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Seismic Protection of Laboratory Contents: The UC Berkeley Science Building Case Study

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The faculty and research staff in the case study building opened their labs and allowed us to intrude repeatedly to document the laboratory conditions. In particular, Barbara Duncan, the building manager, opened doors, answered questions, and helped the research team in countless ways. We could not have completed this research without Barbara's cooperation.

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EXECUTIVE SUMMARY

The research described in this report is a part of the Disaster Resistant University (DRU) initiative funded by the Federal Emergency Management Agency (FEMA) and the University of California, Berkeley. The first phase of the Disaster Resistant University initiative produced a study of potential earthquake losses at U.C. Berkeley together with an analysis of the economic impacts. In that report, Comerio (2000) found that despite the extraordinary building retrofit program, the U.C. Berkeley campus remained vulnerable to losses from nonstructural failures and losses in highly concentrated research facilities. This report is focused on strategies for improving seismic performance for laboratory furnishings and equipment. This report describes a case study of a biology laboratory building and its contents, used as a basis for developing damage mitigation strategies and cost estimates. The data developed here were also used by researchers at the Pacific Earthquake Engineering Research (PEER) Center for the development of loss estimates and for the development of models for performance-based engineering (U.C. Science Testbed Committee, 2002), as well as for a technical manual on retrofitting laboratory contents (Holmes and Comerio, 2003).

For the case study, we used a six-story, concrete-frame laboratory building built in 1988. The building has approximately 200,000 square feet. We chose to study this building because the structural system is expected to perform well and not suffer significant damage in a moderate earthquake. Further, the nonstructural systems have an unusually high compliance with seismic anchorage and bracing requirements for a building of this vintage, and low damage levels can be expected. These building conditions allowed us to focus on seismic issues within the laboratories. We analyzed space usage, surveyed the building contents, evaluated each item in terms of life safety hazards, and coded all items that scientists labeled as critical to research operations. We used the contents database to develop a retrofit strategy.

The building's contents are typical of a wet laboratory: parallel laboratory benches with shelves above, set against or between walls. Every space is densely packed with equipment. There are approximately 10,500 items in the building, of which 44 percent is furniture and 56 percent is equipment. Fifty percent of the furniture is shelving units. Computer equipment forms the largest single equipment group (22 percent), followed by heavy equipment such as refrigerators, freezers, and centrifuges (13 percent). The remainder of the equipment is small and varied—microscopes, incubators, stirrers, and other specialized items.

As part of the survey of the contents, we recorded the replacement value of each scheduled item based on purchase records. The total value of the equipment in the building is about $21 million. Ninety-eight percent of the equipment is valued between $1,500 and $10,000, while the remaining 2 percent range in value from $10,000 to $1 million. In each laboratory, scientists were asked to identify items that were essential to their research. At the top of the list were the refrigerators and freezers that house fragile biological samples, data stored on laboratory computers, and customized equipment. The research team assigned life safety designations to each item, based on weight and location (i.e., its risk as a falling hazard), and created a special category for earthquake-induced chemical hazards.

These attributes—value, importance, and life safety—were used to set damage mitigation priorities. For example, there are approximately 1,300 items (12 percent) coded as Important, Chemical Hazard, or Life Safety Priority D (where D represents the highest risk and A the lowest), or any combination of these codes. There are approximately 4,000 items (40 percent) coded as Valuable (with values over $20,000), Important, Chemical Hazard, Life Safety Priority C or D, or any combination of these codes. This subset of the contents represents the contents that are most critical to research, most difficult to replace, and the most hazardous to the occupants. If these items are carefully anchored, the building would be substantially safer, and research operations would be protected. Ideally, we would like to develop a cost/benefit calculation to make the case for retrofitting laboratory contents; however, until researchers have sufficient data to develop fragility curves on equipment, there is not enough information available to perform such an analysis. Nonetheless, preliminary results from shake table tests by PEER researchers (Hutchinson, 2003; Makris, 2003) suggest that unanchored equipment will slide at least 12inches to 18 inches and occasionally topple.

A targeted retrofit program, focused on a subset of high-priority items is strategically sound and cost effective. We estimate that the items designated as "important" to research could be anchored for about $3.00 per square foot of laboratory space, and all the items rated Important, Valuable (greater than $20,000), Chemical Hazard, or Life Safety Categories C or D, or any combination of these categories (40 percent of the contents), could be retrofitted for about $16.00 per square foot of laboratory space. By comparison, the total cost to anchor all the contents is $25.00 per square foot.

The laboratories in the case study building are typical of most wet laboratories on the University of California, Berkeley, campus, although the age, structural features, and nonstructural conditions of the buildings

will vary. The concentration of scientific and engineering research in approximately 17 of the 114 buildings on the central campus is similar to the concentration of books in four main library buildings. These assets are critical to the continued operation of a major research university after an earthquake. Targeted damage mitigation strategies—focused on critical contents—are cost effective, will improve overall building performance, and will allow most laboratory-based research to continue after an earthquake.

CHAPTER 1

The Potential for Nonstructural Damage: Building Contents Losses at the University of California, Berkeley

Background

The Federal Emergency Management Agency (FEMA) and the University of California, Berkeley funded the research and development component of the Disaster Resistant University (DRU) initiative in 1998. U.C. Berkeley served as the pilot for a national program intended to motivate and enable the nation's universities to assess their vulnerability to local hazards and reduce their losses in foreseeable disasters. Beyond the primary need to protect the lives of students, staff, and faculty, the Disaster Resistant University initiative was designed to help universities safeguard their research capacity and their teaching mission.

Researchers at U.C. Berkeley developed a methodology for hazard assessment and loss estimation, as well as for the evaluation of economic impacts. These are published in a report: *The Economic Benefits of a Disaster Resistant University* (Comerio, 2000). At the same time, U.C. administrators developed a *Strategic Plan for Loss Reduction and Risk Management* (Office of the Vice Provost, 2000). These two documents provided a template for five other universities to undertake similar loss assessment and planning. Based on the combined efforts and experiences at all six institutions, FEMA has developed a national guideline for hazard mitigation in research universities. That report is entitled *The Disaster Resistant Campus Guide* (FEMA, 2003).

The central finding of the Comerio study was that the University of California, Berkeley, remained extremely vulnerable to earthquake losses, despite the extraordinary commitment to improving the life safety of hazardous buildings. The vulnerability was attributed to three factors. First, buildings whose structural systems were expected to perform reasonably well in earthquakes would be subject to significant damage to nonstructural components, including both nonstructural systems and building contents.[1] Second, research laboratories were concentrated in less than 20 percent of the campus buildings, and more than half of these

[1] The nonstructural components of a building are the cladding, glazing, partition, finish materials, mechanical, electrical, and plumbing systems. Contents are items purchased and installed by the owner. When researchers estimate earthquake damage, however, the value of damage to contents and nonstructural systems are often conflated to one category labeled nonstructural (i.e., all damage that is not attributed to the structural system).

were likely to be closed after a major seismic event. Finally, one-third of the replacement value of the campus is in its contents—books, technical instruments and research equipment, art, artifacts, specimens—all highly susceptible to damage and essential to the teaching and research mission of the university. Based on these findings, the study recommended continued investment in life safety improvements to buildings and infrastructure, a damage mitigation program focused on loss reduction for building contents (particularly in libraries and research laboratories), and a strategic plan for business resumption.

In a subsequent study funded by the Pacific Earthquake Engineering Research (PEER) Center, Comerio and Stallmeyer (2001) looked at the potential for nonstructural losses in contents at U.C. Berkeley and concluded that the laboratories should be the focus of further investigations, not only because the equipment and the research data were valuable but also because some contents represent a hazard to the occupants and the general public. The PEER study detailed the types of equipment and contents found in university laboratories and developed prototypical anchoring designs and preliminary installation cost estimates for a variety of laboratory conditions found in chemistry, physics, biological science, and computer science departments.

FEMA and the University of California, Berkeley, extended the initial funding of the Disaster Resistant University (DRU) project on the Berkeley campus to focus on damage mitigation planning in a case study laboratory building. The focus of this report is a detailed investigation of the conditions in a modern biological laboratory building with proposals for mitigating hazards with respect to the building's contents. The contents—the furniture, fixtures, and non-building related equipment—are typically installed by the users after a building is completed. These items can be damaged when earthquake forces cause an item to slide or tip over. This report describes the vulnerability of certain building contents and provides engineering details to secure them. This report also discusses other nonstructural hazards apparent in the building but does not provide specific engineering solutions for these conditions. Rutherford and Chekene, Structural Engineers, served as consultants to the DRU study and to this report.

U.C. Campus Seismic Program

The University of California, Berkeley, is a worldwide leader among universities in research, education, and public service. The central campus houses over 30,000 students, and more than 13,000 faculty and staff in more than 100 academic departments and research units. The

central campus has 114 buildings on 177 acres, with about 5 million net square feet of classrooms, libraries, offices, research laboratories, and other specialized facilities. The annual campus operating budget is about $1 billion, and the sponsored research awards average about $400 million per year.

The U.C. Berkeley campus has done more than any other in the nation to address the threat of earthquakes. The campus has had a seismic corrections program in place since 1978. After a 1997 re-evaluation of building conditions, the campus created the SAFER Program and committed to spend about $20 million per year, for the next 20 years, to improve the structural conditions of campus facilities. To date, the campus has spent $250 million on seismic improvements. The Comerio study (2000) addressed the economic impact of potential losses under various earthquake scenarios. In addition to the cost of repairs, it considered the time needed for repairs to make the campus habitable and operational. Even in a moderate earthquake, the study estimated that 19 percent of laboratory space could require more than 20 months for repair. In a magnitude 7.0 earthquake on the Hayward fault, the estimates ranged from 30 percent to 50 percent of all spaces needing more than 20 months for repair. Although the downtime estimates will clearly be reduced by the aggressive seismic strengthening program on the campus (see Table 1), the potential loss of habitable buildings remains a serious issue for the university.

TABLE 1

Percentage of Space at U.C. Berkeley Needing More Than 20 Months for Repair

Conditions in 1999[1]

	Scenario[4]		
Use	O	R	VR
Classroom	5%	44%	78%
Laboratory	19%	52%	66%
Office	9%	50%	72%
Library	4%	28%	38%
Telecom	2%	46%	50%
Other	11%	36%	50%

Conditions in 2006[2]

	Scenario		
Use	O	R	VR
Classroom	0%	26%	61%
Laboratory	1%	26%	40%
Office	5%	38%	59%
Library	1%	23%	33%
Telecom	1%	45%	49%
Other	7%	31%	45%

Conditions in 2011[3]

	Scenario		
Use	O	R	VR
Classroom	0%	3%	38%
Laboratory	0%	13%	26%
Office	2%	15%	36%
Library	0%	6%	16%
Telecom	1%	11%	16%
Other	0%	14%	29%

Notes:

1) Buildings under construction in 1999 were rated as if they were finished.

2) Based on projections that 10 additional main campus buildings will have completed seismic repairs by 2006.

3) Based on projections that 15 additional main campus buildings will have completed seismic repairs between 2006 and 2011.

4) Earthquake Scenarios used in the loss estimation, defined as Occasional, Rare, and Very Rare.

Source: Comerio, 2000.

Identification of Nonstructural Hazards

The University of California, Berkeley, has three small programs aimed at mitigating nonstructural hazards in campus buildings. The first is a matching-funds program to encourage all units to reduce typical nonstructural hazards in offices and classrooms. This Quake-Bracing Assistance Program, or Q-Brace, has been in place for four years. The second of these programs focuses on the repair or replacement of light fixtures, ceiling systems, and audio-visual equipment in classrooms and libraries—high-occupancy spaces where the threat of a falling hazard is severe. The third is oriented toward the review of library shelving conditions. Although the efforts undertaken have been a remarkable first step in addressing life safety hazards, very little work has been done to evaluate the potential for damage in nonstructural components, such as cladding, partitions, ceiling systems, as well as building contents and mechanical, electrical, and plumbing systems. Further, generic anchoring details have never been designed for specific building conditions or for laboratory equipment, nor have the details ever been adequately tested.

Even though most contemporary building codes do contain provisions aimed at controlling damage to nonstructural (as well as structural) building systems, there are no similar requirements for other nonstructural components, such as a building's contents. Recent earthquakes have demonstrated that significant dollar losses and building closures can be attributed to damage to nonstructural systems and contents. Even if a building is structurally sound, broken pipes, overturned furniture and equipment, and broken ceilings and lights can make a building uninhabitable. After the 2001 Nisqually (Seattle region) earthquake—a magnitude 6.8 with only light-to-moderate ground shaking—a large portion of the estimated $2 billion loss was associated with damage to nonstructural components and the interruption of business operations (Chang and Falit-Baiamonte, 2002; Filiatrault et al., 2001; Mezaros, 2001). Practicing engineers and researchers recognize the importance of nonstructural systems and contents in building performance in earthquakes.

