

Standardizing Respirator Performance in Japan by Quantitative Fit Test

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Abstract

We review research and the standardization of quantitative fit test (QFT) in Japan and present some comments and proposals. The protective performance of respirators depends on the amount of facepiece-to-face seal leakage, and Inouye's formula shows the relationship between the protection factor and the leakage rate of respirators. The scatter amount of the measured leakage rate values are rather large compared with that of filter collection efficiency. Such an undesirable amount of scatter mainly comes from the wearing and the characteristics of face pieces themselves. It is recommended that the protective performance of respirator be evaluated not only by the value of the protection factor but also by its stability scatter. Fundamental and theoretical research is just as important as the accumulation of QFT data in understanding respirator fit. International consensus on QFT methods and application is a highly desirable goal.

Past Research and Development of QFT in Japan.

The research and development of the quantitative fit test (QFT) in Japan was started by T. Inouye and his co-workers at Musashi Institute of Technology (MIT) in 1965 under the financial support of the electric power industry and the Japanese government. This work continues at the Central Research Institute of Electric Power Industry (CRIEPI) and New Protective Systems Research Institute (NEPSRI) today.

M. Murata and others began their work on QFT using NaCl aerosols at the Japan Atomic Energy Research Institute (JAERI) around 1972. M. Ebana and others started their work on QFT at the Power Reactor and Nuclear Fuel Development Cooperation (PRNFDC) in the same year. Later, some co-workers of Inouye improved full facepieces by using QFT. In 1975, Inouye and his co-workers tested full facepieces on 150 subjects from the Tokyo Metropolitan Fire Brigade at the request of H. Ukai. Ukai also tried large-scale tests using tear gas at the Tokyo Metropolitan Fire Defense Authority. After 1980, K. Nozaki, at the National Institute of Industrial Health, and K. Kimura, at the Institute of Labour Science, began their work on QFT at the request of the Ministry of Labour. T. Kômoto and M. Takahashi at the Defense Army Laboratory started their work on QFT around 1980. In recent years, large nuclear plants have started QFT services for power-reactor maintenance workers.

Inouye and co-workers tested more than 20 kinds of full facepieces using 8 types of test contaminants and 5 types of sensors on 400 subjects and 3 types of respirable dummies.

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The freon-22 flame-ionization detector (FID) was developed at CRIEPI and was used by S. Matsuno and T. Iguchi at Nippon Diving Sports. This test system supported the development of a commercial respirator named Air-Freshan. Inouye and co-workers used the SF₆ electron-capture detector (ECD) which evaluates the performance of pressurized whole-body suits whose protection factors are more than 10⁶. This test system was made with the cooperation of H. Kôyama and H. Kanbe at CRIEPI.

Inouye and his co-workers also developed a system to evaluate the performance of facepieces for nuclear power plants at the request of the electric power industry during 1977-1980. Shibata Scientific Instrument Co. also developed another system for evaluating facepieces, including a method for human-subject tests.

Some Comments on Japan's QFT Experiences.

The observed leakage rates of tight-fit, demand-mode (negative-pressure) respirators fluctuate widely. According to our experiences, leakage rates fluctuate between 0.01 to 0.51% or between 0.5 to 11% in cases of 7 full facepieces measured by the Freon-22 FID on 75 subjects. Some results of that protection cannot be evaluated by leakage rates because of these fluctuating rates. But, it is obvious that the leakage rates of facepieces determine the protective performance of respirators, and such a wide range of fluctuation does not come from the testing methods, but rather from the characteristics of the facepieces themselves while being worn. Results of various tests prove this fact.

