Service Life Assessment by Measuring Residual Capacity (end-user’s perspective)

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  - Service life theory
What is Happening when you wear an Air Purifying Respirator (APR)

INFLUENT
Contaminant Level
Above OEL

Air Purifying Respirator
APR

Reduces Contaminant Level by a Reduction or “Protection” Factor

EFFLUENT
Contaminant Level
Below OEL

(must be below IDLH)

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

… Can be measured in the Lab under specific environmental conditions, but …

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

i.e., Service Life is relative to the Challenge applied by environmental conditions
OSHA (USA) Suggestions for Service Life Estimation

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

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

- **Use** NIOSH Multi-Vapor Model … The Most Popular Model
Real-World Service Life

End-User usually estimates by combining …

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

Caveat: When you combine operations, the overall system error is a summation of errors in each operation.
Real-World Service Life (error estimate)

- ERROR (Lab Determination) +
- ERROR (Math Model) +
- ERROR (Input Data including Environmental Conditions)

Summation to get Overall System Error
Factors Entered into Model

Average contaminant concentrations (ppm)
Work Rate (breathing rate in L/min)

Plus …
- Expected temperature
- Expected humidity
- Expected wearing time
- Quantity and Nature of Sorbent in Cartridge
If you don’t select “typical cartridge” the Multi-Vapor Model will ask you for 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
more Factors Entered into Model

If your contaminant is not known by the NIOSH Multi-Vapor Model, you will be asked for the following:

- Molecular weight
- Liquid density \((g/cm^3)\)
- Water Solubility Factor
- Vapor Pressure Co-efficients (Antoine co effs)
- Molar polarizability \((cm^3/mole)\)
Accurate Service Life Estimates
(for setting Change Schedules)

- Available to more sophisticated end-users

- Others Rely on Respirator Mfr recommendations
  - Often guessing at environmental challenge conditions
  - For some conditions, Mfr has no recommendation
End of Service Life
Indicators (ESLI)

( the appeal of )

The end-user does not need to:
(a) Know too Much
(b) Think too much
(c) Do too much
End of Service Life (ESL)

… is the moment when
Effluent Contaminant Level
approaches the OEL

OUR OBJECTIVE:
To provide an alternate method for an
END-USER to detect the ESL
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
(Current Designs Have Limitations)

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

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

1hr 2hr 3hr 4hr

Sorbent Pores Filled
Sorbent Pores Available
Method “A”
Lab Verifies Existing Change Schedule

- Perform a Destructive Test on a “used” Cartridge
  - Wear the respirators & use the cartridges
    - Follow an established change schedule
    - Select cartridges used within each “similar exposure group”
    - Immediately send used cartridges to Lab for Challenge Test
  - Run a single NIOSH Lab Test
  - If cartridges have retained > 10% of capacity,
    - Change Schedule has been validated
Breakthrough Time (Service Life) decreases as Capacity is consumed.
Cost of Method A
(Destructive Test of “used” Cartridges)

- Single (SEG) Similar Exposure Group $1,000 (USD) for testing 3 used cartridges in Lab
- Three (SEGs) Similar Exposure Groups $2,500 (USD) for testing 9 used cartridges in Lab
Method “B”
On-Site Verification of Existing Change Schedule

Non-Destructive Test on a “used” Cartridge
- Wear the respirators & use the cartridges
  - Follow an established change schedule
  - Select cartridges used within each “similar exposure group”
  - Immediately send used cartridges to Lab for Challenge Test

- Run an ON-SITE Adsorption Test

- If cartridges have retained > 10% of capacity,
  - Change Schedule has been validated
Method B
Non-Destructive Test of “used” Cartridges

- Inject Pulse of Weakly Adsorbed Agent into “used” Cartridge
- Measure Passage Time thru Cartridge
- Retention Time Correlates with Residual Capacity

On-Site Test
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.)
Capacity (Service Life) as a function of Reduced Retention Time

Capacity Remaining vs Retention Time

- Capacity Remaining (%) vs Retention Time Parameter
- Graph showing the relationship between capacity remaining and retention time parameter.
Conclusions

In the “real world”, error is generated because users lack accurate data to input into models to generate Service Life and Change Schedules.

End of Service Life Indicators have advantage of not requiring end-users to know very much about environmental conditions or respirators.

Among the approaches to detecting End of Service Life, measuring Residual Capacity has two advantages:
  – Applicable to a wide variety of real-world situations
  – No need to modify respirator by installing exotic sensors.

Residual Capacity testing of “used” cartridges may currently be conducted in a Lab; On-Site Residual Capacity Test under development.
AT Respirator and Filter
Chemical Challenge Test Lab
Assay Technology Facility
(Livermore, California)