Water System Survey:

Staff Guide - Membrane Filtration Treatment Questions

Background

In January 2017, DWS enhanced the Water System Survey membrane treatment questions in order to improve DWS' ability to assess how they are operated and to find out if there were plants that had changed out membranes. Additionally, in August 2020 $LRV_{ambient}$ was incorporated into the survey forms which was necessary to ensure that the facilities meet regulatory requirements. This staff guide was created to help staff implement these changes.

This guide is designed to help the surveyor prepare to conduct the survey and provide a historical reference of survey form changes.

In conducting a survey, staff should try to ascertain the operator's level of understanding and compliance with:

1) Significant deficiencies,
2) Operating limits, and
3) Conditions which should initiate a shut-down of the membrane filter/skid/cell.

Key parameters of these three items are listed below and discussed/defined further within this guide.

1. **Significant Deficiencies** (refer to Significant Deficiency Wording as needed)
   a) Direct integrity testing is not conducted according to OAR 333-061-0036(5)(d)(B)
   b) Indirect integrity testing is not conducted according to OAR 333-061-0036(5)(d)(C) (provide the operator with the Turbidity-Triggered DIT Reporting Form)

2. **Operating limits**

Max allowed TMP [psi]:	LRC [log]:
Max allowed flux [gfd]:	Min $LRV_{ambient}$:
Minimum DIT test pressure [psi]:	
Allowed DIT decay rate [$^{psi}/_{min}$]:	← Upper Control Limit (UCL) per Plan Review

3. **Automatic Shutdown Conditions -** The filters must be taken off-line or otherwise shut down, repaired and re-tested if any of the following occurs:
   a) PDR > UCL. *[The DIT pressure decay rate (PDR) exceeds the [x.xx] $^{psi}/_{min}$ UCL, which is typically assigned as part of plan review]*
   b) $LRV_{ambient}$ < LRC *[The $LRV_{ambient}$ is less than the log removal credit (LRC) which is assigned during the challenge study review and is typically 4.0-log]*
   c) IFE > 0.15 NTU for > 15 min *[The individual filter effluent (IFE) turbidity exceeds 0.15 NTU for more than 15 minutes]*

The format of this guide parallels the survey pages on membranes (rev. 8/21/20) and provides context and explanations for each membrane treatment subsection. If this guide is unclear or doesn't address your question(s), please contact Jay MacPherson, Evan Hofeld, or Pete Farrelly (abbreviated "J, E or P" below).

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The membrane treatment subsections in this guidance include:

- Manufacturer information
- Challenge Test & Plan Review Information
- Direct Integrity Testing (DIT)
- Latest DIT Results
- Indirect Integrity Testing
- Operating Practices
- Maintenance Practices
- Glossary and Acronyms
- Significant Deficiency Wording
- Turbidity-Triggered DIT Reporting Form

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Manufacturer Information (Home)

Manufacturer Info	Modules in use: *Module Make:* _____ *Model Number:* _____ *Year(s) of installation(s):* _____ *Number of modules currently installed per unit/rack/skid/cell:* _____ *Total # of modules:* _____ Unit/rack/skid/cell in use: Unit Make: _____ *Unit Model Number:* _____ *Year of installation:* _____ *Total # of units:* _____ Are there any units used to reclaim backwash water or other wastewater? ☐ Yes ☐ No Manufacturer Contact Info: _____ *Note: Compare this information to the previous survey to determine if there were more modules or different membranes installed since the last survey. Contact PR coordinator if there are changes to the number or type of membranes since last survey (V_{sys}) or if there are units used to reclaim backwash water (VCF).*

The "Manufacturer Information" subsection is intended to assure accurate identification of the equipment in use and provide a record of changes over time. **Multiple models of a manufacturer's membrane modules, or modules from multiple manufacturers, may be in use at the same time**. If so, the surveyor will need to customize the fields above to identify all module models in use. **This situation is uncommon, though if present or if the information in this subsection has changed from the last survey, please contact J, E, or P.**

The total number of modules in use is important because the upper control limit (UCL) and log removal value for ambient conditions ($LRV_{ambient}$) are dependent on this number. The UCL is generally a pressure decay rate measured during an integrity test (called a direct integrity test or "DIT"), which is a test performed on a group of modules mounted in the unit/rack/skid/cell that tests for excessive leakage (possibly due to membrane damage) by measuring a drop in pressure when the modules are pressurized with air. The results of the test are generally expressed as a pressure decay rate in psi/minute.