It is impossible to evaluate the protective performance of respirators quantitatively unless we recognize this fact. Leakage rates of facepieces vary because of the fit between the facepiece and the wearer's face. Inouye studied the relationship between the tightness of the facepiece's harness straps and the leakage around the face seal by using a strain gauge. He found the best performance when the facepiece fit snugly on the wearer, but without excessive tightening. Too much tightening at the facepiece distorts the mask. A good fit that is neither too loose nor too tight produces a minimal amount of leakage. Leakage rates vary because of the techniques of the wearer. Tight-fit respirators with a demand-mode valve can be likened to a hammer. Skill is needed to use a hammer well, but the lack of skill does not deny the intrinsic usefulness of the hammer itself. Of course, we can distinguish better facepieces from others by QFT using a certain group of subjects or a dummy test system. But, it seems that QFT is not the most reliable indicator of protection. Two things could improve this situation. The first is popularizing the use of QFT. The second is requiring QFT as a standard of testing performance. To return to our metaphor of the hammer, the intrinsic usefulness of a hammer can be enhanced by a skilled user. Standardizing respirator fit by using QFT will disallow the variability of a wearer's fit procedure.*

Using QFT as a standard to evaluate respirator performance is preferable to using qualitative fit tests. In Japan, some people have overestimated the accuracy of qualitative fit tests, but we can not find any researcher like N. A. Leidel (USA) who is studying the effects of qualitative fit tests. We would recommend this method as a substitute for QFT only when it is not possible to use QFT.

A Theoretical Approach to Protective Performance of Respirators.

The Freon-22 FID can print out leakage rates in both digital and analog with a 100- μ s response. Dead-space-pressure information is obtained by sampling dead-space air only at inspiration. Figure 1 shows the leakage rates and dead-space pressure in each inspiration measured and recorded in analog using this system. The relationship between dead-space pressure and air flow passing through dead-space in the inspiration is also shown in Figure 1. Dead-space pressure is a function of the air flow passing through the

*It is the belief of the authors that pressure-demand supplied-air respirators and self-contained breathing apparatus (SCBA) do not need to be tested by QFT or qualitative fit tests because air flow is always outward in case of a leak.

dead-space, the actual dead-space-volume, and the air-flow resistance.

The relationship between dead-space pressure and leakage rates tested by 3 kinds of full facepieces is shown in Figure 2. The leakage rate changes with the dead-space pressure within each inspiration.

In the expiration, the leakage rate should be smaller because the dead-space pressure goes positive. But, observed leakage rates in the expiration are not small because part of the contaminants from the preceding inspiration is exhausted into the dead space during expiration. For this reason, air sampling cannot be done during expiration. Data from expired air does not give any real information on leakage rates in a strict sense.

Puncturing the facepiece to sample air is also not desirable. An adaptor for QFT used for full facepiece, shown in Figure 3 was made by Inouye and co-workers. It can be improved by making it lighter in weight, smaller in size, and usable on all kinds of facepieces. Facepieces with a built-in sampling outlet have been recommended to the National Fire Defense Authority by Inouye in his report on breathing apparatus for fire-fighters.

Inouye has proposed the following formula for establishing

$$PF = \frac{100^2}{100^2 - 100 \cdot e + e \cdot I} \quad (1)$$

where

e = the collection efficiency of air filter (in the case of gas masks, e is the removing efficiency estimated from the breakthrough curve by time, humidity and air volume passing through the canister or cartridge; in the case of supplied air respirators or SCBA, e = nearly equal to 100.),

I = leakage rate,

Total leakage per breath (L) is expressed as a sum total of facepiece-to-face seal leakage (L_p), leakage from the outlet or exhalation valve (L_v), and miscellaneous leakage (L_m), such as leakage from connecting part between mask-blanc and cartridge, visor and connecting tube:

$$L = L_p + L_v + L_m \quad (2)$$

The leakage rate is defined as $I = L / I \times 100\%$, where I is a representative volume of air inhaled per breath.

The representative volume of intake of contaminants per breath may be expressed approximately as follows:

$$I \cdot C_i = C_o \cdot (I - L) \cdot (I - e/100) + C_o \cdot L, \quad (3)$$

where C_i is the contaminants concentration in the inspiration and C_o is the contaminants concentration in ambient air.

