September 10, 1999

NSF Protocol P171
Chlorine Resistance of Plastic Piping Materials

September 10, 1999

NSF International, an independent, not-for-profit organization, is dedicated to public health safety and protection of the environment by developing standards, by providing education and by providing superior third-party conformity assessment services while representing the interest of all stakeholders.

This Protocol is subject to revision.
Contact NSF to confirm this revision is current.

Users of this Protocol may request clarifications and interpretations, or propose revisions by contacting:

NSF International
Engineering & Research Services
789 Dixboro Road
Ann Arbor, MI 48105
Phone: (734)769-8010 Telex: 753215 NSF INTL
FAX: (734)769-0109 E-mail: info@nsf.org
Web: http://www.nsf.org

September 10, 1999

NSF Protocol P171
Chlorine Resistance of Plastic Piping Materials

Protocol Developer
NSF International
Engineering & Research Services

Prepared by NSF Engineering & Research Services staff with assistance from NSF Protocol Development Panel members shown below:

Mr. Michael Beaton, Senior Staff Engineer, International Conference of Building Officials (ICBO) Evaluation Services, Inc.

Mr. Pat Chiasson, Executive Vice President and C.O.O., Bow Industrial Corporation

Mr. Mike Kobel, Director of Standards, International Association of Plumbing and Mechanical Officials (IAPMO)

Mr. Carl Mahabir, Technical Service and Development Engineer, AT Plastics inc.

Mr. Stan Mruk, Consultant

Dr. Ken Oliphant, Executive Vice President, Jana Laboratories Inc.

Mr. James Paschal, Director, Physical Performance Testing Laboratory, NSF International

Dr. Gary Sandilands, WRc ETC Ltd.

Mr. Steve Wooden, Product Manager, Padanaplast USA, Inc.

Published by
NSF International
789 Dixboro Road, Ann Arbor, Michigan 48105

For ordering copies or for making inquiries with regard to this Protocol, please reference the protocol title. Without the written permission of NSF, it is strictly prohibited to use this designation in whole or in part, to indicate conformance with this Protocol through the marking of products or packaging, or by any other means.

Printed in the United States of America.

Disclaimers

NSF International (NSF), in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or any other party. The opinions and findings of NSF represent its professional judgment. NSF shall not be responsible to anyone for the use of or reliance upon this protocol by anyone. NSF shall not incur any obligations or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon this protocol.

Participation in NSF's protocol development activities by a representative of a regulatory agency (Federal, state, local) shall not be construed as the agency's endorsement of NSF, its policies, or any of its protocols.

NSF Protocols provide basic criteria to promote and protect public health. Provisions for safety have not been included in this protocol because governmental agencies or other national standards-setting organizations provide safety requirements.

Unless otherwise referenced as normative, the appendices are not considered an integral part of NSF protocols. They are provided as general guidelines to the manufacturer, regulatory agency, user, or certifying organization.

NSF Protocol P171
Chlorine Resistance of Plastic Piping Materials

1 General

1.1 Introduction

Chlorine is the most common disinfectant for potable water. At the levels found in potable water, chlorine can reduce the service life of plumbing system components. This test protocol, using the current industry practice, provides a means of assuring a minimum level of chlorine resistance for potable water applications.

1.2 Scope

This protocol covers the chlorine resistance performance test methods and requirements for plastic piping materials intended for the conveyance of chlorinated potable water. Its applicability to any finished product or end-use application is the responsibility of the user, product standards which reference this protocol, or the authority having jurisdiction.

1.3 Alternate materials

While specific materials are stipulated in this protocol, components that incorporate alternate materials shall be acceptable when it is verified that the component meets the applicable requirements of the protocol based on its intended end-use.

1.4 Certification Mark

Products meeting the requirements of this protocol and NSF International Certification Policies shall be authorized to use one of the following marks, depending upon intended end use:

NSF CI-R	For Domestic Continuous Re-circulation
NSF CI-TD	For Traditional Domestic

*Note: The bulk of plumbing systems are **Traditional Domestic** or on/off systems. In these systems, the hot water pipes see hot water only when the tap is turned on and hot water is flowing through the system. The rest of the time, they are at room temperature. Recently, systems in which the hot water is continuously re-circulated through the hot water side of the plumbing system are being employed (**Domestic Continuous Re-circulation**).*

2 References

ASTM D2122: Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings.

