



Standard Practice for Chemical Permeation through Protective Clothing Materials: Testing Data Analysis by Use of a Computer Program¹

This standard is issued under the fixed designation F2815; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the calculations of all the permeation parameters related to Test Method **F739**, ISO 6529, and Practice **D6978** standards by use of a computer program, referred to as “Permeation Calculator” (DHHS (NIOSH) Publication No. 2007 – 143c).^{2,3}

1.2 The practice is applicable to both open loop and closed loop permeation tests. The closed loop test includes continuous sampling and discrete sampling. The discrete sampling includes tests when sample volume is replaced and also when sample volume is not replaced. For an open loop permeation test, the computer program also allows permeation data files with variable sampling flow rate. Refer to Test Method **F739** for more details about the different types of the permeation testing systems.

1.3 This practice is applicable to the most typical permeation behavior, that is, Type A, where the permeation rate stabilizes at a “steady-state” value. It does not apply to the other types of permeation behaviors. Refer to Test Method **F739** for more details about the various permeation behaviors.

1.4 This practice is not applicable to Test Method **F1383** because the permeation behavior is different under conditions of intermittent contact than under conditions of continuous contact.

1.5 This practice does not address the procedure of permeation testing. Refer to Test Method **F739**, ISO 6529, or Practice **D6978** for the procedures in detail if needed.

2. Referenced Documents

2.1 ASTM Standards:⁴

D6978 Practice for Assessment of Resistance of Medical Gloves to Permeation by Chemotherapy Drugs

F739 Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact

F1194 Guide for Documenting the Results of Chemical Permeation Testing of Materials Used in Protective Clothing

F1383 Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Intermittent Contact

F1494 Terminology Relating to Protective Clothing

2.2 ISO Standards:⁵

ISO 6529 Protective Clothing—Protection against Chemicals—Determination of Resistance of Protective Clothing Materials to Permeation by Liquids and Gases

3. Terminology

3.1 Definitions:

3.1.1 *analytical technique, n*—a procedure whereby the concentration of a challenge chemical in a collection medium is quantitatively determined.

3.1.1.1 *Discussion*—The detailed steps for these procedures are often specific to individual chemical and collection medium combinations. Applicable techniques include but are not limited to flame ionization, photo ionization, electro-chemical, and ultraviolet and infrared spectrophotometry, gas and liquid chromatography, colorimetry, length-of-stain detector tubes, and radionuclide tagging/detection counting.

3.1.2 *breakthrough detection time, n*—the elapsed time measured from the start of the test to the sampling time that immediately precedes the sampling time at which the test chemical is first detected.

¹ This practice is under the jurisdiction of ASTM Committee **F23** on Personal Protective Clothing and Equipment and is the direct responsibility of Subcommittee **F23.30** on Chemicals.

Current edition approved May 1, 2014. Published May 2014. Originally approved in 2010. Last previous edition approved in 2010 as F2815–10. DOI:10.1520/F2815–10R14.

² Gao P, Weise T, and Tomasovic B [2009] Development of a computer program for permeation testing data analysis. *Journal of Occupational & Environmental Hygiene*, 6(6): 363-373.

³ The computer program is available at no-charge either on the National Institute for Occupational Safety and Health website at

<http://www.cdc.gov/niosh/npptl/PermeationCalculator/permeationcalc.html> or on CD by request. Phone: 1-800-CDC-INFO (1-800-232-4636), Fax: 1-888-232-6348, or E-mail: CDCInfo@cdc.gov.

⁴ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

⁵ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

3.1.2.1 *Discussion*—For this practice the breakthrough detection time is calculated by a computer algorithm and is dependent on the sensitivity of the analytical method.

3.1.3 *breakthrough point, n*—the point at which the breakthrough occurs during a permeation test.

3.1.3.1 *Discussion*—The computer program determines the breakthrough point based on the approach shown in 6.2.1 through 6.2.4. The breakthrough point is determined as the first data point used in the last slope's calculation as described in 6.2.3. Note that BP is not an absolute number but rather is dependent on the sensitivity of the analytical method.

3.1.4 *closed loop, adj*—refers to a testing mode in which the collection medium volume is fixed.