Substituting Equation (2) into (3) yields

$$\frac{I \cdot C_o}{I \cdot C_i} = \frac{100^2}{100^2 - 100 \cdot e + e \cdot I} \quad (4)$$

Protection Factor (PF) is defined as $PF = C_o / C_i$, therefore, we can calculate PF by Equation (1) using the observed values of e and A

Fitting Test Respirators

In case of test-fit dust respirators using DOP and NaCl test aerosols, the leakage rate includes the leakage of penetration through the air filter (L_f), therefore, it should be called the overall leakage (L_o) and is expressed as $L_o = L_f + L_p + L_v + L_m$. In Equation (2), L_f is excluded and expressed by e in Equation (1). In our method, e is tested independently or estimated by the breakthrough curve of the canister or cartridge.

Figure 4 shows the BAFLET tester which was used to measure the size of $L_v + L_m$ under $L_p = 0$ using a rubber balloon before QFT. If the size of $L_v + L_m$ is significant, after replacing the valve or adjusting the leak, QFT is tried with the minimum size of $L_v + L_m$. This instrument is like the Dräger's but has an additional capacity to record the test results.

Nowadays, full facepieces are used as a component of dust respirators, gas masks, supplied-air respirators, SCBA. Therefore, by using this formula, the protection performance can be estimated from the observed leakage rate of the facepieces. Of course, leakage rates shall be tested under the same dead-space pressure under actual uses of respirators which involved the air flow passing through dead-space, actual dead-space volume and air flow resistance.

The relationship of I , e , and PF using Equation (1) is shown in Figure 5. When the size of e is lower than 90%, the influence of I to PF is small, but if the size of e is more than 99%, this influence becomes large.

In the case of dust respirators, QFT may be omitted except for fundamental research and HEPA-filter-installed cases. The use of HEPA filters on a dust respirator whose I is larger than 1% may be not effective.

Standardizing QFT in Japan.

In 1968, Inouye reviewed QFT activities and proposed standardizing QFT in Japan in *Safety Digest*, published by the Japan Safety Appliances Association, Inc. At MIT, JAERI, and PRNFDC, QFT studies started during 1965-1972. After more than 10 years, the standardization of QFT has begun.

In 1979, a committee adopted a QFT to evaluate the protective performance of SCBA and use of QFT was authorized by the National Fire Defense Authority (NFDA) in 1980. Another committee looked at disposable dust respirators, adopted the QFT which was authorized by the Ministry of Labour in 1981, [Japanese Industrial Standard or JIS for disposable dust respirators authorized in 1983 (JIS-T-8158)]. The same standard was also applied to air-purifying respirators in 1981.

In 1980, Japan Safety Appliances Association (JSAA) organized a committee to research and discuss the technological basis of QFT. This committee was composed of scientists and technicians engaged in QFT work at that time under the chairmanship of Inouye. Referring to the report of this committee, the JIS testing method for facepieces was authorized in 1983 as JIS T-8159.

In 1982, three committees were organized at the request of the National Technology Board of Ministry of Foreign Trade and Industry (MITI). They are preparing standards on the selection, use, and maintenance of respirators. They are also working on a glossary of terms relating to respiratory protective equipment and a standard on respirators for particulates. These drafts include the QFT, leakage rates of facepiece protection factor, and protection rates. These standards are in a preliminary form which will undergo much revision before completion. It is evident by these activities that Japan is rapidly incorporating QFT into respiratory protection standards.

Some Proposals on QFT

It is very important to consider not only the size of the PF but also the fluctuation range. The size of the PF shows the size of protection in an ideal situation, and the fluctuation range shows the stability of the respirators. The PF of respirators, especially tight-fit, demand-mode respirator must be expressed by both the size of PF and also by the observed leakage rate, or PF.

Collecting actual QFT data is very important, but we think that the theoretical approach and basic research on leakage rates of facepieces by respirable test dummies are also important. The NaCl flame-photometric method is useful for routine QFT by users, but gas methods, including the dummy test, are more appropriate for use by manufacturers and approval authorities.

Actual QFT in plants using one set of portable air samplers and the development of a mass-screening method to detect poor-fitting respirators at controlled-area entrances are also necessary. Also needed is a method which is capable of testing several hundred wearers within 20 to 30 minutes.

It is necessary to exchange technical information to reach a consensus on QFT on a worldwide scale. To this aim, I am proposing that an international committee on QFT be organized by with subcommittees in the individual countries that would report their findings to some main group.

