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## Lessons Learned During the Design of an Arthropod and Pathogen Quarantine Facility

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### Abstract

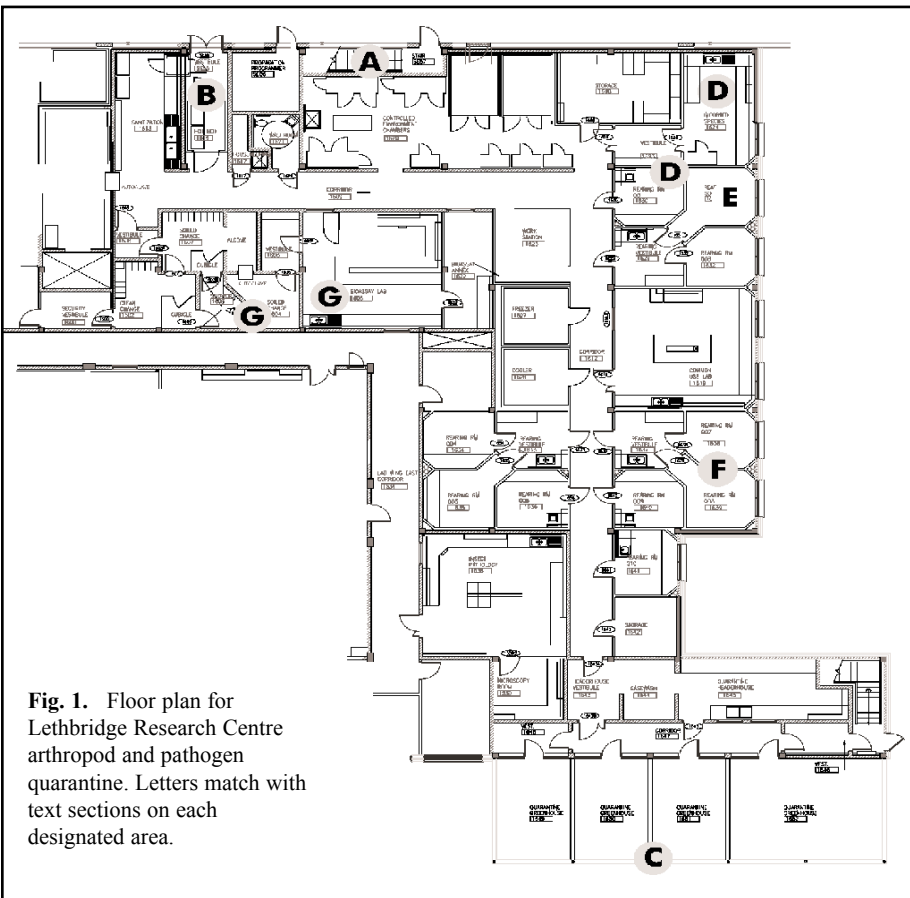
The Lethbridge Research Centre, of Agriculture and Agri-Food Canada, has completed design for a 883 square metre (9500 square foot) quarantine facility for the containment of biocontrol arthropods, and insect and plant pathogens. During the design phase of the project, several quarantine facilities in the U.S. were toured and information was gathered from people involved with quarantine design and maintenance in North America and abroad. From these tours and interviews, and our own challenges in design, we have developed a list of architectural and mechanical engineering solutions to meet user/ regulatory requirements and budget constraints on such a project. These include: 1) Using a clustered, modular design for small insect-rearing rooms. The rooms have special ventilation to address wide temperature range capabilities, elevated relative humidity, and potential allergy problems related to the rearing of insects. 2) Lowered ceilings in insect rearing rooms and imported shipment room to give better control of escaped insects and ease in cleaning. 3) Establishment of quarantine barrier at the ceiling, above which is located all mechanical equipment and electrical and control systems in a large non-quarantine interstitial space. 4) Natural light in many areas within quarantine to enhance work with insects (e.g. for mating and rearing requirements, insect trapping, improved viewing of insects during identification/sorting). 5) Mechanical and air barrier separation of the arthropod from pathogen areas of quarantine. The pathogen suite has its own entrance with shower, controlled pressure differentials, separately-treated waste water, and HEPA filtered exhaust air. 6) Flexible, economical waste management system. This includes triple-tank septic and batch chlorine systems for treatment of liquid wastes from arthropod and pathogen parts of quarantine, respectively, and pass-through autoclave and hot-box for treatment of solid materials. 7) Individual fan coil units for cooling greenhouse compartments versus dedicated air handlers.

