Control of Nuclear Gloveboxes and Enclosures Using the No-Moving-Part Vortex Amplifier (VXA)

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ABSTRACT

This paper describes the components and operation of a no-moving-part control valve known as a Power Fluidic Vortex Amplifier (VXA). VXA's have been successfully used to control the operating environment of nuclear gloveboxes and other enclosures for over 30 years in the United Kingdom. AEA Technology ES. Inc. (AEAT) are now introducing the VXA into the US DOE Complex.

Not only is the VXA capable of controlling the environment of small individual enclosures, such as gloveboxes, but it is also applicable to active facility-level ventilation systems that meet the requirements of the DNFSB's recommendation 2004-2 Revision 1.

VXAs can be regarded as no moving part control dampers that regulate ventilation blower or header depressions down to a manageable level within an enclosure. VXAs are capable of reacting to perturbations such as containment breaches, hence avoiding the egress of contaminated materials into the working environment. For example, when connected to a 1.0 kPa (4" wc) ventilation header, a working pressure of less than 0.25 kPa (1" wc) can be maintained within the glovebox. However, if a loss of glove breach takes place, the VXA can instantaneously react to allow an ingress of air from the operator's environment sufficient to maintain a velocity of 1 ms^{-1} at the breach. On replacement of the glove, the VXA will instantaneously return to the normal operating condition with no action required by the operator.

The VXAs are not limited to the control of small enclosure ventilation systems. They are sufficiently scalable to be applied to large facility-level ventilation systems protecting suites of gloveboxes, personal access enclosures and entire facilities.

The VXA and its uses are presented and discussed in this paper.

INTRODUCTION

In their recent recommendation 2004-2 Rev. 1 (Ref. 1) DNFSB revised its requirements to avoid the use of "Passive" ventilation systems for confinements of radioactive materials. In this revision, the Board clearly states that its "main issue" is:

> "that for the purpose of confining radioactive materials through a facility-level ventilation system, safety system designation should be based on the active safety function (forced air through a HEPA filter system)."

The Vortex Amplifier (VXA) provides active control of such ventilation systems. There are no moving parts that require maintenance or that increase the likelihood of operational downtime. It can be regarded as a "fit-and-forget" system, with no external power supply requirements. VXAs can be relied upon to provide safe and efficient ventilation system control throughout a plant's entire expected design life.

For over 30 years, AEAT's VXA technology has been successfully deployed in nuclear facilities in the United Kingdom to control operating environments such as gloveboxes and other enclosures. AEAT is now introducing the VXA into the United States market.

For convenience, the following description of VXAs and their mode of operation will be limited to a single glovebox control installation. However, the VXA is applicable to multiple glovebox suites and larger enclosure ventilation control.

Most commercially available gloveboxes utilize active control systems that include mechanical or electronic pressure sensors and controllers. These devices must, in turn, operate conventional mechanical dampers that contain moving parts and are hence prone to failure and require regular maintenance. Such systems may also exhibit slow response times to changes in operational conditions such as breaches in containment.

As a result of these conventional system limitations, the inherent reliability and fail-safe nature of the VXA may be a potential benefit to areas within the DOE complex. This is supported by the recommendations of DNFSB's document (Ref. 1).

The currently dominant conventional methods used for glovebox ventilation control utilize oil-filled devices known as bubblers. Such devices, while providing adequate pressure control during normal operation, have significant disadvantages when operating under abnormal conditions such as containment breach and other enclosure pressure perturbations. A significant concern is potential contamination due to oil releases into the containment, operating environment, or ventilation system.

AEAT's VXA technology, however, has significant proven advantages over such conventional systems. In addition to possessing no moving parts, the VXA also contains no materials to contaminate either the glovebox enclosure or ventilation system duct-work. This absence of moving parts also results in a zero maintenance requirement and hence maximizes plant lifetime availability. A comparison of the relative benefits of the passive bubble and VXA technology has been presented in an article for the American Glove Box Society's ENCLOSURE magazine (Ref. 2).

