Altitude, Sample Port Inlet Loading, and Temperature on the Volumetric Flow Rate of the MSA Escort Elf® Constant Flow Rate Pump. Pres. at Second International Conference on the Health of Miners, Pittsburgh, PA, November 11–13, 1995.

Dated: December 19, 1997.

J. Davitt McAteer,

Assistant Secretary for Mine Safety and Health.

Dated: December 19, 1997.

Linda A. Rosentock,

Director, National Institute for Occupational Safety and Health.

Note: For the convenience of the user, notice document 97–33934 is being reprinted in its entirety because of numerous errors in the document originally appearing at 62 FR 68372–68395, December 31, 1997. Those wishing to see a listing of corrections, please call Patricia Silvey, Mine Safety and Health Administration, 703–235–1910.

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DEPARTMENT OF LABOR

Mine Safety and Health Administration

Coal Mine Respirable Dust Standard Noncompliance Determinations

Correction and Republication

Note: For the convenience of the user, notice document 97–33937 is being reprinted in its entirety because of numerous errors in the document originally appearing at 62 FR 68395–68420, December 31, 1997. Those wishing to see a listing of corrections, please call Patricia Silvey, Mine Safety and Health Administration, 703–235–1910.

AGENCY: Mine Safety and Health Administration, Labor.

ACTION: Notice; final policy.

SUMMARY: This notice announces the Mine Safety and Health Administration's (MSHA) final policy concerning the use of single, full-shift respirable dust measurements to determine noncompliance and issue citations, based on samples collected by MSHA, when the applicable respirable dust standard is exceeded. This notice should be read in conjunction with the notice published elsewhere in today's **Federal Register** jointly by the Department of Labor and the Department of Health and Human Services.

EFFECTIVE DATE: This policy is effective March 2, 1998.

FOR FURTHER INFORMATION CONTACT: Ronald Schell, Chief, Division of Health, Coal Mine Safety and Health; MSHA; 703–235–1358.

SUPPLEMENTARY INFORMATION:

I. About This Notice

This notice provides information about MSHA's new enforcement policy for the use of single, full-shift respirable dust measurements obtained by inspectors to determine noncompliance with the respirable dust standard (applicable standard) under the MSHA coal mine respirable dust program. A question and answer format has been used to explain the background for the enforcement policy, the reasons for the policy change, and the specific elements of the new policy. In addition, several appendices are attached to and incorporated with this final notice which address technical issues concerning the new enforcement policy.

II. Background Information

A. How Has MSHA Sampled Coal Mines for Noncompliance in the Past?

Prior to October 1975, noncompliance determinations were based on the average of full-shift measurements collected from individual occupations on multiple shifts. MSHA interprets a full shift for underground coal mines to mean the entire shift worked or 8 hours in duration or whichever time period is less (30 CFR 70.201(b)). The need to reduce the Agency's administrative burden attributable to inspector sampling prompted MSHA to revise its underground health inspection procedures and redirect the Agency's enforcement resources away from sampling and toward assessing the effectiveness of mine operators' respirable dust control programs.

Since October 1975, MSHA has determined noncompliance with the applicable standard based on the average of measurements obtained for different occupations during the same shift of a mechanized mining unit (MMU), or on the average of measurements obtained for the same occupation on successive days. The term MMU is defined in 30 CFR 70.2(h) to mean a unit of mining equipment, including hand loading equipment, used for the production of material. MSHA inspectors routinely sample multiple occupations to determine compliance with the applicable standard, assess the effectiveness of mine operators' dust control programs, determine whether excessive levels of quartz dust are present, and verify the designation of the ''high risk occupation'' (now referred to as the ''designated occupation'' or ''D.O.''—the occupation on a working section exposed to the highest respirable dust concentration) to be sampled by mine operators.

Under the sampling procedures in place between 1975 and 1991, MSHA inspectors would collect full-shift measurements from the working environment of the ''D.O.'' and four other occupations, if available, on the first day of sampling each MMU. The mine operator was cited if the average of all measurements obtained during the same shift exceeded the applicable standard by at least 0.1 milligram of respirable dust per cubic meter of air (mg/m^3). If one or more measurements exceeded the applicable standard but the average did not, the Agency's practice was to continue sampling for up to four additional production shifts or days. If the inspector continued sampling after the first day because a previous measurement exceeded the applicable standard, noncompliance determinations were based on either the average of all measurements taken or on the average of measurements taken on any one occupation. Thus, if the average of measurements taken over more than one day on all occupations was less than or equal to the applicable standard, but the average of measurements taken on any one occupation exceeded the value set by MSHA (based on the cumulative concentration for two or more measurements exceeding 10.4 mg/m^3, which is equivalent to a 5-measurement average exceeding 2.0 mg/m^3), the operator was cited for exceeding the applicable standard.

In some instances, MSHA inspectors sampled for a maximum of five production shifts or days before making a noncompliance determination. However, most citations issued prior to 1991 were based on the average of multiple measurements on different occupations collected during a single shift. To illustrate, MSHA conducted a computer simulation using data from 3,600 MMU inspections conducted between October 1989 and June 1991. This simulation showed that a total of 293 MMUs would have met the criteria to be found in noncompliance with the applicable standard based solely on the average of multiple measurements. Two hundred forty-two of those noncompliance determinations, or 83 percent, met the citation criteria based on sampling results from the first day of MSHA sampling, rather than from multi-day sampling. Only 51 MMUs, or 17 percent, were citable based on the average of measurements collected over multiple shifts or days. These statistics clearly show that the citation criteria were met based not only on the average of measurements taken during several shifts, but also on the average of multiple measurements obtained during the same shift.

B. Why Did MSHA Establish the Coal Mine Respirable Dust Task Group and Initiate the Spot Inspection Program?

In 1991 concerns were raised about the adequacy of MSHA's program to control respirable coal mine dust in underground coal mines. In response to these issues, MSHA established the Coal Mine Respirable Dust Task Group (Task Group) to comprehensively evaluate the effectiveness of the Agency's respirable dust program.

The Task Group was directed to consider all aspects of the current program, including the role of the individual miner in the sampling program; the feasibility of MSHA conducting all sampling; and the development of new and improved monitoring technology, including technology to continuously monitor the mine environment. Among the issues addressed by the Task Group was the actual dust concentration to which miners are exposed. As a result, the Agency initiated a special respirable dust ''spot inspection program'' (SIP), designed to provide the Agency with more accurate information on the dust levels to which miners were exposed, through sampling, in the underground coal mine environment.

C. How Was Sampling Accomplished During the SIP?

Because of the large number of mines and MMUs involved and the need to obtain data within a short time frame, sampling during the SIP was limited to a single shift or day, a departure from MSHA's normal sampling procedures. As a result, the Agency determined that if the average of multiple occupation measurements taken on an MMU during any one-day inspection did not exceed the applicable standard, the inspector would review the result of each sample individually. If any individual measurement exceeded the applicable standard by an amount specified by MSHA, a citation would be issued for noncompliance, requiring the mine operator to take immediate corrective action to lower the average dust concentration.

The sampling practice under the SIP was similar to the practice of the Metal/Nonmetal Health Division of MSHA, and the Occupational Safety and Health Administration (OSHA), which use a single, full-shift measurement for noncompliance determinations, and provides for a margin of error to account for uncertainty in the measurement process (sampling and analytical error). This resulted in the issuance of citations using a single, full-shift measurement only when there was a high level of confidence that the applicable standard was actually exceeded.

Thus, during the SIP inspections, MSHA inspectors cited violations of the current 2.0 mg/m^3 standard if either the average of five measurements taken on a single shift was greater than or equal to 2.1 mg/m^3, or any single, full-shift measurement was greater than or equal to 2.5 mg/m^3. Similar adjustments were made when the 2.0 mg/m^3 standard was reduced due to the presence of quartz (crystalline silica) dust in the mine environment.

D. What Did the SIP Show About MSHA's Sampling Policy?

MSHA's review of the SIP inspections showed that 28 percent of 718 MMUs sampled exceeded the applicable standard and would have been citable based on a single, full-shift measurement, but only 12 percent would have been citable using the average of all measurements for the MMU.

Based on the data from the SIP inspections, the Task Group concluded that the Agency practice of determining noncompliance based solely on the average of multiple measurements did not always reveal situations in which miners were overexposed. For example, if the measurements obtained for five different occupations within the same MMU were 4.1, 1.0, 1.0, 2.5, and 1.4 mg/m^3, the average concentration would be 2.0 mg/m^3 and no enforcement action would be taken, even though the dust measurements for two of these occupations significantly exceeded the applicable standard. While such individual measurements were not cited prior to the SIP, they would clearly demonstrate that some miners were overexposed. MSHA policy prior to the SIP however, required the inspector to return to the mine on the next production day and resume sampling, rather than issue a citation at the time the overexposures were discovered.

E. Why Did MSHA Decide To Permanently Adopt the SIP Procedures?

The SIP inspections revealed instances of overexposure that were masked by the averaging of results across different occupations. This showed that miners would not be adequately protected if noncompliance determinations were based solely on the average of multiple measurements. The process of averaging dilutes a high measurement made at one location with lower measurements made elsewhere. Similarly, averaging a number of full-shift measurements can obscure cases of overexposure.

Additionally, the Task Group recognized that the initial full-shift samples collected by an inspector are likely to show higher dust concentrations than succeeding samples collected on subsequent shifts during the same inspection. MSHA's data showed that the average concentration of all samples taken on the same occupation on the first day of an inspection was almost twice as high as the average concentration of those taken on the second day. MSHA recognized that sampling on successive days after an inspector first appears could result in measurements that are not representative of dust conditions to which miners are typically exposed. Unrepresentative measurements would arise if mine operators anticipated the continuation of inspector sampling and made adjustments in dust control parameters or production rates to reduce dust levels during the subsequent monitoring. None of this is specifically prohibited by MSHA regulations. As a result of these findings, which indicated that miners were at risk of being overexposed, MSHA decided to permanently adopt use of the single, full-shift measurement inspection policy initiated during the SIP. These procedures were used by MSHA until the issuance of the decision by the Federal Mine Safety and Health Review Commission in the case of *Keystone Coal* v. *Sec. of Labor,* 16 FMSHRC 6 (Jan. 4, 1994). Since that decision, MSHA has reverted to its previous practice of basing noncompliance determinations on the average of multiple, full-shift measurements. (Please see the notice of joint finding by the Secretary of Labor and the Secretary of Health and Human Services (HHS) published elsewhere in today's **Federal Register** for an explanation of this decision.)

III. Why MSHA Is Revising Its Enforcement Policy

A. What Has Changed To Warrant Revising the Existing Enforcement Policy?

During the public hearings held on the proposed joint finding that a single, full-shift sample is an accurate measurement, during the public meetings held on this enforcement policy notice, and in other comments submitted to the Agency, several commenters questioned why the current program should be altered. The commenters asserted that MSHA's practice of issuing citations based on the average of multiple measurements has been in effect since the 1970s, that technology and equipment associated with sampling remain essentially the same, and that substantial progress had been made in lowering respirable dust levels at U.S. coal mines.

As stated in the final notice of joint finding published elsewhere in today's **Federal Register**, significant improvements have in fact been made in the dust sampling process. Although MSHA agrees that progress has been made in reducing average dust concentrations, the SIP inspections clearly showed instances of excessive dust concentrations that would have been masked by the procedure of averaging measurements. Specifically, of the 718 SIP MMUs with valid single, full-shift measurements, 203 MMUs had at least one single, full-shift measurement that was citable, while only 88 MMUs met or exceeded the citation threshold based on the average of multiple measurements. This clearly shows that under the procedure of averaging measurements miners would be at risk of being overexposed and MSHA would be unable to require operators to take corrective actions to protect them.

MSHA believes that a single, full-shift measurement is more likely to detect excessive dust concentrations and thus protect miners than a measurement average across multiple occupations on a single shift or across multiple shifts for a single occupation. MSHA's computer simulation which analyzed data from over 3600 MMU inspections conducted between October 1989 and June 1991, showed that 814 MMUs had citable overexposures based on individual samples, but only 298 of these overexposures were citable on the average of measurements made within the MMU. Subsequent to the SIP, between January 1992 and December 1993, MSHA continued making noncompliance determinations on a single, full-shift measurement, and 74 percent or 488 of the 658 MMUs cited by inspectors as having overexposures were found to be out of compliance based on a single, full-shift measurement, requiring mine operators to take appropriate corrective action. This experience clearly demonstrates that citing on a single, full-shift measurement, as opposed to citing on the average of measurements taken over multiple shifts, impacts miners directly, because it requires mine operators to take more prompt corrective action once an overexposure has been identified. This reduces the risk to miners of continued exposure to dust concentrations above the applicable standard on subsequent shifts.

Furthermore, both NIOSH, in its recently issued criteria document, and the Secretary of Labor's Advisory Committee on the Elimination of Pneumoconiosis Among Coal Mine Workers recommended the use of single, full-shift measurements for determining compliance. According to the Committee report, issued in October 1996, the MSHA practice of not issuing citations based on single, full-shift samples ''is not protective of miner health, moreover, it is inconsistent with the stated intent of the Coal Act and the Mine Act, which require that exposure be at or below the exposure limit for each shift.''

B. Why Will MSHA No Longer Rely On Averaged Measurements of Dust Concentrations To Determine Noncompliance?

MSHA's current enforcement strategy does not provide the optimal level of possible health protection. Basing noncompliance determinations on the average of different occupational measurements dilutes a measurement of high dust exposure with a lower measurement made at a different occupational location. Likewise, averaging measurements obtained for the same occupation over different shifts does not ensure that the concentration of respirable dust is maintained at or below the applicable standard during each shift. Section 202(b)(2) of the Mine Act clearly requires that dust concentrations be maintained at or below the applicable standard ''* * * during each shift to which each miner in the active workings'' is exposed.

Some commenters proposed that MSHA continue to average at least five separate measurements prior to making a noncompliance determination. They stated that abandoning this practice would reduce the accuracy of noncompliance determinations. Specifically, these commenters maintain that the average of dust measurements obtained at the same occupational location on different shifts more accurately represents dust exposure to a miner than a single, full-shift measurement. These commenters favored the retention of existing MSHA policy on the grounds that not averaging measurement results would reduce accuracy to unacceptable levels. Other commenters agreed with MSHA that the averaging of multiple samples dilutes measurements of dust concentration and masks specific instances of overexposure. Some of these commenters stated that averaging distorts not only the estimate of dust concentration applicable to individual shifts, but also biases the estimate of exposure levels over a longer term. According to these commenters, this is because dust control measures and work practices affecting dust concentrations are frequently modified in response to the presence of an MSHA inspector over more than a single shift. These commenters argued that the presence of the MSHA inspector causes the mine operator to be more attentive to dust control than normal.

Section 202(b) of the Mine Act requires each mine operator to ''continuously maintain the average concentration of respirable dust in the mine atmosphere during each shift to which each miner is exposed'' at or below the applicable standard. The greater the variation in mining conditions from shift to shift, the less likely it is that a multi-shift average will reflect the average dust concentration on any individual shift. For example, during one shift, production may be high and dust concentrations may also be correspondingly high. However, the next shift may experience lower production levels because of equipment breakdowns or because of unusual mining conditions. In addition, when a mine operator knows that the MSHA inspector is present, more attention may be given to ensuring that dust control measures operate effectively, and this may also affect the concentrations of respirable coal mine dust found on that shift. Because of such factors, multi-shift averaging does not improve the accuracy of a noncompliance determination for the sampled shift. Therefore, MSHA is discontinuing its policy of relying on averaged dust concentrations. A more technical discussion of how averaging measurements affects accuracy is given in Appendix A.

C. Why Has MSHA Decided To Base Noncompliance Determinations Solely on a Single, Full-Shift Measurement?

One commenter suggested that the new enforcement strategy proposed in MSHA's February 1994 notice, involving noncompliance determinations based on either a single sample or on the average of multiple samples, placed operators in ''double jeopardy'' of being cited—that is, it provided for two separate evaluations of whether the applicable standard has been exceeded. This commenter pointed out that this enforcement strategy would reduce the confidence level at which a noncompliance determination could be made.

Under the MSHA policy proposed in the February 1994 notice, measurements made by an MSHA inspector for different occupational locations would have been averaged together, not in order to estimate a hypothetical average concentration, but rather to ascertain whether dust concentration was excessive at any of the sampled locations. If the average of measurements across sampling locations exceeded the applicable standard, then at least one of the sampling locations would almost certainly have been out of compliance on the sampled shift. Therefore, the commenter was correct in asserting that noncompliance at each sampling location would have been evaluated twice: once using the single measurement specific to that location; and, if that test did not result in a citation, once again using the average of all available measurements.

MSHA had determined that this strategy was necessary to provide the level of health protection to miners required by the Mine Act, and included this strategy in the proposed policy notice to protect against cases of evident noncompliance that would otherwise go uncited. For example, if five occupational measurements of 2.08, 2.28, 2.31, 2.25, and 2.17 mg/m^3 were obtained for an MMU on a 2.0 mg/m^3 standard, no enforcement action would be taken if noncompliance is determined solely based on a single, full-shift measurement because no individual measurement meets or exceeds the Citation Threshold Value (CTV), defined in section IV.B. of this notice. On the other hand, averaging the measurements results in an average concentration of 2.22 mg/m^3, indicating, with high confidence, that the applicable standard was exceeded.