The UCL (also in units of psi/minute) is established during the plan review process to ensure that the credit granted for *Cryptosporidium* removal through the modules is achieved. The credit granted for *Cryptosporidium* removal is expressed as the Log Removal Credit or "LRC." The log removal value (LRV) achieved under current or "ambient" operating conditions is referred to as $LRV_{ambient}$. **If operators have removed or shut off flow to individual modules** (e.g., for future repair or replacement), this will alter the UCL and $LRV_{ambient}$ values. **Note this in the survey and inform J, E, or P.**

The 'note' at the bottom of the field is a reminder to compare the current information in this subsection to the information in the last survey and notify J, E, or P if there has been any change. The 'note' also refers to a "VCF" for volumetric concentration factor. Any new introduction of **recycling raw water or filtering backwash** water from other membrane units would require a higher VCF. A change in the number or type of membrane modules may impact the system volume (V_{sys}) under pressure during a direct integrity test, which affects the $LRV_{ambient}$ calculations. **Inform J, E, or P** if either of these cases applies.

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Challenge Test & Plan Review Information (Home)

Challenge Test & Plan Review Info (complete in office)	
	LT2ESWTR compliant challenge tested modules in use? ☐ Yes ☐ No
	Note: Check list of verified models and refer to plan review coordinator if non-LT2 compliant modules are in use.
	Indicate the following:
	Max allowed TMP [psi]: ____ LRC [log]: ____
	Max allowed flux [gallons/ft^2/day (GFD)]: ____ Min LRV$_{ambient}$ [log]: ____
	Minimum DIT test pressure [psi]: ____
	Allowed DIT pressure decay rate (PDR) [$^{psi}/_{min}$]: ____ ← Upper Control Limit (UCL) assigned under PR# _____

The "Challenge Test & Plan Review Information" section is best completed by the surveyor prior to conducting the site visit, however, a change in membranes discovered upon inspection will impact how this section is completed, so it may be advantageous to ask the operator if any changes have been made to the system since the last survey. All the values above can be obtained before the survey, and are available on DWS' web site on plan review (http://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/PlanReview/Documents/MembraneFilters-VerifiedModels.pdf.

The purpose is to document and make the operator aware of operational limits based on manufacturer-selected conditions applied during the Challenge Test and as established during plan review. While a membrane module may be physically able to operate outside these limits, the limits used during the Challenge Test constrain what is allowed for treatment credit from Oregon. This is analogous to a rapid sand filter being able to physically pass more water than is allowed for the log removal credit granted.).

Flux and transmembrane pressure (TMP) should not exceed hydraulic and maximum design flux conditions tested during Challenge Testing specified under OAR 333-061-0050(4)(c)(I)(iv). The Challenge Test is used to establish the log removal credit (LRC) for membrane filter modules, therefore the max allowed TMP and flux are set with the LRC.

Although proper calculation of $LRV_{ambient}$ is verified during the plan review process. By grouping $LRV_{ambient}$ with the other operational limits in one subsection, this helps the surveyor cover all the operating limits the operator needs to meet. Additionally, minimum $LRV_{ambient}$ is often (but not always) the same value as the LRC.

If there are multiple models of modules in use, multiple values are needed from the multiple Challenge Tests. Challenge Tests are model-specific and most manufacturers have more than one Challenge Study. Notify E, J, or P if you encounter a membrane plant using more than one type of module.

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Direct Integrity Testing (Home)

Direct Integrity Testing (DIT)

Y N

☐ ☐ • Does the current Direct Integrity Testing (DIT) meet all of the following: ☐ **30 pts**

- ☐ Done each day of operation *Method*: ☐ Pressure decay test (PDT) ☐ other: ____
- ☐ Minimum required static DIT pressure met daily (WTP target test pressure: ____ *psi)*
- ☐ Membrane unit removed from service after DIT failure (until remedied)
- ☐ Demonstrates membrane integrity using: ☐ PDR or ☐ $LRV_{ambient}$ ***(provide $LRV_{ambient}$ handout if not checked and discuss need to provide implementation plan within 45 days)***

Record the values or set points used to indicate a failed DIT below:

Y N PDR: ____ $^{psi}/_{min}$ $LRV_{ambient}$ ____ -log ☐ other: ____

☐ ☐ If using only a PDR, is this decay rate's corresponding LRV known? LRV = ____ -log

Comments: _____

The next subsection in the survey (Direct Integrity Testing) addresses how the PWS is performing the direct integrity testing in accordance with OAR 333-061-0036(5)(d)(B). By completing this subsection, the surveyor can assure operational settings:

1. Meet rule requirements,
2. Fall within the limits established by the Challenge Test,
3. Are understood or known by the operator(s), and
4. Identify whether recommended practices are followed.

The black dot indicates a rule requirement as in other parts of the survey form.

