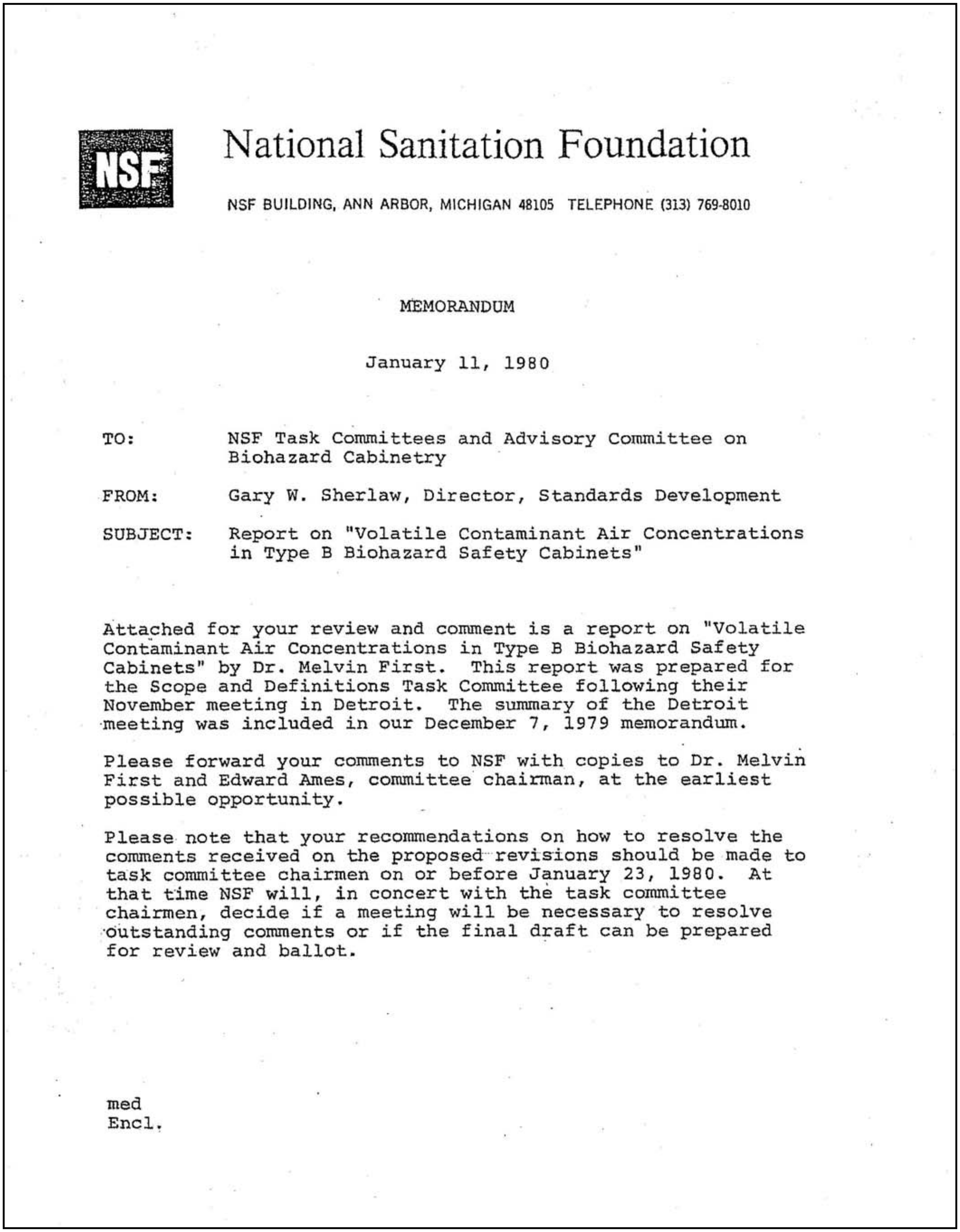
NSF History Report on "Volatile Contaminant Air Concentrations in Type B Biohazard Safety Cabinets"

The following document is an original National Sanitation Foundation (NSF) report prepared for an advisory task group by Dr. Melvin First. The report contains relevant information and data on use of volatiles in biosafety cabinetry.

