GUIDANCE FOR

METHODS DEVELOPMENT

AND

METHODS VALIDATION

FOR THE

RCRA PROGRAM

PREFACE AND OVERVIEW

Test Methods for Evaluating Solid Waste, or SW-846, is the compendium of analytical and test methods approved by EPA's Office of Solid Waste (OSW) for use in determining regulatory compliance under the Resource Conservation and Recovery Act (RCRA). SW-846 functions primarily as a guidance document setting forth acceptable, although not required, methods to be implemented by the user, as appropriate, in responding to RCRA-related sampling and analysis requirements.

There seems to be an impression among methods developers and the regulated community that there is some esoteric or mystical process that must be followed in order to get an analytical method "approved" by regulatory agencies like the USEPA. In this document, OSW would like to dispel these misconceptions, identify some basic principles, and present a logical approach to methods development that is currently followed by OSW in developing methods for SW-846. This approach is based on sound scientific principles, and methods developed according to this process should be acceptable for use in other Agency programs as well as OSW.

Two levels of methods development are covered in this guidance document, initial "proof of concept" and a formal validation. This guidance is applicable to both new methods submitted for potential inclusion in SW-846 or for adapting existing SW-846 methods for additional applications. When measurements for RCRA applications are required for which no validated methods exist, e.g., from unusual matrices or below the quantitation limits of conventional SW-846 or other appropriate methods, qualified analysts can serve as "in-house" methods developers to modify existing methods to meet these regulatory needs following the guidelines delineated in Elements 1 through 9.

The RCRA method development approach utilizes three basic principles for either demonstrating "proof of concept" or for use in a formal validation. These basic scientific principles are:

1) **Identify the scope and application of the proposed method, (What is this method supposed to accomplish?)**

2) **Develop a procedure that will generate data that are consistent with the intended scope and application of the method, and**

3) **Establish appropriate quality control procedures which will ensure that when the proposed procedure is followed, the method will generate the appropriate data from Step 2 that will meet the criteria established in Step 1.**

In some cases, such as a variation of an existing SW-846 method using new equipment or a modified procedure, it is sufficient only to demonstrate validation to the "proof of concept" stage. For new technologies to be considered for inclusion in SW-846, it is necessary for the developer to perform the formal validation procedure including multilaboratory validation.

DEVELOPMENT AND

VALIDATION OF

SW-846 METHODS

PHASE 1:

PRELIMINARY VALIDATION

OR

DEMONSTRATION OF

"PROOF OF CONCEPT"

DEVELOPMENT AND VALIDATION OF SW-846 METHODS
PHASE 1: PRELIMINARY VALIDATION OR "PROOF OF CONCEPT"

The two documents included in this section are letters that were requested by potential methods developers on how to begin a methods development project for submission to OSW for inclusion in SW-846. One letter (dated April 6, 1992) addresses a preliminary validation or "proof of concept" for new sample preparation methods, while the other (dated April 23, 1992) addresses a preliminary validation or "proof of concept" for new screening methods.

A shortened list of target analytes, representative of typical RCRA analyte classes for volatile organics, semivolatile organics, pesticides, and metals were included. These target analyte lists provide a range of target analyte performance within existing methods. The idea in this preliminary stage was that if the potential new method could successfully analyze the target analyte lists included in these documents, it had potential applicability to successfully analyze the compounds on the extended RCRA target analyte lists. These guidance documents also recommend using multiple matrices, e.g., groundwater, TCLP leachate, and wastewater for aqueous matrices, sand, loam, and clay for soil matrices, and multiple spiking concentrations to demonstrate appropriate method performance.

If a new technique performs adequately in this "proof of concept" phase, it is ready for the formal validation process. In this way, by doing a preliminary method development screening, the developer can easily determine if it is worth continuing to invest in a project without a large outlay of time or money.

In some cases, e.g., development of alternative equipment for an existing method, this preliminary validation may be all that is necessary to demonstrate adequate method performance for the intended method application.

April 6, 1992

Dear Colleague:

The Methods Team of the Office of Solid Waste is responsible for the promulgation of rugged and reliable analytical techniques in support of the Resource Conservation and Recovery Act (RCRA) program. The methods published in Test Methods for Evaluating Solid Waste, SW-846, are used to measure the concentration of specific pollutants or to establish whether a waste stream demonstrates a hazardous characteristic (e.g. ignitability, corrosivity, reactivity or toxicity).

A number of sources have developed new methods for preparing samples that could have application for the RCRA program. The U.S. EPA is eager to adopt any new techniques that provide high quality data in a reliable, reproducible and cost-effective manner. This letter provides developers with a description of the type of performance data that is required for an effective initial evaluation of new SW-846 methods. If a developer's data supports adoption of a new method, the Methods Team will work through the SW-846 Work Group process to promulgate it. This letter does not supersede or replace the more rigorous requirements described in Test Method Equivalency Petitions, EPA/530-SW-87-008, OSWER Policy Directive No. 9433.00-2 (2/87). That document provides the requirements for a method equivalency petition which may be used to promulgate a method outside of the Work Group process.

In order to evaluate the performance of sample preparation procedures, data should be submitted for samples prepared using the proposed technique, and analyzed using approved SW-846 quantitative methods. Widely used, multi-analyte procedures such as Method 8270 (GC/MS for semi-volatiles), Method 8081 (GC/ECD for organochlorine insecticides), Method 8260 (GC/MS for volatiles), or Method 6010 (ICP/AES for metals) should generally be employed. New sample preparation techniques need not be validated for the entire target list of a multi-analyte method, but a representative selection of targets should be measured. Examples of representative target analytes and some of the rationale for selecting them are provided in the attachments.

Developers should analyze three different types of matrices. Samples that are analyzed should either be characterized reference materials or spiked matrices containing known amounts of target analytes. In either case, bulk samples should be carefully homogenized to reduce sub-sampling errors. The sample matrices should be selected to represent what is regulated under RCRA (e.g. soil, oily waste or waste waters), not to provide the best performance data. Blanks should be analyzed with each set of samples.