The VXA technology also supports the general ALARA principles applied throughout the nuclear industry and has been proven to be acceptable within the nuclear industry in the United Kingdom.

A key benefit of the VXA technology is its assured availability throughout the associated plant's entire life. As with other AEA Technology no-moving-part Fluidic devices, the VXA can be incorporated at an early stage of a facility's design and be expected to operate successfully for the plant's intended life with no maintenance or likelihood of failure.

THE VORTEX AMPLIFIER (VXA)

The VXA is located between the enclosure to be controlled and the ventilation system blower or system header. For purposes of this discussion, the VXA is controlling the depression and flow rate of ventilation air of a single glovebox.

Basic Concepts of the Vortex Amplifier

A Vortex Amplifier can be regarded as a short cylindrical chamber that incorporates three entry or exit ports. Figure 1 below illustrates the basic concept of the VXA, illustrating these three ports:

- A radial Inlet Port
- An axial Outlet Port
- A tangential Control Port

Immediately after starting the blower, or connecting to the header, ventilation flow enters the VXA from the glovebox via the radial Inlet port and leaves via the axial Exit port. This can be regarded as a low resistance mode of operation of the VXA and is illustrated in Figure 1A below. The glovebox depression is being generated at this stage.

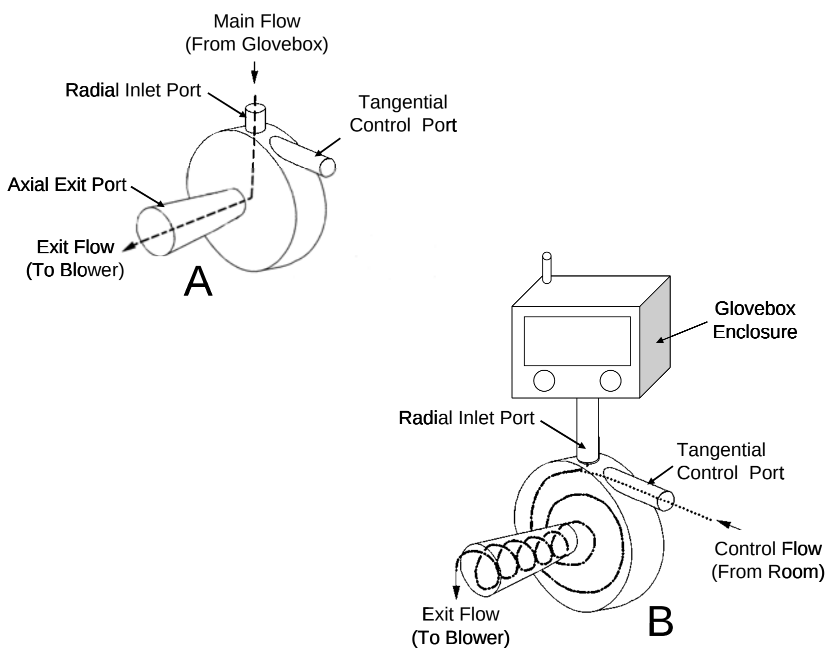

Figure 1 - Vortex Amplifier Ports and Operating Modes

However, the situation changes dramatically as the depression is generated in the glovebox. As illustrated in Figure 1B above, after drawing a depression in the Glovebox, flow must be drawn into the vortex chamber via the tangential Control port. This can be regarded as the high resistance mode of operation of the VXA with the pressure drop generated by the vortex effectively limiting the depression in the Glovebox itself.

The normal operating mode of the VXA is most likely to be between these two states, when a small purge flow is allowed to pass into the glovebox to provide a chosen number of air changes per hour to take place.