Please note that Biosafety cabinetry (BCS) definitions have changed over the years. The information provided for a type B convertible model is equivalent to a class II type A2. The information provided for a NCI type B is equivalent to a class II; type B1.

In providing this information, NuAire does not endorse the use of volatiles within BSC's. The use of volatiles should be reviewed through a risk assessment process with your facility safety personnel. Volatiles can freely pass through HEPA filtration and if used, require the BSC to be exhausted through either direct or canopy connection depending upon the cabinet class and type.



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MEMORANDUM

January 11, 1980

TO: NSF Task Committees and Advisory Committee on Biohazard Cabinetry

FROM: Gary W. Sherlaw, Director, Standards Development

SUBJECT: Report on "Volatile Contaminant Air Concentrations in Type B Biohazard Safety Cabinets"

Attached for your review and comment is a report on "Volatile Contaminant Air Concentrations in Type B Biohazard Safety Cabinets" by Dr. Melvin First. This report was prepared for the Scope and Definitions Task Committee following their November meeting in Detroit. The summary of the Detroit meeting was included in our December 7, 1979 memorandum.

Please forward your comments to NSF with copies to Dr. Melvin First and Edward Ames, committee chairman, at the earliest possible opportunity.

Please note that your recommendations on how to resolve the comments received on the proposed revisions should be made to task committee chairmen on or before January 23, 1980. At that time NSF will, in concert with the task committee chairmen, decide if a meeting will be necessary to resolve outstanding comments or if the final draft can be prepared for review and ballot.

med
Encl.

8 November 1979

Volatile Contaminant Air Concentrations in Type B Biohazard Safety Cabinets

Starting with the drawings prepared by Gary Sherlaw (Figure 1), I reduced each to a simple line diagram in Figure 2 and assigned symbols to air flow rate (Q), volatile contaminant concentration (C) and fraction of down flow air entering the front grill of the cabinet labeled NCI(a).

Using a simple mass balance as the analytical method, it is possible to show that the volatile contaminant concentration in the downflow air of the convertible cabinet (micrograms per cubic meter) is the ratio of the generation rate at the work surface (micrograms per minute) divided by the flow rate through the work opening (cubic meters per minute) and that the downflow air concentration in the NCI cabinet is the same ratio times the fraction of the downflow air that enters the front grill.

If we want to know how much more dilution of the contaminant generated on the work surface occurs in the NCI design, we can take the ratio of the two downflow concentrations. For equal inflow volumes (as shown in Gary's drawings) and equal volatile contamination generation rates, the NCI cabinet will have a downflow volatile concentration equal to the convertible concentration times the fraction of total downflow air that enters the front grill. For example, if the air in the NCI splits 10% through the front grill and 90% through the rear opening, the NCI downflow air will have one-tenth the concentration that will be present in the convertible model; if the split is 20-80, the concentration in the NCI downflow will be one-fifth that of the convertible model; etc. Obviously, if 100% of the downflow air in an NCI cabinet goes through the front grill of the NCI design (or if 100% of the contaminant because the operator is working at the front of the cabinet) the concentration in the downflow air will be the same as would be observed in a convertible cabinet. There is no way that the concentration in an NCI cabinet could exceed the convertible cabinet downflow concentration. At the other limit, if none of the NCI downflow air goes into the front grill (or if all the contaminant generated on the work surface goes into the rear grill), the downflow air will contain no contamination whatsoever.