Method performance is established by analyzing seven replicate aliquots of three different sample matrices spiked at two concentrations. Suggested spiking levels are 5 times the lower quantitation limit for the preparation/analysis method and 50 times the low concentration. As an alternative, specific concentrations for selected target analytes in soil are

provided in the attachments to this letter. The low values are normal reporting limits for routine analyses and the high value is 50 times the low. Recovery, precision, and matrix method detection level must be calculated. Method bias (accuracy) is determined at both concentrations by calculating the mean recovery of the spiked (or characterized) analytes for the seven replicates.

$$\text{bias} = \frac{\bar{x}}{X} \times 100\%$$

$\bar{x}$ = Mean value for the seven replicate determinations

X = Spiked or characterized concentration

Method precision is determined by calculating the percent relative standard deviation of the spiked analyte recoveries for the seven replicates at each concentration.

$$\text{precision} = \frac{s}{\bar{x}} \times 100\%$$

$\bar{x}$ = Mean value for the seven replicate determinations

s = Standard deviation for the seven replicates

The U.S. EPA requires methods that provide reliable measurements at or below regulatory action levels. The lowest level at which accurate quantitation can be attained must be determined for each matrix. To determine the Reliable Quantitation Limit (RQL), the Method Detection Limit (MDL) is first calculated from the low concentration s determined from seven replicate measurements (six degrees of freedom):

$$\text{MDL} = 3.143\ \sigma$$

The RQL is calculated using the following equation:

$$\text{RQL} = 4\ \text{MDL}$$

To summarize, the Methods Team does not require an unreasonable body of data for the initial evaluation of new techniques. With the additional requirement of one blank per matrix, 45 samples will have to be prepared and analyzed to complete the table below.

Type of sample	bias	precision	MDL	RQL
Matrix 1, low				
Matrix 1, high				
Matrix 2, low				
Matrix 2, high				
Matrix 3, low				
Matrix 3, high				

It is our belief that completion of this table represents only a small fraction of a developer's effort in developing a new method. If your technique will improve the quality of EPA monitoring programs, submitting these data should expedite the SW-846 approval process.

I look forward to working with you on this important activity.

Sincerely,

Barry Lesnik
Organic Methods Program Manager
USEPA Office of Solid Waste
Methods Team (5307W)

attachments

REPRESENTATIVE ORGANOCHLORINE PESTICIDES

The following chlorinated pesticides from the Best Demonstrated Available Technology (BDAT) list are representative of analytes for Method 8081. All should be sufficiently resolved to ensure good quantitation using two columns such as the DB-608 or DB-1701 (or equivalents). Suggested low and high concentrations should be appropriate for relatively uncontaminated solid matrices such as soil. Higher concentrations may be required for highly contaminated samples.

COMPOUND	LOW (μg/kg)	HIGH (μg/kg)
Aldrin	5	250
β-BHC	5	250
δ-BHC	5	250
γ-BHC (Lindane)	5	250
α-Chlordane	5	250
γ-Chlordane	5	250
4,4'-DDD	10	500
4,4'-DDE	5	250
4,4'-DDT	5	250
Dieldrin	5	250
Endosulfan I	5	250
Endosulfan II	5	250
Endrin	10	500
Endrin aldehyde	5	250
Heptachlor	5	250
Heptachlor epoxide	5	250

REPRESENTATIVE SEMIVOLATILE COMPOUNDS

The following compounds are representative of analytes for Method 8270. Although many of these compounds are considered difficult, all can be extracted from waste matrices using conventional techniques. Suggested low and high concentrations should be appropriate for relatively uncontaminated solid matrices such as soil. Higher concentrations may be required for highly contaminated samples. Phthalate esters are not spiked but should be reported as a measure of contamination.

COMPOUND	LOW (μg/kg)	HIGH (μg/kg)
Phenol	250	12,500
o-Cresol	250	12,500
2-Methyl phenol	250	12,500
2,4,6-Trichlorophenol	250	12,500
Pentachlorophenol	250	12,500
1,2-Dichlorobenzene	250	12,500
Naphthalene	250	12,500
2-Chloronaphthalene	250	12,500
Anthracene	250	12,500
Chrysene	250	12,500
Benzo(a)anthracene	250	12,500
Benzo(a)pyrene	250	12,500
Fluoranthene	250	12,500
Indeno(1,2,3-cd)pyrene	250	12,500
Benzo(g,h,i)perylene	250	12,500
o-Toluidine	250	12,500
p-Nitrotoluene	250	12,500
2,6-Dinitrotoluene	250	12,500
2-Nitroaniline	250	12,500
Di-n-propylnitrosamine	250	12,500
4-Bromophenyl phenyl ether	250	12,500
3,3'-Dichlorobenzidine	250	12,500

In addition, surrogates should be added such that 50 μg or 100 μg would be present in final extracts assuming 100% recovery.

Nitrobenzene-d_5	50
2-Fluorobiphenyl	50
p-Terphenyl-d_{14}	50
Phenol-d_6	100
2-Fluorophenol	100
2,4,6-Tribromophenol	100

REPRESENTATIVE VOLATILE COMPOUNDS

The following compounds are representative of analytes for Method 8260; many are TCLP analytes. All can be purged from waste matrices using Methods 5030 or 5035. Suggested low and high concentrations should be appropriate for relatively uncontaminated solid matrices such as soil. Higher concentrations may be required for highly contaminated samples.

COMPOUND	LOW (μg/kg)	HIGH (μg/kg)
Vinyl chloride	5	250
Dibromochloromethane	5	250
1,1-dichloroethane	5	250
Chloroform	5	250
Carbon tetrachloride	5	250
Trichloroethylene	5	250
1,1,1-Trichloroethane	5	250
Benzene	5	250
Toluene	5	250
Ethylbenzene	5	250
Chorobenzene	5	250
Nitrobenzene	5	250
Methyl ethyl ketone	5	250
Carbon disulfide	5	250

The following compounds are representative of non-purgeable volatiles which currently require azeotropic distillation. Suggested low and high concentrations should be appropriate for relatively uncontaminated solid matrices such as soil. Higher concentrations may be required for highly contaminated samples.

