Massachusetts Department of ENVIRONMENTAL PROTECTION

t e c h n i c a l u p d a t e

REVIEW DRAFT

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Significant Figures for Risk Characterization

1.0 Introduction

This update provides guidance on the number of significant figures appropriate for MCP risk characterizations. To date, the Department has published no written guidance on the number of significant figures appropriate for Exposure Point Concentrations (EPCs) and risk estimates. Practices for identifying the appropriate number of significant figures have varied. In recognition of the uncertainty inherent in the exposure and toxicity factors used to characterize risk, Method 1 Standards and Method 3 risk estimates have often been expressed as numbers with only one significant figure.

The number of significant figures in EPCs and risk estimates can have a significant impact on risk assessment conclusions and thus on contaminant concentrations left at sites. These impacts result from the process of "rounding" the calculated EPCs or risk estimates to obtain a specific number of significant figures for the final result. The fewer the significant figures, the greater the effect of rounding on the final risk estimate. Using too many significant figures in a risk estimate may imply a greater level of certainty than is justified. However, using too few significant figures may reduce the accuracy of the risk estimate.

A decision on the appropriate number of significant figures for MCP risk assessments must take into account both technical and regulatory considerations.

Section 2.0 of this Update provides a "Significant Figures Primer", which outlines general technical considerations relevant to the number of significant figures appropriate for measurements and calculations that incorporate them. Section 3.0 addresses regulatory and policy considerations. Section 4 provides the Department's recommendation to use two significant figures in MCP risk assessments.

2.0 Significant Figures Primer: Technical Consideration

2.1 Definitions

Significant figures in a numerical result of a measurement or calculation are those that are known with some reasonable degree of certainty, plus the first uncertain digit. The term "significant figures" (or significant digits) has been defined descriptively as "The digits of the decimal number beginning with the leftmost nonzero digit and extending to the right to include all digits warranted by the accuracy in measurement" (1). Table 1 offers examples of the number of significant figures represented by the decimal form of various numbers.

Table 1

Number of Significant Figures	Examples
One	0.3; 0.003; 3; 30000
Two	0.34; 0.0034; 3.4; 34000;
Three	0.347; 0.00347; 3.47; 34700;
Four	0.3478; 0.003478; 3.478; 34780

When the last zero or zeros of a number are significant, the number should be written in scientific notation. For example, if three digits in the number 240 are significant, the number should be written as 2.40×10^2. The practice of writing this number as 240.0 is discouraged, because it implies that four digits are significant.

2.2 Significant Figures in Measurement and Calculation Results

The number of figures used to communicate a measurement result expresses the uncertainty about that result (2,3). The correct number of significant figures in a measurement or a calculation result is obtained by "rounding" the number to eliminate all of the uncertain digits but one. Rounding to the correct number of significant figures ensures that the certainty about the final value is not overstated. The final digit is usually considered uncertain by $\pm$ 1 unless otherwise specified (2,3). Thus, a measured value reported as 2.33 indicates that the true value could actually be anywhere in the range of 2.32 to 2.34.

2.3 Rules for Reporting the Results of a Calculation with the Correct Number of Significant Figures

The number of significant figures in the results of mathematical operations should be consistent with the uncertainty in any input values that are based on

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measurements. The level of certainty in a calculated number is limited by the least certain measurement included in the calculation (2,4). The rule for determining the correct number of significant figures for the result of a calculation depends upon the operations used in the calculation. The rule for addition and subtraction is based on comparison of the absolute uncertainty, while the rule for multiplication and division is based on comparison of relative uncertainty (3). They are given as follows:

- When numbers having different numbers of significant figures are summed or subtracted, the result should be reported with only as many digits to the right of the decimal as the addend with the fewest digits to the right of the decimal. Thus, if a number with three digits after the decimal point is added to a number with no digits after the decimal point, the result is rounded so to have no digits after the decimal point. For example, 200 + 34.798 = 234.

- When values having different numbers of significant figures are multiplied or divided, the result should be reported with the number of digits as the factor with the fewest. Thus, if a number with two significant figures is multiplied by a number with four significant figures, the result should be rounded to two significant figures. For example 3.2 x 24.68 = 79 (rounded from 78.9760).

Exact numbers do not affect the number of significant figures in the result. Values considered exact numbers include counted numbers, defined numbers and simple fractions (2). Examples of exact numbers used in MCP risk calculations include:

- Frequency, duration and averaging period values.
- Conversion factors.
- Intake values such as 1 liter per day or 100 mg/day, which, while based on measurements reported in the scientific literature, are set by policy decisions.
- MCP risk limits.

2.4 Rules for Rounding to Correct Number of Significant Figures

Significant figures rounding rules are general rules for dealing with uncertainty of measured values themselves and with uncertainty in results of calculations that incorporate measured values. Significant figures rounding rules state that final calculated results should be rounded to the least number of significant figures for the values in the calculation. This means dropping of uncertain digits beginning on the right, except for the last uncertain digit to the left. Rules for rounding follow (2,3,):

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1. If the last digit to be dropped is 5 or greater, the last retained digit is increased by one.
2. If the last digit to be dropped is less than 5, the last remaining digit is left as it is.

These rules are consistent with current practice recommended by ORS, which specifies that if the last digit to be dropped is 5 or greater, the last remaining digit is increased by one.