To put this matter into a practical context, it should be kept in mind that the amounts of volatile carcinogens and radioactive tracers contemplated for use in these cabinets are "microgram quantities". When whatever fraction escapes from the experiment is diluted by the inflow air of approximately 300 cfm, we are dealing with concentrations in the range of nanograms per cubic meter of air. It is probably safe to assume that an additional dilution factor of 10 times can be achieved with the NCI cabinet by the application of good work practices. Whether this one order of magnitude reduction in the concentration of the volatile contaminant in the downflow air is important can only be determined by the person responsible for the experimental design. When the added dilution factor is important to the experimenter, the NCI design should be employed, when it is not, either design should be adequate. Should the experimenter need air in the work space that is completely uncontaminated with the volatile chemicals he is working with (an infrequent real need, I would estimate) he should go to a one-pass (or zero recirculation) cabinet. The important thing is for the experimenter to be able to obtain a good estimate of what the maximum concentration of his volatile material is likely to be in the downflow air and this he can do easily by estimating his expected maximum loss rate and dividing this by the inflow air rate. When using the NCI design in the proper manner, he can expect to obtain a downflow concentration that is one-fifth to one-tenth this concentration. I do not believe this matter has any impact on safety: only on tolerable product contamination levels calculated as a maximum.

A safety issue does arise when considering an accidental spill of a substantial quantity of a flammable solvent (not the microgram amounts of carcinogens and radioactive tracers discussed above). This is not a health problem as the volatile solvent is not going to escape from the cabinet and enter the breathing zone of workers; it is solely a fire and explosion hazard and the question to be answered is whether one design of "B" cabinet is safer than the other in this category. The fire hazard from spills is related to the flammability of the solvent (i.e., the lowest concentration in air that will burn)
and its volatility (i.e., the rate at which it will evaporate into the air). Volatility can also be expressed in terms of the solvent's flash point (i.e., the lowest temperature at which it gives off enough vapors to form a flammable mixture with air near the surface of the liquid). Three commonly used solvents can be compared with respect to these properties as follows.

solvent	Flash Point - °F	Lower explosive conc'n in air-% by vol.
acetone	15	2.1
ethanol	71	3.5
diethyl ether	-49	1.7

It will be apparent that absolute ethanol is a reasonable safe solvent even when spilled as it requires an open flame applied to the liquid surface to ignite the vapors inside a ventilated cabinet. Although the vapors rising from an alcohol pool will reach the lower flammable limit of 3.5% at 71°F, this concentration will occur only at the liquid surface. Immediately above the liquid surface the vapors will be diluted to below a flammable concentration by the air movement. By the same criteria, ether is a highly dangerous material when spilled as its saturation vapor pressure at 70°F represents an air concentration 35 times its lower explosive limit of 1.7% by volume and the existance of flammable concentrations is very possible even with normal cabinet air flow. The flammability hazard of acetone is intermediate between these two, the saturation concentration at 70°F being about 15 times its lower explosive limit. Under stagnant air conditions each of the three solvents would produce vapor concentrations in the flammable range but with normal cabinet air flow, alcohol vapors would be below the flammable range, acetone vapors might reach a flammable concentration at 70°F, and ether would be likely to reach this level if sufficient liquid was spilled to produce a large exposed surface of evaporating liquid.

Although it is easy to make fire hazard comparisons between volatile solvents it is exceedingly difficult to define the hazard from a spill in absolute terms because of uncertainties in predicting the resulting liquid surface, the air exchange over the liquid surface and the temperature of liquid and air. Ultimate safety is achieved by limiting the qualtity of liquid that can be introduced inside a cabinet, eliminating open flames, and providing a drainage system that will conduct all of the spilled liquid into a closed container with a minimum sized opening to restrict the loss of solvent by evaporation into the cabinet spaces.

A determination of the maximum amount of solvent that should be permitted inside a cabinet may be approached in the following way. Using Gary's figures of 267 cfm through the working opening and 350 cfm downflow, we can calculate the volume of liquid that would be equivalent to the lower explosive limit when evaporated into this volume of air. For acetone, it is 1,130 ml and for ether, it is 1,300 ml. This seems paradoxical inasmuch as ether has been characterized as the more volatile and more flammable solvent but it comes about because the molecular weight of ether is almost 30% greater and its specific gravity 10% less than acetone. Thus, if 1,130 ml of spilled acetone or 1,300 ml of spilled ether evaporated uniformly over a one minute period inside the cabinet, it would form a mixture that was on the lower flammability borderline. The fire underwriters insist on a 4-times safety factor, or no more than one quarter the lower flammable limit. This would restrict the volume of liquid acetone or ether that would be permitted inside a cabinet to approximately one quarter liter. I think this is a sensible rule to apply to every flammable liquid. Even if it isn't highly volatile,as acetone or ether, it is wise to restrict the amount of combustible matter allowed inside a cabinet.

