Testing Used Respirator Cartridges to Confirm Change Schedules

C.R. (Gus) Manning, PhD, CIH, FAHIA
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What is Happening when you wear an Air Purifying Respirator (APR)

**INFLUENT**
Contaminant Level
Above OEL

Air Purifying Respirator

APR

Reduces Contaminant Level by “Protection” Factor

**EFFLUENT**
Contaminant Level
Below OEL

(must be below IDLH)

IDLH = immediately dangerous to life & health;  OEL = Occupational Exposure Limit
Service Life

Duration of Time a respirator may be worn before contaminant breakthrough exceeds the OEL*

Change Schedule should be based on Hypothetical Service Life plus a safety factor

Hypothetical Service Life is a Projection based on relevant data and theory.

* OEL = Occupational Exposure Limit
Service Life
(hypothetical)

... Can be measured accurately in the Lab under hypothetical environmental conditions, but ...

**Real-World** Service Life depends upon the *environmental conditions in use*.

i.e., Actual Service Life depends upon actual use
Hypothetical Service Life
as determined in a Lab

Effluent Concentration “break through”
When Capacity is Exceeded

Cartridge Effluent Concentration (ppm)

Challenge Test Time (min)

Cartridge 50% Used Up
Fresh Cartridge

OEL
OSHA Suggests Options for Developing a Change Schedule
(OSHA web-site)

- **Measure** Experimentally with Lab Test … in practice, *a model is often used* because influent concentration is low and test time is long

- **Follow** Manufacturer Recommendation …
  Mfr Recommendation usually *based on a Model*

- **Use** a Mathematical Model
  … NIOSH “Multi-Vapor” is the Most Popular Model
In Actual Practice
You get a hypothetical Service Life by combining …

- Lab Service Life Determinations
- A Mathematical Model
- Estimated Environmental Conditions

Caveat: The overall error of your estimate is a summation of errors in each operation.
Projected Service Life
(estimate of errors)

- Error due to
  - Lab Determination
  - Math Model approximations
  - Data input into the Math Model
    - Capacity Data for Cartridge Used
    - Environmental Challenge Conditions
Factors Entered into Model

expected ...

Contaminant Concentration (ppm)
Work Rate (breathing rate in L/min)

Plus expected ...

temperature
humidity
wearing time
Size and Nature of Sorbent in Cartridge

Model  
Projected Service Life
Size and Nature of Sorbent in Cartridge must also be entered into the Model

If you don’t select a standard cartridge from the menu, model will need the following information:

- Carbon Bed Diameter & Depth (cm)
- Weight of sorbent in each cartridge (gm)
- The carbon micropore volume (cm³/g)
- Carbon granule size (ave. diameter in cm)
- Carbon’s Adsorption Potential for Benzene
- Carbon’s Affinity Co-Efficient for Water
- %RH at which Cartridge has been pre-conditioned

Model → Projected Service Life
Factors Related to Contaminant(s) must be entered into Model

If your contaminant is not on the Menu, the Model will need the following:

- Molecular weight
- Liquid density (g/cm³)
- Water Solubility Factor
- Vapor Pressure Co-efficients (Antoine co-effs)
- Molar polarizability (cm³/mole)
Projected Service Life
(for setting Change Schedule)

- Accurate Projections available to sophisticated organizations

- Most Rely on Respirator Mfr recommendations
  - Approximate fitting to Math Model
  - Many parameters estimated
  - If no data … no recommendation
Projected Service Life
(resulting Change Schedule)

- Competent Leading Company IH Mgr
  - Uses Worst-Case estimates & Safety Factors
    - Safe Employees
    - Discard cartridges with un-used capacity

- Untrained non-Leading Company IH Mgr
  - Not using Worst Case Inputs & Safety Factors
    - Unsafe Employees
    - May use Cartridges after capacity is expended
In the event that you are not completely satisfied with your projected Service Life & Change Schedule …

Are there other ways to get improved confidence in your Respirator Change Schedules?
End of Service Life (ESL)

... is the moment when Effluent Contaminant Level approaches the OEL

End of Service Life Indicator (ESLI):
Provides alternate method for an END-USER to detect the ESL
End of Service Life Indicators (ESLI)

(a) Know too Much
(b) Think too much
(c) Do too much
End of Service Life Indicators
(current design approaches)

- A Sensor is placed **ON** the Cartridge
  - Alarm Based on Time-Weighted Average Exposure

- A Sensor is placed **INSIDE** the Cartridge
  - Alarm Based on Instantaneous Concentration
End of Service Life Indicators

The Sensor must be inexpensive and selective for all Agents claimed for that cartridge.

