NSF International

MEMORANDUM

TO: Joint Committee on Public Drinking Water Equipment Performance

FROM: Robert W. Powitz, Chairperson

DATE: February 9, 2017

SUBJECT: Straw ballot for proposed revisions to NSF 419 – *Public Drinking Water Equipment Performance – Membrane and Cartridge Filtration* (419i2r1)

A straw ballot for draft 1 of NSF 419 issue 2 is being forwarded to the Joint Committee for feedback. Please review the draft standard and **submit your ballot by March 13, 2017** via the NSF Online Workspace.

When adding comments, **please identify the section number/name for your comment** and add all comments under one comment number where possible. If you need additional space, please upload a word or pdf version of your comments online via the browse function.

Purpose

This straw ballot provides JC members and observers the opportunity to submit initial feedback on multiple revisions being proposed for NSF/ANSI 419 under sections 1, 3, 5, 6 and Annex C.

Background

At the 2016 Joint Committee meeting, members discussed issue papers submitted by Evan Hofeld and Johnny Mendez on proposed revisions to NSF/ANSI 419. Due to the large number of edits, however, the committee determined that a straw ballot should be sent out to allow time for a more thorough review and the opportunity for those members not present during the teleconference to provide feedback.

Revisions include:

— Clarification of the test methods under section 5 (bags and cartridges) and section 6 (Microfiltration and ultrafiltration membrane modules);

— Change of Annex C from informative to normative;

— Additional minimum reporting specifications outlined under Annex C with standardized data reporting tables for more consistent documentation; and

— Addition of an informative Annex F, which illustrates the differences in how theoretical LRV can be calculated.

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Please see 2016 JC meeting summary and links to additional documents under the referenced items for additional background information.

If you have any questions about the technical content of the ballot, you may contact me in care of:

Chairperson, Joint Committee
c/o Monica Leslie
Joint Committee Secretariat
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[Note – the changes are seen below using strikeout for removal of old text and gray highlights to show the suggested text. ONLY the highlighted text is within the scope of this ballot.**]**

NSF/ANSI Standard
for Public Drinking Water Equipment Performance

Public Drinking Water Equipment Performance – Filtration

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1 General

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1.1 Purpose

It is the purpose of this Standard to establish minimum performance requirements for bag filters, cartridge filters, and microfiltration or ultrafiltration membranes used in the treatment and production of public drinking water.

Reason: Added language per comment submitted by J. Mendez to be more descriptive of the type of filtration devices covered under the Standard.

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1.4 Minimum requirements for testing facility and equipment

Testing should be performed at a test facility/laboratory such that the testing equipment at a minimum shall precisely and accurately control flow rate and has a flow meter upstream and/or downstream of the filter unit or membrane module; and shall ensure that the water is well mixed before sampling (e.g., static mixers or appropriate number of pipe lengths with good mixing confirmed).

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2 Normative references

The following documents contain provisions that constitute requirements of this Standard. At the time of the publication, the indicated editions were valid. All standards are subject to revision, and parties are encouraged to investigate the possibility of applying the recent editions of the standards indicated below. The most recent published edition of the document shall be used for undated references.

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ASTM D6908~~-03~~ *Standard Practice for Integrity Testing of Water Filtration Membrane Systems*[1]

[1] ASTM International, 100 Barr Harbor Drive, West Conshocken, PA 19428-2859 <www.astm.org>.

Reason: Removed date from reference to ensure most recent published edition will be used per 2016 JC meeting discussion.

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3 Definitions

The following terms are used in this document, and were derived from the definitions in the EPA guidance manuals for LT2ESWTR referenced herein.

3.1 bag and cartridge filters: Pressure driven separation devices that remove particles typically greater than 1 µm using an engineered porous filtration media.

3.2 challenge particulate: The target organism or acceptable surrogate used to determine the log removal value (LRV) during a challenge test.

3.3 challenge test: A study conducted to determine the removal efficiency or log removal value for the challenge test ($LRV_{C\text{-}TEST}$) of a membrane module, cartridge, or bag filter for a particular organism, particulate, or surrogate.

Reason: Added definition per E. Hofeld's comment and JC meeting discussion on 10/27/16.

3.~~3~~4 crossflow: 1) The application of water at high velocity tangential to the surface of a membrane to maintain contaminants in suspension; also, 2) suspension mode hydraulic configuration that is typically associated with spiral-wound nanofiltration (NF) and reverse osmosis (RO) systems and a few hollow-fiber microfiltration (MF) and ultrafiltration (UF) systems.

3.~~4~~5 deposition mode: A hydraulic configuration of membrane filtration systems in which contaminants removed from the feed water accumulate at the membrane surface (and in microfiltration (MF)/ultrafiltration (UF) systems are subsequently removed via backwashing).

3.~~5~~6 direct integrity test: A physical test applied to a membrane unit in order to identify and/or isolate integrity breaches.

3.~~6~~7 filtrate: The water produced from a filtration process; typically used to describe the water produced by porous membranes such those used in membrane cartridge filtration (MCF), microfiltration (MF), and ultrafiltration (UF) process, although used in the context of the LT2ESWTR to describe the water produced from all membrane filtration processes, including nanofiltration (NF) and reverse osmosis (RO).

3.~~7~~8 flux: The throughput of a pressure-driven membrane filtration system expressed as flow per unit of membrane area on the feed side surface (e.g., gallons per square foot per day (gfd) or liters per hour per square meter (Lmh)).

Reason: Added language per E. Hofeld's suggestion and JC meeting discussion on 10/27/16 to consistent with AWWA B112-15.

3.~~8~~9 hydraulic configuration: The pattern of flow through a membrane process by which the feed contaminants are removed or concentrated (e.g., crossflow, dead-end, etc.).

3.~~9~~10 log removal value (LRV): Filtration removal efficiency for a target organism, particulate, or surrogate expressed as $\log_{10}$

3.~~10~~11 membrane unit: A group of membrane modules that share common valving which allows the unit to be isolated from the rest of the system for the purpose of integrity testing or other maintenance.

3.~~11~~12 microfiltration (MF): A pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.1 – 0.2 ~~mm~~ µm (nominally 0.1 ~~mm~~ µm).

Reason: Revised per E. Hofeld's suggestion and JC meeting discussion on 10/27/16 to consistent with AWWA B112-15.

3.13 minimum detection limit (MDL)[2]: The minimum concentration of substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero, and is determined from analysis of a sample in a given matrix containing the analyte".

3.~~12~~14 module: The smallest component of a membrane unit in which a specific membrane surface area is housed in a device with a filtrate outlet structure; refers to all types of membrane configurations, including terms such as "element" or "cartridge" that are commonly used in the membrane treatment industry.

3.~~13~~15 non-destructive performance test (NDPT): A physical quality control test typically conducted by a manufacturer to characterize some aspect of process performance without damaging or altering the membrane or membrane module.

3.~~14~~16 quality control release value (QCRV): A minimum quality standard of a non-destructive performance test (NDPT) established by the manufacturer for membrane module production that ensures that the module will attain the targeted log removal value (LRV) demonstrated during challenge testing in compliance with the LT2ESWTR.

3.~~15~~17 terminal pressure drop: The pressure drop across a bag or cartridge filter at which the manufacturer states the filter should be replaced. Establishes the end of the useful life of the filter.

3.~~16~~18 ultrafiltration (UF): A pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.01 – 0.05 ~~mm~~ µm (nominally 0.01 ~~mm~~ µm).

Reason: Revised per E. Hofeld's suggestion and JC meeting discussion on 10/27/16 to be consistent with AWWA B112-15.

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5 Bag and cartridge filter systems

5.1 General requirements

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[2] As defined by the U. S. Environmental Protection Agency (USEPA), 40 CFR 136, Appendix B, revision 1.11, Office of Water, 1200 Pennsylvania Avenue, N.W., Washington, D.C. 20460 www.epa.gov

5.1.1 A complete description of the bag or cartridge system to be tested shall be provided. The description shall include the following information for both filter and pre-filter (if applicable):

– model name/number of cartridge/bag and filter vessel;
– maximum design flow rate;
– maximum inlet pressure;
– terminal pressure drop requiring filter changeout;
– exploded schematic diagram of the filter element and housing; and
– status of ~~module~~ filter certification to NSF/ANSI 61.

Reason: Revised per E. Hofeld's comment and JC meeting discussion on 10/27/16.

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5.3 Challenge particulate

5.3.1 The system shall be tested using polystyrene latex microspheres. The polystyrene microspheres shall have 95% of particles in the range of 3.00 ± 0.15 µm. See Annex E for additional information on challenge particulate selection. The size variation of the polystyrene microspheres shall be confirmed by electron microscopy. The spheres shall have a surface charge content of less than 2 uEq/g. The microspheres shall contain a fluorescein isothiocyanate (FITC) dye or equivalent.

