
Testing Air-Purifying Chemical Respirator Cartridges: A Review of Options

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ABSTRACT

Due to a wide variety of applications many tests have been developed, published, and used to determine if air-purifying respirators and their cartridges (or canisters) for removing airborne chemicals meet government and manufacturing standards. Effectiveness is defined by efficiency of contaminant removal (protection factor) and duration (breakthrough time or service life). Although “There is no widely accepted, standard protocol for performing service life testing” (OSHA website 2017), the U.S. EPA has developed “Interim Recommendations for Determining Organic Vapor Service Life for NIOSH Approved Respirators” (1991, 1995, 2002) based on an earlier published testing protocol (Wood and Ackley 1989). This current article expands on these by describing laboratory and field testing options, advantages, limitations, and needs depending on testing objectives.

Keywords: Air-purifying respirator, cartridge, testing

INTRODUCTION

The Occupational Safety and Health Administration (OSHA) and U.S. Environmental Protection Agency (EPA, 1976) require companies to select, maintain and use respiratory protection in accordance with current NIOSH (2107) and OSHA (2017a) requirements in 42 CFR 84 and 29 CFR 1910.134, respectively. These requirements include establishing cartridge change schedules based on end-of-service-life (ESL) information.

NIOSH/NPPTL (2016) has published and uses Standard Testing Procedures for performing the tests in 42 CFR Part 84 required for chemical cartridges. The purposes of these tests are to determine if cartridge service lives for selected challenge concentrations, air flows, and breakthrough concentrations meet minimum requirements. These bench tests use specific chemical gases and vapors, including carbon tetrachloride and cyclohexane as representatives of organic vapors. Usually only one test concentration is specified, depending on the type of respirator. Total air flow rates are 32 and 64 L/min for non-powered air-purifying respirators (APRs), 115 L/min for tight fitting powered air-purifying respirators (PAPRs), and 170 L/min for loose fitting PAPRs. While such testing determines compliance with minimum requirements, it doesn't provide ESL information for workplace conditions.

OSHA (1998a) does not allow the use of subjective information, such as odor or irritation, to determine cartridge ESL. Therefore, “objective information” is needed. Cartridge manufacturers have breakthrough time data available for only a few of the wide variety of chemicals and use conditions encountered in workplaces. Predictive mathematical models for estimating breakthrough times can be useful if the needed input parameters, including chemical properties, are available; however, such

predictive models (Wood, 2015) are not accurate enough to use in critical situations without experimental confirmation. For these reasons, breakthrough time testing results related to the target vapor, the proposed cartridge, and the anticipated conditions of vapor exposure in a workplace are needed to develop cartridge change schedules.

An EPA (1991) document, "Interim Recommendations for Determining Organic Vapor Cartridge Service Life for NIOSH Approved Respirators," and its revisions have provided a laboratory testing protocol for the case of removal by physical adsorption by a single vapor. These were partially based on an earlier published testing protocol. (Wood and Ackley 1989) This EPA guidance was published verbatim on the OSHA web site in 1998 and was referenced there until 2005, but has been replaced with the statement, "There is no widely accepted, standard protocol for performing service life testing." (OSHA 2017b)

Subsequent developments in data accumulation, understanding, modeling, and considering other mechanisms of removal have revealed a need for an expanded and updated review of testing options which this article provides. Rather than specify a one-size-fits-all set of testing conditions, which is not really practical considering the varieties of cartridges, gas or vapor removal mechanisms, and workplaces that are possible, this article presents options available for developing a testing protocol and the benefits and limits of each option.

PRELIMINARY CONSIDERATIONS

Significant Parameters

There are many factors that affect cartridge service life, such as temperature (T), relative humidity (RH), vapor challenge concentration (C_o), average breathing rate (Q), and other environmental and use conditions (DeCamp et al. 2004 [Attachment 6] and Moyer 1983). Other contaminants (y) at concentrations C_y present in workplace air can affect the performance of a cartridge and should be considered when conducting cartridge testing. The performance of an organic vapor respirator cartridge in removing a selected airborne substance via adsorption or chemical reaction can be determined by measuring the breakthrough time of the substance through the cartridge under various test conditions. C_o , T , RH , Q , and C_y are called "significant parameters" in this article.