High-Impact Building Types—Focus on Laboratory Contents

In certain building types, such as museums, high-technology fabrication facilities, and research laboratories, the contents may be far more valuable than the building, and in some circumstances, may represent a potential hazard to the occupants and the general public. At the University of California, Berkeley, laboratories occupy 30 percent of the overall net usable space on campus. Fifty percent of the research on

the U.C. campus is conducted in 7 buildings, 75 percent in 17 buildings. Seventy-two percent of the approximately $400 million in research funded each year is concentrated in science and engineering. The value of the laboratory contents is estimated at $676 million, or 21 percent of the total insured assets (see Table 2).

TABLE 2

Berkeley Campus Insurable Asset Values for Year 2000

Item	Value	Percentage
Laboratory Contents	$676,199,501	21.0%
Library	$1,829,321,229	56.7%
Fine Art	$708,621,134	22.0%
Vehicles	$9,354,023	0.3%
TOTAL	$3,223,495,887	100 %

Note: The majority (two-thirds) of the library collections are housed in four main buildings. The art and artifacts are in three other buildings.

Source: UC Office of Risk Management, 2000.

Equally important is the inestimable value of the research itself. Refrigerators and freezers contain irreplaceable specimens. Computer hard drives store data for research in progress. Laboratories represent both a concentration of research (as measured by annual funding) and a concentration of valuable equipment and ideas. In a preliminary PEER-funded study of laboratories on the campus, Comerio and Stallmeyer (2001) estimated that the average laboratory contents were valued at $200 to $300 per square foot. By comparison, in a typical office space the value of the contents is usually $25 per square foot.

Lessons from the PEER Laboratories Study—Retrofit Methods and Costs

Comerio and Stallmeyer (2001) catalogued the range of specialized computers, electronic equipment, microscopes, and other mixing, sorting, and measuring equipment, along with storage systems from shelving to freezers, refrigerators, and tanks. These were grouped into five categories based on the similarity of anchorage details within each group:

- Tanks and cylinders
- Large and heavy equipment
- Storage elements

- Bench-top items
- Unique equipment and experimental setups

Prototypical anchorage details, using a range of standard products and engineered designs, were developed to demonstrate the types of solutions necessary and to provide sufficient information on details to develop unit costs. Five campus laboratories were chosen to demonstrate the application of the cost methodology in different settings. Two were in the biological sciences, and one each from chemistry, physics, and computer science. A cost per square foot was calculated for each laboratory (see Table 3). Despite the simplicity of the detailing as described in the PEER laboratory case studies, a number of building-specific issues must be evaluated before the standard details can be applied. The strength and conditions of the anchorage medium—the floors, walls, ceilings—must be evaluated. Similarly, some estimation of the type of shaking the building may experience needs to be part of the design process.

TABLE 3

Cost of Contents Anchoring in Five Case Study Laboratories

Laboratory	Direct Cost	Area in Sq. Ft.	Cost / Sq. Ft.
Lab 1: Biology	$18,675	1,567	$11.92
Lab 2: Biology	$41,655	2,604	$15.99
Lab 3: Computer Science	$28,929	1,845	$15.68
Lab 4: Physics	$11,920	1,137	$10.48
Lab 5: Chemistry	$2,965	310	$9.56

Source: Comerio and Stallmeyer, 2001.

Focus of This Report

The cost estimates developed in the Comerio and Stallmeyer report represent the cost to retrofit every item in the sample laboratories. The costs outlined in Table 3 are direct costs—the cost of the labor and materials only. An independent contractor hired to complete such work would add an additional 25 percent for the contractor's overhead and profit. Even if the work were to be carried out by university staff, some overhead costs would be required. Economies of scale could reduce the overall cost if the work were done over a large number of laboratories in one contract.

Still, $10 to $15 per square foot to provide seismic anchorage for contents is expensive. One explanation for the high cost is the density of equipment in U.C. laboratories, where space is always at a premium. In looking at individual laboratories from different disciplines, it was difficult to determine whether every item in a laboratory really needed anchorage. Some items may be inexpensive and easily replaceable, or they may not present a life safety hazard. If it were possible to establish a hierarchy of contents needing retrofit, then it would be possible to lower anchorage costs while improving the building's chance of remaining operable after an earthquake.

The purpose of this research is to develop a better understanding of the contents in laboratory buildings and a methodology for planning the retrofit of laboratory buildings. In addition, Rutherford and Chekene, the consulting engineers, were asked to provide specific design details and cost estimates for the Case Study Building at U.C. Berkeley. This report documents 1) a detailed investigation of the contents in one modern laboratory building; 2) a methodology for targeting specific subsets of contents for retrofit; and 3) a range of costs for the retrofit options. The Appendices provide the building-specific engineering reports.

Parallel research efforts by the Pacific Earthquake Engineering Research (PEER) Center used the case study building and its contents as a test of the PEER methodology for estimating and improving the seismic performance of existing buildings. Researchers modeled the structural performance of the building to estimate floor accelerations. Shake table tests of bench-top configurations and heavy equipment were conducted to estimate the potential for sliding and overturning. The data from these researchers was used to more accurately estimate potential losses and downtime for the building (U.C. Science Testbed Committee, 2002). Another PEER funded report provides a technical manual for seismic anchorage of furnishings and equipment in new and existing laboratory buildings (Holmes and Comerio, 2003).

In this report, Chapter 2 provides a detailed description of the case study building and the laboratory contents. This chapter also contains both a methodology for identifying critical factors affecting the inventory of contents and a process for using these factors to develop retrofit strategies. Chapter 3 discusses common approaches for anchoring laboratory contents based on the building characteristics and the laboratory environment, in addition to presenting the costs associated with various retrofit strategies. Chapter 4 concludes with a discussion of the potential cost savings and the benefits derived from the mitigation of hazards in laboratory contents.

The appendices contain three engineering reports: Appendix A provides a review of the seismic vulnerabilities of the building's mechanical systems. Appendix B is a review of the seismic anchorage conditions in place at the time of this research. A separate detailed set of engineering drawings for the seismic anchoring of the equipment and furniture in the building (as inventoried for this report) will be provided to U. C. Berkeley, but will not be available as part of this report.

CHAPTER 2
The U.C. Science Building Case Study

Building Conditions

Architectural Features. The Case Study Building studied for this research is a modern concrete building completed in 1988 to provide high-technology research laboratories for organismal biology. The building is 203,800 square feet overall, with 122,000 assignable (net usable) square feet of research laboratories, animal facilities, offices, and related support spaces. The building is six stories plus a basement, and is rectangular in plan with overall dimensions of approximately 306 feet in the longitudinal (north-south) direction and 105 feet in the transverse (east-west) direction. The basement is contained within the periphery of the building.

This building was built as part of a larger campus plan to upgrade research and teaching facilities in the biological sciences. More than 40 faculty members use its laboratory space. The building is designed with a central core of mechanical rooms, circulation, and shared storage and equipment rooms. A loop circulation plan connects the eight to ten laboratories on the east and west sides of the building. An internal corridor provides a secondary circulation system within the laboratories. Research offices are situated within the laboratories.

The laboratories are designed in a modular format so that a laboratory/office space may expand or contract by adding or removing a module along the corridor. Although the building was planned with all laboratories in a standard configuration, the laboratories undergo regular remodels to accommodate new research techniques and equipment. Two secure floors—the basement and the sixth floor—are dedicated to animal facilities. Eighty-two percent of the net usable area is used for laboratory space and animal facilities. The remainder of the space accommodates offices, administrative space, conference rooms, stockrooms, and other support facilities. Figures 1 through 15 provide a graphic description of the building in plan and section, including exterior and interior finishes, structural and mechanical systems.

The building's exterior is simple, with cast-in-place concrete panels, with a light sandblast finish. The windows have a painted extruded aluminum frame with solar grey glass. The rooftop mechanical penthouse is set back from the walls. Ceramic roof tiles are used as a mechanical screen, but the roof is made of a built-up bituminous roofing

system with layers of asphalt and fiberglass felt, covered with black gravel.

Inside, the building has steel-stud (3-5/8" x 25 gauge metal) and gypsum partition walls to divide laboratories. Typically ceilings are open in the laboratories, with exposed mechanical piping. Some offices contain acoustical drop-ceilings, and the corridors have a metal-grid hanging ceiling to cover mechanical equipment. Floors are either vinyl tile or exposed concrete. The floors are not impermeable to toxic spills.

Structural Features. The vertical-load carrying system consists of a reinforced concrete frame. The floor structure is a waffle slab on every level and is composed of a 4½-inch-thick concrete slab supported on 20-inch-deep joists in each direction. The waffle slab is supported by concrete girders, which in turn are supported by concrete columns. The typical bay spacing is 20'-0" in the longitudinal direction and 22'-10" in the transverse direction. The foundations consist of a 38-inch-deep continuous mat foundation.

The building was designed to meet the 1982 Uniform Building Code, and is classified as C2 Building Type 9—Concrete Shear Wall in the SAFER study. The structure was evaluated in 1997 as part of a campus effort to predict the seismic response and potential damage to campus buildings. In a moderate earthquake, defined as an earthquake with a 50 percent chance of exceedance in 50 years, the building was ranked Operational, at level 8 on the 10-level scale of performance as outlined by the Structural Engineers Association of California in Vision 2000 (Hamburger et al., 1995). In this scenario, the building is expected to have minor cracking in exterior pier and spandrel elements, as well as minor cracking in coupling beams in transverse walls. In a magnitude 7.0 earthquake on the Hayward fault, the building was ranked Operational, at level 7 on the 10-level scale. In this scenario, the building might have significant repairable cracking in coupling beams and exterior piers, spandrels, and end framing, as well as minor repairable cracking in the waffle slabs. In a very rare earthquake, a magnitude 7.25 on the Hayward fault, the building was ranked Life-Safe, at level 6. In this scenario, there could be possible fracture of coupling beams and major cracking in shear walls, waffle slabs, and end framing, but collapse is not expected. The building was rated "good" in the U.C. rating system and was not considered to be in need of any structural retrofits (UCB, 1997).

A nonlinear analysis of the building structure was done as part of the development of a performance-based analysis methodology. Details of this building analysis and other related research are available in Pacific Earthquake Engineering Research (PEER) Center research documents and

in-progress testbed reports on the PEER research web site (U.C. Science Testbed Committee, 2002).

Mechanical Equipment. Light fixtures are florescent, suspended, and modular. The mechanical systems are sophisticated to allow for specialized air changes and temperature controls in certain research settings and animal-holding areas. Separate systems for de-ionized water and other chemicals are designed into the mechanical services for laboratories. All laboratories have emergency eyewashes, showers, and fume hoods.

HVAC. The building is air conditioned, with separate air-handling systems and fans for lobbies, conference rooms, offices, laboratories, and animal-holding rooms. All are designed to meet CEC Title 24 requirements. Animal rooms have an independent collected exhaust system with pre-filters at each room inlet. Laboratories with hoods have a manifold exhaust system with vertical riser shafts, and negative pressure is maintained. Special-purpose hoods have independent exhausts, as do glass-washing and cage-cleaning rooms. Two water-cooled chillers provide for cooling. Steam is taken from the existing central plant, but new steam-to-hot-water heat exchangers are in the building.

Electrical System. Service to the building is provided at 12.47 KV. Three phase transformers to bring the power down to 480/277V are on the roof. Additional transformation down is accomplished on each floor. One 600W generator is on the ground floor outside to supply 277/480V emergency power to critical loads; however, there is concern that this system is not monitored and is overloaded.

A 12-inch-wide cable tray system runs on each side of the building, supported on a utility trapeze. Utility drops to each laboratory bench are made through conduit. The building has a multi-zone, combination detection and alarm, Class B, two-wire fire alarm system. Smoke detectors are in elevator lobbies, equipment rooms, and HVAC ducts. Manual pull stations, water-flow switches, and horns and bells are connected to a central control panel. The main building and laboratories are tied to the university central alarm system, while local alarm systems are used in basement animal rooms.

Seismic Performance of Systems. Although not the main target of this study, the traditional nonstructural systems of the building (such as the mechanical, electrical, and plumbing systems) also have an important influence on post-earthquake usability of the building. A visual survey of these systems was performed by the consulting engineers in February 2002 to determine if they were, in general, installed in accordance to seismic requirements of the building code. The purpose of

this evaluation was to determine if any severe seismic deficiencies existed that would override any consideration of performance of the laboratory contents.

