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**Evaluation of Selected Detector
Systems for Products Formed in the
Atmospheric Hydrolysis of
Uranium Hexafluoride**

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EVALUATION OF SELECTED DETECTOR SYSTEMS FOR PRODUCTS FORMED
IN THE ATMOSPHERIC HYDROLYSIS OF URANIUM HEXAFLUORIDE

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I. INTRODUCTION

When gaseous uranium hexafluoride (UF_6) is released into the atmosphere (as may occur from the rupture or failure of cylinders, transfer lines, or reaction vessels containing liquid or gaseous UF_6 (1-3)), it is rapidly hydrolyzed by ambient moisture to form a toxic aerosol (4) comprised of uranyl fluoride (UO_2F_2) particles and hydrogen fluoride vapor (HF):

The health effects of these products and the recommended safe exposure limits are listed in Tables 1 and 2, respectively. (Note that since uranyl fluoride can have both chemical and radiological toxicity, exposure limits are related to the degree of enrichment of uranium in the compound).

Obviously, sensitive detection of UF_6 hydrolysis products, either by discontinuous sampling or by continuous or near real-time monitoring, is an important safety consideration for DOE contractors handling large quantities of UF_6 . Automated continuous or rapid intermittent remote sensing of these reaction products can provide an alarm signal when a preselected threshold value has been exceeded (absolute response) or when a significant emission excursion has occurred (rate of change of response).

In this report we evaluate the performance of selected devices for the detection of airborne materials formed in the release of liquid UF_6 ($\approx 1.3 \text{ g}$) into an enclosed volume of 6 m^3 ; these experiments were initiated on October 23, 1986. The detection principles investigated are described below.

II. PRINCIPLES OF AEROSOL PRODUCT DETECTION

A. Photometric Detection

Airborne uranyl fluoride particles (Equation 1) are formed with average aerodynamic sizes in the range of approximately 0.2 to $0.8 \mu\text{m}$ (5). Particles of this size interact with visible light to produce Mie-type scattering, the intensity of which is strongly concentrated in

Table 1. Health effects of UF_6 hydrolysis products (4)

Species	Health Effect	Exposure Level		Exposure Time
		(mg/m ³)	(mg/m ³)X(min)	
UO ₂ F ₂ (as soluble U)	50% Lethality	---	35,000	Indefinite
	Renal Injury	---	1,250	< 30 min
			750	> 60 min
	No Effect	---	650	< 30 min
			390	> 60 min

HF	Detection by Smell	1	---	Indefinite
	Irritation	26	---	< 10 min
		13	---	> 10 min
	Lethal		53,000	0 to 60 min

Table 2. Guidelines for indefinite exposure to airborne soluble uranium and hydrofluoric acid

Species	% U-235	Concentration	Reference
UO_2F_2 (as soluble U)	< 18 %	0.05 mg/m^3	OSHA (20CFR 1910.1000)
	< 5 %	0.2 mg/m^3	ACGIH (1968) NRC (10 CRF 20)

HF (as fluoride)	---	3 ppm	OSHA
		3 ppm (2 mg/L)	ACGIH (1979)

*OSHA - Occupational Safety and Health Administration

ACGIH - American Conference of Government Industrial Hygienists

NRC - Nuclear Regulatory Commission

the forward direction (6). In addition, hydrated HF can form a mist or fog which can contribute to light scatter (7).

Although it is not inherently selective for UF_6 hydrolysis products, light scatter has been shown to be a very sensitive means to remotely monitor the relative concentration of airborne products (6,8). Monitoring the change of light transmission or light scatter response within an enclosed volume (such as an autoclave) enhances its selectivity.

Since the scattered light intensity is expected to have a strong angular dependence, two photometric techniques were used to follow the release of UF_6 within the experimental chamber. The first technique was based on the attenuation of a laser beam traversing the release vessel by the UO_2F_2 aerosol. The loss in optical signal was correlated with the amount of suspended uranyl particulates to determine the efficiency for which the optical transmission signal could detect the release of UF_6 . The second photometric technique was based on the measurement of light scattered by UO_2F_2 at a 90 degree angle from the incident laser beam. The increase in the scattered optical signal following UF_6 release was compared with results obtained with the optical transmission technique to select the preferred system for the detection of UF_6 release in containment vessels.

