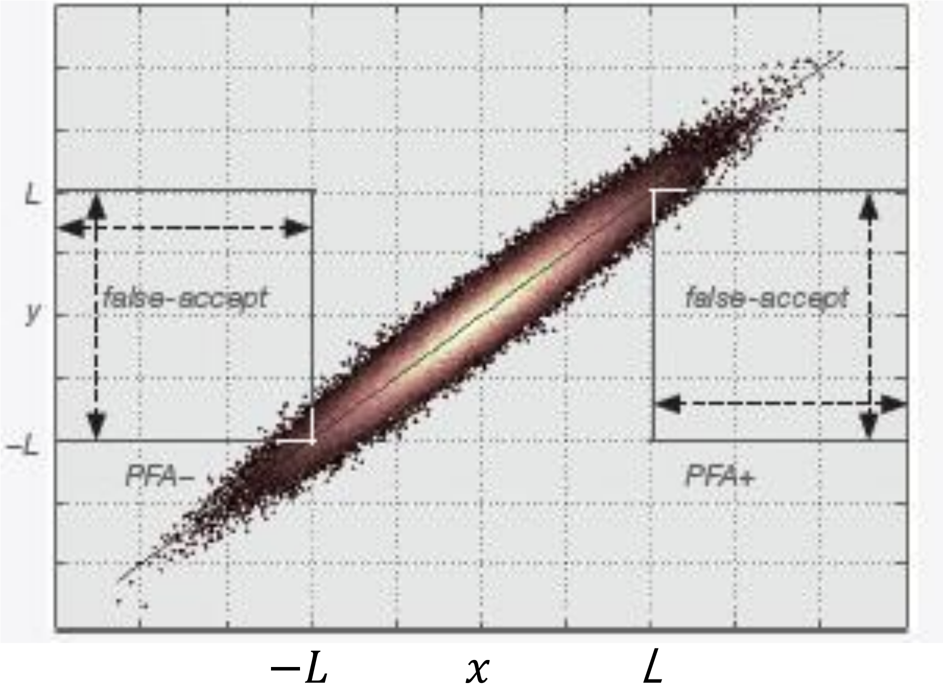
< 소비자 리스크 계산방법 >

Dobbert(2007), *Understanding Measurement Risk*



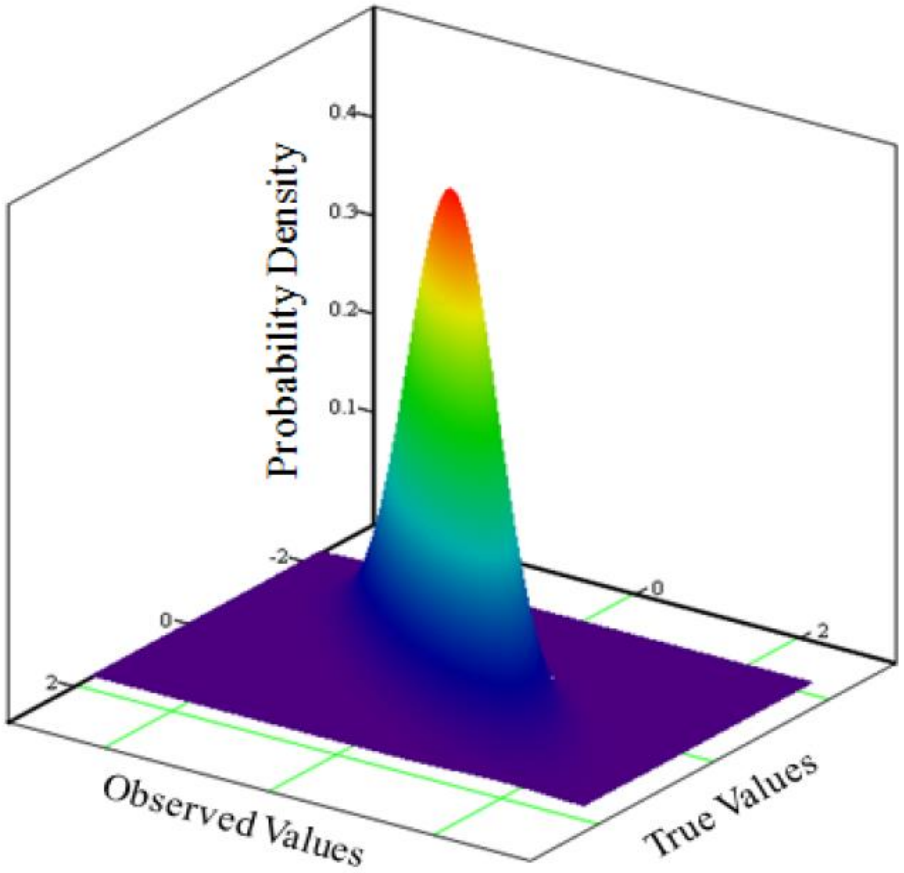
$$p_m = \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{1}{2}\left(\frac{y-x}{\sigma_m}\right)^2}$$

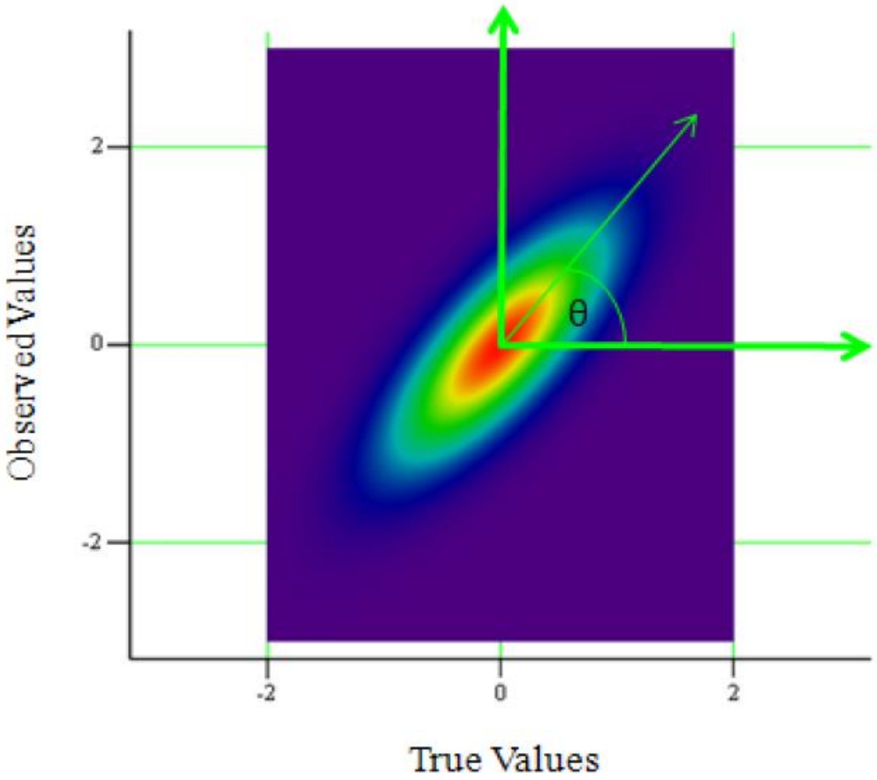
$$p_0 = \frac{1}{\sqrt{2\pi}\sigma_0} e^{-\frac{1}{2}\left(\frac{x}{\sigma_0}\right)^2}$$



03 이론적 배경: 소비자 리스크의 결합확률분포(3차원)

< 소비자 리스크의 결합확률분포 >
Harben 등(2011), *Implementing Strategies for Risk Mitigation In the Modern Calibration Laboratory,* Figure 4.