The engineering survey (conducted by Rutherford and Chekene) covered the normal systems associated with initial construction of a laboratory building. They can be categorized as follows:

- Ducts and piping, including HVAC, plumbing, and chemical, both in functional spaces and in mechanical rooms.
- Rooftop mechanical equipment, including chillers.
- Floor-mounted mechanical equipment, including HVAC and other mechanical systems.
- Floor-mounted electrical equipment, including cabinets and transformers.
- Tanks, including single and multiple compressed gases and water tanks.
- Suspended equipment, including HVAC and electrical systems.

The engineer's evaluation revealed that the building systems feature an unusually high level of compliance with code requirements regarding seismic anchorage and bracing. In fact, the level of anchorage and bracing of the nonstructural systems is more complete than what is considered average for this vintage of building, and low damage levels can be expected, at least in moderate shaking. However, in general, the seismic bracing installed for the larger pipe systems is judged relatively ineffective, and could lead to more than expected damage to those systems, as well as a greater chance of water damage to contents. The building walk-through also indicated that the emergency generator housed in a separate small building near the southeast corner of the building was apparently installed after the building was complete and was not given adequate seismic protection. Until retrofitted, power from this generator should not be counted on after moderate-to-strong shaking. Specific concerns regarding the adequacy of various anchorage conditions are detailed in Appendix A.

Building Contents: Inventory of Scientific Equipment

The building contents are typical of a wet laboratory: laboratory benches with storage shelving above and very densely packed equipment. The laboratories were designed using three modular plans for the arrangement of laboratory benches, sinks, storage space, and office space (see Figure 16). Each of these provides a standard configuration of

parallel laboratory benches against or between walls. Those set against a wall have cabinets or shelves above the bench, attached to the wall. Heavy fixed equipment, such as a fume hood, is typically located against the wall. The benches within the open space are designed as a back-to-back set of laboratory benches with a sink or other shared feature at the end, and open shelves built on a Unistrut system above. Research offices are separated from the main laboratory space by partitions and typically are accessed from the internal corridor. This modular laboratory design seems to work well in the biological sciences where the research depends on a conventional arrangement of bench-top equipment, microscopes, and computers combined with refrigerators and freezers for storage of samples.

There are approximately 10,500 items of furniture (laboratory benches, wall shelves, desk units, etc.) and equipment (tanks, cylinders, microscopes, computers, and other bench-top equipment, as well as heavy equipment such as refrigerators, freezers, incubators, and fume hoods) Forty-four percent of the contents can be classified as furniture, and 56 percent is equipment.

Although there may be many different types of microscopes, roto-baths, and freezers, there are only about 15 different types of furniture and 95 different categories of equipment in the building. The top 5 most numerous furniture types and the top 15 most numerous equipment types are shown in Table 4. It is interesting to note that if all the standard types of computer equipment (CPUs, monitors, printers, fax machines, and copy machines) are added together, these represent some 1300 items (12 percent of the total and 22 percent of the equipment). Refrigerators and freezers together constitute 4.5 percent of the total and 8 percent of the equipment, followed by centrifuges and microscopes, each representing about 3 percent of the total contents and 5 percent of the equipment.

TABLE 4

Common Types of Furniture and Equipment in the Laboratories

Furniture Type	Number of Items
Shelving Unit	2,022
Workbench	674
Cabinet	614
Desk	553
File Cabinet	385
Other	352
Total Furniture	**4,600**

Equipment Types	Number of Items
Monitor	557
CPU	544
Refrigerator	349
Centrifuge	319
Microscope	279
Equipment Rack	273
Mixer	266
Printer	212
Water Bath	141
Power Supply	139
Incubator	131
Gas Cylinder	122
Freezer	119
Fume Hood	104
Stirrer	102
Other	2,243
Total Equipment	**5,900**

Each laboratory was documented in drawings and in a database during the spring and summer of 2001. The floor plans and equipment lists of two sample laboratories are described in Figures 17 to 28. The detailed information presented in this report represents a snapshot in time. Equipment may have been added or changed. Some laboratories may

have moved after the equipment was documented. However, the goal of the research—to understand the issues in a nonstructural retrofit of a laboratory building—is not dependent on an exact representation of each laboratory but rather on the aggregate understanding of the patterns of equipment use and the typical conditions in laboratory buildings.

Value. The database listing each item was assembled by drawing and photographing each laboratory in order to document the equipment's location within the laboratory. The type of equipment was noted as well as the manufacturer, model number, size, and estimated weight. Using the campus equipment purchase records, we coded the value of each item on a 1 to 7 scale as outlined in Table 5. This categorization allowed the data to be sorted by ranges of value, rather than exact purchase prices.

TABLE 5

Value Group Designations for Furniture and Equipment

Designation	Range of Value	Average Cost per Item
0	Room Empty	$0
1	Zero to $5,000	$3,000
2	$5,000 to $10,000	$7,500
3	$10,000 to $20,000	$15,000
4	$20,000 to $50,000	$35,000
5	$50,000 to $100,000	$75,000
6	$100,000 to $250,000	$175,000
7	$250,000 to $1,000,000	$400,000

The value of the scheduled equipment (costing over $1,500) totals $21 million (BETS, 2001). Other equipment (valued less than $1,500) could add another 10 percent to the total value. Eighty-nine percent of the items are valued between $1,500 and $5,000, nine percent are valued between $5,000 and $10,000 (see Figure 29). The majority of these are the bench-top microscopes, stirrers, mixers, and other small equipment. The remaining 2 percent of the equipment ranges in value from $10,000 to $1 million. There are only three confocal microscopes in the building—valued at $500,000 each—serving unique research needs. Since completing the inventory, however, three laser tables with visualization computers, valued at $1.2 million, have been purchased by researchers.

Life Safety. Two assessments were made to evaluate the degree to which each item represented a life safety hazard. The first evaluated direct life safety, that is, risk of injury from the impact of a moving or falling object. Life safety can be threatened by heavy objects falling or tipping directly onto occupants, or by sliding or tipping into a position to block egress from a work area. The second assessment was on indirect life safety issues, that is, from the release of hazardous materials, either directly by broken containment or by two or more released materials combining to create a hazardous substance or fire.

The first assessment of life safety hazards was done by Rutherford and Chekene, consulting engineers. Each item in the database was coded as a potential falling hazard. The categories described in Table 6 are aimed at prevention of serious injury. A 20-pound object falling from 5 feet or more from the floor clearly could cause a death, but it is more likely to cause a serious injury. The breakpoint of 20 pounds is somewhat arbitrary but based on the State of California's code governing hospital construction.

The matrix in Table 6 demonstrates how the life safety priority and the risk will increase from the upper left to the lower right. The locations that qualified as low, medium, or high risk were defined for consistent application. For example, a low-risk item might be floor-mounted with a low aspect ratio, while a high-risk item might be directly overhead.

TABLE 6

Life Safety Priority Levels Assigned to Furniture and Equipment

Weight[1]	Risk of Location		
	Low	Medium	High
< 20 pounds	A[2]	B	C
20-400 pounds	B	C	C
> 400 pounds	C	C	D

Notes:

1. The weight cutoffs are set by judgment. Those shown here are weights used for similar priority settings in building codes.
2. Importance levels:

   A: No specific anchorage requirement; low priority.

   B: Anchorage using a standard, commercially available product; moderate priority.

   C: Anchorage designed by professionals; high priority.

   D: Anchorage designed by professionals; highest priority.

For the assessment of indirect life safety hazards, a specialist from the campus office of Environment, Health and Safety (EH&S) visited each laboratory and noted potential associated chemical and biological hazards. This review was focused on conditions that could be hazardous in the event of an earthquake, separate from the regular EH&S inspections conducted to enforce basic safety standards. In the review undertaken for this study, associated chemical hazards were noted when hazardous materials could cause contamination, fire, release of poisonous gases, or other life-threatening conditions. Table 7 provides a list of the conditions cited. Overall, there were 333 conditions cited. These were coded as to whether the "fix" was administrative (e.g., moving the substance to a safer location) or whether some retrofit was required.

TABLE 7

Chemical Hazard Conditions Noted in the Laboratories

Code	Short Description	Explanation
2C	Secondary containment required	Liquids greater than 1 gallon in size must have a chemically compatible secondary container that could prevent a potential spill from spreading to other chemicals or to the environment.
A/B	Acids stored with bases	Acids and bases could mix with a violent reaction and/or a release of poisonous gases.
CI	No chemical inventory	Federal, state, and local laws require that all hazardous materials (including all compressed gases) must be registered in a chemical inventory. The EH&S Chemical Inventory database is the U.C. Berkeley repository of this information which is essential for appropriate emergency response actions.
CP	Chemical process spill potential	Hazardous chemicals used or stored in any machine or device that could potentially spill during an earthquake due to the device rupturing or falling. Secure the chemicals or device to prevent a spill.
FL	Flammable liquids may spill/ignite	Flammable liquids should be secured and/or secondarily contained to avoid the potential for them falling or spilling near an ignition source (including electrical equipment).
F/O	Flammables stored with oxidizers	Oxidizers will ignite flammables (sometimes explosively) if they are mixed.
GC	Gas cylinder not secured	Gas cylinders must be secured with double chains or non-combustible straps to prevent them from falling and rupturing. If a compressed gas cylinder valve breaks off, the cylinder could "torpedo" with a high force.
HiC	Corrosives above eye-level	Corrosives could damage eyes and cause blindness if spilled. Store corrosives below eye-level.
HiR	Reactives stored high above ground	Reactive chemicals can ignite or explode if shocked by a fall (or if heated while confined). Store reactives in a secure, low-to-ground location to minimize the potential fall force.
HT	Highly toxic chemical spill potential	Highly toxic chemicals may be fatally poisonous if spilled. Minimize the spill potential for highly toxic chemicals by storing them in a secure, low-to-ground location.
OC	Open container	All hazardous chemical containers (including waste collection bottles) must be closed when not actively in use.
Seg	Chemicals not segregated by hazard	Store chemicals segregated by hazard characteristics so that incompatible chemicals are separated and will not mix. Do not store incompatible chemicals alphabetically.
WR	Water reactive near water source	Water reactive chemicals can react violently or explosively with water or other aqueous chemical solutions. Store these chemicals away from sources of water, including water pipes and fire sprinklers.

In the database, each item was coded as Life Safety Priority A, B, C, or D, or as a Chemical Hazard Requiring Administrative Attention (Ch-A), or as a Chemical Hazard Requiring an Actual Retrofit (Ch-R). The engineers also noted the items that had a shelf lip, because many life safety issues, chemical hazards, and potential for contents damage are related to items on shelves. Shelf lips in laboratories are typically 1.25 inches high. The typical shelf-lip height derives from common practice (UCB, 2000a; LBNL, 2000; National Research Council, 1995). The life safety requirements normally enforced by the fire marshal for hazardous materials storage require a shelf lip, but no height is specified (California Building Standards Commission, 2001). In the Case Study Building, there are four types of items typically found on the shelves: glassware, chemicals, equipment, and books. Although we did not inventory these items, observations by the research team and building occupants suggest that the shelf contents are equally divided among these four groups.

Figure 30 provides the number and percentage of items in each life safety category, as well as the number and percentage of items in each category that are life safety hazards due to inadequate shelf lips. More than one-third (36 percent) of the items are categorized as life safety category C and D, or Ch, chemical hazard. Overall, almost one-quarter, (23%) of the total items have shelf lips. While only eight percent are in categories C, D, and Ch—posing life safety hazards—inadequate shelf lips create messy and difficult pose-earthquake clean-up problems.

Importance. As the surveys of the laboratories were being conducted, the study team spoke with researchers in the laboratories to get an understanding of the kind of work they did. These conversations led to a more formal survey of research faculty and/or their lab managers to ascertain which of the items in their laboratories were critical to their research. The survey provided examples of "importance measures" (see Table 8) and asked researchers to list the equipment, data, animals, and storage systems that were critical to their ability to work. Responses were received from more than 50 percent of the laboratories. For those that did not respond after repeated requests, we used the pre-existing list of items to be checked in an emergency situation (on file with the building manager) as a guide to what was considered important in that laboratory. Animals that had been genetically designed and bred, or those whose conditions would be difficult to replicate, were also designated as important. Further, all shared equipment in the building core was designated as important because it serves numerous laboratories. Overall, about 500 items were rated as critical to continuing research. Of these, about 30 percent are genetically designed animals, 20 percent are

refrigerators and freezers containing fragile cell lines, 15 percent are microscopes, and 15 percent are CPUs where current data is stored.

