

Designing a biosafety cabinet to optimize user ergonomics and safety: a review of the Labconco Purifier® Delta® Series Biological Safety Cabinet

by Labconco Corporation and contributing author, Terri Erickson-Harper*, Industrial Designer, Human Factors Practitioner and Assistant Professor of Industrial Design, University of Kansas, Lawrence, Kansas

The goal of Labconco Corporation took just 11 words to state: to produce the most ergonomically efficient and safe laboratory cabinet practical. To bring the goal to reality took considerably more effort.

Jim Hunter, Senior Engineer, was the Project Manager for the development of Labconco's Purifier Delta Series Safety Cabinet. As a microbiologist, he had spent several years working in laboratories and so brought to the design team the perspective of both customer and corporate service. He had experienced first hand the fatigue and strain that result from working at poorly designed work stations. He knew what it was like to become gun-shy after striking his hand on a service valve while working in a cabinet. He recalled the irritations of being unable to get physically closer to a project because the viewing sash got in the way and the tension created by working in a cramped work space.

All of these realities were motivating factors in designing the Purifier Delta Series Safety Cabinet and bringing changes for the better to the laboratory workplace. "We took into account the way people had to work in a cabinet and their comfort. Appearance and quality of operation were also among the top goals. But first and foremost was safety. All things were geared to that."

The process began with a series of sketches. Then, to ensure that every design change applied state-of-the-art knowledge as well as met the required NSF 49 standard, Labconco engineers and marketing specialists began conducting tests, talking with and observing laboratory workers in real-use situations, receiving and reviewing feedback from customers, attending symposia and conferences sponsored by the American Society for Microbiology, the American Biological Safety Association, and others. Then Labconco consulted with world-class experts on biological safety to review the changes incorporated in the design of the Purifier Delta Series Safety Cabinet. These experts included Dr. Jonathan Richmond, Center for Disease Control, Atlanta, Georgia; Mary Ellen Kennedy, retired from the Office of Biosafety, Laboratory Centre for Disease Control, Canada; and Dr. Manuel Barbeito, retired from USDA Agricultural Research Service, Frederick, Maryland.



Labconco Purifier® Delta® Series Biological Safety Cabinet

Design enhancements to this cabinet appear from top to bottom and front to back: in the profile of the front panel; the design of the sash, the air foil and the work surface; the location of gauges and controls; and the height of the base stand.

* Contributing author of anthropometry and ergonomics, Terri Erickson-Harper is currently Assistant Professor at Johnson County Community College, Overland Park, Kansas.



Side view illustrates the inclined sash and the tendency for workers to lean forward when working in the cabinet.

Inclined sliding sash

Labconco recognized the value of the inclined sash, a design feature the company pioneered in the early 1980's. Labconco retained these early ergonomic efforts in the new design but added a safety dimension by making the sash fully closing as well.

- The vertical-sliding sash and exterior front panel of the Purifier Delta Series Safety Cabinet are inclined at a 10 degree angle. This innovative feature recognizes and accommodates the slight forward leaning of the upper body which occurs naturally when laboratory workers perform operations within the cabinet. This feature reduces the frustrating sense of interference caused when the operator's forehead is stopped short by the vertical sashes of traditional cabinets. The 10 degree angle of incline permits flexible, rather than rigid movements of the upper torso and head without compromising desired posture standards and thus preventing neck and back strain.

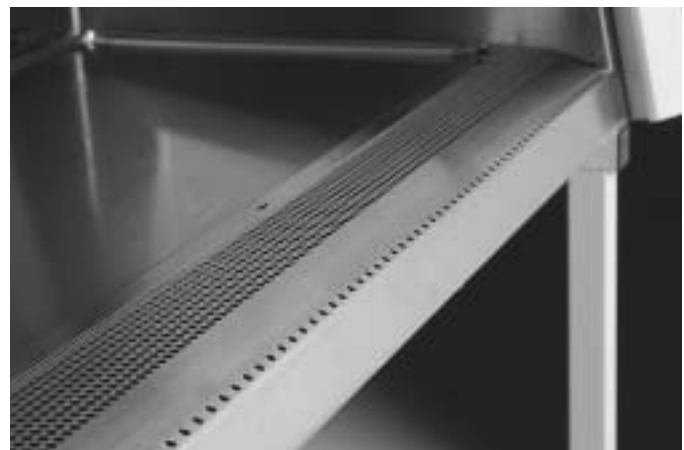
- A further benefit accrues to the laboratory worker as a result of the angled sash. The reflection of laboratory lighting upon the glass of a vertical sash of a biosafety cabinet can cause glare, interfering with the worker's view of operations within the cabinet. The incline of the sash on the Purifier Delta Series Safety Cabinet decreases visual interference caused by light reflection.