Although MSHA originally proposed using a combination of both strategies for determining noncompliance, various bodies of data show that such hypothetical occurrences are extremely improbable in practice. For example, MSHA's computer simulation discussed earlier in this notice showed that, between October 1, 1989, and June 30, 1991, 298 MMUs would have been found in noncompliance with the applicable standard based on averaging multiple measurements. All 298 MMUs would also have been found in noncompliance using the single, full-shift measurement citation criteria. According to the data from the SIP, only one noncompliance determination would have been missed if all averaging had been discontinued. Similarly, analysis of more recent inspector sampling data for 1995 indicates that miners' health will not be compromised by discontinuing all measurement averaging. In fact, only one additional case of noncompliance would have been identified using averaging in addition to citing on a single, full-shift measurement. Therefore, MSHA will not continue to use this combination of strategies.

As explained in the final notice of joint finding published elsewhere in today's **Federal Register**, MSHA's improved sampling and analytical method performs in accordance with the NIOSH Accuracy Criterion whenever a single, full-shift measurement is at or above 0.36 mg/m^3. The Agency believes that, in accordance with section 202(f) of the Mine Act, this enables MSHA to base noncompliance determinations on a single, full-shift measurement whenever that measurement is at or above 0.36 mg/m^3.

IV. The New Enforcement Policy

A. What Is MSHA's New Enforcement Policy?

MSHA will continue its current dust sampling program as it relates to where and how many samples an inspector collects during a sampling shift. Specifically, MSHA will continue to collect multiple occupational samples for each MMU. The criterion for making noncompliance determinations has been revised and, under the new enforcement policy, MSHA will use a control filter capsule to adjust the resulting weight gain obtained on each exposed filter capsule. Noncompliance determinations will be based solely on the results of individual, full-shift samples, and MSHA will issue a citation whenever noncompliance is demonstrated at a high confidence level. The Agency will no longer rely on multi-locational or multi-shift averaging of measurements to determine noncompliance.

The process by which a violation of the applicable standard will be abated by a mine operator will also remain unchanged. MSHA will consider a violation to be abated when samples collected in accordance with 30 CFR 70.201(d) demonstrate that the average dust concentration in the working environment of the cited occupation is at or below the applicable standard.

When a measurement exceeds the applicable standard but is less than the CTV, noncompliance is not demonstrated at a sufficiently high confidence level to warrant a citation. However, MSHA will consider whether to target the MMU or environment for additional dust sampling. See Appendix B for further discussion of why MSHA believes that such measurements indicate probable overexposure.

B. When Will MSHA Issue a Citation for a Violation of the Applicable Standard?

MSHA will issue a citation for noncompliance when a single, full-shift measurement demonstrates, at a high level of confidence, that the applicable standard has been exceeded. Although MSHA will continue to collect multiple occupational samples for each MMU, the Agency will generally issue only one citation for exceeding the applicable standard on a single shift on any one MMU. However, additional citations may be issued when excessive dust concentrations are detected for occupations exposed to different dust generating sources.

To ensure that citations are issued only when there is a high level of confidence that the applicable standard has been exceeded, MSHA has developed the Citation Threshold Values (CTV) below. Each CTV listed is calculated so that citations are issued only when the single, full-shift measurement demonstrates noncompliance with at least 95 percent confidence. Citing in accordance with the CTV table does not constitute a raising of the applicable standard. Instead, it reflects the need for MSHA to ensure a sufficiently high level of confidence in its noncompliance determinations. Mine operators are still required to implement appropriate controls that will maintain the average concentration of respirable dust at or below the applicable standard on all shifts.

CITATION THRESHOLD VALUES (CTV) FOR CITING VIOLATIONS BASED ON SINGLE, FULL-SHIFT MEASUREMENTS

Applicable standard (mg/m^3)	CTV (mg/m^3)
2.0	2.33
1.9	2.22
1.8	2.11
1.7	2.00
1.6	1.90
1.5	1.79
1.4	1.68
1.3	1.58
1.2	1.47
1.1	1.36
1.0	1.26
0.9	1.15
0.8	1.05
0.7	0.94
0.6	0.84
0.5	0.74
0.4	0.64
0.3	0.53
0.2	0.43

C. How Will the CTV Table Be Applied?

Each single, full-shift measurement used to determine noncompliance will be the MRE-equivalent dust concentration as calculated and recorded under MSHA's dust data processing system. Every valid measurement will be compared with the CTV corresponding to the applicable standard in effect. If any measurement meets or exceeds that value, a citation will be issued. However, no more than one citation will be issued based on single, full-shift measurements from the same MMU, unless separate citations are warranted for occupations exposed to different dust generating sources. Therefore, when single, full-shift measurements from two or more occupations show dust concentrations in violation of the applicable standard, as illustrated in the examples below, the inspector will determine the dust generation sources and require the operator to sample the environment of the occupation most affected by these sources which is consistent with current practice. In most cases, this will be the working environment of the ''D.O.'' However, if noncompliance is indicated based on measurements from two or more occupations on the same MMU which are exposed to the same dust generating sources, and which do not involve the ''D.O.,'' the occupation with the highest dust concentration will be identified in the citation as the affected working environment. In any case, when an inspector issues a citation for violation of the applicable standard under the new policy, the citation narrative will identify the specific environment or occupation to be sampled by the operator, as well as any other occupation(s) that exceeded the CTV.

Several commenters requested that the application of the CTV table be clarified. The following examples illustrate how inspectors will apply the CTV table and make noncompliance determinations. Suppose that a measurement of 2.41 mg/m^3 is obtained for the ''D.O.'', and measurements of 2.34, 1.54, and 1.26 mg/m^3, are obtained for three other occupations exposed to the same dust generating sources as the ''D.O.'' during a single shift on an MMU required to comply with an applicable standard of 2.0 mg/m^3. Because at least one of the measurements exceeds the 2.33-mg/m^3 CTV (the citation value when the applicable standard is 2.0 mg/m^3), a citation will be issued for exceeding the applicable standard on the shift sampled. Even though two individual measurements (2.41 and 2.34 mg/m^3) exceeded the CTV, one of which is on the ''D.O.,'' only one citation will be issued, specifying the ''D.O.'' as the affected working environment because all occupations were exposed to the same dust generating sources.

Suppose now that in the previous example the 2.34-mg/m^3 measurement was obtained for a roof bolter, and the MMU was ventilated using a double-split ventilation system. This means that the roof bolter, working on a separate split of air from that of the continuous miner, is exposed to a different dust generating source than the ''D.O.'' and, therefore, may not be adequately protected by dust controls implemented for the ''D.O.'' Consequently, two citations would be issued.

As another example, consider an MMU with measurements of 2.14, 1.92, 1.82, 1.25, and 1.12 mg/m^3. Although none of these measurements meet the CTV, there is reason to believe that the MMU is out of compliance, since one of the measurements exceeds the applicable standard. However, because there is a small chance that the measurement exceeded the applicable standard because of measurement error, a citation would not be issued. As discussed elsewhere in this notice, additional samples would be necessary to verify the adequacy of the control measures under current operating conditions. Therefore, MSHA would select this MMU for additional sampling. As discussed in Appendix B, even if the first measurement were 1.90 mg/m^3 instead of 2.14 mg/m^3, because of measurement error this would not demonstrate that the mine atmosphere sampled was in compliance. To confirm that control measures are adequate, MSHA would need to take additional samples.

D. What Is the Potential for a Citation To Be Issued Due To Measurement Error?

Some commenters expressed concern that noncompliance determinations based on single, full-shift measurements would result in an unacceptable number of erroneous citations due to measurement error. These commenters expected that MSHA's new enforcement policy would result in numerous erroneous citations.

Based on the analysis in Appendix C, MSHA has concluded that, because of the large ''margin of error'' separating each CTV from the corresponding applicable standard, use of the CTV table provides ample protection against erroneous citations. For exceptionally well-controlled environments (e.g., Case 2 of Appendix C), the probability that any given citation is erroneous will be substantially less than 5 percent. This probability is even smaller in environments which are not well controlled (e.g., Case 3 of Appendix C). Therefore, any citation issued in accordance with the CTV table will be much more likely the result of excessive dust concentration rather than measurement error.

E. What Will Happen When the Evidence Is Insufficient To Warrant a Citation?

If the appropriate CTV is not met or exceeded, MSHA will not issue a citation. As discussed earlier, this does not mean that the sampled environment is necessarily in compliance. Although in certain cases there may be insufficient evidence to demonstrate noncompliance, the measurement may nonetheless indicate a possible overexposure. MSHA intends to focus on cases of measurements above the applicable standard but below the CTV, with special emphasis being directed to working environments required to comply with applicable standards below 2.0 mg/m^3.

If follow-up measurements do not warrant a citation but suggest that the dust control measures in use may be inadequate, MSHA may initiate a thorough review of the dust control parameters stipulated in the mine operator's approved ventilation or respirable dust control plan to determine whether the parameters should be upgraded.

V. Consequences of the Use of the CTVs in Conjunction With the Joint MSHA/NIOSH Finding

A. What is the Impact of MSHA's New Enforcement Strategy As Applied Under the MSHA/NIOSH Joint Finding?

The Agency believes that the application of the CTVs in conjunction with the MSHA/NIOSH joint notice of finding published elsewhere in today's **Federal Register** to single, full-shift samples collected by MSHA inspectors provides for more efficient detection of noncompliance by identifying and requiring abatement of individual instances of overexposure which meet the CTVs. While this issue is more appropriately addressed in the MSHA/NIOSH joint notice, the rationale for this conclusion bears repeating here.

The Mine Act is clear in its intent that no miner should be exposed to respirable coal mine dust in excess of the applicable standard on any shift. The effect of the joint finding and the new enforcement strategy set forth here creates incentives for mine operators to control dust exposure on a continuing basis to minimize the chance of being found in noncompliance during any MSHA sampling inspection. To prevent the possibility of any inspector single, full-shift measurement exceeding the CTV and resulting in a violation, mine operators will be more likely to keep dust concentrations at or below the applicable standard, thereby providing better protection to miners from overexposures. This becomes evident upon closer examination of the inspector sampling data from the period when noncompliance determinations were based on single, full-shift measurements.

MSHA reviewed inspector MMU sampling results for FY 1992, the first full year during which noncompliance determinations were based on single, full-shift measurements, and FY 1993, the last year that the Agency issued citations based on single, full-shift measurements. This review showed a decline in the number of ''D.O.'' and nondesignated occupation samples exceeding 2.0 mg/m^3, from 16 percent and 10 percent in FY 1992 to 13 percent and 7 percent, respectively, in FY 1993, suggesting that operators were better able to maintain dust concentrations below the applicable standard. MSHA also conducted a computer simulation using these data which showed that one of every four MMU sampling days in FY 1992 would have been found in noncompliance based on a single, full-shift measurement, compared to one in five MMU sampling days in FY 1993.

Under the previous enforcement strategy, which utilized averaging, inspectors cited violations of the applicable standard on the average of multiple measurements taken on a single shift or on different shifts or days. Consequently, dust concentrations could be excessive for some occupations or work locations, but corrective action would not be required so long as the average of the measurements did not exceed the applicable standard. For example, averaging occupational measurements of 3.2, 2.4, 1.5, 1.3 and 1.0 mg/m^3 results in an average concentration of 1.8 mg/m^3 for the sampled MMU where the applicable standard is 2.0 mg/m^3. Despite the fact that two of the measurements demonstrate noncompliance with a high degree of confidence, corrective action would not have been required because the average concentration was below the applicable standard.

As described in this notice and in conjunction with the MSHA/NIOSH joint notice, under the new enforcement policy, whenever an individual measurement indicates noncompliance (with a high level of confidence), the mine operator will be required to take corrective action to lower the concentration of respirable dust to comply with the applicable standard.

Some commenters expressed concern that MSHA would fail to cite some instances of noncompliance because of the high level of confidence required for a citation. MSHA believes that the new enforcement strategy as applied in conjunction with the finding of the MSHA/NIOSH joint notice will reduce the chances of failing to cite cases of noncompliance as compared to the previous policy of measurement averaging, while at the same time ensuring that noncompliance is cited only when there is a high degree of confidence that the applicable standard has been exceeded. According to the inspector sampling inspections conducted in 1995, only 132 MMUs were found to be in violation of the applicable standard and cited under the previous enforcement policy of measurement averaging, compared to 545 MMUs that would have been citable under the new enforcement policy in conjunction with the joint notice of finding using single, full-shift measurements. This clearly demonstrates that the new enforcement policy, in conjunction with the joint notice, will not compromise miners' health but would, instead, have identified 413 additional instances of overexposure that would have gone unaddressed under the previous policy of measurement averaging.

Some commenters proposed that miners would be even more protected if noncompliance was cited whenever any single, full-shift measurement exceeded the applicable standard by any amount. That is, it was recommended that MSHA not make any allowance for potential measurement errors. MSHA has considered this recommendation but has not adopted it in the final policy because it could result in citations being issued where compliance with the applicable standard is more likely than not. If the mine environment is sufficiently well controlled, it is more likely that a particular measurement exceeds the applicable standard, but not the CTV, due to measurement error rather than due to excessive dust concentration. Furthermore, the rationale used by these commenters to justify their proposed citation criterion breaks down when, as in the case of multiple samples taken during a given shift in the same MMU, more than one measurement is made for a single noncompliance determination. Appendix D addresses technical details relating to this issue.

Some commenters stated that MSHA's new citation criteria implemented in conjunction with the joint notice will not improve respirable dust levels in the environment, but will simply result in MSHA issuing more citations to mine operators. In these commenters view, this will foster a continuation of the adversarial relationship that developed between mine operators and MSHA over allegations of widespread tampering with respirable dust samples.

MSHA firmly believes that basing noncompliance determinations on a single, full-shift measurement will improve working conditions for miners because it will cause mine operators to either implement and maintain more effective dust controls to minimize the chance of being found in noncompliance by an MSHA inspector, or take corrective action sooner to lower dust concentrations that are shown, with high confidence, to be in excess of the applicable standard. The effect of this new enforcement policy in conjunction with the MSHA/NIOSH joint notice will be remedial in nature because it will address instances of overexposure that are not addressed under the current policy of measurement averaging. For example, between January 1992 and December 1993, MSHA continued the practice established under the SIP of making noncompliance determinations based on single, full-shift measurements which demonstrated, with high confidence, that the applicable standard was exceeded, and on the average of multiple measurements. During this period, MSHA inspectors issued a total of 658 citations at MMUs. The majority of these citations (488) were issued based on the result of a single, full-shift measurement. Under the existing enforcement policy, such individual instances of noncompliance would not be cited and corrected, but instead would be factored into an average that could be at or below the applicable standard, resulting in no violation and no corrective action taken by the mine operator.

Some commenters also contended that the joint notice of finding, and this notice of policy, are solely for the administrative convenience of MSHA's mine inspectors. The commenters stated that allowing inspectors to make noncompliance determinations on the basis of a single, full-shift measurement will eliminate the need for inspectors to sample on successive days, as is sometimes required under existing policy.

MSHA recognizes that there are administrative advantages related to the adoption of this new enforcement policy and the joint notice of finding. By eliminating the need to sample on subsequent days, the Agency will be able to utilize its resources more efficiently. That is, inspectors will not be required to return to a mine to conduct additional dust sampling, but the Agency will be able to redirect its resources to other safety and health concerns. This result is consistent with the Mine Act's objective of protecting miner safety and health. While administrative convenience may be a side benefit of this new enforcement policy in conjunction with the MSHA/NIOSH joint notice, the primary reason for implementing it is to achieve the intent of Congress that no miner shall be exposed to dust concentrations above the applicable standard on any shift.

B. What is the Impact of the New Policy on Ventilation Plans?

A number of commenters expressed concern that issuing citations on the result of a single, full-shift measurement will cause MSHA to require carefully developed ventilation plans to be modified needlessly as part of the abatement process. These commenters view such frequent revisions as costly, disruptive and unnecessary. They contend that such revisions, if required, would be made on the basis of incomplete or invalid information, and that they would not necessarily decrease a miner's dust exposure. Some commenters believed that some inspectors would mandate specific changes without realistically evaluating their effectiveness, while other inspectors would not allow operators to make their own adjustments to the plans, or provide an opportunity for them to evaluate the changes in a rational manner.

When a citation is issued based on a single measurement, this can indicate that the control measures in use may no longer be adequate to maintain the environment within the applicable standard. MSHA will consequently review the adequacy of the ventilation plan under the current operating conditions, and will consider the results of operator bimonthly sampling as well as operator compliance with the approved ventilation plan parameters. Under this approach MSHA would require plan revisions only after an examination of all factors has demonstrated that changes are necessary to protect miner health. This enforcement strategy should minimize unnecessary changes to plans that have been determined to provide adequate controls.