In practice, the detail geometry of the Vortex Chamber can be chosen to generate a vortex with a suitable pressure drop. As a result, if a fan drawing a maximum depression of 1 kPa (4 in wc) is selected, a VXA geometry can be chosen to generate a vortex chamber pressure drop of 0.87 kPa (3.4 in wc); hence regulating the glovebox depression down to a figure in the order of 0.15 kPa (0.6 in wc) at the given purge flowrate.

This 0.25 kPa depression is of the order required for ease of manipulation of gloves within a Glovebox. However, the geometry of the VXA can be varied to generate a range of enclosure depressions if required.

These operating conditions are illustrated by the typical VXA characteristic that has been generated assuming a blower depression of 1 kPa shown in Figure 2 below,

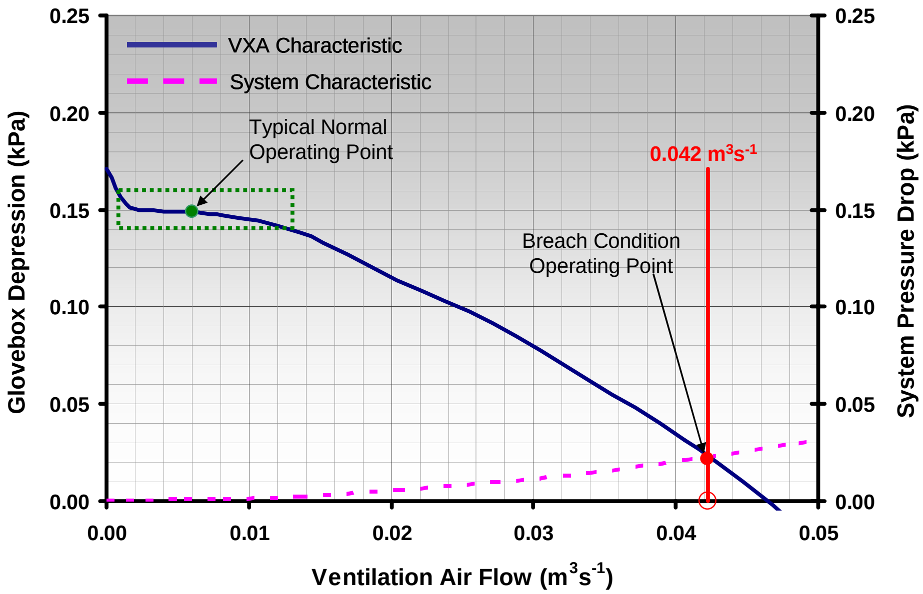

Figure 2 - Typical Glovebox VXA characteristic

Figure 2 illustrates the resulting glovebox pressure over a range of ventilation air flowrates. As indicated above, this is the ventilation flowrate that is allowed into the glovebox to maintain an acceptable number of air changes per hour. The glovebox depression is at its maximum (0.17 kPa) at zero purge flow and falls to zero (atmospheric pressure) at approximately 0.046 m^3s^{-1}.

A key portion of the characteristic is the near-linear region between 0.001 m^3s^{-1} and 0.013 m^3s^{-1}. The result of this linear characteristic region is a near-constant glovebox depression of 0.15 ± 0.01 kPa over a wide range of purge flows. For example, if the system is designed to operate with a purge flow in the center of this region, e.g. 0.07 m^3s^{-1}, the result will be that a variation of $\pm$ 0.06 m^3s^{-1} will have little influence on the glovebox depression. This region can be regarded as the high resistance VXA operating mode described in Figure 1B above.

The VXA's low resistance operating mode (Figure 1A) is therefore represented by the opposite end of the characteristic in Figure 2, at maximum flow and minimum glovebox depression. In this region, the VXA's vortex has been restricted and the only remaining pressure losses in the ventilation system are those of entry and exit losses, ductwork, and filters.

The pressure drop of the system, excluding the VXA, is also represented in Figure 2 above. This System Characteristic is presented as an example in Figure 2 and represents the pressure loss due to system ductwork and components over the VXA's operating characteristic flowrate range. Assumptions have been made for ductwork lengths, filters and other components that are typical for a single glovebox installation.

