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Aspiration Tests in Aqueous Foam Using a Breathing Simulator

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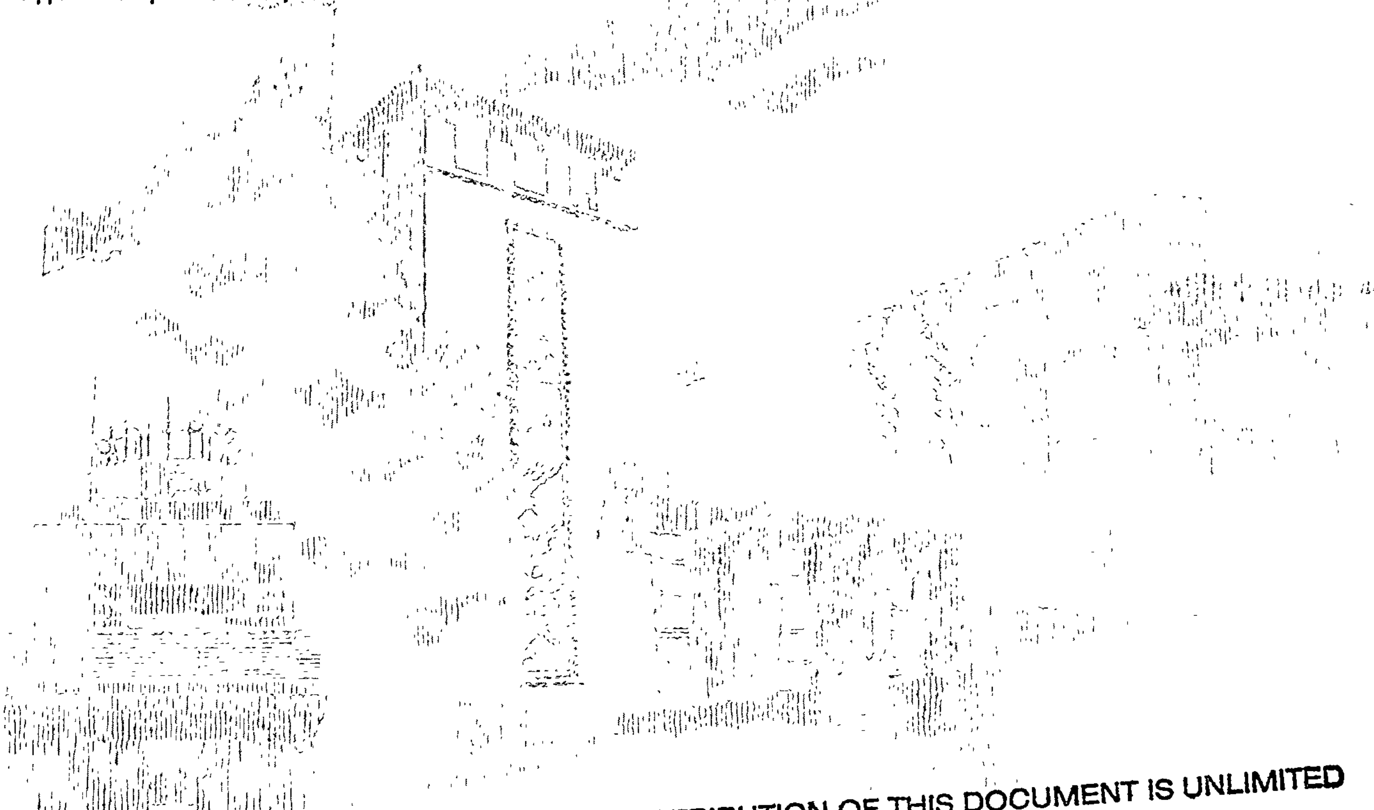

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ASPIRATION TESTS IN AQUEOUS FOAM USING A BREATHING SIMULATOR

**For the National Institute of Justice
Less-Than-Lethal Force Program**

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Abstract

Non-toxic aqueous foams are being developed by Sandia National Laboratories (SNL) for the National Institute of Justice (NIJ) for use in crowd control, cell extractions, and group disturbances in the criminal justice prison systems. The potential for aspiration of aqueous foam during its use and the resulting adverse effects associated with complete immersion in aqueous foam is of major concern to the NIJ when examining the effectiveness and safety of using this technology as a Less-Than-Lethal weapon. This preliminary study was designed to evaluate the maximum quantity of foam that might be aspirated by an individual following total immersion in an SNL-developed aqueous foam. A T.W. Reed Breathing simulator equipped with a 622 Silverman cam was used to simulate the aspiration of an ammonium laureth sulfate aqueous foam developed by SNL and generated at expansion ratios in the range of 500:1 to 1000:1. Although the natural instinct of an individual immersed in foam is to cover their nose and mouth with a hand or cloth, thus breaking the bubbles and decreasing the potential for aspiration, this study was performed to examine a worst case scenario where mouth breathing only was examined, and no attempt was made to block foam entry into the breathing port. Two breathing rates were examined: one that simulated a sedentary individual with a mean breathing rate of 6.27 breaths/minute, and one that simulated an agitated or heavily breathing individual with a mean breathing rate of 23.7 breaths/minute. The results of this study indicate that, if breathing in aqueous foam without movement, an air pocket forms around the nose and mouth within one minute of immersion. Maximal aspiration of the foam occurs in the first 3-5 breaths following immersion, with no additional foam aspirated upon continued exposure. The maximum accumulated amount of foam that was estimated to be aspirated by the breathing simulator was 18 gm (17.5 mls) for a one hour exposure to an aqueous foam generated at an expansion ratio of 500:1. This is less than 25 mls which has been determined to be the critical volume required for the generation of aspiration pneumonia. It appears, therefore, that there is minimal risk of aspiration pneumonia due to aspiration of a critical volume of aqueous foam. The potential for aspiration increases, however, under circumstances involving general anesthesia, intoxication with alcohol or drugs, seizures, strokes, and disorders of the esophagus and trachea, which may be of concern when dealing with an incarcerated individual.