DIT results demonstrate if a membrane filter unit/rack/cell is operating within permissible limits for its treatment credit. Assure all four sub-questions are checked to affirm 'yes' for the black dot question DIT is the backbone of membrane integrity assurance.

- DITs must be done each day of operation (not every 24 hours of use). If a membrane filter is run for 1 hour today, a DIT must be conducted today. While pressure decay tests (PDT) are the only DITs used currently, other tests (e.g. vacuum decay, diffusive airflow, water displacement, particulate or molecular marker) are allowed by rule and should be identified if used.
- "Minimum required static pressure…?" To detect a 3 micron or larger defect in a membrane (required in OAR), the DIT must be conducted above a minimum pressure through to the end of the test. A PWS may conservatively set this minimum pressure at a value above that derived from the Challenge Study. If so, please enter that value.

  Note: Field observations have too frequently found differences between the required minimum test pressure and what is used at the plant. Before the survey,

look at a previous survey for the minimum test pressure used in the Challenge Study, or check the table of verified membrane modules on the plan review page of the DWS website (link above). If the information isn't there, it might be found in a post-2009 plan review letter which should specify that minimum test pressure. If you still haven't found the minimum pressure, once on-site for the survey you may find it in the O&M Manual. It should be in the SCADA system, though operators may not know where to look since it is a forgettable constant. That said, the operator needs to find out if s/he does not know this minimum pressure.

- "Membrane unit removed from service…?" If a DIT fails (and they do sometimes), the unit cannot provide water for public consumption until the DIT passes. The PWS should maintain a log documenting DIT failures and the repair(s) that corrected a failure. Be aware that sometimes DITs fail, no problem is found, and the next DIT succeeds. You may want to provide the operator with the DIT failure reporting form included with these instructions.
- Demonstrates membrane integrity using: ☐ PDR or ☐ LRVambient **(provide $LRV_{ambient}$ handout if not checked and discuss need to provide implementation plan within 45 days).** Although older membrane plants are still allowed to use a pressure decay rate to demonstrate membrane integrity, eventually, LRVambient will be required of each membrane plant in Oregon as this provides the most direct comparison to the LRC. Systems that do not have LRVambient are to be provided a handout describing the importance of this metric and are required to develop a plan for when they will get the programming completed. The timeline is flexible, so it can be done at the time of membrane module changeouts or with pre-planned SCADA changes, however, it must be considered as a future upgrade. 45 days was chosen to align it with the Corrective Active Plan for significant deficiencies. This plan should be provided to DMCE for entry as an informal compliance schedule viewable in SDWIS/Data Online.

The operator should be able to answer the question "What pressure decay rate indicates a failure of a DIT?". Typically these are automated set points viewable in SCADA. These set points should be equal to or less than that required, however, the PWS may be using a more conservative value (a lower decay rate) in which case please document that value on the form. Also, if the LRV for that lower decay rate is known, please add that too. For instance, a system may have a UCL of 0.50 psi/min, which represents an LRV of 4.0-log. Yet they operate with an alarm triggering a failure if the decay rate is "0.45 psi/min" corresponding to an LRV of "4.2-log." This critical DIT metric determines when a membrane filter rack fails. It is also a good conversation point to see if the filters struggle to meet this maximum decay rate routinely. You may discover whether the operator pins fibers infrequently, or throws "pinning parties" to stay sufficiently below this maximum decay rate.

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Latest DIT Results (Home)

Latest DIT Results	When was the most recent passing DIT (refer to SCADA and record DIT results for 1 rack/skid/unit)? Date: ____ Latest DIT results for the following membrane unit (indicate rack/skid/unit ID# or name) ____ ✓ Beginning DIT test pressure = ____ *psi* ✓ Ending DIT test pressure = ____ *psi* *Ending pressure ≥ minimum required pressure?* ☐*Y* ☐*N* ☐ *Unknown* ✓ Duration of DIT = ____ *minutes (2-5 minutes is typical)* ✓ Pressure decay rate (PDR) = ____ $^{psi}/_{min}$ *PDR ≤ UCL?* ☐*Y* ☐*N* ☐ *Unknown* *PDR = (start pressure - end pressure) ÷ (duration of DIT)* ✓ Ambient LRV ($LRV_{ambient}$) = ____ log ☐ N/A *$LRV_{ambient}$ ≥ LRC?* ☐*Y* ☐*N* ☐ *Unknown* ✓ DIT sensitivity (LRV_{DIT}) = ____ log ☐ N/A *LRV_{DIT} ≥ Min Req. LRV_{DIT}?* ☐*Y* ☐*N* ☐ *Unknown* When were the pressure sensors that used to determine the decay rate last verified or calibrated? _____ *(recommend annually and per manufacturer's instructions)* Comments: _____

The reasons to ask for the latest DIT results include assurance that the operator knows how to find this information as well as confirmation that the information meets requirements. The DIT's UCL is most likely found in the plan review documents for the filter.