In the above example, the VXA and System characteristics cross at approximately 0.042 m^3s^{-1}, which suggests that, if the VXA is exhibiting no resistance, the system flowrate would be 0.042 m^3s^{-1} (90 scfm). This case represents a key operational condition that the VXA is designed to account for during glovebox fault situations, i.e. breach of containment where the glovebox pressure rises to atmospheric and ventilation flow is a maximum.

In the glovebox case, the most likely breach condition is regarded as loss of a glove from a glove port. This large breach in containment allows the pressure in the glovebox to rise towards atmospheric conditions and hence return the VXA close to its low resistance mode of operation illustrated in Figure 1A above. Flow into the glovebox, via the breach, is now almost entirely dependant upon the blower depression and losses in the ducting and filter systems (i.e. the intersecting point of the two characteristics in Figure 2).

If a glove port diameter of 0.2 m (8in) is assumed, this results in a velocity of over 1.2ms^{-1} (4 ft/s) into the glovebox at the indicated maximum ventilation flow of 0.042 m^3s^{-1}. The aim of this elevated ventilation flow is to prevent any migration of contaminated particles from the glovebox into the working environment via the breach. It is generally accepted that a velocity of 1ms^{-1} will meet these requirements.

The VXA is therefore capable of not only regulating the blower depression down to an acceptable value, but also capable of instantaneously switching from this regulation mode to a breach protection mode. Once again it must be stressed that the VXA is capable of doing this with no moving parts and with no external power supply other than the ventilation air flow that is required by the glovebox itself.

A further benefit of the VXA in this situation is that the normal operating conditions are restored automatically when the breach is corrected by the replacement of the lost glove. No other action is required.

Deployable Vortex Amplifier Design

The VXA layout described above does not fit well with building ventilation system requirements where axial arrangements are preferred. As a result, AEAT have adapted the basic layout illustrated in Figure 1 to aid system integration. This revised layout is presented in Figure 3 and discussed below.

