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Quality Control for Environmental Measurements

EARL SHIRLEY

A general overview of the quality assurance program for environmental measurements practiced by the California Department of Transportation is presented to illustrate current practice. The discussion, which is general rather than detailed, places the program in perspective and concentrates on equipment used to measure noise and air pollutants and the associated instrumentation and procedures for calibration. A quality assurance program is necessary to ensure the validity and reliability of environmental measurements. Traceability of instrument calibration to an authority such as the National Bureau of Standards is important. The program involves fairly complex instrumentation systems and requires expert technical personnel and good documentation.

One of the fundamental responsibilities of management is the establishment of a continuing program to ensure the reliability and validity of any measured test value. The California Department of Transportation (Caltrans) has been following such a program for a number of years to provide assurance that test data involving materials such as asphalt, soils, and concrete are valid. To achieve this, the department has been participating in national programs sponsored by organizations such as the American Society for Testing and Materials, the Materials Reference Laboratory of the American Association of State Highway and Transportation Officials, and the Cement and Concrete Reference Laboratory of the National Bureau of Standards (NBS) and has been carrying out its own quality control program.

The addition of environmental testing responsibilities to Caltrans' normal duties brought about a need for a quality assurance program (QAP) in those areas also. Specifically involved were test data relating to air quality, water quality, and noise and vibration. Some of the benefits that would result from such a program were seen to be

1. Increased confidence in decisions based on environmental data;
2. A solid, defensible position in the event of litigation involving environmental data;
3. Uniformity in techniques and procedures for the use of instruments and their calibration and for data analysis; and
4. Unqualified acceptance of Caltrans test results by other organizations.

With the need for a QAP identified, it was necessary to decide on the program type and scope that would best fit Caltrans needs. Three basic alternatives were examined:

1. Develop a full "standards laboratory" capability in-house,
2. Make use of equipment manufacturers' regional service centers, or
3. Develop an in-house capability similar to that of a manufacturer's regional service center.

The first alternative was judged to be too costly. For example, the noise portion would require either the rental or the construction of an anechoic chamber. It was also felt that full-scale testing of environmental measurement equipment in accordance with American National Standards Institute, U.S. Environmental Protection Agency (EPA), and NBS procedures was neither cost effective nor necessary for Caltrans operations.

The second alternative, based on previous experience, would lead to long "turn-around" times (up to three months) and tend to discourage regular calibration. In addition, since most of the regular project-related environmental analyses are done by personnel in the 11 Caltrans districts, this alternative would not free headquarters personnel from duties in coordination, documentation, field review, and training.

The third alternative was felt to be the most suitable solution. Much of the instrumentation necessary for such a program was already on hand. Other advantages included information exchange, corrective action on equipment and test procedures, and, in some cases, concurrent certification of testing technicians.

There were two general goals: (a) compliance with state and federal mandates for environmental testing and (b) ensuring the reliability and validity of environmental test results. The following objectives would lead to attainment of those goals:

1. Develop procedures for administration and documentation and define areas of responsibility,
2. Develop procedures for maintaining environmental measuring equipment in calibration and ensure that the instruments used for the calibration are traceable to NBS,
3. Develop procedures for certifying and auditing personnel assigned to perform field and laboratory environmental measurements, and
4. Frame a QAP to include and to implement the above procedures and provide the necessary support in terms of competent technical assistance and adequate calibration instruments.

Keeping these goals and objectives in mind, Caltrans developed QAPs for noise (1), air quality (2), and water quality (3). This paper summarizes the equipment and procedures used in the noise and air quality programs.

ELEMENTS OF A QAP

Framing a QAP to include the necessary administrative and technical procedures led to selection of the following program elements:

1. Program administration includes coordination; scheduling; preparation and transmittal of quality control samples; collection and analysis of data and reporting results; dissemination of instructions, information, and changes in policy and procedures; identification and correction of systematic deviations, bias, and erratic results; preparation of test methods; and equipment purchase and repair.
2. Training, although an administrative function, is treated as a separate element because of its importance. Training covers sampling, field testing, equipment calibration, equipment storage, laboratory testing, and record keeping. It consists of formal in-house courses, on-the-job training, academic courses, and manufacturers' seminars.
3. Instrument calibration involves establishing calibration standards traceable to NBS, determining equipment characteristics to be tested and applicable tolerances, and determining an optimum calibration interval. It is discussed in some detail for both noise and air quality instrumentation in the following sections of this paper.
4. Operator certification and procedural audits recognize that, in addition to calibrated instruments, valid environmental measurements depend to a great degree on the competence of the people who operate the instruments and analyze the data and the degree to which they follow established procedures. Although training is available, it is difficult to establish a policy for periodic retraining. As a result, inexperienced or "rusty" technicians can be involved in environmental measurement and analysis. Due to these inadequacies, it is necessary to evaluate and review the actual measurement procedures on an annual basis.
5. Documentation is an essential feature of a QAP. The bulk of the documentation concerns equipment calibration and is detailed and technical in nature. Documentation for the procedural audit consists of a simple performance certificate.

INSTRUMENT CALIBRATION

Noise

The basic goals of instrument calibration were to detect serious malfunctions or deficiencies in District equipment and to establish calibration documentation attesting to the long-term stability of the equipment. Of the many tests that are commonly performed on noise-measuring equipment, the following were determined to be necessary in terms of disclosing basic equipment malfunctions yet simple enough to be incorporated in a portable calibration program:

1. Calibrators--(a) Calibrator output level and (b) calibrator output frequency;
2. Sound-level meters (SLMs)--(a) Meter scale linearity, (b) 10-dB step attenuator accuracy, (c) A-weighting, (d) internal noise, and (e) SLM output voltage; and
3. Graphic level recorders (GLRs)--(a) Accuracy of response, (b) overshoot-undershoot and creep, (c) chart speed, and (d) writing speed.

With the specific tests decided on, it was necessary to select calibration instrumentation to perform the tests. Table 1 lists this equipment, and Table 2 relates the equipment to the test and gives the allowable tolerances.

Traceability to NBS is achieved by periodically submitting the specially designated "laboratory standard" microphone to NBS for calibration. On its return, this "calibrated" microphone is used to define the sensitivity of another microphone used in the calibration of Caltrans district calibrators. This microphone is referred to as a "working standard" microphone. This program of sending a laboratory standard microphone directly to NBS provides the highest level of NBS traceability (see Figure 1).

If continual calibration capability is to be maintained, it is necessary to have two laboratory standard microphones for cross calibration so that, when one is at NBS for calibration (turnaround time is about three to five weeks), the other is available for use. The Caltrans Transportation Laboratory (TransLab) purchased two 1-in laboratory standard microphones at a cost of about $700 each. Because they could be used on existing Translab equipment, the total cost of setting up a laboratory standard measuring system was minimized. The total cost of all equipment required for this type of system would be about $6000.

Another key instrument for which NBS traceability is necessary is the standard voltmeter used by TransLab in this program. This meter must be a true RMS digital type and is sent annually to its manufacturer for calibration against standards directly traceable to NBS. The instrument is a portable AC/DC unit with an accuracy of 0.05 dB or better and was approved by NBS for our purposes.

The other TransLab standard for which periodic calibration is required is the standard frequency counter. There are two existing standards that provide limited degrees of calibration: (a) tuning forks maintained by the electrical section of TransLab and certified by their manufacturer as to their exact frequency and (b) a 1000-Hz pure tone provided by the telephone company and accessible by dialing.

Although the above references can be used for periodic checks of the frequency counter at a limited number of frequencies, a thorough NBS-traceable calibration of the counter should be performed at least every two years. This is available from the manufacturer. Two years is considered a reasonable interval because the instrument is highly accurate and stable.

The calibration data for the NBS-calibrated laboratory standard microphones are used in adjusting the input sensitivity of the laboratory standard SLM/preamp/microphone system to estabalish a "true-reading" system. The working standard system is then compared with the laboratory standard system by using a pistonphone transfer standard. The pistonphone is a highly precise mechanical device that generates a pure tone of 250 Hz at a sound pressure level of 125 dB and has an accuracy of ±0.2 dB.

Table 1. Calibration equipment for noise instruments.

