King Abdullah University of Science and Technology
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KAUST
King Abdullah University of Science and Technology

Laboratory Design Standards
"Lessons Learned"

EXECUTIVE SUMMARY

Beginning January 2008, KAUST, in collaboration with Saudi Aramco Project Management Team (SAPMT), has developed over 65 Laboratory Fit-Outs (LFOs), opening the first operational laboratory in 2009. New LFOs are regularly designed, constructed, and commissioned for operation as the university hires new faculty and builds its research program. This effort will continue until the university reaches maturity and will extend beyond as the university adapts and changes its research mission.

With many laboratories now in operation, realities relating to laboratory design, construction, operations, and procurement implementation impact several of the original design assumptions developed at the beginning of the LFO process. KAUST must continue to build upon "lessons learned" and adapt onsite operations to meet the needs of laboratories. The laboratory design must also adapt to reflect these changes.

In the absence of a university laboratory design policy at the start of the LFO process, all laboratories at KAUST are designed in accordance with International Building Code (IBC 2006) and the National Fire Protection Association (NFPA 45 2000, NFPA 70 2005) codes. These regulations represent a "minimum standard" for building safety and provide general guidelines for all building types, not just research laboratories. These codes do not necessarily reflect the best practices in laboratory design currently recognized by peer universities and research institutions.

The Laboratory Design & Development (LD&D) Safety Officers, in collaboration with KAUST's Health, Safety and Environment (HSE) department, have taken several actions to review and implement health and safety measures in the laboratories. A safety audit conducted by Cornell University, as well as several laboratory safety regulations now developed by KAUST, have raised several safety concerns in the laboratory design. In order to provide a safe environment that meets the standard of excellence KAUST strives to achieve in its academic setting, certain design guidelines must be implemented that go above and beyond the standard IBC and NFPA codes.

The following actions are therefore recommended:

1. Before any scope of work (SOW) is submitted for a new LFO, a Pre-Operational Safety, Health & Environment Review Form (PORSHER) will be completed by the LD&D Safety Officer and the Principal Investigator (PI) and/or the laboratory manager or lab safety officer. This form will act as the basis of design to document hazards and other considerations anticipated within an LFO. See Appendix A attached.
2. KAUST shall develop and implement laboratory design guidelines to be followed by all KAUST design and maintenance departments as well as contractors entering into design, construction, and maintenance contracts with KAUST. These guidelines shall be developed by Engineering and Project Management (E&PM), Laboratory Design & Development (LD&D), Heath Safety and Environment (HSE), and Campus Support.
3. Until such guidelines are developed, KAUST recommends implementing the following criteria for immediate execution in the design and construction of all new LFOs:
   a. Ground Fault Circuit Interrupters (GFCIs) shall be provided for all electrical outlets within the laboratory.
   b. Lab benches shall be equipped with receptacles spaced at 600mm on center. In order to provide adequate GFCI receptacles, quad outlet boxes are preferred over duplex. 220v -receptacles shall be located on every open wall, including the service corridor, such that there is not more than 2 meters of wall space to a given receptacle. Where a receptacle moulding (e.g. electrical raceway) is provided on a wall, receptacles shall be spaced 600mm on center.
   c. Emergency Power Off (EPO) buttons shall be provided for each LFO. The final location and requirement of each EPO button shall be coordinated by the design and engineering teams.
   d. The location of emergency eyewash units shall be reevaluated by the design and engineering teams.
   e. Additional chemical storage shall be provided for each LFO based on the requirement identified in the PORSHER form. Non-vented chemical storage cabinets shall be used where applicable. Chemical storage shall follow KAUST Lab Safety Manual guidelines and the amount of storage provided shall not exceed building code regulations in any given area.
   f. The standard exhaust capacity specifications for chemical cabinets shall be reevaluated by the design and engineering teams to meet the manufacturer recommendations.

g. The utilization of vacuum pump (C3) cabinets shall be eliminated until another cabinet and exhaust design standard is developed. Where required, exhaust for vacuum pumps shall be connected directly to the building exhaust.
h. The KAUST Facility Design Guideline for Laboratory using Class IIIB and/or Class IV Lasers shall be adhered to where applicable.
i. The LFO design shall account for more use of the Service Corridor, including utilization of the exterior wall for storage and laboratory equipment. It is recommended that equipment and storage placed along the exterior wall be limited to 800mm in height; however, exceptions must be made in certain cases where required.