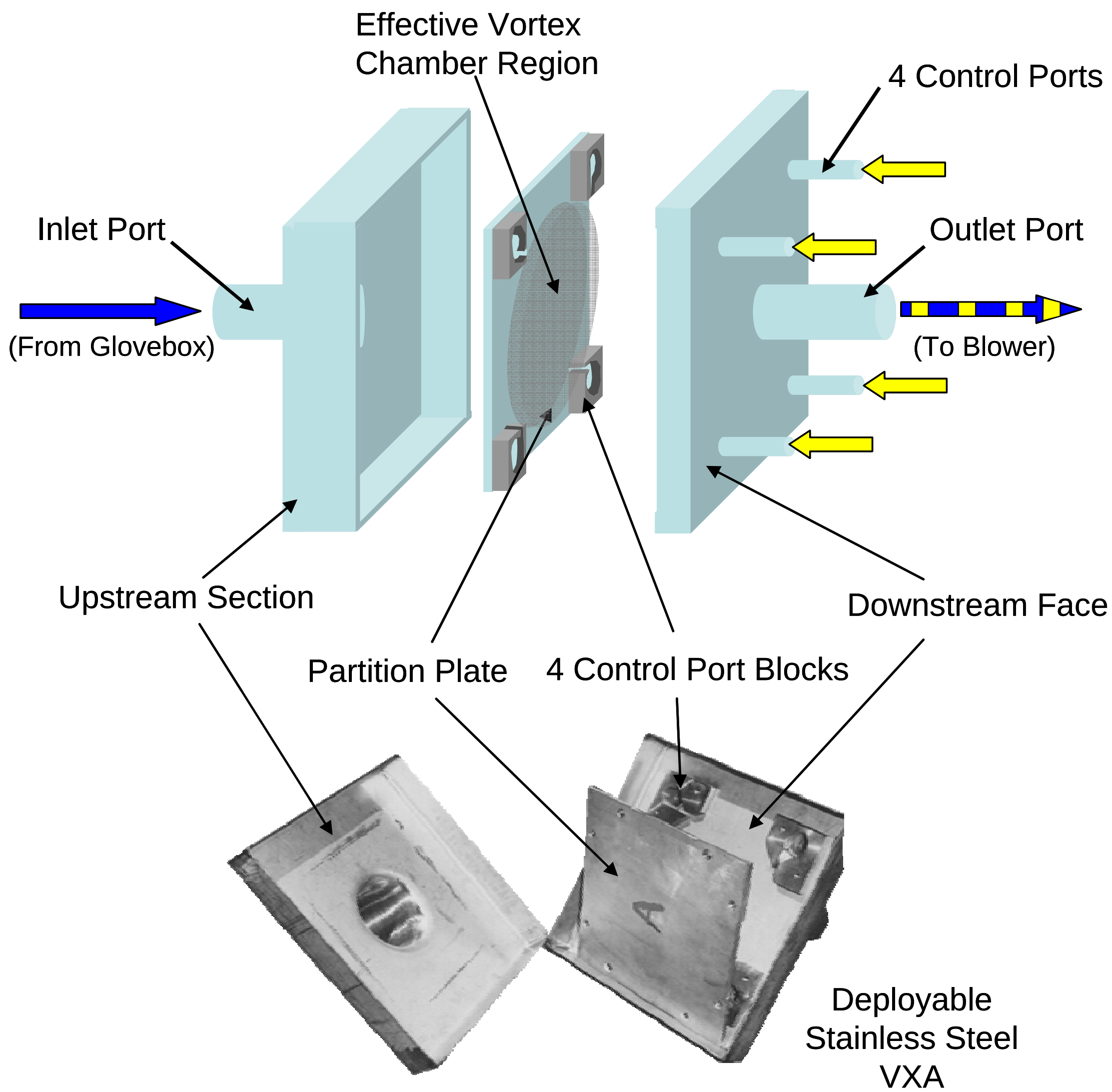

Figure 3 - Axial VXA arrangement

A practical embodiment of the basic VXA layout is illustrated in Figure 3 above together with an illustration of a typical device constructed in Stainless Steel and deployed in nuclear facilities in the United Kingdom. Although, at first inspection, this may look like a major departure from the VXA layout described above, all the main geometries and components are maintained. This VXA is also potentially more effective and simpler to fabricate.

As illustrated in Figure 3, the Axial VXA's key components are now held within a square shallow box that contains:

- An axial Inlet port
- An axial Outlet port
- Four axial Control ports
- An internal Partition Plate
- Four internal Control Blocks

Once again, purge flow entering the VXA is controlled by the Control flow that now enters via four control ports. The combined flow then exits via the axial outlet port. In this case, however, the four Control ports deliver the air into four control blocks. Each of these control blocks contain a small central plenum with a single slot exit that is shaped and located to result in a tangential flow of air into the space between the Partition Plate and the upstream face of the main VXA casing. The VXA's vortex chamber, denoted by the shaded area in Figure 3, is now bounded by these four control blocks, the partition plate, and upstream face.

This axial arrangement provides a VXA external geometry that lends itself to installation in ducting systems, while maintaining the VXA's operating performance. In reality the device can be constructed from many materials but a demonstration model, constructed in Plexiglas, is illustrated in Figure 4 below.

Figure 4 - Demonstration model VXA fitted to Glovebox

VXA SUMMARY

In summary, the overall influence of the VXA is similar to that of having a variable resistance valve and bleed flow into the system. Under normal operation, the resistance of the valve is high with only a small purge flow allowed. Sufficient pressure drop is generated to reduce the available exhaust header's depression to a figure suitable for operations in the glovebox. When a breach in containment occurs, the resistance of the valve automatically reduces, allowing the much larger flow that is now required to maintain a specified inward velocity of air into the glovebox via the breach..