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ASPIRATION TESTS IN AQUEOUS FOAM USING A BREATHING SIMULATOR

For the National Institute of Justice Less-Than-Lethal Force Program

Introduction

Aqueous foams are an important technology in modern fire-fighting and military and civilian defense systems (1). Sandia National Laboratories (SNL) has developed a non-toxic aqueous foam for the National Institute of Justice (NIJ) Less-Than-Lethal Force Weapons Program. This foam is made from non-toxic ammonium laureth sulfate approved for use in cosmetics (2). The proposed use of aqueous foam as a Less-Than-Lethal weapon includes its potential discharge into a populated area, resulting in the immersion of individuals for periods of up to one hour (3). Since aspiration of otherwise non-toxic substances may lead to pulmonary complications, the potential for adverse respiratory or pulmonary effects following immersion in SNL aqueous foam for periods of up to one hour are of major concern to police and security forces intending to use this new technology.

Pulmonary complications related to aspiration are generally referred to as aspiration pneumonia (4). Aspiration pneumonia refers to the abnormal entry of endogenous secretions or exogenous substances into the lower respiratory tract. It has two essential features, compromised lower airway defense mechanisms and a pathologic event resulting from the aspiration insult.

Because of normal airway defense mechanisms, such as the cough reflex, mucociliary transport mechanisms, reflex airway closure on swallowing, and normal pulmonary cellular defenses, pulmonary complications of aspiration seldom occur in otherwise healthy individuals. Occasional aspiration of small amounts of food and liquids is common and usually well tolerated with no significant adverse effects noted. However, depressed levels of consciousness, disorders of the esophagus, and mechanical disruption of these defense mechanisms are risk factors for adverse pulmonary effects due to an aspiration event (5,6).

The primary hazard of aspiration is the induction of disease caused by the aspirated liquids or solids. Although there is reasonable clinical evidence to suggest that aspiration is a frequent clinical event, there are various factors that influence the outcome following an aspiration episode. The extent of lung disease induced by aspirated liquids or solids is dependent on the frequency, volume, and character of the aspirated substance and is a result of infectious complications, direct cytotoxic effects, and airway obstruction (7).

Inhalation or aspiration of contaminated materials is an important route of exposure leading to water-related pulmonary complications. Common gram-negative bacteria can cause pneumonia following aspiration of fresh or salt water, although it is usually associated with submersion and near-drowning. Pneumonia from exposure to contaminated water or water vapors has also been described due to a number of more unusual water-borne bacteria, while respiratory infection due to exposure to algae in water is extremely unusual (8). Asthma associated with sensitization to water-generated bioaerosols occurs both sporadically and less commonly.

Non-infectious diseases are also associated with aspiration of water or liquid chemicals. Aspiration of small amounts of water can lead to severe metabolic abnormalities, as well as effects on water and electrolyte equilibrium of the body, especially with high concentrations of salt water (9). In general, acids, animal fats, mineral oil, alcohol, and hydrocarbons can initiate an inflammatory reaction in the lung that is independent of a bacterial infection. The degree of lung damage is inversely related to the pH of the aspirate, with no disease generally observed following aspiration of liquids with pH above 2.4 (10, 11). In adults, chronic aspiration exposure to mineral oil produces a syndrome that has been called lipid pneumonia. Because of its low viscosity, there is a tendency for mineral oil to enter the trachea from the oral cavity or for mists of mineral oil to be easily aspirated. Its low surface tension and low water solubility allow further penetration and spread into the deep lung resulting in this disease (12). Aspiration of other more volatile hydrocarbons, such as kerosene and gasoline, produces an acute, widespread chemical pneumonitis that mimics adult respiratory distress syndrome, a nonspecific pulmonary disease (13). Furthermore, both fluids and solids can cause obstruction of the airway by mechanical blockage or reflex mechanisms (14).

This study was designed to evaluate the quantity of aqueous foam that might be aspirated by an individual following total immersion in an SNL-developed non-toxic aqueous foam. The natural instinct of an individual immersed in foam is to cover their nose and mouth with their hand or a cloth to break the bubbles and thus release air for breathing. Since no attempt was made in these studies to simulate such actions, these tests examined a worst case scenario in which an individual is injured, asleep, or unconscious and is unable to remove the foam from around their nose and mouth. Furthermore, because of the design of the system, mouth only breathing was simulated. A T.W. Reed Breathing Simulator was used to simulate the aspiration of aqueous foam generated at expansion ratios in the range of 500:1 to 1000:1. Two breathing rates were examined, one that simulated a sedentary individual with a mean breathing rate of 6.3 breaths/minute and one that simulated an agitated or heavily breathing individual with a mean breathing rate of 23.7 breaths/minute. Both quantitative and qualitative observations regarding the potential aspiration of a non-toxic aqueous foam are reported.

Method

Operation of Breathing Simulator

The instrument used to simulate breathing in these studies is a T.W. Reed Breathing Simulator obtained from Los Alamos National Laboratories. The simulator is a simple air movement device that consists of two cylinder pistons attached to a rotating cam that approximates human breathing. The simulator is normally used to test respiratory protective equipment. The simulator used in these studies is a Type BM 2-4--6-30 simulator equipped with a Reliance Electric DC-1 VS® Drive and 622 Silverman cam which is designed to simulate the airflow patterns of breathing during a heavy (622 kg-m/min) work rate. A photograph of the exposure chamber and breathing simulator and a description of each component of the apparatus are given in Figures 1 and 2. The specifications and settings of this apparatus are listed in Table 1.