So, ESLI are not yet widely available.
Could There Be Another Approach to Detecting the End of Service Life?

- Doesn’t require detailed knowledge about the use environment and the sorbent.

- Doesn’t require a super-selective sensor that is cheap enough to be thrown away with each cartridge use?
Measure the “Residual Capacity” of Cartridge

Residual Capacity
– the adsorptive or chemical capacity remaining after normal respirator use

1hr  2hr  3hr  4hr

Sorbent Pores Filled  Sorbent Pores Available
Laboratory Method A
Residual Capacity Test using “suspected” contaminant

Perform a Destructive Test on a “used” Cartridge
- After wearing the respirator
  - Follow an established change schedule, select cartridges from each “similar exposure group”, send “used” cartridges to Lab for Challenge Test

- Run NIOSH-style Challenge Test on “used” cartridges

- If cartridges have retained > 10% of capacity,
  - Change Schedule has been confirmed
Effective Service Life (remaining time to breakthrough) decreases as Capacity is consumed.

Remaining Service Life vs Time Worn

- Cartridge Effluent Concentration (ppm)
- Challenge Test Time (min)
- OEL
- Usage

Effective Service Life decreases as Capacity is consumed.
Effective Service Life (remaining time to breakthrough) decreases as Capacity is consumed.
Cost of Lab Method A
(Destructive Test of “used” Cartridges)

- Single (SEG) Similar Exposure Group $950 (USD) for testing 3 used cartridges in Lab
- Three (SEGs) Similar Exposure Groups $1,950 (USD) for testing 9 used cartridges in Lab
Simple Lab Method “B”
Residual Capacity Test using “surrogate” Contaminant

Non-Destructive Test on a “used” Cartridge
  - After wearing the respirator
    - Follow established change schedule, select cartridges from each “similar exposure group”, and send “used” cartridges for Challenge Test
  - Run non-destructive Challenge Test
    - Using surrogate agent
    - E.g., Methane or Carbon Dioxide
  - If cartridges have retained > 10% of capacity,
    - Change Schedule has been validated
Simple Lab Method B
Non-Destructive Test using “surrogate” contaminant

Inject Pulse of Surrogate Agent into “used” Cartridge

Measure Passage Time thru Cartridge

Retention Time Correlates with Residual Capacity

N. Bac, A. Sacco, & J.L. Hammarstrom
Experimental Design

FIGURE 1 Schematic of the test apparatus.
Simple Lab test B
for Residual Capacity
N. Bac, A. Sacco, & J.L. Hammarstrom
Experimental Data

FIGURE 2  Correlation between the reduced retention time of CH₄ and the percent relative humidity.
(Filters at equilibrium water loadings.)
Test Retention Time correlates with Capacity Used
Test Retention Time correlates with Capacity Remaining

Retention Time (min)

% Capacity Remaining

0%RH 40%RH Pre-Conditioning
Conclusions

- Uncertainty in projected Service Life arises when users lack accurate data to input into models to generate Service Life/Change Schedules.

- End of Service Life Indicators have advantage of requiring little input from end-users, but ESLIs are still rare.

- Measuring Residual Capacity to detect End of Service Life, has advantages:
  - Applicable to a wide variety of real-world situations
  - No need to modify respirator by installing exotic sensors.

- Residual Capacity testing may be conducted using
  (a) actual expected contaminants (expensive, destructive test)
  (b) surrogate contaminant (cheap, non-destructive test)
AT Respirator and Filter
Chemical Challenge Test Lab
Assay Technology Facility
(Livermore, California)