Reason: Added reference to Annex E per comment submitted by J. Mendez (10/21/17).

5.4 Apparatus

The filters shall be tested in a test apparatus that meets the requirements of LT2ESWTR and the objectives of this standard and its scope. At a minimum, a test apparatus suitable for conducting challenge testing should include equipment such as pumps, valves, instrumentation, and controls necessary to evaluate full-scale modules. See figure XX for example test apparatus. The test apparatus should also be designed to mimic the hydraulic configuration of the full-scale system as much as practical. The test equipment should be capable of providing the precision and accuracy necessary to generate data within the requirements of this Standard.

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{Insert Figure similar to that in Figure 3 for membranes}

Figure XX – Example test apparatus for Challenge testing bags and cartridge filters

Reason: Added reference to test apparatus figure per comment submitted by J. Mendez (10/21/17).

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5.6.1 Test dust loading water

The test dust is used to load the filter to create a pressure drop across the filter. Test dust shall be added to the general test water specified in 5.6 to achieve a maximum of 10 NTU. The test dust shall have a nominal 0 to 5 µm size classification and shall have 96% (by volume percent) of its particles within this range and 20 to 40% (by volume percent) of its particles greater than 2.5 µm (see Annex E for more informaiton on test dust selection).

Reason: Added reference to Annex E per comment submitted by J. Mendez (10/21/17).

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5.8 Method

There shall be no conditioning period, other than that specified by the manufacturer to prepare the filters for service.

1) Each test unit shall be individually plumbed to the test rig after the rig has been sanitized and rinsed.

2) The filters shall be conditioned per section 5.7.2. During this period the feed flow and inlet pressure shall be adjusted as necessary to obtain the proper flow for the challenge test per section 5.5 of this Standard.

3) At the end of the conditioning period, negative control filtrate samples shall be collected for challenge microsphere enumeration. At least one negative control sample shall contain the test dust at the concentration to be used during the challenge test. This shall aid in assessing potential interferences with the microsphere enumeration analytical procedures.

4) Filter operation shall begin at the proper flow. Injection of the challenge microsphere suspension shall be started. Feed and filtrate samples shall be collected after at least three void volumes of water containing the challenge microspheres have passed through the test unit, to allow for establishment of equilibrium. The vendor shall provide the unit void volume, or alternatively, the calculated approximate volume of the housing and associated piping should be used ~~to provide an additional safety factor~~ as a conservative estimate of unit void volume. For instance, if the housing is a typical cylinder design, the calculated volume of a cylinder of the height and diameter of the housing, plus the volume of any piping should be used. After the appropriate injection time, grab samples shall be collected from the feed and filtrate sample taps. The sample taps shall be fully flushed prior to sample collection. After sample collection is complete, challenge suspension injection shall be stopped and filter operation shall continue.

5) The filter shall be operated until the pressure drop across the filter is 50% ± 5% of the terminal pressure drop value. At this point, the second microsphere challenge shall be conducted following the procedure in Step 4.

6) Immediately following the second microsphere challenge, resume filter operation until the terminal pressure drop is reached. Repeat Step 4 to conduct the terminal pressure drop microsphere challenge.

7) Immediately after the terminal pressure drop microsphere challenge is complete, filter operation shall be stopped for a five minute rest period, Operation shall then be restarted and injection of microspheres resumed. Samples for polystyrene microsphere analysis shall be collected from the first filtrate water out of the system upon restart, then again after five minutes of operation and ten minutes of operation.

8) LRV values shall be calculated according to the guidelines established in Annex C.

Reason: Revised per comments submitted by J. Mendez (10/21/17)

6 Microfiltration and ultrafiltration membrane modules

6.1 General requirements

6.1.1 A complete description of the microfiltration or ultrafiltration membrane module to be tested shall be provided. The description shall include the following:

– vendor name;
– model name/number of membrane element and vessel (if applicable);
– membrane material;
– mode of operation (cross-flow, dead-end, or either; pressure or vacuum driven);
– type of membrane module configuration (e.g. hollow fiber, spiral wound, etc.);
– water flow through membrane (inside-out or outside-in);
– status of module certification of NSF/ANSI Standard 61, or equivalent; and
– the membrane specifications listed in Table 2.

Table 2 – Membrane module specifications

~~Dimensions:~~ Module Specifications:
Membrane media dimensions (e.g., inside and outside diameter and wall thickness length of hollow-fibers or sheet dimensions, thickness, etc. of spiral-wound filters)
Membrane media symmetry (e.g., symmetric, asymmetric, composite, etc.)
Module outside diameter
Module length
Module volume (gallons and liters) ~~- volume of pressurized air in module (volume of system)~~
Volume of pressurized air in module during direct integrity testing (gallons and liters)
Nominal and maximum membrane pore size, or molecular weight cutoff rating
~~Membrane surface area (feed side)~~
Feed side membrane filtration area within a module (ft^2)
Volumetric Concentration Factor (VCF, dimensionless)
liquid-membrane contact angle (ɵ, degrees)
Net Expansion Factor (Y) if used in calculating the ALCR
Lumen diameter (d, mm) if used in calculating the ALCR
Potting depth or defect length (l, mm) if used in calculating ALCR
Pore shape correction factor (K, dimensionless)
Filtration Flow Direction (i.e., inside-out or outside-in)
Maximum oxidant tolerance
Operating temperature range
Maximum oxidant tolerance
Operating pH range
Target Challenge Test Operating Limits:
Hydraulic configuration (i.e., deposition or suspension)
Maximum design filtrate flux at 20°C
Flow range per module
Maximum inlet module pressure
Maximum transmembrane pressure (TMP) at 20°C
Maximum transmembrane pressure (TMP) (any temperature)
~~Maximum oxidant tolerance~~
Total system volume in challenge test skid (V_{sys}, in both gallons and liters)

	of pressurized air during direct integrity testing.
	Minimum direct integrity test pressure (psi)
	Baseline decay (Dbase)
	Direct integrity test duration (seconds)
	Non-destructive performance test (NDPT) method (e.g., pressure decay, etc.) and results applied to each module subject to challenge testing.
	Quality Control Release Value (QCRV) applied for each module selected for challenge testing (include QCRV units)

Reason: Revised per recommendations from E. Hofeld and J. Mendez and JC meeting discussion on 10/27/16. If the JC agrees that Annex C should be normative as proposed, Table 2 can be removed and this information would be listed under the annex instead.

If the hydraulic mode of operation is suspension (e.g. cross-flow), the vendor shall provide the maximum recommended recovery, so that testing is able to be conducted at the maximum volumetric concentration factor (VCF).

6.1.2 A minimum of five modules shall be tested, and greater than five is recommended. The modules should be selected by the filter manufacturer from five different production runs if possible.

6.2 Challenge organisms

6.2.1 *B. atrophaeus* endospores shall be used as the surrogate for *Cryptosporidium* for testing membrane modules. For virus product specific challenge testing (PSCT), modules shall be challenged with the MS-2 coliphage virus. It is permissible for MS-2 coliphage to be used as a conservative *Cryptosporidium* surrogate.

6.2.2 The challenge organism suspensions shall be injected into the feed water stream with the following recommended target concentrations in the feed water (using consistent units):

Maximum Feed Concentration, $C_{f\text{-}max} = (3.16 \times 10^6) \times$ Minimum Filtrate Detection Limit

Minimum Feed Concentration, $C_{f\text{-}min} = (10^{LRVtarget}) \times$ Minimum Filtrate Detection Limit

Where, LRV_{target} may range from 5.7 - 6.5 $\log_{10}$ (5×10^5 - 3.16×10^6)

Reason: Added per comment by E. Hofeld with the following questions for the JC to consider:

"Or should it be a range of 4 - 6.5 $\log_{10}$ (1.2×10^4 - 3.16×10^6)?? Equation 3.2 of he membrane filtration guidance manual (MFGM) devines the maximum feed concentration Cf-max = (3.16 x 10^6) x detection limit. It seems like the LRVtarget (LRVt) should be 5.7-6.5-log over the detection limit. Should the minimum detection limit be specified, since theoretically challenge testing could be done by a third part using NSF 419 protocol.

Should the minimum feed concentration be explicit (i.e., use Equation 3.3 of the MFGM where Cf-min = (10^LRVt) x detection limit.

This comment may also apply to cartridge and bag where max feed concentration = 1x10^4 x Filtrate Detection Limit per 40 CFR 141.719."

- MS-2 – 5×10^5 to 3.16×10^6 plaque forming units per milliliter (PFU/mL); and

– *B. atrophaeus* – 5 x 10^5 to 3.16 x 10^6 colon forming units (CFU) per 100 mL.