Table 1

Specifications for the Silverman 622 cam

Tidal Volume	Non-adjustable, CAM 622 = 1.62 liters/breath[1]
Breath Frequency	Adjustable for 0-55 breaths/minute
Cylinder cross sectional area	81.07 cm^2 (4.0 inch bore diameter)
Stroke length	9.84 cm (3.875 inches)
Operating ambient temperature	40-95 ° F
Power Requirements	118 VAC grounded 15 AMPS
CAM Assembly	622 kg-m/min work rate

[1] Silverman and Lee, O.S.R.D. Report No. 5732.

The tidal volume is the volume of air in liters exhaled by one revolution of a given breathing machine cam. It is of importance in adjusting the breathing rates to simulate various work loads. The cam specifications state that the tidal volume for the Silverman 622 cam is 1.62 liters/breath. This was verified at SNL using both physical measurements and the pulmonary function test at Sandia National Laboratories Occupational Medical Department. The tidal volume was calculated to be 1.59 liters/breath using the following equations and physical measurements:

(1) $$\text{Tidal Volume} = \frac{2\pi d^2}{4} \cdot S$$

Where:
d = measured diameter of the bore
S = measured stroke length
2 = Factor to account for 2 cylinders in the simulator

Pulmonary function tests were performed at the SNL Occupational Medical Center as a second verification of the tidal volume. The results of this evaluation indicated that the mean tidal volume measured by a standard pulmonary function test for the 622 Silverman cam on the T.W. Reed Simulator was 1.73 liters/breath.

Evaluation of Breathing rates

An individual's physiological response to a particular work load is related to heart rate and subsequently to breathing rate. For a light work load or a sedentary individual, a heart rate of up to 90 beats per minute is usually observed. For an individual undergoing heavy workload conditions, 110 -130 beats per minute is expected. A study performed at the Harvard School of Medicine was conducted to compare air flow characteristics of human subjects with other physiological responses to work load. In this study, inspiratory and expiratory air flows with and without resistance were measured over a wide range of work rates. Standard minute volumes, or liters of air inhaled per minute, expected under various conditions of activity were developed (15). The minute volume, therefore, is related to the amount of work and is a function of the tidal volume and the breathing rate (16). With these known volumes, the breathing rate required for a specified level of work can be calculated by dividing the minute volume for the desired work load (liters/minute) by the tidal volume of the cam (liters/breath) as follows:

$$\text{Breathing rate} = \frac{\text{minute volume}}{\text{tidal volume}} \tag{2}$$

In this study, the breathing rates were set to approximate two levels of work. One setting was meant to simulate an individual under sedentary conditions (i.e., minute volume = 10.3 liters/minute). The other setting was meant to simulate an individual working under a heavy workload scenario (i.e., minute volume = 37.3 liters/minute). The calculated breathing rates, based on a 1.62 liter tidal volume, were 6.3 breaths/minute for a sedentary simulation and 23.7 breaths/minute for a heavy workload simulation.

Aqueous Foam Concentrate

The aqueous foam used in this study consisted of a 2% solution of the surfactant Steol CA-330 in water. Steol CA-330 is an ammonium laureth sulfate surfactant containing trace amounts of 1,4-dioxane. This surfactant is purchased from Stepan Chemical Co as a 35% solution in water. This surfactant was chosen because it met the toxicological criteria established by the requirements of the NIJ (2, 3, 17,18). The pH of the foam and its concentrate was measured to verify that lung damage due to pH of the aspirate would not be expected.

Aqueous Foam Expansion Ratio

A high expansion foam can deliver 200-1000 times the volume of foam for the starting volume of the concentrate solution. As the expansion ratio increases, the drainage time and apparent stabilization also increases. In general, foams with low expansion ratios drain quickly, while foams with higher expansion ratios drain more slowly and thus appear more stable (19). The NIJ requirement for the foams developed for the Less-Than-Lethal Program was for a high expansion, quick draining aqueous foam. Furthermore, Rockwood International determined that aqueous foams with expansion ratios greater that 500:1 were safe for inhalation exposure by humans (20). Therefore, for the proposed use of these foam by the NIJ, foams of expansion ratios between 500:1 and 1000:1, without stabilizers, were developed and examined for aspiration potential.

Procedure
This study consisted of a series of experiments that examined the amount of aqueous foam aspirated by the breathing simulator at two foam expansion ratios. Breathing rates studied included a mean breathing rate of 6.3 breaths/minute to simulate a sedentary individual (minute volume 10.3 liters/minute) or a breathing rate of 23.7 breaths/minute to simulate an individual working under a heavy workload or extremely agitated (minute volume 37.3 liters/minute). In addition, two exposure times were examined: 1) multiple foaming over a period of one hour and 2) single foaming for one 15 minute exposure.

Each test was set up as illustrated in Figure 1. At the start of each test, the pump on the breathing simulator was started, and the breathing rate was verified and adjusted for the level of work being evaluated. Once the breathing rate was set at the required rate, the generation of foam was begun using conditions necessary to produce a foam in the expansion ratio range of 500:1 to 1000:1, as required. For the one hour exposure tests, foam was generated every ten minutes to prevent the collapse of the foam below the breathing port. For the single foam, 15 minute exposures, only one foam generation was made and the foam was allowed to collapse normally. In all tests, foam was collected in a tared trap that was used to measure the amount of foam collected, by weight. The one hour tests were run singularly. The 15 minute single foam tests were repeated 3 to 4 times for each expansion ratio and breathing rate.

Results

pH of Foam Generated for the NIJ Exposure
Because the pH of an aspirate is a risk factor in the generation of aspiration pneumonia, the pH for each of the aspirated foams was determined. The pH for a 2% solution of Steol CA-330 was found to be 6.0 for all expansion ratios studied. The pH of the concentrate, Steol CA-330, is also 6.0.