COMPOUND	LOW (μg/kg)	HIGH (μg/kg)
1,4-Dioxane	10	500
n-Butanol	10	500
iso-butanol	10	500
Ethyl acetate	10	500
Pyridine	10	500

REPRESENTATIVE METALS

The following metals include the TCLP analytes except mercury. Suggested low and high concentrations are based on ICP analysis and should be appropriate for relatively uncontaminated solid matrices such as soil. Higher concentrations may be required for highly contaminated samples.

ELEMENT	LOW (μg/kg)	HIGH (μg/kg)
Arsenic	**2500**	**75,000**
Barium	**100**	**5,000**
Cadmium	**200**	**10,000**
Chromium	**350**	**17,500**
Copper	**300**	**15,000**
Lead	**2000**	**100,000**
Silver	**350**	**17,500**
Zinc	**100**	**5,000**

Mercury is generally analyzed by cold vapor AA.

Mercury	**100**	**5,000**

April 23, 1992

Dear Colleague:

The Methods Team of the Office of Solid Waste is responsible for the promulgation of rugged and reliable analytical techniques in support of the Resource Conservation and Recovery Act (RCRA) program. The methods published in Test Methods for Evaluating Solid Waste, SW-846, are used to measure the concentration of specific pollutants or to establish whether a waste stream demonstrates a hazardous characteristic (e.g. ignitability, corrosivity, reactivity or toxicity).

SW-846 currently provides reliable and sensitive laboratory methods for the analysis of Appendix VIII analytes. However, some of these methods may be too costly or require too much analysis time for some applications. The Methods Team also recognizes the savings that could be achieved by sending only contaminated samples to analytical laboratories for quantitative analysis. Therefore, the Methods Team has recognized the need for more rapid, less expensive field screening procedures.

A number of sources have developed reliable, reproducible and cost-effective field or screening procedures with potential application for the RCRA program. This letter provides developers with a description of the type of performance data that is required for an effective initial evaluation of screening or field procedures. If a developer's data supports adoption of a new method, the Methods Team will work through the SW-846 Work Group process to promulgate it. This letter does not supersede or replace the more rigorous requirements described in Test Method Equivalency Petitions, EPA/530-SW-87-008, OSWER Policy Directive No. 9433.00-2 (2/87). That document provides the requirements for a method equivalency petition which may be used to promulgate a method outside of the Work Group process.

While screening procedures need not be fully quantitative, they should measure the presence or absence of target analytes at or below regulatory action levels. Therefore, initial demonstration of method performance involves measuring the percentage of false negatives and false positives generated using the procedure for a single sample matrix. Data should be submitted for split samples analyzed using the developer's technique and an approved SW-846 quantitative method. A candidate procedure should ideally produce no false negatives. Definition of a false negative is a negative response for a sample that contains the target analyte(s) at or above the stated action level of the method. A candidate procedure should produce no more than 10% false positives. Definition of a false positive is a positive response for a sample that contains the target analyte(s) below the stated action level of the method. Between 20 and 50 samples spiked at one half the detection level should be tested to establish the percentage of false positives. Between 20 and 50 samples spiked at twice the detection level should be tested to establish the percentage of false negatives. It is recommended that a sufficient volume of each spiked sample be prepared to complete each test with one lot of material. Sufficient randomly selected aliquots of each spiked matrix should be analyzed by

appropriate SW-846 methods to demonstrate sample homogeneity and to characterize the sample in terms of target analytes and potential interferences.

A separate study should also be conducted to establish the effect of non-target interferences. A screening procedure should produce no more than 10% false positives for a set of 20 samples that contains a 100 fold excess of interferences. Positive interferences should be selected that are chemically related to the target analytes and are environmentally relevant. Negative interferences (i.e. masking agents) should also be investigated whenever they are suspected.

Developers should also analyze three different types of samples to provide matrix-specific performance data. These samples should either be characterized reference materials or spiked matrices containing known amounts of target analytes. In either case, bulk samples should be carefully homogenized to reduce sub-sampling errors. The sample matrices should be selected to represent what is regulated under RCRA (e.g. soil, oily waste or waste waters), not to provide the best performance data. Blanks should be analyzed with each set of samples.

Matrix-specific performance data, including detection limits and dynamic range, are gathered by analyzing ten replicate aliquots of three different sample matrices spiked at two concentrations. If spiked samples are used, suggested spiking levels are the matrix-specific detection limit and 50 times the detection limit. Positive or negative results should be reported for the low concentration samples. Results for high concentration samples should be reported as either semi-quantitative results or as positive/negative with the dilution factor used for the samples. As an alternative to establishing matrix-specific detection limits, specific spiking concentrations are provided for selected target analytes in the attachments to this letter. The low values are normal reporting limits for routine analyses and the high value is 50 times the low concentrations. The Methods Team recognizes that it may not be appropriate to spike all of the target analytes listed within a chemical class.

If the developer has field data, the Methods Team would welcome the opportunity to compare the results obtained using the screening procedure with sample concentrations determined in a laboratory using SW-846 methods.

To summarize, the Methods Team does not require an unreasonable body of data for the initial evaluation of new techniques. Data will need to be submitted on the percentage of false negatives, percentage of false positives, sensitivity to method interferences, and matrix-specific performance data in order to complete the table below. In addition to these data, the developer should also provide a description of the procedure and a copy of any instructions provided with the test kits.

Type of sample	Number of samples	number of samples greater than the detection limit	number of samples less than the detection limit	semi-quantit-ative results/ dilution factor
False positive	20-50			
False negative	20-50			
Interference	20			
Matrix 1, low	10			
Matrix 1, high	10			
Matrix 2, low	10			
Matrix 2, high	10			
Matrix 3, low	10			
Matrix 3, high	10			

It is our belief that completion of this table represents only a small fraction of a developer's effort in developing a new method. If your technique will improve the quality of EPA monitoring programs, submitting these data should expedite the SW-846 approval process.