**Keywords:** Architecture, containment, laboratory design, mechanical engineering, quarantine.

Plans for a containment facility to house mainly foreign arthropods at Agriculture and Agri-Food Canada's (AAFC) Lethbridge Research Centre (LRC) began with the 1992 move of the AAFC weed biocontrol arthropod quarantine from Regina, Saskatchewan to Lethbridge, Alberta. This temporary facility is currently situated in a 50 year old building

at LRC, and is insufficient in size, layout and mechanical capabilities. In addition to the immediate need for a modern weed biocontrol quarantine, it was realized that a new facility would be required to meet the growing emphasis on biocontrol research both regionally and nationally. Hence, between September 1997 and December 1999, design was completed for a 883 square metre facility for the containment of biocontrol arthropods, and insect and plant pathogens (Fig. 1). Construction is expected to begin in spring 2000.

During the design phase, we concentrated much effort in fact gathering to ensure that our facility would meet both regulatory and user requirements. Because Canada does not have official guidelines for the design of facilities for the containment of biocontrol arthropods or pathogens, we used appropriate parts of quarantine facility guidelines recently drafted by the U.S. Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS 1995a,b). We also referred to Health Canada's Laboratory Biosafety Guidelines (Kennedy 1996) for the design of our pathogen part of quarantine, although they relate specifically to the containment of human rather than plant and insect pathogens. A number of arthropod and pathogen quarantine facilities in the U.S. also were visited, a video tape of the CSIRO, Black Mountain quarantine at Canberra, Australia was obtained and viewed, and there were consultations with numerous quaran-



**Fig. 1.** Floor plan for Lethbridge Research Centre arthropod and pathogen quarantine. Letters match with text sections on each designated area.

tine operators, entomologists and pathologists who have had experience with the design of quarantines. A useful result of these activities was the opportunity to review the plans or visit facilities that were not only built but at various stages of design or construction. Mutual feed-back on design, in some instances, proved invaluable in arriving at a functional layout of our facility.

The intent of this paper is not to summarize what is already accepted in quarantine design and well reviewed elsewhere (Leppla and Ashley 1978; Coulson *et al.* 1991; Ertle 1993; Fisher and Andrés 1999; Kahn and Mathur 1999), but to highlight some of the special features of our facility that emerged as we grappled with each quarantine concept and design challenge. There were five issues of concern which directed our design and are common in the design of any quarantine facility; 1) security or containment of the organisms we will be working with, 2) rearing requirements for the organisms, 3) facilitation of work activities by the users, 4) construction cost and, 5) operation and maintenance. However, as we accumulated information on other facilities, we quickly learned that the design and construction of every quarantine has been constrained by their own unique set of issues and challenges, whether due to user needs, site, climate, politics or budget. What is hoped is that by sharing some of the solutions to our own set of constraints, it will lead to the questions that need to be addressed by those just embarking on quarantine design. Based on the attendance at an adhoc meeting on quarantine operation and design held at the X International Symposium on the Biological Control of Weeds, Bozeman, Montana, July 8, 1999 (ca. 25 people from around the world), it was apparent that there is a growing number of new quarantine facilities being designed or built worldwide and hence, a growing need and desire for such information.