3.1.5 *collection medium, n*—a liquid, gas, or solid that absorbs, adsorbs, dissolves, suspends, or otherwise captures the challenge and does not affect the measured permeation.

3.1.6 *minimum breakthrough detection time, n*—the time in minutes measured from the start of the test to the sampling time at which the permeation rate reaches 0.01 $\mu\text{g}/\text{cm}^2/\text{min}$.

3.1.7 *minimum detectable mass permeated, n*—the smallest mass of test chemical that is detectable with the complete permeation test system.

3.1.7.1 *Discussion*—This value is not necessarily the sensitivity of the analytical instrument.

3.1.8 *minimum detectable permeation rate, n*—the lowest rate of permeation that is measurable with the complete permeation test system.

3.1.8.1 *Discussion*—This value is not necessarily the sensitivity of the analytical instrument.

3.1.9 *normalized breakthrough detection time, n*—in an open-loop test, it is the elapsed time at which the permeation rate reaches 1.0 $\mu\text{g}/\text{cm}^2/\text{min}$. In a closed-loop test, it is the time at which the mass of chemical permeation reaches 2.5 $\mu\text{g}/\text{cm}^2$.

3.1.10 *open loop, adj*—refers to a testing mode in which fresh collection medium flows continuously through the collection chamber of the test cell.

3.1.11 *penetration, n*—for chemical protective clothing, the movement of substances through voids in a chemical protective clothing material or item on a non-molecular level.

3.1.11.1 *Discussion*—Voids include gaps, pores, holes and imperfections in closures, seams, interfaces and protective clothing materials. Penetration does not require a change of state; solid chemicals move through voids in the materials as solids, liquids as liquids, and gases as gases. Penetration is a distinctly different mechanism from permeation.

3.1.12 *permeation, n*—for chemical protective clothing, the movement of chemicals as molecules through protective clothing materials by the processes of (1) absorption of the chemical into the contact surface of the material, (2) diffusion of the absorbed molecules throughout the material, and (3) desorption of the chemical from the opposite surface of the material.

3.1.12.1 *Discussion*—Permeation is a distinctly different mechanism from penetration.

3.1.13 *protective clothing, n*—an item of clothing that is specifically designed and constructed for the intended purpose

of isolating all or part of the body from a potential hazard; or isolating the external environment from contamination by the wearer of the clothing.

3.1.14 *standardized breakthrough time, n*—the first time at which the permeation rate reaches 0.1 $\mu\text{g}/\text{cm}^2/\text{min}$.

3.1.15 *steady-state permeation rate, n*—a constant rate of permeation that occurs after breakthrough when all forces affecting permeation have reached equilibrium.

3.1.16 *test chemical, n*—solid, liquid, gas or mixture thereof, used to evaluate the performance of a protective clothing material.

4. Summary of Practice

4.1 The computer program used in this practice calculates all the permeation parameters listed in Test Method F739, ISO 6529, and Practice D6978, including standardized breakthrough time, normalized breakthrough detection time, breakthrough detection time, minimum breakthrough detection time (if applicable), steady-state permeation rate, cumulative permeation at a given elapsed time, elapsed time at a given cumulative permeation, average permeation rate, and maximum permeation rate if it is an open loop permeation test.

4.2 The operation of the computer program involves the following steps:

4.2.1 *Data Input to the Computer Program*—Input a permeation testing data file that contains data points in time versus concentration. The data must be in a spreadsheet software file with a minimum of seven data points before the breakthrough point and the total number of data points can not exceed 5000. The number of significant figures used for the input data will affect the number of significant figures reported for the permeation parameters, so appropriate significant figures should be used. Refer to Appendix X1 for details in data file requirements.

4.2.2 *Analysis*—After importing the data file and entering required information, the program determines the permeation parameters based on a series of strategies and approaches.

4.2.3 *Output*—Upon completion, the program displays all the permeation parameters together with relevant information and the permeation curve in a spreadsheet software or a text file-formatted report.

5. Significance and Use

5.1 Data analysis for chemical protective clothing permeation testing involves a number of equations and experimental factors. Possible calculation errors are critical issues when determining permeation parameters. Because the calculations of some of the permeation parameters are mathematically complex, this computer program will be useful.