I look forward to working with you on this important activity.

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COMPOUND	LOW (μg/kg)	HIGH (μg/kg)
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β-BHC	5	250
δ-BHC	5	250
γ-BHC (Lindane)	5	250
α-Chlordane	5	250
γ-Chlordane	5	250
4,4'-DDD	10	500
4,4'-DDE	5	250
4,4'-DDT	5	250
Dieldrin	5	250
Endosulfan I	5	250
Endosulfan II	5	250
Endrin	10	500
Endrin aldehyde	5	250
Heptachlor	5	250
Heptachlor epoxide	5	250

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The following compounds are representative of analytes for Method 8270. Although many of these compounds are considered difficult, all can be extracted from waste matrices using conventional techniques. Suggested low and high concentrations should be appropriate for relatively uncontaminated solid matrices such as soil. Higher concentrations may be required for highly contaminated samples. Phthalate esters are not spiked but should be reported as a measure of contamination.

COMPOUND	LOW (μg/kg)	HIGH (μg/kg)
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Pentachlorophenol	250	12,500
1,2-Dichlorobenzene	250	12,500
Naphthalene	250	12,500
2-Chloronaphthalene	250	12,500
Anthracene	250	12,500
Chrysene	250	12,500
Benzo(a)anthracene	250	12,500
Benzo(a)pyrene	250	12,500
Fluoranthene	250	12,500
Indeno(1,2,3-cd)pyrene	250	12,500
Benzo(g,h,i)perylene	250	12,500
o-Toluidine	250	12,500
p-Nitrotoluene	250	12,500
2,6-Dinitrotoluene	250	12,500
2-Nitroaniline	250	12,500
Di-n-propylnitrosamine	250	12,500
4-Bromophenyl phenyl ether	250	12,500
3,3'-Dichlorobenzidine	250	12,500

In addition, surrogates should be added such that 50 μg or 100 μg would be present in final extracts assuming 100% recovery.

Nitrobenzene-d_5	50
2-Fluorobiphenyl	50
p-Terphenyl-d_{14}	50
Phenol-d_6	100
2-Fluorophenol	100
2,4,6-Tribromophenol	100

REPRESENTATIVE VOLATILE COMPOUNDS

The following compounds are representative of analytes for Method 8260; many are TCLP analytes. All can be purged from waste matrices using Methods 5030 or 5035. Suggested low and high concentrations should be appropriate for relatively uncontaminated solid matrices such as soil. Higher concentrations may be required for highly contaminated samples.

COMPOUND	LOW (μg/kg)	HIGH (μg/kg)
Vinyl chloride	5	250
Dibromochloromethane	5	250
1,1-dichloroethane	5	250
Chloroform	5	250
Carbon tetrachloride	5	250
Trichloroethylene	5	250
1,1,1-Trichloroethane	5	250
Benzene	5	250
Toluene	5	250
Ethylbenzene	5	250
Chlorobenzene	5	250
Nitrobenzene	5	250
Methyl ethyl ketone	5	250
Carbon disulfide	5	250

The following compounds are representative of non-purgeable volatiles which currently require azeotropic distillation. Suggested low and high concentrations should be appropriate for relatively uncontaminated solid matrices such as soil. Higher concentrations may be required for highly contaminated samples.

COMPOUND	LOW (μg/kg)	HIGH (μg/kg)
1,4-Dioxane	10	500
n-Butanol	10	500
iso-butanol	10	500
Ethyl acetate	10	500
Pyridine	10	500

REPRESENTATIVE METALS

The following metals include the TCLP analytes except mercury. Suggested low and high concentrations are based on ICP analysis and should be appropriate for relatively uncontaminated solid matrices such as soil. Higher concentrations may be required for highly contaminated samples.

ELEMENT	LOW (μg/kg)	HIGH (μg/kg)
Arsenic	**2500**	**75,000**
Barium	**100**	**5,000**
Cadmium	**200**	**10,000**
Chromium	**350**	**17,500**
Copper	**300**	**15,000**
Lead	**2000**	**100,000**
Silver	**350**	**17,500**
Zinc	**100**	**5,000**

Mercury is generally analyzed by cold vapor AA.

Mercury	**100**	**5,000**

DEVELOPMENT AND

VALIDATION OF

SW-846 METHODS

PHASE 2:

FORMAL VALIDATION

DEVELOPMENT AND VALIDATION OF SW-846 METHODS
PHASE 2: FORMAL VALIDATION

If a methods developer successfully demonstrates that the method appears to be applicable for its intended application(s) through the "proof of concept" stage, as described in the previous section of this document, OSW will then consider incorporating the proposed method into SW-846 after it has completed the formal validation process. The document included in this section describes OSW's formal validation process and documentation requirements for new methods submissions. Multilaboratory validation data is necessary for a method to be considered for inclusion in SW-846.

The document included in this section delineates OSW's basic approach to developing and validating analytical methods for the RCRA Program. It is based on the performance-based approach to RCRA regulatory policy, i.e., the generator must demonstrate the ability to measure the analytes of concern in the matrices of concern at the regulatory limits. It involves the same elements for method development that RCRA requires for a demonstration of analyst and method proficiency in the standard Quality Assurance Project Plans (QAPjP) described in Chapter One and the technique-specific methods, e.g., Method 8000 in SW-846.

The RCRA method development approach utilizes three basic principles:

1) **Identify the scope and application of the proposed method, (What is this method supposed to accomplish?)**

2) **Develop a procedure that will generate data that are consistent with the intended scope and application of the method, and**

3) **Establish appropriate quality control procedures which will ensure that when the proposed procedure is followed, the method will generate the appropriate data from Step 2 that will meet the criteria established in Step 1.**

A developer must also meet two other specific criteria before a method will be considered for inclusion in SW-846 are: 1) Is there either an existing or anticipated RCRA regulatory need for this method, and 2) Is it significantly different in principle or approach from existing SW-846 methods?