### **A. Quarantine barrier/interstitial space**

One of the first concepts that we educated ourselves and the designers on was the location of the quarantine barrier. We made the mistake of thinking that it would be intuitive to all involved that the barrier is at the ceiling, floor and outer walls of the facility, especially after emphasizing that all penetrations through the barrier must be carefully sealed. However, it was not intuitive to our designers and, neither is the issue clearly discussed in the literature on quarantine design. Ertle (1993) mentions that each room within quarantine is a sealed off area that also contains the equipment, machinery and controls needed to maintain and monitor the room's environment (e.g., heating, cooling, relative humidity, lighting). The housing of all of this mechanical equipment within laboratory space is not very feasible from the perspective of cleanliness and loss of working space, hence, we do not subscribe to this approach. Ertle (1993) also mentions that the USDA Newark facility includes within its quarantine envelope the attic space, which houses the water and electrical ducts/conduits and air-handlers. Although the attic is a better location for mechanical equipment than within laboratory space, the roof of the Newark facility becomes the upper boundary of quarantine rather than the ceiling of their rooms. There was a mix of designs encountered in our visits of other quarantine facilities, however, the majority treat an above interstitial space with equipment as being outside of the quarantine boundary. We chose and stuck with this concept, despite a major redesign effort when it was learned that our designers were on a different track. Our objective was to have a barrier which is durable, obvious, discernable, and verifiable for the purposes of quality assurance (i.e. no insect escapes) in addition to the need to clean and decontaminate (i.e., wipe down) the laboratory on a regular basis.

Our reasoning for treating the interstitial space as outside of quarantine also has to do with minimizing traffic into and out of the facility. All mechanical and electrical equipment requires regular operation and maintenance work. Providing an interstitial space and locating such equipment there will facilitate those activities without maintenance personnel having to enter quarantine. Neither will tools or other service equipment have to be moved into and out of the facility. This will avoid decontamination of tools and minimize disturbances to on-going research activities, while also isolating sources of heat, noise, dust, and vibration from the laboratory space below. Furthermore, the High Efficiency Particulate Air (HEPA) filter and its housing for the pathogen part of our quarantine will be located in the interstitial space and, can be easily maintained, decontaminated, and certified with appropriate dampers and decontamination ports without entering into the laboratories.

The separation between the laboratories and the interstitial space for our planned facility is a structural concrete slab. This construction is ideally suited for the secure installation of air-tight and insect-tight penetrations for piping and duct work, as well as electrical conduits. With standard coating products applied to the concrete, a suitable containment barrier is achieved. Duct, piping, and electrical conduit penetrations are complete with 100 mm long extensions at the concrete slab and properly sealed. The top surface of the slab within the mechanical room is further coated with a waterproof membrane to guard against inadvertent spills above.

A further benefit to the interstitial concept lies in the impact on the life cycle of laboratory facilities. While the program at this site is presently well-defined and well-accommodated by our quarantine design, we recognize that advancing science will require changes to the facility. Any future program changes here can be much more readily accommodated by virtue of the fact that all mechanical and electrical equipment lies outside the laboratory space and quarantine barrier, thus simplifying the re-fit of rooms and layouts below.

## **B. Waste management**

A waste management system has been planned for pathogen and arthropod parts of quarantine which is both economical and allows for flexibility dependent on the materials to be treated. As a cost saving measure, the more voluminous waste liquids from the arthropod part of quarantine will be treated in a multi-tank septic system instead of batch heated or chemically treated as is typical in other arthropod quarantine facilities. Only the waste liquid from our pathogen area will be chemically treated. Although we will make use of pass-through autoclaves to decontaminate solid materials from both parts of quarantine, we also will have a 'hot-box/fumigation chamber' for treatment of bulk materials (e.g. soil) or more fragile materials that we wish to save after leaving quarantine (e.g., insect cages, small growth cabinets or other equipment that may need repairs). Details of the liquid waste management system and hot-box are outlined below.

## **Pathogen area**

To address pathogen containment, all liquid wastes from this area will be treated with chlorine. A chlorine sensing element will be provided in the system to indicate the chlorine concentration, and the proper amount of chlorine will be injected into the system to ensure 100% kill of the pathogens. We will attempt to minimize the amount of organic matter or other solids entering this stream in an effort to minimize tying-up the injected

chlorine, thus maximizing its efficacy. Agitation capability will be provided to ensure uniformity of treatment.