5.2 This practice is to help researchers and industrial hygienists avoid labor intensive hand calculations of the permeation parameters. From a standardization point of view, this practice prevents variability or inconsistency caused by different experimenters thus ensuring identical permeation parameters or results will be obtained from a given permeation test data file.

5.3 Protective clothing manufacturers worldwide will benefit since they must inform customers about the permeation parameters of their products in a consistent manner. The practice will also help diagnostic laboratories and research centers involved in the chemical protective clothing testing.

6. Calculation

6.1 *Symbols*—The following symbols are used in the calculations, where:

a	= a coefficient for a polynomial equation, Eq 1-3 and Eq 15; an arbitrary data point before data point b , Eq 6-10,
A	= area of the material specimen contacted, cm ² , Eq 4, Eq 5, Eq 11, Eq 13, and Eq 14,
b	= a constant for a polynomial equation, Eq 1-3 and Eq 15; an arbitrary data point after data point a , Eq 10,
c	= a constant for a polynomial equation, Eq 1,
C	= concentration of test chemical in collection medium, µg/L, Eq 11, Eq 13, and Eq 14,
$\bar{C}$	= average concentration of test chemical in collection medium, µg/L, Eq 5,
CP	= cumulative permeation beginning with initial chemical contact, µg/cm ² , Eq 6-11, Eq 13, and Eq 14,
F	= flow rate of collection medium through the permeation cell, L/min, Eq 5,
i	= data point, Eq 11-14; data point immediately before data point a or b , Eq 6-9,
m	= a collection or a series of data points i , Eq 7 and Eq 9,
n	= total number of data points i , Eq 11, Eq 13, and Eq 14,
P	= permeation rate, µg/cm ² /min,
$\bar{P}$	= average permeation rate for the time interval T_a to T_b , µg/cm ² /min, Eq 10,
R	= correlation coefficient of a regression analysis,
$SSPR$	= steady-state permeation rate, µg/cm ² /min, Eq 4 and Eq 5,
T	= elapsed time, min, Eq 6-10,
V_i	= remaining medium volume at t_i , Eq 12,
V_s	= volume of discrete sample removed from the collection medium, L, Eq 11-Eq 14,
V_t	= total volume of the collection medium, L, Eq 4, Eq 12-Eq 14,
x	= value of x axis in a permeation curve, min, and
y	= value of y axis in a permeation curve, µg/L, µg/cm ² , or µg/cm ² /min.

6.2 *Breakthrough detection time for open-loop permeation test and closed-loop permeation test with continuous sampling:*

6.2.1 Calculate the slope and regression correlation coefficient centered on each data point n starting at $n = 8$, by performing a linear regression for points $n-7$ to $n+7$.

6.2.2 Calculate the slope between the data point closest to 50 % and the data point closest to 90 % of the maximum concentration, that is, $(y_{90}-y_{50})/(x_{90}-x_{50})$. This is referred to as the largest slope.

6.2.3 Stop when all of the following conditions are met: (1) the slopes calculated in 6.2.1 increase consecutively for seven times, (2) each of these seven slopes is greater than 2 % of the

largest slope calculated in 6.2.2, and (3) the square of the correlation coefficient (R^2) for the last slope is greater than 0.9.

NOTE 1—Conditions (1) and (3) in 6.2.3 are to filter out the background noise and Condition (2) is to avoid determining the breakthrough detection time in a flat region before the real breakthrough. The values specified for these three conditions were optimized using hundreds of permeation data files. Refer to Section 9 on the precision and bias. In addition, adequately predicting the real tendency of the data for determining the breakthrough detection time could not be ensured when using fewer data points for the linear regression analysis.

6.2.4 When the last slope is determined in 6.2.3, select the first data point used in that slope's calculation as the breakthrough point (BP).

6.2.5 Using the data points from BP to the point closest to 15 % of the maximum concentration, perform a regression analysis to obtain a polynomial equation ($y_{BP} = ax^2+bx+c$) as illustrated in Fig. 1(a).