Starting Assumptions

This article assumes that 1) the OSHA decision logic (OSHA 2017c) has been followed to the selection of APRs as the means of worker protection, 2) the contaminant vapor has been identified, and 3) a type and brand of respirator approved by NIOSH (2017) and its associated cartridges have been selected for use, and 4) the allowable chemical exposure level (e.g., PEL, TLV, or EPA NCEL with safety factor) has been established.

Identifying Vapor Properties

The more that can be known about the vapor, the better for 1) cartridge selection, 2) breakthrough detection, 3) the application of breakthrough time estimation models, and 4) extrapolations of measured breakthrough times to untested conditions (Wood 2015). This includes physical properties (structure, vapor pressures, water solubility, etc.) and chemical properties (reactivity with activated carbon and its impurities, impregnants, or water).

Identifying Cartridge Properties

It is helpful for applications of predictive models to cartridges (Wood 2015) to know the sorbent properties and bed geometry. Ideally, these would be available from the cartridge manufacturer. Some of these properties, such as the identity of chemical impregnants (see definitions), can be useful for determining removal mechanisms; however this information might not be available for proprietary reasons. Some properties, such as micropore volume, might be estimated (Wood and Snyder 2004). Others, such as packed carbon bed dimensions, can be easily measured.

Applying Initial Screening with a Predictive Model

Predictive models can be useful to initially screen whether a cartridge might be appropriate for a new chemical substance. Even though breakthrough time estimating models have limitations as objective data (see above), they can be useful for decision-making and extrapolation of data (Wood 2015). For vapor removal by physical adsorption when the needed vapor, cartridge, and use parameters are known or can be estimated, such models currently available can 1) help decide if it is practical to pursue testing, 2) select testing conditions for the best results, or 3) aid in the selection of a cartridge or a surrogate vapor (see below). For example, if the model predicts a breakthrough time of less than 20 minutes for the vapor, then an OV cartridge may not be appropriate for the substance and the use of a supplied-air respirator might be reconsidered instead of performing cartridge service life testing. Alternately, a larger cartridge might be chosen. If the prediction is longer than 10 hours, the testing concentrations might be increased to get a measurable breakthrough time in a reasonable testing period, e.g. a normal lab work shift and/or overnight. One such model for adsorption (Wood and Snyder 2007) is available as a downloadable computer program, MultiVapor (NIOSH/NPPTL 2016). It improves on an earlier model (Wood 1994) by including better established adsorption kinetics, all humidities, and possible covapors in the workplace. Several cartridge manufacturers have developed and posted adaptations of the earlier model for their products (DeCamp et al. 2004 [Attachment 5]).

LABORATORY TESTING FOR GENERAL QUALIFICATION

General Qualification (GQ vs. Specific Workplace Qualification, SWQ) refers to the objective of determining the performance of a selected cartridge for a selected vapor over wide ranges of workplace environmental and use conditions. For example, a cartridge manufacturer might want to have testing done so that he could sell his product to many companies in a variety of industries. Or, in a single company the workplace conditions may vary widely due to seasonal changes (T, RH), workplace locations (C_o, T), or work effort (Q).

Advantage and Disadvantage

General Qualification provides the data for the most thorough understanding of the vapor removal process and how, qualitatively and quantitatively, the workplace conditions affect breakthrough time. However, the large number of tests required for GQ involve considerable time and cost.

Example

A flexible and comprehensive testing protocol has been published (Wood and Ackley 1989). GQ can be accomplished by testing with a full matrix of 4 parameters (C_o, Q, T, RH) represented by a cube in this reference. Using 18 sets of conditions including high, low, and intermediate parameter values and at least duplicate tests means at least 36 tests. Table I shows the ranges of parameters suggested.

Table I. Test Parameters

Suggested Values		Low	Intermediate	High
Vapor Concentration	C_o	0.1 Cr	Cr	10 Cr
Relative Humidity	RH	20%	50%	85%
Temperature	T (°C)	15	25	35
Air Flow Rate	Q (L/min)			64 (worst case)

where Cr is a reference value of 100 times the allowable exposure.

Use of Breakthrough Data for General Qualification

Breakthrough times from such tests can be correlated with equations which are then used for extrapolation or interpolation to actual workplace conditions (Wood 2015). At least two, preferably three or more, values of each parameter are needed to define trends and correlate results. Alternately, the smallest breakthrough time measured could be taken as the worst-case time as long as workplace conditions are not more extreme than the parameter values in the testing sets. Observed deleterious effects of covapor concentrations C_y would be used in modeling and worst-case selections.