The choice of this treatment method was made in light of the minimal quantities of liquid waste expected to be generated in this relatively small area (ca. 80 sq. m.), the majority of which will be generated by the shower. Thus, batch treatment within a 1300 liter tank is thought to be manageable and not overly time-consuming. In addition, given the low concentration of chlorine in the effluent (i.e., in the order of 10 ppm) it is felt that the environmental impact will be negligible when such small volumes are mixed with the significant volumes of sanitary wastes generated at the site.

A small basement area lies directly below the quarantine to house the treatment tank. All piping from the quarantine area will be exposed to facilitate inspection, modification, and repair, if necessary. This area can be treated as a contained area for any potential spill of untreated liquid from the sewage system. Should new treatment technology emerge in the future, it will be relatively easy to adapt this dedicated area to suit any new approach.

### **Arthropod area**

Liquid wastes will be treated in a gravity, continuous-flow triple septic tank system. Each tank will have a volume of approximately 1300 liters, and will be connected via piping configured to provide a 'liquid lock' (i.e., pipes filled with water) between the three tanks. Water flows from tank to tank in progression entering each tank from near the top. Effluent which exits the third and final tank is pumped to the building sanitary system. Outlet pipes will be near the bottom of each tank and some distance underwater and away from the intake pipes. Air vents at the top of each tank will be covered with 100 mesh screen. It is expected that any quarantined insects that make it into the septic tanks will be trapped and will not survive. For instance, escaped insects will likely float on the water's surface and may climb the walls into the air space at the top of the tanks, but will not be able to escape because of the screened vents. The configuration of the intake and outlet pipes, the liquid lock between tanks, and the low flow rates through the system, also will make underwater escape by insects unlikely. The triple-tank system is analogous to a triple vestibule/light lock system, which reduces the possibility of insect escape through a series of traps and barriers. If there should be a rare escape of concern, the whole system also can be closed and decontaminated by diverting the effluent leaving the third tank back to the first via a bypass pipe and injecting chlorine into the system.

As mentioned, solid wastes will exit the facility through a double door autoclave or through a pass-through 'hot box/fumigation' chamber. Similar to the autoclave, the hot box is configured on the quarantine boundary. However, it will use dry heat (50-60° C for 12-24 hours) to assure kill, based on the assumption that raising an insect's body temperature to 50° C for 12-24 hours would be lethal to the insect. Upper lethal limits for short exposure periods have been reported to be between 40 and 50° C for a number of insect species (Bursell 1974; Yokoyama and Miller 1987; Hansen 1992). In addition to the absolute temperature, rate of heating contributes to insect mortality, with quicker mortality occurring at more rapid rates of heating. Rates of heating which have been reported to assure insect mortality range between 0.067 to 6.25° C/min (Sharp and Chew 1987; Yokoyama *et al.* 1991; Neven and Rehfield 1995; Neven 1998). Our system exceeds the capacity to go from 24° C to 60° C in one hour (i.e., 0.60° C/min.), which falls within this range. However, the actual rate of heating will be directly affected by the mass of the equipment/material placed within the hot box. The upper temperature limit for the hot box

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will be 70°C to allow for maneuverability when setting a high end temperature. In rare situations, the hot box will serve as a de-con chamber for gas decontamination of items leaving or entering the quarantine. The hot box has been sized to accept oversized items, up to and including a E-15 growth chamber, if necessary.

