

HEPA Filter Efficiency After Hydrogen Fluoride Exposure

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Overview

- Objective:
 - Develop a model that predicts HEPA filter aerosol penetration after exposure to HF
- Approach:
 - Derive an equation of HEPA filter penetration as a function of HF exposure and key filter parameters
 - Incorporate experimental values of filter fiber size and filter weights
 - Incorporate the HF reaction kinetics from experimental studies
- Result:

$$P_{Gl} = 0.003 + 100 e^{-13.74 \left(0.794 - 1.821 e^{-2405/T} C_{HF, ppm, M}^{1.3} t \right)}$$

Penetration (%)

Temperature (°K)

Time (days)

HF Concentration (ppm)



Derivation of filter particle penetration model

$$dN = -NELD dT$$

dN = decrease in number of particles in air

N = number of particles

D = fiber diameter

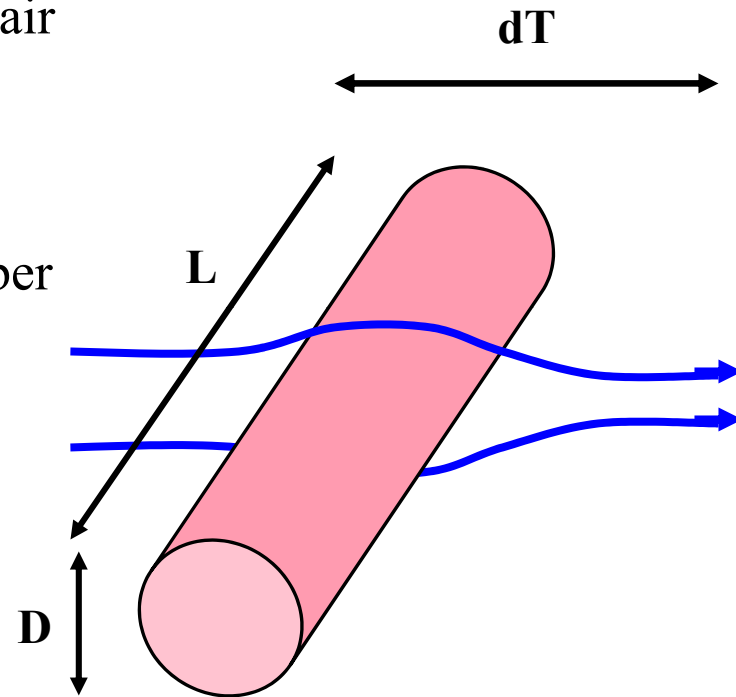
L = fiber length

E = efficiency of particle capture by fiber

dT = slice of filter thickness, T

Adding all of the thickness slices

$$N = N_0 e^{-ETLD}$$



Derivation of filter particle penetration model, Continued

Filter penetration, P, in % is

$$P = \frac{N}{N_0} = 100 e^{-ETLD} = 100 e^{-kLD}$$

Where E and T are constant for a given filter and combined into k

For mixtures of different diameter and type of fibers we have

$$P = 100 e^{-k \sum L_i D_i}$$

Adding the effect of media pinholes and defects yields

$$P = P_0 + 100 e^{-k \sum L_i D_i}$$



Derivation of filter particle penetration model, Continued

- Lung inhalation studies (weight loss) show acid exposure reduces the fiber diameter