B. Gas Detector Tubes

Gas detector tubes contain a selective reagent adsorbed onto a silica gel matrix. A known volume of air, containing the constituent to be measured, is drawn through the tube with use of a manual syringe pump. The reactive constituent in the gas sample contacts the adsorbed reagent, producing a colored reaction product or "stain"; the length of the stain produced within the tube is proportional to the concentration of the sought-for substance.

C. Electrochemical Sensor

The HF Alert unit is manufactured by Sensidyne, Inc., Largo Florida. Acidic HF vapor diffusing through a thin, porous hydrophobic membrane into an internal electrolyte solution produces a galvanic response proportional to the partial pressure of the acidic component.

III. EXPERIMENTAL DESIGN

A. Photometric Detection

Two laser systems were set up for the measurement of optical light transmission during the release experiment. The condensed transmission beam (CTB) system contains only the most basic optical components required to perform the transmission experiment. The expanded transmission beam (ETB) system contains additional or higher quality optical components. The performance of these two systems during the release experiment were compared to determine the most reliable and economical equipment required for UF_6 detection based on a light transmission technique.

A schematic of the ETB system is given below (Figure 1); Table 3 summarizes the differences between the two optical transmission systems. The light source for both units is a helium-neon (HeNe) laser, providing 1 mW of optical power at 633 nm. The HeNe laser in the CTB system transmits unpolarized monochromatic light, whereas the ETB system used a polarized HeNe laser. An optical beam expander was attached to the polarized HeNe laser to expand the optical beam diameter from 0.6 mm to 6 mm. The 10X beam expander was added to the optical system to decrease the effect of ambient room dust on the stability of the optical signal and also to increase the volume of the containment vessel sampled by the optical beam. The CTB system did not include a beam expander; its optical signal stability would then be compared with that of the ETB system. A microscope slide, aligned obliquely to the laser beam, was used to deflect a portion of the laser intensity through a 633 nm optical filter to a 1 cm diameter silicon photodiode reference detector. The 10 nm bandpass filter was used to minimize the effect of stray room light on the photodiode. The reference beam in both transmission systems was used to correct for fluctuations in laser light intensity. The majority of the laser light, in both the CTB and ETB systems, then traversed the containment vessel and was focused on a second optical filter and 1 cm silicon photodiode. The bandpass of the second optical filter was 10 nm and 1 nm for the CTB and ETB systems, respectively. The 1 nm bandpass filter

will provide better discrimination against ambient room light, if it is required, but will also reduce the light level of the transmitted beam in the ETB system.

Figure 1. Schematic of the ETB transmission system

Table 3. Characteristics of the CTB and ETB Transmission Systems

System	Laser	Beam Width	Reference Filter Bandpass	Measurement Filter Bandpass
CTB	unpolarized	0.6 mm	10 nm	10 nm
ETB	polarized	6.0 mm	10 nm	1 nm

Reflection of HeNe light off UO_2F_2 particles and into two additional photodiodes was used to follow the UF_6 release based on the light scatter technique. Two photodiodes were oriented orthogonally, and at the same vertical height, to the HeNe lasers. A 1 nm bandpass optical filter preceded one of the reflectance photodiodes; a 10 nm bandpass filter preceded the second reflectance detector.

The electronic current from all photodiodes was converted to voltage and amplified by the circuit presented in Figure 2. The series of circuit boards for the six photodiodes differed only by the magnitude of the load resistor (R_L) in the feedback loop of the amplifier circuit. The amplification factor of each circuit is

Figure 2. Detector amplifier circuit

directly proportional to the value of R_L . The amplified outputs from the ETB reference and measurement diodes were additionally connected to a buffer and subtraction circuit. These circuits (Figure 3) were used to zero the voltage difference between the two ETB diodes prior to UF_6 release. The nulled response in the absence of UF_6 corrects for light transmission losses through the viewing windows of the release vessel; the negative voltage output of the circuits during UF_6 release monitors the extent of light loss in the ETB laser system.