The VXA inlet depression characteristic shown in Figure 2 illustrates that the Point 1 "Normal Operating" condition lies in the lower end of a flow range, over which the VXA inlet depression changes gradually with increasing exhaust flow. This means that considerable changes in the glovebox purge flow can take place without causing great changes in glovebox depression.

Point 2, in Figure 2, represents the "Breach Condition" where flow from the glovebox reaches its maximum. It is this flow that will generate the required inward flow velocity required at the breach.

PLANT INSTALLATIONS

The above is an outline of the basic principles of glovebox ventilation control using VXAs. There are naturally many considerations to be taken into account when designing and operating an actual system.

In practice, there are likely to be one or more stages of HEPA filtration downstream of the glovebox. The effects of these can be calculated using conventional ventilation system design techniques. Their influence will vary depending whether the filters are installed upstream or downstream of the VXA.

Other physical arrangements of the VXA than described above have been used for particular applications, hence maximizing the flexibility of the technology.

As indicated above, the VXA is not limited to the control of single glovebox ventilation systems. It is applicable to any containment system that requires pressure regulation during normal operation and control during off normal breach conditions. In fact, the VXA can be integrated into entire facility ventilation systems enabling control of the facility's breathing air and the environment within large glovebox suites.

The VXAs illustrated in Figure 3and Figure 4 above are for installation in single glovebox systems. As a result, they are relatively small in external dimensions. Typical single glovebox installations utilize what is known as a 1ft VXA, which refers to the external dimensions of the main rectangular body which is 300mm (1 foot) square and approximately 100mm (4") deep.

Large Gloveboxes and Suites

Many nuclear facilities utilize both large, multi-station gloveboxes and large suites of multiple gloveboxes. As a result, the purge flow is likely to be significantly greater. This additional purge flow requirement can be accounted for by an increase in the physical size of the VXA. AEAT have a range of VXA sizes to suit the majority of potential applications. The standard range of VXA sizes are 1ft, 1½ft, 2ft, and 3ft, which again refers to the size of the VXA's main box section. Larger VXAs can be considered for specific applications but these models are the standard range that would be expected to meet the requirements of larger gloveboxes or glovebox suites.

As indicated in Figure 1, the 1ft VXA used for the single glovebox case results in a purge flow range up to 0.01 m^3s^{-1}, for little variation in glovebox depression.

Examples of typical purge flow range for standard AEAT VXA are illustrated in Table 1 below.

Table 1 - Examples of Typical VXA Purge Flow Ranges

VXA Model	Glovebox Depression at Zero Purge Flow	Typical Acceptable Maximum Purge Flow
1 Foot	0.17 Pa	0.01 m^3s^{-1}
1½ Foot	0.17 Pa	0.02 m^3s^{-1}
2 Foot	0.17 Pa	0.025 m^3s^{-1}

For instance, as can be seen from Table 1, if a typical operating purge flow of 0.005 m^3s^{-1} per glovebox is chosen (50% of the 1ft VXA maximum), the 1½ ft VXA in Table 1 will supply this to two gloveboxes and the 2ft VXA to a suite of 4 gloveboxes. Of course, the above is merely presented here as an example and in all cases, specific VXA's would be designed to meet specific requirements in a given facility.

Larger VXA models will also allow account to be taken of the potential of larger breach flows (i.e. if multiple glove losses in a suite of gloveboxes or a larger containment breach in a larger single containment case).

This final case, of a larger single containment, introduces a further potential application of the VXA (i.e. the control of a room sized enclosure ventilation system).