Note that the application of significant figure rounding rules does not address the need for a conservative estimate of the arithmetic average (310 CMR 40.0926(3)) when calculating EPCs or a conservative risk limit when calculating Excess Lifetime Cancer Risk or Hazard Indices. As previously discussed, rounding a number that exceeds the risk limit may result in a value that does not exceed the limit and does not indicate the need for remediation.

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3.0 Policy Considerations

In a number of cases, rounding to one significant figure can have a significant effect on the result of the risk characterization resulting in both (1) a substantial decrease in the risk estimate or EPC used to characterize risk, and (2) a concomitant shift from an estimate that indicates a significant risk to one that indicates "no significant risk".

As an example, consider the effect of rounding on a calculated hazard index of 1.44:

- If two significant figures were used, the result would be rounded to 1.4, leading to the conclusion that the risk exceeds the MCP hazard index limit of 1.
- If one significant figure were used, the result would be rounded to 1, leading to a conclusion that the risk does not exceed the MCP hazard index limit of 1.

This example demonstrates that the use of one significant figure can lead to a conclusion of "no significant risk" even when the calculated risk estimate is almost 50% higher than the risk limit[1]. Note that the same rounding effect occurs when comparing site concentrations with values of 1.4, 14, 140 or 1400 to Method 1 Standards with values of 1, 10, 100, or 1000 respectively.

The appropriate number of significant figures for Method 3 risk estimates is ultimately a policy decision, which should take into account program objectives and practical considerations in addition to the uncertainty about the toxicity values and exposure factors used to estimate risk. A few of the toxicity

[1] The effect of rounding in this example is due to the use of one significant figure combined with the regulatory risk limit of "1 or below", as opposed to "below 1".

and exposure factors employed in risk calculations may be reasonably considered accurate to only one significant figure. Nevertheless, certain program and policy considerations warrant the use of two significant figures rather than one. These include the MCP requirement of conservative exposure estimates, the central nature of environmental contaminant concentration measurements for both risk assessment and risk management, and the need for consistent application of "bright line" risk management criteria. Each of these program/policy considerations is discussed in more detail in the following bullet points:

- The MCP requires (at 310 CMR 40.0992(2)) that a conservative estimate of exposures be used to assess the impact of the release on human receptors. Rounding a risk estimate down by as much as 40% prior to comparing it to the risk limit may result in an underestimate of risk. This in effect runs contrary to the health protective intent and stipulations of the regulations.

- Contaminant concentration measurements are of central importance to the risk assessment and the ensuing risk management process, considering that:
  - In the risk assessment, measured concentrations are used to estimate the EPCs that link the receptor with the toxicity.
  - Site contaminant concentration data are often the only truly site-specific exposure factors used in the risk assessment.
  - In risk management activities, environmental concentrations are the sole focus of any cleanup efforts.

- Analytical results for environmental media are generally considered accurate to at least two significant figures. A discussion regarding significant figures in analytical data reporting was held at a 2008 MassDEP Air Phase Petroleum (APH) workgroup attended by representatives of several Massachusetts analytical laboratories. (Reference: Significant Figures in Laboratory Reporting, Memorandum, June 11, 2008.) Laboratories are generally reporting analytical data to two significant figures. Measuring devices including gas chromatographs, scales and syringes can deliver measurement results to at least two significant figures. Even simple rulers and pipets deliver two or more significant figures. There do not seem to be any laboratory measuring devices that deliver results to only significant figure.

- Rounding to only one significant figure could effectively negate a great deal of the information contained in concentration measurements. Rounding risk estimates to one significant figure diminishes the value of the information provided by the high-quality analytical data on which most risk assessments and risk management decisions are based.

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- The structure of MassDEP's the Waste Site Cleanup program calls for clear and consistent risk management criteria. Using one significant figure for risk estimates effectively establishes a risk range where the estimate is equal to the MCP risk limit (i.e. a hazard index of 1 to 1.4) rather than a clear "bright line" risk management criterion. In contrast, using two significant figures would mean that a calculated hazard index of 1.1 exceeds the MCP non-cancer risk limit of 1. Further, uncertainty among individual project managers about rounding and applying one significant figure for risk characterization decisions can lead to inconsistent practices among different sites.

In theory, the appropriate number of significant figures to use for the result of chemical analysis depends upon the chemical in question, the procedure used for the analysis and the magnitude of the result. Case-by-case decisions about significant figures for MCP risk assessments may be impractical though. Such an approach would place a large burden of QA/QC responsibility on investigators and audit staff. Laboratories do not follow one consistent practice when reporting results, and often report measured concentrations with too many figures, suggesting greater accuracy and certainty than is justified.

4.0 Recommendation

For risk characterization under the MCP, the Department recommends the use of two significant figures rather than one. More specifically:

- For Method 3 risk assessments, two significant figures should be used for the risk estimates (i.e., cancer risk estimates and hazard indices) that are compared with the MCP risk limits.
- For Method 1 risk assessments, two significant figures should be used for the EPCs that are compared with the Method 1 Standards.

5.0 Summary

For both Method 1 and Method 3 risk characterization under the MCP, the Department recommends the use of two significant figures. This recommendation is based on both technical and policy considerations. The uncertainty inherent in risk characterization is considerable, but there are policy considerations that warrant the use of two significant figures rather than one.

One major consideration in this recommendation is that analytical data is generally considered accurate to at least two significant figures. Analytical data is central to risk assessment and risk management under the MCP. It

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forms the basis for every step of the process, from reporting to site assessment to remediation. Using only one significant figure may lead to lost information and in some cases decisions that are not consistent with the level of protection prescribed by the MCP.

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