OSW has identified eleven key elements essential to a sound method development and validation effort. These are listed in Table 1 on the next page.

These principles should also be followed when an analyst uses the built-in flexibility of SW-846 to modify methods for particular applications. Qualified analysts should be considered as "in-house" methods developers (Elements 1 to 9) when measurements are to be made from unusual matrices or below the quantitation limits provided with conventional SW-846 or other appropriate methods.

Table 1: Key Elements for Regulatory Methods Development

Element 1:	**Identification of Scope and Application and Regulatory Need**
Element 2:	**QA/QC Requirements**
Element 3:	**Analytical Approach**
Element 4:	**Method/Instrument Sensitivity**
Element 5:	**Method Optimization and Ruggedness Testing**
Element 6:	**Accuracy, Precision and Repeatability (Clean Matrix)**
Element 7:	**Effect of Interferences**
Element 8:	**Matrix Suitability**
Element 9:	**Quantitation and Detection Limits**
Element 10:	**Laboratory Reproducibility (Multiple Operators and Multiple Laboratories)**
Element 11:	**Document Submission and Workgroup Evaluation**

METHODS DEVELOPMENT AND VALIDATION FOR THE RCRA PROGRAM

Introduction

There seems to be an impression among methods developers and the regulated community that there is some esoteric or mystical process that must be followed in order to get an analytical method "approved" by regulatory agencies like the USEPA. In this document, OSW would like to dispel these misconceptions, identify some basic principles, and present a logical approach to methods development that is currently followed by the Office of Solid Waste (OSW) in developing methods for SW-846. This approach is based on sound scientific principles, and methods developed according to this process should be acceptable for use in other Agency programs as well as OSW.

Basic Principles

The basic principles involved in analytical methods development are very simple adaptations of the scientific method and can be summarized in the following three steps:

1) **Identify the scope and application of the proposed method, (What is this method supposed to accomplish?)**

2) **Develop a procedure that will generate data that are consistent with the intended scope and application of the method, and**

3) **Establish appropriate quality control procedures which will ensure that when the proposed procedure is followed, the method will generate the appropriate data from Step 2 that will meet the criteria established in Step 1.**

Two other specific criteria that a developer must also meet before a method will be considered for inclusion in SW-846 as a separate method are: 1) Is there either an existing or anticipated RCRA regulatory need for this method, and 2) Is it significantly different in principle or approach from existing SW-846 methods? The rest of this document will provide more detail, including eleven key elements for methods development, and two examples of how this approach has been used successfully in the development of methods for SW-846.

The Nature of Regulatory Analysis

Regulatory analyses cover a wide variety of applications from regulatory compliance to informational data gathering. Some analyses are used to satisfy legal requirements, while others are used for monitoring of internal waste streams within a generator's facility.

Analyses used to determine the extent of contamination of a grossly contaminated site in the high ppm to low % range do not need to be performed with the same degree of precision and accuracy as analyses performed to demonstrate compliance with corrective action cleanup

levels in the low ppm to ppb range. Other factors to be considered in performing regulatory analyses include intended use of the data generated (i.e., project data quality objectives), method ruggedness and sensitivity, analyte/matrix interactions, laboratory performance, availability of equipment, and cost. All of these factors and more are taken into consideration when developing methods for regulatory purposes.

Key Elements for Regulatory Methods Development

Methods developers should address the following eleven elements, which are listed in Table 1, when developing methods for OSW and other regulatory programs:

1. Identification of Scope and Application and Regulatory Need

The key factor that a developer must establish before proceeding with a method development project is a clearly defined scope and application for the proposed method. Factors to be considered should include type of method, (i.e., screening or assay), applicable target analytes, appropriate matrices, sensitivity, bias and precision, availability of equipment, and cost. It is advisable to limit the scope of most potential new methods, because a method that works well for a few specific applications is usually much more useful (and marketable) than one which is marginal for a large number of applications. Also, remember that it is usually much easier to develop and market a method that is designed around commercially available equipment. Cost is also a significant factor in determining whether a method has potential utility and marketability. Very few laboratories are prepared to buy expensive equipment today when comparable methods will do an adequate job at a much more affordable cost.

When establishing the scope and application for a potential new method, it is essential that the method developer identify that there is a regulatory need for the method. This can be a current or anticipated program office regulatory requirement determined by the methods staff, a Regional need, or a need for a method improvement identified by calls to Agency information services such as the MICE line. A method may be scientifically elegant, but it has very little value if there is no application for its use in the regulatory program for which it is intended. For example, tissue samples and nutrients, e.g., ammonia and nitrate, are not usually of concern to the RCRA program. Therefore, methods addressing these matrices and analytes would be of low priority to OSW, although they may be of great interest to other Agency programs.

2. Quality Control Requirements

When developing a method, the developer needs to identify the appropriate quality control procedures that must be performed to unequivocally demonstrate that the data generated by the method will meet the objectives defined in the scope and intended application(s). General QC procedures for RCRA analyses can be found in Chapter One of SW-846. Technique-specific QC procedures are included in the overview methods in SW-846,

e.g., Method 8000 (Chromatography), Method 3500 (Extraction), Method 3600 (Sample Preparation for Volatile Organics), Method 4000 (Immunoassay) and Method 7000 (Atomic Absorption). Method-specific QC procedures are included in the Quality Control section of the individual methods. When an apparent contradiction between QC criteria occurs in SW-846, the order of precedence is as follows: method-specific QC criteria have precedence over technique-specific QC criteria which have precedence over Chapter One QC criteria.

Examples of QC factors include appropriate calibration or tuning criteria, the need for replicate analyses, appropriate surrogates, blanks and spikes. QC criteria specific to the particular method should be well-documented and included in the QC section of the method as well as the method development project report. General and technique-specific QC requirements should be included in the Quality Assurance Project Plan (QAPjP) during the planning stage and in the project report (Section 11).