REDUCING LABORATORY TESTING BY WORST CASE SELECTION

Worst-case selection is one way to reduce the number of tests that need to be done. It's accomplished by selecting and using only very high or very low values of one or more significant parameters, the extreme values of which are expected to give the smallest breakthrough time (worst case).

Example

In Table I above an air flow rate of 64 L/min was selected as an extreme and worst-case value. Breakthrough time increases as air flow rate decreases (approximately an inverse correlation). A worst-case air flow rate (breathing) average of 50 L/min is more appropriate for a full work shift than is 64 L/min which corresponds to a very heavy workload and may be an appropriate extreme only for shorter work periods. 60 L/min has also been used. Half flow can be used in testing one cartridge of a pair used on an APR or a third of the flow for one of three PAPR cartridges used together.

Disadvantage and Cautions

Worst-case selections need some knowledge of the removal mechanism and corresponding qualitative effects of the parameters. For example, high humidity is detrimental in the case of a weakly physically-adsorbed vapor to an extent determined in part by the water affinity factor. However, humidity could yield longer breakthrough times if the vapor reacts (hydrolyzes) with water adsorbed on the carbon from high humidity air. Higher temperatures are expected to reduce adsorption capacities of vapors, and therefore breakthrough times, but may increase the reactivity of a vapor with an impregnant (see definitions). At low concentrations capacity of a physically adsorbed vapor increases with concentration, while at high concentrations (only) it may be nearly independent of it. For reactive removal by a fixed amount of impregnant the capacity may be constant at all vapor concentrations. Breakthrough time is

approximately proportional to capacity W_e divided by C_o , as seen in both terms of the Reaction Kinetic (Wheeler) equation (Wood 2015).

REDUCING LABORATORY TESTING BY PROGRESSIVE TESTING

Preliminary testing at selected (e.g., intermediate) values of significant parameters may give clues as to which direction (higher or lower) to change testing parameters to get measurable or practical (e.g., 8-16 hours) breakthrough times.

Advantage

This may eliminate tests that give no useful results. Mathematical models, appropriate for the removal mechanism and “calibrated” with preliminary data (Wood 2015) could be useful for selecting follow-up testing conditions. Follow-up testing conditions may also be determined by expected use conditions, e.g., at no higher than the respirator Assigned Protection Factor (APF) times the allowable exposure concentration.

REDUCING LABORATORY TESTING BY ACTUAL CASE TESTING

The most obvious way to reduce the number of tests is to restrict testing ranges and values of significant parameters to those actually found in a specific workplace. This is called Specific Workplace Qualification (SWQ) in contrast to General Qualification (above).

Thorough workplace characterization and monitoring for values of significant environmental and use parameters are essential for the selection of testing conditions. Table II could be used to report the workplace situation.

Table II. Workplace Environmental and Use Parameters

Significant Parameter	Identity	Value(s)	Ranges Expected*
Primary Vapor	x	C_x	
Covapor(s)	y	C_y	
Relative Humidity		RH	
Temperature		T	
Worker(s) Effort(s)**		Q	

* Measured or expected high and low values in the workers' breathing zones over an appropriate time period (day, week, production cycle, season, year, etc.)

** Sitting, lifting, walking, stressful activities, etc. from which an average volumetric breathing rate Q (e.g., L/min) can be estimated (Wood 2015).

The testing protocol can be based on parameter ranges. Extremes of these ranges of parameters can all be tested or worst-case values can be used, if justified.

FIELD TESTING FOR ACTUAL CASE IN WORKPLACE

Field testing (FT) is an acceptable alternate way to do Actual Case testing for SWQ by measuring breakthrough times in a defined workplace at air flow rates approximating normal breathing (OSHA 1998a, Appendix A, Workplace Simulations). A cartridge change schedule can be based on results obtained in this workplace; however, this schedule will likely not apply in another workplace. FT might be necessary if laboratory testing is not available.

Advantages

Complicating factors such as the presence of other vapors and vapor concentration, humidity, and temperature variations during a work period are automatically taken into account.