### **C. Quarantine greenhouse**

The quarantine greenhouse will be a self-contained facility and, designed mainly for experiments using insect biocontrol agents. Base cooling and heating will be provided by the central air handling unit and supplemented by individual fan coil units for each greenhouse compartment. This differs from some facilities we visited where each greenhouse compartment has it's own air handler (e.g. USDA-APHIS, Mission, TX and USDA-ARS, Albany, CA). It was felt that the space temperature and air flow rates of the compartments of our planned greenhouse can be adjusted to meet individual research requirements and to address energy conservation. While moisture from the plants and soil within insect cages will influence humidity at the micro level, we also have the ability to add humidity to each compartment independently. This feature also will provide the flexibility to deal with the possibility of inadvertent dehumidification of the space arising from the cooling mode of the fan coil.

From a quarantine perspective the greenhouse is treated as simply an extension of the remainder of the arthropod quarantine but with the added feature that substantial quantities of natural and artificial light are provided for plant growth and insect behavior purposes. Glazing selection is a balance between light transmissivity (see E. Natural light) and security of the quarantine boundary. It is our judgement that a commercial, 'off the shelf' greenhouse envelope approach is inadequate for containment purposes. At the same time it is important that the builder of the greenhouse be schooled in the unique objectives of his task of providing a secure envelope. We have selected insulated glass units composed of tempered glass outer panes and laminated glass inner panes. The glazing system, and its attachment to the greenhouse frame with structural silicone and, connection to the quarantine headhouse are critical to the continuity of the quarantine boundary and should be reviewed carefully during design.

Automated shading, lighting, and irrigation systems for each of the four greenhouse compartments will provide flexibility in growth conditions. Benching systems have been chosen to facilitate operations rather than to maximize the bench to floor area ratio. For all compartments, we will use stationary (i.e., versus rolling) benching which can be reconfigured dependent on the experiments that are being conducted.

### **D. Lowered ceilings**

During our investigations into arthropod quarantine design, the question of whether or not lowered ceilings are needed or useful came up repeatedly. Facilities such as the arthropod quarantine at the University of California, Riverside, and the CSIRO, Black Mountain arthropod/pathogen quarantine at Canberra have lowered ceilings (7' or 2.1 m throughout at Riverside (Fisher 1978) and 7' in rearing cubicles at Black Mountain). Those involved with quarantine operation at these facilities are adamant that reachable ceilings are necessary for ease of cleaning and for recapture of escaped insects. It became apparent that trade-offs in design requirements and differences in philosophy on what quarantine was supposed to accomplish affected whether or not a facility had lowered ceilings. For instance, the ARS facility at Albany was designed with energy efficiency in

mind and, high ceilings instead of an air conditioner help keep the facility comfortably cool. Their response to the trade-off between energy efficiency and low ceilings is that if insects escape from cages within quarantine, it does not matter as long as the integrity of the quarantine boundary is maintained (i.e., the escaped insects may get away within the facility, but they won't get far before dying) (J. Balciunas, USDA-ARS, Albany, CA, personal communication). In contrast, the Australian philosophy is that every insect that enters quarantine and is used in tests must be accounted for, hence, lowered ceilings become more critical in quarantine design.

In the design of our facility we have decided to compromise on height and location of lowered ceilings. The ceilings will be 7.5 feet high (2.3 m) in the Imported Species Room, where packages with insects will be opened, and in all Insect Rearing Rooms. Remaining areas will be a standard 8.5 feet (2.6 m) high. Hence, the lowered ceilings will be only in those areas where there will be a high risk of insect escape due to unpackaging or rearing activities. Given that the biocontrol insects are valuable and difficult to replace, we subscribe to the notion that every attempt should be made to recapture escapees.

### **E. Natural light**

A number of quarantine facilities make use of natural light for work with insects, and based on our review of this topic, we chose to add windows to as many spaces as possible within our arthropod quarantine to allow for flexibility. From interviews, it was apparent that the light can serve several purposes within an arthropod facility including, facilitation of insect rearing, attracting and thus trapping escaped insects and, providing improved vision during insect identification or sorting activities. The windows of our planned quarantine will be located in five of the 12 Insect Rearing Rooms, the Common Use Laboratory and in the Imported Species Room (Fig. 1), which are all areas where we will be actively working with insects.