$$D = D_0 - 2Rt$$

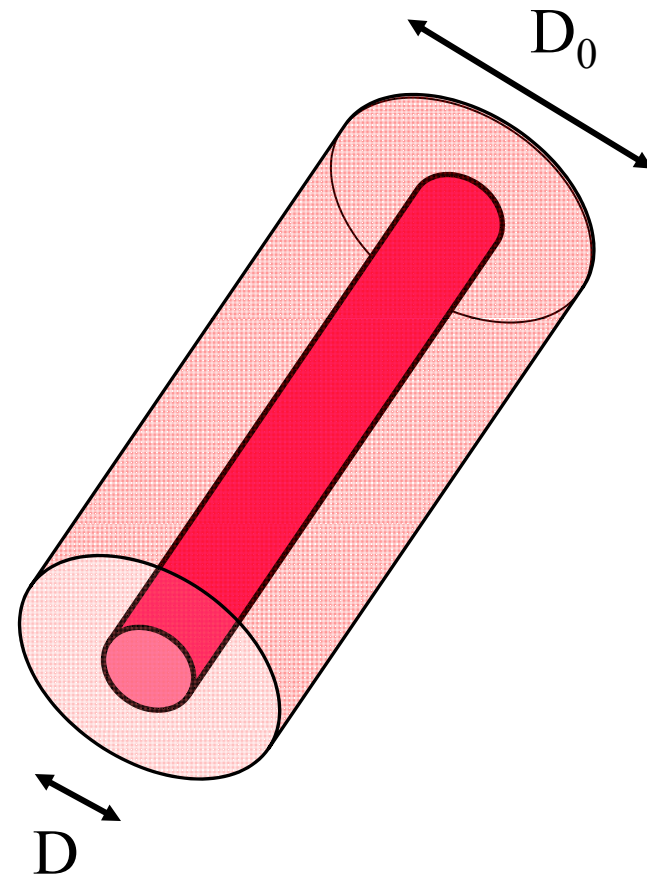
D = fiber diameter, nm

D_0 = initial fiber diameter, nm

R = etch rate, nm/day

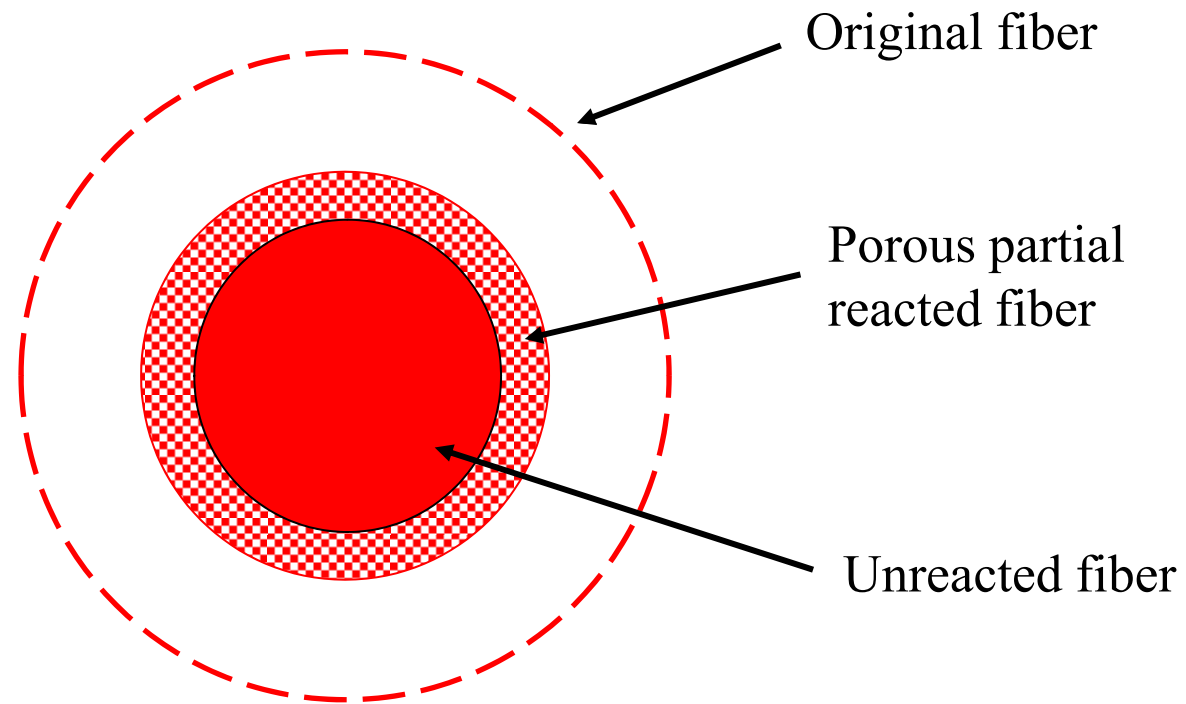
t = time, days

- Equation for diameter reduction is consistent with DOP penetration measurements on HEPA media following HF exposure



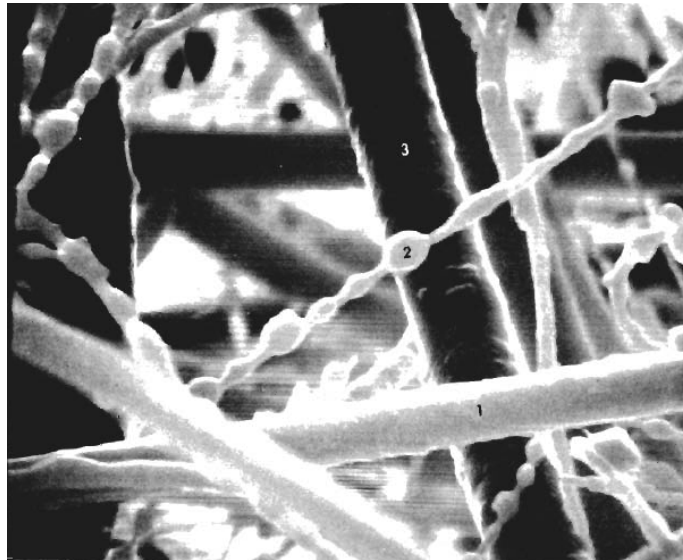
Reduction in fiber diameter is more complex

HF attack results in a partial leaching of glass components leaving a more porous exterior before complete dissolution (From lung inhalation studies)



Reduction in fiber diameter is more complex

- HF attack produces a liquid surface that forms beads on small fibers due to surface tension.
- Larger diameter fibers do not have sufficient liquid to form beads.
- HEPA filter penetration measurements following HF exposure suggest the reduced diameter model yields satisfactory results.



Derivation of filter particle penetration model, Continued

Adding the decrease in fiber diameter with HF attack on glass fiber HEPA filters yields

$$P_{gl} = P_0 + 100 e^{-kL_{gl}(D_{gl,0} - 2Rt)}$$

If the HEPA filter also has acid resistant fibers, then

$$P_{gl,A} = P_0 + 100 e^{-k(L_A D_A + L_{gl}(D_{gl,0} - 2Rt))}$$

The parameter values are obtained from experimental data



Determine fiber diameters and lengths for model

- Experimental data is provided from hand sheets made for the HF study
- Diameter of fibers:
 - glass fiber diameters are obtained from Johns Manville BET adsorption measurements (JM 110 glass = 2.7 μm ; JM 106 glass = 0.65 μm)
 - asbestos and Nomex diameters are obtained from ΔP and mass measurements
- Lengths of fibers:
 - are derived from fiber diameter and mass measurements
- Lack of mass data on filter hand sheets limits accuracy of these parameters
 - use mass data from H&V HEPA media to approximate missing data



Fiber diameter determined from pressure drop and mass measurements

$$\Delta P = K \left(\sum \alpha_i \right)^{1/2} \left(\sum \frac{\alpha_i}{D_i^2} \right)$$

K = constant for filter media

$\alpha_i = \frac{(M/A)_i}{\rho_i T}$ = fiber volume fraction of component i

D_i = fiber diameter of component i

M = mass of filter media (not reported, used H & V data)