Cautions

It is necessary to establish that the workplace environmental and use conditions do not change significantly with time and that the locations are representative or else more field testing needs to be done to incorporate such variations; therefore, it is still necessary to characterize and monitor the workplace (Table 2). The sensitivity and specificity of the breakthrough detection method need to be adequate to measure acceptable breathing levels of vapor. If the workplace location is variable, the field test system should also be moveable.

Method

Like laboratory testing, field testing uses a pump to draw air through a cartridge and a detector to monitor vapor in the effluent from it. However, humidity, temperature, and vapor(s) concentration controls are not needed. Pumps capable of drawing high air flows (e.g., up to 64 L/min) are needed. If the workplace location is not fixed in one spot, the pump should be moved around with the cartridge holder or, within limits, tubing from the pump to the cartridge can be used. Likewise, effluent vapor detectors/monitors attached to sampling adapters may need to be moveable. Lengthy tubing to a detector is not advisable unless it has been demonstrated that no sample losses occur in the sampling line. Fortunately, advances in miniaturization of gas chromatographs, photoionization detectors, infrared spectrometers, and semiconductor gas sensors are being made (Rios et al. 2009). Vapor detector tubes are available only for a limited number of well-known vapors. Sampling tubes with subsequent laboratory analysis need well-established methods taking into account collection and desorption efficiencies and other potential sample losses.

Examples

In a study to validate the use of respirator cartridge tubes (see below) Cohen et al. (1991) measured breakthrough times of carbon tetrachloride and pyridine through commercial cartridges exposed to work site air. Air flow rate through each cartridge from a pair was 30 L/min. Temperatures varied from 28 to 39 °C. The effluent monitor for carbon tetrachloride was an infrared spectrometer; a charcoal sampling tube with subsequent laboratory analysis was also used for pyridine and carbon tetrachloride in challenge and effluent air.

A procedure has been proposed for evaluating (not establishing) respirator cartridge change schedules (OSHA 2017d; Nelson and Janssen 1999). It uses human respiration as the pump with sampling through a special adapter between the cartridge and the facepiece. This procedure cannot be used for unknown breakthrough times because of potential exposures and because the adapter violates NIOSH approval.

OTHER TESTING POSSIBILITIES

Respirator cartridge tubes

An extensive laboratory and field study has shown that breakthrough times of respirator OV cartridges can be well predicted by workplace samples taken with smaller (1.1-cm diameter) respirator cartridge tubes (RCTs) at lower flow rates (2.7 L/min) if the air residence times are taken into account (Cohen et al. 1991). The RCTs are packed with carbon from the commercial cartridges. Testing tubes have long been used for convenience in laboratory testing in place of full cartridges (Jonas and Rehrmann 1973). If RCTs are proposed for laboratory or field testing in place of full cartridges, the extrapolation from small sorbent weight and bed geometries to larger ones should be justified by logic, data, and/or mathematical models, taking into account the removal mechanism.

Stacked cartridges

Another method that has been used to extract capacity and kinetic removal parameters is to vary the total amount of sorbent by connecting cartridges in series and monitoring vapor effluent concentrations between and after the cartridges (Moyer 1987). This can be done both in laboratory and field testing, but may need long testing times.

Surrogate vapor testing

OSHA has discussed the possibility of relying on breakthrough times from “chemicals having analogous chemical structure to the contaminant under evaluation for breakthrough.” (OSHA 1998a, Appendix A, Analogous Chemical Structures). A surrogate vapor might be considered if the target vapor 1) is not available for testing, 2) is not volatile enough for testing, or 3) is too toxic for testing. It needs to be shown by data, logical arguments, or mathematical models that 1) surrogate breakthrough times are expected to equivalent to or less than those for the target vapor at the same conditions and 2) the removal mechanisms are the same. With removal by adsorption and vapors that differ by a methyl or phenyl group, the lower molecular vapor would be expected to have a lower breakthrough time. Mathematical models or data correlations for adsorption can be used to confirm this (Wood 2015). For a reactive removal case the reactive group(s) need to be the same, but the higher molecular weight vapor might be significantly less reactive or less soluble in adsorbed water. For an example of a surrogate application, cyclohexane might be proposed for testing in place of carcinogenic benzene. At 1 ppm breakthrough for 100 ppm challenge the NIOSH MultiVapor program (NIOSH/NPPTL 2016) predicts a breakthrough time of 1332 min for cyclohexane vs. 1542 min for benzene for a typical OV cartridge and program default conditions. Therefore, cyclohexane can be used as the surrogate for benzene in breakthrough time testing and setting a change schedule.