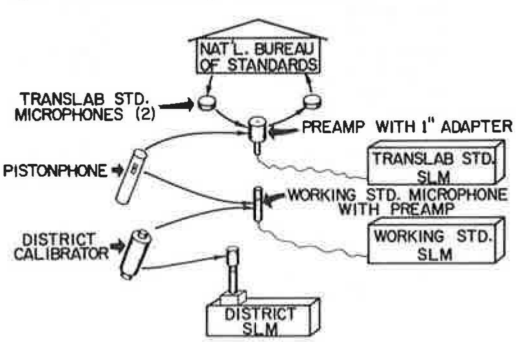
Category	Equipment No.	Equipment
Laboratory standard	1	SLM/preamp/microphone system
	2	Frequency counter
	3	Digital voltmeter
	4	Pistonphone transfer standard
Working standard	5	SLM/preamp/microphone system
Ancillary equipment	6	Acoustical signal generator (signal generator, amplifier, attenuator set, "slave" calibrator)
	7	Dummy microphone
	8	Stopwatch and ruler

Table 2. Tests and equipment for noise instrument calibration.

Test Item	Equipment No.[a]	Tolerance
Calibrator		
Output level	5	±0.5 dB
Output frequency(s)	2,5	±0.2 dB @ 1000 Hz
Sound-level meter		
Meter scale linearity	2,6	±0.4 dB @ 250, 500, and 1000 Hz
10-dB step attenuator accuracy	6	±0.5 dB @ 250, 500, and 1000 Hz
A-weighting	6	Depends on octave band
Internal noise	7	<30 dB
SLM output voltage	3,6	±0.4 dB for 5-dB steps @ 250, 500, and 1000 Hz
Graphic level recorder		
Accuracy of response	6	±0.5 dB
Overshoot-undershoot and creep	–	±1.0 dB (20-dB step)
Chart speed	8	±10 percent between runs
Writing speed	8	

[a]From Table 1.

Figure 1. NBS traceability: noise instruments.



Tests of SLM characteristics are made electroacoustically; that is to say, the SLM is subjected to acoustical input signals so that the microphone, as well as the meter electronics, is tested. It would be possible to remove the SLM microphone and input electrical signals directly to the SLM, but separate microphone tests would then have to be conducted.

Ideally, electroacoustical tests on SLMs are done in a reflector-free environment such as an anechoic chamber. Because of the trouble and expense involved in constructing one of these chambers, and because of the nature of the Caltrans calibration program, a relatively simple system was devised that would allow a controllable acoustical signal to be input to an SLM. This system requires the use of what will be called a "slave" calibrator, which is nothing more than a calibrator driven externally by a signal generator. The calibrator in this situation is simply serving as a transducer or loudspeaker, converting an electrical signal into an acoustical one. An infinite variation of signal amplitudes and frequencies can therefore be obtained by adjusting the signal generator.

The output frequencies of the signal generator are measured by the standard frequency counter. Placed in series with this system is an attenuator box capable of providing 10- and 1-dB step changes in signal level. Also in series with this array is an amplifier for increasing the output range of the system (see Figure 2).

Such a system as this can only be useful if its acoustical output can be accurately characterized with respect to frequency response. Here again, the laboratory standard microphone is required. By mounting the "slave" calibrator on the standard microphone and "sweeping" the frequency spectrum on the signal generator controls, the frequency response of the slave system can be exactly defined. It must be stressed that this slave system should not be used unless frequency response data are first obtained by using a standard microphone.

Air Quality

During the early years of air pollution monitoring, the methods of analysis were heavily based on wet chemical tests and were usually performed by chemical laboratory personnel. It is understandable that many early calibration methods and standards were derived from involved chemical reactions. Many relied on color changes of solutions exposed to air samples by fritted glass bubblers. The color changes were read by photometers at specific wavelengths characteristic of the reaction being studied. Calibration was achieved by mixing the pollutant in question in known quantities with the solution and documenting the color change. These basic methods were complex, time consuming, and very susceptible to conditions that existed when the mixing and testing were performed. They were also highly dependent on the quality of the chemicals and personnel involved.

New developments in instrumentation methods, coupled with the uncertainties involved in chemical analysis and the discrepancies between tests performed by different monitoring groups, brought new means of analysis and calibration to the forefront. The time period from the early 1970s to the present has seen the development of permeation tubes, flow dilution systems, especially lined cylinders, standard reference materials (SRMs) supplied by NBS, and the sensitive new gas phase reaction and optical method instruments.