As these requirements may involve several modifications to the present design and engineering specifications, a full review with design and engineering teams is required to determine the final recommendations for implementation.

RECOMMENDED GUIDELINES

Electrical:

1.1 Ground Fault Circuit Interrupters (GFCIs) shall be provided for all electrical outlets within the laboratory unless otherwise recommended by an equipment manufacturer.

Best Practice.

Recommendation is a more stringent application of NFPA 70

Adapted from University of California, Environment, Health & Safety (EH&S) Laboratory Safety Design Guide, 2nd Edition, Sept. 2007

Even though the code requirements for GFCIs are not very extensive, these inexpensive devices are among the most effective measures that can be taken to prevent electric shock.

KAUST Lessons Learned:

1. Several laboratories utilize complex experimental set-ups where water and electricity co-exist.
2. Due to the placement of electrical outlets near sinks, equipment is often plugged in and operated next to water.
3. Due to a lack of available power outlets, extension cords and power strips that defeat ground connection are heavily utilized and pose a safety risk.
4. Several laboratories have experienced water leaks that have damaged electrical equipment and endangered users.
5. KAUST is implementing a pilot study to implement GFCI outlets in the Analytical Core Laboratory (LFO 29). The existing electrical outlets will be replaced with a quad outlet box that provides one GFCI unit and three grounded electrical outlets.

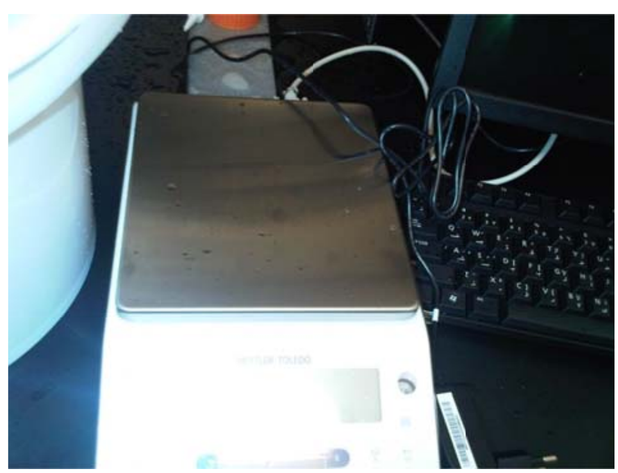
Considerations / Exceptions:

1. In the event an equipment manufacturer notes GFCI outlets should not be used, a standard electrical outlet should be provided and prominently labeled “Caution: Not Protected by GFCI”.
2. Consideration should be given before using GFCI outlets for refrigeration, sump pumps, or gas detectors.

Figure 1: Experiments with water usage is common.

Figure 2 & 3: Equipment operated next to a sink and electrical cord draped across sink.

Figure 4 & 5: Water leak within a laboratory that has damaged equipment.



1.2 Lab benches shall be equipped with receptacles spaced at 600mm on center. In order to provide adequate GFCI receptacles, quad outlet boxes are preferred over duplex. 220v -receptacles shall be located on every open wall, including the service corridor, such that there is not more than 2 meters of wall space to a given receptacle. Where a receptacle moulding (e.g. electrical raceway) is provided on a wall, receptacles shall be spaced 600mm on center.

Best Practice.

Cornell Safety Audit Recommendation

Adapted from University of California, Environment, Health & Safety (EH&S) Laboratory Safety Design Guide, 2nd Edition, Sept. 2007

One of the most common electrical shock and fire hazards is the overuse of extension cords and various receptacle multipliers. The designer can preclude this hazard by anticipating heavy need for receptacles everywhere in the laboratory space. In research laboratories, it is rare to have too many receptacles.

KAUST Lessons Learned:

1. Due to a lack of available power outlets, extension cords and power strips that defeat ground connection are heavily utilized and pose a safety risk.
2. Users are resorting to improvise electrical connections where power is not available.



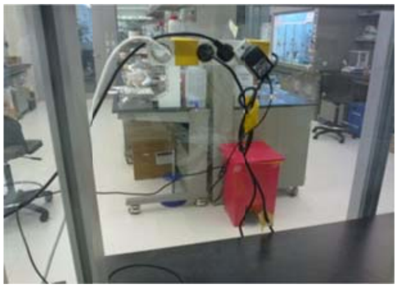



Figure 6, 7, 8, 9:

Overuse of extension cords and power strips and improvised electrical connections.