Based on the information reviewed above, I propose the following definitions for Type A and Type B cabinets.

Type A. Cabinets that maintain a minimum calculated average inflow velocity of 75 fpm thru the work access opening and recycle within the cabinet as downflow air a volume equivalent to 100% of the downflow. The remaining air, equivalent to 100% of the inflow air volume, is exhausted to the laboratory room or to the outside atmosphere after passage thru a HEPA filter.

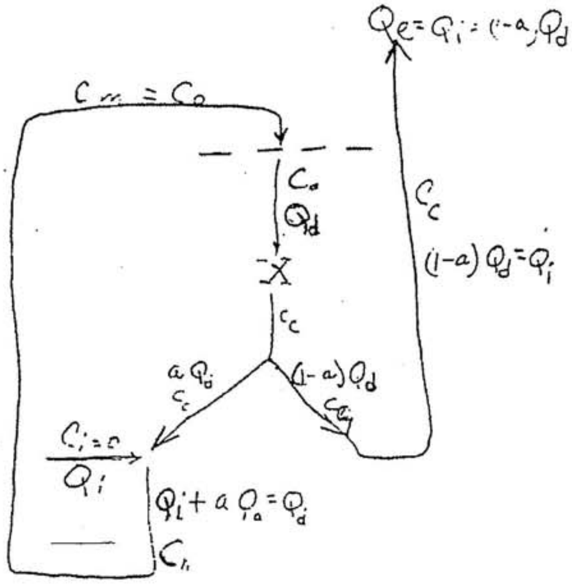
Type B. Cabinets that maintain a minimum calculated or measured average inflow velocity of 100 fpm thru the work access opening and recycle within the cabinet as downflow air a volume equal to or less than the total downflow air volume, zero cycle being permitted. The remaining cabinet air flow is exhausted to the outside atmosphere after passage thru a HEPA filter and, when appropriate, thru a charcoal or other vapor adsorbers. All potentially contaminated air passages are maintained under negative pressure or enclosed within a negative pressure zone.

Note: Type B cabinets qualified under this standard are of three distinct types relative to the source of the downflow air supply: (1) Type B cabinets, often referred to as "convertible", in which the downflow air is extracted from a portion of the combined and mixed total inflow and total downflow air streams (2) Type B cabinets, often referred to as "NCI" in which the downflow air is extracted from a mixture made up of most of the inflow air plus a fraction of the downflow air, the fractionation of the downflow airstream being effected by the simultaneous operation of a return air grill (i.e., to the downflow) located in the front of the work surface and a discharge air grill (i.e., to the outdoor environment) located at the back of the work surface (3) Type B cabinets, often referred to as "one pass" or "100% fresh air", in which all of the downflow air is extracted from the laboratory room or from a supply air system and all of it is discharged to the outdoor environment, as is the total volume of inflow air.

It is my opinion that if Type A and Type B cabinets are recognized and defined in NSF Standard No. 49, it will be necessary to issue a separate acceptance for each type. This will mean that a convertible cabinet meeting all the criteria of a Type B will have to undergo a separate acceptance test for the A mode and another for the B mode if it is to carry both approvals even tho the only difference may be that the cabinet is discharging air to the laboratory during the A test and into a duct during the B test. This comes about because the Type A cabinet may discharge to the room and hence it must be tested in this mode as it is the mode that represents a high risk. The convertible B console model in Figure 1 might meet A and B criteria but the convertible B bench model could not as it has a potentially contaminated plenum under positive pressure between blower exhaust and downflow HEPA filter. This could probably be overcome by completing the enclosure of the positive pressure plenum within negative pressure passages.

Melvin W. First

NCI B



Symbols

same as Conv. "B"

plus "a" = fraction of downflow air going into front Grill.