Aspiration of Foam Following a 1 Hour Foam Exposure
The one hour foam exposure study consisted of refoaming the exposure chamber approximately every 10 minutes to ensure that the level of foam did not drop below the inhalation port. Aspiration of the foam primarily occurred during the first few breaths following immersion (Figure 3). After the initial aspiration, an air pocket formed around the nose and mouth (breathing port) of the breathing simulator and no additional aspiration occurred (Figure 4). This air pocket formed due to the breathing alone and without any physical agitation of the foam. Although the normal defense mechanisms such

as coughing and swallowing would be present in a healthy individual, no attempt was make to simulate these mechanisms. Furthermore, no attempt was made in these studies to remove foam from the breathing port as would be expected from a conscious, moving individual exposed to the foam. Refoaming the exposure chamber, however, resulted in additional aspiration of the foam when the wet foam filled the air pocket. Again, after the first couple of breaths another air pocket formed which did not allow additional aspiration. The aspirated foam was collected in a trap, and the total quantity accumulated was measured by weighing the tared trap (Figure 5 and Figure 6). The total quantity of foam that accumulated over one hour for each foaming experiment is given in Table 2. Only one test was run for each expansion ratio and breathing rate.

Table 2
One Hour Aspiration Study in Aqueous Foam

Test #	Breathing Rates[1]	Expansion Ratio	Amount of Foam (g)
1	6.26 breaths/min	500:1	9.4 g
2	6.31 breaths/min	1000:1	0.8 g
3	23.8 breaths/min	500:1	1.6 g
4	23.6 breaths/min	1000:1	0.2 g

[1] Breathing rates calculated using cam Tidal Volume = 1.62 liter/breath

Aspiration of Foam Following a 15 Minute Foam Exposure
Single foam generations for 15 minute exposures were conducted and used to estimate the cumulative exposure over one hour. In these tests a single foaming was allowed to drain naturally without assistance or agitation. For all of the 15 minute experiments the level of foam did not drop below the inhalation port of the breathing simulator at any time during the experiment. Three to four replicates were run for each expansion ratio and breathing rate. The results of this study are presented in Table 3.

Table 3
Fifteen Minute Aspiration Study in Aqueous Foam

Test #	N	Breathing Rates[1]	Expansion Ratio	Amount of Foam (g)[4]
1	4	Sedentary[2]	500:1	1.4 g ± 0.6
2	4	Sedentary	1000:1	1.0 g ± 0.2
3	3	Heavy work[3]	500:1	3.0 g ± 0.5
4	3	Heavy work	1000:1	1.1 g ± 0.1

[1] Breathing rates calculated using cam Tidal Volume = 1.62 liter/breath
[2] Sedentary breathing rate = 6.3 breaths/min (n=8)
[3] Heavy work breathing rate = 23.7 breaths/min (n=6)
[4] Average of 3 - 4 tests for each expansion ratio and breathing rate.

Discussion

Physiological factors which are important in respiration under sedentary and working conditions include the following: minute volume, mean inspiratory flow, instantaneous air flow, expiratory air flow, inspiratory and expiratory resistance to air flow, work rate, and respiratory work rate. The physiological factors used in setting up the conditions of the breathing simulator included the minute volume, tidal volume, and breathing rate.

The tidal volume is of importance in the physiological response to work. This is the volume of air per breath and, in an individual, can readily be determined from the minute volume and respiration rate. In the case of the breathing simulator, the tidal volume is a constant and can be used to set the breathing rate to obtain minute volumes that correspond to various work loads. The tidal volume used in this study is a function of the cam used and was determined by Silverman to be 1.62 liters/breath for the 622 cam (21). This was verified by the SNL Occupational Medical Center through the use of a pulmonary function test which measured the observed tidal volume to be 1.73 liters/breath and by physical measurements which calculated the tidal volume for the 622 cam to be 1.59 liters/breath.

The minute volume is the volume of air breathed per minute by an individual and varies from a minimum of 5 liters for someone under sedentary conditions to above 100 liters for maximum exertion under heavy workload conditions (15). For purposes of this study, minute volumes of 10.3 liters/minute and 37.3 liters/minute were used to simulate sedentary and heavy workload conditions, respectively. This study was designed to determine the amount of foam that might be aspirated by an individual immersed for periods of up to one hour under these two working conditions.

The results of this study indicated that the maximum accumulated amount of foam aspirated during a one-hour exposure with refoaming occurring every ten minutes was 9.4 g for a 500:1 expansion aqueous foam. The aspiration occurred during the initial first couple of breaths following each foam generation for the accumulated exposure time measured. Since an average of six foam generations was used to maintain the foam for one hour, this result is consistent with a mean of 1.4 g (n=4) of foam aspirated following single foam generations for 15 minute exposures. Because of foam drainage, drying, and the formation of an air pocket in the breathing zone during the one hour test, the amount of foam aspirated did not correlate with the expansion ratio or work rate. That is, in the one hour tests, the amount of aqueous foam aspirated did not increase with a decreased expansion ratio or increased work rate. When the 1000:1 foam was evaluated for one hour, the accumulated amount of aqueous foam was found to be only 0.8 g. This was equivalent to the amount of foam aspirated following a single foam generation of the 1000:1 expansion foam. When heavy work load breathing conditions were examined for a one hour exposure, the results were similar. The 500:1 expansion foam had a maximum accumulated amount of foam of 1.6 g, and the 1000:1 expansion foam had a maximum accumulated amount of foam of 0.2 g (Table 2). These results are both less than that determined from the single foam generation test where the average amount of foam aspirated for the 500:1 or 1000:1 foam was found to be 3.0 g and 1.1 g, respectively. It appeared from these studies, that the long term tests using a breathing simulator, were not a good mechanism for measuring the total amount of foam aspirated over a period of time since the action of the simulator, during the longer testing periods, may cause the foam to dry in the tared trap, resulting in a weight much lower than was actually aspirated. Therefore short term single foam experiments were used to estimate the risk of a longer exposure.