1.3 Emergency Power Off (EPO) buttons shall be provided for each LFO. The final location and requirement of each EPO button shall be coordinated by the design and engineering teams.

Good Practice.

Adapted from IEC 364-4-46

A means shall be provided for emergency switching off any part of an installation where it may be necessary to control the supply to remove unexpected danger.

In accordance with standard practices and design criteria, the circuit breaker panels are not located in the laboratories, but instead are placed in the interstitial catwalk above the laboratory ceiling. While the placement of the circuit breaker outside of a laboratory is good practice, in the event of an emergency, users do not have direct access to terminate power within the laboratory. Current KAUST procedures require users to call the operator of the Building Management System (BMS) for emergency power shut-down.

In order to provide adequate safety, users should have direct access to an EPO in order to terminate power in an emergency situation.

KAUST Lessons Learned:

1. In events where water leaks have posed risks to electrical equipment, users have not had any way to shut-off power and safely remove electrical equipment from the water source.

Considerations / Exceptions:

1. The current process of calling the BMS operator requires a significant amount of time when users could immediately cut-off the power supply. The BMS operator will also initiate a building quadrant power shutdown instead of a localized power shutdown.
2. The exact location of the EPO needs to be reviewed.
3. Impact to the electrical system design should be considered.

2. Emergency Eyewash

2.1 The location of emergency eyewash units shall be reevaluated by the design and engineering teams to ensure the eyewash units cannot be obstructed by any objects and hinder accessibility in the event of an emergency.

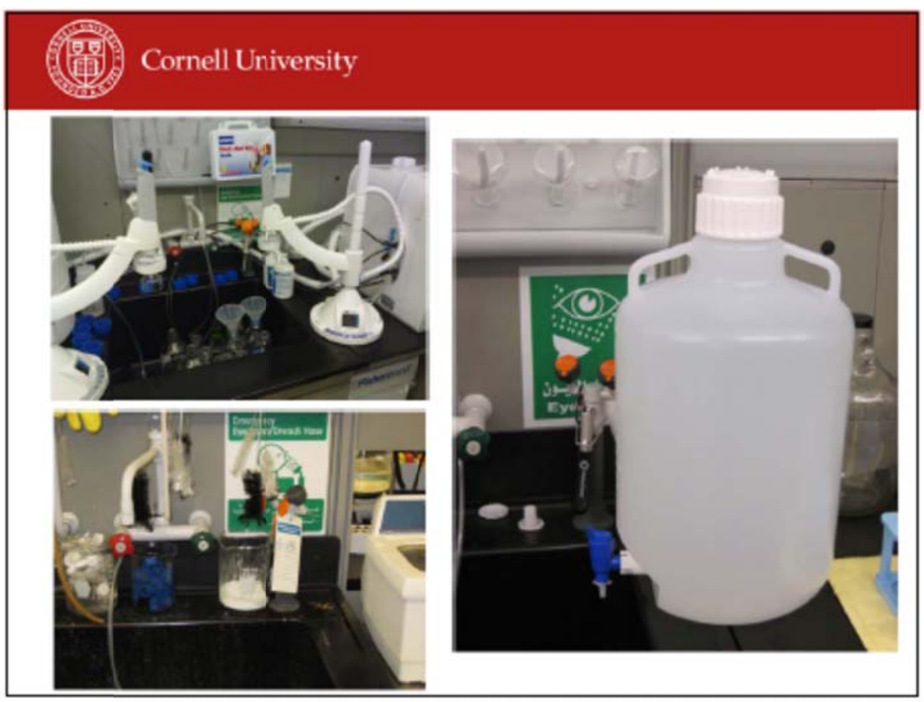
Good Practice.

Cornell Safety Audit Recommendation

KAUST Lessons Learned:

1. The existing handheld drench-hose emergency eyewash is installed at the back of the sink often allow users to unintentionally obstruct the eyewash units, particularly when the eyewash unit is located adjacent to additional bench space.
2. The drying peg-boards above the sinks often allow users to block the emergency eyewash units when items are hung above the sink.

Figure 10: Obstruction of emergency eyewash.



3. Storage

3.1 Additional chemical storage shall be provided for each LFO based on the requirement identified in the PORSHER form and within the limits permitted by building code. Non-vented chemical storage cabinets shall be used where applicable. Chemical storage shall follow KAUST Lab Safety Manual guidelines and the amount of storage provided shall not exceed code regulations in any given area.