A = area of filter media

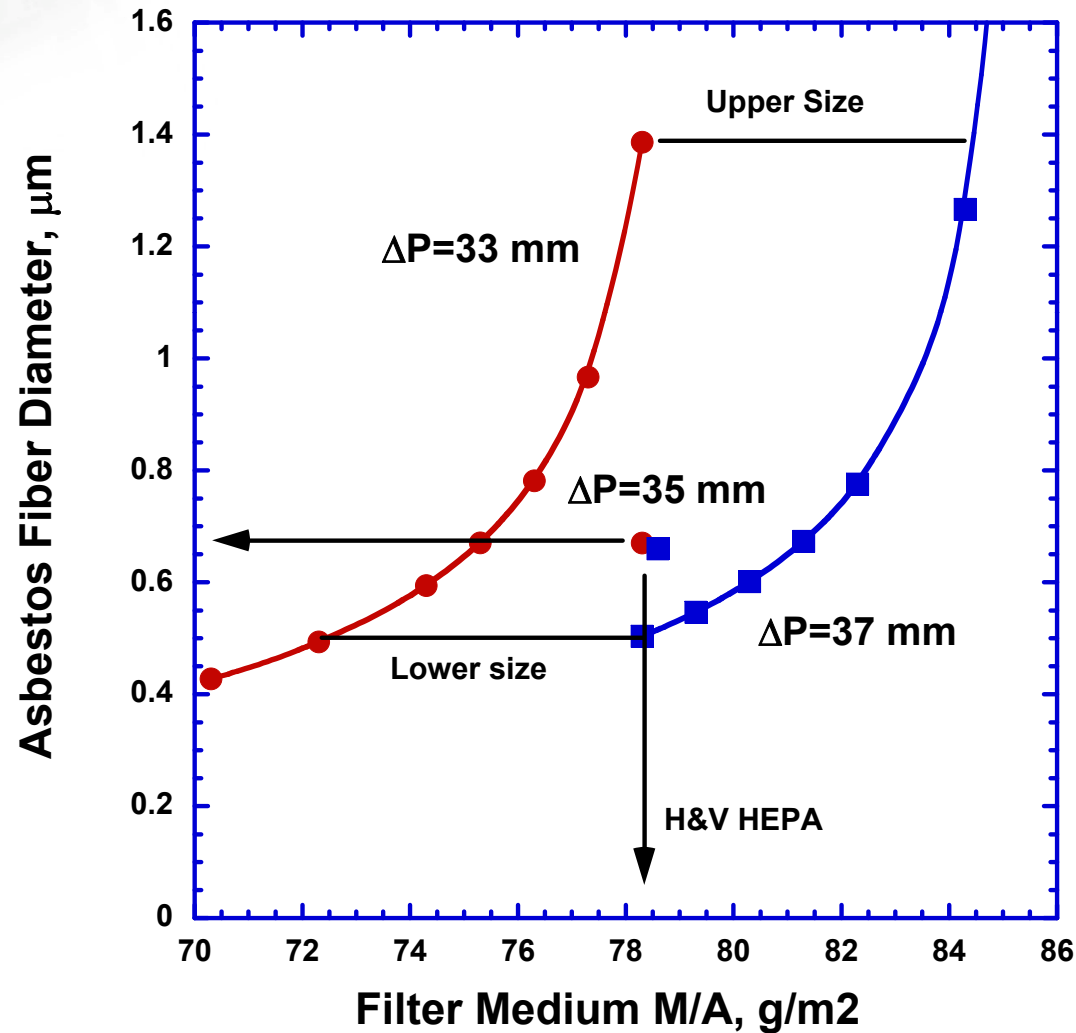
T = thickness of filter media (not reported, used H & V data)

ρ_i = density of filter fiber



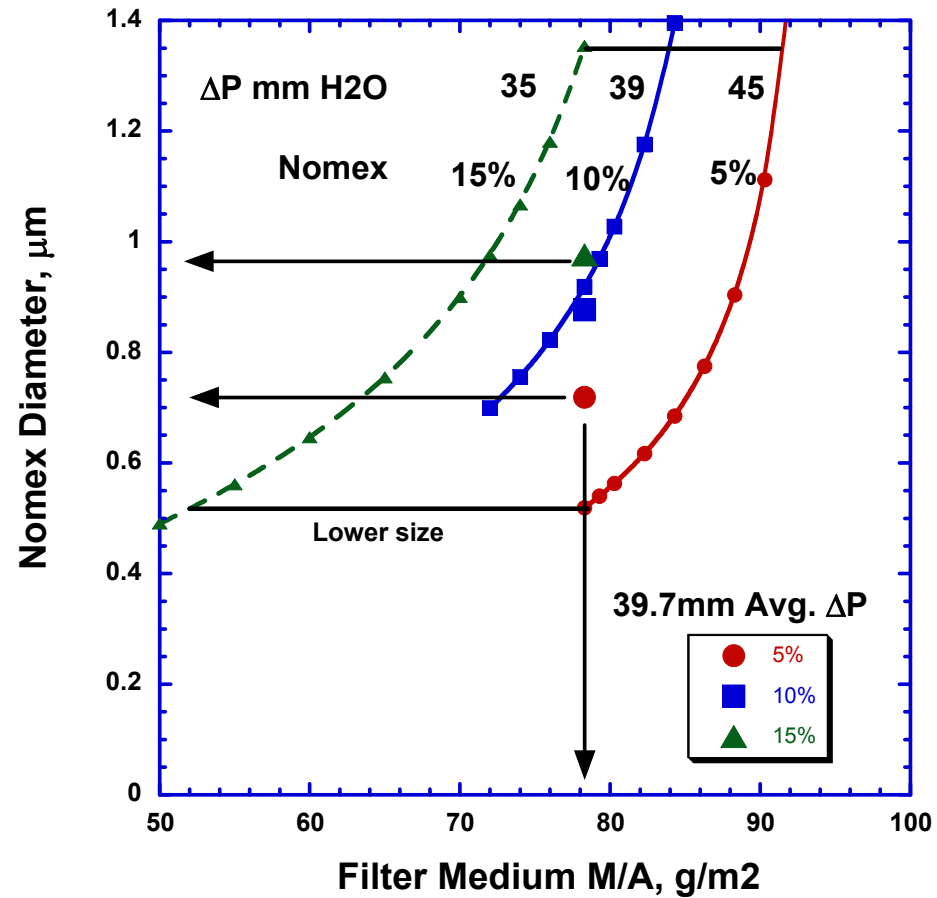
Asbestos diameter estimated from pressure drop measurements

- Uncertainty range in fiber diameter and media weight defined by ΔP equation
- Unique fiber diameter of $0.670 \mu\text{m}$ determined when assuming H&V media weight.



Nomex diameter estimated from pressure drop measurements

- Uncertainty range in fiber diameter and media weight defined by ΔP equation
- Diameter range of 0.719-0.976 μm determined when assuming average ΔP and H&V media weight. Average diameter of 0.857 μm has uncertainty.
- Lack of single diameter shows assumption of constant filter mass is false



Determination of fiber length

- Fiber mass determined from H&V HEPA media mass and mass percent of specific fiber
- Fiber diameter determined from ΔP measurements
- Fiber length determined with the following formula

$$L_i = \frac{4 m_i}{\rho_i \pi D_i^2}$$



Determine HF reaction rate with glass fibers

- No studies are found on the reaction rate of HF with glass fibers used in HEPA filters.
- The HEPA filter HF studies at Rocky Flats have only one HF concentration and is not sufficient for determining reaction kinetics.
- The reaction kinetics of HF reaction with other glasses is obtained from semi-conductor and inhalation toxicology studies. For the concentration region of interest, the rate is

$$Rate = k C_{HF}^{1.3}$$

- Data suggests that HF in vapor and in water solution etch HEPA glass fibers at the same rate