- The inclined sash of the Purifier Delta Series is available at either an 8-inch or a 10-inch sash operating height. The 8-inch sash height provides an opening which permits the range of arm movement necessary for laboratory tasks for male and female laboratory workers who fall between the 2.5 percentile and the 50th percentile (57.2" - 69.1" tall). The 10-inch sash height accommodates the taller laboratory worker, up to the 97.5 percentile (74.0" tall). The 10-inch sash opening also permits a greater range of arm movement that may assist cleaning the work surface for all users.

- The user/product test revealed that the 97.5 percentile users (74.0" tall) were able to perform laboratory tests within an 8-inch sash opening but needed the 10-inch height to assist the reach necessary to wipe the work surface. It is also worth noting that workers who fall into the higher height percentiles might experience upper arm interference with the sash edge set at 8 inches during operations that necessitate lifting the arm or extending the arm into the back region of the work area.

- To ensure safe and optimal operating conditions at the Purifier Delta Series Safety Cabinet, a sash position indicator provides tactile feedback to the lab worker. When the sash is raised on both the 8-inch and the 10-inch models, the user feels a change in resistance when the sash reaches its optimal operating height. The sash position indicator is supplemented by a sash position audible/visual alarm that alerts the user when the sash is raised above its optimal height.

- The sash edge extrusion on the Purifier Delta Series has been substantially reduced in height to provide optimal viewing range inside the cabinet. This is especially significant for the range of vision of the 2.5 percentile small female user (57.2" tall) at the cabinet whose range, because of her physical height, is concentrated in the lower region of the sash. The slim extrusion prevents the visual obstruction that could potentially occur for the 2.5 percentile small female user or for the wheelchair-bound operator, depending upon the height of the wheelchair.

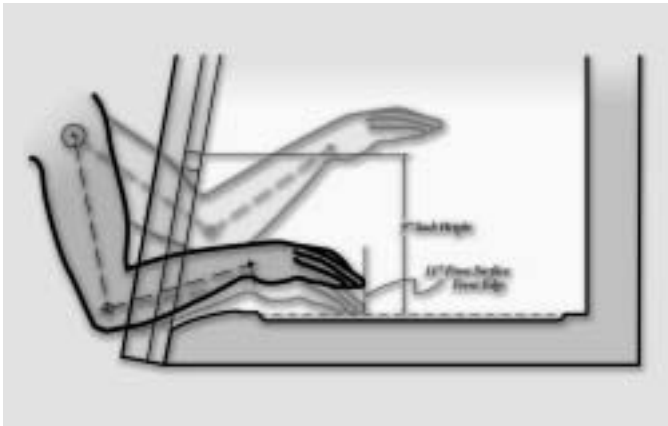


The curved air foil is comfortable for the user and features Reserve-Air Secondary Airflow Slots in front of the grille to ensure safe airflow even when the grille may be inadvertently blocked by the user.

Radiused air foil

Taking the realities of the workplace into further consideration, Labconco recognized the problems that have occurred because of the traditional design of the front edge of the grille and cabinet.

The first deals with the reality that the flow of air required to maintain safe working conditions is often at odds with the need laboratory workers have to rest their forearms for a short period. Such a rest provides a necessary recovery from symptomatic fatigue and pain in the neck, forearms, elbows and shoulders that can result from sustained elevated arm positions required to perform repetitive laboratory tasks. However, such rest is often discouraged because forearm placement on the grille has customarily resulted in serious impairment of the airflow.



The radiused air foil provides a comfortable surface for forearms resting on it.