NOTE – The MFGM calls for the maximum challenge concentration to be 6.5 log_{10} above the organism's detection limit (3.16 x 10^6). The goal for the *B. atrophaeus* challenges is to be able to measure log reductions as close to 6.0 log_{10} without exceeding 6.5 log_{10}.

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6.3 Apparatus

The filters shall be tested in a test apparatus that meets the objectives of this standard and its scope. At a minimum, a test apparatus suitable for conducting challenge testing should include equipment such as pumps, valves, instrumentation, and controls necessary to evaluate full-scale modules. The test apparatus should also be designed to mimic the hydraulic configuration of the full-scale system as much as practical; however, it is permissible for the test apparatus to utilize a more conservative recovery (i.e. hydraulic efficiency) than the full-scale system. The test apparatus should allow the membrane module to undergo direct integrity testing both before and after the challenge test. The test equipment should be capable of providing the precision and accuracy necessary to generate data within the requirements of this Standard.

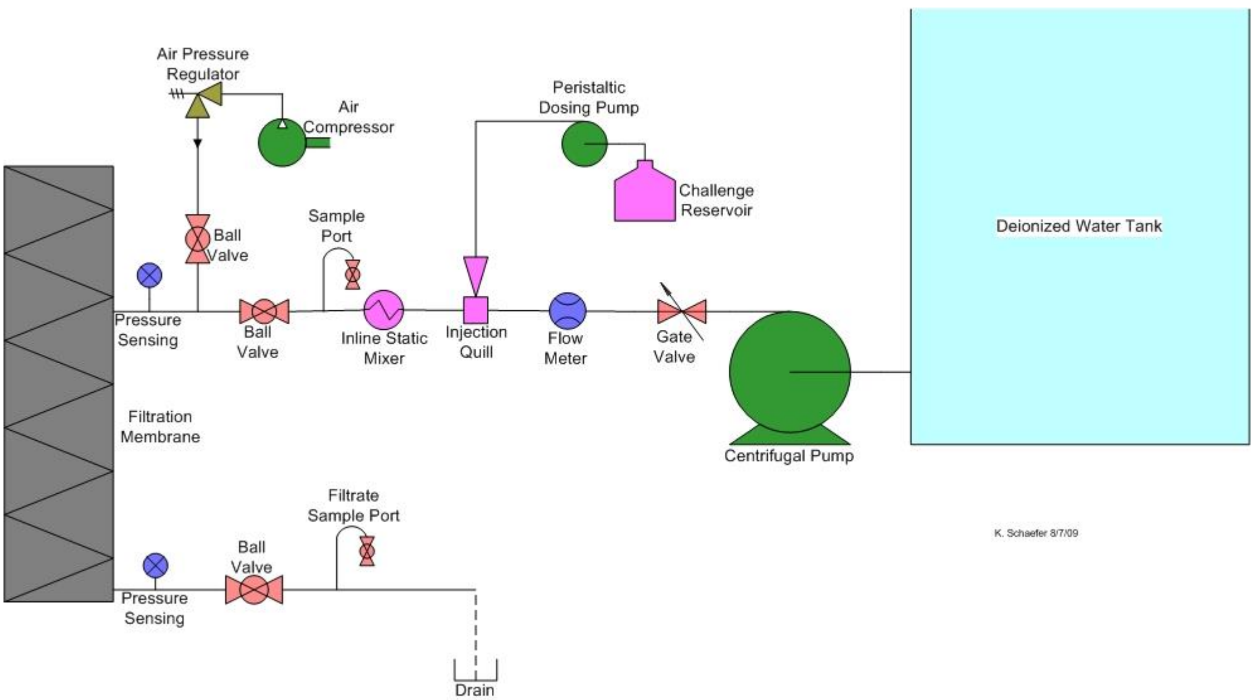

Figure 3 – Example test apparatus for a deposition mode membrane system

Reason: Revised per comments submitted by J. Mendez (10/21/17) with the following question for the JC to consider: "Do we also want an example diagram for a suspension mode system (e.g. one with cross-flow hydraulic configuration)?"

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6.5 General test water

A dechlorinated, potable water supply shall be used with the following characteristics:

alkalinity	≥ 20 mg/L
HPC	< 500 bacterial colonies/mL
iron[1]	Recommended non-detectable levels and < 0.3 mg/L
manganese[1]	Recommended non-detectable levels and < 0.3 mg/L
pH	6.5-8.5
residual disinfection or oxidants in tap water (e.g., free chlorine, total chlorine, potassium permanganate, and chloramines)	None ~~detected~~ added
temperature	10 - 27 °C (50 - 81 °F)
total organic carbon (TOC)[1]	Measure and report values in test report
turbidity	<0.3 NTU
[1]The levels of these parameters and any others present in the test water shall not be of a type and quantity to form a cake on the filtration media that could bias the observed reduction of challenge organisms over the performance of the test.	

Reason: Revised per comment submitted by E. Hofeld.

6.6.2 Conditioning

Prior to testing, the modules shall be conditioned following a procedure supplied by the vendor. Immediately prior to testing, each module shall also be backflushed per the vendor's specifications, if appropriate. Conditioning shall include operation through at least one cycle of each anticipated backwash process (e.g., water backwash, air backwash, chemically enhanced backwash, etc.) and one clean-in-place.

Reason: Revised per comment submitted by E. Hofeld.

6.7 Membrane integrity tests

Prior to testing, each module shall be subject to the same non-destructive performance test (NDPT) that the manufacturer uses at the production facility for quality control testing of each module manufactured. The results of ~~this~~ challenge testing should be used to reset the manufacturing quality control release value (QCRV). Immediately before and after each individual module challenge test, the module shall undergo the manufacturer's recommended daily direct integrity test (DIT) for modules in-use.

A manufacturer's procedure for conducting a NDPT shall ensure that the QCRV associated with the minimal result from the NDPT, is indicative of a NSDPT resolution of 3 µm. Thus the NDPT shall be responsive to an integrity breach on the order of 3 µm or less ~~(40 CFR 141.710 (b)(ii))~~. The methods to determine the 3 µm resolution shall be done as described in section 4.2 Test Resolution of the Membrane Filtration Guidance Manual ~~or in ASTM Method D 6908-03: *Standard Practice for Integrity Testing of Water Filtration Membrane Systems.*~~

Reason: Comments from E. Hofeld regarding Section 6.7:

Admittedly, I'm a little confused by this section. Section 3.7 of the MFGM indicates two different approaches to selecting modules for the challenge test. One approach is a random sampling and

the other is based on previous QC data from the product line in a manufacturer may already have results of NDPT and have established a QCRV and provided the NDPT meets the 3 micron resolution, it reasonable that all production modules will meet a QCRV established based on challenge test results. Does NSF-419 specifically seek to exclude the random sampling option and is the intent to specify that modules tested must have passed a NDPT and QCRV that meets the 3 micron resolution requirement?

The MFGM defines QCRV as a minimum quality standard of non-destructive performance test established by the manufacturer for membrane module production that ensures that the module will attain the targeted LRV demonstrated in the challenge test. In other words, isn't the QCRV determined after LRVC-TEST is determined?

Pg 3-10 of the MFGM states: "After a group of modules has been subjected to challenge testing, the NDPT is applied to those modules to determine an appropriate QCRV associated with the removal efficiency observed during the test."

This section is a bit confusing. 40 CFR 141.719(b)(3)(ii) addresses direct integrity tests (after installation at a water treatment plant). 40 CFR 141.719(b)(2)(vii) addresses NDPT sufficient to demonstrate the QCRV, but does not address having to meet a 3 micron resolution. The 3 micron resolution requirement only applies to the direct integrity test. MFGM Section 4.2 defines resolution as the size of the smallest integrity brach that contributes to a response from a direct integrity test. Any direct integrity test applied to meet the requirements of the LT2ESWTR is required to have a resolution of 3 microns or less.

NDPT is addressed under MFGM section 3.6 and that section does state that the NDPT used must be consistent with the resolution requirement of the LT2ESWTR in order for a module to be eligible for Crypto removal credit. This would imply that the manufacturer should document the type of test used (likely pressure based) and the variables used in determining the NDPT test pressures similar to that contained in MFGM Equation 4.1 in which $P_{test} = (0.193 \times K \times \sigma \times \cos \theta) + BP_{max}$ ***in which 0.193 is a factor that includes unit conversions and accounts for the 3 micron resolution. This is why I added K, σ, ɵ, and*** BP_{max} ***to Table 2.***

I don't think ASTM 6908 addresses the resolution requirement like the MFGM does as it relates to LT2.

6.8 Method

Each of the modules shall be challenged individually, and separate challenge tests shall be conducted for each challenge organism. The modules shall not have been used previously when challenged. There shall be no seasoning period, other than that specified by the vendor to sufficiently rinse out the membrane preservative, ~~and~~ wet the membranes, and satisfy the conditioning requirements in section 6.6.2.