The analog output of each circuit was digitized using an HP 3497A Data Acquisition/Control Unit and a 3465A Digital Voltmeter. Data acquisition and statistical analysis were performed using an HP 85A computer. During the release experiment, the HP system was programmed to acquire and average three optical readings taken at two second intervals for each of the six diodes. The optical data was then stored on magnetic tape; the data was also printed to provide a hard copy of experimental results. After the data had been taped and printed, there was a time delay of 10 seconds before the optical transmission and light scatter data was again collected.

The storage of the optical data on magnetic tape requires approximately one minute, which limits the rate that optical data can be acquired digitally. Therefore, the optical voltages from the measurement diodes in both the ETB and CTB laser systems were also followed with an analog strip chart recorder to observe photometric data continuously. A summary of the amplification and electronic monitoring of the photodiode optical signals is presented in Figure 4.

B. Gas Detector Tubes

Gastec hydrogen fluoride detector tubes (catalog No. 17; lot No. QC-51135), containing the pH indicator 4-phenylazodiphenylamine as the selective reagent, were used in the release experiment. The indicator dye changes color from yellow to pink when exposed to acidic vapors. Migration distances for nominal HF concentrations of 0.5, 1, 2, 5, 10, 15, and 20 ppm are indicated on the tube (Figure 5) for 4 pump strokes. Interpolation of scale readings were performed with reference to Figure 6. Concentrations greater than 20 ppm were estimated by using fewer

Figure 3. Block diagram of buffer and subtraction circuit

Figure 4. Summary of signal amplification and data output devices for CTB, ETB and Reflectance Photodiodes

Figure 5. Photograph of Gastec HF detector tubes after sampling UF_6 -release containment chamber (see also Table 5 of text)

Figure 6. Nominal scale calibration (HF, ppm) vs stain migration distance for Gastec HF detector tube

than 4 pump strokes (< 400 mL sample) and multiplying the tube scale reading by the empirical corrections given in Table 4 (derived from the data of Table 6).

Table 4. Empirical scale reading correction factors for use with Gastec HF detector tubes

<u>Pump Strokes</u>	<u>Correction Factor*</u>
1	4.76
2	2.22
3	1.37
4	1.00

*HF = (Scale Reading) X (Correction Factor)

Literature enclosed with the tubes indicate that nominal scale readings must be corrected for the relative humidity of the gas being sampled (presumably, this is related to the co-adsorption of water vapor onto the silica gel matrix containing the indicator). However, the release on October 23, 1986, was performed under ambient conditions of 65°F and 50% RH, which (according to the tube manufacturer) requires no further correction of the data.

C. Sensidyne HF Alert Monitor

One week prior to the experimental release of UF₆, we replaced the sensor membrane cap (Sensidyne Part No. 7010163-1). One day prior to the test, the internal electrolyte solution (Sensidyne Part No. 7010686-7) was replenished. The sensor was calibrated using a flow cell assembly coupled to Kin-TEK Laboratories Model 570C Precision Gas Standards Generator (10). The Sensidyne probe was exposed to a continuous plug flow of 3 ppm HF vapor (from a permeation tube source) in 2.1 liters per minute dry nitrogen carrier gas. The sensor responded to this exposure with a time constant ($t_{1/2}$) of ≈ 7 seconds (i.e., exposed to 3 ppm HF, the unit indicated a response of 1.5 ppm within 7 seconds, and had attained $\approx 95\%$ of its equilibrium response within 30 seconds) (10). When the probe was removed from the

calibration cell, the sensor response recovered with a time constant of ≈ 21 seconds.