< 소비자 리스크 수식 전개 >
Dobbert(2007), *Understanding Measurement Risk*

$$p_0 = \frac{1}{\sqrt{2\pi}\sigma_0} e^{-\frac{1}{2}\left(\frac{x}{\sigma_0}\right)^2} \qquad X \sim N(0, \sigma_0)$$

$$p_m = \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{1}{2}\left(\frac{y-x}{\sigma_m}\right)^2} \qquad Y \sim N(x, \sigma_m)$$

p_0 : PDF for the device population
p_m : PDF for measurement error
$p(x,y)$: Joint PDF of p_0 and p_m
L : Tolerance Limit

$$p(x,y) = p_0(x)p_m(y-x) = \frac{1}{\sqrt{2\pi}\sigma_0} e^{-\frac{1}{2}\left(\frac{x}{\sigma_0}\right)^2} \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{1}{2}\left(\frac{y-x}{\sigma_m}\right)^2}$$

$$\begin{gathered}Probability\ of\ False\ Acceptance \\ (Unconditional\ Probability\ Case)\end{gathered} = \int_{-\infty}^{-L}\int_{-L}^{L} p_0(x)p_m(y-x)\,dy\,dx + \int_{L}^{\infty}\int_{-L}^{L} p_0(x)p_m(y-x)\,dy\,dx$$

< 소비자 리스크 수식에서 정확도비(accuracy ratio) 유도 >

Mimb(2007), *Measurement Decision Risk –The Importance of Definitions*

$$t = \frac{x}{\sigma_0}\ , \quad s = \frac{y-x}{\sigma_m} = \frac{y-\sigma_0 t}{\sigma_m} \qquad L = k_0\sigma_0\ , \quad r = \frac{\sigma_0}{\sigma_m} = \frac{\sigma_0}{u_m} = accuracy\ ratio$$

$$\begin{aligned} &Probability\ of\ False\ Acceptance\ (Unconditional\ Probability\ Case) = \int_{-\infty}^{-L}\int_{-L}^{L} p_0(x)p_m(y-x)dydx + \int_{L}^{\infty}\int_{-L}^{L} p_0(x)p_m(y-x)dydx \\ &= 2\int_{L}^{\infty}\int_{-L}^{L} p_0(x)p_m(y-x)dydx = 2\int_{L}^{\infty}\int_{-L}^{L} \frac{1}{\sqrt{2\pi}\sigma_0}e^{-\frac{1}{2}\left(\frac{x}{\sigma_0}\right)^2}\frac{1}{\sqrt{2\pi}\sigma_m}e^{-\frac{1}{2}\left(\frac{y-x}{\sigma_m}\right)^2}dydx \\ &= \frac{1}{\pi}\int_{k_0}^{\infty}\int_{-r(k_0+t)}^{r(k_0-t)} e^{-\frac{1}{2}t^2}e^{-\frac{1}{2}s^2}dsdt = \frac{1}{\pi}\int_{k_0}^{\infty}\int_{-r(k_0+t)}^{r(k_0-t)} e^{-\frac{(t^2+s^2)}{2}}dsdt \end{aligned}$$

$$x = L \rightarrow t = \frac{L}{\sigma_0} = \frac{k_0\sigma_0}{\sigma_0} = k_0\ , \qquad y = L \rightarrow s = \frac{L-\sigma_0 t}{\sigma_m} = \frac{k_0\sigma_0-\sigma_0 t}{\sigma_m} = \frac{\sigma_0}{\sigma_m}(k_0-t) = r(k_0-t)$$

$$y = -L \rightarrow s = \frac{-L-\sigma_0 t}{\sigma_m} = \frac{-k_0\sigma_0-\sigma_0 t}{\sigma_m} = -\frac{\sigma_0}{\sigma_m}(k_0+t) = -r(k_0+t)$$

03 이론적 배경: 소비자 리스크 수식에서 정확도비 유도

< 소비자 리스크 수식에서 정확도비(accuracy ratio) 유도 >

$$t = \frac{x}{\sigma_0}\ , \qquad s = \frac{y - x}{\sigma_m} = \frac{y - \sigma_0 t}{\sigma_m}$$

$$L = k_0\sigma_0\ , \quad r = \frac{\sigma_0}{\sigma_m} = \frac{\sigma_0}{u_m} = accuracy\ ratio$$

$$Probability\ of\ False\ Acceptance\ (Unconditional\ Probability\ Case) = \frac{1}{\pi}\int_{L}^{\infty}\int_{-L}^{L} \frac{1}{\sigma_0} e^{-\frac{1}{2}\left(\frac{x}{\sigma_0}\right)^2} \frac{1}{\sigma_m} e^{-\frac{1}{2}\left(\frac{y-x}{\sigma_m}\right)^2} dydx,$$

$$= \frac{1}{\pi}\int_{k_0}^{\infty}\int_{-r(k_0+t)}^{r(k_0-t)} \frac{1}{\sigma_0} e^{-\frac{1}{2}t^2} \frac{1}{\sigma_m} e^{-\frac{1}{2}s^2} J dsdt$$

$$= \frac{1}{\pi}\int_{k_0}^{\infty}\int_{-r(k_0+t)}^{r(k_0-t)} e^{-\frac{(t^2+s^2)}{2}} dsdt$$

$$J = \begin{vmatrix} \frac{\partial x}{\partial t} & \frac{\partial x}{\partial s} \\ \frac{\partial y}{\partial t} & \frac{\partial x}{\partial s} \end{vmatrix} = \begin{vmatrix} \sigma_0 & 0 \\ \sigma_0 & \sigma_m \end{vmatrix} = \sigma_0\sigma_m$$