Reason: Revised per comment submitted by E. Hofeld.

Each membrane shall be individually plumbed to the test rig after the rig has been sanitized and rinsed. If it is the first time the module is installed, it shall be flushed per the vendor's flushing and conditioning procedure. If the module has already been tested with another challenge organism, the module shall only be backwashed following a procedure supplied by the vendor, then forward flushed for at least five minutes at the test flow rate.

Following the forward flush, the pre-test DIT described in 6.7 shall be conducted.

After completion of the DIT, the module shall again be forward flushed for at least five minutes using the test water (minus challenge organism injection) specified in 6.5. After five minutes of flushing, two feed samples and two filtrate samples shall be collected. One sample from each process stream shall serve as a negative control, and shall be enumerated the challenge organism. The second sample pair shall serve as positive controls, and shall be spiked with the challenge organism (See Annex B for definition of positive and negative controls and other QA/QC elements).

Reason: Added reference to Annex B per comment submitted by J. Mendez.

During the forward flush, the feed flow, and also the reject flow if necessary, shall be adjusted to reach the proper flows for the challenge test.

The time needed for sampling the challenge particle from the filtrate ~~Each~~ during the challenge test shall be approximately 35 minutes in length, excluding the time needed to reach the equilibrium volume (V_{eq}). The challenge organism shall be injected into the feed stream at start-up, after 15 minutes of operation, and after 30 minutes of operation. As required in 6.3, the challenge organisms shall be intermittently injected into the feed stream prior to, and during sample collection. The feed and filtrate samples after each injection period (start-up, after 15 minutes, and after 30 minutes) shall not be collected until at least three hold-up volumes of water containing the challenge organism have passed through the membrane, to allow for establishment of equilibrium (equilibrium volume). The hold-up volume is defined as the “unfiltered test solution volume that would remain in the system on the feed side of the membrane at the end of the test.” The hold up volume would include the feed side piping and ~~The vendor shall provide~~ the module hold-up volume on the feed side of the membrane, or alternatively, the volume of the entire module shall be used to provide an additional safety factor.

The total volume needed to complete the test can be calculated using MFGM Equation 3.1 as shown below:

$$V_{test} = ((QxT)/R) + V_{hold} + V_{eq}) \text{ x } SF$$

Where,

Vtest = Minimum challenge test solution volume (gallons)
Q = filtrate flow (gpm)
T = challenge test duration (min)
R = system recovery during the test (decimal percent)
V_{hold} = hold-up volume of the test system, which is the unfiltered test solution volume that would remain in the system on the feed side of the membrane barrier at the end of the test and could include the feed side volume within the membrane module as well as associated feed-side piping (gallons).
V_{eq} = System volume required to attain equilibrium feed concentration (gallons)
SF = Safety factor (dimensionless). The safety factor typically ranges from 1.1 - 2.

Since the challenge particulate is injected at three different times (intermittent injection with the first injection at start-up, the second after 15 minutes of operation, and the third after 30 minutes of operation), it is necessary to ensure that equilibrium is achieved during each seeding event prior to collection of any feed or filtrate samples. Therefore, the equation for V_{test} will need to be used three times to determine the total test volume with each injection event.

Reason: Added clarifying language per comments submitted by E. Hofeld.

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After the appropriate injection time, grab samples shall be collected from the feed and filtrate sample taps. The sample taps shall be flame sterilized, and then fully flushed prior to sample collection. After sample collection is complete, the challenge suspension injection shall be stopped and clean test water shall be pumped through the modules until the next sampling point.

Log reduction values (LRV) shall be calculated, and a test report created using the guidelines provided in Annex C.

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Annex C[3]

(~~informative~~Normative)

Data management, analysis, and reporting

Reason: Annex C was refined to specify information only for membrane challenge studies that should be included in every challenge study report. Since the expectation that this data is to be included in every report, it is believed that this should be a normative Annex with standardized data reporting tables for more consistent documentation. This change was proposed by E. Hofeld.

Data management, analysis, and reporting

C.1 Data management and analysis

All operational and analytical data shall ~~should~~ be gathered and included in the challenge test report. The data shall ~~should~~ consist of results of analyses and measurements and QA/QC reports. The challenge test report shall consist of the following:

- introduction;
- description and identification of product tested;
- procedures and methods used in testing;
- results and discussion, including QA/QC discussion; ~~and~~
- LRV and the theoretical LRV ($LRV_{ambient}$) for each module tested;
- $LRV_{C\text{-}TEST}$;
- direct integrity test results and sensitivity (LRVDIT)
- Description of the non-destructive performance test (NDPT)
- QCRV based on $LRV_{C\text{-}TEST}$; and
- references.

C.2 Work plan

The following is the work plan to manage challenge test data: ~~for data management:~~

- Laboratory personnel shall record equipment operation, water quality and analytical data by hand on bench sheets.

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[3] ~~The information contained in this annex is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this annex may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Standard.~~

- All bench sheet entries shall be made in water-insoluble ink.
- All corrections on the bench sheets shall be made by placing one line through the erroneous information. Any corrections shall be dated and initialed by the lab personnel making the correction.

- ~~Pertinent information from the bench sheets shall be entered into a laboratory information management system or equivalent.~~

~~The database for verification testing programs shall be set up in the form of custom-designed spreadsheets.~~ Pertinent lab data shall be entered into ~~the appropriate~~ spreadsheets for validating calculations. ~~All recorded calculations shall also be checked at this time.~~ Following data entry, the spreadsheet shall be printed out and the printout checked against the official laboratory data reports or bench sheets.

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C.3 Performance reporting

The results of individual module performance (LRV) and the overall performance for the make and model of module tested ($LRV_{C\text{-}TEST}$) shall be documented in the challenge test report. The sensitivity of the direct integrity test (LRV_{DIT}) as well as the theoretical performance of each module ($LRV_{ambient}$) shall also be documented. More information on the differences in the documented terms of LRV are provided below and information on the differences in how LRV_{DIT} and $LRV_{ambient}$ are calculated is contained in Annex F. The data tables provided in section C.4 accomodate the reporting of LRV, $LRV_{C\text{-}TEST}$, LRV_{DIT}, and $LRV_{ambient}$.

C.3.1 LRV and $LRV_{C\text{-}TEST}$

Microorganism removal shall be evaluated through log reduction calculations. All challenge organism samples shall be analyzed in triplicate, and geometric means calculated. The geometric means shall be log transformed for the purpose of calculating log reductions. To calculate average log reductions, the arithmetic means of the logs of the individual sampling points shall be calculated.

C.3.1.1 Log Removal Calculations for Membranes:

The LT2ESWTR requires that a single LRV be generated for each module tested for the product line under evaluation. The LRVs for each respective module tested are then combined to yield a single value of $LRV_{C\text{-}Test}$ that is representative of the product line.

Under the LT2ESWTR, the LRV is calculated according to the following equation (40 CFR 141.719(b)(2)(v)):

$LRV = \log(Cf) - \log(Cp)$ (MFGM Equation 3.7)

Where:
LRV = log removal value demonstrated during a challenge test
Cf = feed concentration of the challenge particulate
(number or mass / volume)
Cp = filtrate concentration of the challenge particulate
(number or mass / volume)

Note that the feed and filtrate concentrations must be expressed in identical units (i.e., based on equivalent volumes) in order for Equation 3.7 to yield a valid LRV. If the challenge particulate is not detected in the filtrate, then the term Cp is set equal to the detection limit.

There are several methods that could be used to calculate the representative LRV for a module. If multiple feed/filtrate sample pairs are collected, a LRV can be calculated for each set of paired data, and the LRV for the tested module could be selected as the lowest LRV (more conservative) or the average of the LRVs (less conservative). NSF Standard 419 will use the latter method.

The overall value of $LRV_{C\text{-}Test}$ (i.e., the removal efficiency of the product) is based on the entire set of LRVs obtained during challenge testing, with one representative LRV established per module tested. The manner in which $LRV_{C\text{-}Test}$ is determined from these individual LRVs depends on the number of modules tested. Under the LT2ESWTR, if fewer than 20 modules are tested, then the lowest representative LRV among the various modules tested is the $LRV_{C\text{-}Test}$. If 20 or more modules are tested, then the 10th percentile of the representative LRVs is the $LRV_{C\text{-}Test}$. The percentile is defined by [i/(n+1)] where "i" is the rank of "n" individual data Chapter 3 – Challenge Testing points ordered from lowest to highest. It may be necessary to calculate the 10th percentile using linear interpolation (40 CFR 141.719(b)(2)(vi)).