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Table 1. Protection factors of respirators as calculated by Inouye's equation.

Collection Efficiency (%)	Leakage Rate (%)										
	5.0	4.0	3.0	2.5	2.0	1.5	1.0	0.75	0.5	0.25	0.1
85	5	5	5.5	5.5	5.5	6	6	6	6	6.5	6.5
90	6.5	7	7.5	8	8	8.5	9	9	9.5	9.5	9.5
95	10	11	12	13	14	14	15	16	17	17	19
99	16	20	25	28	33	40	50	55	65	65	90
99.5	19	24	28	33	40	50	66	80	100	100	166
99.9	19	24	32	38	47	66	90	115	165	165	500
99.99	19	24	33	39	49	66	99	130	195	195	900
100	20	25	33	40	50	66	100	130	200	200	1000

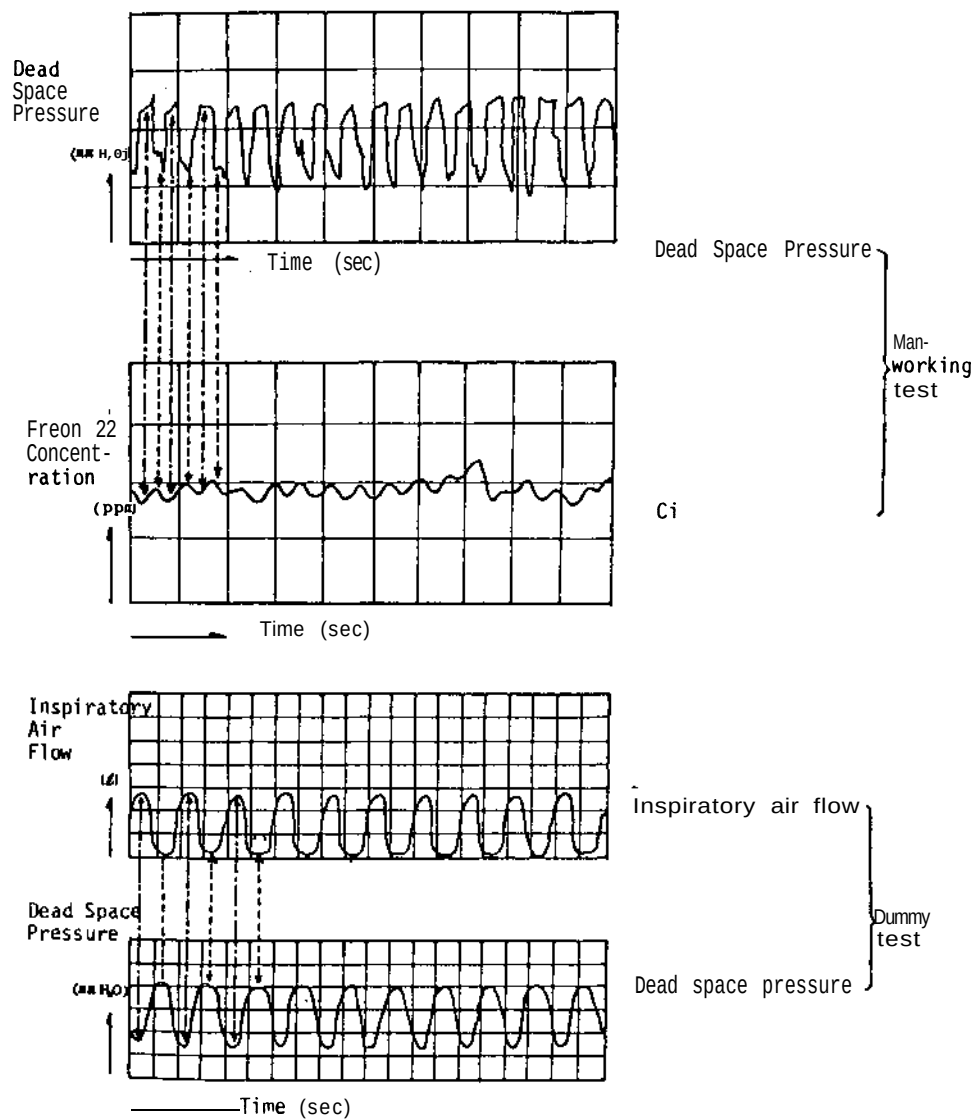


Figure 1. Relation between C_i and deadspace pressure. Also relation between inspiratory air flow and deadspace pressure observed in Freon 22FID test.