$$x = \sigma_0 t\ , \ y = \sigma_0 t + \sigma_m s$$

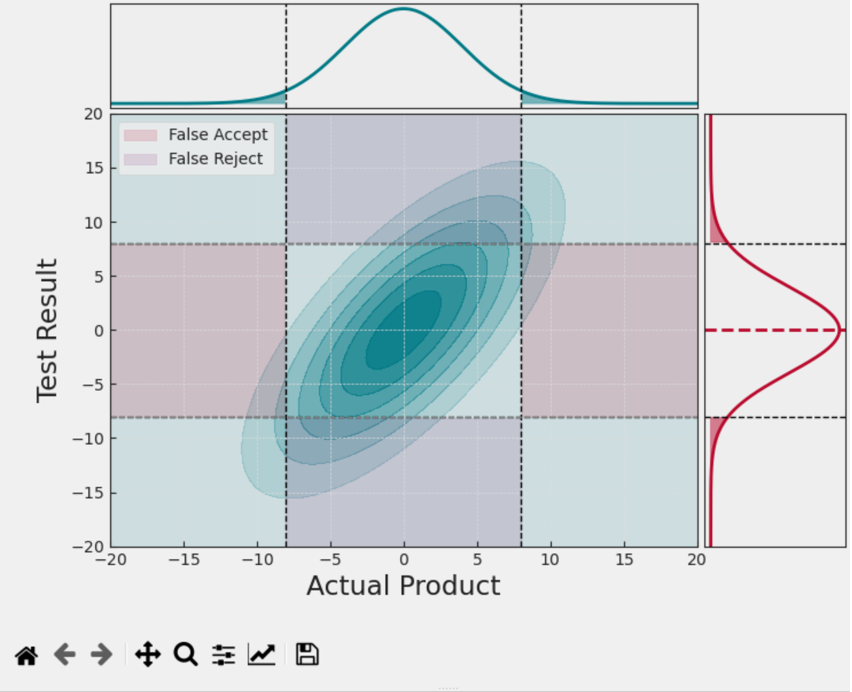
$$x = L \rightarrow t = \frac{L}{\sigma_0} = \frac{k_0\sigma_0}{\sigma_0} = k_0\ , \quad y = L \rightarrow s = \frac{L-\sigma_0 t}{\sigma_m} = \frac{k_0\sigma_0-\sigma_0 t}{\sigma_m} = \frac{\sigma_0}{\sigma_m}(k_0\text{-}t) = r(k_0-t)$$

$$y = -L \rightarrow s = \frac{-L-\sigma_0 t}{\sigma_m} = \frac{-k_0\sigma_0-\sigma_0 t}{\sigma_m} = -\frac{\sigma_0}{\sigma_m}(k_0+t) = \text{-}r(k_0+t)$$

이론적 배경: T.U.R n:1일 때 결합확률분포 그래프(2차원)

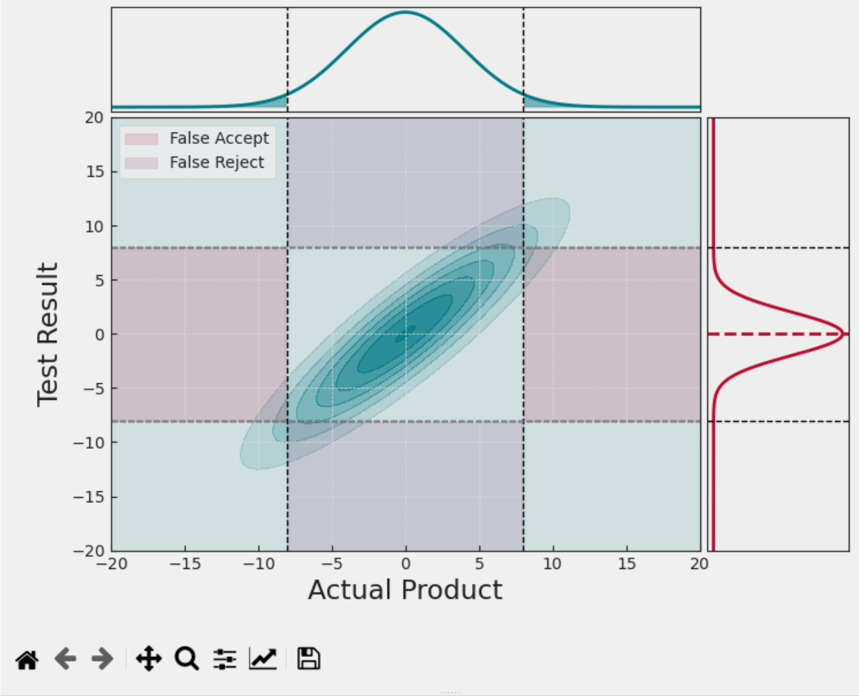
< 소비자 리스크와 정확도 비 관계(k_0 = 2 일 때) >
The Sandia Uncertainty Calculator, Sandia National Laboratories(Primary Standard Laboratory)
(https://sandiapsl.github.io/)

TUR 1:1



Process Risk	Specific Measurement Risk	Global Risk
Process Risk: 4.6%	TUR: 1.0	Total PFA: 1.7%
Upper limit risk: 2.3%	Measured value: 0.0	Total PFR: 13%
Lower limit risk: 2.3%	Specific FA Risk: 4.6%	
Process capability index (Cpk): 0.67	Worst-Case Specific Risk: 50%	

TUR 2:1



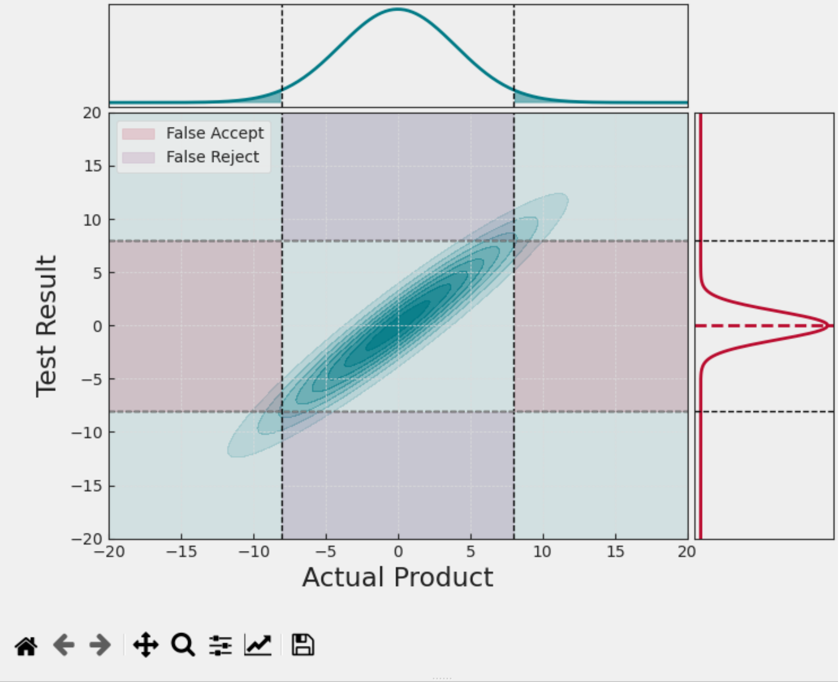
Process Risk	Specific Measurement Risk	Global Risk
Process Risk: 4.6%	TUR: 2.0	Total PFA: 1.2%
Upper limit risk: 2.3%	Measured value: 0.0	Total PFR: 4.1%
Lower limit risk: 2.3%	Specific FA Risk: 0.0063%	
Process capability index (Cpk): 0.67	Worst-Case Specific Risk: 50%	

03 이론적 배경: T.U.R n:1일 때 결합확률분포 그래프(2차원)