C.3.1.2 Log Removal Calculations for Bag and Cartridge Filters

The LRV calculations for bag and cartridge filters shall follow the same procedure outlined in section C3.1.1 with the following exceptions:

- The LRV assigned to an individual bag or cartridge tested (LRV_{Filter}) should be the minimum value obtained from the three differential pressure challenge cycles.
- If fewer than 20 filters are tested, the overal LRV ($LRV_{C\text{-}Test}$) for the entire product line tested shall be equal to the lowest LRV_{Filter}
- If more than 20 filters are tested, $LRV_{C\text{-}Test}$ shall be equal to the 10^{th} percentile of the LRV_{Filter} values for the various filters tested.

C.3.1.3 QCRV determination During Challenge Testing:

Challenge testing is used to establish the LRV of an integral module of a particular product type, it does not necessarily guarantee that all such modules produced will achieve the same level of performance due to variability in the manufacturing process. In order to address this issue, a Non-Destructive Performance Test (NDPT) is applied to all subsequently manufactured modules that are not subject to challenge testing to ensure that these modules meet the performance established during challenge testing.

The minimum passing test result for a NDPT is known as the quality control release value (QCRV). After a group of modules has been subjected to challenge testing, the NDPT is applied to those modules to determine an appropriate QCRV associated with the removal efficiency observed during the test. Subsequently, all modules that are not subjected to challenge testing must pass the same NDPT by exceeding the established QCRV applicable to Cryptosporidium removal under the LT2ESWTR. Modules that do not pass the NDPT at the QCRV would not be eligible for Cryptosporidium removal credit under the rule and could not be used in any membrane filtration systems applied for this purpose (40 CFR 141.719(b)(2)(vii)).

The LT2ESWTR does not specify a particular procedure for determining the QCRV from the various modules that are subjected to challenge testing. Therefore, the independent testing organization in consultation with the manufacturer can have discretion in selecting an appropriate methodology. This standard recommends employing a methodology similar to that required for determining the overall removal efficiency based on the number of LRV observations for each module tested (see determination of $LRV_{C\text{-}Test}$ in section C3.1.1 above).

~~**C.3.2 Information on Liquid Contact Angle and others for Annex C Data Management, Analysis, and Reporting**~~

~~Liquid-membrane contact (e.g., "wetting") angle is measured in degrees and indicated by Θ. The Θ value is used in equations to achieve a resolution of 3 µ with pressure-based direct integrity tests The pressure applied during the test must be great enough to overcome the capillary forces 3 µ hole thus ensuring that any breach large enough to pass *Cryptosporidium* oocysts would also pass air during the test. The amount of pressure needed to achieve a 3 µ resolution is important to compliance the LT2ESWTR~~

~~The liquid-membrane contact angle ranges from 0-90º and is primarily a function of the membrane hydrophilicity, which can be characterized in general terms as the affinity of the membrane material for water or the ability of the membrane to become wetted with water. For an ideally hydrophilic membrane, the liquid-membrane contact angle is 0 degrees. Although many membranes used for drinking water applications are manufactured using hydrophilic materials, an ideally hydrophilic membrane is purely theoretical.~~

~~The Θ value is unique to a membrane material and type. In the absence of data supplied by the membrane manufacturer, a conservative value of Θ = 0 is suggested in the LTESWTR MFGM. Because a less conservative contact angle can significantly reduce the minimum required integrity test pressure, any value for Θ other than 0 degrees should be well documented and approved by the State if used for the purposes of regulatory compliance such as under the LT2SWTR.~~

~~Log Removal Value (LRV) estimate from PDT test data~~

~~When using PDT data, an LRV can be estimated by calculation LRV_{calc}. The LRV_{calc} can be calculated using an equation and measurement during the PDT. However, there are some assumptions which should be discussed and resolved.~~

~~The equation for the LRV_{calc} calculation is:~~

~~$LRV_{calc} = \log [(Qp * ALCR*Patm)/(\Delta Ptest*Vsys*VCF)]$~~

~~The terms in the equation are:~~

- ~~Qp - flow measured prior to testing (average of pre and post challenge flow measured);~~
- ~~ALCR - air-liquid conversion ratio (dimensionless) and read discussion on ALCR;~~
- ~~Patm - atmospheric pressure at sea level = 14.7 psi;~~
- ~~Δptest - decay rate in psi/min (pre and post challenge average);~~
- ~~Vsys - volume (L) of pressurized air in the system during the test which is the hold-up volume;~~
- ~~VCF - value for deposition mode = 1~~

~~The equation for ACLR calculation is:~~
~~$ACLR = 170 \times Y \sqrt{((Ptest-BP)^* \times (Ptest+ Patm)\div[(460+T)*TMP])}$~~

~~The terms of the equation are:~~

- ~~Y = net expansion factor for compressible flow through a pipe to a larger area (dimensionless) but see Crane 1988. Shall we assume isothermal flow through fibers? The range from Page A-22 of Crane are 0.588 - 0.718. So shall we use the middle of the range?~~

~~Ptest - direct integrity test pressure (psi);~~
~~BP - backpressure on the system during the integrity test (psi) which is always 0 as it is open to the atmosphere;~~

~~Patm - atmospheric pressure (psia) and the atmospheric pressure at sea level = 14.7;~~

~~T - water temperature (F);~~

~~TMP- trans-membrane pressure during normal operation (psi) which is difference between inlet and outlet measured pressure during testing.~~

~~Are the assumptions acceptable?~~

Reason: See new proposed Annex F for language to illustrate the differences in how theoretical LRV can be calculated.

C.3.2 LRV_{DIT}

In addition to log reductions determined empirically through the challenge test, a log reduction value representing the sensitivity of the direct integrity tests conducted as part of the challenge study, represented by the expresion LRV_{DIT}, shall also be determined using a theoretical formula provided by the manufacturer. This formula shall be identical to the formula recommended by the manufacturer for use at full-scale installations of production modules for determing the direct integrity test sensitivity at water treatment plants, however, it is understood that some of the variables used at full-scale installations will necessarily be site-specific. LRV_{DIT} may be similar to the measured log removal value (LRV) for each module tested, however, the intent of this calculation is to quantify the sensitivity, expressed as a log removal value, of the direct integrity test conducted on each module in detecting a response from a 3 µm breach. The sensitivity of the direct integrity test is dependent upon the applied direct integrity test pressure as well as the sensitivity of the instruments used to detect the pressure decay rate.

C.3.3 $LRV_{ambient}$

The same formula used to calculate LRV_{DIT} shall be used to calculate a theoretical LRV based on current or "ambient" operating conditions during the challenge test using the actual direct integrity test data. This theoretical log removal value is distiquished from LRV_{DIT} by the term $LRV_{ambient}$. Although theoretical in nature, $LRV_{ambient}$ should be similar to the measured log removal value (LRV) for each module tested.

C.3.4 Information from the manufacturer

The following tables present minimum information to be provided by manufacturers to be included in the final report:

Table C-1. Make and Model Specifications for Cartridges and Bag Filters	
Parameter	**Value**
Model Name/Number of filtration system	
Model name/Number of replacement filter cartridges or bags	
Model name/Number of filter vessel	
Nominal Pore Size of filter and pre-filter (if applicable) (µm)	
Maximum design flow rate (gpm)	
Maximum inlet pressure (psi)	
Maximum design differential pressure across filter cartridges or bags (psi)	

Terminal pressure drop requiring filter chang-out (psi)	
NSF/ANSI certification status	

Table ~~X-Y~~C-2. Make and Model Module Specifications for Membranes	
Parameter	**Value**
~~Dimensions~~ Specifications:	
Nominal Membrane Pore Size (µm)	
Fiber Inner Diameter (mm)	
Fiber Outer Diameter (mm)	
Module diameter (mm)	
Module length (m)	
Feed side membrane filtration area within a module (ft^2) ~~Membrane surface area~~	
Filtration Flow Direction	
Volumetric Concentration Factor (VCF, dimensionless)	
Contact angle in degrees (ɵ)	
Net Expansion Factor (Y) if used in calculating the ALCR	
Lumen diameter (d, mm) if used in calculating the ALCR	
Potting depth or defect length (l, mm) if used in calculating ALCR	
Pore shape correction factor (K, dimensionless)	
Liquid-membrane contact angle (ɵ, degrees)	
Operating Conditions:	
Filtration Flow Direction (i.e., inside-out or outside-in)	
Hydraulic configuration (i.e., deposition or suspension)	
Operating Limits:	
Maximum certified flux at 20 °C	
Maximum certified flow at 20 °C per module	
Operating temperature range	
Maximum feed pressure	
Maximum transmembrane pressure (TMP) at 20 °C	
Maximum transmembrane pressure (TMP)	
Operating pH range	
Maximum chlorine tolerance	
Manufacturing NDPT	
Method	
Quality Control Release Value (QCRV)	

Reason: Addition of minimum reporting requirements per comments submitted by E. Hofeld and J. Mendez.