KAUST Laboratory Safety Manual

Cornell Safety Audit Recommendation

NFPA 30

KAUST is currently facing a lack of chemical storage space within the labs. Current design practices generally provide one vented chemical storage cabinet per LFO or one vented chemical storage cabinet outside each exit of the service corridor. This is based on a design assumption that all chemicals will be delivered to the laboratories with a "just-in-time" supply chain management system.

Since the KAUST procurement process no longer requires a "just-in-time" delivery system, the design assumption must account for additional chemical storage within the laboratory where required.

Future LFOs will utilize the PORSHER form to determine the types of chemicals anticipated for use in a laboratory in order to provide adequate storage to properly segregate the chemicals utilized in a laboratory. The PORSHER will also help design teams estimate the total quantities anticipated for use and, with approval from the Health & Safety Officers, will recommend the total number chemical storage cabinets required.

KAUST Lessons Learned:

1. A number of chemical storage cabinets were observed with chemical bottles piled on top of each other or bottles lying on their sides. This increases the risk of bottles falling and breaking.
2. The lack of chemical storage space results in chemical containers not being stored in secondary containment (such as trays) or being properly segregated by hazard classes.
3. The lack of chemical storage cabinets also encourages users to place solvents in metal storage cabinets, often corroding the cabinet.

4. In order to provide adequate access of chemicals to laboratories, a proposal for a chemical stockroom is currently under development. Although this will alleviate the need to store more common, fast-moving chemicals within the laboratories, it will not eliminate the need to store and safely segregate chemicals within the lab.

Considerations / Exceptions:

1. For LFOs developed in a laboratory neighborhood incorporating multiple, independent PI laboratories, the total storage capacity of the neighborhood must be reviewed and coordinated amongst all present laboratories. The total chemical storage in any laboratory neighborhood shall not exceed building code regulations.
2. Not all chemical storage requires ventilation. Consider providing non-ventilated cabinets where applicable and in accordance with building codes.

Figure 11: Chemical bottles piled on top of each other vs. properly segregated chemicals.

Figure 12: Non-vented flammable storage cabinet

4. Ventilation

4.1 The standard exhaust capacity specifications for chemical cabinets shall be reevaluated by the design and engineering teams to meet the manufacturer recommendations. Non-vented chemical storage cabinets are also suitable means for chemical storage and should be considered in the laboratory design.

KAUST Lab Safety Specialist Recommendation

NFPA 45 (2004)

NFPA 30

Since the current exhaust specification of 24 liters / second is well above the manufacturer's recommendation for exhaust flow rates of 10 air changes per hour and is not required for fire and health protection purposes, it is KAUST's preference to reduce the specified flow rates for vented cabinets to the manufacturer's recommendation in order to maximize the available exhaust capacity of the laboratory neighborhood. In addition, non-vented storage cabinets are an acceptable option:

> NFPA 45 (2004), 9.2.3.5, Storage cabinets used in laboratories shall not be required to be vented for fire protection purposes.
>
> NFPA 30, A.9.2.3.5, See *Flammable and Combustible Liquids Code*, for performance-based requirements if storage cabinets are vented for any reason.
>
> NFPA 30, A.9.5.4, Venting of storage cabinets has not been demonstrated to be necessary for fire protection purposes. Additionally, venting a cabinet could compromise the ability of the cabinet to adequately protect its contents from involvement in a fire, because cabinets are not generally tested with any venting. Therefore, venting of storage cabinets is not recommended.
>
> However, it is recognized that some jurisdictions might require storage cabinets to be vented and that venting can also be desirable for other reasons, such as health and safety. In such cases, the venting system should be installed so as to not substantially affect the desired performance of the cabinet during a fire. Means of accomplishing this can include thermally actuated dampers on the vent openings or sufficiently insulating the vent piping system to prevent the internal temperature of the cabinet from rising above that specified. Any make-up air to the cabinet should also be arranged in a similar manner.

If vented, the cabinet should be vented from the bottom with make-up air supplied to the top. Also, mechanical exhaust ventilation is preferred and should comply with NFPA 91, *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Noncombustible Particulate Solids*. Manifolding the vents of multiple storage cabinets should be avoided.

KAUST Lessons Learned:

1. An increase in the total number of chemical storage cabinets vented at the current extraction rate greatly diminishes the total available exhaust within a laboratory neighborhood. In labs where the exhaust systems are currently operating close to maximum capacity, the addition of vented chemical storage cabinets is extremely difficult. Reducing the extraction rate to meet the manufacturer recommendations will allow more flexibility and reduce the demand on the exhaust system.