3. Analytical Approach

In developing an analytical approach, the developer should keep in mind that the ultimate goal of the project is to develop a method that will be published for general use by the analytical community. Therefore, it is essential that any analytical instrumentation or equipment used in the development of the method needs to be commercially available to potential users at the time of the publication of the method. OSW encourages the use of either conventional or innovative technology, provided that it is demonstrated to be appropriate for the intended method application and provides data of sufficient quality to satisfy the criteria delineated in the scope of the method. OSW has been leading the effort to introduce new innovative analytical technologies to EPA's regulatory programs. Examples of new technologies first introduced in SW-846 include microwave digestion, potentiometric voltammetry, HPLC/MS, Immunoassay, Supercritical Fluid Extraction (SFE), and Accelerated Solvent Extraction (ASE). Those who criticize regulatory methods because they do not include innovative technologies are not aware of the level of review required for method promulgation.

In order to be considered for inclusion is SW-846, a method must be practical, i.e., has the potential for general use in the environmental analytical community, address a RCRA regulatory need, and be significantly different from existing SW-846 methods. Neutron Activation is a technique which has been used for analysis of metals for RCRA compliance. However, it is not an appropriate candidate for inclusion in SW-846 as a general-use method, since relatively few analytical laboratories have ready access to a nuclear reactor.

4. Method/Instrument Sensitivity

The method sensitivity requirements for a proposed new method are influenced by several factors. These include the instrument detection limits, method quantitation limits, and the regulatory requirements for the proposed applications. RCRA regulations basically require that an analyst demonstrate the ability to measure the analytes of regulatory concern in the matrices of concern at the regulatory levels. Therefore, a method must exhibit analytical

sensitivity appropriate for its intended application, as delineated in the scope of the method, before it will be considered for inclusion in SW-846. Many applications in the RCRA and other EPA programs do not require the use of methods at their extreme limits of instrument or method sensitivity. Pertinent performance information submitted in the methods package should include the instrument or method detection and quantitation limits, i.e., the minimum mass of analyte which can be quantitated (or detected, in the case of screening methods), the instrument or method calibration range for all target analytes, and information as to whether the calibrations are linear or non-linear (per the criteria in Method 8000). At this stage in the methods development process, the analyst should demonstrate the appropriate analytical parameters and procedure on clean standards of known concentration.

5. Method Optimization and Ruggedness Testing

After determining that the chosen analytical approach should work for its intended application with appropriate sensitivity, the method developer should begin to optimize the method and determine whether it possesses sufficient ruggedness to be considered for inclusion in SW-846. This is also accomplished using known standards.

The initial parameters should be chosen according to the analyst's best judgment. These are varied systematically (usually using Youden pairs as described in J. K. Taylor, Quality Assurance in Analytical Measurements) to obtain the greatest response, least interference, greatest repeatability, etc. Developers must determine those variables which should not be changed without adversely affecting method performance. Potential operator-sensitive steps, e.g., color development time in colorimetric methods or other timed reactions, also need to be identified at this stage.

6. Accuracy (Bias), Precision, Repeatability (or Long-term Precision) in a Clean Matrix

Accuracy, or in most cases method bias, is defined as nearness to the true value. Precision is defined as the dispersion of results around the mean value. Repeatability (or long-term precision) is defined as the ability to reproduce a measurement from one week to the next.

Bias is measured by determination of % recovery of target analytes spiked into the matrix of concern. An acceptable spike recovery range for most method development applications is from 80% to 120%. Precision is measured as relative % difference of target analyte concentration(s) between duplicates or duplicate spikes, and should usually be <20%. Repeatability is measured as long-term, e.g., weekly, precision, when the instrument is calibrated using comparable standards, and on a different day should not vary by more than 15%.

These are key method performance factors which determine how a method can be used in real world situations. The initial determination of bias, precision and repeatability should be made in a spiked clean matrix which is similar to a real environmental matrix, but free from interferences, e.g., reagent water, sand, soil (for inorganic methods), vermiculite or ash. These

values should be obtained using multiple replicates at both high and low spike concentrations. Guidance on bias and precision determinations and preliminary method evaluation for new sample preparation and screening methods is available from the Office of Solid Waste.

7. Effect of Interferences

The determination of method interferences, both positive and negative is a key factor in method development. It is a critical element in methods development for the developer to determine the effects of potential analytical interferences and to develop techniques to minimize or eliminate these interferences. In chromatographic methods, interferences include coeluting peaks and/or analyte degradation due to interaction with either the injector port, transfer line or column. In spectroscopic methods, interferences can result from overlapping spectral lines causing either positive or negative signal enhancement. In immunoassay methods, interferences include cross-reacting compounds.

Method interferences should be determined in a spiked clean matrix. Developers should determine the effects of interferences in a potential new method between target analytes and other compounds reasonably expected to be present in waste matrices.

False negative rates, i.e., the percentage that a method generates a negative result when the sample contains the target analytes at or above the action level and false positive rates, i.e., the percentage that a method generates a positive result when the sample contains the target analytes below the action level, are critical factors which will determine the utility of a potential method for its intended application.

Documentation of interferences should include any coelution of or with target analytes, any enhancement or suppression of target analyte signals caused by interferences, any necessary or optional cleanup procedures to minimize the effect of interferences, and any matrix-specific difficulties.

8. Matrix Suitability

The previous elements of the methods development process involved the use of either known standards or target analytes spiked into clean matrices, designed to indicate potential method performance in real RCRA matrices. Once the potential new method has passed all of the preliminary tests, it is now ready for the most important demonstration in the entire methods development process, i.e., how it will perform in the real world matrices for which it is intended to be used.

The method should be suitable for a variety of matrix types. Therefore, the developer should choose appropriate RCRA matrices for the demonstration of method performance. By matrix types, OSW refers to different matrices within a particular medium, e.g. water, soil and ash. Appropriate RCRA water matrices include groundwater, TCLP leachate and wastewater, while appropriate RCRA soil matrices include sand, loam and clay. Appropriate ash matrices

include bottom ash, fly ash and/or combined ash. The method should perform adequately in a variety of spiked matrices and then in a variety of well-characterized natural samples or standard reference materials (SRMs) when SRMs are available. Performance data including matrix, precision, bias, quantitation limits (see next section), and any other pertinent data should be documented in appropriate tables. A summary of the single-laboratory performance data should be included in tabular format in the method while the detailed performance data, including QC, should be included in the supporting document (Section 11).