MISCELLANEOUS CONSIDERATIONS

Duration of tests

Ideally, breakthrough testing should be continued at least until the effluent concentration is 10% of the challenge vapor concentration. Breakthrough times at lower effluent concentrations (e.g., 1%) should be recorded to create a breakthrough curve. If possible, the acceptable breathing level breakthrough time should also be recorded. However, the detector may not have the range to measure these levels. On the other hand, detectable breakthrough concentration may not occur in tests lasting 8 or more hours, after which testing may be terminated for practical reasons. Such a test duration sets a lower

limit for the actual breakthrough time, from which a conservative change schedule incorporating a safety factor (see below) can be set.

Thermal monitoring

For reactive removal cases it is essential that use of the cartridge for the vapor will not result in high effluent temperatures ($>20^{\circ}\text{C}$ above ambient temperature) from heats of adsorption or reaction with the sorbent material of the cartridge. Temperatures are easily measured in the effluent stream during testing. For substances which generate such high temperatures from heats of reaction, only non-oxidizing sorbent materials must be used (not activated carbon).

Cartridge preparation for testing

Cartridges and canisters are best tested as-received without any preconditioning (e.g., extended humidity exposure before testing) unless justified for a particular application. Cartridges used in pairs on an air-purifying respirator should be tested in parallel in pairs, or total airflow rates should be halved for testing them singly.

Replicates and reproducibility

A minimum of two replicates is needed for each testing condition to establish reproducibility. More tests need to be done if the variability among breakthrough time results for each set of replicates exceeds $\pm 10\%$ from the average until this reproducibility is met by statistically discarding outliers.

Parameter controls

Relative Humidity ($\pm 3\%$), Temperature ($\pm 1^{\circ}\text{C}$), and Air Flow ($\pm 5\%$) are ideal control ranges (Manning and Nelson 2006).

Safety factor

A safety factor of 60% of the cartridge service life for field application has been recommended to account for possible differences between laboratory measurements and actual field performance (EPA 1991). For example, for a change schedule of 8 hours a service life of at least $8 \times 1.6 = 12.8$ hours needs to be established.

Desorption

Depending on the use conditions, additional testing may be needed to investigate vapor desorption at elevated temperatures.

Reusability

If extended cartridge change schedules (longer than 1 work shift) are desired, additional testing will be needed to demonstrate that significant desorption and migration of contaminant vapor through the cartridge bed do not occur between shifts and during repeated storage and reuse. In the case of adsorption of a single vapor an estimation model has been published (Wood and Snyder 2013), but experimental confirmation is still needed.

Covapors

If there is potential for inhalation exposure to multiple contaminants, additional service life testing may be necessary incorporating the range of interfering covapors to demonstrate that the cartridge or canister selected is still appropriate. Multiple OV adsorption has been studied and modeled. (Yoon et al. 1996; Wood and Snyder 2007). In other cases airborne contaminants are to be considered as interferents if 1) they may be removed by the same mechanism (reaction, catalysis, hydrolysis, etc.) as the primary vapor and 2) their concentrations are comparable to that of the primary vapor.

Change of cartridge from a tested one to an untested one

This can only be justified by objective data, such as additional breakthrough studies and/or the use of mathematical models. For example, an organic vapor-acid gas (OV/AG) cartridge may be used for protection against a tested vapor provided the sorption capacity of the OV/AG cartridge is equivalent to or greater than that of the tested cartridge (e.g., an OV cartridge).

Products of reactive removal

Such products (compounds formed with impregnants, from catalysis, or by hydrolysis) need to be identified by chemistry or measurements. If these products are volatile enough to elute from a cartridge, their toxicity and breakthrough times need to be taken into account. Example: Nelson et al. 2007.