MSHA believes that the primary focus of the federal dust program is to minimize miners' overexposures to respirable dust through the application of appropriate environmental controls, which are stipulated in the operator's approved mine ventilation plan. After these controls are evaluated and shown to be effective under typical mining conditions, if properly maintained, they should provide reasonable assurance that no miner will be overexposed. Therefore, one of the objectives of MSHA's dust sampling is to verify that the controls stipulated in ventilation plans continue to adequately control dust concentrations under existing operating conditions. In conjunction with these sampling and other inspections an inspector checks and measures the dust control parameters early in the shift to determine whether the approved ventilation plan is being followed. A mine operator's failure to follow the parameters stipulated in the plan will result in the issuance of a citation, which requires immediate corrective action to abate the violation. The type of corrective actions taken to abate plan violations can vary from unplugging clogged water sprays to increasing the amount of ventilating air delivered to the MMU. However, mere correction of these deficiencies to ensure that the ''status quo'' of the plan is being maintained may not always be effective in controlling miners' exposure to respirable dust. The required plan parameters may no longer be effective in maintaining compliance, and may need to be upgraded. The determination of how the plan should be revised is complicated by the fact that, generally, most approved plans do not incorporate all the control measures that were in place when MSHA sampled. Consequently, most plan revisions have simply incorporated into the plan only those dust controls that were in use when MSHA sampled, rather than requiring significant upgrading of the plan. As an example, an MSHA inspector might require an increase in the water pressure stipulated in the plan from 75 pounds per square inch (psi) to 125 psi to reflect the 125 psi that the MSHA inspector actually measured. If, instead, the operator was required to significantly increase the quantity of air being delivered to the MMU, this would be considered a major upgrade. MSHA recognizes that a determination of noncompliance should not automatically necessitate the revision of a plan. Instead, it should result in a thorough review of the plan's continued adequacy.

When an operator of an underground mine is cited for excessive dust, 30 CFR 70.201(d) requires the operator to ''take corrective action to lower the concentration of respirable dust to within the permissible concentration.'' When the citation is based on MSHA samples, the inspector may request that the operator describe what type of corrective action will be taken. The inspector then determines if the corrective action is appropriate. If it is not appropriate in the specific situation, the inspector may either suggest or require other corrective action or control measures. Operators are provided with the opportunity to make adjustments to their dust controls and to evaluate their effectiveness in a rational manner during the time for abatement set by the inspector, which is based on the complexity of the problem, availability of controls, and the types of changes the operator intends to make. This abatement time may be extended by the inspector based on the operator's performance in reducing the dust concentration in the affected area of the mine. Typically, the operator then demonstrates, through sampling, that the underlying condition or conditions causing the violation have been corrected. Failure to take corrective action prior to sampling that shows continuing noncompliance may lead to the issuance of a withdrawal order. However, this occurs infrequently.

C. Will the New Enforcement Policy Increase Citations on Individual Shifts, Even if the So-Called ''Average Concentration Over the Longer Term'' Meets the Standard?

Some commenters claimed that even when the average dust concentration is well below the applicable standard, normal variability from shift to shift results in a substantial fraction of shifts for which the dust standard is exceeded. According to these commenters, a determination of noncompliance is warranted only if the average dust concentration to which a miner is exposed exceeds the standard over a period of time greater than a single shift, such as a bimonthly sampling period, a year, or a miner's working lifetime. Therefore, they consider it ''unfair'' to cite operators for exceeding the applicable standard on individual shifts, so long as the average over the longer term meets the applicable standard. For example, based on historical sampling data provided by one commenter, the commenter concluded that, ''* * * there is at least a 1 in 6 or 17% probability that any single sample can show potential overexposure when one does not exist.'' These commenters contend that use of the CTV to determine noncompliance, based on one sample collected on a single shift, will substantially increase the frequency of ''unfair'' citations, compared to existing MSHA policy.

MSHA believes that such comments reflect a misunderstanding of both the requirements of the Mine Act and MSHA's longstanding policy with respect to single, full-shift noncompliance determinations. It should be recognized that MSHA has been basing noncompliance determinations on the average of multiple occupation measurements obtained on the same shift since 1975. In addition, some of the commenters confused the average dust concentration over the course of an individual shift with the average dust concentration over some longer term. The joint notice of finding issued by the Secretaries of Labor and HHS addresses this issue. Since the Mine Act requires that dust concentration be kept continuously at or below the applicable standard on every shift, it is appropriate to cite noncompliance when any single, full-shift measurement at a particular location demonstrates, with high confidence, that the applicable standard has been exceeded on an individual shift.

Section 201(b) of the Mine Act mandates that MSHA ensure ''to the greatest extent possible, that the working conditions in each underground coal mine are sufficiently free of respirable dust concentrations * * * to permit each miner the opportunity to work underground during the entire period of his adult life without incurring any disability from pneumoconiosis or any other occupation-related disease during or at the end of such a period.'' Since neither past nor future exposure levels can be assumed for any miner, MSHA's enforcement strategy must be to limit the exposure on every shift as intended by the Mine Act.

D. Will There Be Any Changes in Operator Bimonthly Sampling?

Several commenters were unclear about the impact of the joint MSHA/NIOSH finding and this policy on operator sampling for compliance and for abatement of violations. One commenter suggested that 30 CFR 70.207(a) be revised to allow the operator to submit one single, full-shift sample, instead of five samples every bimonthly period as currently required. Another commenter suggested that MSHA assume responsibility for dust sampling from the mine operators.

MSHA has previously noted that the change in its enforcement policy announced through this final notice affects only how it will determine noncompliance based on measurements obtained by MSHA inspectors. There will be no change in how MSHA evaluates operator-collected respirable dust samples for compliance. Under the regulations currently in effect, the Agency will continue to average operator samples taken on multiple shifts or days to make noncompliance determinations. MSHA is committed to revising procedures with respect to operator-collected respirable dust samples through the rulemaking process for consistency with this final finding.

Several commenters expressed concerns about the credibility of the operator sampling program because of alleged operator tampering with respirable dust samples and alleged operator manipulation of mine conditions during dust sampling periods. As a result, these commenters felt that mine operators should no longer have responsibility for sampling because their sampling results are unreliable. Another commenter expressed support for the Agency to compel coal mine operators to comply with existing dust standards. Another commenter voiced concern that a mine operator could be wrongly cited due to the loss or mishandling of a single, full-shift sample by MSHA, and claimed that such occurrences had happened in the past. Some commenters believe that if noncompliance can be determined based on a single, full-shift sample, an operator should be allowed to abate a citation with a single, full-shift sample, particularly if the operator has recently demonstrated compliance through bimonthly samples. Another commenter questioned the impact of the proposed program on the operator's program, specifically, whether MSHA would require each of the abatement samples to meet the single, full-shift sample citation threshold values, in addition to meeting the dust standard based on the average of five abatement samples.

Issues concerning operator sampling are not germane to this enforcement policy notice, which concerns only the use of samples collected by MSHA inspectors. The changes set forth in this final notice only address how MSHA will determine noncompliance when sampling is conducted by federal mine inspectors. There is no change in how MSHA evaluates either operator-collected bimonthly samples or samples taken to abate a dust citation. MSHA is committed to revising any procedures with respect to the operator program through the rulemaking process for consistency with this final finding.

Concerning the credibility of the operator sampling program, MSHA recognizes that there have been instances of abuse under the current operator sampling program. The Task Group found that the majority of operators do not engage in such conduct. MSHA will continue to monitor the operator sampling program, increase the frequency of inspector sampling, and target problem mines for additional inspections, as appropriate.

MSHA processes over 80,000 samples annually and it is not unrealistic to expect some samples to be either lost in the mail or accidentally misplaced. MSHA's experience of processing more than 7 million dust samples since 1970 indicates that this occurs infrequently. In the event a sample is lost, the mine operator is afforded ample opportunity to submit a replacement sample. If a citation is issued due to the operator's failure to submit the required number of samples, the affected operator can present evidence that the required number of samples had been submitted and request that MSHA vacate the citation.

E. How Can MSHA Base a Noncompliance Determination on a Single, Full-Shift Sample, When Five Samples Are Required in Operator Bimonthly Sampling?

Once a finding has been made that a single, full-shift measurement will accurately represent atmospheric conditions to which a miner is exposed during such shift, MSHA is bound by the terms of the Mine Act to make noncompliance determinations based on single, full-shift measurements. No regulatory action is required to implement this change in MSHA's dust sampling program. On the other hand, the present regulatory scheme for operator sampling was developed based on noncompliance determinations being made by averaging the results of multiple samples over five successive shifts or days. In order for MSHA to incorporate the single, full-shift sample concept into the operator sampling program, the Agency must revise the operator sampling regulations through notice and comment rulemaking.

F. Do the New Citation Criteria Have any Impact on Permissible Exposure Limits?

Some commenters contended that a policy of citing in accordance with the CTV table, rather than citing whenever a measurement exceeds the applicable standard, effectively increases the allowable dust concentration limit. Other commenters stated that the enforcement of the applicable standard as a limit on each shift, rather than as a limit on the average concentration over some longer time period, effectively reduces the standard.

Citing in accordance with the stated CTV neither increases nor decreases the dust standard. Operators are required to maintain compliance with the applicable standard at all times. MSHA's citing of noncompliance only when there is high confidence that the applicable standard has been exceeded does not increase the permissible concentration limit. Again, mine operators must maintain compliance with the applicable standard. MSHA requires that dust controls maintain dust concentrations at or below the applicable standard on all shifts, not merely at or below the CTV. It is also MSHA's intent under this new enforcement policy that if a measurement exceeds the applicable standard by an amount insufficient to warrant citation—that is, the level does not meet or exceed the CTV—MSHA will target that mine or area for additional sampling to ensure that dust controls are adequate.

Those commenters who stated that applying the applicable standard to each shift will effectively reduce the respirable dust standard overlooked the fact that, since 1975, MSHA has taken enforcement action based on average of measurements obtained for different occupations during a single shift. This new enforcement policy does not change MSHA's interpretation of section 202(b) of the Mine Act that dust concentrations be maintained at or below the applicable standard on each shift. The new enforcement policy merely reflects a change in the technical criteria used to cite violations of the applicable dust standard.

Appendix A—The Effects of Averaging Dust Concentration Measurements

MSHA's measurement objective in collecting a dust sample is to determine the average dust concentration at the sampling location on the shift sampled. As discussed in the joint notice of finding published elsewhere in today's **Federal Register**, a single, full-shift measurement can accurately represent the average full-shift dust concentration being measured. Nevertheless, because of sampling and analytical errors inherent in even the most accurate measurement process, the true value of the average dust concentration on the sampled shift can never be known with complete certainty. However accurate the representation, a measurement can provide only an estimate of the true dust concentration. Some commenters contended that MSHA should not rely on single samples for making noncompliance determinations, because an average of results from multiple samples would estimate the true dust concentration more accurately than any single measurement.

Contrary to the views expressed by these commenters, averaging a number of measurements does not necessarily improve the accuracy of an estimation procedure. Consider, for example, an archer aiming at targets mounted at random and possibly overlapping positions on a long partition. Each arrow might be aimed at a different target. Suppose that an observer, on the opposite side of the partition from the archer, cannot see the targets but must estimate the position of each bull's eye by locating protruding arrowheads.

Each protruding arrowhead provides a measurement of where some bull's eye is located. If two arrowheads are found on opposite ends of the partition, averaging the positions of these two arrowheads would not be a good way of determining where any real target is located. To estimate the location of an actual target, it would generally be preferable to use the position of a single arrow. The average would represent nothing more than a ''phantom'' target somewhere near the center, where the archer probably did not aim on either shot and where no target may even exist.

The archery example can be extended to illustrate conditions under which averaging dust concentration measurements does or does not improve accuracy. If each arrowhead is taken to represent a full-shift dust sample, then the true average dust concentration at the sampling location on a given shift can be identified with the location of the bull's eye at which the corresponding arrow was aimed. The *accuracy* of a measurement refers to how closely the measurement can be expected to come to the quantity being measured. Statistically, accuracy is the combination of two distinct concepts: *precision,* which pertains to the consistency or variability of replicated measurements of exactly the same quantity; and *bias,* which pertains to the average amount by which these replicated measurements deviate from the quantity being measured. Bias and precision are equally important components of measurement accuracy.

To illustrate, arrows aimed at the same target might consistently hit a sector on the lower right side of the bull's eye. The protruding arrowheads would provide more or less precise measurements of where the bull's eye was located, depending on how tightly they were clustered; but they would all be biased to the lower right. On the other hand, the arrows might be distributed randomly around the center of the bull's eye, and hence unbiased, but spread far out all over the target. The protruding arrowheads would then provide unbiased but relatively imprecise measurements.

More complicated situations can easily be envisioned. Arrows aimed at a second target would provide biased measurements relative to the first target. Alternatively, if the archer always aims at the same target, the first shot in a given session might tend to hit near the center, with successive shots tending to fall off further and further to the lower right as the archer's arm tires; or shots might progressively improve, as the archer adjusts aim in response to prior results.

Averaging reduces the effects of random errors in the archer's aim, thereby increasing precision in the estimation procedure. If the archer always aims at the same target and is equally adept on every shot (i.e., if the arrowheads are all randomly and identically distributed around a fixed point), then averaging improves the estimate's precision without introducing any bias. Averaging in such cases provides a more accurate method of estimating the bull's eye location than reliance on any single arrowhead. If, however, the archer intentionally or unintentionally switches targets, or if the archer's aim progressively deteriorates, then averaging can introduce or increase bias in the estimate. If the gain in precision outweighs this increase in bias, then averaging several independent measurements may still improve accuracy. However, averaging can also introduce a bias large enough to offset or even surpass the improvement in precision. In such cases, the average position of several arrowheads can be expected to locate the bull's eye *less* accurately than the position of a single arrowhead.

I. Multi-Locational Averaging

Some commenters opposed MSHA's use of a single, full-shift measurement for enforcement purposes, claiming that determinations based on such measurements would be less accurate than those made under MSHA's existing enforcement policy of averaging multiple measurements taken on an MMU. There are two distinctly different types of multi-locational measurement averages that could theoretically be compiled on a given shift: (1) the average might combine measurements taken for different occupational locations and (2) the average might combine measurements all taken for the same occupational location. For MMUs, the averages used in MSHA's sampling program usually involve measurements taken for different occupational locations on the same shift. These are averages of the first type. MSHA's sampling program has never utilized averages of the second type. Therefore, those commenters who claimed that reliance on a single, full-shift measurement would reduce the accuracy of noncompliance determinations, as compared to MSHA's existing enforcement policy, are implicitly claiming that accuracy is increased by averaging across different occupational locations.

Averaging measurements obtained from different occupational locations on an MMU is like averaging together the positions of arrows aimed at different targets. The average of such measurements is an artificial, mathematical construct that does not correspond to the dust concentration for any actual occupational location. Therefore, this type of averaging introduces a bias proportional to the degree of variability in actual dust concentration at the various locations averaged.

The gain in precision that results from averaging measurements taken at different locations outweighs this bias only if variability from location to location is smaller than variability in measurement error. However, commenters opposed to MSHA's use of single, full-shift measurements for enforcement purposes argued that this is not generally the case and even submitted data and statistical analyses in support of this position. Commenters in favor of noncompliance determinations based on a single, full-shift measurement agreed that variability in dust concentration is extensive for different occupational locations and argued that MSHA's existing policy of measurement averaging is not sufficiently protective of miners working at the dustiest locations.

Since an average of the first type combines measurement from the dustiest location with measurements from less dusty locations, it must always fall below the best available estimate of dust concentration at the dustiest location. In effect, averaging across different occupational locations dilutes the dust concentration observed for the most highly exposed occupations or dustiest work positions. Therefore, such averaging results in a systematic bias against detecting excessive dust concentrations for those miners at greatest risk of overexposure.

A somewhat better case can be made for the second type of multi-locational averaging, which combines measurements obtained on the same shift from a single occupational location. As some commenters pointed out, however, there is ample evidence that spatial variability in dust concentration, even within relatively small areas, is frequently much larger than variability due to measurement error. Therefore, the same kind of bias introduced by averaging across occupational locations would also arise, but on a lesser scale, if the average measurement within a relatively small radius were used to represent dust concentration at every point in the atmosphere to which a miner is exposed. A miner is potentially exposed to the atmospheric conditions at any valid sampling location. Consistent with the Mine Act and implementing regulations, MSHA's enforcement strategy is to limit atmospheric dust concentration wherever miners normally work or travel. Therefore, the more spatial variability in dust concentration there is within the work environment, the less appropriate it is to use measurement averaging to enforce the applicable standard by averaging measurements obtained at different sampling locations.

Some of the comments implied that instead of measuring average dust concentration at a specific sampling location, MSHA's objective should be to estimate the average dust concentration throughout a miner's ''breathing zone'' or other area near a miner. If estimating average dust concentration throughout some zone were really the objective of MSHA's enforcement strategy, then averaging measurements made at random points within the zone would improve precision of the estimate without introducing a bias. This type of averaging, however, has never been employed in either the MSHA or operator dust sampling programs. MSHA's current policy of averaging measurements obtained from different zones does not address spatial variability in the area immediately surrounding a sampler unit. Therefore, even if averaging measurements from within a zone were somehow beneficial, this would not demonstrate that MSHA's existing enforcement policy is more reliable than the new policy of basing noncompliance on a single, full-shift measurement.