- The curved air foil of the Purifier Delta Series Safety Cabinet was designed to provide ergonomic support without compromising proper airflow — and without forcing the researcher further away from the work area. Reserve-Air™ Secondary Airflow Slots permit the laboratory worker to relax his/her arms without blocking the airflow necessary for safety. The slots, located in front of the air foil's inflow grille, draw air into the Purifier should the operator inadvertently block the grille area. This ensures that safe airflow is always maintained. The curved surface enhances smoother airflow and because it is not flat, operators cannot place papers or supplies on the grille, blocking the airflow.
- Labconco engineers have also suggested that the safety could be further enhanced by applying a bright color to the air foil as a reminder to avoid this area. This optional design feature serves to remind lab operators not to place materials in this area and to locate work well within the cabinet interior where containment is greatest.

The second problem solved by Labconco engineers in designing a curved air foil was that the blunt front edge of the cabinet common to biosafety cabinets is eliminated. This edge can cause contact stress on the flexor muscles, tendons, and nerves of the forearms, potentially resulting in ulnar nerve injury.¹

- Labconco designed the air foil of The Purifier Delta Series Safety Cabinet with a gradual downward curve from the dished work surface to the front edge of the cabinet. This feature eliminates a sharp work-top edge and the subsequent hazards of contact stresses, allowing lab technicians to comfortably support their forearms during periods of rest. It also complies with Americans with Disabilities Act (ADA) laboratory guidelines requiring a contoured air foil for wheelchair-bound operators.¹¹



Removable work surface with radiused dish

- Labconco is the first to offer a stainless-steel work surface with a seamless radiused dish. This enhancement makes it easier to wipe clean and disinfect the work surface and prevents liquids and contaminants from accumulating in the sharp corners and edges common to biosafety cabinet work surfaces. This feature reduces strain to neck and shoulder muscles that can result from the extreme flexion of the shoulder joint required to reach and clean these work surfaces.
- Further strain reduction is realized by the size of the interior of the cabinet — the most spacious in the industry. This large-capacity work space provides laboratory workers much-desired space for multi-tasking, allowing them to keep relevant materials within reach but out of the way of the immediate task at hand.



The Purifier Delta Series Safety Cabinet has a spacious interior.

- All this is accomplished within the engineers' efficiency of space principle. The external dimensions of the cabinet are less than an inch wider than competitive models but the interior is more than 2-1/2 inches wider. This means that the Purifier Delta Series Safety Cabinets increase the working area of the user without contributing to the shortage of space that exists within most laboratories.

- User test studies revealed that the back wall of the work surface, which is approximately 24.5 inches deep from the front edge of the air foil, is easily reached by laboratory workers from the 97.5 percentile large adult female user to the 2.5 percentile small female (68.0"-57.2" tall).

Optimum accessibility service fixtures

In designing the Purifier Delta Series, Labconco Corporation's engineers considered the reach required to access service fixtures and the resulting impact on lab workers. Most biosafety cabinets are equipped with service fixtures on the back region of the cabinet side wall, the farthest point from the user. The reach necessary to manipulate the valve controls requires extreme lateral bending and flexion of the torso as well as flexion of the shoulder joint which can cause back, neck and shoulder strain.

In response to this knowledge and in keeping with the ergonomic goals for the Purifier Delta Series Safety Cabinet, Labconco located two service fixtures along the frontal region of both interior side walls. This allows any operator, including wheelchair-bound operators, to access these fixtures without the potential ergonomic stress to neck and shoulder muscles caused by extended reaching. The user seated at the Purifier Delta Series Safety Cabinet can comfortably access the service fixtures with his/her back supported by the chair while naturally raising the upper arm to operate the valve.

Minihelic* II pressure gauge

Biosafety cabinets which feature the gauge on the upper front panel are physically demanding: the user must extend the torso and neck backward (leading to strain) or stand up from the chair (inconvenient) to read the gauge.



- By locating the Minihelic II pressure gauge in the lower region of the interior back wall, Labconco engineers have ensured that The Purifier Delta Series Safety Cabinet provides optimum visibility of the gauge.

ADA-compliant controls and switches

The controls of biosafety cabinets are commonly located on the upper fascia, necessitating extreme extension of the neck and flexion of the shoulder joint for operational visibility and reach. The position of these controls demands physical maneuvers that produce unnecessary neck and shoulder strain; furthermore, they do not accommodate the wheelchair-bound user.

ADA standards require that the controls and switches on biosafety cabinets be located no more than 54 inches from the floor.ⁱⁱⁱ

- The power and alarm switches of the Purifier Delta Series Safety Cabinet are located 15 inches from the base of the cabinet on the angled corner post. This location is easily reached from the seated position at the cabinet. The minimum base stand height of 27.5 inches positions the power switch 42.5 inches from the floor and the maximum base stand height of 33.5 inches locates the power switch 48.5 inches from the floor. These dimensions are in compliance with the range of side reach required by the ADA.