TABLE 8

Importance Measures for Equipment and Materials in the Laboratories

Equipment replacement cost
Equipment replacement time (weeks, months)
Data or material replacement cost
Data or material replacement time (weeks, months)
Irreplaceability
Interruption sensitivity (can tolerate none, or very little)
Loss of research benefits (income, salutary applications)
Related hazards that may occasion long clean-up periods (chemicals, biohazard)

Identification of Critical Factors Affecting Inventory: Life Safety, Chemical Hazard, Importance, and Value

Together, the detailed drawings documenting the equipment in each laboratory and the database provide a mechanism for understanding the number and types of equipment as well as the issues involved in planning for the seismic retrofit of laboratory contents. Table 9 provides a complete list of all the categories of data about each item. Several factors appear to be critical to the ongoing function of a research laboratory. These are Importance, Value, Life Safety Hazards, and Chemical Hazards.

Any item designated important by the researcher is essential to continued research—whether it is an animal, a cell line that took years to develop, or customized equipment. Similarly, high-value equipment is essential because it may require a long lead-time for purchase or may require specialized equipment funding not always available to researchers. Life safety designations C or D imply real hazards to the occupants of the laboratories. Likewise, chemical hazards put not only the occupants at risk but also the larger community. Equally important, a chemical spill could add months or years to a building being out of service after an earthquake (even if the building has no damage) as a result of the time needed for clean-up.

TABLE 9

Data Categories for the Furniture and Equipment Inventory

Laboratory Name
Room Number
Sub-Number
Equipment Key (to Drawings)
Equipment Name
Equipment Manufacturer*
Equipment Model Number*
Equipment Information*
Weight (estimate if greater than 50 pounds)
Life Safety Hazard Code
Chemical Hazard (Yes/No)**
Estimated Value (by Category)
Importance (Yes/No)
Retrofit Attempt (Yes/No)
Quantity

* Included when available.

** If Chemical Hazard is noted, additional data includes: Finding Number, Location, Lab Name, Date, Finding Code, and a Detailed Description of the Conditions.

Only 1,287 items (about 10 percent) are tagged as Important, Chemical Hazard, or Life Safety Priority D, or some combination of these codes. With Life Safety Category C, the total reaches 3,993 items. The High Value category was found to be a subset of those designated Important. There are only 65 items in the building valued at more than $20,000. Thus, the combination of Important, Chemical Hazard, Life Safety Priority C and D, and Value category 4 through 7, puts the number of items that could be considered critical to operations at 40 percent of the total contents in the building (see Figure 32). Thus, 40 percent of the contents are tools and specimens that are critical to research, valuable and hard to replace, or a threat to life safety, or any combination of these categories. If this subset of items were to be seismically anchored, the overall benefit to limiting downtime would be significant. These should become a first priority in any plan to retrofit contents. Although it may be ideal to consider anchoring every item in a laboratory, it may not be practical or cost effective.

The research team was initially surprised by the fact that the great majority of the equipment in the building had a replacement cost of less than $10,000. However, most of the bench-top equipment in biological research is small, and lab staff and students need many more ordinary microscopes and mixers than they need high-tech optics.

Although we have powerful examples of devastating losses to laboratory contents in past earthquakes, such as the loss of the Chemistry Building at Cal State Northridge in 1994 (caused by chemical fires), there is no statistical data on contents losses from past earthquakes. Ideally, we would like to develop a cost/benefit calculation to make the case for contents retrofitting, but there is no fragility information available to do such an analysis. Preliminary results from shake table tests of bench-top equipment suggest that the earthquake motions are amplified one to two times at the bench and that unanchored objects will slide into other equipment or off the bench (Hutchinson, 2003). The tests on heavy equipment suggest that tall refrigerators and freezers will slide between 12 inches and 18 inches and may overturn if one of the legs buckles (Makris, 2003).

Implications of Using Critical Factors to Target Retrofits

In evaluating the kind of equipment and furnishings that populate the laboratories of the U.C. Science Case Study Building, the three categories of critical factors—important, valuable, and a life safety concern (including falling and chemical hazards)—are the obvious first priority for a retrofit program. This applies not only to this case study building but also to any other science laboratory. It would be possible for any researcher to identify the critical items in his or her laboratory in terms of their importance to the research, their value, or the length of time needed to replace a unique item. The list of critical items could be combined with an assessment of potential life safety hazards to create a first-priority retrofit list. Other items could be added as the laboratory users deemed necessary.

The obvious response to the threat of damage from earthquakes is to provide restraint for all contents in the laboratory environment. There are two primary reasons why this may not always be necessary or appropriate: 1) cost and, 2) the potential effects of seismic restraint on the function of the element or the laboratory as a whole. Restraining a portable bench-top instrument, even with a quick-release system to facilitate changes in location, may reduce efficiency and may not be used by staff. Similarly, providing a docking station for wheeled equipment may take up space and inhibit movement in the room.

Given cost and functionality concerns, it is prudent to prioritize contents with respect to their potential to cause hazards or losses. We recommend here that the Life Safety category be considered first, then Importance, and finally Value, although any order could be used to evaluate the contents of a laboratory.

Prior Anchorage

In the Case Study Building, the research team observed a number of existing nonstructural seismic restraints on furnishings and equipment. Most of these were funded by the Quake-Bracing Assistance Program (Q-Brace), which allowed individual units to reinforce bookshelves, file cabinets, and other heavy equipment that could pose a life safety risk during an earthquake. The number of items with existing restraints was documented and evaluated by Rutherford and Chekene. Most of the existing nonstructural seismic restraints fell into the following three categories:

1. Refrigerators, incubators, racks, and other large and heavy equipment had been attached to walls, strongbacks, or each other with chains. Manual latches were also added to some refrigerators or cabinets to prevent doors from opening.
2. Lips, elastic cords, or metal plates had been added to some cabinets or open shelves in order to prevent chemicals, lab samples, or books from falling. Some floor-mounted bookcases and cabinets had been attached directly to shear walls or partitions with screws, nails, or bolts.
3. Commercial fabric tethers had been attached with adhesive to some computers, microscopes, microwave ovens, and other small items to secure them to desks or shelves. See Table 10.

TABLE 10

Equipment in the Laboratories with Prior Retrofits

Name	Quantity	Retrofit
Environmental Chamber	2	2
Low Temp. Incubator	13	6
Freezer	119	48
DNA Sequencer	6	2
Liquid Tank	9	3
Gas Cylinder	122	30
Biological Safety Cabinet	56	12
Refrigerator	349	70
Incubator	131	21
Bookcase	181	28
Gravity Convection Incubator	13	2
Ice Maker	8	1
Cryogenic Container	36	4
Electronic Rack	60	3
Shelving Unit	234	10
Cabinet	614	23
CPU	486	14
Monitor	499	10
Other		27
TOTAL		316

The number of prior retrofits in the building raises some concerns: First, the effectiveness of the existing attachments and second, the cost of removing and replacing them, if necessary. Where prior anchorages exist, the engineers questioned the effectiveness of the restraint cables attached to much heavy equipment. They were concerned both with the adequacy of the connection and with the effectiveness of the partitions to serve as restraints. They likewise questioned whether the typical 1.25 inch shelf lips were adequate to restrain objects with high centers of gravity. The fabric tethers were not always installed correctly, and the adhesives used may not perform well over time. A report on the evaluating equipment with prior strengthening is in Appendix B.

It would be very difficult to estimate the adequacy of the existing anchors without detailed testing of the specific conditions. In the PEER shake table tests of heavy equipment (Makris, 2003) refrigerators and freezers were attached with chains to the partition wall in a subset of the tests. Preliminary results indicate that the restraints were able to reduce displacements, but the anchors pulled loose from the wall. Based on the tests and engineering calculations, it is our judgment that the existing anchors are not well detailed and should eventually be replaced with the kinds of details suggested in this report.

Summary

The analysis of the contents in the Case Study Building raises a number of issues that were not evident in the review of individual laboratories. First, even though laboratory space occupies more than 80 percent of the net usable area, the laboratories still account for only about half the overall gross square footage of the building. Thus, the valuable contents are concentrated in about 50 percent of the building area. Second, the laboratory contents are almost equally divided between furnishings and equipment. Shelving units, computers, and heavy equipment, such as refrigerators, freezers, and centrifuges, constitute the majority of the items in the building. Third, the items of critical importance to researchers include the refrigerators and freezers containing biological samples, the cages and racks housing animals, and the computers where current research data is stored.

When considering the potential threat of damage from earthquakes, the first concern is the life safety of the building occupants. The second concern is the protection of data and ongoing experiments. A third concern is the protection of valuable or hard-to-get equipment. Taken together, these concerns suggest that is possible to prioritize any building's contents with respect to their potential to cause hazards or losses. In the Case Study Building, heavy equipment such as refrigerators and freezers are a top priority for seismic anchoring because they are a life safety hazard, they contain critical contents, and there are many located throughout the building. Equipment racks, animal cage racks, and other heavy equipment are similar in hazard level, importance, and number. Equally significant is the risk posed by inadequate shelf lips. Shelving units are the single largest category of all the building contents. Those that contain chemicals and glassware can represent serious hazards, and the anchorage of shelves and their contents are key safety concerns.

Based on the observations of the number and type of items in the Case Study Building, it seems appropriate to develop an evaluation system

that will result in a priority rating system for all contents based on Life Safety (both falling and chemical hazards) first, Importance, second, and Dollar Value, third. Although researchers will need to make careful judgments when assessing the contents of their laboratories and categorizing their equipment into one or more priority levels, the systematic approach developed here will assist the process. In the Case Study Building, we found that only about 40 percent of the contents required anchorage if these criteria were applied.

In the next Chapter, we will discuss the common approaches to the anchoring of contents and the installation costs as estimated for the Case Study Building.

CHAPTER 3

Issues and Costs in the Anchoring of Laboratory Contents

Most seismic protection of contents consists of restraint against sliding or tipping during the building motion induced by an earthquake. This restraint is obtained by attaching the item to a stable building component that itself is strong enough to resist the shaking and provide anchorage. This section briefly describes installation issues that affect building components that can be used for anchorage, including floors, ceilings and overhead structure, walls, and built-in furniture. These are general concerns about building conditions and their relation to the seismic anchorage of contents. All installation details need to be specific to individual building conditions. Detailed technical guidelines are available in a companion publication, *Implementation Manual for the Seismic Protection of Laboratory Contents* (Holmes and Comerio, 2003).

The building code (Uniform Building Code, 1997) contains provisions for anchoring nonstructural building systems to the structure but no provisions for anchoring building contents. Anchorage is required to sustain lateral forces measured as a percentage of element weight dependent on location relative to active faults, site soils conditions, and location in the building. It is possible to apply generic rules based on the building code, or building specific rules based on guidelines in the National Earthquake Hazards Reduction Program (NEHRP) Provisions, a national source document for future codes (Building Seismic Safety Council, 1998), to the Case Study building's contents to determine the appropriate design forces for anchoring equipment. Below is a discussion of various building materials and their capacities as anchorage mediums for contents, followed by a discussion of specific anchorage issues for various types of equipment. Finally, we present cost analyses and prioritization strategies.

Building Conditions

There are five common materials requiring different types of anchors: concrete, metal, wood, plastic, and gypsum board. Anchorage to concrete slabs is achieved by drilling a hole and inserting one of a variety of bolts made for this purpose. Many of these anchors are sensitive to the installation procedure in order to achieve the necessary strength. Items are connected to sheet metal or steel with bolts, sheet metal screws, or welding. Because welding requires a high level of expertise and

cumbersome equipment, it is not normally used for seismic anchorage of contents. Bolts require pre-placed holes of the correct size in the items to be connected. Wood screws are normally used to connect seismic anchorage to wood because of their high tensile load capacity and their removability. Larger wood screws may also need a pre-drilled hole to facilitate installation and to prevent splitting.

Nonstructural walls in buildings, called partitions, are most often made up of steel or wood vertical studs spaced at one to two feet apart and covered with ½ inch to 1 inch of gypsum wallboard or plaster. There are many fasteners manufactured to attach light loads to these surfaces such as plastic plugs that expand when a screw is inserted or "mollybolts" and "butterfly" anchors that open up to create a threaded nut on the inside face of the wall. These anchors are intended for pictures, light shelving, or other decorative items, are dependent on the integrity of the gypsum board or plaster for their strength, and, in general, should not be used for seismic anchorage. However, plaster surfaces, depending on the thickness of plaster and the style of lath, can be quite strong and can be suitable for seismic anchorage for smaller loads. In instances where such uses are unavoidable and backing plates are not available, a simple testing program can establish reliable tension loads for various styles of anchors.

A wide variety of adhesives are available for wood, metal, and plastics, and even concrete, including glue, epoxy, and double-backed tape. When installers use these products as attachments for seismic restraint, a number of conditions must be reviewed. Will the adhesive be destructive to the equipment or surfaces on which it is used? What will be the environmental effects over time—for example, will it be damaged by sunlight, chemical, or other conditions? As with most anchors, adhesives have installation requirements and strength ratings. Anchorage details must take all of these variables into account.