- Are the beginning and ending DIT test pressures enough to see the pressure drop of concern and was the ending pressure above the minimum required? The minimum required test pressure must be maintained throughout the test.
- "How long did the DIT last?" This is asked to check math and establish a history. There are instances of DIT duration changes by operators or manufacturers. Duration must be sufficient to see a decay rate of concern and may be increased to improve sensitivity of the DIT.
- "When were pressure sensors last verified or calibrated?" This is one of the most common omissions observed at membrane filtration plants. Some have never done this since initial startup years ago. While the rule does not provide explicit conditions for verification or calibration, since the monitoring of membrane unit function is primarily dependent on pressure sensors/transducers, it is essential these devices generate accurate data. This is analogous to calibrating turbidimeters. Verification quarterly is sufficient, though at the very least, this check should be done annually.
- $LRV_{ambient}$ - The results of the direct integrity test are to be used to determine the log removal value of *Cryptosporidium* based on ambient or current operating conditions ($LRV_{ambient}$). LRVDIT is calculated using design flow. See the glossary for more information. Keep in mind, not all (older) membrane plants have $LRV_{ambient}$, and in those cases PDR ≤ UCL is the key performance indicator.

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Indirect Integrity Testing (Home)

Indirect Integrity Testing	**Y N** ☐ ☐ • Does the current Indirect Integrity Testing (e.g. turbidity monitoring) meet all the following: ☐ **30 pts** ☐ Each membrane unit/rack/skid/cell has an individual filter effluent (IFE) turbidimeter *Type:* ☐ standard turbidimeter ☐ laser turbidimeter ☐ Measurements are conducted at least every 15 minutes. *Freq.:* ☐ 1 min ☐ 15 min ☐ other ☐ DIT done if individual filter effluent turbidity exceeds 0.15 NTU in 2 consecutive 15 min readings What IFE turbidity level triggers a DIT? _____ *NTU* ☐ DIT's triggered due to IFE turbidity over 0.15 NTU for more than 15 minutes are reported to OHA-DWS. Comments: _____

The "Indirect Integrity Testing" section addresses primarily turbidity monitoring required under OAR 333-061-0036(5)(d)(C), which is a method of indirectly assessing the integrity of the membranes. This method of integrity monitoring is not as sensitive, so turbidity will typically not catch smaller breaches in the membranes, but rather is used to catch a large breach that would not otherwise be detected until the next direct integrity test.

- Each membrane unit must have an individual filter effluent turbidimeter, which can be of the standard turbidimeter with bulb or a laser turbidimeter, which is much more appropriate for membranes due their ability to detect very low levels of turbidity typical of membrane performance. OAR 333-061-0036(5)(d)(C)(iii). Plan review requirements also address the need for individual filter effluent turbidimeters under OAR 333-061-0050(4)(C)(G)
- Measurements must be conducted at least every 15 minutes, which is, in effect, continuous. OAR 333-061-0036(5)(d)(C)(ii).
- IFE monitoring results can trigger a DIT. Turbidity exceeding 0.15 NTU on 2 consecutive 15 minute readings triggers a DIT by rule OAR 333-061-0036(5)(d)(C)(iv). A system may set a lower turbidity threshold for this trigger, and if so, please document that lower value.
- If they have exceeded this trigger, it must be reported to DWS as indicated in -0036(5)(d)(C). A "turbidity-triggered" direct integrity test reporting form has been developed for this reporting and is located in the survey forms folder on the shared drive.

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Operating Practices (Home)

Operating Practices

Y N

☐ ☐ Are flux and TMP below the following limits: *Max flux:* ____ *gfd Max TMP:* ____ *psi?* ☐ **30 pts**

Indicate max recommended flux from O&M ____ gfd & alarm set-point ____ gfd (enter "None" if none)

Indicate max recommended TMP from O&M psi & alarm set-point psi (enter "None" if none)

Y N

☐ ☐ Does the O&M manual include a diagnosis and repair plan? ☐ **10 pts**

The O&M manual should include all three elements listed below:

☐ DIT process and response ☐ diagnostic testing ☐ membrane fiber repair plan

Comments: _____

While the jargon is obscure, there are simple concepts here. The flux is the filter loading rate (gal/ft^2/day aka gfd) and TMP is the headloss (psi). The significance of flux is analogous to the filter loading rate of a rapid sand filter. TMP is analogous to the pressure differential of a cartridge/bag filter. The point is to assure flux and TMP do not exceed limits established by the Challenge Study or in plan review.