- This design feature ensures that there is no physical exertion or extraneous maneuvers imposed upon users to access the controls of the Purifier Delta Series Safety Cabinet. All users, including wheelchair-bound operators, can comfortably raise their arms to reach these controls from their seated position at the work station without extreme lateral bending of the torso and abduction of the shoulder joint.

Low-profile front panel

The front panel housing the fluorescent light necessary for illuminating the work surface has been dramatically streamlined on the Purifier Delta Series Cabinet, creating an attractive, flush exterior panel. The lamp casing has a smooth surface with large radiused edges that eliminate any opportunity for the worker's forehead to bump against a hard, sharp metal edge. This feature is especially significant to the 97.5 percentile adult male (74.0" tall) and female (68.0" tall) users who, when rising from their seat, could easily be subject to bumping their foreheads when a lamp casing is protruding from the panel. It is also psychologically important to workers in the lower percentiles whose sense of an overhead protruding object may easily cause tense neck and shoulder muscles.

Base stand height

As part of the design development process, Labconco engineers and an industrial designer, practiced in the application of anthropometric data-to-product design development, studied the human factor variables of biosafety cabinet users. This study, conducted in 1999, was designed to ensure optimum operations at the Purifier Delta Series Safety Cabinet while maintaining a base stand height necessary to secure the stability of the upright cabinet. The process included overlaying accurate human silhouettes onto cross-sections of the proposed cabinet, followed by mock procedures with actual humans who fall into different height or physical ability categories.

- The Telescoping Base Stand of the Purifier Delta Series Safety Cabinet is equipped with a leg extension adjustable to a fixed height in increments of 1 inch, providing a 6 inch range of height variance from 27.5 inches to 33.5 inches. The personal anthropometrics of the user and the laboratory tasks to

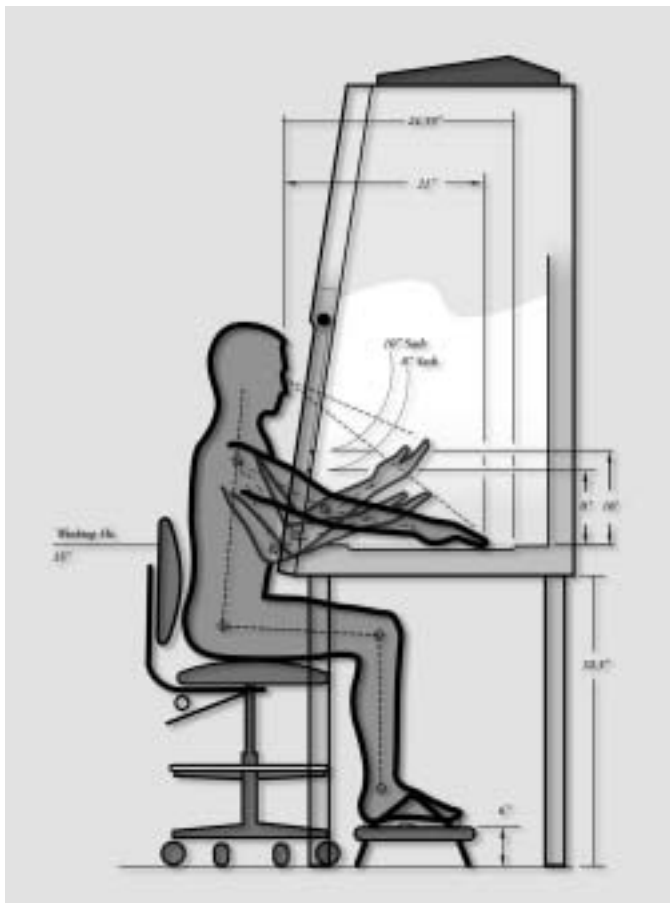


Figure 1. Illustration of a male of average height (5' 9.1") using the Purifier Delta Series Safety Cabinet.