In the short term experiments used to evaluate the amount of foam aspirated following a single foam generation over a 15 minute exposure, the majority of the aspiration appeared to occur with the first 3-5 breaths taken. An air pocket was formed subsequent to the initial exposure. The mean results of 3-4 tests for each foam and breathing condition were 1.4 g and 3.0 g aspirated for a 500:1 foam under sedentary and heavy workload breathing conditions, respectively, and aspirations of 1.0 g and 1.1 g aspirated for a 1000:1 expansion foam under the same conditions.

Using the results of the single foam exposure, the maximum amount of foam that might be aspirated with a multiple foaming event over a period of one hour was estimated. Assumptions made were that an equal amount of foam is aspirated every time the individual is exposed in the exposure chamber during a refoaming event, and that the amount of foam required to sustain a full immersion over a one hour period required an average of 6 foam generations. The maximum amount of foam aspirated, therefore, was estimated to be 8.4 g for a 500:1 foam and 6.0 g for a 1000:1 foam under sedentary breathing conditions. For breathing rates that simulated heavy workload conditions, the maximum amount of foam aspirated was estimated to be 18 g for a 500:1 foam and 6.6 g for a 1000:1 foam.

Frequency, volume, and character of the aspirate are factors that determine the occurrence and extent of pulmonary complications following aspiration. Therefore, the amount of foam aspirated by the T.W. Reed Breathing apparatus and the toxicity of the foam generated were used to evaluate the risk associated with total immersion in an SNL-developed aqueous foam. The results of this study indicated that the estimated maximum quantity of foam aspirated by an individual would not be enough to generate an adverse pulmonary effect. The amount of foam aspirated resulting from the single 15 minute exposure and estimated for the multiple one hour exposure were significantly less than that of 25 ml which has been determined to be the critical volume necessary for the generation of aspiration pneumonia (22). The pH of the foam and the concentrate used to make it is 6.0. This is significantly greater than the threshold pH of 2.0 generally required to produce chemical pneumonia (10).

The reflex and defense mechanisms of the respiratory system available in normal healthy adults and physical agitation of the foam were not considered in these tests. However, the estimates determined in these studies represent a worst case scenario and approximate that expected for an individual with depressed respiratory defense mechanisms incapable of removing the foam from their face or nose, or unable to collapse the foam with agitation. It is believed that if an individual moves around in the foam, causing the bubbles to burst and release air, sufficient oxygen will be released to allow a person to breath. Furthermore, reflex respiratory mechanisms will reduce the amount of foam that is aspirated and potentially available for producing adverse pulmonary effects. The small amounts of foam that might be aspirated are expected, therefore, to be less than that estimated in this study and should not produce significant adverse effects. If, however, animals or humans are intoxicated, comatose, seizing, or debilitated, or have swallowing dysfunction or esophageal abnormalities, they may have a significantly greater potential for developing adverse pulmonary effects due to the aspiration incident.

A study was conducted by H.H. Wandall and associates to study the effects of high expansion foam on dogs and to discuss the possibility of survival in high expansion foam following an extended exposure (23). The effects on blood circulation and blood gases of a living being breathing in a closed, foam-filled room were evaluated. In no case did the investigators observe any accumulation of foam or liquid in the trachea or bronchial tree, and no inflammatory changes in tracheae or bronchia could be demonstrated by microscopy. It was observed that while breathing in a foam-filled room resulted in a reduction in the oxygen content of the blood, this did not result in adverse physiological effects unless the oxygen content of the room decreased to less than 5%. Furthermore, no accumulation of carbon dioxide was observed in the breathing zone with exposure for periods of up to one hour. It was also evident from these experiments that although anoxia due to immersion in foam is a risk factor, it appears only after immersion times of 60 minutes or more. This is further validated by the absence of ill effects observed among healthy adults who have been documented to aspirate while sleeping or while under general anesthesia (24).

A study to document collected data on past human aspiration exposure due to immersion in various aqueous foams was conducted by SNL (25). This study documented first hand knowledge of ten individuals regarding immersion in aqueous foams for periods of up to twenty minutes. No breathing protection was used, but the individuals did use handkerchiefs and/or a hand over the nose and mouth to break up the foam. In most cases, individuals indicated that they had either aspirated or swallowed small amounts of foam without significant adverse effects. The major complaint following exposure was irritation of the eyes and nose, and some individuals complained of diarrhea following exposure. No allergic reactions or significant adverse effects were noted following any of the exposures. In addition, several individuals had additional second hand knowledge of human exposure without respiratory protection to aqueous foam. These exposures included training of fire-fighting or military personnel in aqueous foam for periods of up to 20 minutes, as well as exposure of civilians during recreational activities and/or contests for periods of 1-10 minutes. None of these exposures have resulted in acute, immediately life threatening effects or chronic, long-term, non-reversible effects. Rockwood Systems Corporation has also studied the aspiration of their Rockwood Macrofoam™, an aqueous foam made of ammonium-neutralized sulfate esters (similar to the ammonium laureth sulfates used in the SNL foam), medium chain fatty alcohols, and a phosphate salt. Their studies indicated that aspiration of a toxic amount of aqueous foam would require an exposure of 7.5 hours (20).

The preliminary study presented in this report, used a breathing simulator to predict the quantity of foam potentially aspirated by an individual immersed in an SNL-developed non-toxic aqueous foam. This study does not predict how far into the lung the foam might penetrate nor does it examine what happens to the foam when collapsed by the normal human respiratory defense mechanisms. However, based on the toxicity of the foam, the maximun quantity of aspirate predicted for a foaming exposure requiring repeated foam generations or foam agitation, and the absence of significant adverse effects noted in the two aqueous foam aspiration studies identified above, it is predicted that aspiration of this non-toxic aqueous foam for periods of less than one hour, should not produce a significant risk of aspiration pneumonia. Special precautions should be taken, however, to reduce the time of exposure in the event an injured, comatose, or intoxicated individual is immersed in the foam.