Anchorage Locations in the Case Study Building

There are typically no ceilings in the laboratory area, and the concrete structure of the floor above is exposed. The laboratory utilities run exposed overhead, supported on trapezes. The trapeze structures do not necessarily have any excess loading capacity and should not be used to support or brace laboratory contents. The floors are generally protected against chemical spilling by vinyl tiles or coating. Walls are either concrete, or steel stud and gypsum board. The typical built-in laboratory benches and cabinets are wood backed to vertical Unistrut posts running from the floor to structure above. These posts are designed to support the laboratory benches, cabinets, and their contents, and should not be used to

hang additional equipment or to provide seismic restraint for floor mounted equipment, except small residential refrigerators, or shelving.

Anchorage to Floors. Floors throughout the building are concrete waffle slabs, except in the basement, which has a 38-inch-thick solid concrete slab resting on the ground below. Care should be taken to not drill through the slabs. Many drilling systems used for the installation of mechanical and chemical anchors will easily cut through reinforcing steel embedded in concrete. Main reinforcing steel is located directly over rib joists, and these bars should not be cut. Smaller bars are also located in the slab areas, and they should also be avoided if possible. Magnetic bar detectors can be used to find bars located close to the surface. Current codes for laboratory floors require resistance to moisture or chemical penetration, requirements that could easily be compromised by drilled-in seismic anchors. A completed installation of a mechanical anchor will certainly break a surface seal and could lead to a penetrable floor, as well as corrosion of the anchor inside the hole. Chemical anchors are less likely to cause these problems, but the acceptability of any anchorage into laboratory floors should be checked with the appropriate building staff.

In general, it is not recommended to restrain owner-furnished contents by bolting them to the floor. Exceptions include those pieces of equipment that are designed with plates and bolt holes for floor mounting, such as tanks with legs and certain cylinder restraint products. Most floor-supported equipment is mounted on wheels, leveling legs, or a framework not designed to anchor the weight of the equipment for lateral loads. Instead, it is better to provide restraint from existing partitions or steel strongbacks. (A strongback is a steel tube, Unistrut, or steel channel running from the floor below to the structural floor above to provide lateral support for the equipment.)

Anchorage to Overhead Structures. Anchors may be placed in the concrete surfaces of the underside of the waffle slabs. Anchors should not be placed on the bottom of ribs, as main reinforcing runs below the surface. Anchors may be placed into the sides of joists (above the bottom reinforcing) or into the bottom surface of the slab. Chemical anchors should not be used in configurations that will put them in constant tension (e.g., to hang an item from the slab soffit) because epoxy under constant loading will creep.

In general, anchors should be avoided in suspended ceilings, such as those made of gypsum board supported by light-gauge metal, or the metal ceiling panels used in the corridors to cover mechanical and electrical piping above. In general, it's not recommended to attach anything to the mechanical, electrical, or piping utilities in the building.

However, pipe trapezes may be used to support very light loads of less than 20 pounds.

Anchorage to Concrete Walls or Columns. Concrete columns and walls can present problems similar to those in floors. The main concern with the installation of drilled-in anchors on vertical concrete surfaces is the cutting of reinforcing bars. Vertical bars in columns or at the edges of openings should never be cut. The reinforcing steel in the walls is similar to slab steel: it should be avoided, but could be cut if other options are not available.

Anchorage to Non-Concrete Walls. The partition walls in the building are typically constructed with metal studs. A metal stud wall partition consists of metal tracks at the top and bottom of the wall, metal studs, and blocking or backing plates. The top and bottom tracks are continuous horizontal channels bolted to the concrete slab above and the concrete floor below at specific intervals. The studs run vertically between the top and bottom tracks at a nominal spacing and are positively attached to the bottom track with metal sheet screws. The studs may be similarly attached to the top track, providing a larger lateral capacity, or they may be unattached to allow for thermal expansion.

Any connections to metal stud walls should be made directly to the stud or through a backing. A backing can be a plate, a channel, or a Unistrut spanning across several studs and attached to them by weld, bolts, or screws. Steel backing plates are often installed beneath the gypsum board to facilitate screw attachment to the wall, but most designs will not spread the load to multiple studs. For example, a single refrigerator might require a 400-pound attachment on each side. If multiple refrigerators are next to each other, a single stud may be loaded to 800 pounds. In these cases, elements must be used to spread the load to multiple studs.

In the Case Study Building, backing plates were already provided inside some walls at specified heights where wall cabinets were attached. New backing may be installed inside or outside the wall where additional support is required. Commonly, metal stud walls are covered and protected by gypsum board. Therefore, it is more practical to install a Unistrut over the gypsum board and bolt it through the gypsum board directly to the metal studs.

Anchorage to Built-In (Anchored) Laboratory Furniture. A common component of a typical laboratory is the central bench. It consists of two rows of back-to-back benches, often with cabinets above them, located at the center of the laboratory and supported by a curtain of central steel posts or strongbacks at a specific spacing. These benches and

their supporting strongbacks can be used to restrain light- and medium-weight equipment on the bench-tops or nearby.

In the Case Study Building's central workbenches, Unistrut P1001's at 48 inches on center are typically used. Benches are bolted to both of the Unistruts and to the concrete floor below. Cabinets are typically supported by a pair of Unistruts running horizontally along the length of the bench and bolted to the vertical posts. Another horizontal Unistrut may be installed about 6 inches higher than the bench and bolted to the central posts. This Unistrut may be used to support several light items attached to it with removable links.

Where laboratory benches, cabinets, or bookshelves are located next to a wall, they are typically anchored to the concrete floor below, the wall behind, or both. After the verification of the capacity and existence of their anchorage, these items may also be used to support nearby light- and medium-weight equipment. In addition, freestanding tables, cabinets, files, or shelves may be possible candidates for restraining other light objects. However, they should be anchored to the concrete floor before any such restraint can be considered effective.

Seismic Anchorage of Laboratory Equipment

Although there are many ways to categorize laboratory equipment (as discussed in Chapter 2), it is useful to group the building contents according to the similarity of their anchorage conditions or details. For this purpose, laboratory contents can be classified as follows,

- Tanks and Cylinders
- Large and Heavy Equipment
- Storage Elements
- Bench-Top Items
- Unique Equipment and Experimental Setups.

Tanks and Cylinders. Tanks and gas cylinders are widely prevalent and can be found in many types and sizes. They may contain liquids, either at atmospheric pressure or compressed, and may be kept at room or other temperatures. They may contain compressed gases, such as oxygen, nitrogen, hydrogen, or carbon dioxide. The liquids and gases may be flammable, volatile, or relatively inert. Many tanks and cylinders have semi-permanent locations and are only moved from these locations when they require refilling. Others however, like liquid nitrogen dewars, are mobile and attached to wheeled dollies. In addition to these tanks,

experimental setups that are filled with large quantities of liquefied gases are included in this category.

Large and Heavy Equipment. This category comprises floor-mounted items, typically weighing over 400 pounds, but may also include items of large bulk that weigh somewhat less than 400 pounds. These items do not normally require portability within the laboratory. Refrigerators and freezers are the most common pieces of large equipment, but specialized equipment such as chromatographs, glass washers, and centrifuges also fall into this category.

Storage Elements. All types of shelves, cabinets, cupboards, and equipment-racking systems are in this category, in addition to the contents stored in or on them. Thus, items in this category can be assessed in two ways. First, if the shelf, cabinet, or rack does not perform well in an earthquake, its contents will be at risk. Second, the contents stored on or in the item may need additional restraint. For example, a shelf may perform satisfactorily, but the glassware may fall from the shelf in an earthquake. Thus, storage restraints such as shelf lips—their presence and efficacy—need to be understood.

Bench-Top Items. Bench-top items account for a diverse array of small- and medium-sized equipment. A small piece of equipment typically has a footprint less than 2 feet square, is less than 2 feet in height, and weighs less than 25 pounds. Balances, small centrifuges, small microscopes, numerous computer monitors, and CPUs are in this size range. Other items, such as DNA sequencers, centrifuges, and small incubators, have larger footprints, of 30inches to 42 inches, and weigh 25 pounds to 100 pounds. Some bench-top items have higher centers of gravity and small footprints, including items like larger microscope setups and mixer/bath machines.

Unique Equipment and Experimental Setups. Although the four categories above are able to encompass most items in typical laboratories, there are experimental setups that defy categorization. This final category separates out items that need special attention owing to their unique vulnerability or high cost, or both. A custom-built apparatus for a particular experiment might be difficult to restrain or costly to rebuild. Electron microscopes or laser tables present unique challenges to mitigation because of their geometry and function, in addition to being very expensive to replace.

Typical and Recommended Anchorage Details

In a previous study, Comerio and Stallmeyer (2001) developed a series of details based on the typical conditions represented by the five

categories of contents described above. These solutions were categorized into three types:

- **SD**: Standard Detail—elements available from one or more proprietary suppliers.
- **ESD**: Engineered Standard Detail—generic detail sketched for a project.
- **Custom**: Custom anchorage developed for each unique case.

For this report, specific engineering details for basic restraint were developed for items coded important, valuable, and life safety categories C, D, and Ch in the case study building. The engineers have also provided engineered standard details for items in life safety categories A and B. The details developed are for the restraint of all objects in the contents inventory of the case study building as described in this report and in the survey of laboratories conducted for this research. The details are intended to prevent excessive movement of various elements during strong earthquake motion. The restraint is expected to protect occupants from serious injury and significantly reduce the incidence of functional damage to the component. The continued functionality of any restrained piece of equipment following an earthquake depends on the susceptibility of the item to damage from shocks transmitted through the restraint. Functionality may also depend on continued utility services such as water, electricity, or gasses, that are not addressed by the details.

Additional protection of the contents of shelving, racks, refrigerators, freezers, incubators, etc. is not specifically detailed in the drawings. Instead, the issue of protection of the contents of furniture and equipment is covered in the general notes to the drawings. For example, for sensitive contents on shelving, lips of one-half the height of the contents should be installed. Protective racks or trays separating individual contents may also be necessary.

The details developed for the Case Study Building and were provided to U.C. Berkeley in a separate document. Laboratory users may be able to install some of the restraint details, but others will require installation by experienced tradespersons who are part of the building staff, the University staff, or are employed by private contractors.

Costs Associated with Anchoring Building Contents

The Comerio and Stallmeyer (2001) report also developed cost estimates for the anchorage of laboratory contents in five prototypical laboratories on the U.C. Berkeley campus. Although the details were not intended as precise construction specifications for conditions in the five

buildings, there was sufficient information on construction methods to allow for the estimate of unit costs. The cost estimator provided a breakdown of direct costs (including both labor and materials) for each engineered detail in such a way that components of a detail could be added or removed based on the situation. For example, the cost of anchorage of a small refrigerator has a base cost for the equipment, plus additions for a door latch and contents trays.

The estimated costs of anchoring assume union labor rates and retail pricing. If a general contractor were engaged to do the work, an 18 percent to 25 percent contractor profit and overhead markup would need to be added to the overall estimate. Similarly, there could be an additional markup for campus staff to do project oversight. Cost reductions could be achieved if large quantities of material were purchased at wholesale prices.

The direct costs for contents anchorage developed in the previous study have been used in the estimate of costs for anchoring the equipment in the Case Study Building. The total cost to anchor all the equipment in the building would be $2,495,543 ($25 per square foot of laboratory space, or $20 per square foot of net usable building area). By comparison, to anchor the proposed combination of items tagged as Life Safety Priority C or D, Important, Value category 4 through 7 (items worth more than $20,000), or any combination of these codes, the cost would be $1,616,493 ($16 per square foot of laboratory space, or $13 per square foot of net usable building area). If a smaller subset of these categories is anchored (Life Safety Priority D, Important, Value categories 6 and 7—items valued at over $100,000, or any combination of these categories), then the cost of anchoring drops to $933,048 ($9 per square foot of laboratory space). These costs represent only 6 percent to 10 percent of the replacement value of the items (see Figure 32). It should be noted that items are not double-counted—if an item has more than one designation (e.g., as valuable and important) it is only counted once in the cost estimates.

Another method for evaluating costs is to combine the items tagged as Important with various combinations of Life Safety priorities, broken into the categories A through D, plus those items identified as having inadequate shelf lips. Figure 33 demonstrates that replacing all the shelf lips costs $392,040. This graph also demonstrates that valuable items are subsumed in the items included in categories Important, Life Safety C, D, and CH, as the costs for these is identical to the costs for the three groups.

For analytic purposes, costs can be broken down by each critical factor, as a cost and as a percentage of replacement costs. Retrofit costs for the life safety designations are shown in Figure 34, and cumulative costs by life safety designation are shown in Figure 35. Here again, these graphs illustrate that the items in Life Safety Priorities C, D, and CH overlap with the items designated important or valuable, or both. In these graphs, Life Safety Priority D stands out because the retrofit cost is 20 percent of the replacement cost, a significantly higher percentage than in other categories. The retrofit costs are high because these items are often heavy pieces of equipment requiring more complex anchoring solutions.