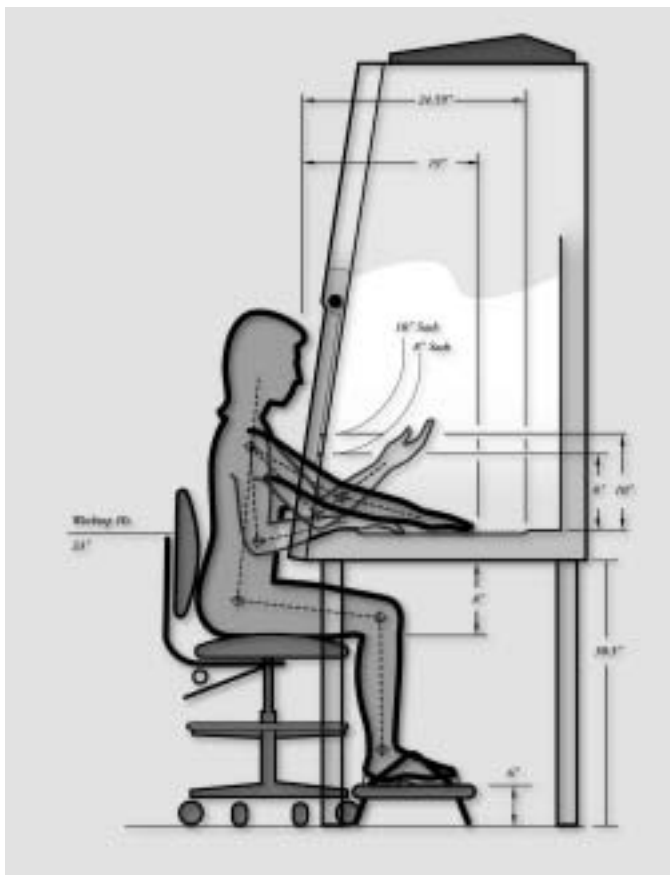


Figure 2. Illustration of a female of average height (5' 3") using the Purifier Delta Series Safety Cabinet.

be performed at the cabinet hood are significant factors in determining the work surface height. The leg extension feature of the accessory base stand, together with appropriate chair and footrest, enables the user to select a height optimal for particular laboratory tasks, ergonomic recommendations and ADA guidelines.

- These incremental adjustments also allow the wheelchair-bound user to select and install the Telescoping Base Stand at a fixed height between 27.5 and 30.5 inches high, providing adequate clearance for a wheelchair to fit beneath the cabinet.
- These base stand heights position the work top approximately 31 to 36 inches high, complying with the 31 to 34 inch work surface height specified for wheelchair bound operators in "Issues in Lab Ventilation, Making Fume Hoods Accessible to the Disabled."^{iv}

The Manual for the Identification, Evaluation, and Control of Ergonomic Hazards in the Laboratory advises, "Adjust the workstation so the worker doesn't have to work with their arms in an elevated position." It further states that light laboratory tasks require the work surface to be positioned slightly below elbow height while heavy work requires this surface to be 4 to 6 inches below elbow height. Following that recommendation, users are encouraged — before the height is fixed — to establish the optimum height by having the laboratory worker actually sit at the cabinet before installation of the Telescoping Base Stand at a fixed height. In 2002, Labconco introduced Hydraulic Lift Base Stands that may be infinitely adjusted to provide a work top height from 29 to 36 inches. Since these stands may be easily adjusted with the push of a button or turn of a crank, height may be changed to fit each user's preference.

The accessory Telescoping or Hydraulic Lift Base Stand works together with a chair and footrest which Labconco recommends to achieve the proper positioning for individuals using the cabinet.

- The Labconco Ergonomic Chair provides a range of seat height adjustments that allows the user to access the work surface within its full range of height adjustments. It also is equipped with an adjustable lumbar support necessary to accommodate the particular anthropometrics of the user. Attention to the adjustment of the seat height in relation to the work surface height of the cabinet hood is necessary to support the user's posture and prevent lower back flexion.
- A foot stool is necessary to support the posture when the work surface and seat height do not permit the user to support his/her feet upon the floor. It is important that the user be seated at a height which positions the foot pad firmly on the floor or a footrest. Labconco Corporation recommends its articulating Adjustable Footrest which offers a horizontal position for supporting the feet and legs and is easily maneuvered by the feet, gliding into any angle adjustable to the user's need and comfort.

Figure 1 and Figure 2 indicate the base stand height and seating arrangement for the 50 percentile adult female and male user, illustrating the

chair and footrest Labconco Corporation recommends to support laboratory operations at the Purifier Delta Series Safety Cabinet.