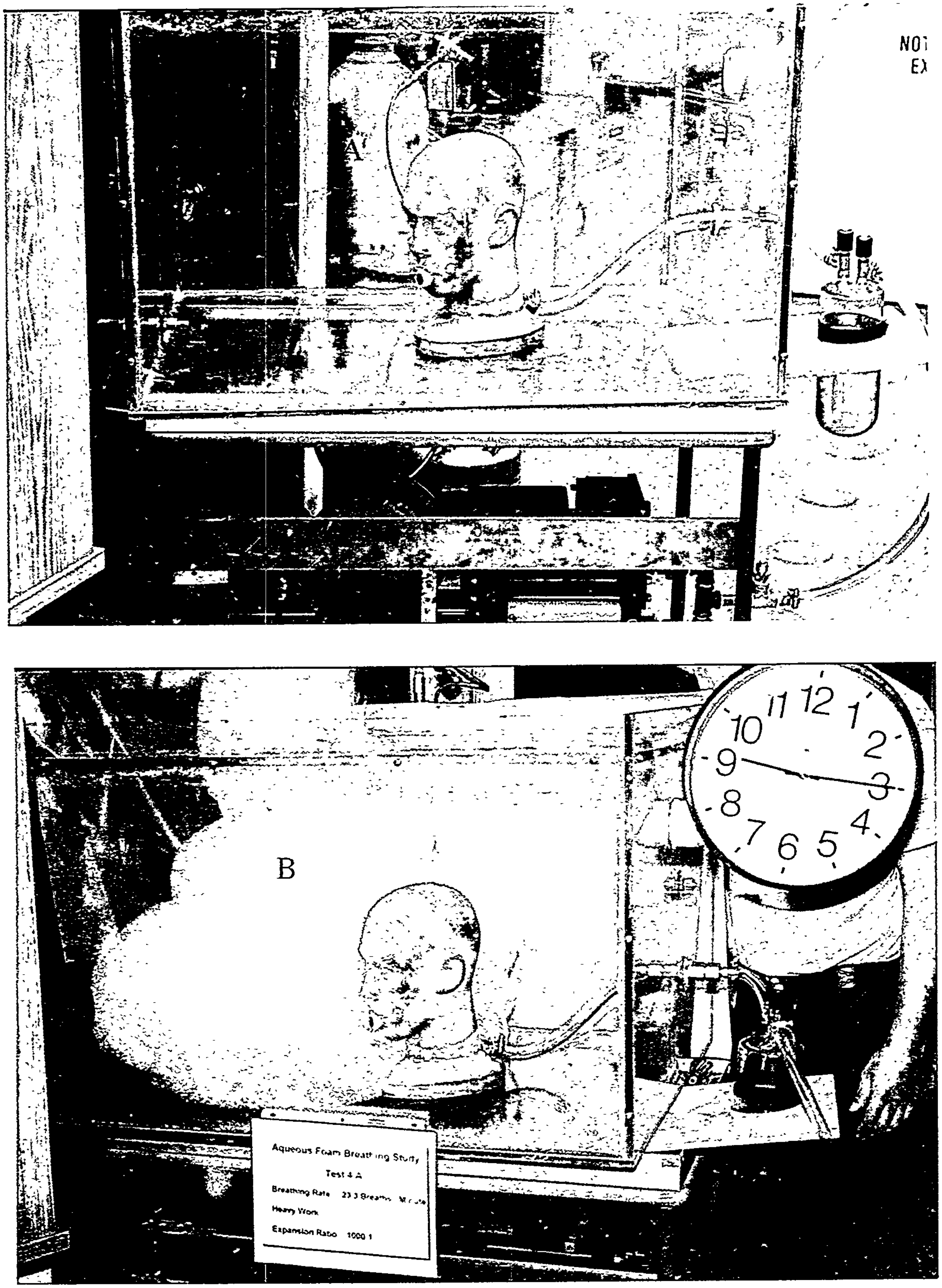

Figure 1: Set Up of the Exposure Chamber and the Breathing Simulator (A) before and (B) after introduction of foam.