"Do written protocols cover the following topics?" It is a construction standard requirement under OAR 333-061-0050(4)(c)(G) that "*The operation and maintenance manual must include a diagnosis and repair plan such that the ability to remove pathogens is not compromised*." This plan should have protocols for conducting a DIT, how to respond to and document DIT failures, and how to repair the system so that it passes a DIT. Repairs often involve pinning or gluing fibers that may have integrity breaches, looking for system leaks, tightening fittings, etc.

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Maintenance Practices (Home)

Maintenance Practices	Which of the following performance metrics is monitored long-term (e.g., monitored over years)? ☐ Permeability [$^{flux}/_{TMP}$] ☐ Resistance ☐ LRV ☐ TMP ☐ Other: ____ What could trigger a backwash? ☐ Permeability [$^{gal}/_{SF*day*psi}$] or [$^{gfd}/_{psi}$] ☐ Resistance ☐ Time ☐ TMP ☐ Production Comments: ____ What could trigger a clean in place (CIP)? ☐ Permeability [$^{gal}/_{SF*day*psi}$] or [$^{gfd}/_{psi}$] ☐ Resistance ☐ Time ☐ TMP ☐ Production **Y N** Comments: ____ ☐ ☐ Are CIP chemicals NSF/ANSI Standard 60 certified? ☐ **10 pts** CIP chemicals used: ☐ Citric ☐ Muriatic ☐ Caustic ☐ Chlorine ☐ Other: ____

The "Maintenance Practices" relate to DWS recommended practices. Permeability (or its inverse, resistance) along with LRV and TMP provide information on irreversible filter degradation and/or fouling, the efficacy of clean-in-place (CIP) practices, and differences in seasonal loading rates. They can be used to discern probable filter lifetime, whether CIPs are adequate, and seasonal effects.

Backwash triggers are most commonly based on time, though alarms may exist for TMP, permeability, or amount of water processed. Membrane filter lifetime can be maximized by avoiding irreversible filter degradation/fouling for which sufficiently frequent backwashes are essential. Typical backwash intervals are every 30 to 90 minutes. Backwash duration may be as brief as 1 minute and are rarely longer than a few minutes.

Triggers for a CIP most often are based on time. However, seasonal differences in water quality may result in fixed time-based intervals being insufficient. For instance, CIPs may be scheduled for every 60 days. However, during an algal bloom, more frequent CIPs could reduce the irreversible fouling algae often create. Alternative triggers like permeability and TMP may be a more effective way to account for water quality differences.

A CIP is the main mechanism to remove deposits that backwashing cannot remove. These maintenance practices are not required explicitly by rule. (CIP chemicals should meet NSF/ANSI Std 60 certification, though not explicitly required in Oregon as in other states.)

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Glossary & Acronyms (Home)

4. **Automatic Shutdown Conditions -** The filters must be taken off-line or otherwise shut down, repaired and re-tested if any of the following occurs:
    1. PDR > UCL. *[The DIT PDR exceeds the [x.xx] $^{psi}/_{min}$ UCL]*
    2. $LRV_{ambient}$ < LRC *[The $LRV_{ambient}$ is less than the 4.0 log removal credit (LRC)]*
    3. IFE > 0.15 NTU for > 15 min *[The individual filter effluent (IFE) turbidity exceeds 0.15 NTU for more than 15 minutes]*

5. **Challenge Test/Study** – the test or study that confirms a membrane's efficacy in removing *Cryptosporidium*-sized particles. It also establishes parameters for the correct operation of the filter (e.g., log removal credit, max allowable flux, minimum test pressure, and max TMP). A challenge test is typically performed in a lab on one or maybe a few modules and is not the same as a pilot test, which is typically performed on-site of a water system, using the source water intended to be filtered once fully installed. Challenge studies always included dosing a crypto-sized particle or organism and directly measuring the removal of that particle or organism.

6. **CIP** – Clean in Place. A CIP is intense chemical cleaning process that usually involves alternating caustic and acid soaks. Some systems may use a "maintenance wash" or "enhanced flux maintenance," which is generally just a 50-ppm chlorine rinse.

7. **DIT** – Direct Integrity Test (e.g. pressure decay test). The primary method of directly testing membrane integrity and thereby the filter's efficacy in removing pathogens. It is the only practical test that yields a decay rate that can be used to calculate the removal of *Cryptosporidium*.