Furthermore, if MSHA's objective were really to estimate average dust concentration throughout some specified zone on a given shift, then it would be necessary to obtain far more than five simultaneous measurements within the zone. This is not only because of potentially large local differences in dust concentration. In order to use such measurements for enforcement purposes, variability in dust concentration within the sampled area would have to be estimated along with the average dust concentration itself. As some commenters correctly pointed out, doing this in a statistically valid way would generally require at least twenty to thirty measurements. One of these commenters also pointed out that such an estimate, based on even this many measurements in the same zone, could be regarded as accurate only under certain questionable assumptions about the distribution of dust concentrations. This commenter calculated that hundreds of measurements would be required in order to avoid these tenuous assumptions. Clearly, this shows that the objective of estimating average dust concentration throughout a zone is not consistent with any viable enforcement strategy to limit dust concentration on each shift in the highly heterogeneous and dynamic mining environment. The large number of measurements required to accurately characterize dust concentration over even a small area merely demonstrates why it is not feasible to base enforcement decisions on estimated atmospheric conditions beyond the sampling location.

MSHA recognizes that a single, full-shift measurement will not provide an accurate estimate of average dust concentration anywhere beyond the sampling location. The Mine Act, however, does not require MSHA to estimate average dust concentration at locations that are not sampled or to estimate dust concentration averaged over any zone or region of the mine, and doing so is not part of MSHA's enforcement program. Instead, MSHA's enforcement strategy is to ensure that a miner will not be exposed to excessive dust wherever he/she normally works or travels. This is accomplished by maintaining the average dust concentration at each valid sampling location at or below the applicable standard during each shift.

II. Multi-Shift Averaging

Some commenters maintained that in order to reduce the risk of erroneous noncompliance determinations, MSHA should average measurements obtained from the same occupation on different shifts. These commenters contended that the average of measurements from several shifts represents the average dust concentration to which a miner is exposed more accurately than a single, full-shift measurement. Other commenters, who favored noncompliance determinations based on single, full-shift measurements, claimed that conditions are sometimes manipulated so as to produce unusually low dust concentrations on some of the sampled shifts. These commenters suggested that, due to these unrepresentative shifts, multi-shift averaging can yield unrealistically low estimates of the dust concentration to which a miner is typically exposed. Some of these commenters also argued that the Mine Act requires the dust concentration to be regulated on each shift, and that multi-shift averaging is inherently misleading in detecting excessive dust concentration on an individual shift.

Those advocating multi-shift averaging generally assumed that a noncompliance determination involves estimating a miner's average dust exposure over a period longer than an individual shift. This assumption is flawed because section 202(b) of the Mine Act specifies that each operator shall continuously maintain the average concentration of respirable dust in the mine atmosphere during each shift at or below the applicable standard. Some of those advocating multi-shift averaging, however, suggested that MSHA should average measurements obtained on different shifts even if the quantity of interest is dust concentration on an individual shift. These commenters argued that averaging smooths out the effects of measurement errors, and that therefore the average over several shifts would represent dust concentration on each shift more accurately than the corresponding individual, full-shift measurement.

The Secretary recognizes that there are circumstances, not experienced in mining environments, under which averaging across shifts could improve the accuracy of an estimate for an individual shift. Just as averaging the positions of arrows aimed at nearly coinciding targets might better locate the bull's eye than the position of any individual arrow, the gain in precision obtained by averaging dust concentrations observed on different shifts could, under analogous circumstances, outweigh the bias introduced by using the average to estimate dust concentration for an individual shift. This would be the case, however, only if variability in dust concentration among shifts were small compared to variability due to measurement imprecision. It would do no good to average the location of arrows aimed at different targets unless the targets were at nearly identical locations.

To the contrary, several commenters pointed out that variability in dust concentration from shift to shift tends to be much larger than variability due to measurement error and introduced evidence in support of this observation. Measurements on different shifts are like arrows aimed at widely divergent targets. The more that conditions vary, for any reason, from shift to shift, the more bias is introduced by using a multi-shift average to represent dust concentration for any individual shift. Under these circumstances, any improvement in precision to be gained by simply averaging results is small compared to the bias introduced by such averaging. Therefore, the Secretary has concluded that MSHA's existing practice of averaging measurements collected on different shifts does not improve accuracy in estimating dust concentration to which a miner is exposed on any individual shift. To paraphrase one commenter, averaging Monday's exposure measurement with Tuesday's does not improve the estimate of Monday's average dust concentration.

Some commenters argued that since the risk of pneumoconiosis depends on cumulative exposure, MSHA's objective should be to estimate the dust concentration to which a miner is typically exposed and to identify cases of excessive dust concentration over a longer term than a single shift. Other commenters claimed that a multi-shift average does not provide a good estimate of either typical dust concentrations or exposures over the longer term. These commenters claimed that different shifts are not equally representative of the usual atmospheric conditions to which miners are exposed, implying that the average of measurements made on different shifts of a multi-day MSHA inspection tends to systematically underestimate typical dust concentrations.

The Secretary interprets section 202(b) of the Mine Act as requiring that dust concentrations be kept at or below the applicable standard on each and every shift. Nevertheless, the Secretary recognizes that, under certain conditions, the average of measurements from multiple shifts can be a better estimate of ''typical'' atmospheric conditions than a single measurement. This applies, however, only if the sampled shifts comprise a random or representative selection of shifts from whatever longer term may be under consideration. As shown below, evidence to the contrary exists, supporting those commenters who maintained that measurements collected over several days of a multi-day MSHA inspections do not meet this requirement. Therefore, the Secretary has concluded that averaging such measurements is likely to be misleading even for the purpose of estimating dust concentrations to which miners are typically exposed.

Whether the objective is to measure average dust concentration on an individual shift or to estimate dust concentration typical of a longer term, the arguments presented for averaging across shifts all depend on the assumption that every shift sampled during an MSHA inspection provides an unbiased representation of dust exposure over the time period of interest.[1] To check this assumption, MSHA performed a statistical analysis of multi-shift MSHA inspections carried out prior to the SIP. This analysis, placed into the record in September 1994, examined the pattern of dust concentrations measured over the course of these multi-shift inspections and compared results from the final shift with results from a subsequent single-shift sampling inspection [1].

The analysis found that dust concentrations measured on different shifts of the same MSHA inspection were not randomly distributed. The later samples tended to show significantly lower results than earlier samples, indicating that dust concentrations on later shifts of a single inspection may decline in response to the presence of an inspector. Furthermore, the analysis provided evidence that the reduction in dust concentration tends to be reversed after the inspection is terminated. These two results led to the conclusion that averaging dust concentrations measured on different shifts of a multi-day MSHA inspection introduces a bias toward unrealistically low dust concentrations.

One commenter questioned the validity of this analysis, stating that ''there is absolutely no basis in the * * * report for the assertion that the trend is reversed after the inspection is terminated.'' This commenter apparently overlooked Table 3 of the report. That table shows a statistically significant reversal at those mine entities included in the analysis that were subsequently inspected under MSHA's SIP. Dust concentrations measured at these mine entities had declined significantly between the first and last days of the multi-shift inspection. It was primarily to address the commenter's implication that these reductions reflected permanent ''adjustments in dust control measures'' that the analysis included a comparison with the subsequent SIP inspection. An increase, representing a reversal of the previous trend, was observed on the single shift of the subsequent

[1] Technically, the assumption is that dust concentrations on all shifts sampled are independently and identically distributed around the quantity being estimated.

inspection, relative to the dust concentration measured on the final shift of the previous multi-shift inspec tion. This reversal was found to be ''statistically significant at a confidence level of more than 99.99 percent.''

The same commenter also stated that MSHA ''* * * fails to address the systematic [selection] bias of the study. MSHA only does multiple day sampling when the initial results are higher, but not out of compliance.'' It is true that in order to be selected for revisitation, a mine entity must have shown relatively high concentrations on the first shift—though not, in the case of an MMU, so high as to warrant a citation on first shift. Since no experimental data were available on mine entities randomly selected to receive multi-shift inspections, the only cases in which patterns over the course of a multi-shift inspection could be examined were cases selected for multi-shift inspection under these criteria.

Although the impact of the selection criteria was not explicitly addressed, it was recognized that entities selected for multi-day inspections do not constitute a random selection of mine entities. This recognition motivated, in part, the report's comparison of the final shift measurement to the dust concentration measured during a subsequent single-shift inspection. The magnitude of the average reversal indicates that most of the reduction observed over the course of the multi-shift inspection cannot be attributed to the selection criteria. Furthermore, it was not only mine entities with relatively low dust concentration measurements that were left out of the study group. Mine entities with the highest dust concentration measurements were immediately cited based on the average of measurements taken and excluded from the group subjected to multi-shift dust inspections. Therefore, the effect on the analysis of selecting mine entities with relatively high initial dust concentration measurements was largely offset by the effect of excluding those entities with even higher initial measurements. In any event, the magnitude of the average reduction between first and last shifts of a multi-shift inspection was significantly greater than what can be explained by selection for revisitation due to measurement error on the first shift sampled.

The assumption that multiple shifts sampled during a single MSHA inspection are equally representative is clearly violated if, as some commenters alleged, operating conditions are deliberately altered after the first shift in response to the continued presence of an MSHA inspector and then changed back after the inspector leaves. However, if samples are collected on successive or otherwise systematically determined shifts or days, the assumption can also be violated by changes arising as part of the normal mining cycle. As one commenter pointed out, multi-shift averaging within a single MSHA inspection potentially introduces biases typical of ''campaign sampling,'' in which observations of a dynamic process are clustered together over a relatively narrow time span. In order to construct an unbiased, multi-shift average for each phase of mining activity, it would be necessary to collect samples from several shifts operating under essentially the same conditions. Alternatively, to construct an unbiased, multi-shift estimate of dust concentration over a longer term, it would be necessary to collect samples from randomly selected shifts over a period great enough to reflect the full range of changing conditions. Neither requirement is met by multi-shift MSHA inspections because (1) the mine environment is dynamic and no two shifts are alike and (2) MSHA inspectors are not there long enough to observe every condition in their inspection.

Based on the analysis presented by Kogut [1] and also on public comments received in response to the February 18 and June 6, 1994, notices, the Secretary has concluded that it should not be assumed that multiple shifts sampled during a single MSHA inspection are equally representative of atmospheric conditions to which a miner is typically exposed. This conclusion undercuts the rationale for multi-shift averaging within a single MSHA inspection, regardless of whether the objective is to estimate dust concentration for the individual shifts sampled as it is for MSHA inspector sampling or for typical shifts over a longer term as implied by some commenters. Measurements collected by MSHA on consecutive days or shifts of the same inspection do not comprise a random or otherwise representative sample from any larger population of shifts that would properly represent a long-term exposure or a particular phase of the mining cycle. Therefore, there is no basis for assuming that multi-shift averaging improves accuracy or reduces the risk of an erroneous enforcement determination.

Appendix B—Citation Threshold Values (CTV)

I. Interpretation of the CTV Table

Each CTV was calculated to ensure that, if the CTV is met or exceeded, noncompliance with the applicable standard can be inferred with at least 95-percent confidence. It is assumed that whatever dust standard happens to be in effect at the sampling location is binding, and that a citation is warranted whenever there is sufficient evidence that an established standard has been exceeded. The CTV table does not depend on how the applicable standard was established, or on any measurement uncertainties in the process of setting the applicable standard.

Some commenters argued that in order to construct a valid table of CTVs, MSHA would have to take into account the statistical distribution of dust concentrations over many shifts and locations. One commenter suggested that stochastic properties of the dust concentrations, which describe variability over time in probabilistic terms, should also be taken into account. MSHA, however, intends to use single, full-shift measurements only in determining noncompliance with the applicable standard on a particular shift and at the sampling location consistent with the measurement objective described in the MSHA and NIOSH joint finding published elsewhere in today's **Federal Register**. This is analogous to using a single measurement to identify individual suitcases that are unacceptable because they weigh more than five pounds. The efficacy of using a single measurement to identify unacceptable suitcases depends on the accuracy of the scale and the skill of the weigher. It does not depend on the statistical distribution of weights among suitcases or on any stochastic properties of the suitcase production process. These considerations would be relevant to estimating average weight for all suitcases produced, but they have nothing whatsoever to do with determining the weight of an individual suitcase using a sufficiently accurate scale. Averaging the weights of several suitcases would be entirely inappropriate and extremely misleading, since the object is to identify individual suitcases weighing more than five pounds. Although the measured weight of an individual suitcase is liable to contain some error (so the decision might be uncertain for a suitcase weighing five pounds and one ounce), a suitcase weighing seven or eight pounds could be rejected with high confidence on the first weighing. Additional weighings (of the same suitcase) would be required only for those suitcases whose initial measurement was very close to five pounds.

The CTV table provides criteria for testing a tentative, or presumptive, hypothesis that the true full-shift average dust concentration did not exceed the applicable standard (S) at each of the individual locations sampled during a particular shift. For purposes of this test, the mine atmosphere at each such location is presumed to be in compliance unless the corresponding full-shift measurement provides sufficient evidence to the contrary. The ''true full-shift average'' does *not* refer, in this context, to an average across different occupations, locations, or shifts. Instead, it refers entirely to the dust concentration at the specific location of the sampler unit, averaged over the course of the particular shift during which the measurement was obtained. The CTV table is *not* designed to estimate or test the average dust concentration across occupational locations, or within any zone or mine area, or in the air actually inhaled by any particular miner.

Some commenters questioned why more than one sample might be required, if the first sample collected does not exceed the CTV. One of these commenters argued that in such case, ''compliance has already been established at a 95% confidence level based on the first single shift sample.'' This line of argument confuses confidence in issuing a citation with confidence of compliance. It also shows a basic misunderstanding of how the citation criteria relate to the requirement of continuous compliance under section 202(b) of the Mine Act.

The CTV table ensures that noncompliance is cited only when there is a 95-percent level of confidence that the applicable standard has actually been exceeded. If a single measurement does not meet the criterion for citation, this does not necessarily imply probable compliance with the dust standard—let alone compliance at a 95-percent confidence level. For example, a single, full-shift measurement of 2.14 mg/m^3 would not, according to the CTV table, indicate noncompliance with sufficient confidence to warrant a citation if S = 2.0 mg/m^3. This does not imply that the mine atmosphere was in compliance on the shift and at the location sampled. On the contrary, unless contradictory evidence were available, this measurement would indicate that the MMU was probably *out* of compliance. However, because there is a small chance that the measurement exceeded the standard only because of measurement error, a citation would not be issued. Additional measurements would be necessary to verify the apparent lack of adequate control measures. Similarly, a single, full-shift measurement of 1.92 mg/m^3 would not warrant citation; but, because of possible measurement error, neither would it warrant concluding that the mine atmosphere sampled was in compliance. To confirm that control measures are adequate, it would be necessary to obtain additional measurements.

Furthermore, even if a single, full-shift measurement were to demonstrate, at a high confidence level, that the mine atmosphere was in compliance at the sampling location on a given shift, additional measurements would be required to demonstrate compliance on each shift. For example, if S = 2.0 mg/m^3, then a valid measurement of 1.65 mg/m^3 would demonstrate compliance on the particular shift and at the particular location sampled. It would not, however, demonstrate compliance on other shifts or at other locations.

II. Derivation of the CTV Table

Some commenters requested an explanation of the statistical theory underlying the CTV table. To understand how the CTVs are derived and justified, it is first necessary to distinguish between variability due to measurement error and variability due to actual differences in dust concentration. The variability observed among individual measurements obtained at different locations (or at different times) combines both: dust concentration measurements vary partly because of measurement error and partly because of genuine differences in the dust concentration being measured. This distinction, between measurement error and variation in the true dust concentration, can more easily be explained by first carefully defining some notational abbreviations.

One or more dust samples are collected in the same MMU or other mine area on a particular shift. Since it is necessary to distinguish between different samples in the same MMU, let X_i represent the MRE-equivalent dust concentration measurement obtained from the ith sample. The quantity being measured is the true, full-shift average dust concentration at the ith sampling location and is denoted by μ_i. Because of potential measurement errors, μ_i can never be known with complete certainty. A ''sample,'' ''measurement,'' or ''observation'' always refers to an instance of X_i rather than μ_i.

The overall measurement error associated with an individual measurement is nothing more than the difference between the measurement (X_i) and the quantity being measured (μ_i). Therefore, this error can be represented as

$$\varepsilon_i = X_i - \mu_i.$$

Equivalently, any measurement can be regarded as the true concentration in the atmosphere sampled, with a measurement error added on:

$$X_i = \mu_i + \varepsilon_i.$$

For two different measurements (X_1 and X_2), it follows that X_1 may differ from X_2 not only because of the combined effects of ε_1 and ε_2, but also because μ_1 differs from μ_2.

The probability distribution of X_i around μ_i depends only on the probability distribution of ε_i and should not be confused with the statistical distribution of μ_i itself, which arises from spatial and/or temporal variability in dust concentration. This variability [i.e., among μ_i for different values of I] is not associated with inadequacies of the measurement system, but real variation in exposures due to the fact that contaminant generation rates vary greatly in time and contaminants are heterogeneously distributed in workplace air.

Since noncompliance determinations are made relative to individual sampling locations on individual shifts, derivation of the CTV table requires no assumptions or inferences about the spatial or temporal pattern of atmospheric dust concentrations—i.e., the statistical distribution of μ_i. MSHA is not evaluating dust concentrations averaged across the various sampler locations. Therefore, the degree and pattern of variability observed among different measurements obtained during an MSHA inspection are not used in establishing any CTV. Instead, the CTV for each applicable standard (S) is based entirely on the distribution of measurement errors (ε_i) expected for the maximum dust concentration in compliance with that standard—i.e., a concentration equal to S itself.