NOTE 2—Calculating breakthrough detection time by taking the regression analysis and then solving the polynomial equation is to avoid reporting the standardized breakthrough time only at the times (T_i) that are shown in the data file but not really at a time within a data collection time interval (same purpose for the calculations of standardized breakthrough time and normalized breakthrough detection time as to be described below).

6.2.6 Calculate the breakthrough detection time by solving the polynomial equation for x . Take the root x_1 or x_2 , whichever is closest to x_{BP} .

6.3 *Standardized breakthrough time:*

6.3.1 *Closed-loop permeation test with continuous sampling:*

6.3.1.1 As shown in Fig. 1(b), for a permeation curve of y (µg/cm²) against x (min), the program performs a regression analysis using a range of data points to obtain a polynomial equation, that is, Eq 1. The first data point is the one with an elapsed time closest to 75 % of the time value for the BP, as determined previously for calculation of the breakthrough detection time, and the last data point is the one with a CP closest to 15 % of the maximum CP .

$$y = ax^2 + bx + c \quad (1)$$

6.3.1.2 Take the derivative to obtain the permeation rate in µg/cm²/min:

$$\frac{dy}{dx} = 2ax + b \quad (2)$$

6.3.1.3 Based on the ASTM definition stated above, let

$$2ax + b = 0.1 \quad (3)$$

6.3.1.4 Solve Eq 3 for the standardized breakthrough time (x). If the calculated x value is outside the time range for the data points used for the regression, repeat the above procedures. The data for the next regression analysis uses the same number of data points but the starting point is incremented by one.

6.3.1.5 Report the value of x determined in 6.3.1.4 as standardized breakthrough time for a closed-loop permeation test once the conditions are satisfied.