Etch rate of Glass varies widely

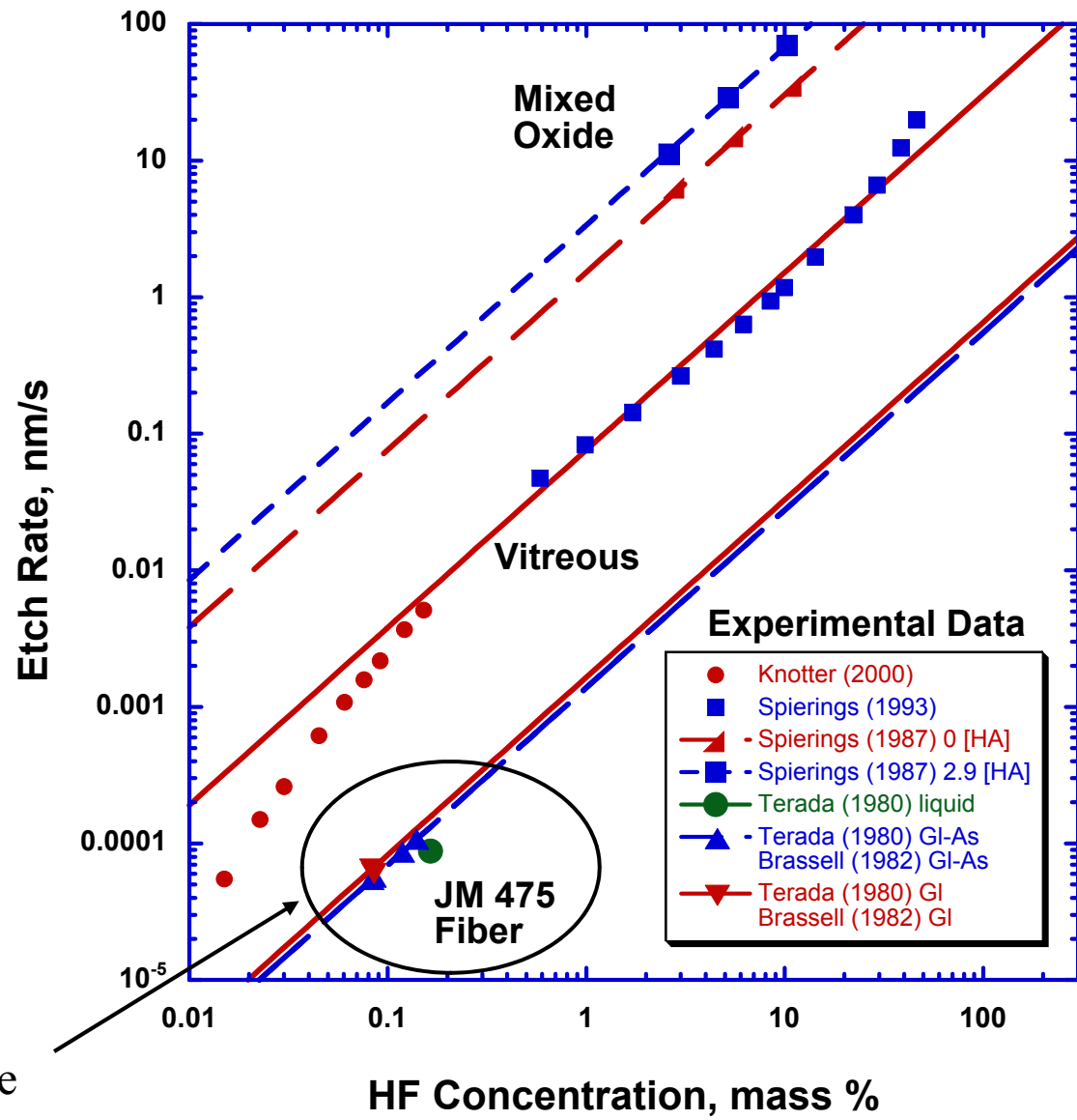
Note the log-log scale

Depends on:

- Type of glass
- HF concentration
- Need water (vap or liq)
- Enhanced with acids
- Rate = $k C^{1.3}$

Major Findings:

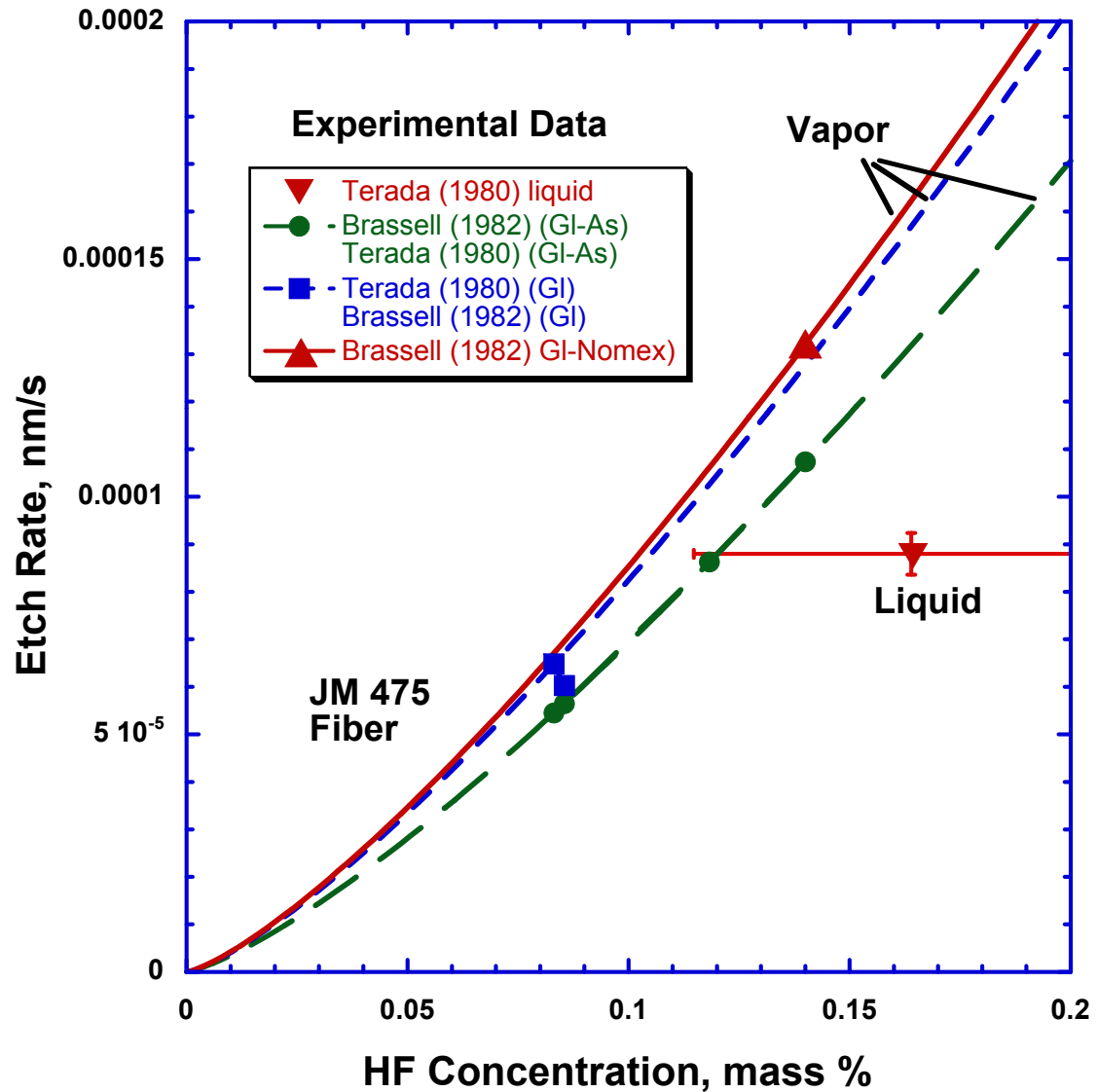
- HEPA fibers are mixed oxides but have 1000 times slower etch rate.
- Etch rate of HF vapor and solution is the same



