Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22-23, 2025

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

Jinhong JOO
Korea Foundation of Nuclear Safety
jjh@kofons.or.kr

***Keywords :** ASME NQA-1 Requirement 12, 302 Reference Standard, Conformity Assessment of Measurement and Test Equipment, Consumer Risk, the 4:1 Rule

1. Introduction

In the 302 Reference Standard of the Requirement 12 of ASME NQA-1(2017 Edition), it is written that "Reference standards used to calibrate measuring and test equipment shall have a minimum accuracy four times greater than that of the measuring and test equipment being calibrated. This is to ensure that errors in the reference standards contribute no more than one-fourth of the allowable calibration tolerance. Where this 4:1 ration cannot be maintained, the basis for selection of the standard in question shall be technically justified." This clause 302 was introduced to ASME NQA-1(2008 Edition) for the first time. The clause is usually called "The 4:1 Rule." It is established to improve the accuracy of Measuring and Test Equipment(M&TE).

In this paper, the history, the meaning and the application method of 'the 4:1 Rule' are presented.

2. History, Meaning and Application Method

2.1 History

'The 4:1 Rule' was invented by Jerry L. Hayes, one of the founders of two technical societies: the Measured Science Conference and the National Conference of Standards Laboratories. According to [1] Mimbs(2007), in 1955, the U.S. Navy encountered problems in the their guided missile program due to failures in missiles that had passed the tests in the factory. Jerry Hayes studied the causes of these problems and proposed "the 4:1 Rule", a rule of thumb, as the acceptance criteria of M&TE. His proposal was based on the consumer risk analysis. The consumer risk analysis, which calculates the probability of accepting a poor-quality product.

This proposal was accepted by the U.S. Navy and U.S Navy contractors were required to implement it. This 4:1 Rule became known as the TAR(Test Accuracy Ratio) and later evolved into the TUR(Test Uncertainty Ratio).

"The 4:1 Rule" was introduced to the U.S Military Standard, MIL-STD 45662A clause 5.2 in 1988. In 1994, ANSI/NCSL Z540.1-1994, the U.S. National Standard also incorporated this rule. This standard was adopted by the U.S Military Standard. The U.S Nuclear Regulatory Commission participated in the establishment of this standard, too. In ANSI/NCSL Z540.3-2006, "The 4:1 Rule" was transformed to the concept of TUR and the probability of false acceptance being lower than 2%.

2.2 Meaning

The purpose of "The 4:1 Rule" is to establish the conformity assessment criteria for M&TE. Jerry L. Hayes used consumer risk, 0.8% as the acceptance criteria for the conformity assessment of M&TE. The consumer risk of M&TE is [1]:

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

Where:

- $r=\frac{\sigma_x}{\sigma_e}=\frac{\sigma_x}{u_e}$: accuracy ratio,
- TUR$=\frac{Upper-Lower}{2U_{95}}=\frac{Upper-Lower}{2k_e u_e}=\frac{2k_x\sigma_x}{2k_e u_e}=\frac{k_x\sigma_x}{k_e u_e}$
- 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

The relationship between r and k_x is depicted in Fig.1

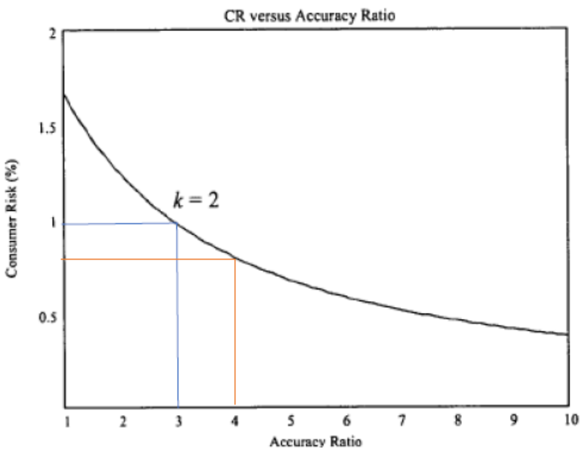

Fig 1. Consumer Risk vs Accuracy Ratio, quoted from [1] & added by author

Initially, Jerry L. Hayes suggested that consumer risk should be lower than 1% by applying an accuracy ratio of 3:1. However, to add a little extra margin, 4:1 became the established "rule of thumb."

2.3 Application Method

Clause 5.3 b) of ANSI/NCSL Z540.3-2006, the U.S. National Standard, states that "Where calibrations provide 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".

This means that "The 4:1 Rule' should be replaced with "the Probability of the False Acceptance < 2%" rule, and that the "rule of thumb" could be used if calculating this probability is too difficult.

The "Handbook for the ANSI/NCSL Z540.3-2006" recommends six methods for the calculating the probability of false acceptance. [2] Deaver(2010) suggests the "Guard Band Based on TUR" method because it is more cost-effective than other methods. The "Guard Band Based on TUR" method provides the smallest Guard Band and requires the least effort among the six methods.

"Guard Band Based on TUR" methods are also introduced as "choice C" in clause "6. Decision Rules Selection Flow Chart" in [3] the 'Guidelines on Decision Rules and Statements of Conformity', published by International Laboratory Accreditation Cooperation (ILAC) for Calibration laboratories accredited by 'ISO/IEC 17025:2017', the international standard for test and calibration laboratories.

Notably, [4] Delker(2021), supported by the U.S. Department of Energy, recommends the "Dobbert method" and "Root-Sum-Square method" as "Guard Band Based on TUR" methods for the Nuclear Security Enterprise. The "Root-Sum-Square method" is also represented in [3] the 'Guidelines on Decision Rules and Statements of Conformity.'

3. Conclusions

"The 4:1 Rule" was a "rule of thumb" developed in the 1950s to improve the accuracy of M&TE without requiring high-performance computers.

The 302 Reference Standard of the Requirement 12 of ASME NQA-1 should be implemented using current computing capabilities and the "Guard Band Based on TUR" method (especially "Dobbert method" and "Root-Sum-Square method") for the conformity assessment of M&TE.

REFERENCES

[1] Scott M. Mimbs, Measurement Decision Risk – The Importance of Definitions, 2007
[2] David K. Deaver, A Study of and Recommendation for Applying the False Acceptance Risk Specification of Z540.3, Proc., NCSL Workshop & Symposium, 2010
[3] ILAC-G8: Guidelines on Decision Rules and Statements of Conformity, 2019
[4] Collin J. Delker, Evaluation of Guardbanding Methods for Calibration and Product Acceptance, Sandia National Laboratories, 2021