    DIT Turbidity Trigger (IFE > 0.15 NTU for > 15 min): A direct integrity test (DIT) must be performed if the turbidity is greater than 0.15 NTU for more than 15 minutes. **This must be programmed into the SCADA system.**

    DIT Daily Trigger - A DIT is also required each day of operation. If the pressure decay rate (PDR) drops below the upper control limit (UCL) of [x.xx] $^{psi}/_{minute}$, then the DIT is considered to have failed and the unit must be automatically taken off-line, repaired, and retested to show that it passes a DIT before being placed back into service. In other words, **should the PDR of the daily PDT (or "air hold test") exceed [x.xx] $^{psi}/_{minute}$, this should indicate a "failed" DIT and the membrane must be taken out of service and may not be placed into service until it passes a DIT. A new DIT may be immediately run after a DIT failure, or repairs may be needed first (e.g. fibers pinned, leaks at pipe fittings repaired, etc.) followed by passing a new DIT.**

DIT test pressure: The minimum DIT pressure (i.e., the test pressure at the end of the DIT) must not drop below a level in psi determined in during plan review. **Should the pressure during a DIT drop below [xx.x] psi, the DIT is considered invalid and must be repeated.**

DIT Sensitivity (LRV_{DIT}): The results of the direct integrity test (pressure decay rate or "PDR") and the design flow are sometimes used to determine the DIT sensitivity, expressed as a log removal value of *Cryptosporidium* (LRV_{DIT}). This LRV_{DIT} must be equal to or greater than the log removal credit (LRC, e.g., LRC = 4.0-log). Typically, a certain PDR of [x.xx] $^{psi}/_{min}$ equates to an LRV_{DIT} of 4.0-log. Plan review letters should request that **LRV_{DIT} values displayed in SCADA are calculated using formulae and variables specified during plan review. DIT sensitivity is closely related to the sensitivity of the pressure sensors used to measure the PDR and the sensor's minimum detectable pressure decay rate is often used in the equation for LRV_{DIT}.**

8. **Flux [$^{gal}/_{SF*day}$]** – Flow per feed-side area of the membrane. If you know the total process flow rate, the surface area of a single module, and how many modules are in the rack, flux can easily be converted to & from flow per membrane unit. Similarly, if the membrane unit flow is known, the flux can be determined by dividing the total flow by the product of the number of modules and the feed-side area of each module (typically documented during a challenge study review). The equation can be written as:

   flux [$^{gal/SqFt}/_{day}$]= membrane unit flow in gpm / (filter feed area per module in sq. ft. x number of modules in service)

9. **HMI** – Human Machine Interface. Another term for the SCADA screen used to monitor the filter. HMIs may also be built into a control panel (separate from the SCADA computer). It is the way operators can visually monitor and manage the membrane filter.

10. **$LRV_{ambient}$ (membrane performance)** - The results of the direct integrity test can also be used to determine the log removal value of *Cryptosporidium* that is based on ambient or current operating conditions ($LRV_{ambient}$). The main difference between LRV_{DIT} and $LRV_{ambient}$ is the use of the current operating flow when calculating $LRV_{ambient}$. Lower flows could yield a lower (less conservative) LRV value. **Since pathogen removal credit is in terms of 4.0-log, membrane performance must be determined to demonstrate compliance with the pathogen credit awarded [log]** i.e., membrane should only be operating when $LRV_{ambient} \geq$ LRC**.**

    The formula for $LRV_{ambient}$ is based on Equation 4.9 of the Membrane Filtration Guidance (MFGM pp 4-11, USEPA, 2005), with the exception that current flow, TMP, and the most recent direct integrity test is used.

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

Where:

$LRV_{ambient}$= calculated log removal value as demonstrated by the most recent direct integrity test (expressed as LOG_{10})
Qp = Current membrane unit filtrate flow (L/min)
ALCR = Air to 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)

For comparison, Equation 4.9 is shown below:

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

Where:
LRV_{DIT} = direct integrity test sensitivity in terms of LRV (dimensionless)
Q_p = membrane unit design capacity filtrate flow (L/min)
ALCR = air-liquid conversion ratio (dimensionless)
P_{atm} = atmospheric pressure (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 test (L)
VCF = volumetric concentration factor (dimensionless)

The ALCR is generally calculated in one of two ways:

1. **The turbulent or "Darcy" flow model or "regime"**
2. **The laminar or "Hagen-Poiseuille" flow model**

The models have to do with if the flow is turbulent or laminar, depending upon if the breach is a hole in a membrane fiber or a broken or torn fiber. Manufacturers may use either model, however, the turbulent or "Darcy" flow model is generally considered more conservative, yielding a calculated LRV of about 0.5-log lower than using the laminar model.

Table 4.1 of the MFGM (pp 4-12) summarizes the formulas used in the two ALCR flow models.