C_m = Conc'n of volatile contaminant after mixing with inflow air – mg/m³

Mass balance: $C_o Q_o + \bar{\underline{X}} = aQ_d C_c + (1-a)Q_d C_c$

To Substitute for Q_d:

$$Q_d = Q_i + aQ_d$$
$$Q_d - aQ_d = Q_i$$
$$Q_o(1-a) = Q_i$$
$$\boxed{Q_d = \frac{Q_i}{1-a}}$$

To Substitute for C_c;

$$C_m = \frac{aQ_o C_c}{aQ_o + Q_i} = C_o$$
$$C_o aQ_a + C_o Q_i = aQ_o C_c$$
$$C_0 + \frac{C_o Q_i}{aC_o} = C_c$$
$$C_o\left(1 + \frac{Q_i}{aQ_d}\right) = C_c$$

substituting $Q_d = \frac{Q_i}{(1-a)}$;

$$C_o\left[1 + \frac{\cancel{Q_i}}{\frac{a\cancel{Q_i}}{(1-a)}}\right] = C_c$$
$$C_o\left[1 + \frac{(1-a)}{a}\right] = C_c$$
$$C_o\left[\frac{a+1-a}{a}\right] = C_c$$
$$\boxed{C_o/a = C_c}$$

NCI B

Substituting for C_d and C_c in mass balance equation to put it in terms of C_o, X, Q_i, and a:

$$C_o \frac{Q_i}{(1-a)} + X = \cancel{a} \frac{Q_i}{(1-a)} \frac{C_o}{\cancel{a}} + (1-a) \frac{Q_i}{(1-a)} \frac{C_o}{a}$$

$$C_o \frac{Q_i}{(1-a)} + X = \frac{Q_i C_o}{(1-a)} + \frac{Q_i C_o}{a}$$

$$-C_o \frac{Q_i}{(1-a)} \qquad X = \frac{Q_i C_o}{a}$$

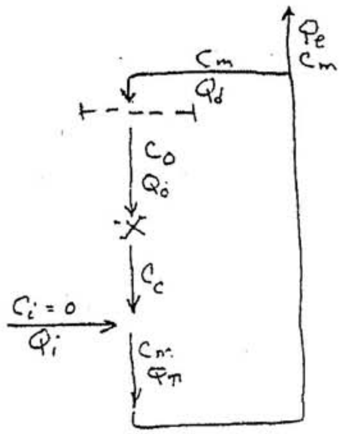
$$\boxed{C_o = \frac{X a}{Q_i}}$$

Relationship between concentration of volatile contaminant in downflow air in NCI and Conv. cabinets is their ratio:

$$\frac{\text{conc'n in CONV. downflow}}{\text{conc'n in NCI downflow}} = \boxed{\frac{C_c}{C_{o_N}} = \frac{\frac{X}{Q_i}}{\frac{X a}{Q_i}} = \frac{1}{a}}$$

As "a" is a fraction less than 1, the contaminant concentration in the CONV. CABINET downflow air will be a multiple of that in the NCI cabinet by the value "1/a". This relationship can be altered by improper work practices such as working in the extreme front of the NCI CABINET.

CONV. "B"



Symbols

Q_d = downflow Air rate · m³/min

C_o = Conc'n of volatile contaminant in downflow – mg/m³

X = volatile contaminant release rate – mg/min

C_c = Conc'n after introduction of volatile contaminant · mg/m³

Q_i = inflow air thru work opening m³/m

C_i = Conc'n in inflow air = zero

Q_T = $Q_d + Q_i$ – m³/min

C_m = Conc'n in air under work surface – mg/m³

mass balance: $C_m Q_T = X + C_o Q_d$

$$Q_T = Q_d + Q_i$$
$$C_m = C_o$$

making the indicated substitutions: $C_o (Q_d + Q_i) = X + C_o Q_d$

$\div C_o$ $\qquad Q_d + Q_i = \frac{X}{C_o} + Q_d$

$- Q_d$ $\qquad Q_i = \frac{X}{C_o}$

$\times C_o, \div Q_i$ $\qquad \boxed{C_o = \frac{X}{Q_i}}$