Journal of Aerosol Science 80 (2015) 75–85

Contents lists available at ScienceDirect

Journal of Aerosol Science

journal homepage: www.elsevier.com/locate/jaerosci

Capture of aerosolized spores from air streams impinging onto fabrics

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ARTICLE INFO

Article history:
Received 4 April 2014
Received in revised form
24 October 2014
Accepted 29 October 2014
Available online 12 November 2014

Keywords:
Aerosol
Airlock
Boundary layer
Deposition
Modeling
Spores

ABSTRACT

The zero-volume airlock concept minimizes the volume of air in and transiting through the airlock by effusing air from the clean area through spaces between deformable air bladders. An individual transiting through the airlock into a shelter displaces the bladders and creates ephemeral regions of varying dimensions and air velocities, which affect deposition and reaerosolization of particles. Properties of the aerosols and bladder surfaces are also influences, so the airlock may be treated to shed or retain particles and possibly to promote decontamination of them; the uniform material determines the protection from or exposure to these particles that the wearer experiences. To initiate evolution of a predictive computational model for the deposition and disposition of airborne particles in an airlock, this study presents measurements of deposition rates of *Bacillus atrophaeus* spores, a common simulant for anthrax spores, on a variety of fabrics as a function of airspeed and angle of incidence at ~22 °C and ~55% RH in a laboratory-scale aerosol tunnel. A computational model using inert surface properties consistently underpredicted experimental results by a factor of 2–10, suggesting that the variation in results across the test panel can be exploited to generate empirical parameters that can be substituted into the model to improve its predictive capability. Factors and possible approaches to computational descriptions are considered.

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1. Introduction

The US Department of Defense relies on three mechanisms to protect personnel from contamination in the field of action, in the following order: avoidance, protection and decontamination (Dickinson, 1999). This effort engages two of those areas, protection and decontamination. Military airlocks are designed to serve as a gateway into and out of a toxic-free area (TFA), through which an individual can rapidly transit and carry minimal or, ideally, no contamination into the TFA. Airlock entry

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http://dx.doi.org/10.1016/j.jaerosci.2014.10.010
0021-8502/Published by Elsevier Ltd.

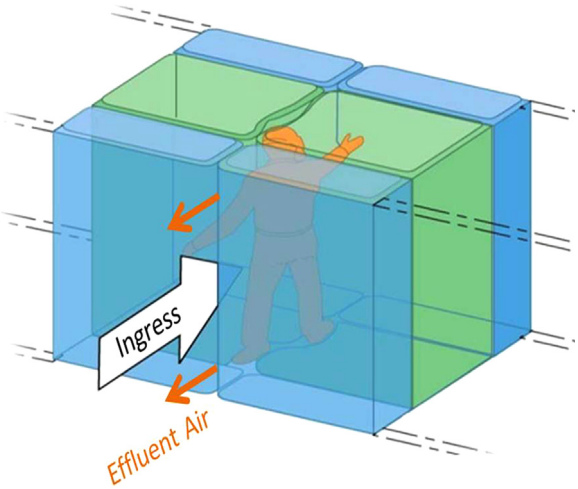

Fig. 1. Inflated elements of zero-volume airlock. Entry is achieved by squirming between the inflated surfaces along the path indicated by the white arrow, upstream to effluent air; the path is downstream to exit. Legends were added to the illustration, which was provided by Technical Products, Inc., Ayer, MA, USA.

and exit portals vary but the common principle is to conduct air exchanges in a confined space to sweep out contaminants prior to opening it into the TFA. In the zero-volume airlock concept (Fig. 1) the entry is sealed by large, inflatable bladders abutting each other, through which individuals squirm their way into or out of the TFA. The TFA is kept at a positive pressure and, by design, during ingress a relatively small volume of "clean air" effuses at speeds approaching 1 m/s from the pressurized area through gaps created in the airlock to the outside. Thus, clean air provides a dynamic sweep around the individual entering or exiting the TFA. Pressure internal to the large entry air bladders (Fig. 1) of the airlock is kept sufficiently high to effectively seal the empty chamber and minimize air loss. The bladder surfaces are compliant and to a large extent conform to the body during transit. In this way, surface contact combined with airflow sweeps the contaminants toward the outside and away from the clean zone. The concept is elegantly simple—and involves no moving parts except in the source of pressurization to the bladders.

In practice, frictional resistance to movement through the zero-volume airlock (ZVA) is substantial. Transfer of deposited contaminants can occur between the bladder face and the garments of personnel both via direct contact or via air as mediator—both mechanisms are of concern, and they are directly influenced by the characteristics of the two fabrics, which can be manipulated to minimize either or, possibly with compromises, both problems. However, conformance of the slightly elastic bladder surface to the entering individual is imperfect (and varies with the individual) and movement will create transient spaces through which air movement occurs, carrying, depositing and reaerosolizing contaminants. These processes in air are analogous to those occurring in historical airlocks that employ larger air spaces and no direct contact with the airlock wall. We suggest that a common modeling approach with appropriate scaling may provide a predictive description of the physical fate and transport of contaminants in and exiting such portals. Such a model can be used for the design and selection of fabrics, evaluation and planning of dimensions and pressure of the bladders, and other factors that influence the exposure risk to personnel in the airlock. In this way, trades between rates of ingress and egress, and efficiency of contaminant exclusion can be balanced on a rational basis.

To create a base of information from which development of an analytical description of particle deposition in airlocks can be initiated, an Air Force Research Laboratory (AFRL) team collected samples of nine commercial fabrics, including several prepared as candidate materials for use in protective gear, and a fluorosilanated cotton on which to measure the fractional capture of particulate contaminants from an air stream impinging at three incident angles and three air speeds. As deposition of tiny numbers of viable particles can be measured directly by culture methods and counting, the experimental design was based on capture of respirable, culturable particles. The choice of *Bacillus atrophaeus* (Bg) spores for this role was guided by their use also as a common surrogate for the bioweapon, *Bacillus anthracis* (Ba).

2. Materials and methods

2.1. Preparation of Bg spores

Bg cells were grown in liquid sporulation medium at 35 °C with reciprocal mixing at 240 rpm for 5 days, until approximately 95% of the population were phase-bright spores (Buhr et al., 2008). The preparation was harvested by centrifugation (10 krpm for 15 min) and the pellet was resuspended in a volume of sterile water one-half that of the original growth medium. The preparation was heated to 80 °C for 30 min to heat-inactivate remaining vegetative cells and germinated spores. The preparation was then washed in sterile water three times to remove any cell debris. The spore

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