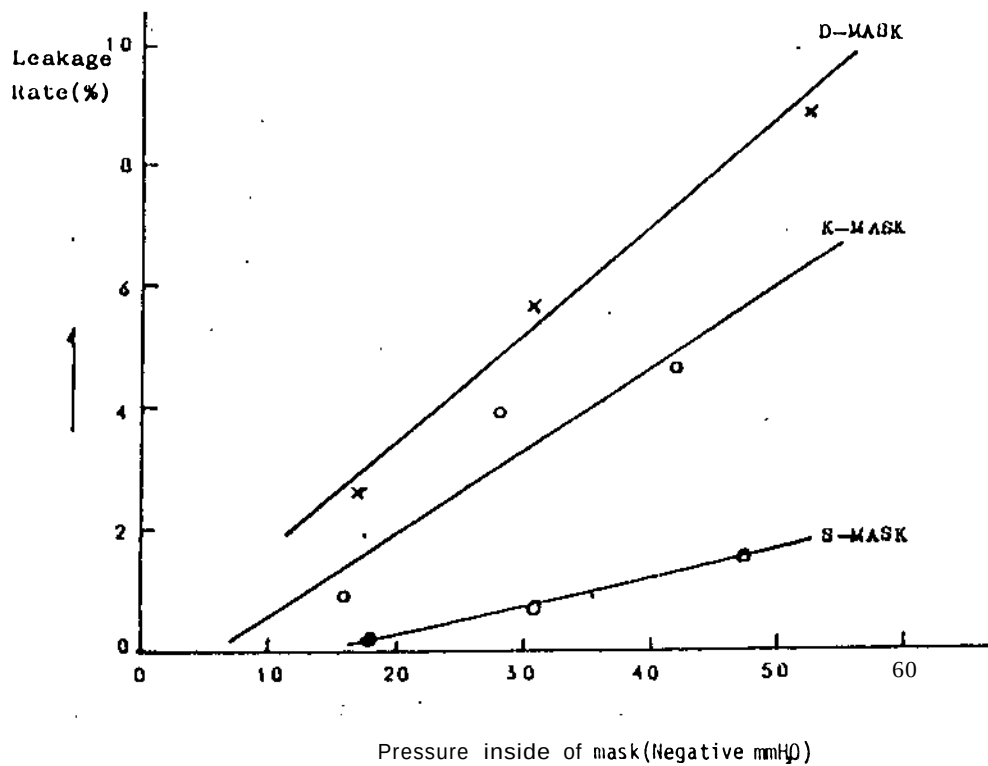


Figure 2. Leakage rates versus inside pressure of 3 kinds of full face-pieces. (T. Inouye et al.)

Figure 3. Adapter for full face piece QFT INLET VALVE System (T. Inouye et al.).