Table 4.1 Approaches for Calculating the ALCR

Module Type	Defect Flow Regime	Model	ALCR Equation	Appendix C Equation
Hollow-fiber[1]	Turbulent[2]	Darcy pipe flow	$170 \bullet Y \bullet \sqrt{\frac{(P_{test} - BP) \bullet (P_{test} + P_{atm})}{(460 + T) \bullet TMP}}$	C.4
	Laminar	Hagen-Poiseuille[3]	$\frac{527 \bullet \Delta P_{eff} \bullet (175 - 2.71 \bullet T + 0.0137 \bullet T^2)}{TMP \bullet (460 + T)}$	C.15
Flat sheet[4]	Turbulent	Orifice	$170 \bullet Y \bullet \sqrt{\frac{(P_{test} - BP) \bullet (P_{test} + P_{atm})}{(460 + T) \bullet TMP}}$	C.9
	Laminar	Hagen-Poiseuille[3]	$\frac{527 \bullet \Delta P_{eff} \bullet (175 - 2.71 \bullet T + 0.0137 \bullet T^2)}{TMP \bullet (460 + T)}$	C.15

1 Or hollow-fine-fiber
2 Typically characteristic of larger diameter fibers and higher differential pressures
3 The binomial in the Hagen-Poiseuille equation (C.15) approximates the ratio of water viscosity to air viscosity and is valid for temperatures ranging from approximately 32 to 86 °F. Additional details are provided in Appendix C.
4 Includes spiral-wound and cartridge configurations

11. **PDT / PDR** – Pressure Decay Test or Pressure Decay Rate. PDTs are pressure-hold tests. When the operator initiates the PDT, a rack of membrane modules is pressurized to a predetermined pressure. Once pressure is stabilized, the test begins and the pressure is held for 30 seconds to 10 minutes, depending upon the manufacturer. The pressure leakage (or decay) is measured during that 30 second to 5-minute period. Typically, the pressure sensor on the filtrate (filter effluent) side of the filter is used to measure this pressure drop. The difference in the starting test pressure and the ending test pressure provides the total decay in psi, which is then divided by the test duration in minutes to arrive at a decay rate in psi/minute. This value cannot be greater than the upper control limit established in order to ensure that the removal of *Cryptosporidium* is equal to or greater than the unit's treatment credit.

12. **Permeability [$^{gfd}/_{psi}$]** – $^{1}/_{resistance.}$ This is probably the most sensitive metric to determine membrane health. It is the flux divided by the pressure and typically normalized to a standard temperature like 20°C (to account for viscosity effects of colder water).

13. **Resistance [$^{psi}/_{gfd}$]** – $^{1}/_{permeability.}$ (i.e., permeability is an indication of how easily water passes through the membrane and resistance is how much resistance there is to the passage of water).

14. **TMP** – **Transmembrane Pressure [psi]** – The pressure drop across the membrane. Exceeding the maximum TMP can cause fiber breakage and pathogen breakthrough.

15. **Volumetric Concentration Factor [VCF]** - is used in log-removal value calculations to account for concentrating of pathogens caused by reuse of reject water. This is something addressed in plan review. However, if equipment has changed since plan review, the VCF may also need to be changed. Changing the type of module used in a membrane plant or converting a unit into a backwash recovery unit (a unit that filters backwash water received from the other membrane units) can greatly impact VCF.

    Upper Control Limit (UCL) – [x.xx] psi/min - Every membrane system has an Upper Control Limit (UCL) measured in $^{psi}/_{min}$. The UCL is the highest **p**ressure **d**ecay **r**ate (PDR) allowed during a direct integrity test (DIT). Exceeding the UCL indicates DIT failure. The failing membrane unit shall not operate until it passes a DIT. Based on a review of [WS's] specific system and information provided by the membrane manufacturers, the UCL is established during plan review in terms of $^{psi}/_{min}$. Direct integrity tests that pass indicate that the membrane removes pathogens at the rate credited, e.g. 4.0 log (or 99.99%). Surveyors should ensure that the SCADA/PLC system is programmed to account for this UCL. For reference, the UCL is calculated using Equation 4.17 of the MFGM (pp 4-22) as follows:

Similarly, Equation 4.9 can be rearranged to establish an expression for calculating the UCL in terms of a pressure decay rate, as shown in Equation 4.17:

$$UCL = \frac{Q_p \bullet ALCR \bullet P_{atm}}{10^{LRC} \bullet V_{sys} \bullet VCF} \qquad \text{Equation 4.17}$$

Where:

UCL	=	upper control limit in terms of pressure decay rate (psi/min)
Q_p	=	membrane unit design capacity filtrate flow (L/min)
ALCR	=	air-liquid conversion ratio (dimensionless)
P_{atm}	=	atmospheric pressure (psia)
LRC	=	log removal credit (dimensionless)
V_{sys}	=	volume of pressurized air in the system during the test (L)
VCF	=	volumetric concentration factor (dimensionless)

Values for the parameters in Equations 4.16 and 4.17 should be the same as the analogous terms used to calculate sensitivity using Equations 4.7 and 4.9, respectively. Note that to the extent possible, these values should be selected to yield a conservative result for the UCL.