DIN EN ISO 13760: Plastics pipes for the conveyance of fluids under pressure - Miner's Rule - Calculation method for cumulative damage.

ISO 9080: Plastics Piping and Ducting Systems - Determination of Long-Term Hydrostatic Strength of Thermoplastics Materials in Pipe Form By Extrapolation.

PPI TR-3 'Policies and Procedures for Developing Hydrostatic Design Bases and Maximum Recommended Hydrostatic Design Stresses for Thermoplastic Piping Materials'.

3 Definitions

3.1 Chlorine Level

The level of chlorine in the water as free chlorine, expressed in units of mg/L as measured by a suitable measuring device.

3.2 Brittle Failure

The term brittle failure refers to failures that are typically localized, non-propagating slit failures.

3.3 Design Factor

The Design Factor is a multiplier less than 1.0, that takes into consideration variables and degrees of safety involved in piping installation.

3.4 Estimated Minimum Chlorine Resistance Service Lifetime

The estimated minimum lifetime of the product determined by the application of a 0.5 design factor on the extrapolated test lifetime. This is the time the sample would be reasonably expected to survive exposure to chlorinated potable water under the testing conditions.

3.5 Extrapolated Test Lifetime

The extrapolated time to failure under a particular set of conditions based on the model developed through multiple variable linear regression.

3.6 Miner's Rule

A method for estimating the effect of multiple exposure conditions on a material's lifetime based on a cumulative damage model. (See Section 2 References for method used by this Protocol).

3.7 Multiple Variable Linear Regression

Linear regression involving the independent variables of temperature and hoop stress and the dependent variable of time to failure. The three coefficient rate process extrapolation equation is used to model the data (see Appendix A). (See Section 2 References for method used by this Protocol).

3.8 Oxidation Reduction Potential

A measure of the oxidizing potential of a solution. ORP electrodes measure a voltage (typically expressed in millivolts (mV)) that is dependent on the type and amount of oxidizing species present in the water. The more oxidizing species present, the higher the ORP.

4 Requirements

Test specimens shall have an Estimated Minimum Chlorine Resistance Service Lifetime at end use conditions greater than 40 years. This estimate is established by applying a 0.5 design factor on the Extrapolated Test Lifetime as determined through testing per Section 5 (Chlorine Resistance Test Method). Initial certification shall be according to this protocol. Annual Compliance testing as proscribed by NSF Certification Policy is required to maintain certification. Any change in material formulation or processing conditions must be evaluated against this protocol.

5 Chlorine Resistance Test Method

5.1 Summary

Testing is conducted on actual end use samples under pressure in a flowing system. Samples are tested to failure under typical use conditions of chlorine level, pH and pressure. Elevated temperatures are used to accelerate failure. Testing is conducted at a minimum of three temperatures and two stress levels (pressures) per temperature. At one temperature, testing is conducted at three pressures. Multiple linear regression is then used to determine an extrapolated test lifetime under end use conditions. An extrapolated Chlorine Resistance Lifetime is then calculated based on Miner's Rule and the application of a 0.5 design factor.

5.2 Test Equipment

5.2.1 Water Temperature Control

The test water temperature control shall ensure that the test fluid entering and exiting the test specimen(s) is maintained at a constant temperature within ± 2.0°C (± 3.6°F) throughout the duration of the test.

5.2.2 External Air Temperature Control

The external air environment around the test specimen shall be maintained within ± 2.0°C (± 3.6°F) of the test temperature throughout the duration of the test. The external air temperature shall be maintained at the same set-point as the water temperature so that there is no temperature gradient through the specimen wall.

5.2.3 Dynamic Flowing Pressure System

The dynamic flowing pressure system shall apply a constant internal pressure within the tolerances specified in Table 1, while allowing a continuous flow through the test specimens. Devices that create cyclic pressure variations shall not be used.

5.2.4 Pressure Gage

A pressure measuring instrument capable of determining the internal pressure of the test specimen(s) within the tolerances specified in Table 1 shall be installed up-stream of the test specimens.

5.2.5 Timing Device

A timing device shall be installed capable of determining the time-to-failure to the tolerances specified in Table 1.