Reporting Recommendations

- 1) Purpose of the testing done.
 - Purpose A: General Qualification for a specific cartridge for protection against a specific chemical vapor in a variety of workplaces with possibly wide-ranging environmental and use conditions.
 - Purpose B: Specific Workplace Qualification for a specific cartridge for protection against a specific chemical vapor in a specific workplace with a defined set of environmental and use conditions.
- 2) Type of testing done.
 - Laboratory (Purposes A or B)
 - Field (Purpose B)
- 3) Workplace characterization results (Table II), including average atmospheric pressure for use in calculations and models.
- 4) Physical and chemical properties of the vapor(s) in as much detail as is available.
- 5) Cartridge, sorbent bed, and sorbent properties in as much detail as is available.
- 6) Description and justification of the testing protocol selected (Table III).
- 7) For laboratory testing:
 - a) Parameter sets selection process and values.
 - b) Worst case selection(s), if any.
 - c) Progressive testing, if any.
 - d) Surrogate vapor selection, if any.
 - e) Alternate testing options, if any (see above).
 - f) Vapor(s) and humidity generation methods and stabilities (Table III).
 - g) Average atmospheric pressure in the laboratory for use in calculations.
 - h) Effluent vapor monitoring methods, including a description of the method, calibrations, limit of detection, range of applicability, accuracy, and precision.

Table III. Vapor(s) and Humidity Generation Methods and Stabilities

	Method Description	Method of Monitoring**	Value(s) Selected	Other
Generation of Vapors	x y		C _o C _y	Stability? *
Generation of Humidity			RH	Stability? *
Control of Temperature			T	Stability? *
Control of Air Flow			Q	Stability? *
Detection of Effluent Vapors			C _b	Limits of Detection and Quantification

*The range ($\pm$ %) from the average during tests

** Includes calibrations and frequencies of calibrations.

8) For field testing:

- a) Air flow method and stability (Table IV).
- b) Effluent vapor monitoring methods, including a description of the method, calibrations, the limit of detection, range of applicability, accuracy, and precision.

Table IV. Air Flow Method and Stability

	Method Description	Method of Monitoring**	Value(s) Used	Other
Control of Air Flow			Q	Stability *
Detection of Vapors			C _b	Limits of Detection and Quantification

*The range ($\pm$ %) from the average during tests.

** Includes calibrations and frequencies of calibrations.

- 9) Tabulated breakthrough times or lower limits (if no breakthrough was observed) for corresponding sets of actual testing parameters (Table V).

Table V. Template for Tabulated Breakthrough Times or Lower Limits

BT (min)	C_o	C_b	Q	RH	T	W	C_y for y

- 10) The actual breakthrough curves (tabulated concentrations versus time) for each set of testing parameters, if measured.

- 11) Calculations of reproducibility.

- 12) Additional information and results, including:
 - a) Effluent thermal monitoring or documentation that the vapor(s) will not result in high temperatures ($>20^{\circ}\text{C}$ above ambient) from heats of reaction or adsorption.
 - b) Cartridge preparation, if any.
 - c) Desorption studies, if any.
 - d) Reusability studies, if any.
- 13) Change schedule decisions and justifications, including:
 - a) Objective data basis.
 - b) Logic.
 - c) Application of a safety factor.
- 14) Any administrative actions to be incorporated into a respiratory protection program.
- 15) Qualifications of the testing organization and its personnel, whether for laboratory, field, or other testing done.

DEFINITIONS AND SYMBOLS

The following definitions and abbreviations are supplemental, integral parts of this article.

Organic Vapor (OV) – A chemical substance that can exist partially in gaseous form (vapor) at ordinary ambient temperatures and contains a carbon atom in its molecular structure. In this article this term also includes non-condensable gases that may not have a carbon atom (inorganic).

Organic Vapor Cartridge – A package designed for removing volatile contaminants from air drawn or pushed through it by the removal action of a packed bed of granulated material (sorbent) it contains. Usually “OV cartridge” refers to one containing activated carbon granules which work by adsorption and condensation of vapors in micropores. In this article this term also includes a cartridge containing any other sorbent. **Canister** refers to a larger cartridge usually used singly rather than in pairs with an **air-purifying respirator (APR)**; the term “cartridge” in this article includes “canister.” Cartridges may also be used in multiples with a **powered air-purifying respirator (PAPR)**.