9. Method Detection and Quantitation Limits

In a new method submission, OSW is most concerned about the performance of the method in the RCRA matrices of concern. The developer should generate estimated method quantitation (EQL) and method detection limits (MDL) for the analytes of concern in the matrices of concern following the guidelines established in Chapter One of SW-846. The practice of generating MDLs based on reagent water is not usually a very useful parameter for most RCRA methods.

Method detection and quantitation limits for a determinative method are usually based on a specific sample size and a specific sample preparation scheme. The limits determined in clean matrices indicate the limits of the acceptable performance for the method. Matrix effects may affect the achievable quantitation limits on real world samples. However, the method quantitation limits for the target analytes in the target matrices must meet the analytical requirements of the intended application, as defined in the scope of the method, before it can be considered for inclusion in SW-846. Quantitation limits for the target analytes in representative matrices should be included in summary tables in the methods, while the rationale for and details of the MDL and EQL concentrations should be included in the supporting document (Section 11).

10. Laboratory Reproducibility (Multiple Operators and Multiple Laboratories)

The final stage in the method development process, prior to the submission of the method for Agency review, is the determination of laboratory reproducibility. By reproducibility, OSW means that multiple operators and multiple laboratories should be able to obtain comparable performance data on split samples using the method. Since all of the previous elements involved single operators or single laboratories, it is necessary to demonstrate that satisfactory method performance is not limited to the individual operator or laboratory that developed the method.

The minimum number of laboratories that are needed to participate in a multilaboratory method validation is three, with preferably more. In previous years, when the Agency budget permitted, multilaboratory validations of new methods were funded by the Agency. Large numbers of laboratories were paid to participate in these studies with EPA doing the "data-crunching". Agency funding can no longer support these types of studies, so developers of new methods today need to do a limited multilaboratory evaluation and provide

the individual laboratory and summary performance data in the method submission. Developers are encouraged to consult with the appropriate regulatory agency when planning a multilaboratory study.

In order to minimize the number of variables involved in method validation, the developer needs to follow a few simple guidelines to demonstrate appropriate multilaboratory method performance. When validating a sample preparation method, the participating laboratories should only perform the sample preparation procedure. The collected samples should then be sent to one laboratory for analysis. The analysis should be done by a single operator on a single instrument in a single batch to minimize analytical variability inherent to the determinative method. Conversely, if a determinative method is to be validated, the developer should have a single operator perform all of the sample preparation operations in order to minimize operator and laboratory variability inherent to the sample preparative procedures. The sample extracts should then be split and sent to the laboratories participating in the validation study for the analytical determination.

11. Document Submission and Workgroup Evaluation

When the method project is completed, the developer must assemble a package of documents describing the project, and submit it to the Agency for review and evaluation. This documentation package should include 1) draft copies, both hard and electronic, of the method in an appropriate Agency format; 2) a supporting document describing the rationale behind the methods development effort and how the key elements of the methods development project as described in this document were addressed; 3) a data package containing both the raw and summarized single laboratory and multilaboratory data; 4) any specific equipment diagrams and chromatograms, spectra, etc. pertinent to the demonstration of appropriate performance for the intended application of the method; 5) copies of any references listed in the method; and 6) any method-specific quality control criteria.

The OSW Methods Team reviews the methods submission package for completeness and quality, and then decides whether the method is ready to be sent to the SW-846 Workgroup for review or back to the developer for additional work. OSW has several standing SW-846 Methods Workgroups which meet formally each July to review the methods packages submitted by developers for potential inclusion in SW-846. Workgroup members are Agency scientists from the EPA Program Offices, Regional Laboratories, Office of Research and Development (ORD), and the National Enforcement Investigations Center (NEIC) who evaluate the procedures and performance data submitted by the methods developers. Workgroup members provide the benefit of their own experience in performing and evaluating analyses. Workgroup comments address both the written method and the completeness of the performance data, other method documentation, and interpretation of the data. Methods which the Workgroups accept for inclusion in SW-846 are edited based on Workgroup comments. After editing, the OSW-Methods Team distributes them as draft methods until the SW-846 Update package of which they are a part is ready to be submitted for Agency approval through the official regulatory "notice and comment" process. The

supporting documentation for each method is then put into the RCRA Docket for public review immediately before the initial proposal of the new SW-846 Update package.

Conclusion

OSW believes that the information provided here clarifies the RCRA method development process. Qualified analysts should be considered as "in-house" methods developers (Elements 1 to 9) when measurements are to be made from unusual matrices or below the quantitation limits provided with conventional SW-846 or other appropriate methods. The need for such a demonstration of analyst/laboratory proficiency has been implicit in SW-846 Chapter One and Method 8000. These implicit requirements have been clarified and made explicit in Method 8000B, which is included in Update 3.

Practical Examples of Methods Developed Using the RCRA Validation Process

This section of the document provides two examples of methods developed for and included in Update 3 of SW-846. Example Number One is of a sample preparation method developed for use with existing SW-846 determinative methods. Example Number Two is of a screening method for determining the range of concentrations of PAHs in soils.