If control filters are used to eliminate potential biases, then each ε_i arises from a combination of four weighing errors (pre-and post-exposure for both the control and exposed filter capsule) and a continuous summation of instantaneous measurement errors accumulated over the course of an eight-hour sample. Since the eight-hour period can be subdivided into an arbitrarily large number of sub-intervals, and some fraction of ε_i is associated with each sub-interval, ε_i can be represented as comprising the sum of an arbitrarily large number of sub-interval errors. By the Central Limit Theorem, such a summation tends to be normally distributed, regardless of the distribution of subinterval errors. This does not depend on the distribution of

μ_i, which is generally represented as being lognormal.

Furthermore, each measurement made by an MSHA inspector is based on the difference between pre- and post-exposure weights of a dust sample, as determined in the same laboratory, and adjusted by the weight gain or loss of the control filter capsule. Any systematic error or bias in the weighing process attributable to the laboratory is mathematically canceled out by subtraction. Furthermore, any bias that may be associated with day-to-day changes in laboratory conditions or introduced during storage and handling of the filter capsules is also mathematically canceled out. Elimination of the sources of systematic errors identified above, together with the fact that the concentration of respirable dust is defined by section 202(e) of the Mine Act to mean the average concentration of respirable dust measured by an approved sampler unit, implies that the measurements are unbiased. This means that ε_i is equally likely to be positive or negative and, on average, equal to zero.

Therefore, each ε_i is assumed to be normally distributed, with a mean value of zero and a degree of variability represented by its standard deviation

$$\sigma_i = \mu_i \cdot CV_{total} .$$

Since $X_i = \mu_i + \varepsilon_i$, it follows that for a given value of μ_i, X_i is normally distributed with expected value equal to μ_i and standard deviation equal to σ_i. CV_{total}, described in the MSHA and NIOSH joint finding published elsewhere in today's **Federal Register**, is the *coefficient of variation* in measurements corresponding to a given value of μ_i. CV_{total} relates entirely to variability due to measurement errors and not at all to variability in actual dust concentrations.

MSHA's procedure for citing noncompliance based on the CTV table consists of formally testing a presumption of compliance at every location sampled. Compliance with the applicable standard at the i^{th} sampling location is expressed by the relation $\mu_i \le S$. Max$\{\mu_i\}$ denotes the maximum dust concentration, among all of the sampling locations within an MMU. Therefore, if Max$\{\mu_i\} \le S$, none of the sampler units in the MMU were exposed to excessive dust concentration. Since the burden of proof is on MSHA to demonstrate noncompliance, the hypothesis being tested (called the *null hypothesis, or H_0,*) is that the concentration at every location sampled is *in* compliance with the applicable standard. Equivalently, for an MMU the null hypothesis (H_0) is that max$\{\mu_i\} \le S$. In other areas, where only one, full-shift measurement is made, the null hypothesis is simply that $\mu_i \le S$.

The test consists of evaluating the likelihood of measurements obtained during an MSHA inspection, under the assumption that H_0 is true. Since $X_i = \mu_i + \varepsilon_i$, X_i (or max$\{X_i\}$ in the case of an MMU) can exceed S even under that assumption. However, based on the normal distribution of measurement errors, it is possible to calculate the probability that a measurement error would be large enough to fully account for the measurement's exceeding the standard. The greater the amount by which X_i exceeds S, the less likely it is that this would be due to measurement error alone. If, under H_0, this probability is less than five percent, then H_0 can be rejected at a 95-percent confidence level and a citation is warranted. For an MMU, rejecting H_0 (and therefore issuing a citation) is equivalent to determining that $\mu_i > S$ for at least one value of *I.*

Each CTV listed was calculated to ensure that citations will be issued at a confidence level of at least 95 percent. As described in MSHA's February 1994 notice and explained further by Kogut [2], the tabled CTV corresponding to each S was calculated on the assumption that, at each sampling location:

$$CV_{total} \le CV_{CTV} = \sqrt{\left(\frac{0.14\ \text{mg/m}^3}{\mu_i\ \text{mg/m}^3} \cdot 100\%\right)^2 + (5\%)^2 + (5\%)^2}$$

The MSHA and NIOSH joint finding establishes that for valid measurements made with an approved sampler unit, CV_{total} is in fact less than CV_{CTV} at all dust concentrations (μ^i).

The situation in which measurement error is most likely to cause an erroneous noncompliance determination is the hypothetical case of $\mu_i = S$ for either a single, full-shift measurement or for all of the measurements made in the same MMU. In that borderline situation—i.e., the worst case consistent with H_o—the standard deviation is identical for all measurement errors. Therefore, the value of s used in constructing the CTV table is the product of S and CV_{CTV} evaluated for a dust concentration equal to S:

$$\sigma = S \cdot \sqrt{\left(\frac{0.14}{S}\right)^2 + (.05)^2 + (.05)^2}$$

Assuming a normal distribution of measurement errors as explained above, it follows that the probability a single measurement would equal or exceed the critical value

$$c = S + 1.64 \cdot \sigma$$

is five percent under H_o when $CV_{total} = CV_{CTV}$. The tabled CTV corresponding to S is derived by simply raising the critical value *c* up to the next exact multiple of 0.01 mg/m^3.

For example, at a dust concentration (μ_i) just meeting the applicable standard of S = 2 mg/m^3, CV_{CTV} is 9.95 percent. Therefore, the calculated value of *c* is 2.326 and the CTV is 2.33 mg/m^3. Any valid single, full-shift measurement at or above this CTV is unlikely to be this large simply because of measurement error. Therefore, any such measurement warrants a noncompliance citation.

The probability that a measurement exceeds the CTV is even smaller if $\mu_i > S$ for any I. Furthermore, to the extent that CV_{total} is actually less than CV_{CTV}, σ is actually less than $S \bullet CV_{CTV}$. This results in an even lower probability that the critical value would be exceeded under the null hypothesis. Consequently, if any single, full-shift measurement equals or exceeds *c*, then H_o can be rejected at confidence level of at least 95-percent. Since rejection of H_o implies that $\mu_i \le S$ for at least one value of I, this warrants a noncompliance citation.

It should be noted that when each of several measurements is separately compared to the CTV table, the probability that at least one ε_i will be large enough to force $X_i \ge$ CTV when $\mu_i \le S$ is greater than the probability when only a single comparison is made. For example (still assuming S = 2 mg/m^3), if CV_{total} is actually 6.6%, then the standard deviation of ε_i is 6.6% of 2.0 mg/m^3, or 0.132 mg/m^3, when μ_i = S. Using properties of the normal distribution, the probability that any single measurement would exceed the CTV in this borderline situation is calculated to be 0.0062. However, the probability that at least one of five such measurements results in a citation is 1—$(0.9938)^5$ = 3.1 percent. Therefore, the confidence level at which a citation can be issued, based on the maximum of five measurements made in the same MMU on a given shift, is 97%.

The constant 1.64 used in calculating the CTV is a *1-tailed 95-percent confidence coefficient* and is derived from the standard normal probability distribution. At least one commenter expressed confusion about whether the CTV table is based on a 1-tailed or a 2-tailed confidence coefficient. This commenter claimed that MSHA's use of a confidence coefficient equal to 1.64 ''clearly establishes a 90% confidence level'' rather than 95%. The commenter apparently confused the CTV for rejecting a 1-tailed hypothesis ($\mu_i \leq S$) with the pair of critical values for rejecting a 2-tailed hypothesis ($\mu_i = S$) and inferring that μ_i simply differs from S in either direction. The criterion for rejecting the latter hypothesis would be a measurement either sufficiently above the applicable standard or sufficiently below it. In testing for a difference of arbitrary direction, 1.64 would indeed yield a pair of 90-percent confidence limits, with a 5-percent chance of erring on either side. The purpose of the CTV table, however, is to provide criteria for determining that the true dust concentration strictly exceeds the applicable standard. Since such a determination can occur only when a single, full-shift measurement is sufficiently high, there is exactly zero probability of erroneously citing noncompliance when a measurement falls below the lower confidence limit. Consequently, the total probability of erroneously citing noncompliance equals the probability that a standard normal random variable exceeds 1.64, which is 5 percent.

One commenter alluded to testimony in the *Keystone* case (*Keystone* v. *Secretary of Labor*, 16 FMSHRC 6 (Jan. 4, 1994)), suggesting that application of the CTV to a single measurement involves an invalid comparison of two distributions or comparison of two means. Contrary to much of the testimony presented in that case, a determination of noncompliance using the CTV table is based on the decision procedure described above. It does not involve any comparison of probability distributions or means. Nor does it involve any statistical distribution of dust concentrations. It involves only the comparison of an individual full-shift measurement to the applicable standard. There is only one probability distribution involved in this comparison: namely, the distribution of random measurement errors by which each full-shift measurement deviates from the true dust concentration to which the sampler unit is exposed.

Some commenters apparently misunderstood the effect of potential weighing errors on the formula for calculating the CTV corresponding to different applicable standards. Weight gain is estimated from the difference between two weighings of an exposed filter capsule, adjusted by subtracting the difference between two weighings of a control filter capsule. Since weight gains are small compared to the total weight of capsules being weighed, any dependence of weighing error on the magnitude of the mass being weighed is canceled in the process of calculating the difference. Since the standard deviation of the error in weight gain is, therefore, essentially constant, the ratio of that standard deviation to the dust concentration being measured decreases with increasing dust concentration. This causes CV_{CTV} to decrease as the dust concentration increases. As explained above, the CTV corresponding to S is calculated using the value of CV_{CTV} for dust concentrations exactly equal to S. Consequently, the CTV corresponding to a standard of 2.0 mg/m^3 is based on a smaller value of CV_{CTV} than the CTV corresponding to a standard of 0.2 mg/m^3.

One commenter implied that use of the CTV table relies on an assumption that CV_{total} declines at concentrations greater than 2.0 mg/m^3 (or S in general). As explained previously, the CTV corresponding to different applicable standards is designed to test the null hypothesis that S is not exceeded. For each applicable standard, entries are based on the probability distribution of observations expected under that presumption. Consequently, the magnitude of CV_{total} assumed in establishing or applying any CTV does not decrease below the value of CV_{total} calculated for a concentration of 2.0 mg/m^3, since that is the maximum applicable standard being tested. Because the probability of wrongly citing noncompliance is zero when S is exceeded, measurement uncertainty at concentrations greater than S is not relevant to noncompliance determinations. (It would, however, be relevant to inferring compliance at a specified confidence level—i.e., to a test of the alternative hypothesis that S is not exceeded.)

III. Validity of the CTV table

Some commenters questioned the validity of the CTV table and challenged the formula used to calculate each CTV listed. Some objected to the use of a normal distribution and claimed that a lognormal distribution or nonparametric assumptions would be more appropriate. Other commenters objected specifically to the use of a confidence coefficient based on a standard normal probability distribution, rather than a t-distribution. The validity of using $\sqrt{n}$, rather than $\sqrt{(n-1)}$, in the formula used to calculate citation threshold values in MSHA's February 1994 notice, was also questioned. At least one commenter contended that the formula used to generate the CTV table is not valid for use with only one measurement.

Such comments would have some validity if the CTV table were intended to test or estimate average concentration over some spatially distributed region of a mine or some period greater than the single shift during which each measurement is taken. In either case, it might be necessary and appropriate to estimate variation in concentration directly from the measurement samples obtained. Such an estimate could conceivably be used in establishing a site-specific threshold value for citation. This would, indeed, require a theoretical minimum of two samples, or far more for valid practical applications. Estimating variability from the samples collected would also require additional assumptions or nonparametric methods to reflect the pattern of variation in dust concentration between locations or shifts.

The objections raised, however, apply to a very different task from the one for which the CTV table is designed. As explained previously, the CTV table is not meant to test dust concentration averaged over any period greater than the shift during which measurements were taken. Nor is it meant to test dust concentration averaged across different occupational locations or throughout any spatially distributed region of the mine. Instead, the CTV table provides criteria for determining noncompliance at individual sampling locations on individual shifts. Neither the spatial nor temporal distribution of the dust concentrations is germane to the intended citation criteria. Although several measurements may be taken during a single inspection, MSHA regards each of these measurements as relating to the dust concentration uniquely associated on a given shift with a separate sampling location. Each such dust concentration (μ_i) is the average for the atmosphere at the sampling location, accumulated over the course of the single, full shift sampled. Since the enforcement objective is to determine whether $\mu_i > S$ for any individual I, it is not necessary to estimate or assume anything about the degree to which μ_i varies from location to location or from shift to shift. Nor is it necessary to assume anything about the spatial or temporal statistical distribution of μ_i. No such assumptions are built into the CTV table. A normal distribution is imputed only to ε_i, the difference between X_i and μ_i. Since the mean across various μ_i is not being estimated or tested, it is not necessary to estimate variability among the μ_i from measurements taken during the inspection. MSHA emphatically agrees with those commenters who stressed the impossibility of doing so with a single measurement.

Those commenters who objected to MSHA's use of a normal distribution, claiming that a lognormal distribution or nonparametric assumptions would be more appropriate, apparently confused the distribution of dust concentrations over time and between locations with the distribution of errors that arise when measuring dust concentration at a specific time and location. In other words, they confused the distribution of μ_i with the distribution of ε_i. The concerns about non-normality stem from confusion about what quantity is being estimated.

MSHA does not dispute the fact that lognormal or nonparametric methods are often appropriate for modeling variability in occupational dust concentrations. MSHA, however, is explicitly not claiming to estimate any quantity beyond the average dust concentration at a particular sampling location on a single shift. MSHA does not claim that dust concentrations are normally distributed from shift to shift, from occupation to occupation, or from location to location; nor is any such assumption built into the CTV table. Since the object is not to estimate average concentration over a range of different locations or shifts, the statistical distribution of μ_i is irrelevant, and application of lognormal or nonparametric techniques in constructing citation criteria is both unnecessary and inappropriate.

In constructing the CTV table, MSHA used a normal probability distribution solely to represent a potential measurement error, ε_i. This measurement error causes a measurement X_i to deviate from μ_i, the actual dust concentration at a specific time and place. As distinguished from the statistical distribution of dust concentrations, it is generally accepted that the distribution of measurement errors around a given concentration is *normal* [3]. This was explicitly acknowledged by members of the industry panel in their Morgantown testimony.

Similarly, criticism directed against MSHA's use of a confidence coefficient derived from the standard normal distribution instead of the t-distribution arises from a basic misunder standing of what is or is not being estimated in the decision procedure. Contrary to the remark of one commenter, use of the t-distribution is not justified as a "compromise" between normal-theoretic and nonparametric assumptions. The t-distribution arises in statistical theory when a normally distributed random variable is divided by an estimate of its standard deviation. Typically it is applied to situations in which the mean and standard deviation are estimated from the same normally distributed data, consisting of fewer than about thirty or forty random data points. If the estimate of standard deviation is based on more data, then the confidence coefficient derived from the t-distribution is approximately equal to the corresponding value derived from the standard normal distribution. Use of the t-distribution is appropriate, for example, when a group of normally distributed observations is "standardized" by subtracting the group mean from each observation and dividing the result by the group standard deviation.

Those commenters advocating a confidence coefficient based on the t-distribution failed to recognize that CV_{CTV} was not derived from the measurements that MSHA inspectors will use to test for compliance with S. Use of the t-distribution is *not* appropriate when an independently known or stipulated standard deviation is used in comparing observations to a standard [3]. The standard deviation of measurement errors used in constructing the CTV table is derived from prior knowledge, rather than estimated from a few measurements taken during an inspection. Experimental analysis has shown that CV_{total} is less than CV_{CTV}. So long as this is true, use of a confidence coefficient derived from the standard normal distribution is entirely appropriate.

Contrary to the claims of some commenters, there is no valid basis for including a so-called $[n/(n-1)]^{1/2}$ "correction factor" in the formula for establishing a CTV. (The "n" in this expression would refer to the number of measurements, if a noncompliance determination were based on the average of several measurements.) The theory behind such a factor does not apply when, as in the case of the CTV table, a predetermined or maximum tolerated variability in measurement error is used in comparing observations to a standard [3]. It would apply only if variability in measurements observed during each inspection were somehow used to construct a CTV specific to that inspection. The variability observed among multiple samples collected during an MSHA inspection has little to do with the accuracy of an individual measurement and is not used at all in constructing the CTV table.

Although no explicit reason was given for the claim by some commenters that the formula used to generate the CTV table is not valid for use with a single measurement, this would follow if either: (1) the appropriate basis for the confidence coefficient were a t-distribution rather than a standard normal distribution; or (2) it were necessary to multiply the CTV by $[n/(n-1)]^{1/2}$, where n is the number of measurements on which a noncompliance determination is based. In the former case, the standard normal distribution would not adequately approximate the t-distribution; and in the latter case, n = 1 would cause the so-called correction factor, and hence the CTV, to be mathematically indeterminate for determinations based on a single sample. It has already been explained, however, that neither of these considerations are applicable to the CTV table.