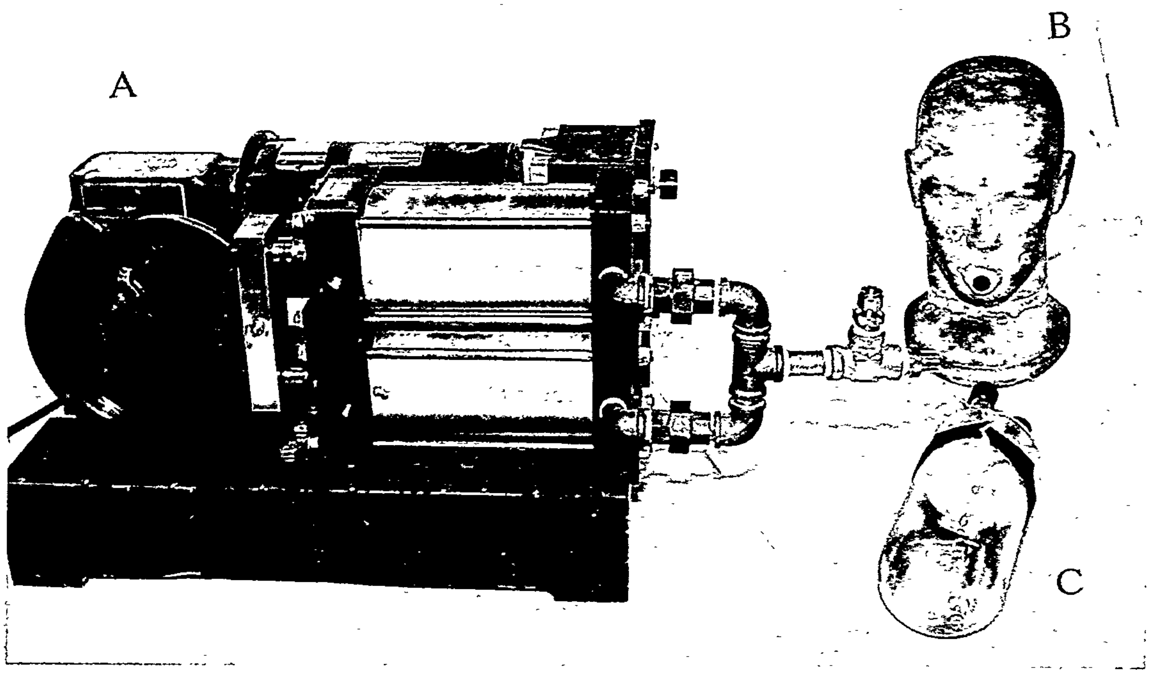

Figure 2: The Components of the Breathing Simulator Apparatus. (A) The T.W. Reed Breathing Machine equipped with a 622 Silverman CAM. (B) The inhalation port of the breathing simulator. (C) The trap used to collect the aqueous foam once aspirated by the breathing simulator.

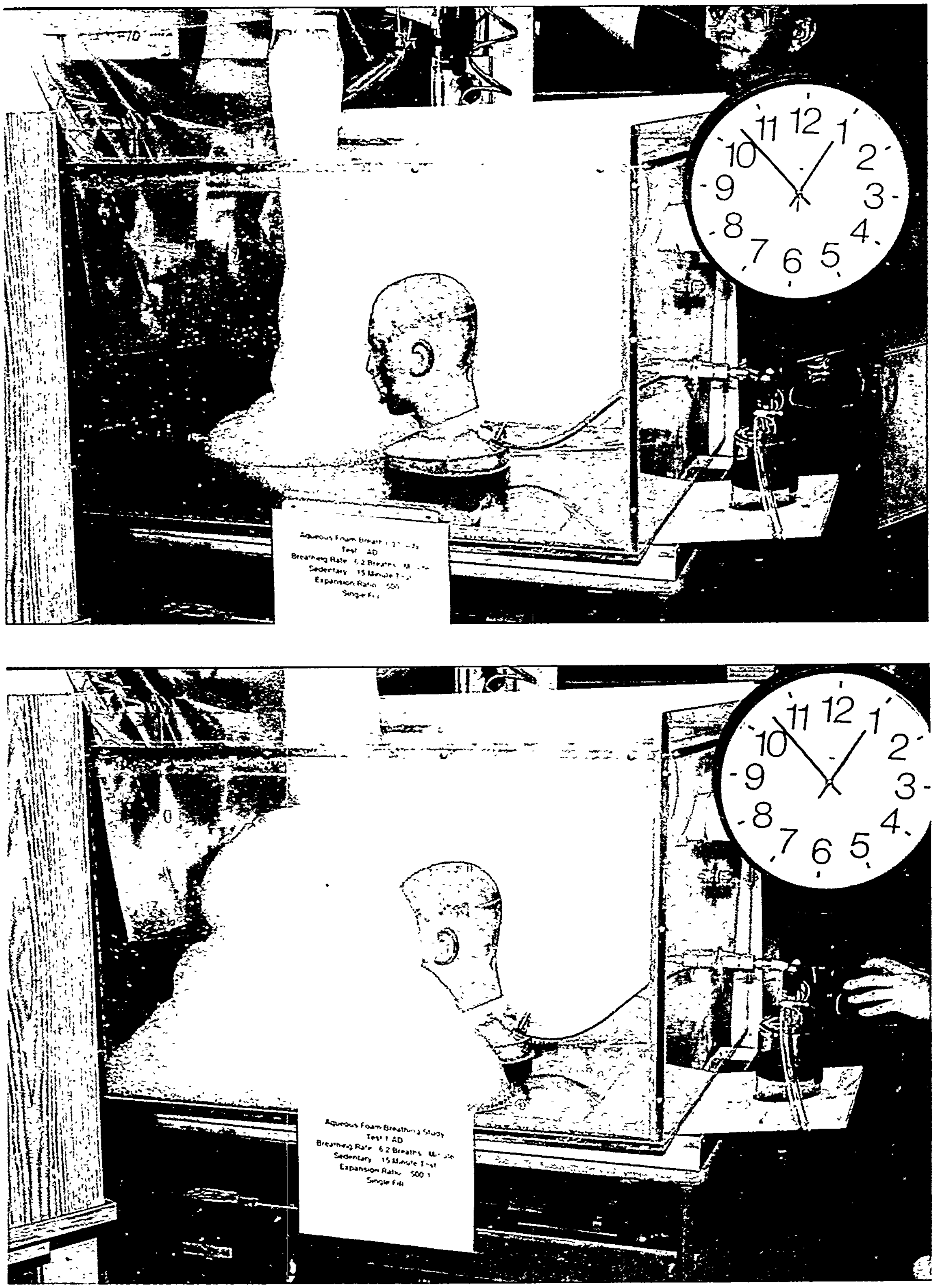

Figure 3: Aspiration of Foam by the Breathing Simulator. Note that five seconds after the beginning of the foam generation (A) aspiration in the tubing is visible (B).