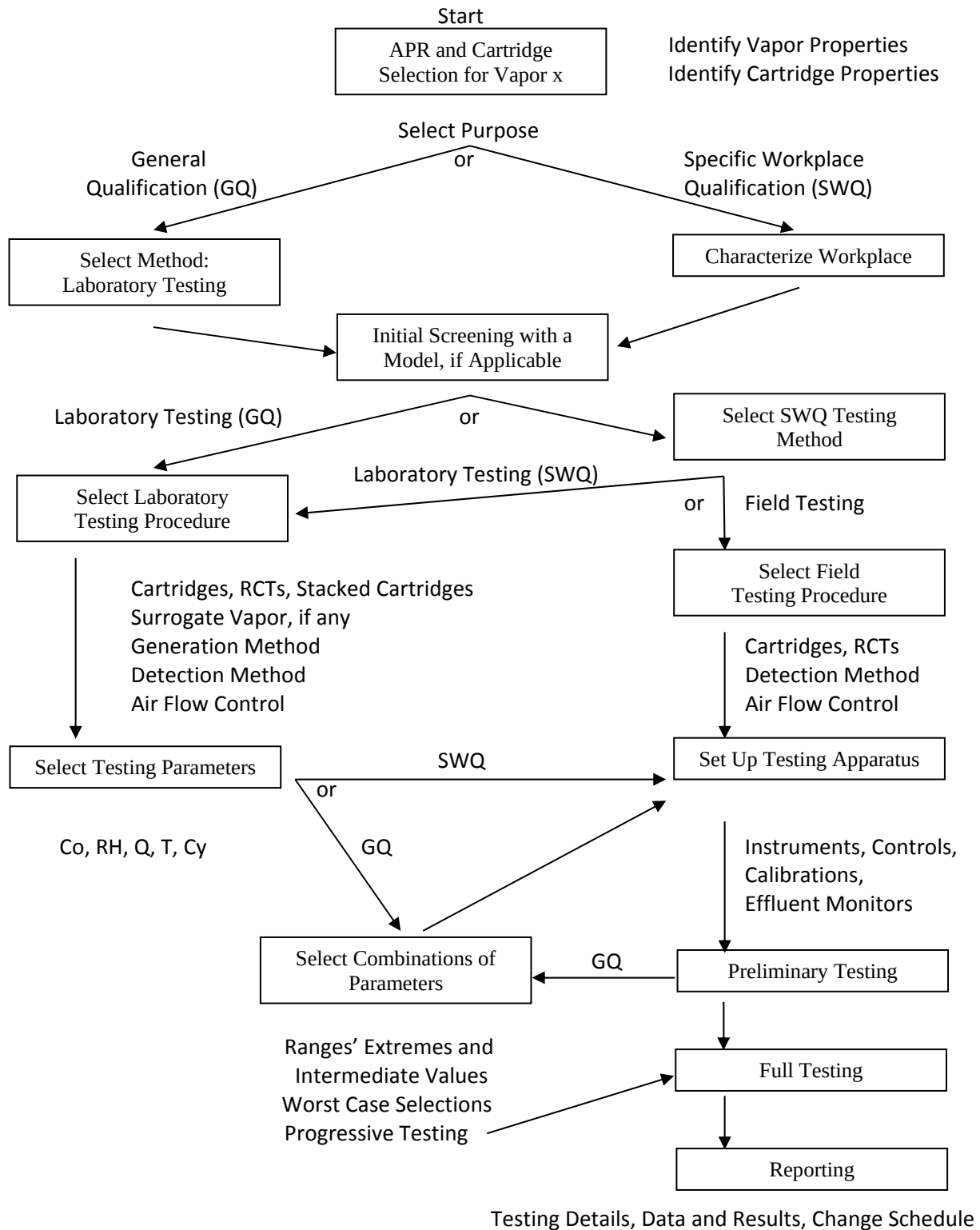
Impregnants -- Chemicals added to activated carbon sorbents which are intended to remove vapors or gases by reactions (compound formation with impregnants or catalytic breakdown by them); for example, an Acid Gas (AG) cartridge contains impregnated carbon.

Breakthrough Time (BT) – refers to the time at which a defined concentration of vapor is attained in the effluent of a cartridge under a defined set of testing conditions. It is similar to **Service Life** for a defined set of workplace conditions.

CONCLUSIONS

A variety of options are available for APR cartridge testing. Choices among these options depend on objectives (GQ, SWQ, or meeting minimum standards) and available resources (time, money, effort, facilities). Each option has advantages and limitations. It is important to characterize and report all variables, measurements, and conditions under which tests are conducted. The following Decision Logic Flow Chart has been prepared as a guide through the options available.

DECISION LOGIC FLOW CHART



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