The development process of the Purifier Delta Series Safety Cabinet involved the observation of users performing laboratory operations at the cabinet using these support products. The users fit the anthropometric dimensions of the 2.5 percentile small adult, 50 percentile average adult and 97.5 percentile large adult female and male (57.2" to 74.0" tall). The variables of this user/product test exhibited that adjustments in the seat height in relation to the work surface height allowed each of these users to comfortably position themselves at the work station and perform laboratory operations.

Some users may be able to operate at multiple work surface heights. To determine the optimum ergonomic height, however, it is important to assess which work surface location provides the best support of their posture for the tasks they will perform. The user test of the 97.5 percentile female (68.0" tall) at the Purifier Delta Series Safety Cabinet illustrates this.

The observed user first performed at a 32.5 inch base stand height which locates the work top at approximately 36 inches. In this case, she required a footrest to support her posture. She was then tested at a 28.5 inch base stand height, locating the work surface height at approximately 33 inches. The seat height of the adjustable chair was positioned to permit the user to support her feet flat on the floor, eliminating the need for the footrest. She indicated that this lower position was preferable to the 32.5 inch base stand height. It was observed that this work surface height was above the elbow, reducing the hunch of the thoracic curve of the back which occurs when the seat height is too high in relation to the work surface height.

This test was an important one because the arrangement of work surface height and seat height also allowed this user to support her forearms on the curve of the air foil, an ergonomic design feature of the Purifier Delta Series Safety Cabinet.

It took 15 months of concentrated effort before Jim Hunter and his Project Team were satisfied that they had accomplished their goal of producing the most ergonomically efficient and safe laboratory cabinet practical. The Purifier Delta Series Safety Cabinet takes the laboratory worker's ease of use, personal comfort, and overall safety into consideration in each and every component from the base stand, chair and footrest, to the design of the exterior cabinet and the interior work space, all the way to the controls and gauges.

ⁱ Department of Health and Human Services. NIH Division of Safety Occupational Safety and Health Branch Laboratory Ergonomics: *A Manual for the Identification, Evaluation, and Control of Ergonomic Hazards in the Laboratory*. Section 2: Laboratory Ergonomic Assessment: Risk Factors.

BioSafety Cabinets and Laboratory Workbenches: Contact stresses. In laboratories, ulnar nerve injury can result from pressing the forearms against the edge of an uncushioned laboratory workbench. pg. 23

ⁱⁱ *Issues in Lab Ventilation. Making Fume Hoods Accessible to the Disabled*. Vol. 1-No.2 January 1993.

The Requirements. Protection. The most obvious requirement for an accessible fume hood is that it gives the same level of protection as a normal laboratory hood. For this reason it is important that it has a profiled entrance including contoured vertical fascias and a bottom air foil. pg. 2

ⁱⁱⁱ *Issues in Lab Ventilation. Making Fume Hoods Accessible to the Disabled*. Vol. 1-No.2, January 1993.

The Requirements. Reach Limits. The hood alarm and switches can be located higher than the fixtures since these do not have to be accessed from the working position, but can be accessed with the wheelchair parallel to the hood. These should be at a maximum height of 54 inches. pg. 2

^{iv} *Issues in Lab Ventilation. Making Fume Hoods Accessible to the Disabled*. Vol. 1-No.2, January, 1993.

The Requirements. "Worktop height. There is no worktop height that is optimum for all people in wheelchairs. A tall person is most comfortable with a worktop height of about 34 inches, while a short person may prefer a worktop height of about 29 inches. However the clearance height for the wheelchair imposes a lower limit on the height of the worktop. Also the worktop support may add to the required height...Because of the constraints, a worktop height of between 31 inches and 33 inches works best in most instances." pg. 2

The Requirements. "Room for wheelchair...sufficient room for the wheelchair to roll beneath the hood. According to the guidelines, a space 30 inches wide by 30 inches high by 25 inches deep is the minimum required." pg. 2

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For more information, please contact us:

[ExpotechUSA](#)
[10700 Rockley Road](#)
[Houston, Texas 77099](#)
[USA](#)

[281-496-0900 \[voice\]](#)

[281-496-0400 \[fax\]](#)

E-mail: sales@expotechusa.com

Website: www.ExpotechUSA.com