Table 1. Tolerance Requirements for Testing

Test Period (hours)	Pressure (percent)	Time (percent)
0 to 10	± 0.5	±0.5
10 to 100	± 0.5	±1.0
100 +	± 1.0	±2.0

5.2.6 Chlorinated Water Supply

The system shall deliver a constant supply of water with a chlorine level of 4.3 ± 0.3 mg/L free available chlorine and a pH of 6.8 ± 0.2. These set-points are such that a minimum chlorine level of 4.0 mg/L and a maximum pH of 7.0 are maintained throughout the duration of the test. The pH shall be adjusted in a manner that does not interfere with the chlorine chemistry other than the pH dependent equilibrium. The chlorine level shall be continuously monitored throughout the duration of the test by a monitoring device calibrated versus the USEPA approved DPD Colorimetric or Amperometric methods. The pH shall be continuously monitored throughout the duration of the test by a monitoring device calibrated against nationally traceable standards (e.g. NIST). Both the chlorine level and pH shall be monitored upstream of the test specimens.

The starting water quality shall have a total dissolved solids of no more than 20 ppm and shall be free of metal ions. The system shall be a once through system or, if water is to be recycled, the recycle stream shall be purified to meet the starting water quality requirements above.

5.2.7 Flow Control

The flow control device shall maintain flow within ± 10% of the set-point.

5.2.8 Materials of Construction

The materials in contact with the test fluid and/or the test specimens shall be constructed of an inert non-metallic material.

Note: Metals (copper, brass, titanium, etc..) are known to have a deleterious effect on the oxidative stability of many polymers and should not be used for the construction of the test device. Inert polymeric materials such as Polyvinylidene Fluoride (PVDF) and Perfluoroalkoxy (PFA) have been found to be suitable in practice.

5.3 Test Specimens

Material evaluation shall be performed on specimens in the intended end use form. Specimens shall be produced on commercial equipment under normal production processes from a standard production lot material.

5.3.1 Pipe

5.3.1.1 Testing shall be conduced on 1/2" nominal size pipe samples. This is considered to represent the pipe diameter that will produce the shortest failure times (most aggressive size) as it is generally a size that maximizes the hoop stress at a given internal pressure for the lowest wall thickness in a SDR series. For product lines with a more aggressive pipe size, testing shall be handled on a case-by-case basis.

Note: Testing of the most aggressive pipe size is conducted to allow, by extension, certification of less aggressive product sizes.

5.3.1.2 The specimen length shall be not less than 5 times the nominal outside diameter of the pipe, but in no case less than 300 millimeters (12 inches).

5.3.1.3 Pipe shall be tested as a system which includes representative fittings for which it is intended for use. For pipe intended for use with metal fittings, testing shall be conducted with applicable metal fittings.

Note: Metal fittings are considered to be the 'worst case' due to the potential for metal ion catalysis of the chlorine induced oxidation of the pipe material.

5.3.2 Other

Samples other than pipe shall be tested in a configuration suitable for flow through testing. The test configuration shall as closely as possible represent the end-use application.

5.3.3 End-Use Products

Actual commercial designs simulating end-use products shall be representative of the final product design and manufacturing process.

5.3.4 Systems and Assemblies

System or subsystem designs that include joints or other assembly techniques that represent field installations, or both, may be tested.

Note: Certification of system components other than pipe shall be evaluated on a case-by-case basis to determine testing specifics and suitability of the extrapolation method.

5.3.5 Measurements

Dimensions shall be determined in accordance with ASTM Test Method D2122, where applicable.

5.4 Test Conditions

5.4.1 Temperature

Testing shall be conducted at a minimum of three temperatures. Adjacent temperatures shall be separated by at least 10°C (18°F). Elevated test temperatures are typically chosen to accelerate failure times. The highest test temperature shall be chosen on the basis of experience such that the same failure mechanism is observed at all temperatures and a successful Arrhenius confirmation (Section 5.7.2) is obtained. Test temperatures should be chosen in conjunction with test pressures to provide for brittle failure of the material.

5.4.2 Pressure

For each test temperature, testing shall be conducted at a minimum of two test pressures separated by a minimum of 0.14 MPa (20 psi). Test pressures shall be chosen in conjunction with test temperatures to provide brittle failure of the material. One of the test pressures shall be common for all three temperatures. For one temperature, testing shall occur at three different pressures.

5.4.3 Chlorine Level

Testing shall be conducted at a chlorine level of 4.3 ± 0.3 mg/L in order to ensure a minimum chlorine level of 4.0 mg/L throughout the testing.