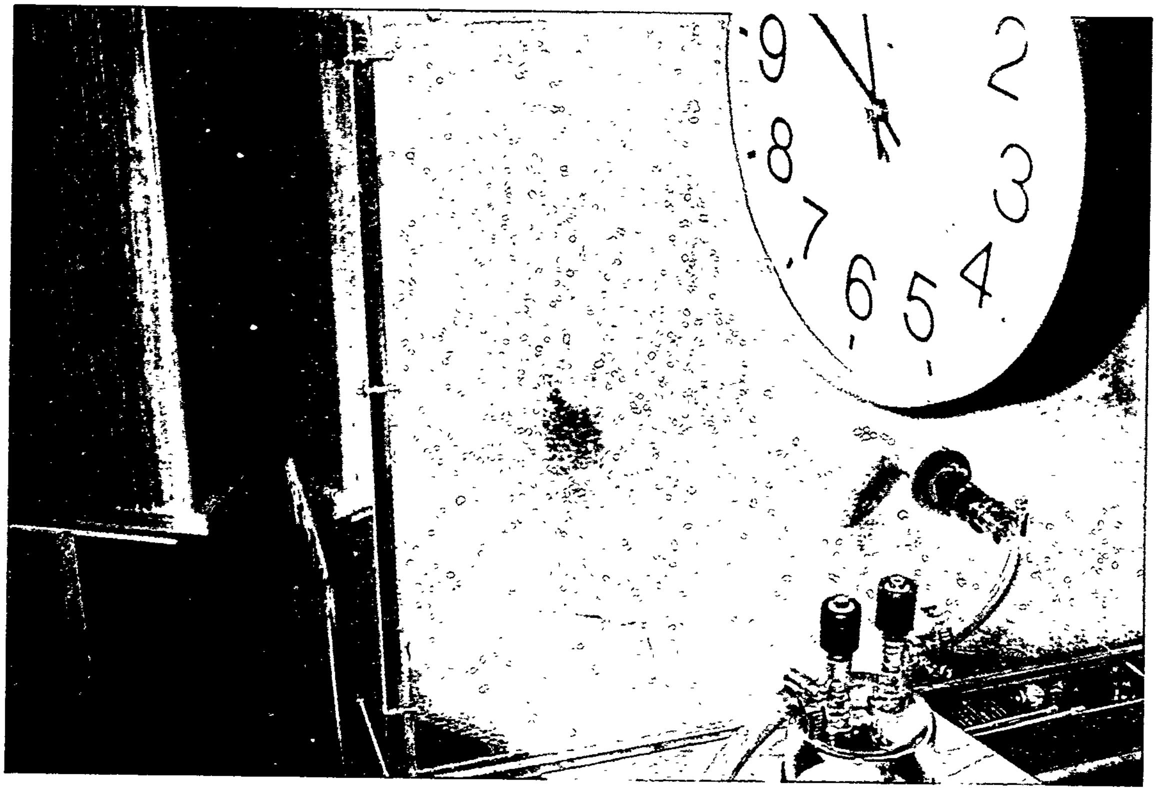

Figure 4: Generation of an Air Pocket. This air pocket was visible between five and ten minutes after the initiation of foaming and continued unless agitation of the foam or refoaming occurred.

Figure 5: Trap Used to Collect Aspirate From the Breathing Simulator.

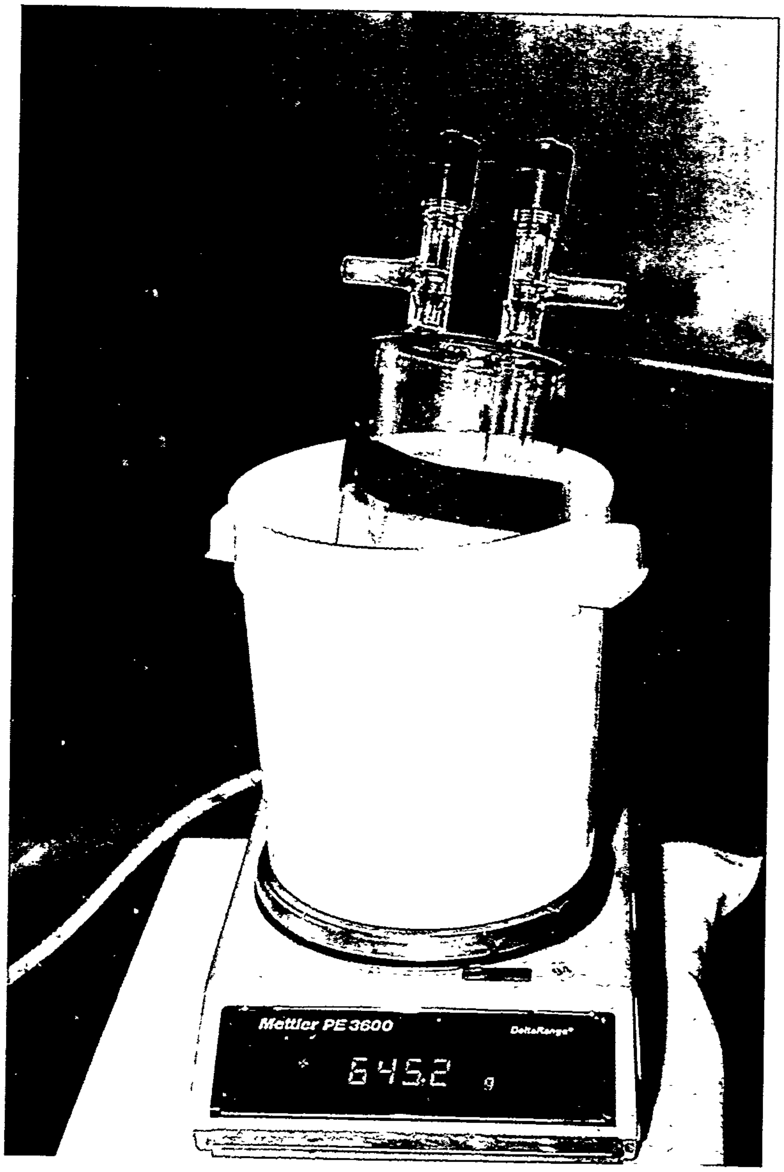

Figure 6: Weighing of the Collection Trap. The amount of aspirate that was collected during the test by the breathing simulator was measured by weighing it in the tared collection trap.

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