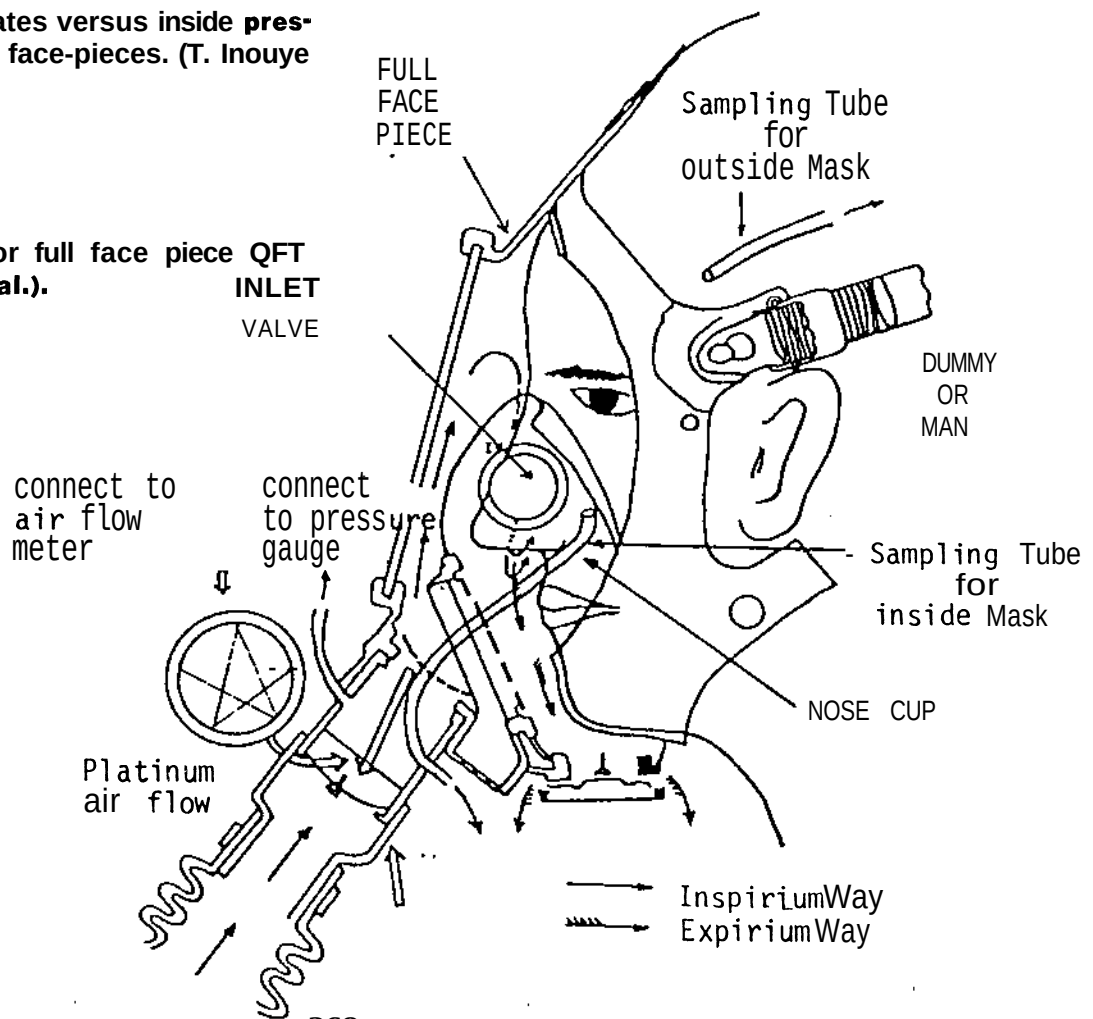


Figure 4. BAFLET testing device

(Courtesy NEPSRI Ltd.)

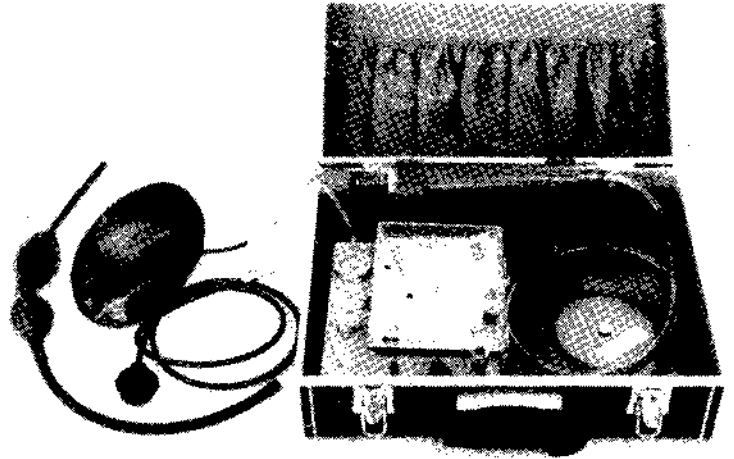


Figure 5. Relationship between PF, e and I.