5.4.4 pH

Testing shall be conducted at a pH of 6.8 ± 0.2 in order to ensure a maximum pH of 7.0 throughout the testing.

5.4.5 Flow-rate

Testing shall be conducted at a flow rate of 0.1 ± 10% US GPM.

5.4.6 Failure Points

A minimum of 2 failure points is required per test condition, with a minimum of 5 failure points at the highest temperature and pressure condition, for a minimum total of 17 failure points overall.

5.5 Test Sample Conditioning

The internal test water shall be pumped through the test specimens at a temperature of 150 °F (66°C) for a period of 2 hours. After conditioning at 150 °F (66°C), the temperature shall be raised to the test temperature over a period of 1 hour. The pressure shall also be adjusted to the test pressure over this period. Once the internal water and external air environment have reached the test temperature and the system is at the test pressure, timing for the test shall begin.

5.6 Test Procedure

5.6.1 Attach the specimens or assemblies to the system supported in a manner that will minimize externally induced stresses.

5.6.2 After conditioning the specimens as specified in Section 5.5, start the timing devices.

5.6.3 The internal water and external air temperatures, pressure, chlorine level and pH shall be recorded a minimum of hourly throughout the duration of the test. The flow rate shall be checked a minimum of every 72 hours throughout the duration of the test. ORP shall be recorded using a platinum ORP electrode to the nearest ± 10 mV a minimum of every 72 hours throughout the duration of the test for reporting purposes.

5.6.4 Any loss of test fluid through the wall of the specimen or assembly constitutes a failure. The time to failure shall be noted for each failed specimen to the tolerances specified in Table 1. Failures of a clearly ductile nature shall not be used for calculating test life extrapolations. Failures that occur within the fittings will be handled on a case by case basis to determine suitability of the extrapolation method or the requirements for any additional testing prior to certification.

5.6.5 All data shall be reported, whether employed in the regression analysis or not. Widely scattered failures may be indicative of performance to be expected in the field. If circumstances can be determined for inconsistent test performance, the reason shall be noted with the failure time.

5.7 Data Analysis

5.7.1 Data Suitability

Only those data points that represent the same type and general location of brittle failure should be used for analysis.

5.7.2 Arrhenius Confirmation

For the data generated at the same hoop stress (pressure) for all three temperatures, perform regression analysis based on hoop stress, according to the Arrhenius equation:

$$\ln (ft) = a + b/T$$

where:
ft = time to failure in hours;
T = temperature in Rankin (Kelvin)
a = a constant
b = a constant

Pressure may be used in place of hoop stress for products of complex geometries that do not permit the calculation of hoop stress.

The data shall have a R^2 value greater than 0.8 to be considered acceptable for use with this protocol.

5.7.3 Pressure Linearity Confirmation

For the data generated at the same temperature at three different hoop stresses (pressures), perform regression analysis based on hoop stress according to the equation:

$$\log (ft) = a + b \log (S)$$

where:
ft = time to failure in hours;
S = hoop stress, MPa (psi) as given by the ISO equation below
a = a constant
b = a constant

Pressure may be used in place of hoop stress for products of complex geometries that do not permit the calculation of hoop stress.

The data shall have a R^2 value greater than 0.8 to be considered acceptable for use with this protocol.

5.7.4 Regression Analysis

Perform a multiple variable linear regression on the failure data in accordance with the three coefficient rate process model (or model Q of ISO 9080 (see Appendix A)). Data shall be analyzed based on hoop stress as calculated by the ISO equation:

$$S = P (D - t)/2t$$

where:
S = hoop stress, MPa (psi)
P = internal pressure, MPag (psig), and
D = average outside diameter, mm (inches)
t = minimum wall thickness, mm (inches)

Pressure may be used in place of hoop stress for products of complex geometries that to not permit the calculation of hoop stress.

The data shall have a R^2 value greater than 0.8 to be considered acceptable for use with this protocol.

Note: The three coefficient rate process model and model Q of ISO 9080 are identical. Any statistical analysis program capable of multiple linear regression analysis is suitable for analysis.

5.7.5 Test Lifetime Extrapolation

Extrapolate the test lifetime based on the relevant conditions in Table 2. For estimation of test lifetimes under variable temperatures apply Miner's Rule (ISO/DIS 13760) (see Appendix B). The resulting value is the Extrapolated Test Lifetime.