6.3.2 *Open-loop permeation test:*

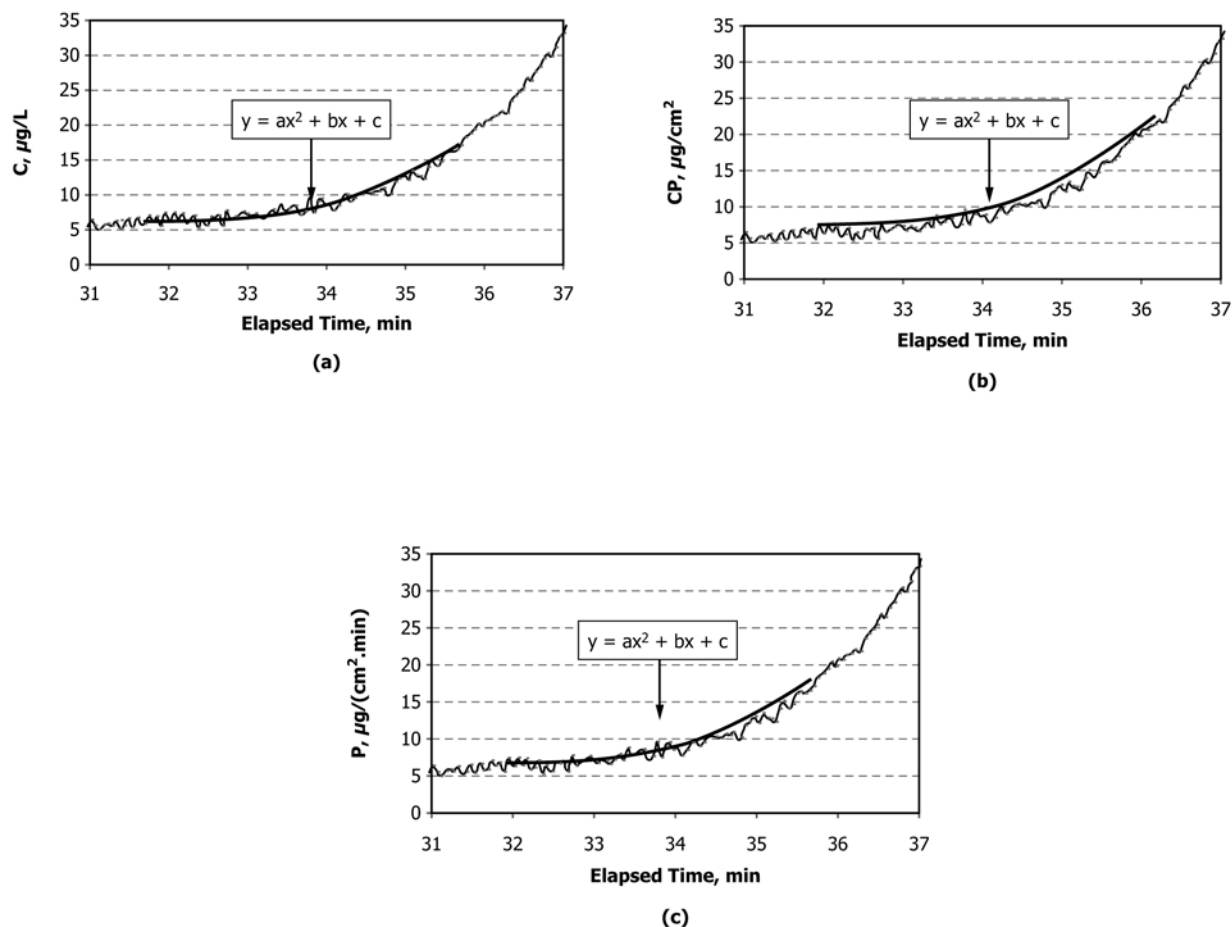


FIG. 1 Determination for Various Breakthrough Times

6.3.2.1 Find two consecutive points where the permeation rate at point $i < 0.1 \mu\text{g}/(\text{cm}^2 \cdot \text{min})$ and point $i+1 \geq 0.1 \mu\text{g}/(\text{cm}^2 \cdot \text{min})$. Select the point with a permeation rate closest to $0.1 \mu\text{g}/(\text{cm}^2 \cdot \text{min})$.

6.3.2.2 Perform a regression analysis using 11 data points centered on the selected point from Step 6.3.2.1 to obtain a polynomial equation ($0.1 = ax^2 + bx + c$) as illustrated in Fig. 1(c).

6.3.2.3 Calculate the standardized breakthrough time by solving the polynomial equation. Take the root x_1 or x_2 , whichever is closest to the time of the point determined in 6.3.2.1.

6.4 Normalized breakthrough detection time:

6.4.1 Closed-loop permeation test with continuous sampling:

6.4.1.1 Find two consecutive points where the cumulative permeation at point $i < 2.5 \mu\text{g}/\text{cm}^2$ and point $i+1 \geq 2.5 \mu\text{g}/\text{cm}^2$. Select the point with a cumulative permeation closest to $2.5 \mu\text{g}/\text{cm}^2$.

6.4.1.2 Perform a regression analysis using eleven data points centered on the selected point from Step 6.4.1.1 to obtain a polynomial equation ($2.5 = ax^2 + bx + c$) as illustrated in Fig. 1(b).

6.4.1.3 Calculate normalized breakthrough detection time by solving the polynomial equation. Take the root x_1 or x_2 , whichever is closest to the time of the point determined in 6.4.1.1.

6.4.2 Open-loop permeation test:

6.4.2.1 Find two consecutive points where the permeation rate at point $i < 1.0 \mu\text{g}/(\text{cm}^2 \cdot \text{min})$ and point $i+1 \geq 1.0 \mu\text{g}/(\text{cm}^2 \cdot \text{min})$. Select the point with a permeation rate closest to $1.0 \mu\text{g}/(\text{cm}^2 \cdot \text{min})$.

6.4.2.2 Perform a regression analysis using eleven data points centered on the selected point from Step 6.4.2.1 to obtain a polynomial equation ($1.0 = ax^2 + bx + c$) as shown in Fig. 1(c).

6.4.2.3 Calculate normalized breakthrough detection time by solving the polynomial equation. Take the root x_1 or x_2 , whichever is closest to the time of the point determined in 6.4.2.1.

6.5 Steady-state permeation rate (SSPR):

6.5.1 Closed-loop permeation test with continuous sampling:

6.5.1.1 For a permeation curve of y ($\mu\text{g}/\text{L}$) against x (min), determine the slope of the steady-state region by taking a linear regression of the data points between