D. UF_6 Release Facility

The experimental release chamber is constructed from 3/4 inch thick plexiglass sheets, with outside dimensions of 5 ft X 6 ft X 7 ft (volume 210 ft^3 or $\approx 6 \text{ m}^3$). The chamber and the mechanism for the rapid release of UF_6 therein have been described by Pickrell (9). The box and an exploded view indicating sampling ports and optical windows are illustrated in Figure 7. Windows for transmission and detection of the HeNe laser beam were made from plate glass, attached to the exterior surface of the chamber, covering 1/2 inch holes bored into the chamber walls. Note in Figure 7 that the laser beams and "side" sampling port are located near the bottom of the chamber, relatively close to the release mechanism. On the other hand, the Sensidyne probe was placed at the top of the chamber, and penetrated into the inner dimension of the chamber of only 1-1/8 inches. The "top" sampling port was adjacent to the Sensidyne probe.

The release experiment was initiated at 11:14 AM on October 23, 1986. Approximately 1.35 g of liquid UF_6 (≈ 0.91 g as U) was rapidly released into ambient air at 65°F (18°C) and 50% relative humidity. No forced convection was used to further disperse or homogenize the hydrolysis products formed within the enclosed chamber. A white cloud or smoke appeared instantaneously with the release of UF_6 , and initially rose (due to buoyant forces), followed by relatively slow mixing with the quiescent air, and agglomeration and eventual sedimentation of the particulate component of the aerosol.

E. Sampling and Chemical Analysis

At selected time intervals, the airborne materials within the chamber were sampled for chemical analysis. Samples were withdrawn from a point within 1-2 inches of the condensed laser beam with use of a sample probe (11-in. length X 1/4-in. ID steel tube) attached to a filter holder and pump assembly. Particulates were collected in air sampling cassettes (cat. No. MAW-P037AO, Millipore Corp., Bedford, MA) containing 0.8- μm pore cellulose ester membranes. The membranes were

Figure 7. "Exploded" view of release chamber, indicating location of sampling and detection ports

removed, extracted in 0.1 M HCl using ultrasonic agitation, and the extract was analyzed for total uranium via fluorometric assay.

Additional samples were taken using a dual membrane assembly for the separate collection of particulate and gaseous fluorides (8). Pre-wetted 1.0- μ m pore Teflon prefilters (for UO_2F_2) and formate-impregnated membranes (for HF) were extracted using acetate buffer. Extracts were assayed for fluoride ion with use of an ion-selective electrode. Aliquots of extracts were also assayed for uranium using the fluorometric procedure. Greater than 99.9% of the total U collected was found on the prefilter, and the molar ratio of fluoride-to-uranium on the prefilter was found to be approximately 2.0 (consistent with the empirical formula $\text{UO}_2\text{F}_2 \cdot n\text{H}_2\text{O}$).

IV. EXPERIMENTAL RESULTS

A. Photometric Detection

Prior to UF_6 release, several experiments were run to determine the stability of the optical signals and the effect of ambient room lighting on the light transmission and light scatter measurements. Not shown on the diagram of the containment vessel (Figure 7) is the location of an exterior building door relative to the photodiodes. The door opened directly opposite the faces of the light scatter diodes, orthogonal to the CTB and ETB measurement diodes and approximately 45° to both reference diodes. By opening the exterior door, the ambient room light could be increased significantly. With both HeNe lasers turned off, the background dark currents of the photodiodes were measured when the door was opened and closed; this was compared with the optical voltage when the HeNe laser was turned on. Results in Table 5 suggest that the light scatter diodes were most affected by ambient room lighting. The scattered light level in the presence of an aerosol was so low that a large load resistor (1 Meg Ω) was required to obtain a maximum amplified optical voltage of 0.1 volts. The large amplification factor also increases the magnitude of the background light signal so that the signal-to-noise ratio is poor for light scatter measurements. The light intensity in the transmission technique is great enough that only a modest-sized load resistor is

required. If the bandpass of the optical filter is limited to 1 nm, the effect of ambient room light is insignificant. When the reference signal was used to correct for changes in room lighting and fluctuations in laser intensity, the transmission signals from both the CTB and ETB signals did not vary by more than 1%.