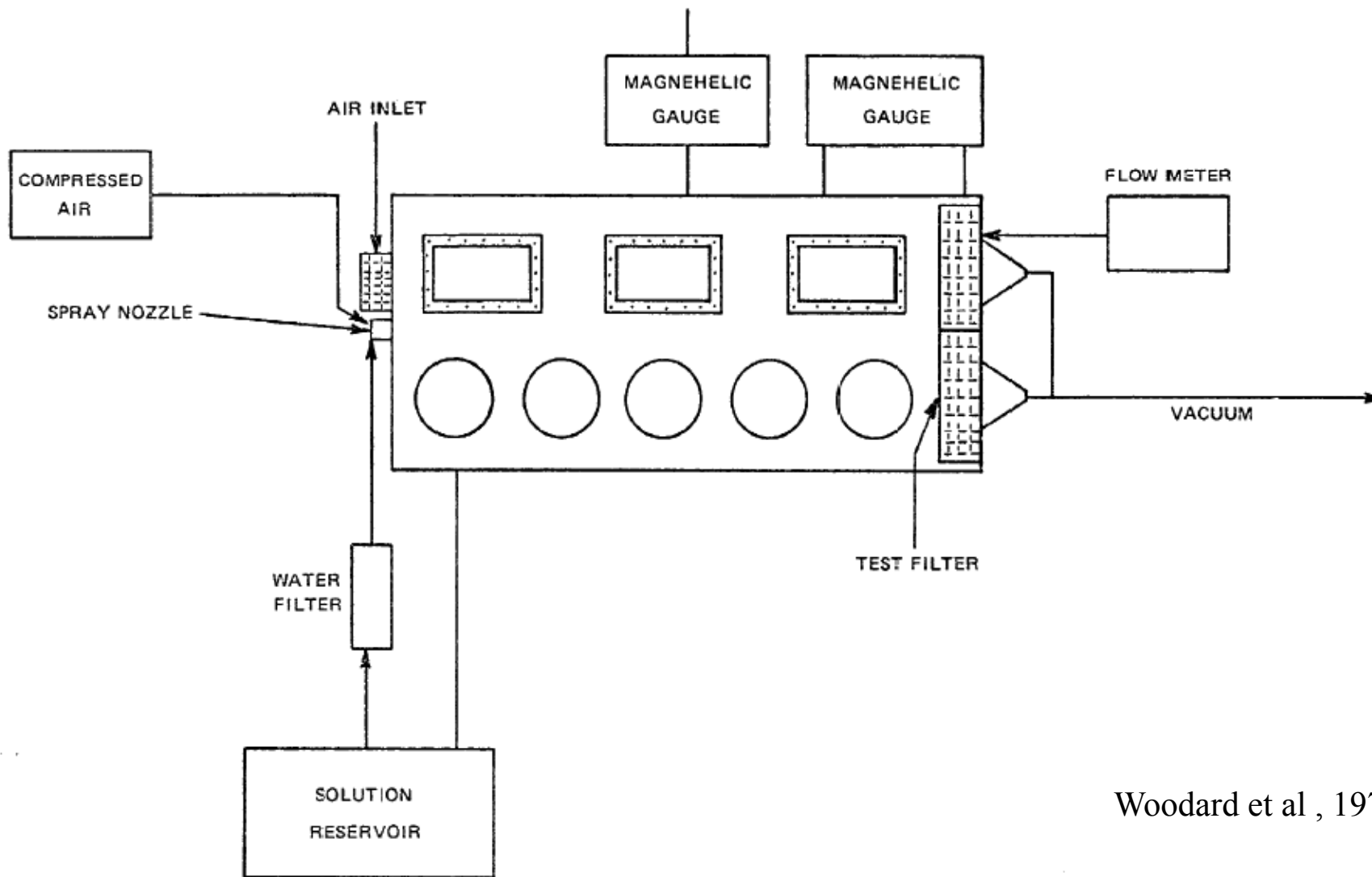
Blow-up on next slide

Etch rate of HEPA glass fibers (JM 475 fibers)

- All data should fall on a single curve. The variation is due to missing filter mass and HF concentration data.
- The liquid etch point concentration has large uncertainty.
- The highest etch rates are used to be conservative.