Some commenters stated that a single measurement cannot accurately be used to detect excessive dust concentrations, even if the noncompliance determination applies only to a specific shift and location. These commenters implied that due to random, temporary fluctuations in dust concentration, a single measurement is inherently unstable and misleading. Such arguments fail to differentiate a full-shift sample from a "grab sample," which is typically a sample collected over only a few minutes or seconds and used to estimate average conditions over an entire shift. In contrast to a grab sample, each full-shift dust sample is collected continuously over the full period to which the measurement applies. An 8-hour dust sample consists of 480 1-minute grab samples, or an arbitrarily large number of even shorter grab samples. A full-shift dust sample can be viewed as measuring average concentration over the entire shift by averaging together all of these shorter subsamples. Although short-term fluctuations in dust concentration, as well as random changes in flow rate and collection efficiency, may cause many of the subsamples to poorly represent average concentration over the entire shift, random short-term aberrations tend to cancel one another when the subsamples are combined. Therefore, a full-shift dust sample does not suffer from lack of sample size.

Appendix C—Risk of Erroneous Enforcement Determinations

I. What Constitutes Compliance or Noncompliance?

To simplify the following discussion, let μ denote the average dust concentration to which a sampler unit is exposed on a given shift, let S denote the applicable standard, and let X denote a valid, full-shift measurement of μ. Also, let c be the CTV in the table corresponding to S so that a citation is issued when $X \geq c$. Section 202(b)(2) of the Mine Act requires that the average dust concentration during each shift be maintained at or below the applicable standard wherever miners normally work or travel. This means that, on any given shift, the average dust concentration (μ) at any valid sampling location must not exceed the applicable standard (S).

Since the CTVs listed always exceed S it can happen that a full-shift measurement (X) falls between S and c. In such instances, MSHA will not issue a citation. This does not, however, imply that MSHA considers the mine atmosphere sampled to have been in compliance with the Mine Act or that cases of marginal noncompliance are tolerable. MSHA's use of the CTVs is not motivated by any tacit acceptance of marginal noncompliance. Rather, it is motivated by the necessity to avoid unsustainable violations. When X falls between S and c, this provides some evidence that $\mu > S$; but the evidence is insufficient to warrant a citation.

Although $\mu > S$ constitutes a violation, X greater than S but less than the CTV does not provide compelling evidence that $\mu > S$. This is because, in a sufficiently well-controlled mining environment, X is more likely to slightly exceed S due to measurement error than due to $\mu > S$. In fact, as demonstrated in Appendix D, citing when $X > S$ but $X < c$ could result in citations when the probability of compliance ($\mu \leq S$) on the shift and location sampled is greater than 50 percent. Use of the CTV table is necessary in order to avoid citing in such cases.

There are two sorts of conclusions that might be drawn from the results of a single MSHA inspection: those relating to the individual shift sampled and those relating to some longer time period, such as the full interval between MSHA inspections. Therefore, in evaluating the probability of erroneous enforcement determinations, it is essential to distinguish between (1) compliance or noncompliance with the applicable standard on the shift sampled and (2) compliance or noncompliance with the full requirement of the Mine Act as it applies to every shift over a longer term, such as the period between MSHA inspections.

If $\mu > S$ on some proportion of shifts, say $P < 1$, then the mine does not comply with the applicable standard on some individual shifts and, therefore, does not comply with the Mine Act over the longer term. At the same time, the mine is in compliance with the applicable standard (at the location sampled) on a complementary proportion, equal to 1—P, of individual shifts. If an MSHA inspection happens to fall on one of those shifts that is out of compliance, then a correct determination with respect to the individual shift would also be correct with respect to the longer term. If, on the other hand, the MSHA inspection happens to fall on a shift that is in compliance, then it would be a mistake to assume compliance on subsequent shifts and vice versa. Although MSHA interprets the Mine Act as requiring $\mu \leq$ S on each shift and at each sampling location to which miners in the active workings are exposed, the immediate objective of an MSHA dust inspection can only be to determine compliance or noncompliance for the shift and location sampled. Therefore, MSHA does not consider a compliance or noncompliance determination to be erroneous if it is correct with respect to the individual shift and location but incorrect with respect to other shifts or locations.

II. Uncertainty in the Standard-Setting Process

In response to the March, 12, 1996 MSHA/NIOSH **Federal Register** notice, a commenter claimed that a noncompliance determination based on a single, full-shift measurement could be erroneous if the applicable standard was improperly established due to measurement errors associated with silica analysis. It was, therefore, suggested that uncertainty in the standard-setting process should be factored into the risk of erroneous enforcement decisions. MSHA agrees that, like any measurement process, the sampling and analytical method used to quantify the silica content of a respirable dust sample in order to set the applicable standard is subject to potential measurement errors. Therefore, MSHA uses an analytical procedure that meets the requirement of a NIOSH Class B analytical method. Applicable standards are set based on results of silica analysis using the most up-to-date laboratory equipment.

The Secretary, however, considers the accuracy of the standard-setting process to be a separate issue from the accuracy of noncompliance determinations based on a single-full-shift measurement, once the applicable standard has been set. The present notice relates only to the enforcement of the applicable standard in effect at time of the sampling inspection. Therefore, the following discussion treats any applicable standard in effect at the time of sampling as binding and evaluates the risk of erroneous determinations relative to that standard.

III. Measurement Uncertainty and Dust Concentration Variability

Variability in dust concentration refers to the differing values of μ on different shifts or at different locations. For a given value of μ, measurement uncertainty refers to the differing measurement results that could arise because of different potential measurement errors. If $\mu \leq S$, measurement error can cause an erroneous citation. Similarly, if $\mu > S$, then measurement error can cause an erroneous failure to cite.

The ''margin of error'' separating each CTV from the corresponding applicable standard does not eliminate the possibility of erroneous enforcement determinations due to uncertainty in the measurement process. A determination based on comparing X to the CTV could be erroneous in either of two ways with respect to the individual shift sampled: (1) the comparison could erroneously indicate noncompliance on the shift (i.e, $X \geq c$ but $\mu \leq S$) or (2) the comparison could erroneously fail to indicate noncompliance on the shift (i.e, $X < c$ but $\mu > S$). The margin of error built into the CTV table reduces the probability of erroneous citations but increases the probability of erroneous failures to cite.

MSHA recognizes that in determining how large the margin of error should be, there is a tradeoff between the probabilities of these two mistakes—i.e., if the chance of erroneously failing to cite is reduced, then the chance of erroneously citing is increased, and vice versa. MSHA has constructed the CTV. table so as to ensure that citations will be issued only when they can be issued at a high level of confidence. As will be shown below, doing this provides assurance that for any given citation, μ is more likely than not to actually exceed S. In contrast, if there were no margin of error, citations more likely than not to be erroneous could occasionally be issued. Examples of this are given in Appendix D.

In the discussion below, the risk of erroneous citations and erroneous failures to cite is quantified for noncompliance determinations based on the CTV table. To illustrate points in the theoretical discussion, three different mining environments will be used as examples. These environments exemplify different degrees of dust concentration variability and dust control effectiveness. The first example (Case 1) is based on historical mine data provided by commenters in connection with these proceedings. The second and third examples (Case 2 and Case 3) are hypothetical and are designed to reflect extremely well-controlled and poorly controlled mining environments, respectively. In these three examples, it will be assumed that μ is lognormally distributed from shift to shift. This is a standard assumption for airborne contaminants in an occupational setting [3]. The three cases considered are characterized as follows:

Case	Dust concentration (mg/m^3)				
	Arithmetic mean, E{μ}	Arithmetic Std. Dev., SD{μ}	Geometric mean	Geometric Std. Dev.	Prb {μ>S} (percent)
1	1.66	0.70	1.53	1.50	25.4
2	1.20	0.24	1.18	1.22	0.4
3	2.20	1.32	1.89	1.74	45.8

In addition to the variability in dust concentrations described by the arithmetic and geometric standard deviations of μ, full-shift measurements contain a degree of uncertainty described by CV_{total}, the coefficient of variation for measurements of the same dust concentration. In calculating the probability of erroneous determinations for the three example cases, it will also be assumed that the applicable standard is S = 2.0 mg/m^3 and that the coefficient of variation in full-shift measurements taken at a given value of μ is:

$$CV_{total} = \sqrt{\left(\frac{1.38 \cdot \frac{1000\,\text{Liters}/\text{m}^3 \cdot \sigma_e \sqrt{2}}{2\,\text{Liters}/\text{min} \cdot 480\,\text{min}}}{\mu}\right)^2 + \left(CV_{pump}\right)^2 + \left(CV_{sampler}\right)^2}$$

Where σ_e = 9.12 μg is the standard deviation of error in weight gain, as determined from MSHA's 1995 field investigation of measurement precision [4]; 1.38 is the MRE-equivalent conversion factor for measurements made with an approved sampler unit; the first quantity being squared is CV_{weight}; CV_{pump} = 4.2% and $CV_{sampler}$ = 5%, as explained in Appendix B.II of the joint MSHA and NIOSH notice of finding published elsewhere in today's **Federal Register**.

It should be noted that the ''total'' in CV_{total} refers to total measurement uncertainty and is not meant to include the effects of variability in dust concentration.

Because it employs a higher value for $CV_{sampler}$ (reflecting variability amongst used rather than new 10-mm nylon cyclones), this composite estimate of CV_{total} is slightly greater and perhaps slightly more realistic than that obtained directly from MSHA's 1995 field investigation. It declines from 11.3% at dust concentrations of 0.2 mg/m^3 to no more than 6.6% at concentrations of 2.0 mg/m^3 or greater. At all dust concentrations within this range, it falls well below the 12.8% maximum value permitted for a method meeting the NIOSH Accuracy Criterion [5]. It is also smaller than the value, CV_{CTV}, used to construct the CTV table. As explained in Appendix B, this ensures that any citation issued will be warranted at a confidence level of at least 95 percent.

To simplify the discussion below on risk of erroneous citations and erroneous failures to cite, it is necessary to introduce some additional notation and to focus on just one measurement collected during each inspection.[2] This could be the ''D.O.'' sample in a MMU, or the measurement collected for a designated area. Let ε = X − μ represent the measurement error in a valid measurement. For reasons explained in Appendix B, ε is assumed to be normally distributed with zero mean and standard deviation equal to σ = μ•CV_{total}. Consequently, X is normally distributed with mean equal to μ and standard deviation equal to σ. This normal distribution of X around μ reflects uncertainty in the measurement of a given dust concentration. On any given shift, the probability distribution of X is determined by the value of μ for that shift and sampling location. Therefore, the probability of citation on a given shift is conditional on μ and is denoted by Prb{X≥c | μ .}[3]

Since μ varies from shift to shift, variability in dust concentration is represented by the probability distribution of μ. Let E {μ} denote the expected (i.e., arithmetic mean) dust concentration over some longer term of interest, such as the interval between MSHA inspections; and let SD{μ} denote the standard deviation of μ over the same period. Although the value of μ on any individual shift is unknown, Prb{X≥c} can be calculated using the probability distribution of μ. In particular, if the probability is known that μ fulfills a specified condition, such as μ ≤ S or μ > S, then

Prb{X≥c} = Prb{X≥c | μ ≤S}
•Prb{μ≤S}+Prb{X≥c | μ >S}
•Prb{μ>S}.

Over a sufficiently long term, with respect to any particular sampling

[2] Appendix D addresses cases in which a noncompliance determination is based on the maximum of several measurements.

[3] A vertical bar is used to denote conditional probability. Prb {A | B} denotes the conditional probability of event A, given the occurrence of event B. For any events A and B,

Prb{A|B}=Prb{A and B}/Prb {B}=Prb{B|A}•Prb {A}/Prb{B} location, Prb{μ>S} and Prb{μ≤S} can be identified, respectively, with the proportion of noncompliant shifts, P, and the proportion of compliant shifts, 1 − P. P is sometimes called the noncompliance fraction and more or less defines the likelihood that the applicable standard is or is not exceeded on the particular shift inspected.[4]

If the statistical distribution of μ can be adequately represented by a probability density function, denoted f(μ), then Prb{μ>S} and Prb{μ≤S} can also be calculated by integrating f(μ) over the desired range. The probability that μ falls in any interval, say between a and b, is given by:

$$\mathrm{Prb}\left\{a < \mu \le b\right\} = \int_a^b f(\mu)d\mu \quad .$$

It follows that:

$$\mathrm{Prb}\left\{X > c \middle| a < \mu \le b\right\} = \frac{\int_a^b \mathrm{Prb}\left\{X > c \middle| \mu\right\} \cdot f(\mu)d\mu}{\int_a^b f(\mu)d\mu}$$

IV. Risk of Erroneous Citation

Some commenters argued that a citation for noncompliance is warranted only if the average dust concentration to which a miner is exposed exceeds the applicable standard over a period of time greater than a single shift, such as a bimonthly sampling period, a year, or a miner's lifetime. Therefore, these commenters called it ''unfair'' to cite individual shifts on which the applicable standard is exceeded, so long as the average over this longer term meets the applicable standard. For example, based on the historical sampling data provided by a commenter and employed here as Case 1, one commenter concluded that ''* * * there is at least a 1 in 6 or 17% probability that any single sample can show potential overexposure [using the CTV table] when one does not exist.'' Further, these commenters maintained that basing citations on a single, full-shift measurement would substantially increase the frequency of unfair citations, compared to existing MSHA policy.

Using the notation introduced above, these commenters have confused μ with E(μ) and confounded the noncompliance fraction *P* with the probability of erroneous citation. For example, the 17-percent figure mentioned above includes all cases in which X ≥ c, regardless of whether μ > S on the shift sampled. In the discussion accompanying the data, commenters argue that since E(μ) is approximately 1.66 mg/m³, or less than 1.85 mg/m³ at a high confidence level, ''* * * [cases of X ≥ c] show potential overexposure when one does not exist.'' This statement depends on the unwarranted assumption that miners exposed to these conditions have been exposed to similarly distributed dust concentrations in the past and that they will be exposed to similarly distributed concentrations in the future. These commenters' own analysis indicates that the dust concentration has not been kept below the standard on each shift. Therefore, a citation is warranted under the Mine Act.

To more fully explore what is going on in Case 1, suppose, as these commenters suggest, that dust concentrations over the period observed are lognormally distributed from shift to shift, with E{μ} = 1.66 mg/m³ and a geometric standard deviation of about 1.5 mg/m³. Under this assumption, μ > 2.0 mg/m³ on more than 25 percent of all shifts, and μ > 2.33 mg/m³ on 15 percent. These percentages pertain to actual dust concentrations and have nothing to do with measurement error or accuracy of an individual measurement. Therefore, a 2.0 mg/m³ dust standard would be violated on 25 percent of all production shifts. The applicable standard would be violated by an amount greater than 0.33 mg/m³ on 15 percent. Since 2.33 is the CTV for a single measurement, this 15 percent actually represents shifts sufficiently far out of compliance that they would probably be cited if inspected. Nevertheless, the commenters' analysis includes such shifts in the 17 percent claimed as cases subject to erroneous or unfair citation.

The expected value of the noncompliance fraction (P) in Case 1 is 25 percent. Therefore, close to 25 percent of all single shift measurements made under the conditions of Case 1 would be expected to exceed the standard. Only 17 percent of the single full-shift measurements taken, however, exceeded the CTV and would have warranted citations. Using the estimate of CV_{total} described above, 15 percent of all single shift measurements would be expected to do so. Therefore, contrary to the commenters' conclusion, Case 1 does not demonstrate a high probability of erroneously identifying overexposures. Instead, it illustrates an effect of the high confidence level required for citation: the margin of error built into the CTV reduces the probability of citing whatever shift happens to be selected for inspection from about 25 percent to 15 percent. Although the applicable standard is violated on 25 percent of the shifts, there is only a 15 percent chance that any particular measurement meets the citation criterion.

To correctly and unambiguously quantify the risk of ''unfair'' citations, it is necessary to identify three distinct ways of interpreting the risk of erroneous noncompliance determinations. This risk can be defined alternatively as:

(1) the probability of citing when the mine atmosphere sampled is actually in compliance, Prb{X≥c|μ≤S};

(2) the probability that the mine atmosphere on a shift randomly selected for inspection is in compliance but is nevertheless cited, Prb{μ≤S and X≥c}; or

(3) the probability that a given citation is erroneous,

Prb{μ≤S|X≥c}.

These three different probabilities apply to three different base populations. Although the different interpretations of risk give rise to quantitatively different probabilities, the expected total number of erroneous citations, denoted N_α, remains constant if each probability is multiplied by the size of the population to which it applies. To obtain N_α, the first probability must be multiplied by the number of valid measurements made when μ ≤ S, the second by the total number of valid measurements, and the third by the total number of citations issued—i.e., valid measurements for which X ≥ c.

The CTV table limits the probability of erroneously citing defined by the first two interpretations to a maximum of less than five percent. However, in a

[4] P defines this likelihood exactly only if shifts are randomly selected for MSHA inspection and there is no adjustment of conditions in response to the inspection.

well-controlled mining environment, where citations are rarely warranted, the third probability can be larger than the first two. Since the burden of proof rests with MSHA to demonstrate noncompliance, it is essential that α° be kept well below 50 percent. As will be shown by example, the use of the CTV table accomplishes this goal.

Each of the three different probabilities related to erroneous noncompliance determinations will now be explained in detail. Calculations for all examples are performed under the assumptions (1) that μ is lognormally distributed and (2) that ε is normally distributed with mean equal to zero and standard deviation equal to $\mu \bullet CV_{total}$.