Figure 13: Exhaust connection for vented chemical storage cabinets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4.2 The utilization of vacuum pump (C3) cabinets shall be eliminated until another cabinet and exhaust design standard is developed. Where required, exhaust for vacuum pumps shall be connected directly to the building exhaust.

KAUST Lab Safety Specialist Recommendation

Performance Notification Request (PNR) issued for C3 cabinets

C3 cabinets are specified as an enclosure for vacuum pump cabinets to exhaust heat and potentially harmful vapors released by the vacuum pump, reduce noise, and to contain other pollutants such as oil mist from the laboratory. While it is preferred to locate the vacuum pump in an enclosure for the reasons noted above, the C3 cabinets are currently causing the vacuum pumps to overheat.

KAUST Lessons Learned:

1. Vents that allow proper air circulation in the pump cabinet are located on the back of the unit; however, the vents are often blocked when the cabinet is placed under the table, limiting proper air circulation and heat release.
2. Vacuum pumps are often oversized for the C3 cabinet and do not fit.
3. The exhaust connection provided for C3 cabinets is larger than the connection point provided on the cabinet itself. The exhaust flow rate for the C3 cabinets should be reviewed.

Figure 14: The vacuum pump is too large for the C3 cabinet. The vents at the back of the cabinet are blocked by the utility carrier.

Figure 15, 16: Exhaust connection for C3 cabinet.

5. Laser Safety

5.1 The KAUST Facility Design Guideline for Laboratory using Class IIIB and/or Class IV Lasers shall be adhered to where applicable and all "Laser in Use" signs shall be placed at eye level of the door entry.

Cornell Safety Audit Recommendation

KAUST Laser Safety Manual

For labs using Class IIIB and Class IV lasers, a "Controlled Laser Area" shall have appropriate entry control, interlocks, signage, and barriers to prevent unauthorized entry and to contain, at all times, all laser radiation in excess of relevant maximum permissible exposure (MPE) within the controlled area.

Walls, doors, and ceiling of suitable material and construction are the preferred materials to contain stray laser beams. Entrance to doors to Class IIIB and Class IV laser labs shall be interlocked with the lasers to prevent emission from the lasers if the doors are opened

KAUST Lessons Learned:

1. While the required installation of warning signs for high powered Lasers and equipment generating X-rays is adhered to in the laboratory design, the warning signs have been places at the very top of doors in such a manner that it would be easy for someone, particularly someone who had not been properly trained, or maintenance or service staff – to not look up and inadvertently enter a room at the inappropriate time when a Laser hazard or X-ray hazard was present. Such lighted warning signs should be placed at eye level next to doors and not at the top of doors where they can be easily missed.
2. Laser curtains are often installed instead of walls. As per the Laser Safety Manual, walls shall be used as preferred option unless curtains are approved by the Lab Safety Officer.
3. Door interlocks are not currently provided as requirement in the laboratory design.

Figure 17: "Laser In Use" light is currently provided above doors.

6. Service Corridor

6.1 The LFO design shall account for greater utilization of the Service Corridor, including use of the exterior wall for storage and laboratory equipment.

Lab Space & Equipment Allocation Committee Request

In order to maximize the available storage and equipment space within a laboratory, the service corridor is utilized for ancillary equipment such as refrigerators, incubators, and ice machines, gas cabinets, gas manifolds, and chemical and general storage. However, the service corridors are currently limited to placing equipment along the interior wall only. Increased demands for chemical storage as well as primary lab space require the maximum utilization of the service corridor, including storage and equipment placement along the exterior wall.

It is recommended that equipment and storage placed along the exterior wall be limited to 800mm in height; however, exceptions must be made in certain cases where required.

As the service corridor is utilized as the primary Hazardous Materials (HAZMAT) route as well as equipment delivery and access, maintaining a circulation clearance of 1.5 meters is recommended.

KAUST Lessons Learned:

1. Users are currently utilizing the exterior wall for storage. Due to lack of power outlets on the exterior wall, users are currently unable to place equipment on the exterior wall.
2. Additional storage should be accounted for in the initial design.
3. Where possible, blocking the windows on the exterior wall should be avoided, however, this is not a requirement. The primary function of the service corridor should be to provide the required support to the laboratory.

Figure 18: Service Corridor Utilization