Experimental system used to expose glass HEPA filter media



Woodard et al , 1979



Experimental system used to expose glass HEPA filter media

- Three different studies conducted at Rocky Flats on HEPA media exposure to HF: Woodard et al 1978, Terada et al 1980, Brassell et al 1982
- Exposure consisted of spraying HF/water solution into a glove box having four 8” x 8” filter media sheets in the exhaust. The filter sheets were made as part of the study.
- All studies lacked key data for developing HF exposure model
 - HEPA media weight and fiber diameters not specified
 - HF challenge concentration either not stated or not reliable
- Approach for obtaining missing information:
 - Assume HEPA media weight is the same as commercial media
 - Compute fiber diameters from ΔP measurements
 - Compute HF exposure from related measurements
 - Use the HF degradation of a reference media for estimating HF concentration (a litmus paper test for HF)



Determination of HF concentration from known solution concentration

- Sealed glove box ensures that the only source of water is from the acid spray
- Use water from the HF/water spray as a tracer for the HF
 - Used relative humidity, temperature and air flow measurements to compute the water content, C_w , in the chamber
 - Measured the HF content, C_{HF} % mass, in the spray solution

$$ppm_{HF,m} \approx \frac{C_{HF} C_w \times 10^6}{100 \rho_{air}}$$

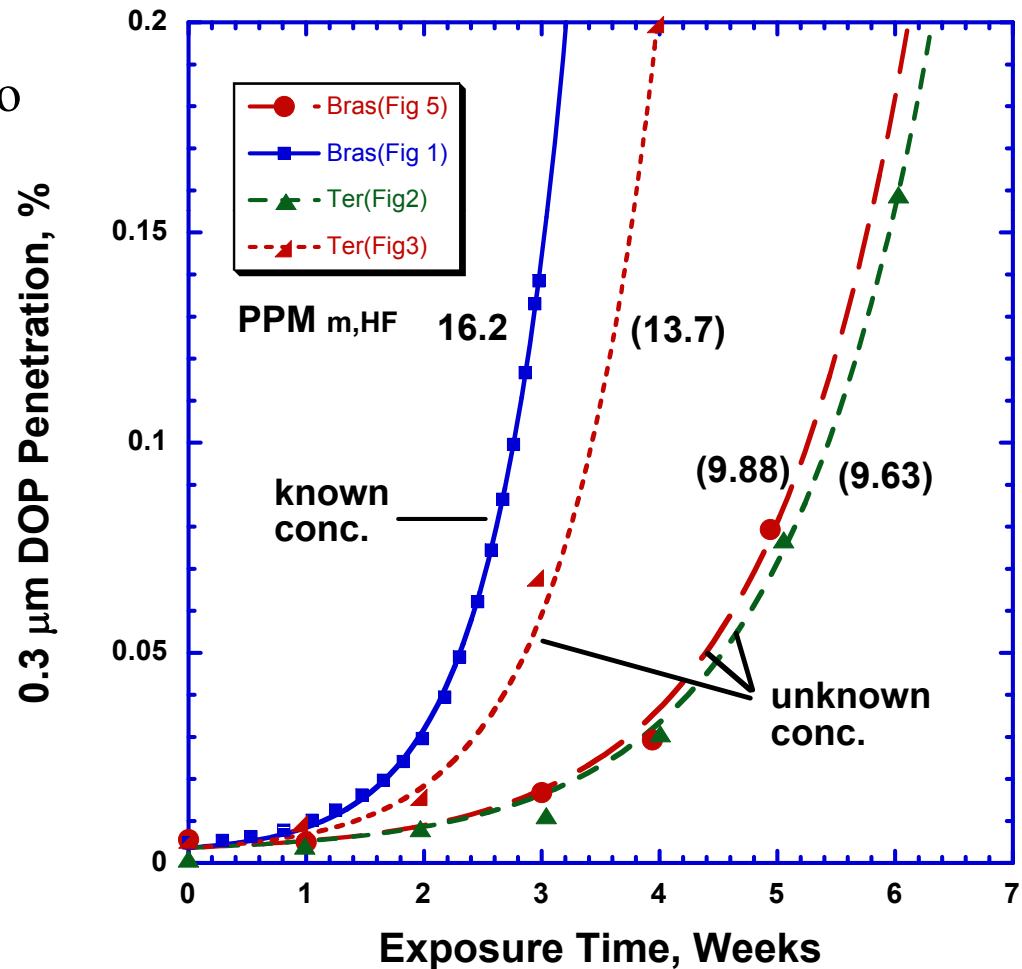


Determination of HF concentration using GI-As reference filters

(1) Develop the reference filter equation using a known HF concentration

$$P_{gl,5\%As} = 0.0024 + 100 e^{-0.3294 \left(2.191 + 40.62 \left[0.789 - 0.0004494 C_{HF,ppm,M}^{1.3} \right] \right)}$$

(2) Fit the reference equation to penetration data to obtain the unknown HF concentration



Determination of HF concentration

HF concentrations derived from solution concentration or from degradation of reference filter

Reference	Filter Media	HF Concentration		
		Reported, ppm	Computed from solution, ppm	Computed from reference filter degradation, ppm
Brassell Fig 1	5% asbestos	5 ppm	16.2 ppm	---
Brassell Fig. 3	5% asbestos, 5% Nomex	5 ppm	16.2 ppm	---
Brassell Fig. 5	Glass, 5% asbestos	2 ppm	---	9.88 ppm
Terada Fig. 2	Glass, 5% asbestos	---	---	9.63 ppm
Terada Fig. 3	5% Nomex, 5% asbestos	---	---	13.73 ppm



Putting it all together: adding experimental parameters

- Adding the experimental parameter values yields the HF filter model

$$P_{gl, 5\%As} = 0.0024 + 100 e^{-0.3294 \left(2.191 + 40.62 \left[0.789 - 0.0004494 C_{HF, ppm, M}^{1.3} \right] \right)}$$

- This equation predicts the DOP % penetration of a glass fiber HEPA media with 5% asbestos as a function of HF exposure at 70°F.
- Note, this equation applies to both media samples and any full-scale HEPA filter. There is no velocity dependence.
- This equation is used as a reference filter to determine the HF concentration in other tests.