< 소비자 리스크와 정확도 비 관계(k_0 = 2 일 때) >

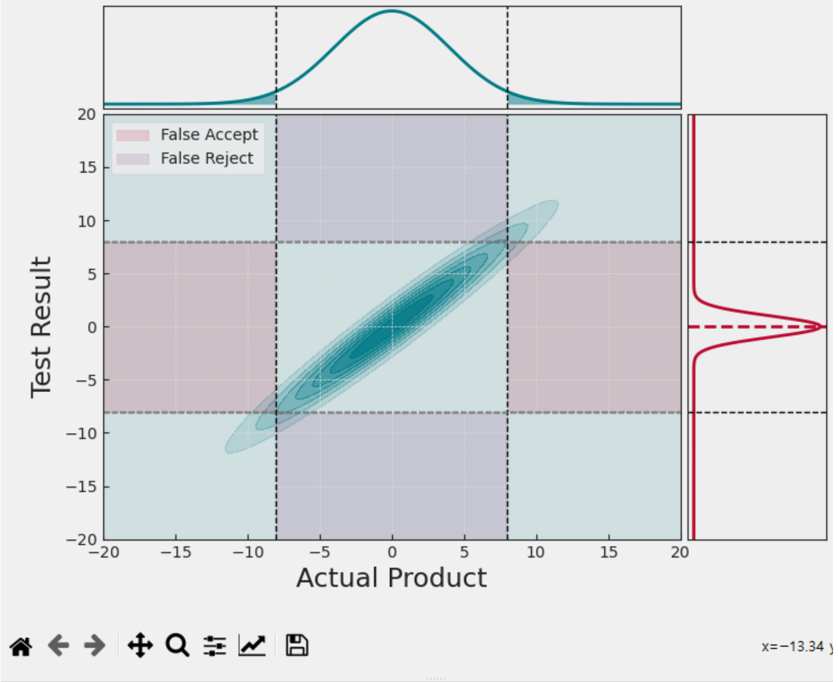
The Sandia Uncertainty Calculator, Sandia National Laboratories(Primary Standard Laboratory)
(https://sandiapsl.github.io/)

TUR 3:1



Process Risk	Specific Measurement Risk	Global Risk
Process Risk: 4.6%	TUR: 3.0	Total PFA: 0.98%
Upper limit risk: 2.3%	Measured value: 0.0	Total PFR: 2.2%
Lower limit risk: 2.3%	Specific FA Risk: 2.0e-07%	
Process capability index (Cpk): 0.67	Worst-Case Specific Risk: 50%	

TUR 4:1



Process Risk	Specific Measurement Risk	Global Risk
Process Risk: 4.6%	TUR: 4.0	Total PFA: 0.80%
Upper limit risk: 2.3%	Measured value: 0.0	Total PFR: 1.5%
Lower limit risk: 2.3%	Specific FA Risk: 1.3e-13%	
Process capability index (Cpk): 0.67	Worst-Case Specific Risk: 50%	

04 적용 방법: T.A.R vs. T.U.R

NEQ NUCLEAR EQUIPMENT QUALIFICATION

< 4대1 요건 관련 미국 교정 기술기준 >

미국 교정 관련 기술기준	내용
ANSI/NCSL Z540.1-1994	$Test\,Accuracy\,Ratio = \frac{The\ acceptable\ Tolerance(of\ manufacturer's\ specification, regulation, etc)}{The\ Collective\ uncertainty\ of\ the\ measurement\ standards}$ * Tolerance: limits of permissible error(of a measuring instrument) (z540.1 clause 3.9)
ANSI/NCSL Z540.3-2006	$Test\,Uncertainty\,Ratio = \frac{The\ span\ of\ the\ Tolerance\ of\ a\ measurement\ quantity\ subject\ to\ calibration}{2\times(95\%\ expanded\ uncertainty\ of\ the\ measurement\ process\ used\ for\ calibration)}$ * Tolerance: Extreme values of an error permitted by specifications, regulations, etc. for a given measuring instrument, test, or measurement application (z540.3 clause 3.12)

04 적용 방법: 미국 교정 기술기준에 의한 방법

< *Handbook for the ANSI/NCSLi Z540.3-2006*의 6가지 방법 (Deaver & Somppi(2010) 참조)>

방법	요약
1. Unconditional PFA, Test Point Population Data	Calculation based on the probability density function(PDF) of both the measurement process and the individual point being measured. Calculating the convolution of the two PDFs.
2. Unconditional PFA, MT&E Population Data	Using In-Tolerance Reliability(End-Of-Period-Reliability) of the unit under test by making a calculation based on the PDF of the unit under test.
3. Conditional PFA, Acceptance Subpopulation	Using PDFs from both the measurement process and the individual points being measured. The PDF for the unit under test is a subset of only the accepted points.
4. Conditional PFA, Bayesian	Using PDFs from both the measurement process and the individual points being measured with Bayesian calculations.
5. Guard Bands Based on Measurement Uncertainty	Calculation Not using the PDF of the unit under test at all, But using only the measurement uncertainty. The test limit is determined based on the worst case PFA
6. Guard Bands Based on TUR (TUR을 이용한 보호대역 적용 방법)	Calculation Not using the PDF of the unit under test, But using TUR.

04 적용 방법: 미국 교정 기술기준에 의한 방법(계속)

< Deaver, D., and Somppi, J.(2010),
A study of and recommendation for applying the false acceptance risk specification of Z540.3 >

Guard Band Required (Small → Large)

Method 5		Method 4
	Method 2	Method 3
Method 6		Method 1

Effort (Small → Large)

Table 1: Effort of Implementation and Size of Resulting Guard Bands

적용 방법: 미국 교정 기술기준에 의한 방법(계속)

< TUR, EOPR, PFA 관계 >

Harben 등(2011), *Implementing Strategies for Risk Mitigation In the Modern Calibration Laboratory,* Figure 7.