A crucial question affecting the cost of retrofits is whether the existing anchorages already in place on many refrigerators, freezers, bookshelves, and other equipment will perform adequately in an earthquake. Although a final assessment is not complete, the preliminary results from shake table testing of these typical conditions, and the calculations from consulting engineers, suggest that the existing anchorages will eventually need to be replaced.

Although only 3 percent of laboratory items (316 items) have some type of seismic anchorage, 40 percent of the freezers and 20 percent of the refrigerators—items considered important—have been anchored. (See data in Chapter 2 and Appendix 2.) If the in-place anchors were adequate, the total cost for contents anchoring in this building would be lower. Figure 36 shows the difference between the total cost of anchorage for all items in each life safety category and the total cost if the existing anchorages already in place are excluded from the estimate. Clearly, the continued use of existing anchorage would have significantly affected the estimated costs of anchoring the heavy equipment in category D and the costs of installing the shelf lips. If the existing anchorages had been adequate, the cost for anchorage in category D could have been reduced by $434,665 (65 percent).

Figure 37 shows the costs for retrofitting only those items designated important. Although this represents a relatively small portion of the overall retrofit costs, it should be noted that this category is the most variable. When making final choices about what equipment to anchor, researchers may designate many more items in this category than previously indicated. Still, these tend to overlap with items that are also life safety priorities—so that changes in the "importance" designation should not change the overall cost estimates dramatically.

Figures 38 and 39 provide the breakdown (individually and cumulatively) of costs for items by Value categories. In this case, the predominance of items (89 percent) have values below $5,000. Nearly 60

percent of the total cost of anchoring all the items in the building can be attributed to small bench-top items. However, because these items are small and light, the anchorage cost is only about 5 percent of the replacement value of the item, and the fix is often easy and inexpensive. Simple off-the-shelf instrument fasteners, lassos, and friction pads can be used with many CPUs, printers, microscopes, small centrifuges, and other small bench-top equipment. It is probably impractical to anchor all the small items on bench-tops—the items researchers use and move most often. Although most are easily replaceable if they do fall and break, there is a trade-off between the front-end cost of anchorage (and the inconvenience of anchorage to researchers) and the potential cost and time to clean up and replace large numbers of bench-top items after an event.

To summarize, the cost of anchoring all the equipment in the Case Study Building would be $25 per square foot of laboratory space (or $20 if measured by assignable square foot). This cost is comparable to costs estimated for individual laboratories in other buildings on the University of California, Berkeley, campus. The significant lesson from the case study of a single laboratory building is that about 40 percent of the contents are potentially hazardous, critical to research, valuable and difficult to replace, or any combination of these categories. Seismic retrofit of this subset of the contents should be a first priority. The cost will range between $10 and $16 per square foot of laboratory space ($8 to $13 per assignable square foot), depending on how some items are classified. Figure 40 shows a range of first-priority categories and their costs.

CHAPTER 4
Summary and Conclusions

This report completes the research regarding damage mitigation for nonstructural systems and building contents funded by the Federal Emergency Management Agency and the University of California, Berkeley. The first phase of the Disaster Resistant University initiative produced a study of potential earthquake losses at U.C. Berkeley together with an analysis of the economic impacts. This report lays out a method for assessing risks and mitigating hazards in laboratory contents. The report describes the methodology used to inventory and assess laboratory contents in a case study building. The report also provides an overall framework that can be used by other laboratory managers or other universities. The appendices have equipment evaluations and design details specific to the case study building to be used in a damage mitigation program.

The work represented in this report is part of a PEER research project to develop analytic models for performance-based design. Our work has been focused on understanding earthquake losses resulting from damage to building contents and nonstructural systems. By documenting the typical contents in laboratory buildings, we have been able to catalogue a series of typical retrofit options and set a baseline for damage mitigation costs. In our first study of five individual laboratories (Comerio and Stallmeyer, 2001), we catalogued typical laboratory equipment and estimated the cost to anchor these contents. In that study we found that direct costs ranged from $10 to $16 per square foot. Although these estimates may appear expensive, it is important to note that the laboratories are densely packed with equipment, and the estimates are for anchoring every object in the space.

In this review of the contents of a laboratory building, we analyzed space usage, surveyed the building contents, evaluated each item in terms of life safety hazards, and coded all items that scientists labeled as critical to research operations. We found that the laboratories and their related animal spaces use only about 50 percent of the total building area. Mechanical services, corridors, offices, and other support space make up the remainder of the building.

The building's contents are typical of a wet laboratory: parallel laboratory benches with shelves above, set against or between walls. Every space is densely packed with equipment. There are approximately 10,500 items in the building, of which 44 percent is furniture and 56

percent is equipment. Fifty percent of the furniture is shelving units. Computer equipment forms the largest single equipment group (22 percent), followed by heavy equipment, such as refrigerators, freezers, and centrifuges (13 percent). The remainder of the equipment is small and varied—microscopes, incubators, stirrers, and other specialized items.

As part of the survey of the contents, we recorded the replacement value of each item based on purchase records. The total value of the equipment in the building is about $21 million. Ninety-eight percent of the items are valued between $1,500 and $10,000, while the remaining 2 percent range in value from $10,000 to $1 million. In each laboratory, scientists were asked to identify items that were essential to their research. At the top of the list were the refrigerators and freezers that house fragile biological samples, data stored on laboratory computers, and customized equipment. The research team assigned life safety factors to each item, based on weight and location (i.e., its risk as a falling hazard), and created a special category for earthquake-induced chemical hazards.

These attributes—value, importance, and life safety—were used to set damage mitigation priorities. For example, there are approximately 1,300 items (12 percent) coded as Important, Chemical Hazard, Life Safety Priority D, or some combination of these categories. There are approximately 4,000 items (40 percent) coded as Valuable (with values over $20,000), Important, Chemical Hazard, Life Safety Priority C or D, or some combination of these categories. This subset of the contents represents the contents that are most critical to research, most difficult to replace, and the most hazardous to the occupants. If these items are carefully anchored, the building would be substantially safer, and research operations would be protected.

Ideally, we would like to develop a cost/benefit calculation to make the case for retrofitting laboratory contents; however, until researchers have sufficient data to develop fragility curves on equipment, there is not enough information available to perform such an analysis. Nonetheless, preliminary results from shake table tests by PEER researchers (Hutchinson, 2003; Makris, 2003) suggest that unanchored equipment will slide at least 12 inches to 18 inches and occasionally topple.

A targeted retrofit program, focused on a subset of high-priority items is strategically sound and cost effective. We estimate that the items designated as important to research could be anchored for about $3.00 per square foot of laboratory space, and all the items rated Important, Valuable (greater than $20,000), Chemical Hazard, Life Safety Priority C or D, or some combination of these categories (40 percent of the contents)

could be retrofitted for about $16.00 per square foot of laboratory space. By comparison, the total cost to anchor all the contents is $25.00 per square foot.

The laboratories in the case study building are typical of most wet laboratories on the University of California, Berkeley, campus, although the age, structural features, and nonstructural conditions of the buildings will vary. The concentration of scientific and engineering research in approximately 17 of the 114 buildings on the central campus is similar to the concentration of books in four main library buildings. These assets are critical to the continued operation of a major research university after an earthquake. Targeted damage mitigation strategies—focused on critical contents—are cost effective, will improve overall building performance, and will allow most research to continue after an earthquake.

The work undertaken by PEER researchers will provide a better understanding of the vulnerabilities of building contents and nonstructural systems and will provide estimates of contents losses as a portion of overall earthquake losses. This research will allow cost/benefit calculations to be done on damage mitigation for building contents.

Although there is much work to be done on the role of contents and nonstructural systems in loss estimation, the research thus far has raised a number of important questions: Will the anchoring of heavy equipment (such as refrigerators, freezers, and centrifuges) hurt the functionality of the equipment by damaging internal components? Further, will the anchoring of such equipment transfer the load to the contents, making a "bio-shake" of the fragile biological samples? Only systematic testing will allow us to define detailed fragility and vulnerability curves for equipment, equipment contents, and anchorage designs.

Clearly there is a great deal more to be done before we can integrate contents losses into building performance assessments with confidence. In addition to testing, we need to collect systematic data on contents losses and nonstructural system losses in future earthquakes. Such data is essential to calibrate the tests as well as the loss models. Still, the research begun with these laboratory studies—research that can be transferred to other building types—establishes a model for categorizing and quantifying building contents. The model both sets a baseline for costs to assess mitigation strategies and provides a systematic method for including contents in loss modeling.

Figure 1: Exterior Photograph of UC Science Case Study Building

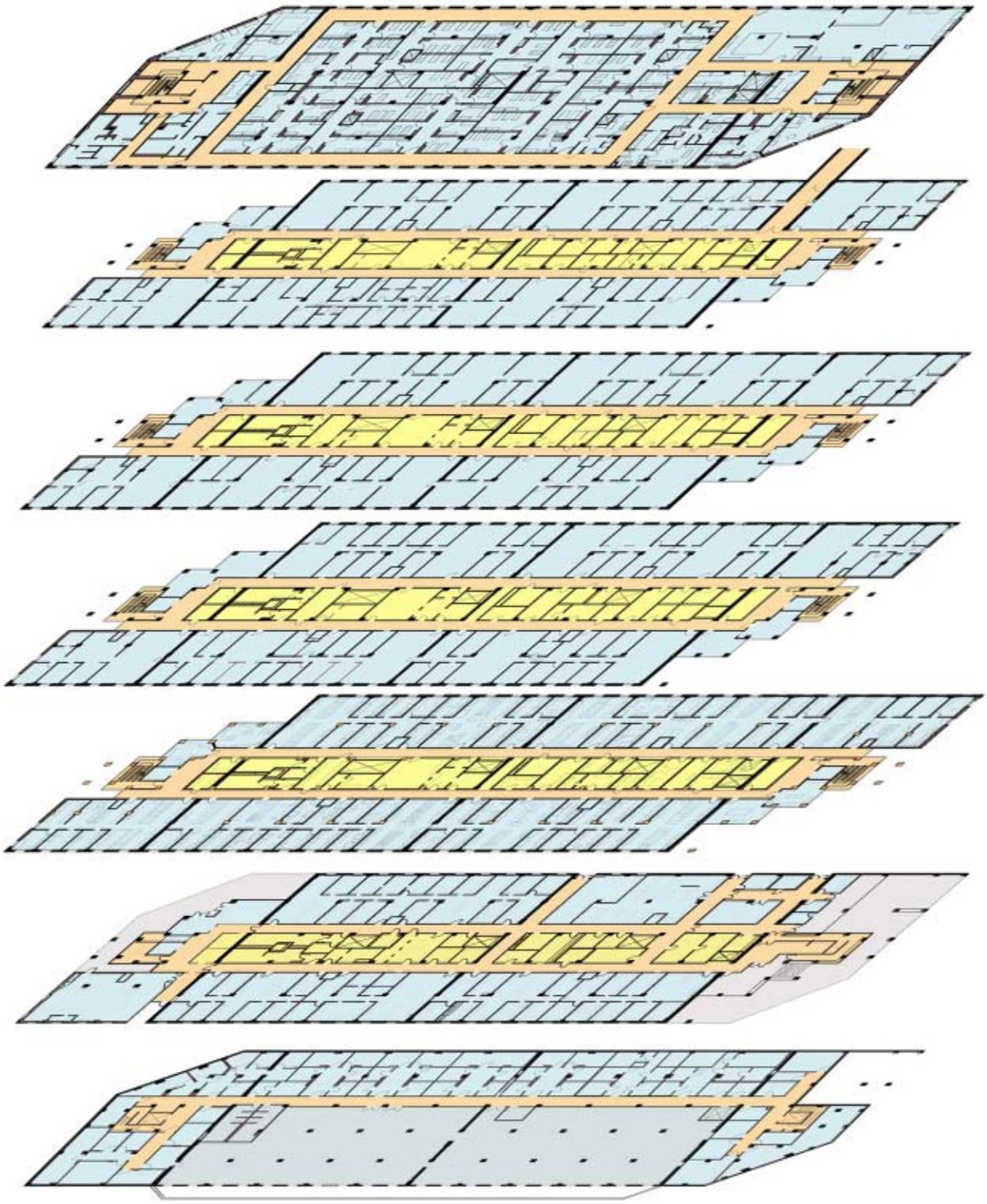
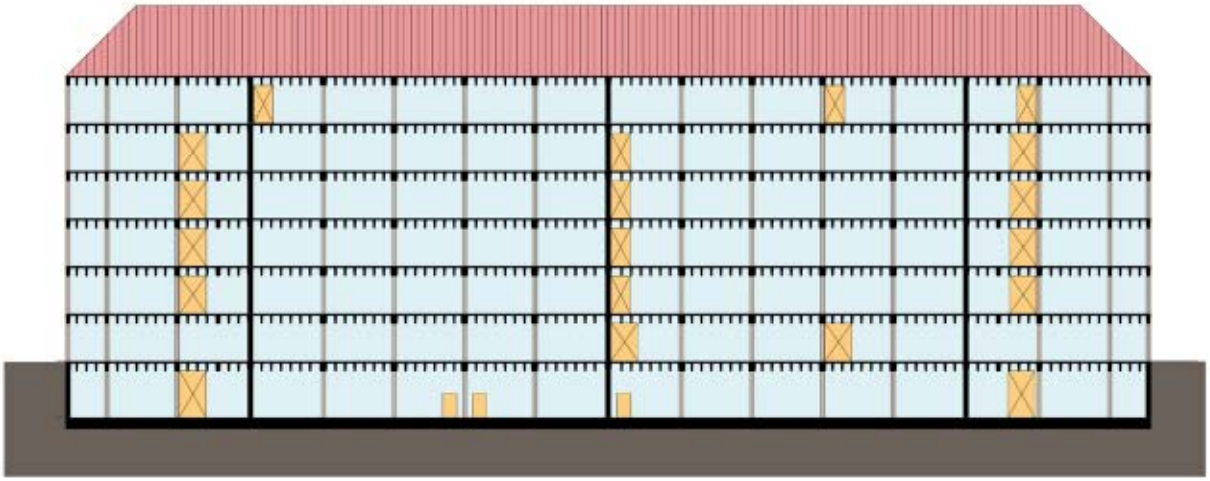