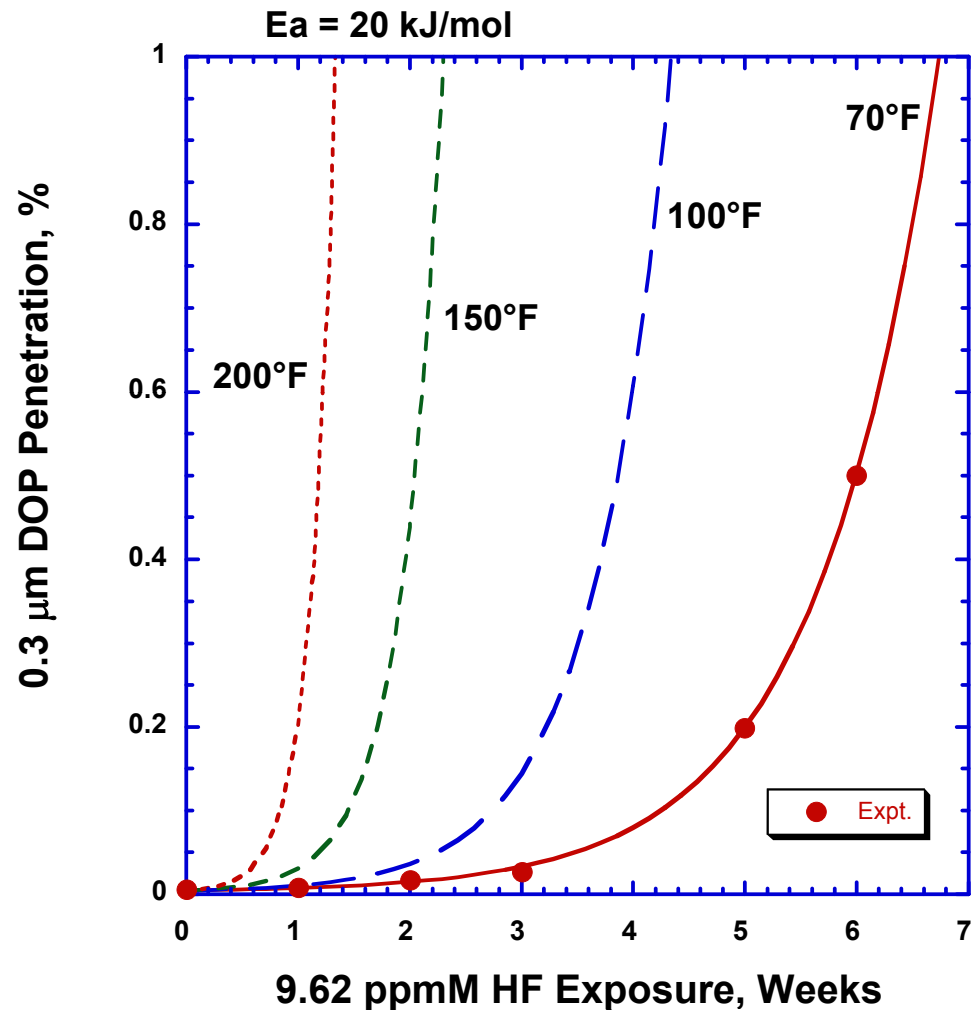


Putting it all together: adding temperature effects

The etching rate increases with temperature.

$$\text{Rate} = k_{Gl}^1 \exp\left(-\frac{E_a}{RT}\right) C_{HF, ppm, M}^{1.3}$$

- The E_a for the HEPA glass fibers is not known.
- An estimate based on mixed oxide glass is 20kJ/mol.



Models for glass, glass-asbestos and glass-Nomex filters

Glass HEPA filters

$$P_{Gl} = 0.003 + 100 e^{-13.74(0.794 - 1.821 e^{-2405/T} C_{HF, ppm, M}^{1.3} t)}$$

Glass-asbestos HEPA filters

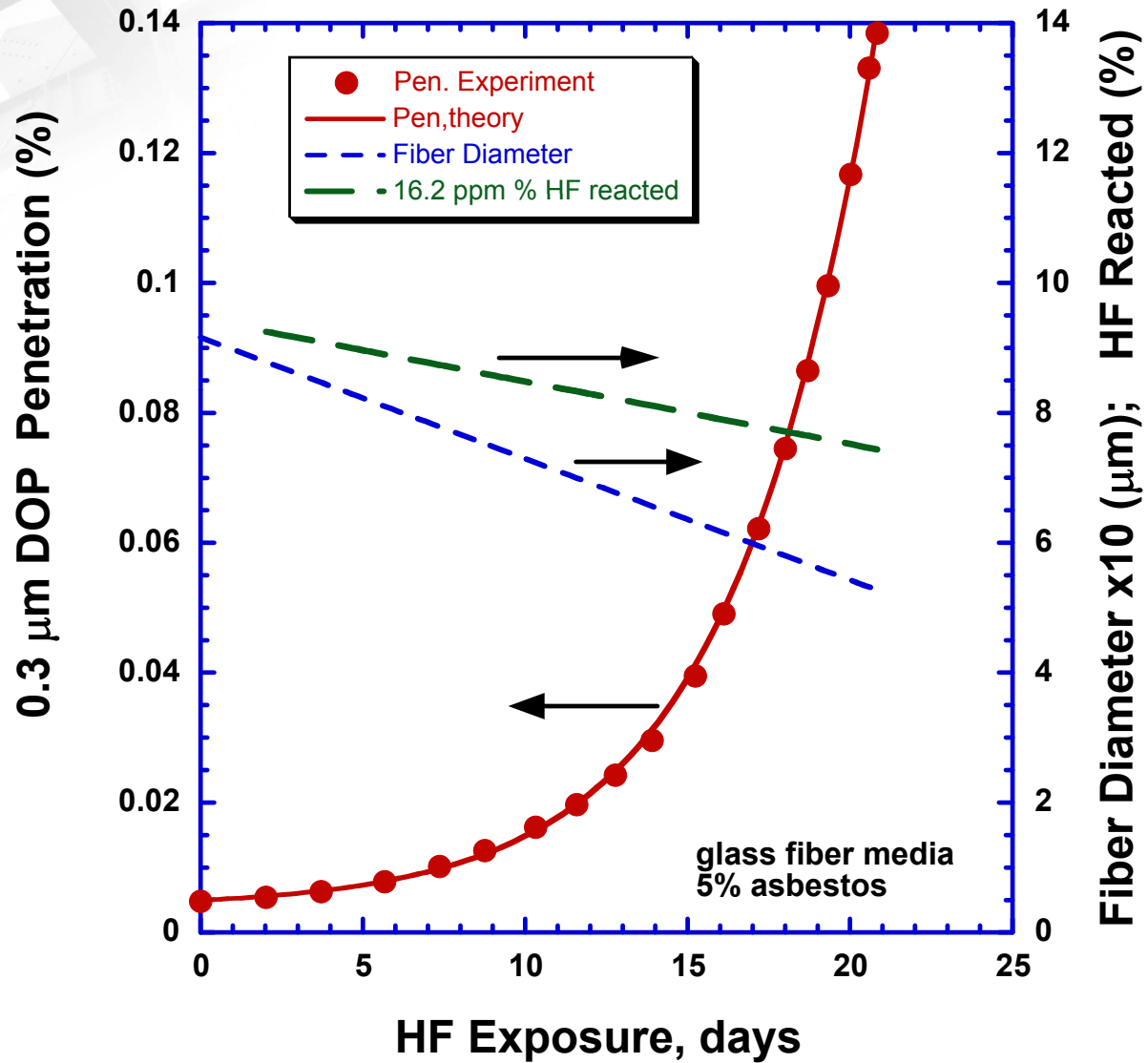
$$P_{As-Gl} = 0.0024 + 48.59 e^{-13.38(0.789 - 1.602 e^{-2405/T} C_{HF, ppm, M}^{1.3} t)}$$