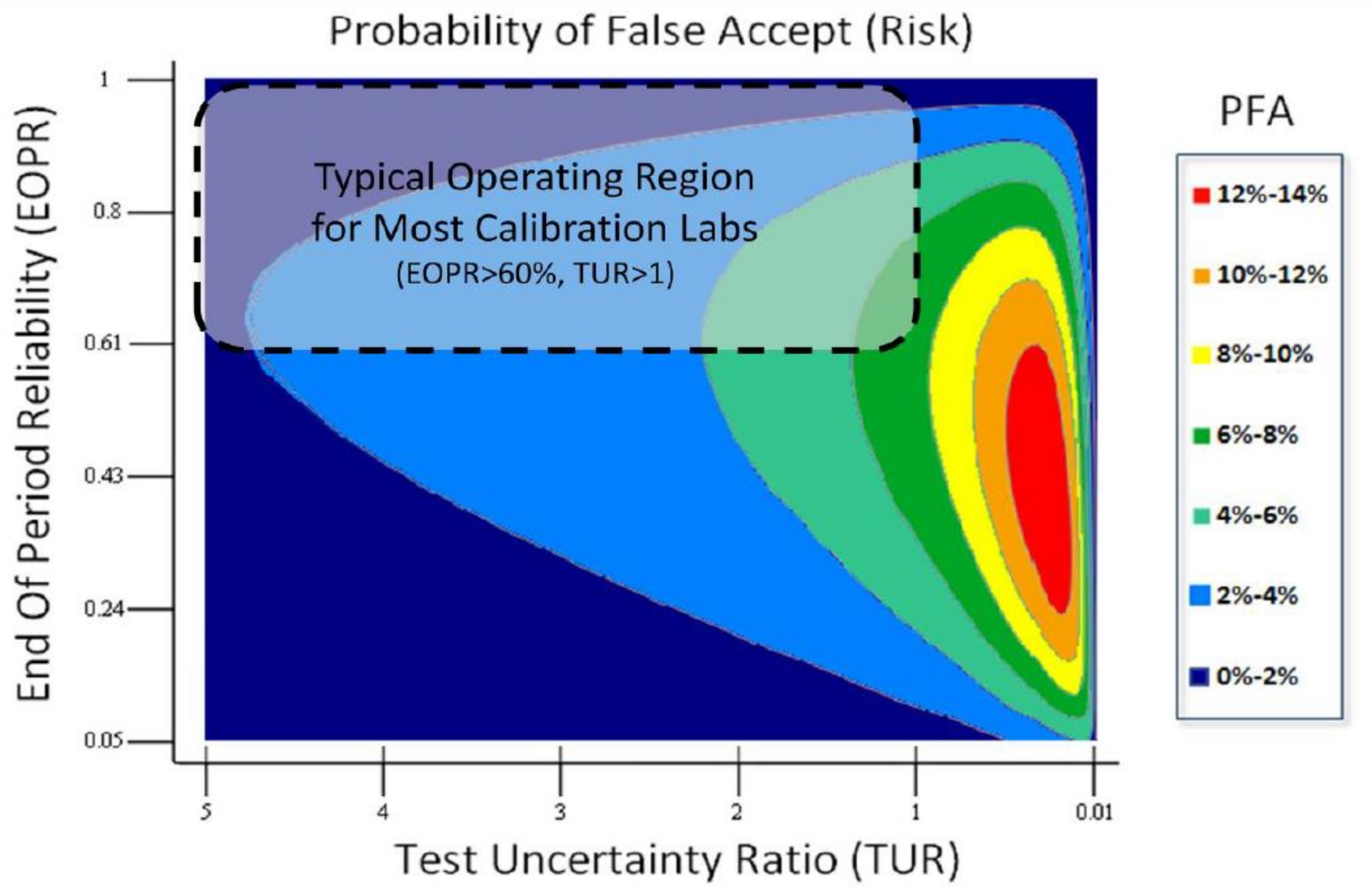


Figure 7. Topographical Contour Map of False Accept Risk as a Function of TUR and EOPR

04 적용 방법: 미국 교정 기술기준에 의한 방법(계속)

< TUR, EOPR, PFA 관계 >

Harben 등(2011), *Implementing Strategies for Risk Mitigation In the Modern Calibration Laboratory,* Figure 8.

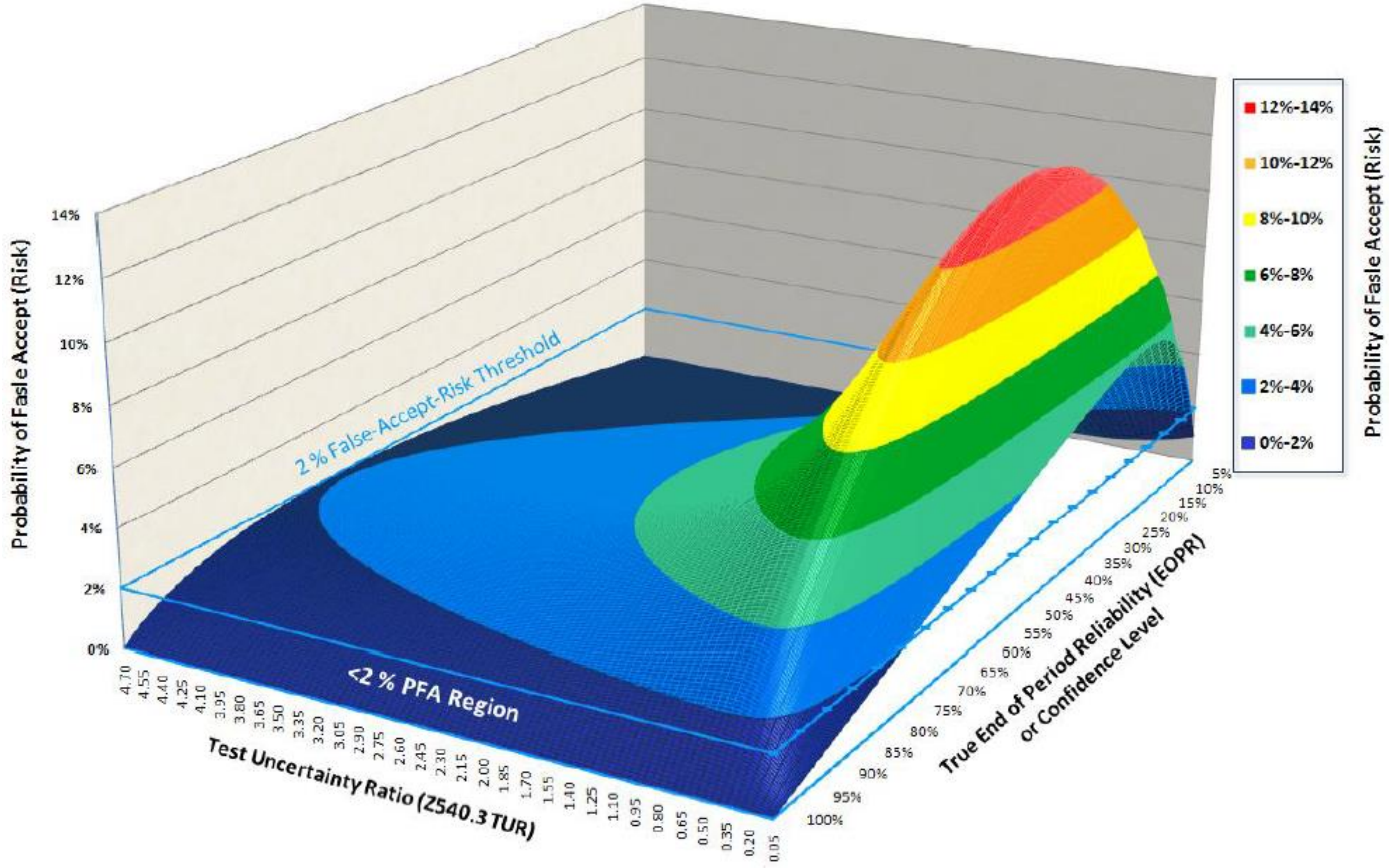


Figure 8. Surface Plot of False Accept Risk as a Function of TUR and EOPR

< Worst-Case EOPR에서 TUR과 PFA 관계 >

Harben 등(2011), *Implementing Strategies for Risk Mitigation In the Modern Calibration Laboratory,* Figure 9.