Significant deficiency wording for survey cover letters (Home)

Example language for survey cover letters is provided below:

Direct integrity testing is not conducted according to OAR 333-061-0036(5)(d)(B). OAR 333-061-0036(5)(d)(B) addresses direct integrity testing (e.g. pressure decay testing), and requires that the testing:

1. be conducted at least once each day of operation (-0036(5)(d)(B)(vi));
2. meets the minimum required test pressure that is needed in order to demonstrate that the test direct integrity test method has a resolution of 3 µm or less (roughly the size range of *Cryptosporidium* oocysts), where resolution is defined as the size of the smallest integrity breach that contributes to a response (i.e. is measurable) from the direct integrity test (-00036(5)(d)(B)(ii));
3. be repeated and the membrane unit not returned to service until such time (e.g. following fiber repairs) as direct integrity testing demonstrates that the decay rate does not exceeded the regulatory upper control limit established for the membrane units being tested (-0036(5)(d)(B)(v)). This means that no membrane unit may be placed into service until it passes a direct integrity test meeting the requirements of OAR 333-061-0036(5)(d)(B)).

At the time of the survey [include 1,2, or 3 as needed] was not being done. Please ensure that direct integrity testing meets the requirements of OAR 333-061-0036(5)(d)(B).

Indirect integrity testing is not conducted according to OAR 333-061-0036(5)(d)(C). OAR 333-061-0036(5)(d)(C) addresses indirect integrity testing (e.g. turbidity monitoring), and contains the following requirements:

1. Continuous monitoring must take place every 15 minutes on each membrane unit and must include turbidity unless an alternative, like particle counting, is approved (-0036(5)(d)(C)(i), (ii) and (iii)).
2. If turbidity is above 0.15 NTU for more than 15 minutes (i.e., two consecutive 15-minute readings above 0.15 NTU), direct integrity testing must be performed on the affected unit (-0036(5)(d)(C)(iv)).
3. A monthly report must be submitted summarizing all continuous indirect integrity results which triggered direct integrity testing and a description of corrective action that was taken in each case (-0036(5)(d)(C)).

At the time of the survey [include 1,2, or 3 as needed] was not being done. Please ensure that indirect integrity testing meets the requirements of OAR 333-061-0036(5)(d)(C).

Staff Guide: Membrane Filtration Treatment Questions

Turbidity-triggered DIT reporting form (Home)

- Use the following reporting form to report turbidity-triggered direct integrity tests.

Membrane Filtration Reporting Form
Turbidity-Triggered Pressure Decay Test (Direct Integrity Test) Results
(For compliance with OAR 333-061-0036(5)(d)(C)(iv)*)

Water System Name:	
Water System ID:	
Treatment Plant ID: WTP-	
County:	
Month - Year:	____ - ____ *(e.g. January - 2020)*
Upper Control Limit (UCL):	____ psi/minute *(i.e., maximum allowable pressure decay rate)*
Log Removal Credit (LRC):	____ log *($LRV_{ambient}$ shall be ≥ LRC when units are in service)*

Date/Time	Membrane unit/skid/ rack/cell ID#	Turbidity level resulting in corrective action [NTU]	Corrective action	Was membrane unit removed from service until it passed a direct integrity test (DIT)? Indicate return-to-service DIT Results	Return-to-service turbidity [NTU]	Return to service $LRV_{ambient}$ [LOG]
				☐ Yes ☐ No ____ psi/min		
				☐ Yes ☐ No ____ psi/min		
				☐ Yes ☐ No ____ psi/min		
				☐ Yes ☐ No ____ psi/min		

Monthly Summary	
All membrane units removed from service until a DIT passes?	☐ Yes ☐ No
All return to service turbidity readings ≤ 0.15 NTU?	☐ Yes ☐ No
All units met LRC prior to returning to service?	☐ Yes ☐ No

*OAR 333-061-0036(5)(d)(C)(iv) states that if indirect integrity monitoring includes turbidity and the filtrate turbidity readings are above 0.15 NTU for a period greater than 15 minutes (i.e., two consecutive 15-minute readings above 0.15 NTU), direct integrity testing in accordance with subparagraphs (5)(d)(B)(i) through (v) of this rule must immediately be performed on the associated membrane unit.

Name:			
Signature:		**Date:**	
Phone #:	(____) ____ - ____	**Cert #:**	

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