Table 5. Effect of ambient room lighting on photodiode dark current

Photodiode	Load Resistor (ohms)	Filter Bandpass	Dark Current Voltage			Laser Signal (volts)
			Open Door	Closed Door		
CTB Transmission	50K	10 nm	0.010	/	0.003	4.0
CTB Reference	200K	10 nm	0.127	/	0.008	1.8
ETB Transmission	20K	1 nm	0.0001	/	0.0003	5.7
ETB Reference	100K	10 nm	0.050	/	0.003	5.1
Light Scatter #1	1 Meg	1 nm	0.002	/	-0.0002	0.002

Figure 8 presents the analog and digitally acquired data taken during the release experiments. The discrete data points indicate prerelease optical voltages of 6.2, 3.8 and 0 volts for the ETB, CTB and Buffer-Subtraction circuit, respectively. Immediately after release, the analog ETB and CTB signals drop to less than 0.5 volts, increase sharply and finally stabilize one minute into the experiment as the aerosol disperses in the reaction vessel. The first digital data is acquired 1 minute into the experiment, after the distribution of the aerosol has stabilized. Not shown on this plot are the optical signals from the light scatter diodes. The aerosol was initially so dense that the laser beam was obscured to a point that the laser source did not provide enough light for scatter measurements. The light scatter signal, therefore, did not rise above background during this portion of the experiment.

The actual analog signals for the first four minutes of the experiment are presented in Figure 9. The CTB and ETB signals track each other, although the noise level in the expanded beam is larger.

Figure 8. Digital and analog data for CTB and ETB optical signals after UF_6 release

Figure 9. Tracing of a segment of analog laser light transmission data at initial time of UF₆ release

This may be due to the ability to detect changes in aerosol homogeneity in the larger sampling volume of the ETB system.

B. Hydrogen Fluoride Detector Tubes

Samples of aerosol were withdrawn from the "front" sample port (cf. Figure 7) using the Gastec detector tube and manual pump. Stain migration and estimated HF concentrations are summarized in Table 6. The color contrast of the stain (red/pink against a yellow background, cf. Figure 5) was adequate for easy determination of the stain migration. The stains continued to slowly migrate after sampling (Table 7) and became more diffuse with time, presumably due to a chromatographic displacement with water adsorbed from the atmosphere.

Table 6. Results from sampling with use of Gastec HF detector tubes

Tube #	Elapsed Time ^a (min.)	Number of Pump Strokes	Stain Migration (in.)	Scale Reading ^b	Nominal [HF], ppm ^c
2	3	1	1.00	12.8	61
6 ^d	18	1	0.50	4.5	21.4
7	20	2	0.82	9.6	21.4
8	22	3	1.15	15.6	21.4
9	48	1	0.35	2.4	11.4
10	50	2	0.55	5.2	11.6
11	52	4	0.93	11.5	11.5
12	151	4	0.60	6.0	6.0
13	249	4	0.58	6.0	6.0
14	1351	4	0.45	3.8	3.8

a Time elapsed from instant of UF₆ release

b Interpolated using Figure 6

c Nominal [HF] = (Scale Reading) x (Correction Factor), where correction factors are given in Table 4

d Tubes 6-8 are illustrated in Figure 5.

The accuracy of the detector tubes for monitoring HF in air has not yet been validated in this laboratory, but it is apparent from Table 6 that they possess good sensitivity under the ambient conditions of the experimental release (65°C and 50% RH). The determination of the effect of varying conditions of temperature and humidity upon initial stain production by HF vapor is currently in progress and will be reported separately.

Table 7. Post-sampling stain migration on Gastec HF detector tubes

<u>Tube No.*</u>	<u>Stain Migration (inches)</u>		
	<u>Day 1</u>	<u>Day 10</u>	<u>Day 17</u>
2	1.00	1.15	1.20
9	0.35	0.45	0.50
10	0.55	0.71	0.76
11	0.93	1.11	1.17