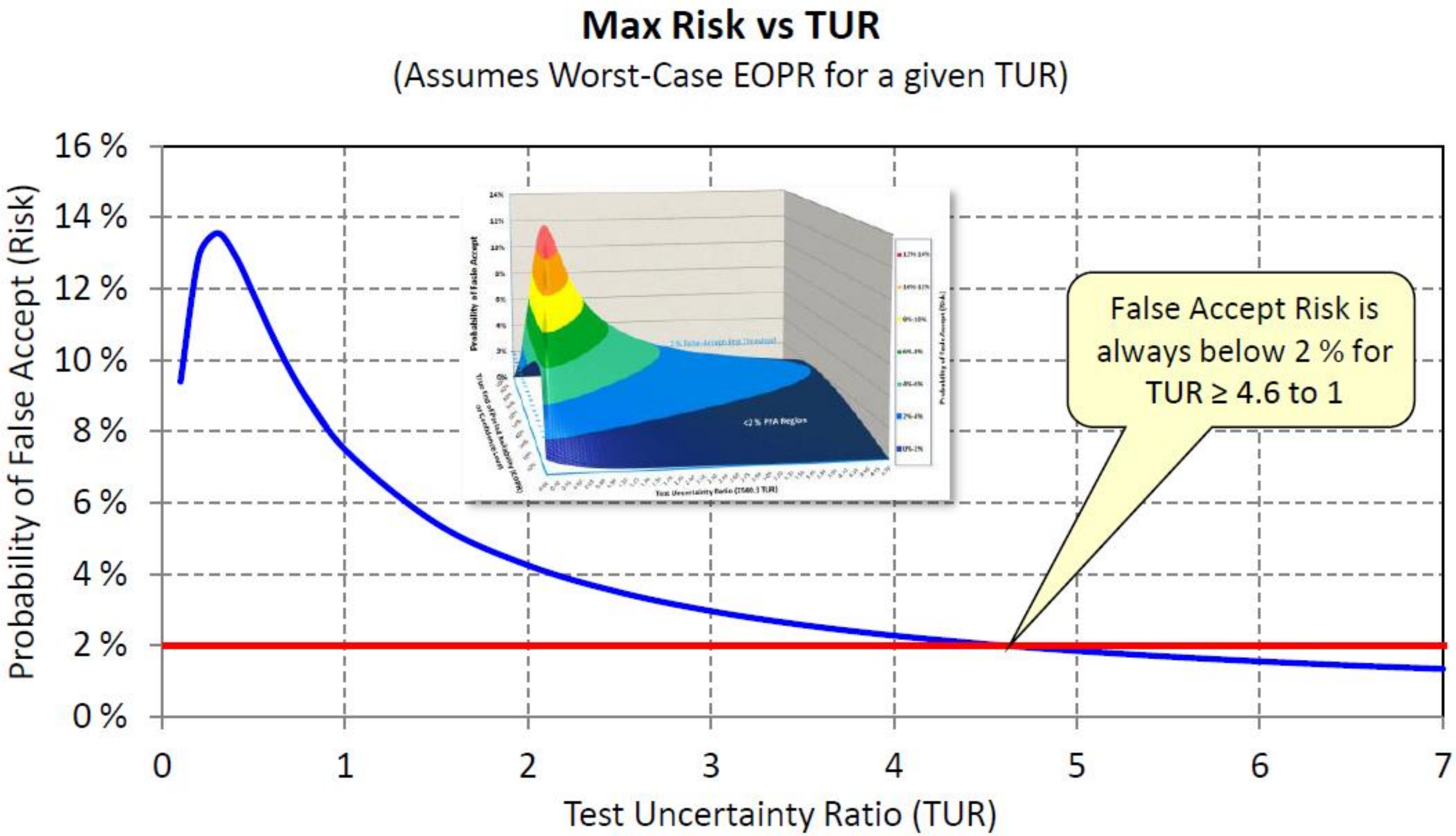


Figure 9. Worst Case False Accept Risk vs. TUR

< Worst-Case TUR에서 EOPR과 PFA 관계 >

Harben 등(2011), *Implementing Strategies for Risk Mitigation In the Modern Calibration Laboratory,* Figure 10.

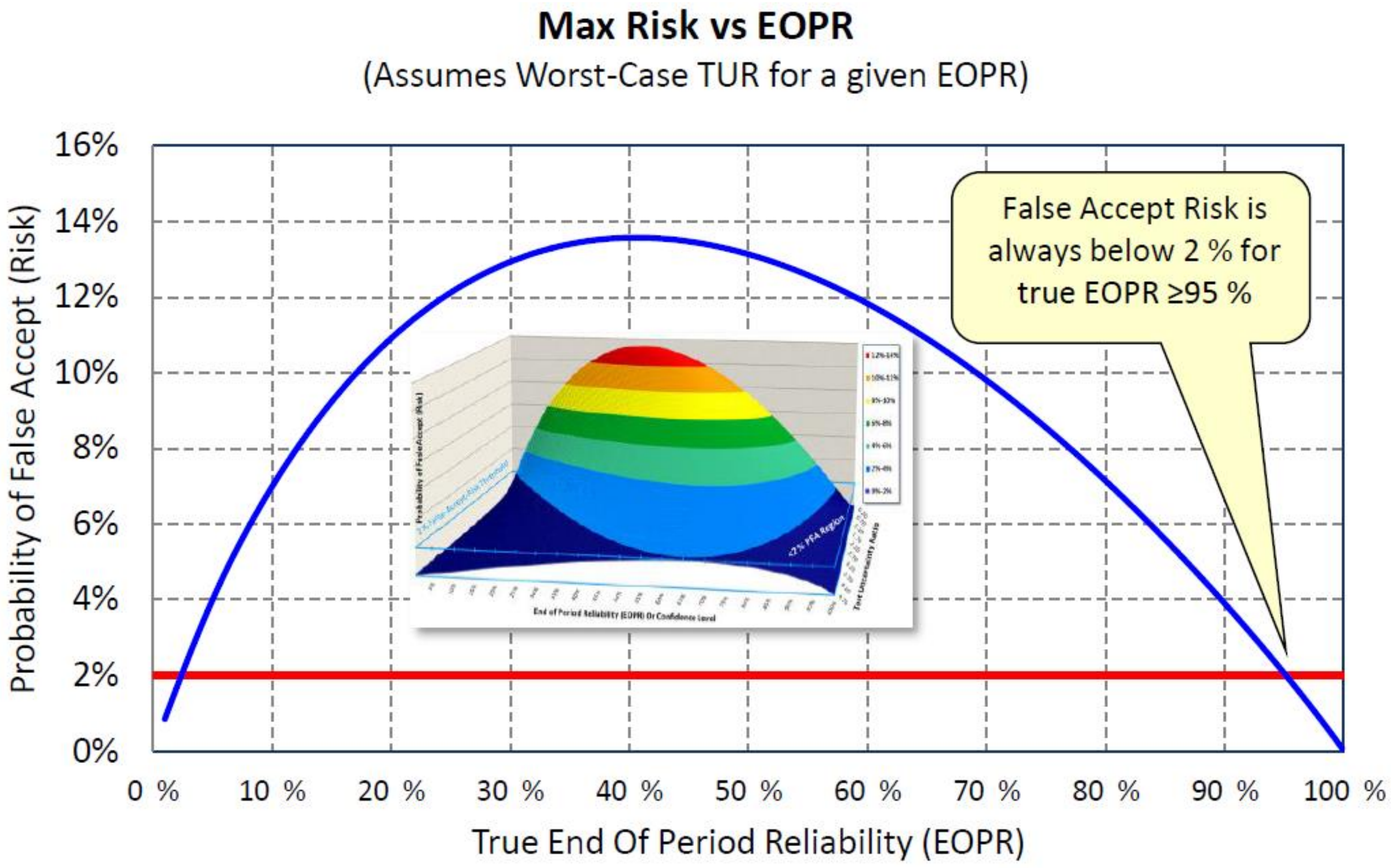


Figure 10. Worst Case False Accept Risk vs. EOPR

< Worst-Case TUR에서 EOPR과 PFA 관계 >

Harben 등(2011), *Implementing Strategies for Risk Mitigation In the Modern Calibration Laboratory,* Figure 12.