Figure 2: Architectural Floor Plans (Basement to 6th Floor)



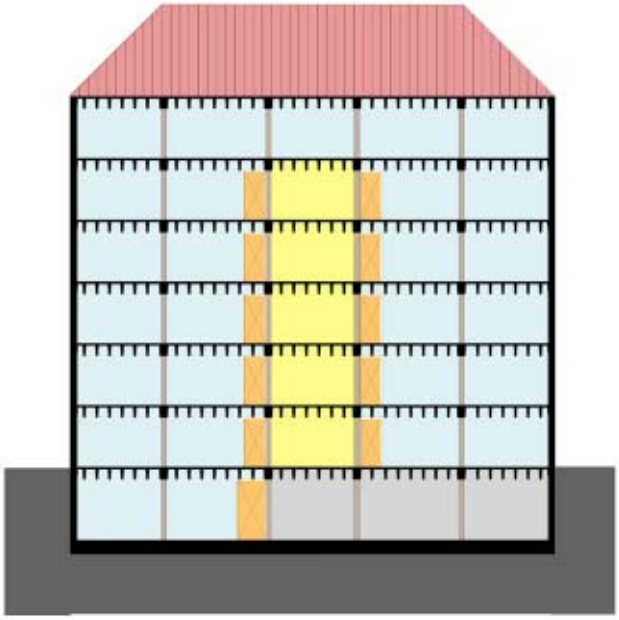
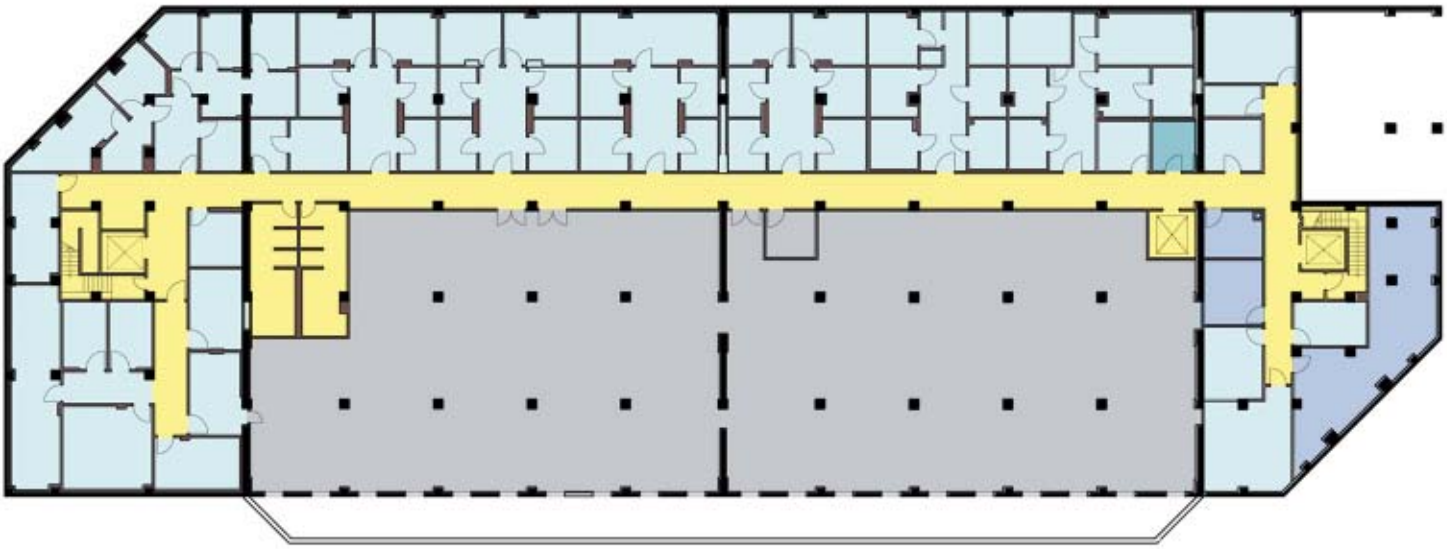


Figure 3: Building Sections



Animal Space: 9,877 SF
Office Space : 99 SF
Storage/ Other : 1,403 SF
Corridor/ Public : 3,314 SF
Mechanical Space : 11,442 SF

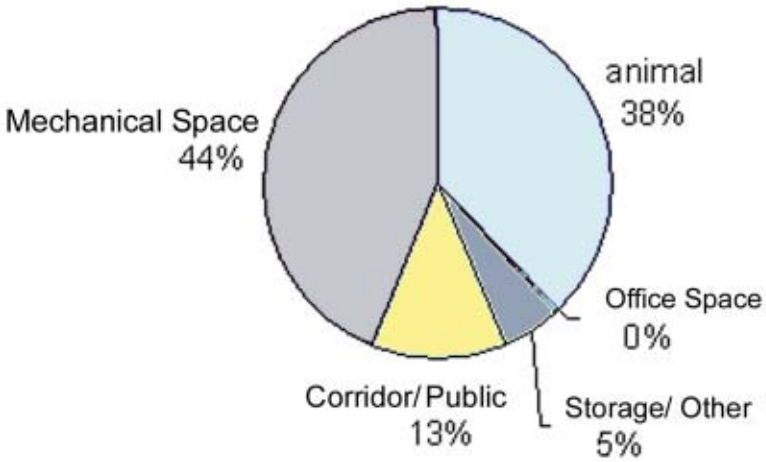


Figure 4: Basement-Floor Plan and Space Use

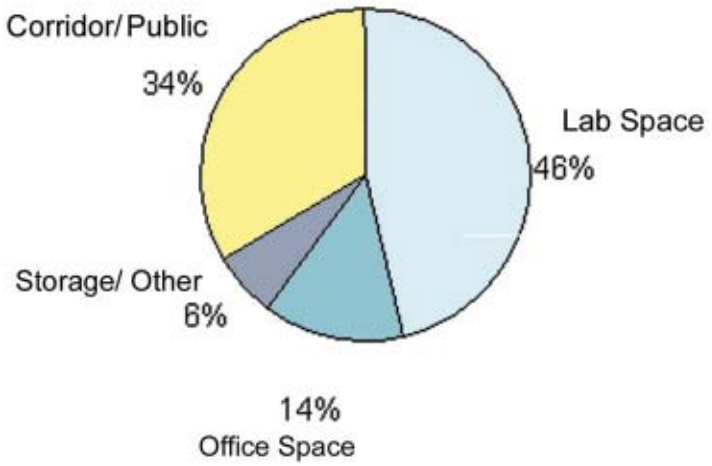
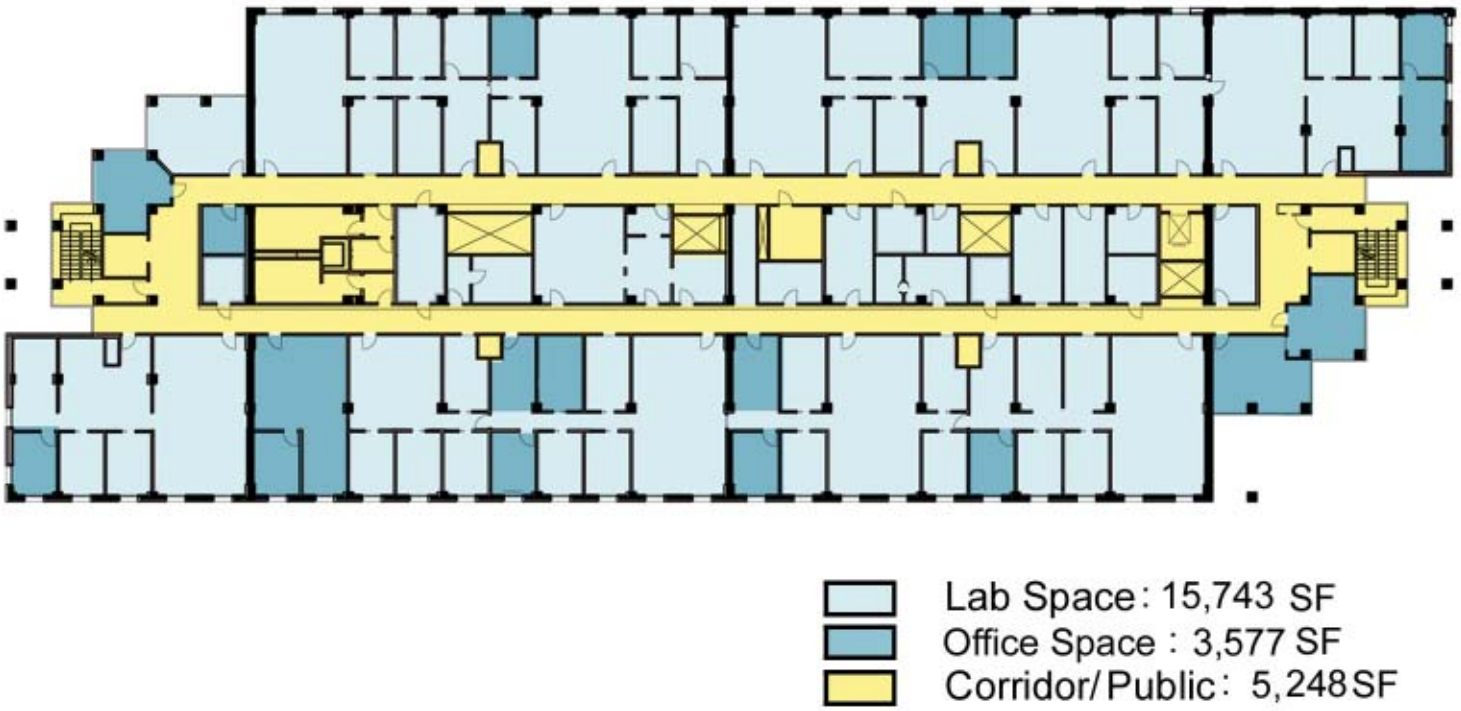