Some species or groups of insects may require natural light to induce mating (e.g., Tachinid flies; P. Parker, USDA-APHIS, Mission, TX, personal communication) or for development. Based on personal experiences, it was felt by many entomologists that natural light somehow improves insect rearing conditions, since light is known to play a very important role in the life cycle of insects (e.g., photoperiod's role in diapause induction; Romoser and Stoffolano 1998). With this in mind, we have attempted to select window glazing which does not unduly impair light transmissivity, keeping in mind that the only other method of increasing the quantity of natural light is to provide larger windows. The high transmissivity also will be important given that our quarantine windows will be east-facing, and direct light somewhat blocked by the presence of greenhouses to the east. Of interest, there was a preference by some interviewed people for north or east-facing windows because of the uniformity of light and reduced heat load as compared to south or west-facing windows.

Also of importance to insects and, something to carefully consider when choosing the glazing for quarantine windows, is light wavelength. Insects respond to wavelengths over a wide spectrum, but tend to be particularly sensitive to those in the ultraviolet (i.e., 300 mu range) and to a somewhat lesser degree to parts of the visible spectrum (ca. 400-700 mu) (Chapman 1969). Unfortunately, most glazing materials remove a high portion of UV radiation. A single pane of glass removes 40-50% of UV light and, once the glazing is double or triple paned and laminated for quarantine security, it is anticipated that a large portion of the UV radiation will be blocked (Brault and Denis 1999). Of note is that the

UV transmissivity of polycarbonate and other plastic glazings is less than that of glass. The reduction in UV, however, does not seem to be an issue for those who firmly believe that windows help their insect-rearing efforts. Perhaps, wavelengths in the visible spectrum are sufficient in the functioning of most insects.

Other design issues pertaining to quarantine windows, and oddly interconnected, are related to functionality or use, security and insulation/condensation. Where windows are being actively used in quarantine facilities (e.g., University of California, Riverside; USDA-APHIS, Mission, TX; USDA-ARS, Yakima, WA), they are located at or near bench height rather than clerestorey (i.e., near the ceiling). This allows a) the natural light to reach caged insects sitting on benches, b) people who are handling or inspecting insects to sit in front of the windows at a bench and thereby directly access the light and, c) easy access to escaped insects for recapture. Some facilities have clerestorey windows for security reasons (i.e., to reduce outside accessibility) or to allow interior wall space for placement of equipment. However, the clerestorey positioning of windows was pointed out as a design flaw by interviewed entomologists. Here is an example of where functionality and other issues can clash in the design of a quarantine facility. We chose to place our windows at bench height and for the sake of security, will provide double or triple glazing with a tempered outer pane and laminated inner pane of glass. The amount of glazing is not just a security issue, however, especially in our cold climate. We will minimize both condensation and heat loss not only through insulation of the glazing, but by providing thermally broken frames.

#### **F. Clustered, modular rearing rooms**

There is nothing new about the use of a modular design for quarantine facilities (Leppia and Ashley 1978; Ertle 1993; Aggarwal and Mathur 1999; Fisher and Andrés 1999). In this approach, many small, isolated rooms are preferred over a few, large rooms and, each room is an individually sealed area, separate from all other such rooms (Ertle 1993). The benefits to such a design include increased control over separate arthropod or pathogen colonies/cultures, prevention of cross-contamination by the biocontrol agents held in separate areas within quarantine and, the possibility of setting separate environmental parameters between rooms dependent on the individual requirements of the organisms being housed (Fisher and Andrés 1999). Furthermore, from a cost and maintenance perspective, the modular approach allows flexibility in construction and operations (Aggarwal and Mathur 1999). The modular design of the CSIRO, Black Mountain quarantine in Australia, for instance, allowed the facility to be built in stages when funding was available. Their stage two construction took place without halting quarantine operations because the organisms were contained and compartmentalized in the first sealed modules to be built. Similarly, if there is problem within one of the modules, this should not mean a shut-down of the whole quarantine, but simply of the affected module until decontamination or repairs are completed.