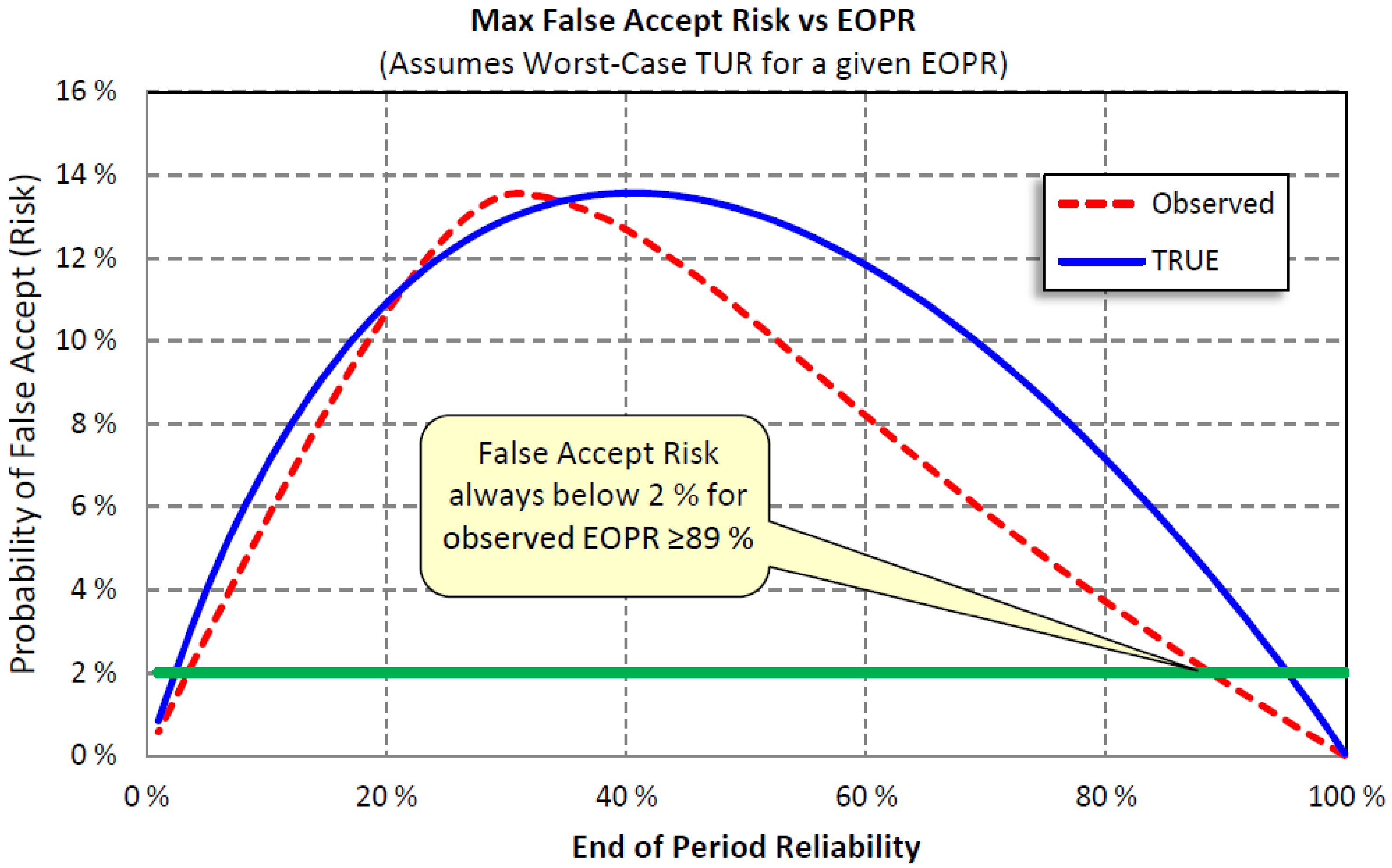


Figure 12. PFA Assumes Worst Case TUR for *True* EOPR and *Observed* EOPR.

04 적용 방법: 적합성 의사결정 규칙 선정 흐름도(ILAC-G8(2019))