1. $\alpha = Prb\{X \geq c | \mu \leq S\}$

The first risk to be considered is the probability of citing noncompliance when the mine atmosphere sampled is actually in compliance. This probability represents the proportion of those measurements made when $\mu \leq S$ that result in $X \geq c$. In other words, $\alpha = Prb\{X \geq c | \mu \leq S\}$ is the probability that, due to measurement error, a citation is issued under the condition that $\mu \leq S$. This is the probability associated with what is commonly designated Type I error for testing the null hypothesis: $\mu \leq S$ on the shift sampled.

Essentially, α is the expected (i.e., mean) probability of citation over all those shifts sampled that are at or below the applicable standard. The relative frequency distribution of μ over those shifts is described by its probability density function, $f(\mu)$. Therefore, α can be calculated as follows:

$$\alpha = \int_0^S \frac{Prb\{X \geq c | \mu\}}{1 - P} f(\mu) d\mu$$

If μ did not vary, then α would be directly related to the confidence level at which the null hypothesis could be rejected when $X \geq c$. That confidence level, which applies to citations issued in accordance with the CTV table, is defined as the minimum possible value of $1 - Prb\{X \geq c | \mu\}$, subject to the restriction that $\mu \leq S$. There is a subtle but extremely important distinction between this and $1 - \alpha$. Among all those shifts on which $\mu \leq S$, $Prb\{X \geq c | \mu\}$ is maximized when $\mu = S$. Therefore, the minimum possible value of $1 - \alpha$, arises when $\mu = S$ on every shift. The resulting confidence level for concluding $\mu > S$ when $X \geq c$ is equal to $1 - Prb\{X \geq c | \mu = S\}$. For the value of CV_{total} described above (i.e., 6.6% when $\mu = S = 2.0$ mg/m^3), this works out to a confidence level of 0.99, or 99%.

Although MSHA interprets the Mine Act as requiring $\mu \leq S$ on each shift at any location to which a miner in the active workings is exposed, citations for noncompliance are intended to apply only to the shift and location sampled. Therefore, MSHA makes no assumption regarding the relative frequency distribution of μ from shift to shift. This is consistent with the concept of defining the confidence level according to the scenario most susceptible to an erroneous determination under the null hypothesis. However, the resulting confidence level for citing when $X \geq c$ really applies only to the hypothetical case most susceptible to erroneous citation.

In reality, so long as μ falls below S on some shifts, α will be smaller than 0.01. The further μ falls below the applicable standard, and the more shifts on which this occurs, the less likely it becomes that measurement error alone (ε) will be great enough to cause $X \geq c$ on a shift randomly selected for inspection. For example, if S = 2.0 mg/m^3, then c = 2.33 mg/m^3.

Therefore, if $\mu = 1.8$ mg/m^3, a citation would be issued only if $\varepsilon \geq c - \mu$. An $\varepsilon \geq 0.53$ mg/m^3 (resulting in $X \geq 2.33$ mg/m^3) amounts to a measurement error greater than 29 percent of the true dust concentration. If the sample is valid, then the probability of such an occurrence (given that CV_{total} = 6.6% at $\mu = 1.8$ mg/m^3) is less than 4 per million. This illustrates the general point that $Prb\{X \geq c | \mu\}$ can be far less than 0.01 when $\mu < S$.

Since $Prb\{X \geq c | \mu\}$ is smaller the further μ falls below S, $Prb\{X \geq c | \mu \leq S\}$ depends on the probability distribution of μ. This probability distribution is expressed by the relative frequency with which μ assumes each possible dust concentration at or below S. If μ falls substantially below the applicable standard on many shifts, then many of the corresponding values of $Prb\{X > c | \mu\}$ averaged into the calculation of α should be much smaller than 0.01, as shown by the foregoing example. Consequently, in a mining environment where the dust concentration is usually well below the applicable standard, α can reasonably be expected to fall substantially below its maximum possible value.

The number of erroneous citations expected (N_α), is obtained by first multiplying the total number of production shifts during the period of interest by the expected proportion of these shifts for which $\mu \leq S$. This proportion is $1 - P$. The result is the number of production shifts expected to be in compliance at the sampling location. This must then be multiplied by α to calculate N_α.

In Case 1, which is based on real sampling data (submitted by commenters), $E\{\mu\}$ is 1.66 mg/m^3 and $SD\{\mu\}$ is 0.70 mg/m^3. As mentioned earlier, P is expected to be 0.25 in this case. This distribution results in a negligible probability of citing when the mine atmosphere sampled is in compliance: $\alpha = 0.00012$. If 10,000 production shifts are sampled in this type of environment, 7500 of these would be expected to be in compliance at the sampling location. Approximately one of these 7500 samples (i.e., $7500 \bullet \alpha$) would be erroneously cited.

In Case 2, which is meant to represent a more controlled mining environment, less than one percent of the shifts are expected to exceed the standard: P = 0.0037. Furthermore, μ can be expected to fall below the geometric mean of 1.18 mg/m^3 on about half of the shifts. Therefore, α is even smaller than in the first case: $\alpha = 0.0000079$. Out of 10,000 sampled shifts, 9963 would be expected to be in compliance. Since $9963 \bullet \alpha$ is less than 0.1, it is unlikely that any of these shifts would be cited erroneously.

Case 3 is meant to represent a poorly controlled mining environment, in which $E\{\mu\}$ exceeds the applicable standard and the coefficient of variation in shift-to-shift dust concentrations is a relatively high 60% (i.e., $1.32 \div 2.20$). The geometric mean, however, falls slightly below the applicable standard, so μ is expected to fall below the applicable standard on more than 50% of the shifts. The noncompliance fraction is expected to be P = 0.46. Also, because of the high shift-to-shift variability, μ is not very close to its geometric mean on most shifts, and a fairly large percentage of shifts can be expected to experience μ well below the standard. The probability of citing when the mine atmosphere is in compliance is: $\alpha = 0.00015$. If 10,000 of shifts in this environment are sampled, then 5400 of these shifts would be expected to comply with the applicable standard at the sampling location. As in Case 1, an erroneous citation would be expected on about one of these shifts.

2. $\alpha^* = Prb\{\mu \leq S \text{ and } X \geq c\}$

The probability of erroneous citation can also be defined unconditionally. The second way of interpreting this risk represents the proportion of all measurements expected to result in an erroneous citation. Let $\alpha^* = Prb\{\mu \leq S \text{ and } X \geq c\}$ be the probability that a shift and/or mine atmosphere randomly selected for inspection is in compliance but, because of measurement error, is nevertheless cited. For an erroneous citation to occur, two events must take place: first, the atmosphere sampled must be in compliance ($\mu \leq S$); second, a measurement error must occur of sufficient magnitude that a citation is issued ($X \geq c$). The probability that a randomly selected shift will be in compliance is $Prb\{\mu \leq S\} = 1-P$. The probability of citation, given compliance on the sampled shift, has already been quantified above as $Prb\{X \geq c|\mu \leq S\} = \alpha$. The probability that both events occur is the product of these two probabilities—i.e.,

$$Prb\{\mu \leq S \text{ and } X \geq c\} = Prb\{\mu \leq S\} \bullet Prb\{X \geq c|\mu \leq S\}$$

Therefore, $\alpha^* = (1-P) \bullet \alpha$.

If the applicable standard is exceeded on all shifts, it is exceeded on the shift sampled, so there is no chance of erroneously citing that shift: i.e., P = 1, so $\alpha^* = (1-1) \bullet \alpha = 0$. At the opposite limit, if the applicable standard is never exceeded, then P = 0 and $\alpha^* = \alpha$. Between these two extremes, α^* decreases as the noncompliance fraction P increases, so that α^* is always less than α. To get the number of erroneous citations, α^* is simply multiplied by the number of shifts sampled. This always gives an identical result for N_α as that obtained from multiplying the number of compliant shifts by α.

In Case 1, P = 0.25. Therefore, the probability of erroneously citing a randomly selected shift is $\alpha^* = 0.75 \bullet \alpha = 0.00009$, or about nine in 100,000. If 10,000 shifts are sampled, then $10{,}000 \bullet \alpha^*$ gives the same number of erroneous citations as α multiplied by the 7500 compliant shifts expected in this case.

In the relatively well-controlled environment exemplified by Case 2, dust concentrations on most shifts generally fall well below the standard. Only occasional excursions approaching or (rarely) exceeding the standard occur, so P is near zero. Therefore, α^* is only slightly smaller than α. Since P = 0.0037, $\alpha^* = 0.9963 \bullet \alpha$. In this environment, the chance of erroneously citing a randomly selected shift is less than one in 100,000.

In Case 3, the noncompliance fraction is much greater: *P* = 46%. Therefore, α^* is substantially smaller than α. In this environment the probability of erroneously citing a randomly selected shift is $\alpha^* = 0.00008$, or about eight in 100,000.

3. $\alpha° = Prb\{\mu \leq S|X \geq c\}$

Finally, the risk of an erroneous citation can be interpreted as the probability, given a measurement of sufficient magnitude to warrant citation ($X \geq c$), that the dust concentration measured actually complies with the standard ($\mu \leq S$). Let $\alpha° = Prb\{\mu \leq S|X \geq c\}$ denote this probability, which represents the expected proportion of all citations issued because of measurement error. If any particular citation, based on a valid single, full-shift measurement, is selected for scrutiny, then $\alpha°$ is the probability that this citation is erroneous. Using the definition of conditional probability:

$$\begin{aligned}\alpha^o &= Prb\{\mu \leq S|X \geq c\} \\ &= \frac{Prb\{\mu \leq S \text{ and } X \geq c\}}{Prb\{X \geq c\}} \\ &= \frac{\alpha^*}{Prb\{X \geq c \text{ and } \mu \leq S\} + Prb\{X \geq c \text{ and } \mu > S\}} \\ &= \frac{\alpha^*}{\alpha^* + Prb\{X \geq c|\mu > S\} \cdot Prb\{\mu > S\}} \\ &= \frac{\alpha^*}{\alpha^* + P \cdot Prb\{X \geq c|\mu > S\}}\end{aligned}$$

$Prb\{X \geq c|\mu > S\}$ represents the power of the citation criterion to identify cases of noncompliance when they actually occur. This probability is calculated as follows:

$$Prb\{X \geq c|\mu > S\} = \int_S^\infty \frac{Prb\{X \geq c|\mu\}}{P} f(\mu)d\mu$$

When the distribution of dust concentrations is such that the applicable standard is rarely exceeded (i.e., when *P* is near zero), the denominator in the expression for $\alpha°$ namely

$$Prb\{X \geq c\} = \alpha^* + P \cdot Prb\{X \geq c|\mu > S\},$$

is only slightly greater than the numerator, α^*. This implies that $\alpha°$ is not constrained to be smaller than α or α^*. Since this situation arises in environments where the applicable standard is rarely exceeded, such citations will not often be issued. However, when one is issued, the probability that it is erroneous can exceed α.

For example, in the relatively well-controlled environment exemplified by Case 2, α^* is 0.00000788, *P* is 0.00370, and $Prb\{X \geq c|\mu > S\} = 0.133$. Therefore, in this example, $\alpha° = 0.0158$, or about 1.6 percent. That is to say, 1.6 percent of the citations issued under these circumstances will be erroneous. This is considerably greater than α, which was earlier shown to equal only 0.00079 percent. However the expected proportion of measurements resulting in citation, given by $Prb\{X \geq c\}$, is only 0.000498, or 0.050%. Therefore, out of

10,000 shifts sampled, it is expected that only five would be cited. Since on average only 1.6% of these five citations would be erroneous, it is unlikely that the 10,000 samples would result in any erroneous citations.

Case 2 represents an environment in which the noncompliance fraction is less than one percent. In contrast, the noncompliance fraction in Case 3 is nearly 50%: $P = 0.458$. For this case, $\alpha = 0.000147$, $\alpha^* = 0.0000799$, and $\alpha^\circ = 0.000227$. The calculated value of Prb{X≥c} is 0.3513, so approximately 35 percent of all measurements would result in citation. Only about 0.027% of these citations, however, would be erroneous. Therefore, out of 10,000 shifts sampled in such an environment, 3513 citations could be expected; and only about one of these citations ($3513\alpha\bullet^\circ$) would be expected to be erroneous.

In Case 2, the probability (α°) that a given citation is erroneous is relatively high (though low enough to sustain a citation), but the probability of citing noncompliance in such an environment is very low. In Case 3, the probability of citation is more than 700 times higher, but α° is commensurately lower than in Case 2. Comparison of Cases 2 and 3 illustrates the general principle: as the noncompliance fraction *P* increases, the probability of citation increases but the probability that a given citation is erroneous decreases.

It is important to note that even in the well-controlled environment of Case 2, the probability that a given citation is erroneous (α°) remains substantially below five percent and far below 50 percent. Although environments even more well controlled could give rise to somewhat greater values of α°, the probability of citing in such environments would be even smaller than the probability in Case 2. If a citation is issued because $X > c$, then the probability that $\mu > S$ is simply $1 - \alpha^\circ$. This shows that in any particular instance where a citation based on a single, full-shift measurement is reasonably likely to be issued according to the CTV table, there would be compelling evidence that $\mu > S$.

V. Risk of Erroneous Failure to Cite

Use of the CTV implies that citations will be issued only when they can be issued with high confidence that the applicable standard has actually been exceeded on the shift sampled. On the other hand, failure to meet or exceed the CTV does not in itself imply compliance at a similarly high confidence level—even on the shift sampled, let alone continuously over any longer term. Because of limited resources, MSHA inspections are relatively infrequent and serve only to identify instances in which the rest of the dust control program has been ineffective. They cannot be relied upon to ensure continuous compliance.

It should be remembered, however, that MSHA does not rely exclusively on sampling by inspectors to ensure compliance. The MSHA inspection is only one element of the Agency's comprehensive health protection program, which includes mandatory implementation and maintenance by operators of effective dust control methods to control dust levels where miners normally work or travel. It also provides for periodic evaluation by mine operators of the quality of mine air and of the effectiveness of the operator's dust control system through operator bimonthly sampling. If they are not detected during an MSHA inspection, poorly controlled environments, which are out of compliance with the dust standard in a substantial fraction of instances, are likely to be detected during some other phase of the MSHA's enforcement program.

It should also be remembered that MSHA's new enforcement policy eliminates an important source of sampling bias due to averaging, as explained in Appendix A. Under the existing policy, measurements made at the dustiest occupational locations or during the dustiest shifts sampled are diluted by averaging them with measurements made under less dusty conditions. As shown by the SIP data, this practice has frequently caused failures to cite clear cases of excessive dust concentration.

1. $\beta = \text{Prb}\{X<c|\mu>S\}$

The complement of *power,* the probability of detecting cases of noncompliance when they occur, is the probability of erroneously failing to detect such cases. Let $\beta = \text{Prb}\{X<c|\mu>S\}$ be the probability that a citation will not be issued when the true dust concentration being measured exceeds the standard. This is the probability of what is commonly called Type II error for testing the null hypothesis that $\mu \leq S$. Since $\beta = 1 - \text{Prb}\{X\geq c|\mu>S\}$, the power of the citation criterion, formulated earlier as Prb{X≥c|μ>S}, can be used to calculate β. The expected number of erroneous failures to cite, N_β is obtained by multiplying β by the number of shifts for which $\mu > S$.

It is true that due to the high confidence level required for citation, β is greater than it would be if a citation were issued whenever $X > S$. In fact, setting the CTV to any value greater than S results in Prb{X<c|μ} potentially greater than 50 percent when a single dust concentration exceeding the standard is being measured. For example, if $\mu = 2.12$ mg/m³ and $S = 2.0$ mg/m³, then the CTV is $c = 2.33$ mg/m³. Since the probability distribution for X is centered on μ, any individual measurement is more likely to fall below the CTV than to exceed it. The probability of erroneously failing to cite in this instance, based only on a single measurement, would be $\text{Prb}\{X<2.33|\mu=2.12\} = 93$ percent.

Citing in accordance with the CTV table does not, however, necessarily result in $\beta > 50\%$. When more than one measurement is made during a single shift in the same general area of a mine, such as in the same MMU, the dust concentrations are correlated. This increases the chances that if μ exceeds the standard at one of the sampled locations, at least one of the measurements will meet the citation criteria. More importantly for the present discussion, however, the value of β depends on the distribution of μ even when only a single measurement is considered on each shift.

This is because the magnitude of β depends on the average magnitude of Prb{X<c|μ} over all those instances in which $\mu > S$. Although Prb{X<c|μ} exceeds 50 percent when $\mu < c$, it does not exceed 50 percent when $\mu > c$. Poorly controlled environments are likely to experience a significant number of shifts during which μ exceeds not only S but also the CTV. If these shifts ''outweigh'' those shifts on which $S < \mu \leq c$, then this will result in $\beta < 50$ percent.

On those shifts for which $\mu > S$, Prb{X<c|μ} exceeds 50% only when μ falls between S and c. In contrast, the range of potential values of $\mu>c$ is essentially unlimited, and Prb{X<c|μ} approaches zero as μ increases. Therefore, β is less than 50% whenever the distribution of μ is such that $\text{Prb}\{\mu>c\} > \text{Prb}\{S<\mu\leq c\}$. In a poorly controlled environment, μ is more likely to exceed the CTV than to fall into the relatively narrow interval between S and the CTV.