The planned arthropod portion of the LRC quarantine facility also will be modular in design, but it will differ from similar facilities in the layout of the Insect Rearing Rooms. Some of the modular rearing rooms will be clustered, so that two rooms (ca. 10 square metres each) will share a common vestibule. This will allow for increased isolation of insect colonies, but also for the concentration and sharing of insect-rearing activities. For instance, a cluster may be assigned to one insect species that requires special isolation within containment. To allow as much flexibility as possible in meeting insect-rearing

needs as they arise, some of the rooms will have windows/access to natural light, some will have the capacity to reach a relative humidity of 75%, but all will have a temperature range capacity of 10-28°C. To meet cooling requirements, each room will be handled by a separate fan-coil unit off of a brine chiller system. When needed for particular trials, portable humidifiers will be brought into rearing rooms and powered by wall receptacles which are under the control of the Building Management System (BMS). Temperature and humidity sensors in each room provide the capability of trending as well as controlling the environment using the BMS.

One other design issue of relevance to the Insect Rearing Rooms was provision of a healthy environment for people working closely with the biocontrol insects. Continued exposure of workers to the scales and frass produced by insects can produce allergies (Leppla and Ashley 1978). To reduce the potential for allergy problems, we will provide bench sweeps or mobile isolators (i.e., biohazard hoods) in rearing rooms to house insects with a high potential of causing allergies. We also will have an elevated air change rate in the rearing areas of quarantine (13 air changes per hour versus about 7-8 air changes per hour in a typical lab).

### **G. Separation of arthropod and pathogen parts of quarantine.**

Pathogen work can be safely performed in the pathogen part of quarantine (Bioassay Suite; Fig. 1) due to its enhanced containment provisions. These include HEPA filtration of exhaust air, directional air flow, pressurization control, local pressure differential gauges, alarms to the central building computer (BMS), redundant exhaust fans, fast response positive seal dampers, premium ceiling/wall/floor coatings, and gas decontamination capability. For arthropod work in the remainder of the facility these features and their extra cost are unwarranted. However, we have ensured that 100 mesh screening of all HVAC penetrations and all plumbing drains, plus a secure quarantine barrier will be provided throughout the facility, including the electrical and security conduits.

After passing through the initial light lock which provides access to the entire quarantine (Fig. 1), personnel then must choose between entering the pathogen area or the arthropod area. Thus, the design does not 'nest' one area within the other. It is felt that this allows for more effective use of protocols specific to each of the two areas, as well as less chance for negative impact of one area's work on the other. However, strategic location of the body shower for the Bioassay Suite leaves open the possibility of it also being accessible to workers exiting the arthropod areas, should some unique program requirement arise (i.e., during work with small arthropods such as thrips or mites).

As mentioned previously (see B. Waste management), the liquid waste from the Bioassay Suite flows by gravity to a batch chlorine treatment tank, while the liquids from the arthropod area continuously flow through a triple tank septic treatment system.

### **Conclusions**

Quarantine design continues to evolve and improve with the building of each new facility, but will always be driven by the individual philosophies of the users and various constraints unique to each facility. The ultimate aim is to contain our biocontrol organisms, but we must not forget in designing the facilities that both experimental organisms and people must function within its walls and there must be provision for maintenance and operation of the specialized mechanical equipment associated with quarantine. Because no one has an unlimited budget for construction, there will be trade-offs and sometimes,

difficult decisions to be made in design. The major lesson we have learned in the design of our facility is that cost-cutting measures can be implemented without compromising the purposes of the facility, but an open mind and open, continuous communication between designers, users, regulators and maintenance personnel are critical. We also have learned that many of the design parameters that are set by regulators and researchers for quarantine facilities (e.g., negative air pressure, black painted vestibules etc.) are our best guesses at what will work in containing organisms based on past knowledge and experience in working with insects or pathogens, however, frequently have not been experimentally tested on site. Hence, major contributions in the field of quarantine design are possible through cooperative research between quarantine users and design engineers.

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