These new instruments use the following methods of measurement:

1. Nondispersive infrared absorption for carbon monoxide (CO) measurement,
2. Chemiluminescence for ozone (O_3) and nitric oxide (NO_x) measurement,
3. Ultraviolet light absorption for O_3 measurement, and
4. Gas chromatography with flame photometric and flame ionization detection for sulfur dioxide (SO_2) and total hydrocarbon (THC) measurement, respectively.

These new detection methods brought with them sensitivities of 0.5 ppm or less and accuracies of 1-2 percent. This stretched the limits of past calibration methods and emphasized the need for standardization of procedures, tightening of tolerances on span gases, documentation of instrument performance, and in-use surveys of precision and linearity.

Calibration of these instruments, not including some of their internal preparatory calibration procedures, was restricted to certain tests, and appropriate calibration instrumentation was selected to perform these tests. Table 3 lists the equipment, and Table 4 relates the equipment to the individual test.

Traceability to NBS is achieved through the use of SRMs as laboratory standards (see Figure 3). These are in the form of bottled gases with precisely measured concentrations of the pollutants of interest. An exception is ozone. The laboratory standard, which in this case is also a working standard, is an ozone comparator that is verified quarterly with a reference photometer in the California Air Resources Board (CARB) Laboratory.

Two other working standards receive regular verification by CARB. The gas calibration system receives a check of the flow dilution settings and is supplied with a verified multigas cylinder that contains high concentrations of CO, NO_x, THC, and methane (CH_4). The dry gas flow meter is calibrated by use of a positive displacement instrument with a mercury-sealed piston. In addition, the digital multimeter is calibrated by NBS-traceable standards in the Caltrans electronics laboratory.

The calibration program for district air quality instrumentation begins with reference analyzers that are maintained in the Caltrans central laboratory under controlled environmental (temperature and humidity) conditions. These instruments are calibrated on the NBS SRMs. Individual cylinders of gases with pollutant concentrations determined by these analyzers are then used as transfer standards to calibrate upscale readings on field analyzers. Linearity checks are made with the gas calibration system.

Quality control is enhanced by a periodic interlaboratory testing effort that uses "unknowns" prepared by the central laboratory.

Figure 2. Calibration signal production.

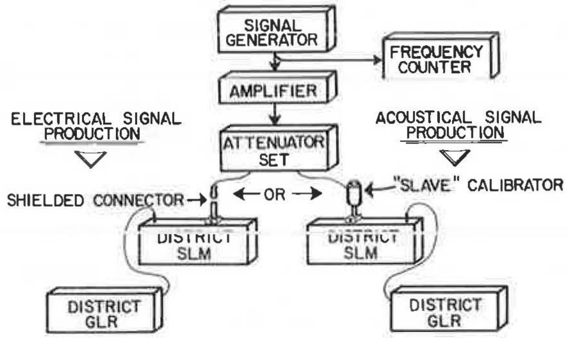


Table 3. Calibration equipment for air quality instruments.

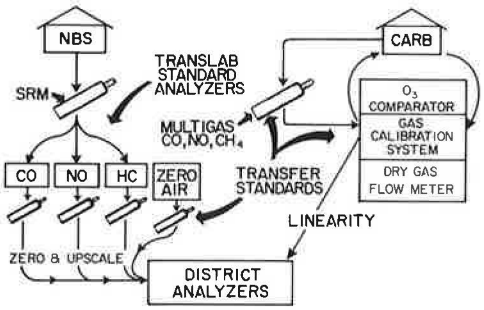
Category	Equipment No.	Equipment
Laboratory standard	1	NBS SRM for CO
	2	NBS SRM for NO_x
	3	NBS SRM for CH_4
	4	Reference analyzers (CO, NO_x, HC, O_3)
	5	Zero air system
Working standard	6	Transfer gas cylinders (CO, NO_x, CH_4, zero air)
	7	Ozone comparator
	8	Gas calibration system (includes multigas cylinder)
	9	Digital multimeter
	10	Dry gas flow meter
	11	Bubble flow meter
Ancillary equipment	12	Digital temperature sensor
	13	Strip chart recorder
	14	Stopwatch

Table 4. Tests and equipment for air quality instrument calibration.