C.4 Report of equipment testing

The report should be issued in draft form for review prior to final publication. The reports should be prepared and consist of the following:

_ Executive Summary:

    - Summary description of membrane filtration product
    - Summary of challenge test protocol
    - LRV demonstrated during challenge testing
    - Quality control release value for non-destructive performance testing
- introduction;
    - Description of testing organization
    - Test site
    - Description of membrane filtration product
    - Testing objectives (including target LRV)
- description and identification of product tested, including manufacturer's non-destructive performance testing
- procedures and methods used in testing;
    - Description of test apparatus
    - Challenge particulate (including rationale for selection)
    - System operating conditions
    - Challenge test solution design
    - Seeding method
    - Process monitoring
    - Detailed sampling plan
    - QA/QC procedures
    - Data management
- results and discussion, including QA/QC discussion;
    - Summary of measured system operating conditions
    - Summary of LRV results for each module tested
    - $LRV_{C\text{-}TEST;}$
    - Summary of system integrity evaluation, including calculations showing V_{test}, feed concentration, recommended pressure decay rate. ALCR and LRV_{DIT}
    - Determination of removal efficiency
    - Summary of NDPT results for each module tested,
    - QCRV determination based on the results of non-destructive performance testing
    - Statistical evaluation of results (if applicable) ~~and~~
- references~~.~~;

The challenge test results shall be reported in data tables having the format shown in C.4.1 - C.4.8.

C.4.1 Challenge test summary results

Challenge Test Summary Results

Membrane make	
Membrane model number	
Membrane type[1]	
Membrane classification[2]	
Challenge Test Date	
Challenge Particle	
$LRV_{C\text{-}TEST}$ (log)	
Challenge Test Flux (gfd)	
Challenge Test TMP (psi)	
Non Destructive Performance Test (NDPT) Method	
Quality Control Release Value (QCRV)	
Equation for Air-Liquid Conversion Ratio (ALCR)	
Equation for LRV_{DIT}	

[1]Membrane type shall be denoted by "hollow fiber", "flat sheet", or similar expression.
[2]Membrane classification shall be denoted by "ultrafiltration", "microfiltration", or similar expression.

C.4.2 Membrane specifications and integrity information

For hollow fiber membrane modules, the following data tables shall be used to document the membrane specifications and integrity information. The format may need to be modified to accomodate flat sheet or spiral wound membranes, however, the information provided should match as close as possible to that shown in the table below.

Membrane Specifications

Description	
Membrane Make	
Membrane Model Number	
ANSI/NSF Standard 61 certification	
Membrane type[1]	
Membrane classification[2]	
Nominal and maximum membrane pore size, or molecular weight cutoff rating	
Membrane media symmetry[3]	
Membrane material	
Feed side membrane filtration area (ft^2)	
Membrane module dimensions[4]	
Module outside diameter (mm)	
Module length (mm)	
Module volume (gallons and liters)	
Potting depth (mm)	
Membrane fiber characteristics[4]	
Number of fibers per module	
Inside fiber diameter (mm)	

Fiber wall thickness (mm)	
Active fiber length (mm)	
Filtration Flow Direction (i.e., inside-out or outside-in)	
Hydraulic configuration (i.e., deposition or suspension)	
Operating Limits	
Maximum design filtrate flux at 20°C (gfd)	
Maximum inlet module pressure (psi)	
Maximum design transmembrane pressure (TMP) at 20°C	
Maximum transmembrane pressure (TMP) not to be exceeded at any temperature	
Maximum oxidant tolerance (cleaning)	
Maximum oxidant tolerance (normal operation)	
pH tolerance range (cleaning)	
pH tolerance range (normal operation)	
Temperature tolerance range	

[1]Membrane type shall be denoted by "hollow fiber", "flat sheet", or similar expression.
[2]Membrane classification shall be denoted by "ultrafiltration", "microfiltration", or similar expression.
[3]Membrane media symmetry shall be denoted by "symmetric", "asymmetric", or "composite".
[4]This information may vary based on membrane type.

Membrane Integrity Information

Revised non-destructive performance test (NDPT) method and quality control release value (QCRV)[1]	
NDPT method (e.g., pressure decay, etc.)	
QCRV (include units)	
Equations for use in determining LRV_{DIT}, ALCR, and direct integrity test pressures	
LRV_{DIT} equation	
ALCR equation	
Direct integrity test pressure equation	
Constants for use in determining LRV_{DIT}, ALCR, and direct integrity test pressures	
Volume of pressurized air in module during direct integrity testing (gallons)	
Volume of pressurized air in module during direct integrity testing (liters)	
Volumetric Concentration Factor (VCF, dimensionless)	
Net Expansion Factor (Y)	
Lumen diameter (d, mm)	
Potting depth or defect length (l, mm)	
Pore shape correction factor (K, dimensionless)	
liquid-membrane contact angle (ɵ, degrees)	
Maximum design flow rate per module (L/min)	

[1]The "revised" non-destructive performance test (NDPT) method and quality control release value (QCRV) are the NDPT and QCRV established as a result of the challenge study that will demonstrate meeting the 3 micron resolution requirement (with calculations and variables used) and that the modules will meet the removal efficiency demonstrated by the challenge test ($LRV_{C\text{-}TEST}$). These may not have changed from what the manufacturer was already using, however, the term "revised" is used to denote the NDPT and QCRV to be used as a result of the challenge test.

C.4.3 Challenge test results

Challenge Test Results

Module Make/Model						
Challenge Particle						
Size Range (µm)						
Test Method						
Detection Limit						
# of Modules Tested						
$LRV_{C\text{-}TEST}$						
Revised QCRV						
Revised NDPT						
Module Number/ID	**Sample**	**Feed Challenge**		**Filtrate Challenge**		**LRV**
		Concentration	**Log$_{10}$**	**Concentration**	**Log$_{10}$**	
1	Flush					
	Matrix Spike					
	Start up					
	Start up (Dup)					
	After 15 min					
	After 30 min					
		Mean:		Mean:		
2	Flush					
	Matrix Spike					
	Start up					
	Start up (Dup)					
	After 15 min					
	After 30 min					
		Mean:		Mean:		
3	Flush					
	Matrix Spike					
	Start up					
	Start up (Dup)					
	After 15 min					
	After 30 min					
		Mean:		Mean:		
4	Flush					
	Matrix Spike					
	Start up					
	Start up (Dup)					
	After 15 min					
	After 30 min					
		Mean:		Mean:		
5	Flush					
	Matrix Spike					
	Start up					
	Start up (Dup)					
	After 15 min					
	After 30 min					
		Mean:		Mean:		

C.4.4 P_{test}, ALCR, LRV_{DIT} and $LRV_{Ambient}$

P_{test}

Fixed Constants		P_{test} Equation	
K			
σ (dynes/cm)			
ɵ (degrees)			
BP_{max} (psi)			
D_{base} (psi/min)[1]		Challenge test target P_{test} determined from formula above (psi)	
DIT Duration (min)		DIT Test pressure recommended by membrane manufacturer (psi)	

Module ID	Test	Starting DIT Test Pressure (psi)	Ending DIT Test Pressure (psi)	ΔP_{test} (psi/min)	Ending DIT Test Pressure ≥ Target P_{test}? (Yes/No)
	Pre-Challenge				
	Post Challenge				

[1]D_{base} is the diffusive loss through a fully integral membrane module that may be measurable during integrity testing. For example, a theoretical P_{test} may be determined using a formula, however, the starting test pressure may need to be higher to account for diffusive losses during the test in order to ensure that the pressures dictated by P_{test} are met through the entire test duration (i.e. P_{test} must be met at the end of the integrity test).

ALCR

Fixed Constants		ALCR Equation[1]
Y		
BP (psi)		
P_{atm} (psi)		

Module ID	Test	Ending DIT Test Pressure (psi)	Water Temp (F)	TMP (psi)	ALCR	Average ALCR
	Pre-Challenge					
	Post Challenge					

[1]If emperical ALCR is used, provide the source and value of the ALCR.

$LRV_{ambient}$ & LRV_{DIT}

Fixed Constants		LRV_{DIT} Equation[1]
VCF		
V_{sys} (liters)		
P_{atm} (psi)		
Design Qp (lpm)		

Module ID	Test	ΔP_{test} (psi/min)	Ambient Flow Rate, Q_p (lpm)			ALCR	$LRV_{ambient}$	LRV_{DIT}	Mear LRV
			Initial	Final	Average				
	Pre-Challenge								
	Post Challenge								

[1]This equation shall be used for both LRV_{DIT} and $LRV_{ambient}$, however, LRV_{DIT} shall be determined using the the Design Q_P while $LRV_{ambient}$ shall be determined using the average ambient Q_p.