*see also Table 6

C. Sensidyne HF Alert Monitor

In order to confirm the accuracy of the calibration (see Section IIIC) and to demonstrate that the device responds selectively to HF rather than total fluoride, a sample of aerosol was collected near the Sensidyne probe with use of a dual membrane assembly for the separate collection of particulate (UO_2F_2) and gaseous (HF) fluoride; the results are given in Table 8. The response of the probe, calibrated with use of HF vapor, was in good agreement with the chemical assay for gaseous fluoride. Note that the molar ratio of fluoride to uranium on the prefilter is 2.0, consistent with UO_2F_2 hydrate as the particulate species (cf. Equation 1). Note also that the stoichiometric equation (1) predicts a yield of two moles of gaseous fluoride (HF) for each

mole of particulate fluoride (UO_2F_2), assuming homogeneous dispersion of reaction products. In contrast, the data of Table 8 indicate that only ≈ 0.4 moles of HF per mole of UO_2F_2 were collected after ≈ 34 minutes at the top of the chamber; this indicates that, without forced convection, the HF component of the aerosol was not homogeneously dispersed at the time of sampling.

The response of the Sensidyne HF Alert assembly versus time elapsed from the instant of UF_6 release is shown in Fig. 10. Also shown is the

Table 8. Comparison of Sensidyne HF Alert response to chemical composition

Sensidyne HF Alert ¹		Chemical Sampling & Analysis ²	
airborne fluoride		airborne uranium	airborne fluoride
		Prefilter ³	Prefilter ³
Chemisorption ⁴		Chemisorption ⁴	
4.0 ppm HF			3.6 ppm HF
(3.2 mg F/m ³)	50.2 mg U/m ³	0.019 mg U/m ³	8.0 mg F/m ³ (2.8 mg F/m ³)

-
1. Previously calibrated with permeation device, using dry nitrogen carrier gas
 2. 17.2 liters of gas at 18°C sampled during the interval of 32-36 minutes subsequent to UF_6 release. Sample was taken at "top" port, near Sensidyne probe (see Figure 8).
 3. Teflon prefilter, 1.0 μm pore
 4. Formate-impregnated cellulose acetate chemisorption filter, 5.0 μm pore
-

response of the assembly to a prior release on May 19, 1986 (see Table 9), in which forced convection was provided by a small fan (nominal 2.5 m³/min flow velocity) for 3.5 minutes subsequent to the release. With forced convection, the Sensidyne unit indicated a 3 ppm HF threshold value within ≈ 15 seconds; note also in Figure 11 that HF concentration

Figure 10. Response of Sensidyne HF alert to experimental release of UF₆: effect of forced convection within chamber

near the top of the chamber rapidly declined after forced convection was terminated. In contrast, the release with no forced convection required approximately 100-times as long to indicate a 3 ppm threshold value at the top of the chamber; peak response was 5.7 ppm after ≈ 100 minutes elapsed time (cf. Table 6 for nominal HF concentrations near the bottom of the chamber as indicated with use of the Gastek gas detector tubes.) These data suggest that hydrated HF tends to sediment near the bottom of the chamber and does not homogeneously disperse without forced convection.

Table 9. Experimental releases of UF_6 into a 6 m^3 Chamber

Experiment Date	UF_6 (g)	Theoretical Yield*	
		U (mg/m^3)	HF (ppm)
May 19, 1986	0.98	163	45
October 23, 1986	1.35	225	62

*Assuming complete hydrolysis and dispersion of reaction products with the following stoichiometry:

V. COMPARISON OF DETECTION DEVICES AND THEIR RESPONSE

As the laser beam propagates through a medium containing suspended particles, its intensity is attenuated to an extent dependent upon the concentration of scattering centers and the sampling pathlength. This represents turbidometric measurement, which usually obeys a Beer's law relationship:

$$A = \log_{10} (I_0/I_t) = kbc \quad (2)$$

where A is absorbance, I_0 is the intensity of the incident beam, I_t is the intensity of the transmitted beam, b is the pathlength, c is a measure of concentration, and k is a proportionality constant.

In Figure 11, the absorbance signals for the CTB and the ETB lasers are compared to the airborne uranium concentration as a function of time elapsed from the instant of UF_6 release. (Note: intensities used for the computation of absorbance were taken from the continuous analog signals, a portion of which is shown in Figure 9.)