Analyzer	Method	Calibration Test	Equipment[a]
CO	Nondispersive infrared absorption	Instrument bias	9, 13
		Zero reading	6, 8, 9, 13
		Upscale reading (span)	6, 9, 13
		Sample flow	10, 14
		Output linearity	8, 9, 13
O_3	Ultraviolet absorption	Zero reading	6, 8, 9, 13
		Catalytic O_3 scrubber	7, 9
		Upscale reading (span)	7, 9, 13
		Sample flow	10, 14
		Output linearity	7, 9, 13
NO_x	Chemiluminescence	Zero reading (including dark current)	6, 8, 9, 13
		Upscale reading (span)	6, 9, 13
		NO_2 - NO converter	7, 9, 12, 13
		Sample flow	10, 14
		Output linearity	7, 9, 13
HC	Gas chromatography with flame ionization detection	Flow rates (all gases)	11, 14
		Function and gate timing	13, 14
		Zero reading	6, 8, 9, 13
		Upscale reading (span)	6, 8, 9, 13
		Output linearity	7, 9, 13

[a] Refers to designation in Table 3.

Figure 3. NBS traceability: air quality instruments.



PROGRAM EXPERIENCE

Calibration of noise-measuring equipment, prior to the formal QAP, had been left up to the Caltrans districts. Appropriate intervals had been recommended, but practice varied considerably. There are 41 SLMs, 16 GLRs, 45 microphones, 7 analyzers, and 41 calibrators involved in the program. When the QAP was initiated, it was found that two years had elapsed since some instruments were calibrated. Fortunately, only about 6 percent of the instruments were out of specified tolerances. About 15 percent of the instruments showed problems that needed correction.

The program for air quality measurements interfaced with a previous program carried out by the California Air and Industrial Hygiene Laboratory. This meant that the equipment was in good calibration when the program started. Calibration, however, had been based on one or two upscale points, and it was found that linearity adjustments were necessary for the lower-scale values. Seventeen CO analyzers and eight each for O_3, HC, and NO_x are calibrated in this program. The hydrocarbon analyzers are more troublesome than the rest because of their complexity.

The procedures developed for the program seem adequate. Having the equipment adjusted and put in good repair as part of the calibration process is a great advantage. It is too early to draw conclusions about long-term instrument stability, but as we accumulate calibration history it will be one of the things that will affect calibration frequency.

The need for environmental measurement has diminished along with capital improvements, and Caltrans is doing much less today than a few years ago. As long as any measurements are made, however, a QAP will continue to be a necessary part of our work.

ACKNOWLEDGMENT

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Quick Fix for Washington Metro Brake Squeal

GUMMULURU N. SASTRY AND EDGAR C. GREEN, JR.

When the Washington Metropolitan Area Transit Authority (WMATA) made some changes in the brake system configuration of pads and discs to increase the wear life of the brake system in the fall of 1980, the quality, duration, and frequency of brake squeal increased dramatically, causing citywide complaints and adverse publicity. A quick fix had to be found within a few weeks to mitigate this squeal and avoid further losses of ridership. A test program was designed to find a solution simple enough to incorporate into the system immediately. Several configurations of brake pads were tested and a "quiet pad" that does not generate the annoying squeal was found among those pads made available to WMATA. Abex 1389b pads were retrofitted to the system, and the squeal disappeared.

When the Washington, D.C., Metro system was first opened to the public in 1976, quietness, speed, and comfort were the trademarks of the system and were highly praised by the public. But a letter to the editor of the Washington Post published on January 5, 1981, read as follows: "As a visiting New Yorker, I find the noise levels of arriving Metro trains intolerable. As a worker a year ago in Washington I knew this was not the case. Trains arrived with some quietness....Why has this been allowed to go unchecked? Where are the environmentalists?....Are D.C. travelers so immune to this insane decibel level that they ignore it?"

This rider's observation of the increased noise level in the Washington, D.C., Metro system was one of the more mildly worded of the widespread adverse reactions. Meanwhile, Washington Metropolitan Area Transit Authority (WMATA) environmentalists were aware of this annoying problem and were frantically working to alleviate the noise.

WMATA cars were designed with disc brakes as the primary friction braking system. There have been several investigations and tests over the past few years aimed at improving brake pad and disc life and mitigating the noise problem. When WMATA made some changes in the brake system configuration of pads and discs in the fall of 1980 in order to increase brake pad and disc life, the quality, duration, and frequency of the squeal changed dramatically, causing citywide complaints and adverse publicity. This