C.4.5 Test skid

Test Skid

Test Skid	
Skid manufacturer	
Skid model number	
V_{sys} of skid piping (gallons)	
V_{sys} of skid piping (liters)	
Maximum back pressure (BP_{max}, psi) during direct integrity testing	
Hydraulic configuration (deposition or cross-flow)	
Flow direction (inside-out or outside-in)	
Flow Meter	
Location (feed side, filtrate side, etc.)	
Meter make	
Meter model number	
Range (gpm)	
Resolution (gpm)	
Accuracy (%)	
Repeatability/precision (%)	
Transducer linearity (%)	
Feed side pressure sensor	
Purpose (TMP, PDR, etc.)	
Sensor make	
Sensor model number	
Range (psi)	
Resolution (psi)	
Accuracy (%)	
Repeatability/precision (%)	
Transducer linearity (%)	
Filtrate side pressure sensor	
Purpose (TMP, PDR, etc.)	
Sensor make	
Sensor model number	
Range (psi)	
Resolution (psi)	
Accuracy (%)	
Repeatability/precision (%)	
Transducer linearity (%)	

C.4.6 Test operating conditions

Test Operating Conditions

Parameter					
Module manufacturer					
Module model number					
Background PDR or D_{base} (psi/min)					
Target LRV (LRV_t, Log_{10})					
Challenge Particle Feed Rate (gpm)					
Hold up volume (V_{hold}, gallons)					
Equilibrium volume (V_{eq}, gallonsl)					
Safety Factor (SF)					
Total Volume (V_{test}, gallons)					
Minimum feed concentration target (Cf-min)					
Maximum feed concentration target (Cf-max)					
NDPT Method					
NDPT target pressure					
Initial QCRV (psi/min)					
Module number/ID	1	2	3	4	5
Module serial number					
Backwash flow rate (gpm)					
Backwash time (min)					
Rinse flow rate (gpm)					
Rinse time (min)					
Starting flow rate (gpm)					
Ending flow rate (gpm)					
Recovery (%)					
Average flux (gfd) =>					
Starting flux (gfd)					
Ending flux (gfd)					
Average TMP (psi) =>					
Starting feed pressure (psi)					
Ending feed pressure (psi)					
Starting filtrate pressure (psi)					
Ending filtrate pressure (psi)					
Starting TMP (psi)					
Ending TMP (psi)					
Average Direct Integrity Test PDR (psi/min) =>					
Pre-Challenge Test DIT Results					
DIT starting pressure (psi)					
DIT ending pressure (psi)					
DIT duration (minutes)					
Pre-test PDR (psi/min)					
Post Challenge Test DIT Results					
DIT starting pressure (psi)					
DIT ending pressure (psi)					
DIT duration (minutes)					

Post-test PDR (psi/min)					

C.4.7 Test water quality data

Test Water Quality

Module	Test	Temp (°F)	pH	Turbidity (NTU)	Total Chlorine (mg/l)	Alkalinity (mg/l C_aCO_3)	TOC (mg/l)	TDS (mg/l)	Iron (mg/l)	Mn (mg/l)	HPC (CFU/100 ml)	Passed QA/QC and met criteria? (Yes/No)

Test Water Quality

Sample ID	Sample Description	Analyte	Results	Passed QA/QC? (Yes/No)

C.4.8 Analytical methods

Analytical Methods

Analyte	Standard Method[1]	Hold Time	Analytical Equipment	Minimum Detection Limit	Criteria
[Challenge Particulate]					N/A
Temperature	N/A				10-27°C (50-81°F)
pH	SM 4500-H^+B				6.5-8.5
Turbidity	SM 2130B				< 0.3 NTU
Total Chlorine[2]	SM 4500-Cl G				None Detected
Alkalinity (total, as $CaCO_3$)	SM 2320B				$\geq$ 20 mg/l
Total Organic Carbon (TOC)	SM 5310B				N/A
Total Dissolved Solids (TDS)	SM 2540 C				N/A
Iron[3]	SM 200.7				<0.3 mg/l
Manganese[3]	SM 200.7				<0.3 mg/l
HPC	SM 9125				<500 CFU/100 ml

[1]Standard Methods for the Examination of Water and Wastewater
[2]Add as needed to indicate all oxidants detected or potentially present in test water.
[3]The levels of these parameters and any others present in the test water shall not be of a type and quantity to form a cake on the filtration media that could bias the observed reduction of challenge microspheres over the performance of the test.

Reason: Addition of minimum reporting requirements per comments submitted by E. Hofeld and J. Mendez.

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Annex E[4]

(informative)

Validation testing for microspheres as surrogates for oocysts

E.1 Summary Report to the DWTU *Cryptosporidium* Task Group on the Filtration Efficiency Comparison Study

E.2 Test Dust Study {

include test dust study mentioned in the Power Point Presentation given by NSF in July 2013 titled "*Method Development and Validation of Oocyst and Microsphere Reduction by Point-of-Use, Point-of-Entry and Bottled Water Plant Filtration Systems."* The study had compared two types of test dust (ISO 12103-1 fine test dust vs. Nominal 0-5 um test dust) and determined that one was more conservative than the other}

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Annex F

(informative)

LRV and ALCR Calculations

Reason: Annex F was added as an information annex to illustrate the differences in theoretical LRV can be calculated. This may assist the manufacturer in selecting certain variables used in the LRV as well as to illustrate the differences in LRV_{DIT} used for regulatory compliance to quantify the sensitivity of the direct integrity test and $LRV_{ambient}$, which may be used more for process control as this represents membrane performance with respect to the current operating conditions. Manufacturers have many options how to calculate theoretical LRV values in full-scale installations, therefore, it was deemed beyond the scope of this standard to prescribe how this is done (this direction may be bettter left to AWWA Standard B112). This change was proposed by E. Hofeld.

F.1 Differences in how LRV is Calculated

Field experience has shown that there are several ways of calculating LRV. Differences may arise in how an individual manufacturer determines LRV, what has been requested by the client, and what is required by regulation. In an effort to simplify and standardize these approaches, two methods to determine LRV

[4] The information contained in this annex is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this annex may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Standard.

are proposed here, with an attempt to distinguish the differences between LRV considered useful for process optimization ($LRV_{ambient}$) and the maximum log removal value that can be reliably verified by a direct integrity test (LRV_{DIT}) required by many regulatory authorities under the LT2ESWTR. Although briefly summarized below, both of these approaches are discussed in further detail in the Membrane Filtration Guidance Manual (MFGM) prepared by the USEPA and released in 2005. Example 4.6 Establishing Direct Integrity Test Parameters on page 4-24 of the MFGM provides an example of how each approach may be used.

F.2 LRV_{DIT} (MFGM) - Direct Integrity Test Sensitivity

A common expression for LRV_{DIT} is represented by equation 4.9 from Chapter 4 of the MFGM. Equation 4.9 is as follows:

$$LRV_{DIT} = \log_{10}\left(\frac{Q_P \bullet ALCR \bullet P_{atm}}{\Delta P_{test} \bullet V_{sys} \bullet VCF}\right) \qquad \text{Equation 4.9}$$

Where:

- LRV_{DIT} = direct integrity test sensitivity in terms of LRV (dimensionless)
- Qp = membrane unit design capacity filtrate flow (L/min)
- $ALCR$ = Air-Liquid Conversion Ratio (dimensionless)
- P_{atm} = atmospheric pressure at the elevation of the membrane system (psia)
- ΔP_{test} = smallest rate of pressure decay that can be reliably measured and associated with a known integrity breach during the integrity test (psi/min)
- V_{sys} = volume of pressurized air in the system during the direct integrity test (L)
- VCF = volumetric concentration factor (dimensionless)

Note: VCF is typically equal to 1 for dead end deposition mode of operation unless an alternative VCF has been verified by a third party. VCF typically ranges from 1 to 20. A higher value VCF results in a lower LRV which is more conservative.

In this form, LRV_{DIT} is the maximum removal value that the membrane filtration system is capable of verifying. The variables used are conservative in order to generate the lowest LRV_{DIT}. If calculations using conservative values result in an LRV_{DIT} that is greater than or equal to the Log Removal Credit (LRC) assigned by the regulating agency, then one can reasonably conclude that the membrane filter is capable of meeting the test sensitivity requirements under the LT2ESWTR.

ALCR is typically calculated for hollow-fiber membranes in one of two ways, depending upon the flow regime (laminar or turbulent) that is anticipated with a breach in the integrity of the membrane.