Apply a 0.5 design factor to the Extrapolated Test Lifetime. The resulting value is the Estimated Minimum Chlorine Resistance Service Lifetime of the tested material exposed to typical chlorinated potable water. The Estimated Minimum Chlorine Resistance Service Lifetime shall be greater than 40 years.

The Extrapolated Test Lifetime and Estimated Minimum Chlorine Resistance Service Lifetime provided by this protocol are for conditions equivalent to those under which the test data were obtained and do not take into account other environmental factors that may lead to a reduction in lifetime for the evaluated material.

Table 2. Product End-Use Conditions

Product Type	Extrapolation Pressure	Extrapolation Service Time @ Temperature
Domestic Continuous Re-circulation	0.55 MPa (80 psi)	100% @ 60°C (140 °F)
Traditional Domestic	0.55 MPa (80 psi)	25% @ 60°C (140 °F) 75% @ 23°C (73 °F)

5.8 Report

The final report shall include at a minimum, the following information:

5.8.1 Complete identification of the sample, including material type, source, method of manufacture, manufacturing process details, and manufacturer's name.

5.8.2 Specimen dimensions, including nominal size and, when applicable, average and minimum wall thickness, average outside diameter and length to diameter ratio for before and after testing. When testing configurations other than pipe, include all critical dimensions based on the specific configuration being tested.

5.8.3 A description/drawing/photograph, including sufficient information to identify all components of the test specimen shall be included in the report.

5.8.4 All process conditions, including pressure, water temperature, air temperature, temperature drop across samples, chlorine level, pH, flow-rate and ORP.

5.8.5 A table of temperatures, pressures and time to failure in hours for all the specimens tested.

5.8.6 A description of the nature of the failures and location of the failures.

5.8.7 Any unusual behavior observed in the tests. Any change in color, surface texture, or other change in appearance that may be the result of a physical, chemical, or environmental effect must be reported, whether or not such change played a role in the failure of the part.

5.8.8 Dates of tests

5.8.9 A summary of the regression analysis and the extrapolated test lifetime.

5.8.10 Name of laboratory and signature of the supervisor of the tests.

Appendix A
Regression Analysis

The multiple linear regression analysis shall be based on the three coefficient rate process extrapolation model (or the equivalent three parameter standard extrapolation model (SEM) of ISO 9080):

$$\log_{10} ft = A + B/T + C(\log_{10} S)/T \qquad (1)$$

where:

ft = time to failure in hours;
T = temperature in Rankin (Kelvin);
S = hoop stress, in MPa (psi);
A,B,C = constant;

The four parameter model of ISO 9080 may be used if can be demonstrated to provide better statistical fit to the data:

$$\log_{10} ft = c_1 + c_2/T + c_3\log_{10} S + c_4(\log_{10} S)/T + e \qquad (2)$$

where:

c_i = a parameter
e = the error variable, having a Laplace-Gauss distribution, with zero mean and constant variance. The errors are assumed to be independent

Appendix B
Application of Miner's Rule

1) Perform regression analysis per Appendix A.

2) Based on the regression analysis equation, obtain an extrapolated test lifetime at the following end use conditions:

   A) A pressure of 0.55 MPa (80 psi) and a temperature of 60°C (140 °F).

   B) A pressure of 0.55 MPa (80 psi) and a temperature of 23°C (73 °F).

   Convert the extrapolated test lifetime to years.

3) Calculate the lifetime at 25% service at 60°C (140 °F) and 75% service at 23°C (73 °F) based on Miner's Rule (DIN EN ISO 13760 - 1998).

Example Calculation:

1) Condition A extrapolated test lifetime = t_A
   Condition B extrapolated test lifetime = t_B

2) The total damage per year (TDY) is;

   $TDY = 25/t_A + 75/t_B$

3) The extrapolated test lifetime for 25% service at condition A and 75% service at condition B is;

   $t_c = 100/TDY$ years

Note: Miner's rule provides an estimate of performance under multiple exposure environments. It currently provides what is believed to be the best available method for making this type of estimation. The accuracy of this method may vary with material or product. The percentage of time at higher temperature (60 °C, 140 °F) has been set higher than is reported in actual practice in an attempt to minimize any over-prediction of lifetime that may result due to the possible inaccuracies of Miner's Rule.