< 적합성 의사결정 규칙 선정 흐름도(ILAC-G8(2019)) >

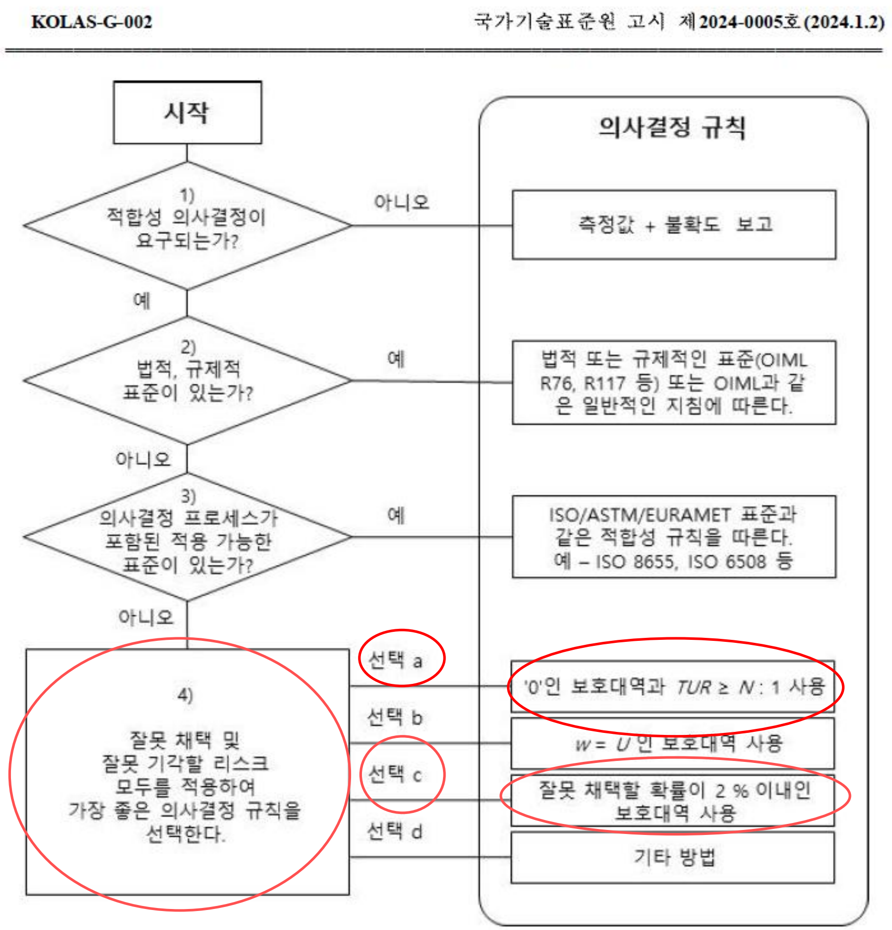


그림 1 합격/불합격 적합성 의사결정 규칙 선정 흐름도

< KOLAS G-002, P. 17 >

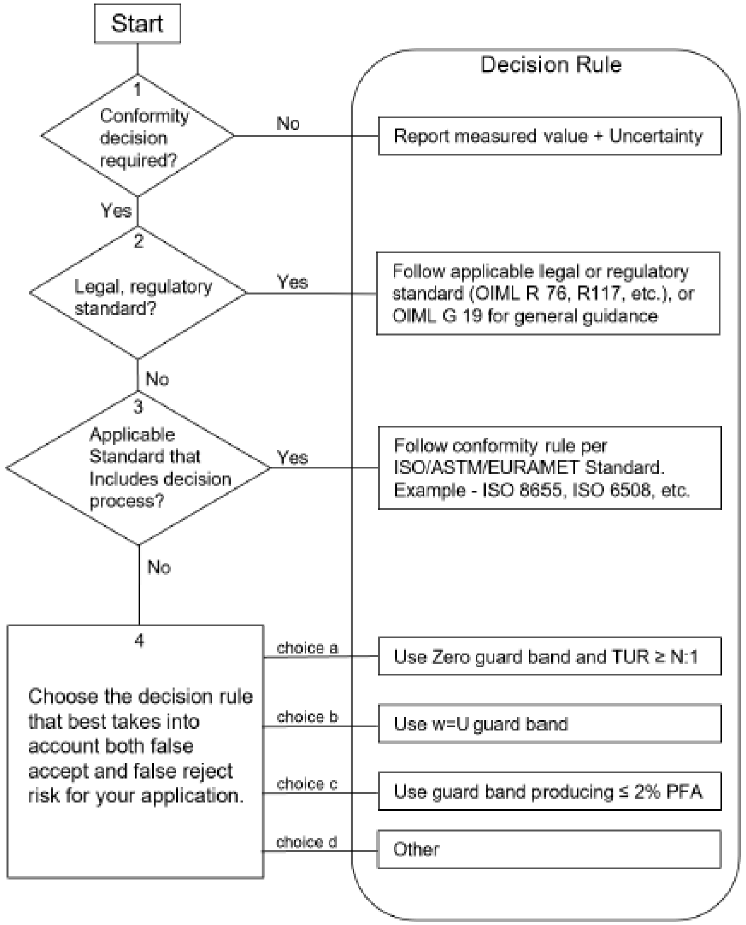


Figure 7. Pass/Fail Conformity Decision Rule selection flow chart.

< ILAC-G8(2019), P. 14 >

적용 방법: Root-Sum-Square 방법과 Dobbert 방법

< TUR을 이용한 보호대역 적용 방법 >

방법	수식
Root-Sum-Square	$AL = \sqrt{(TL^2 - U^2)}$ Where: AL: Acceptance Limit TL: Tolerance Limit U: 95% *expanded uncertainty of the measurement process used for calibration*
Dobbert	$AL = TL - U \times (1.04 - e^{(0.38\, ln(TUR) - 0.54)})$ Where: AL: Acceptance Limit TL: Tolerance Limit U: 95% *expanded uncertainty of the measurement process used for calibration* TUR: Test Uncertainty Ratio

04 적용 방법: FLUKE 사의 적합성 진술 정책(FCM 7008.1)

FLUKE

POLICY FOR MAKING STATEMENTS OF CONFORMITY IN CALIBRATION CERTIFICATES

Purpose: This policy is intended to proactively communicate the decision rules used by Fluke calibration laboratories regarding how the expanded uncertainty in a calibration is taken into account to make statements of conformity to a specification.

Application: This policy is for calibrations where the resultant measurement error, i.e. the difference between the measured quantity value and the reference quantity value, is evaluated for verification to a product specification. There are many calibrations where the result of a measurement and its associated uncertainty are all that is reported. This policy is not applicable to those calibrations.

Policy: When making statements of conformity, Fluke uses methodologies based upon a 2% false accept risk estimate. This is accomplished by the following methods assuming a worst-case end of period reliability of 85%. The methods used to control this are as follows:

1. Maintenance of no less than 4:1 test uncertainty ratio. Fluke's goal is to always provide a calibration with an expanded uncertainty that is at least four times less than the specification. In this case 2% probability of false accept is assured, and there is no need to guardband.

2. Use of a Guardband. In cases where it is not possible to ensure an expanded uncertainty to be four times less than the specification Fluke uses guardband methods that ensure there is a maximum false accept risk of 2%. In this case there is some possibility that there may be a conditional pass result. This is where the measurement error is less than the specification (i.e. in tolerance or pass), but because of expanded uncertainty the false accept risk may exceed 2%. Note that it is extremely rare, even with TURs approaching 1:1 to have a false accept risk greater than 10%. The possible guardband methods used are:

    a. Root-difference-square (RDS) guardband (G) ILAC-G8:09/2019, APPX B, example 3. The square root of the square of the specification (S) minus the square of the expanded uncertainty (U) at a 95% confidence level.

    $$G = \sqrt{S^2 - U^2{}_{95\%}}$$

    b. ILAC-G8:09/2019, APPX B, example 2. Specification minus the expanded uncertainty at a 95% confidence level.

    $$G = S - U_{95\%}$$

    c. Dobbert method. Based on the paper "A Guard-Band Strategy for Managing False-Accept Risk", Michael Dobbert, Keysight Technologies Inc., 2008 NCSL International Workshop and Symposium.

    d. Calculated using RiskGuard™ software, Integrated Sciences Group. By entering 2% as false accept limit, uncertainty and confidence, the appropriate end of period reliability and using the resultant guardband.

Please understand that these methods are not available options for every calibration but are possibilities based on the laboratory location and the product being calibrated. The calibration certificate may only describe the method used by referencing this policy and applicable paragraph such as "FCM 7008.1, paragraph 2a".

If the methods described above are not acceptable to you, it must be indicated at the time your request is submitted to Fluke. This may be done through a purchase order, in the RMA request, or by communicating directly to one of our call center personnel. Though we always want to comply to our customer's request, it is possible we may not be able to accommodate a different decision rule depending on the complexity or laboratory restraints.

Fluke Statements of Conformity Policy
FCM 7008.1
Page 1 of 1
Fluke Corporation
Revision: 002

23. 8. 30. 오전 10:13 cstools.asme.org/Interpretation/InterpretationDetail.cfm?TrackingNumber=15617

Interpretation Detail

Standard Designation:	NQA-1
Edition/Addenda:	NQA-1-2008, NQA-1a-2009, & NQA-1-2015
Para./Fig./Table No:	Req. 11, Para. 200, and Req. 12. Para 200
Subject Description:	NQA Inquiry; use of uncertainty/tolerance of M&TE
Date Issued:	08/29/2017
Record Number:	16-2780
Interpretation Number :	NQA-1-17-06
Question(s) and Reply(ies):	Question: Do NQA-1-2008, NQA-1a-2009 & NQA-1-2015, Requirement 12, Paragraph 200, and Requirement 11, Para. 200 require that M&TE uncertainty/tolerance be combined with the acceptance criteria when testing a structure, system, or component? Reply: No

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