Example 1: Method 3545 - Accelerated Solvent Extraction (ASE)

The Accelerated Solvent Extraction Method (Method 3545) was developed by Dionex as a rigorous, rapid sample preparation method for extractable organic analytes in solid matrices using small quantities of solvent. The following paragraphs provide a brief overview of how Method 3545 was developed using the analytical approach discussed in this document:

1) **ASE was developed as a general-purpose, rigorous extraction procedure for RCRA extractable analytes amenable to the Soxhlet technique, either manual or automated, and with comparable performance. It also uses much less extraction solvent than the existing general-purpose techniques, thus helping to promote the Agency's policy of pollution prevention in analytical methods.**

2) **No method-specific QC procedures are necessary.**

3) **The analytical approach uses conventional solvents as the extraction fluid rather than supercritical CO_2, while utilizing the basic operations of supercritical fluid extraction (SFE), e.g., elevated temperature, elevated pressure, and minimum void volume. Dionex has demonstrated that these conditions provide a rigorous extraction of the target analytes from a solid matrix in minutes instead of hours.**

4) **The method sensitivity using standard determinative methods, i.e, Methods 8270, 8081, 8082, 8141, and 8151, is comparable to Soxhlet using the same sample size.**

5) **The method was optimized using about a 10-minute extraction with the appropriate extraction solvents for the target analytes, e.g., methylene chloride, hexane:acetone, etc., at a temperature of about 100°C and a pressure of about 2000 psi (a relatively low pressure for SFE). Sample size can be varied without changing the extraction conditions by varying the size of the extraction vessels used.**

6) **Recoveries (bias) in a sandy soil, a loam, and a clay were comparable to Soxhlet extraction, while precision (%RSD) was a little better than standard Soxhlet and about the same as Automated Soxhlet. Repeatability was not a problem.**

7) **ASE did not appear to generate any additional interferences other than those commonly encountered in Soxhlet procedures.**

8) **Method 3545 was validated in a variety of soil matrices ranging from sand to clay and demonstrated performance comparable to that of automated Soxhlet extraction. Due to time and cost factors, the method was not evaluated in other RCRA matrices. However, OSW believes that it should be appropriate for all RCRA matrices for which Soxhlet extraction is currently used, based on the performance data submitted with the method.**

9) **Quantitation and detection limits based on Method 3545 recovery data from soils for the standard determinative methods were comparable to those obtained using automated Soxhlet extraction.**

10) **The method was performed in three laboratories, all of which obtained acceptable results.**

11) **Method 3545 was reviewed by the SW-846 Organic Methods Workgroup in July, 1994, and was accepted for inclusion in Update 3 of SW-846. Dionex submitted a second documentation package containing performance data for additional analytes in November, 1994. Both reports are included in the RCRA Docket supporting Update 3.**

Example 2: Method 4035 - Screening Method for PAHs in Soil by Immunoassay

The PAH immunoassay method was developed by EnSys as a screening method for PAHs in soils at cleanup levels. It was the first method included in RCRA's second group of immunoassay methods accepted for inclusion in Update 3 of SW-846. The following paragraphs provide a brief overview of how Method 4035 was developed using the analytical approach discussed in this document:

1) **Method 4035 was developed as a screening method for PAHs containing 3- and 4-ringed PAHs at the nominal RCRA/CERCLA cleanup action level of 1 ppm. It was also one of a series of methods which addressed the Agency's need for low-cost, rapid, effective screening methods which could be used either on-site or in a fixed laboratory. The target false negative rate for screening methods is 0%, while the target false positive rate is 10%.**

2) **Standard QC requirements apply to immunoassay testing. However, there are some specific QC criteria for immunoassay methods which must be followed. These include 1) do not use test kits past their expiration date; 2) do not use tubes or reagents designated for use with other kits; and 3) use the test kits within the specified storage temperature and operating temperature limits.**

3) **The analytical approach used was an inverse colorimetric method utilizing a competitive antibody technique sensitive to the target PAHs, i.e., color was discharged when the target PAHs were present at or above the action level.**

4) **The sensitivity of the test is influenced by the binding of the target analyte to the antibodies used in the kit. The commercial PAH kit used for evaluation of this method is most sensitive to the three- (i.e., phenanthrene, anthracene, fluorene) and four- (i.e. benzo(a)anthracene, chrysene, fluoranthene, pyrene) ring PAH compounds listed in Method 8310, and also recognizes most of the five- and six-ring compounds listed. The method can be used for screening the target PAHs at various predetermined action levels down to 1 ppm.**

5) **Method 4035 (EnSys) was optimized for PAHs containing 3- and 4-ringed PAHs in a variety of soil matrices.**

6) **Screening data correlated >95% with the reference method used (Method 3540/8270) for the target analytes.**

7) **Interferences for immunoassay methods are referred to as cross-reactivity. The target compound for the EnSys PAH kit with a cross-reactivity of 1 was phenanthrene. The other 3- and 4-ringed compounds had similar responses. All of the 16 RCRA target compounds had a cross-reactivity within one order of magnitude of phenanthrene, except for naphthalene (200), dibenzo(a,h)anthracene and benzo(g,h,i)perylene (both >200). The kit was optimized to respond to three and four ring PAHs. The sensitivity of the test to individual PAHs is highly variable. Naphthalene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene have 0.5 percent or less than the reactivity of phenanthrene with the enzyme conjugate. The alkyl-substituted PAHs, chlorinated aromatic compounds, and other aromatic hydrocarbons, such as dibenzofuran, have been demonstrated to be cross-reactive with the immobilized anti-PAH antibody. The presence of these compounds in the sample may contribute to false**

positives.

8) The EnSys PAH kit was designed for use in soil matrices. It was demonstrated to be applicable to a cross-section of soil types from sand to loam to clay.

9) Method 4035 is designed to act as a screening method at a predetermined action level (usually 1 ppm). Using the test kit from which this method was developed, $\geq$95% of samples confirmed to have concentrations of PAHs below detection limits will produce a negative result in the 1 ppm test configuration.

10) Multiple field trials involving split samples were conducted at a power plant site and on a variety of well-characterized samples from Region 10 ranging in concentration from <0.1 ppm to >200 ppm. Several operators and laboratories participated in the studies. Actual false negative rates were <5%, while false positive rates ranged between 10 and 15%.

11) Method 4035 was reviewed by the SW-846 Organic Methods Workgroup in July, 1993, and was accepted for inclusion in Update 3 of SW-846. The method has been available in draft form from OSW since early in 1994. The original data submission package and the Region 10 study results are included in the RCRA Docket supporting Update 3.