F.3 $LRV_{ambient}$ (Current or "Ambient" Conditions)

For process optimization purposes, it is recommended that the more common expression for LRV_{DIT} represented by equation 4.9 from Chapter 4 of the MFG be used, with a few modifications. This modified version is referred to herein as $LRV_{ambient}$ and differs from LRV_{DIT} in the variables used, which are bolded as follows:

$$LRV_{ambient} = \log_{10}\left(\frac{Q_P \bullet ALCR \bullet P_{atm}}{\Delta P_{test} \bullet V_{sys} \bullet VCF}\right)$$

Where:

$LRV_{ambient}$= calculated log removal value as demonstrated by the most recent direct integrity test (dimensionless)
***Qp* = Current membrane unit filtrate flow (L/min)**
ALCR = Air-Liquid Conversion Ratio (dimensionless)
P_{atm} = atmospheric pressure at the elevation of the membrane system (psia)
ΔP_{test} = pressure decay determined from the last DIT (psi/min)
V_{sys} = volume of pressurized air in the system during the last DIT (L)
VCF = volumetric concentration factor (dimensionless)

Note: For the purposes of this goal, VCF should be set equal to 1 for dead end deposition mode of operation unless an alternative VCF has been verified by a third party. A higher value VCF results in a lower LRV which is more conservative.

F.4 Air-Liquid Conversion Ratio (ALCR)

The air-liquid conversion ratio (ALCR) is typically calculated for hollow-fiber membranes in one of two ways, depending upon the flow regime (laminar or turbulent) that is anticipated with a breach in the integrity of the membrane. Manufacturers may prefer either approach, so they are both presented here.

For process control, it is recommended that the ALCR be calculated using the Darcy Pipe Flow model, similar to equation C.4 of the MFGM, though with the use of ambient feed water temperature, transmembrane pressure, backpressure on the system during the most recent DIT, and minimum test pressure experienced during the most recent DIT, which is typically the ending test pressure.

F.4.1 $ALCR_{Laminar}$

In the case of laminar flow through a breach, ALCR (referred to as $ALCR_{Laminar}$ in this document) is calculated using the Hagen-Poiseuille model as defined in Equation C.15 of the MFGM. Equation C.15 is as follows:

$$ALCR_{Laminar} = \frac{527 \bullet \Delta P_{eff} \bullet (175 - 2.71T + 0.0137T^2)}{TMP \bullet (460 + T)} \qquad \text{Equation C.15}$$

Where:

- ALCR = Air-Liquid Conversion Ratio (dimensionless)
- T = Feed water temperature (°F)
- TMP = Transmembrane pressure (psi)
- ΔP_{eff} = effective integrity test pressure (psi)

ΔP_{eff} is calculated using MFGM Equation C.12 as follows:

$$\Delta P_{eff} = [(P_{test} - BP)] \bullet \left[\frac{(P_{test} + P_{atm}) + (BP + P_{atm})}{2 \bullet (BP + P_{atm})}\right] \bullet \left[\frac{(BP + P_{atm})}{P_{atm}}\right] \qquad \text{Equation C.12}$$

Where:

- ΔP_{eff} = Effective air integrity test pressure (psi)
- P_{test} = Applied direct integrity test pressure (psi)
- BP = Backpressure on the system during a DIT (psi)
- P_{atm} = Atmospheric pressure (psia)

> **Note:** Calculating ΔP_{eff} using the maximum anticipated backpressure (BP_{max}), results in a lower value ΔP_{eff}, ALCR, and LRV which is more conservative.

F.4.2 $ALCR_{Turbulent}$

In the case of turbulent flow through a breach, ALCR (referred to as $ALCR_{Turbulent}$ in this document) is calculated using the Darcy Pipe Flow model as defined in Equation C.4 of the MFGM. Equation C.4 is as follows:

$$ALCR_{Turbulent} = 170 \bullet Y \bullet \sqrt{\frac{(P_{test} - BP) \bullet (P_{test} + P_{atm})}{(460 + T) \bullet TMP}} \qquad \text{Equation C.4}$$

Where:

- ALCR = Air-Liquid Conversion Ratio (dimensionless)
- *Y* = Net expansion factor for compressible flow through a pipe to a larger area (dimensionless). The net expansion factor is obtained from charts in various hydraulics references, such as Crane (1988) page A-22[1].
- P_{test} = direct integrity test pressure (psi). If diffusion through an integral membrane unit (i.e., baseline pressure decay was significant, the cumulative decay over the duration of the test would be subtracted from the initial test pressure before applying this parameter to Equation C.4 to yield a conservative result for ALCR.
- BP = backpressure on the system during the integrity test (psi)
- P_{atm} = atmospheric pressure (psia)
- T = Water Temperature (°F)
- TMP = Transmembrane pressure (psi)

> **Note:** Using the maximum anticipated backpressure (BP_{max}), maximum allowable TMP, maximum anticipated temperature, and a low net expansion factor (minimum of Y = 0.588, which is the lowest value from Crane, pg A-22) results in a lower value ALCR and LRV which is more conservative.

[1]Crane Co. 1988. *Flow of fluids through valves, fittings, and pipe*. Technical Paper No. 410. Stamford, CT.

F.5 P_{test} - Applied Direct Integrity Test Pressure

The following calculations are focused on determining log removal values that can be obtained through direct integrity testing (DIT). This is a key operational component for verifying the effective performance of membranes used as microbial treatment barriers. It is also relevant for obtaining regulatory approval of membranes for such treatment; the LT2ESWTR states a membrane will be awarded *Cryptospridum* removal credit based on the lower of either the challenge testing LRV or the maximum LRV that can be verified through DIT (40 CFR 141.719(b)(1)). There are two main types of DIT methods: pressure-based tests and marjer-based tests. This section will focus on pressure-based tests since they are typically applied to microfiltration and ultrafiltration membranes.

For the purposes of meeting the required DIT resolution of 3 µm, the following equation is used to determine the direct integrity test pressure (P_{test}):

$$P_{test} = (0.193 * K * \sigma * \cos \Theta) + BP_{max} + (t * D_{base})$$

Where:

- P_{test} = The minimum applied pressure throughout the duration of a direct integrity test (psi)
- 0.193 = a factor that incorporates the 3µm defect diameter
- K = pore shape correction factor (dimensionless)
- σ = surface tension at the air-liquid interface (dynes/cm)
- Θ = liquid-membrane contact angle (degrees)
- BP_{max} = maximum backpressure on the system during the test (psi)
- D_{base} = Baseline decay (if known) of the module, fully intact without integrity breaches, over the duration of the direct integrity test (psi/min)
- t = duration of the direct integrity test (minutes)

<u>Liquid-membrane contact</u> (e.g., "wetting") angle is measured in degrees and indicated by Θ. The Θ value is used in determining the direct integrity test pressures needed to meet the 3 µm resolution requirements under the LT2ESWTR. The pressure applied during a direct integrity test must be great enough to overcome the capillary forces due to a 3 µm ~~hole~~ breach thus ensuring that any breach large enough to pass *Cryptosporidium* oocysts would also pass air during the test.

The liquid-membrane contact angle ranges from 0-90º and is primarily a function of the membrane hydrophilicity, which can be characterized in general terms as the affinity of the membrane material for water or the ability of the membrane to become wetted with water. For an ideally hydrophilic membrane, the liquid-membrane contact angle is 0 degrees. Although many membranes used for drinking water applications are manufactured using hydrophilic materials, an ideally hydrophilic membrane is purely theoretical.

The Θ value is unique to a membrane material and type. In the absence of data supplied by the membrane manufacturer, a conservative value of Θ = 0 degrees is suggested in the MFGM. Because a less conservative contact angle can significantly reduce the minimum required integrity test pressure, any value for Θ other than 0 degrees will need to be well documented and and approved by the regulatory authority if used for the purposes of compliance with the LT2ESWTR and may be needed to meet agency-specific requirements.

> **<u>Note:</u>** Conservative values yielding the highest test sensitivity can be achieved by using the following substitutions:
> - K = 1
> - σ = 74.9 dynes/cm at 5°C water temperature
> - Θ = 0 degrees
> - D_{base} = 0 psi/min (setting D_{base} to zero means that any diffusive losses, even from a fully integral membrane module, will contribute to the measured loss from any integrity breaches)

Given the substitutions above, the equation for the applied test pressure simplifies to the following form:

$$P_{test}\text{ , in psi} = 14.5 + BP_{max} \qquad \text{(MFGM Equation 4.2)}$$

Equation 4.2 indicates that the minimum test pressure necessary to achieve a 3 µm resolution is 14.5 psi plus the maximum backpressure on the system during application of a pressure-based direct integrity test (at a conservative temperature of 5ºC). A DIT must have an applied pressure equal to or greater than that provided in MFGM Equation 4.2 from the beginning to the end of the test in order to have met the DIT resolution goal. Once the applied test pressure has been confirmed to be $\geq$ the minimum applied test pressure, the applied test pressure used is referred to as P_{test} for the purposes of determining the ALCR.