Glass-5% Nomex HEPA filters

$$P_{N-Gl} = 0.003 + 21.47 e^{-14.99(0.785 - 2.108 e^{-2405/T} C_{HF, ppm, M}^{1.3} t)}$$

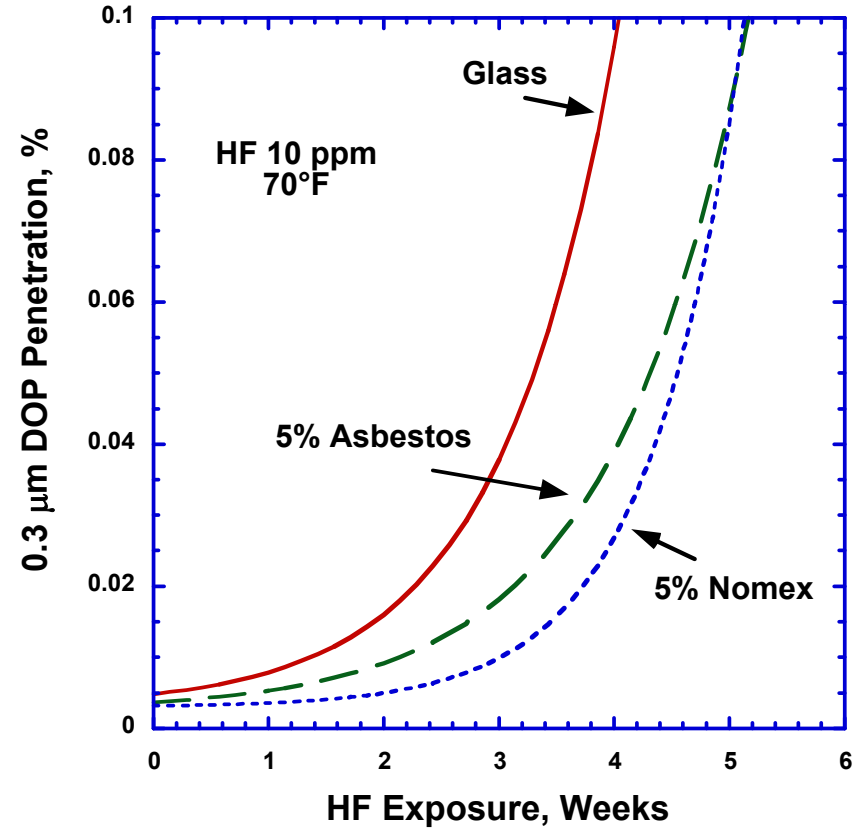
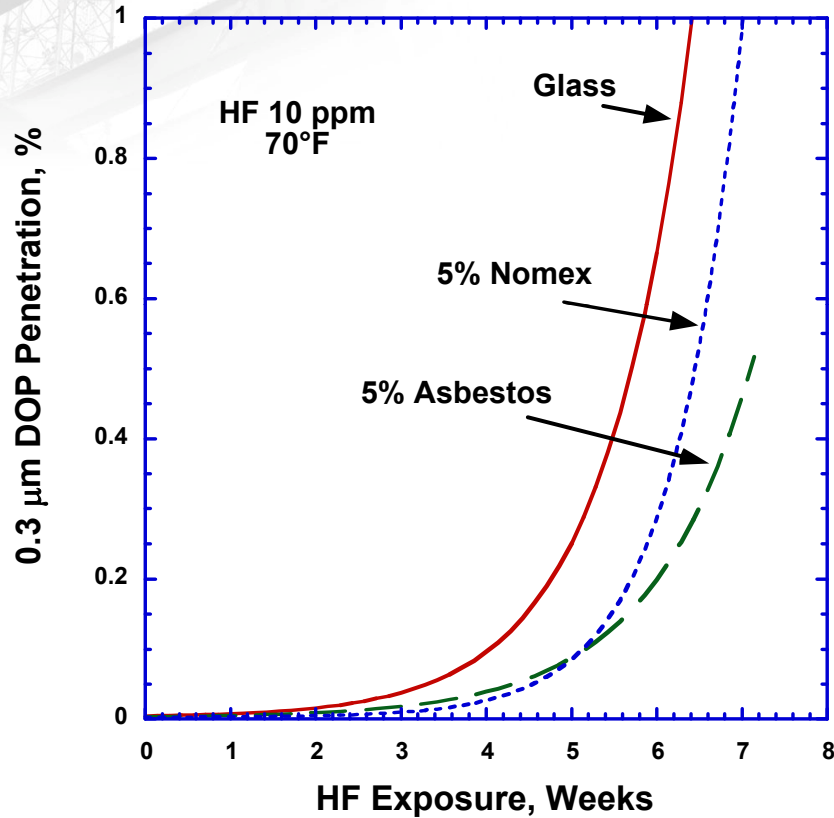


General trends in HF filter model



Comparison of different HEPA filters to HF exposure

Asbestos and Nomex increase HEPA life slightly



Conclusion

- Models are developed for predicting HEPA filter penetration following HF exposure for glass, glass-asbestos and glass-Nomex fiber filters. The glass HEPA filter model is:

$$P_{Gl} = 0.003 + 100 e^{-13.74 \left(0.794 - 1.821 e^{-2405/T} C_{HF, ppm, M}^{1.3} t \right)}$$

Penetration (%)

Temperature (°K)

Time (days)

HF Concentration (ppm)

- The accuracy of the models is based on a single HF concentration measurement and the following assumptions:
 - mass of the media is the same as commercial HEPA media
 - the HF reaction rate for HEPA fibers is similar to the rate for other glasses = $kC_{HF}^{1.3}$
 - The temperature dependence is based on an activation energy of 20 kJ/mol for mixed oxide glass.