As shown in Figure 11, absorbance of the laser beam is maximum (i.e., transmission of light is minimal) before the peak concentration of airborne uranium occurs, suggesting that species other than particulate uranium may contribute to the observed laser light attenuation. Figure 12 compares the absorbance of the laser light to the apparent HF concentration, as determined with use of the Gastec HF gas detector tube. Apparent HF concentration near the bottom of the chamber peaks early, as does the laser beam response. It is thus probable that condensable hydrated HF also contributes to the laser beam attenuation by light scatter.

The sensitivity for monitoring UO_2F_2 by laser light attenuation can be estimated by comparing the observed absorbance with uranium concentration for all data occurring at times greater than 100 minutes after UF_6 release. Beyond this time, the contribution of HF to light attenuation is minimal. Figure 11 indicates that there is a loss of 5 milliabsorbance (mA) per mg U/m^3 , using a 6-foot optical path length. Thus the proportionality constant, k , is equivalent to approximately 0.9 mA per mg U/m^3 per foot for either the CTB or ETB laser system.

If one assumes that a 3% light loss (13 mA) can be detected with the transmission system, then a minimum of 3.8 mg U (5.6 mg UF_6) release could be detected in an autoclave having a 1.5 m^3 (52 ft^3) volume and 4 foot optical path. Because HF also contributes to light loss during the release, the actual sensitivity to UF_6 release will be slightly greater.

VI. RECOMMENDATIONS

A. Laser UF_6 Release Monitor

Monitoring UF_6 release based on the 90-degree scatter of laser light is not recommended. This technique failed for two reasons: first, the scattered signal is so weak that ambient room lighting contributes significantly to the total signal, even when the best

Figure 11. Comparison of airborne uranium concentration (sampled at "side" port, CF. Fig. 7) vs absorbance of laser beam during UF_6 -release experiment

optical filtering is used. Second, when there is a sudden, large release of UF_6 , the laser beam is totally obscured and little scattered light can reach the detector. This can result in a false negative signal from the release monitor.

The UF_6 release monitor can be based on the attenuation of a laser beam traversing the containment vessel. The beam can be expanded for monitoring a larger volume of the vessel; however, if there is forced convection this probably is not necessary. According to Figure 12 there is little difference in sensitivity between the ETB and CTB system, although the ETB system data was slightly noisier during the release experiment. Both the reference and measurement photodiodes should be preceded by a 1 nm bandpass optical filter to minimize the interference caused by ambient room lighting during monitor operation.

The optical signals from the photodiodes can be measured either by analog circuitry or digitally. An analog signal provides an instantaneous response to UF_6 release. However, a 5-second response time should be possible with the digital HP data acquisition system if data is not stored on magnetic tape or logged with a printer. Faster response times can be obtained with other brands of digital data acquisition equipment. Several controls should be available to 1) check for voltage over-range and subsequent amplifier saturation, 2) correct the ambient room light contribution and autoclave port window fouling, and 3) check for laser power level and photodiode sensitivity. Because of the amount of time that would be required to design these features with analog circuitry, it may be advisable to use an analog amplifier circuit for the photodiode current, followed by an analog-to-digital converter and computer. Development of control features through computer software may prove less time consuming and more economical.

B. HF Gas Detector Tube

The Gastec HF detector tubes have been shown to be very sensitive to UF_6 hydrolysis products under the conditions of the experimental release (see Figure 12). The stain migration distance for a given concentration of HF is expected to increase at elevated temperatures and at lower absolute humidities. The performance of these detectors

Figure 12. Comparison of airborne HF concentration (sampled at "side" port, using Gastec HF detector tubes) vs absorption of laser beam during UF_6 -release experiment

under the ambient conditions within an autoclave or reactor remains to be evaluated.

C. Sensidyne HF Alert Monitor

This device has been demonstrated to have good sensitivity and a rapid response toward HF vapor (10). However, as discussed in Section IV, hydrated HF vapor or mist appears to remain near ground level in the absence of forced convection. Therefore, for accurate monitoring of HF we recommend use of forced convection near the sensor or active transport of sample to the sensor membrane.

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