VXAs have been shown to be capable of controlling room and building ventilation systems. In such cases, a major implication on the use of a VXA is that the breach flowrate is likely to be significantly greater than that expected from a single glovebox. For example, we may consider the ventilation control of a room sized enclosure in which a potential breach case may be the failure of interlocks maintaining airlock integrity. This may result in the requirement to maintain a significant inward air flowrate via the open airlock doors. A VXA can be specified, sized and designed to meet such an application and indeed has already been used within nuclear facilities in the United Kingdom. Such a facility would clearly require a large VXA to allow not only the breach flow at containment failure, but also the significantly larger number of air changes per hour required during normal operations. A typical VXA for such an application would be a 6ft VXA (i.e. a main section box dimension of 6ft).

An additional large-scale VXA application that has been implemented in the UK is the control of a large facility's vessel central off-gas system in which a 10ft VXA was deployed.

The VXA is therefore not limited to the control of glovebox ventilation systems and can be applied to wider applications within the DOE complex. As indicated above, the DNFSB has warned against the use of "Passive" ventilation systems for confinement of radioactive materials in their recommendation 2004-2 Rev. 1 (Ref. 1). The VXA ventilation system control is clearly relevant to this DNFSB requirement.

Care must be taken when considering the DNFSB requirements (Ref. 1). In this case, "passive" is regarded as a local, non-active, method such as a small HEPA filter that may be considered for the environmental control of a drum containing waste materials. Expansion and contraction, due to temperature changes, result in the drum being allowed to breathe via the passive filter. The result is that filter failure may lead to contamination of the local area with a potential to spread within and ultimately outside the facility.

The VXA could be regarded as a passive device due to no moving parts and no external power requirements. However, VXA is merely a passive component that is controlling an active facility-level ventilation system.

Ultimately, VXAs can be considered as providing a potentially integrated ventilation system to ensure that not only are individual gloveboxes or operating enclosures protected, but also, that the entire ventilation system within a facility can prevent egress of contaminated particles to the external environment. This clearly meets the requirements of the DNFSB Recommendation 2004-2 Rev. 1 (Ref. 1).

Glovebag Operations

As discussed above, the flexibility of VXA technology allows it to be applied over a wide range of specific applications. One such requirement is for a small portable device that can form part of a readily-deployable materials handling facility. Such a requirement has been highlighted by AEAT’s attendance at the ALARA workshop held in June, 2006.

AEA Technology were invited by the ALARA Center to demonstrate the VXA technology at a workshop held in Richland, WA. AEAT provided a demonstration facility that contained a small single phase blower, a proprietary glovebox, and the Plexiglas VXA illustrated in Figure 4 above.

A great deal of interest was generated during the workshop that has led to discussions with site operators. AEAT is conducting testing on the VXA to determine specific Hanford applications. The VXA is also being tested against baseline technologies already accepted by ALARA.

The specific application under consideration is Hanford site operator’s potential need for the safe control of a glovebag’s operating environment using a portable HEPA Filter unit and a VXA. The ultimate objective will be to conduct a site demonstration of the proposed facility for potential deployment at the Hanford site and elsewhere in the DOE complex.

It is intended to utilize currently available equipment such as a HEPA-filtered fan unit with an integrated VXA controller, to facilitate safe on-site operations using readily available glovebags. The components will be portable and hence deployable in all areas where such operations are currently conducted within the DOE complex.

CONCLUSIONS

The VXA ventilation system control technology complements the stated objectives of the DNFSB’s recommendation 2004-2 Revision 1.

Incorporation of the VXA within a facility-level ventilation system provides a highly reliable means for controlling glovebox and other differential pressure enclosures. The nature of the design allows the VXA to be incorporated into a wide range of facilities and can be relied upon to meet individual and facility wide ventilation needs. The VXA can accomplish this without the potential disadvantages of other pressure control methods and has the ability to control a large range of ventilation flows.

REFERENCES

Ref. 1. Facilities Safety Board for Defense Nuclear Facilities Safety Board
Recommendation 2004-2
Active Confinement Systems Implementation Plan - July 2006 - Revision 1

Ref. 2. Passive Pressure Control of Glovebox Enclosures
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