For example, in Case 1 the probability that μ exceeds $c = 2.33$ is 14.9 percent, whereas the probability that μ falls between S and c is only $P - 14.9 = 10.5$ percent. Therefore, in this environment, the probability of erroneously failing to cite an instance of $\mu > S$ works out to be somewhat less than 50 percent: $\beta = 1 - \text{Prb}\{X\geq c|\mu>S\} = 0.404$, or 40.4%.

For worse offenders, β is considerably smaller. In Case 3, $\text{Prb}\{\mu>c\} = 35.2\%$, whereas $\text{Prb}\{S<\mu\leq c\}$ is 10.6%. In this case, even though dust concentrations below the applicable standard are expected on a majority of shifts (as indicated by the geometric mean), β is calculated to be only 23.3%. Stated another way, if MSHA were to select 10,000 shifts in this environment, an expected 4580 of those shifts would be out of compliance. It is expected that on 76.7% of those 4580 shifts a single measurement would be sufficiently large to warrant citation.

There are inherent tradeoffs, not only between β and α, but also between β and the probability that a given citation is erroneous, $\alpha° = Prb\{\mu \leq S | X \geq c\}$. Decreasing the CTV in order to reduce β forces both α and α° to increase. Even if α remains below 50 percent, the effect on α° can be so great as to render some citations clearly unsustainable. In particular, setting the CTV at or near S could result in citations more likely than not to be erroneous. Circumstances in which this can occur are discussed in Appendix D. Use of the CTV, on the other hand, ensures that any given citation based on $X \geq c$ is more likely than not to represent a case of actual noncompliance (i.e., $\mu > S$).

Failure to issue a citation based on a single, full-shift measurement collected during an MSHA inspection does not imply failure to detect and correct a noncompliant condition in the context of MSHA's entire enforcement program. Those commenters expressing concern over the potential magnitude of β have largely ignored other means MSHA uses to protect miners from excessive dust concentrations relative to the longer term. As stated earlier in this notice, MSHA's health protection program provides for the implementation and maintenance by mine operators of effective methods to control dust concentrations where miners normally work or travel, as well as for periodic evaluation of the quality of mine air to which miners may be exposed and the effectiveness of the operator's dust control program through operator bimonthly sampling. Furthermore, MSHA intends to continue its long-standing practice of collecting additional measurements when the standard is exceeded by an amount insufficient to warrant citation at a high confidence level.

VI. Summary and Conclusions

Use of the CTV table is based on MSHA's need for sufficient evidence to issue a citation and show, by a preponderance of the evidence, that a violation occurred. The burden rests with MSHA to show that the applicable standard has in fact been violated on the particular shift cited. Accordingly, the CTV table is designed so that the risk of erroneously not citing is subordinated to the risk of erroneously issuing a citation. However, the probability of erroneously failing to cite a case of noncompliance at a given sampling location is less than 50 percent when the applicable standard is exceeded on a significant proportion of shifts at that location.

Three cases were used to illustrate the risk of erroneous enforcement determinations over a broad range of environmental conditions. The results calculated for each of the three cases considered are summarized in the following table.

Case	Probability (percent)						Average number of erroneous determinations (per 10,000 sampled shifts)	
	Prb{X>S}	Prb{X≥c}	α	α*	α°	β	N_α	N_β
1	25.51	15.14	0.0121	0.00903	0.060	40.4	0.9	1,026
2	0.53	0.05	.000791	.000788	1.581	86.7	.1	32
3	45.69	35.17	.0147	.00799	0.0227	23.3	.8	1,067

Based on this analysis, it can be concluded that application of the CTV table provides ample protection against erroneous citations. The probability (α) of issuing a citation when the mine atmosphere sampled is actually in compliance is constrained to fall below a maximum of five percent. This maximum defines the 95-percent confidence level claimed for any citation issued. The expected proportion (α*) of all valid samples resulting in an erroneous citation is constrained not to exceed α. In practice, both α and α* are expected to fall far below five percent in a broad range of mining environments.

Furthermore, even in an exceptionally well-controlled environment, where μ is very unlikely to exceed the applicable standard on any particular shift, the probability (α°) that a given citation is erroneous will also fall substantially below five percent. If a measurement exceeds the CTV, the probability that the standard has actually been exceeded is (1–α°). Therefore, any citation issued in accordance with the CTV table will be based on clear and compelling evidence that the standard has been exceeded on the particular shift sampled.

Although it is increased by the margin of error built into the CTV table, the probability (β) of erroneously failing to cite noncompliance using a single measurement is expected to be significantly less than 50 percent in mining environments where $\mu > S$ on a substantial percentage of shifts. For the example considered of a poorly controlled mining environment (Case 3), β was calculated to be about 23 percent. This means that on any given shift for which $\mu > S$, there would be a 77-percent chance that X would exceed the CTV, thereby warranting a citation. Despite the high confidence level required for single-sample citations, β is considerably less than 50 percent even in the better-controlled environment exemplified by Case 1. Although citing whenever $X > S$ would increase the probability of detecting conditions of excessive dust concentration, Appendix D shows that doing so instead of using the CTV table could result in citations under conditions of probable compliance. As shown by the small values of α° in the table above, use of the CTV table makes it very unlikely that this would happen.

Moreover, poorly controlled environments are likely to be detected and cited during some other phase of MSHA's enforcement program even if they are not immediately cited on a particular MSHA sampling inspection. Regardless of the value of β, it can safely be concluded that the risk of failing to detect excessive dust is lower under MSHA's new enforcement policy than under existing procedures, in which measurements of high dust concentration are diluted by averaging.

Appendix D—Consequences of Eliminating the Margin of Error

Several commenters objected to the emphasis placed on avoiding erroneous citations and took issue with MSHA's intention to cite noncompliance only when indicated at a high confidence level. These commenters proposed that it is unfair to limit citations to cases in which a measurement (X) meets or exceeds some critical value (c) greater than the applicable standard (S). They argued that such an approach unfairly exposes miners to a far higher probability of wrongly failing to cite than the maximum probability specified for wrongly citing. Their recommendation was to divide the burden equally between proving noncompliance and ensuring compliance. They maintained that if X exceeds S by an arbitrarily small amount, noncompliance is more likely than compliance and that under such circumstances a citation should be issued.

Using notation explained in Appendix C, $X = \mu + \varepsilon$, where ε is a random, normally distributed measurement error whose standard deviation is $\sigma=\mu \cdot CV_{total}$. CV_{total} is given by the formula presented in Appendix C. A citation based on a single, full-shift measurement applies specifically to the shift and location sampled, and hence to a distinct value of μ. For the citation to be upheld, the preponderance of evidence must indicate that $\mu > S$ at one or more of the sampling locations on the cited shift.

Those commenters who maintained that a citation should be issued whenever $X > S$ all assumed (1) that a citation could withstand legal challenge so long as noncompliance is more likely than compliance, even if the probability of compliance is nearly 50 percent; and (2) that if $X > S$, then noncompliance is more likely than compliance. Aside from the question of the legal validity of the first assumption (which equates preponderance of evidence with any probability greater than 50 percent), the second assumption is not always true. Specifically, the second assumption fails to hold in relatively well-controlled environments or in cases where more than one measurement is used to check for noncompliance. Commenters making this assumption confused $\mathrm{Prb}\{X>S|\mu\le S\}$ with $\mathrm{Prb}\{\mu\le S|X>S\}$ and also failed to consider citations based on the maximum of several measurements.

I. Well-controlled Environments

In a relatively well-controlled environment, where μ is generally below the applicable standard, the probability that $X > S$ due to a large value of ε can exceed the probability that $X > S$ due to $\mu > S$. If $X < c$ and sampling records indicate that the environment is relatively well-controlled, the preponderance of evidence may support $\mu \le S$ on the particular shift sampled.

For example, suppose a citation is based on a single, full-shift measurement that barely exceeds S=2.0 mg/m³, but dust sampling records for the environment indicate a pattern of dust concentrations resembling Case 2 in Appendix C. That is to say, the statistical distribution of μ is lognormal, with arithmetic mean and standard deviation of 1.2 mg/m³ and 0.24 mg/m³, respectively. As in Appendix C, let $f(\mu)$ denote the lognormal probability density function. Then the probability that $\mu\le S$, given a single full-shift measurement that falls between S and c, is:

$$\begin{aligned}
\mathrm{Prb}\{\mu \le S | S < X \le c\} &= \frac{\mathrm{Prb}\{S < X \le c \text{ and } \mu \le S\}}{\mathrm{Prb}\{S < X \le c\}} \\
&= \frac{\int_0^S \mathrm{Prb}\{S < X \le c|\mu\} f(\mu)\,d\mu}{\int_0^\infty \mathrm{Prb}\{S < X \le c|\mu\} f(\mu)\,d\mu} \\
&= \frac{0.00252}{0.00481} \\
&= 0.52\%.
\end{aligned}$$

In other words, when X falls between S and c in this environment, there is a 52-percent chance that the standard has not actually been exceeded. It is more likely that $X>S$ due to a large measurement error than because μ itself has exceeded the applicable standard. It would be unreasonable to cite noncompliance in such situations. By citing when and only when $X\ge c$, the probability that $\mu\le S$ is reduced to α°=1.5%, as shown for Case 2 in Appendix C.

II. Multiple Samples

Proponents of citing whenever $X>S$ based their argument on a premise of symmetry: since potential measurement errors (ε) are symmetrically distributed around μ, they assumed that citing when $X=S$ would result in equal probabilities of erroneously citing and erroneously failing to cite. From this, they argued that if $X>S$ by an arbitrarily small amount, the probability of erroneously failing to cite would exceed the probability of erroneously citing.

The symmetry argument for citing whenever $X>S$ fails to hold if, on a single inspection, more than one measurement is compared to the standard. In MSHA's dust inspection program, several measurements are routinely made on the same shift, within the same MMU. MSHA intends to use each of these measurements individually to determine noncompliance at the MMU. However, as described in the notice to which this Appendix is attached, no more than one citation will be issued based on single, full-shift measurements from the same MMU. The commenters advocating issuance of a citation whenever $X>S$ all endorsed such single-sample determinations. Since any of several measurements could warrant a citation against the MMU, the citation will be based, in most cases, on the maximum measurement taken in the MMU during the shift. If each of several measurements is compared directly to the applicable standard, then the symmetry assumed for citing whenever $X>S$ breaks down. The mistake of wrongly citing occurs when any one of the measurements exceeds the applicable standard because of a sufficiently large measurement error, but the mistake of wrongly failing to cite occurs only when each and every measurement is at or below the standard. Each additional measurement reduces the probability of erroneously failing to cite while increasing the probability of erroneously citing.

A few examples will be used to demonstrate how the premise of symmetric error probabilities breaks down when more than a single measurement is taken. These examples demonstrate that noncompliance determinations made by comparing so few as two measurements directly to the S can result in citations issued at a confidence level substantially below 50 percent.

Using I to index different valid measurements for the same MMU, let $\max\{X_i\}$ denote the maximum measurement, and let $\max\{\mu_i\}$ denote the maximum true dust concentration. Note that due to potential measurement errors, the maximum dust concentration does not necessarily correspond to the maximum measurement. For example, $\max\{X_i\}$ might be X_3 even though $\max\{\mu_i\}=\mu_2$. Since the object is to examine the consequences of citing whenever any of several measurements exceeds S by any amount, it will be assumed in these examples that the citation criterion is $\max\{X_i\}>S$ rather than $\max\{X_i\}>c$.

As in Appendix C, let α be the probability of citing under conditions of compliance, and let β be the probability of erroneously failing to cite. Then:

$$\alpha = \text{Prb}\{\max\{X_i\} > S \mid \max\{\mu_i\} \le S\} \text{ and } \beta = \text{Prb}\{\max\{X_i\} \le S \mid \max\{\mu_i\} > S\}.$$

For simplicity, suppose S=2.0 mg/m³. The following quantities will be used in the calculations:

μ (mg/m³)	CV_{total} (percent)	$\sigma=\mu\cdot CV_{total}$ (mg/m³)	Prb{X>2.0|μ} (percent)	Prb{X≤2.0|μ} (percent)
1.90	6.602	0.1254	21.3	78.7
1.99	6.596	0.1385	47.1	52.9
2.00	6.595	0.1319	50.0	50.0
2.01	6.595	0.1326	53.0	47.0

If exactly one measurement is taken and μ=1.99 mg/m³, then σ=0.1385 mg/m³. Using the standard normal probability distribution for ε/σ,

$$\begin{aligned}\alpha &= \text{Prb}\{X > 2.0 \mid \mu = 1.99\}\\ &= \text{Prb}\left\{\frac{X-1.99}{0.1385} > \frac{2.0-1.99}{0.1385}\right\}\\ &= \text{Prb}\left\{\frac{\varepsilon}{\sigma} > 0.0722\right\}\\ &= 47.1\%.\end{aligned}$$

On the other hand, if μ=2.01 mg/m³, then σ=.1319 mg/m³; so

$$\begin{aligned}\beta &= \text{Prb}\{X \le 2.0 \mid \mu = 2.01\}\\ &= \text{Prb}\left\{\frac{X-2.01}{0.1326} \le \frac{2.0-2.01}{0.1326}\right\}\\ &= \text{Prb}\left\{\frac{\varepsilon}{\sigma} \le -0.0754\right\}\\ &= 47.0\%.\end{aligned}$$

It is this approximate equality of α and β, for values of μ symmetrically falling below or above S=2.0 mg/m³ that motivates the premise of symmetric error probabilities.

Suppose now that two measurements are taken, and a citation is issued if either X_1 or X_2 exceeds S=2.0. Suppose further that μ_1=1.99 and μ_2=1.90. Then:

$$\begin{aligned}\alpha &= \text{Prb}\{\max\{X_i\} > S \mid \mu_1 = 1.99 \text{ and } \mu_2 = 1.90\}\\ &= 1 - \text{Prb}\{X_1 \le 2.0 \mid \mu_1 = 1.99\}\cdot\text{Prb}\{X_2 \le 2.0 \mid \mu_2 = 1.90\}\\ &= 1-(0.531)\cdot(0.789)\\ &= 58\%.\end{aligned}$$

Since a citation is justified if $\mu_i > S$ for any I, the greatest probability of wrongly not citing in a comparable case of noncompliance is obtained when μ_1=2.01 and μ_2 is held at 1.90. In that case:

$$\begin{aligned}\beta &= \text{Prb}\{\max\{X_i\} \le S \mid \mu_1 = 2.01 \text{ and } \mu_2 = 1.90\}\\ &= \text{Prb}\{X_1 \le 2.0 \mid \mu_1 = 2.01\}\cdot\text{Prb}\{X_2 \le 2.0 \mid \mu_2 = 1.90\}\\ &= (0.470)\cdot(0.787)\\ &= 37\%.\end{aligned}$$

This example illustrates the point that α can exceed β by a substantial amount when as few as two measurements are directly compared to the applicable standard. If μ_2 were actually 1.99, then the discrepancy would be even greater: α=72% and β=25%. Notice, furthermore, that in both cases, α would be greater than 50%. The confidence level at which a citation is issued depends on the maximum possible value of α. Therefore, when one measurement out of two marginally exceeds S, the confidence level at which a citation can be issued is less than 28% (i.e., 100% − 72%). Such a citation would be difficult to defend if challenged.

If five measurements are made, as is routinely done during MSHA inspections of an MMU, then citing whenever $\max\{X_i\}>S$ is even less defensible. The confidence level for a citation based on the maximum of five measurements is defined by the value of α when $\mu_i=S$ for all five values of I. Under these circumstances, the probability that at least one of the five measurements would exceed the applicable standard is:

$$\alpha = \text{Prb}\left\{\max\left\{X_i\right\} > S \middle| \mu_i = S \text{ for all } i\right\}$$
$$= 1-(0.5)^5$$
$$= 97\%.$$

Therefore, the confidence level at which a citation could be issued is only 3%. At the same time, the probability that none of the five measurements will exceed S is $\beta=(0.5)^5=3\%$, so the probability that a citation would be issued is 97%.

III. Conclusion

MSHA, along with other federal agencies, recognizes that in issuing citations, the burden rests with the Agency to show that a violation of the applicable standard occurred. Use of the CTV table will severely limit the risk of an erroneous citation, even when the true dust concentration being measured is exactly equal to or slightly below the applicable standard. If a single measurement falls between S and the CTV, then the measurement does not necessarily provide sufficient evidence of $\mu>S$ to support a citation. Consequently, MSHA cannot justify issuing a citation whenever a measurement exceeds the applicable standard by an arbitrarily small amount. Although citing whenever $X>S$ would result in a smaller probability (β) of erroneously failing to cite, and hence in a greater level of protection for the miner, doing so would result in citations that may not withstand legal challenge. However, as stated earlier in the notice, if the measurement exceeds the applicable standard but not the CTV, MSHA intends to target environments for additional sampling to confirm that dust control measures in use are adequate. These follow-up inspections, in conjunction with operator dust sampling and MSHA monitoring of operator compliance with approved dust control parameters, should further help to protect miners from excessive dust concentration.

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Dated: December 19, 1997.

J. Davitt McAteer,

Assistant Secretary for Mine Safety and Health.

Note: For the convenience of the user, notice document 97–33937 is being reprinted in its entirety because of numerous errors in the document originally appearing at 62 FR 68395–68420, December 31, 1997. Those wishing to see a listing of corrections, please call Patricia Silvey, Mine Safety and Health Administration, 703–235–1910.

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