Figure 5: First-Floor Plan and Space Use



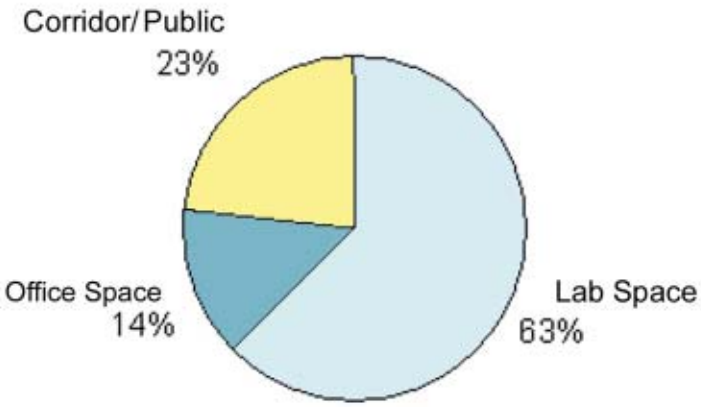
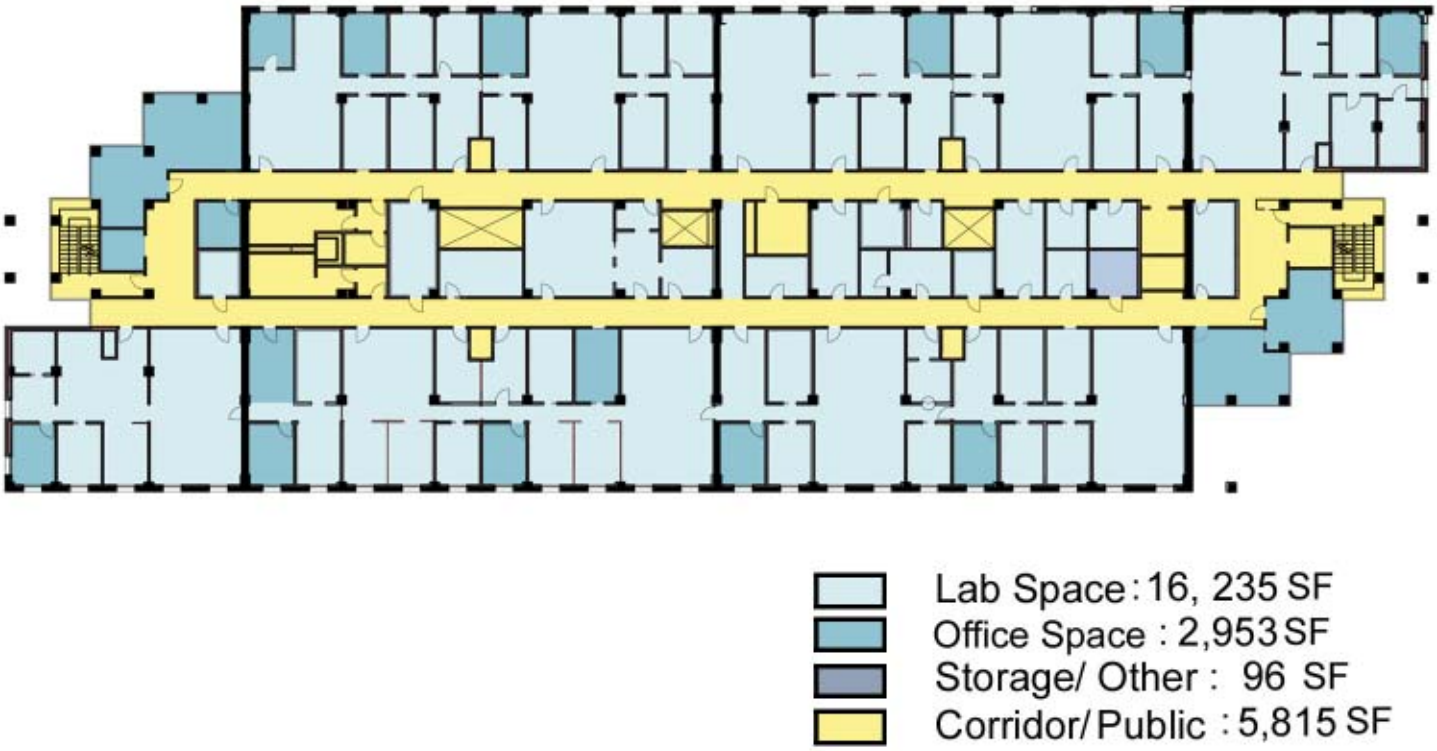


Figure 6: Second-Floor Plan and Space Use



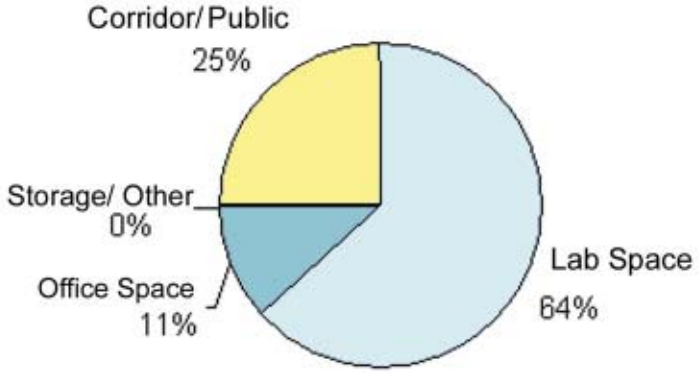
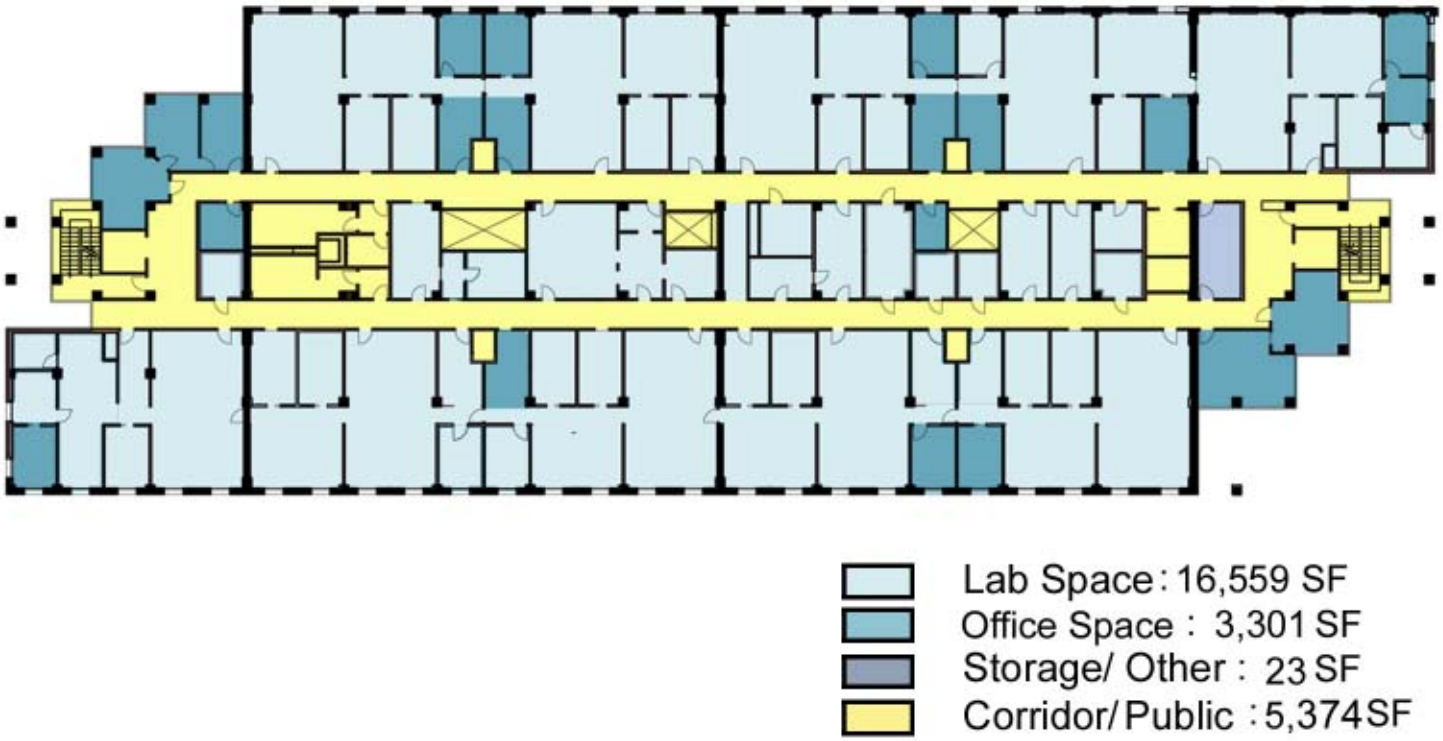


Figure 7: Third-Floor Plan and Space Use



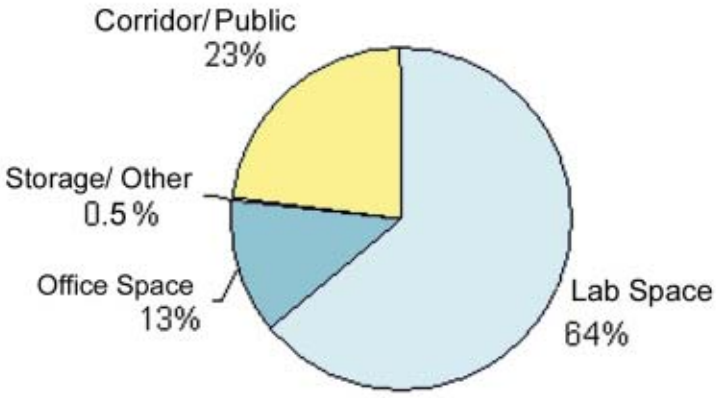
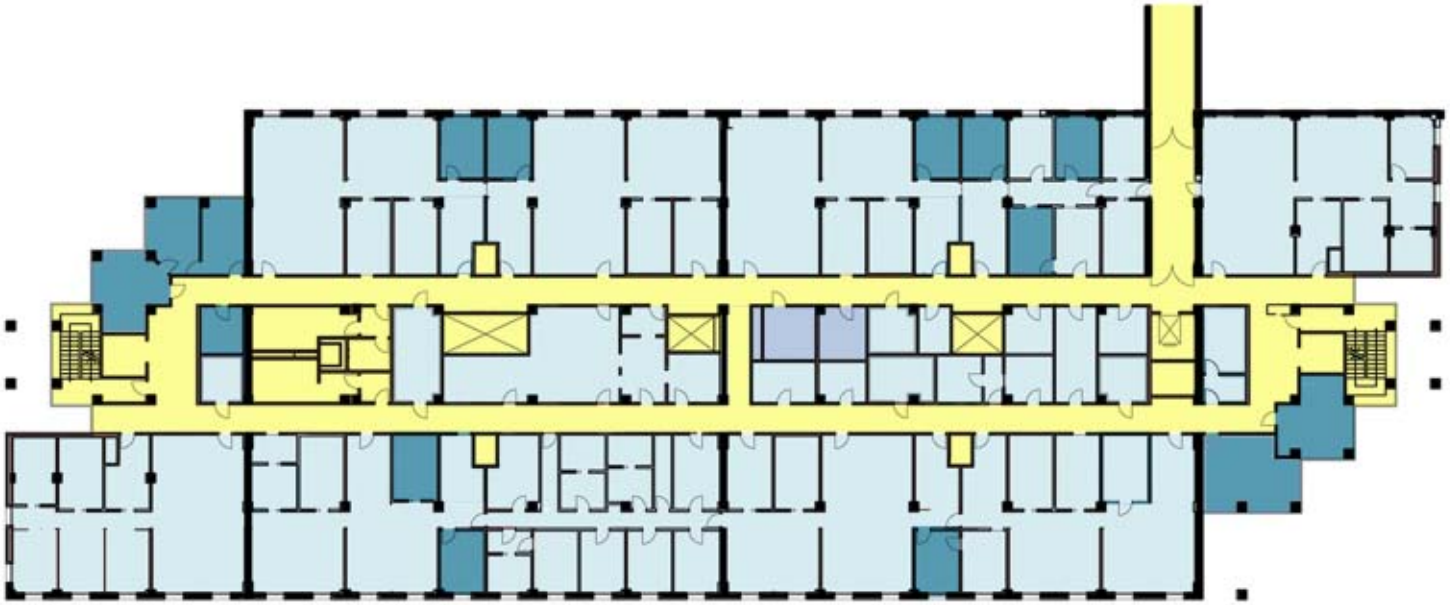


Figure 8: Fourth-Floor Plan and Space Use



Lab Space : 16,748 SF
Office Space : 2,649 SF
Storage/ Other : 147 SF
Corridor/ Public : 5,531 SF

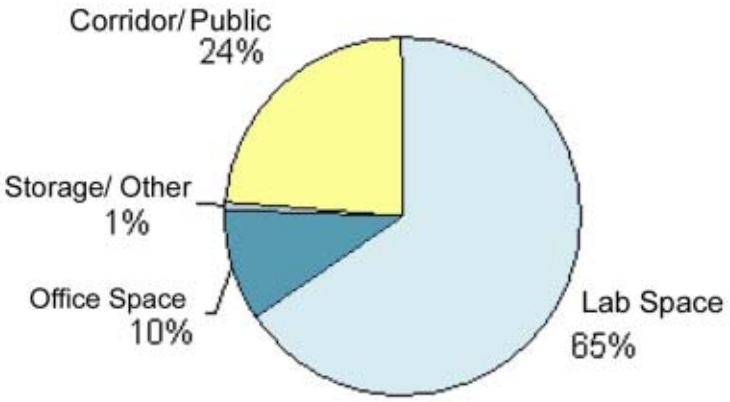
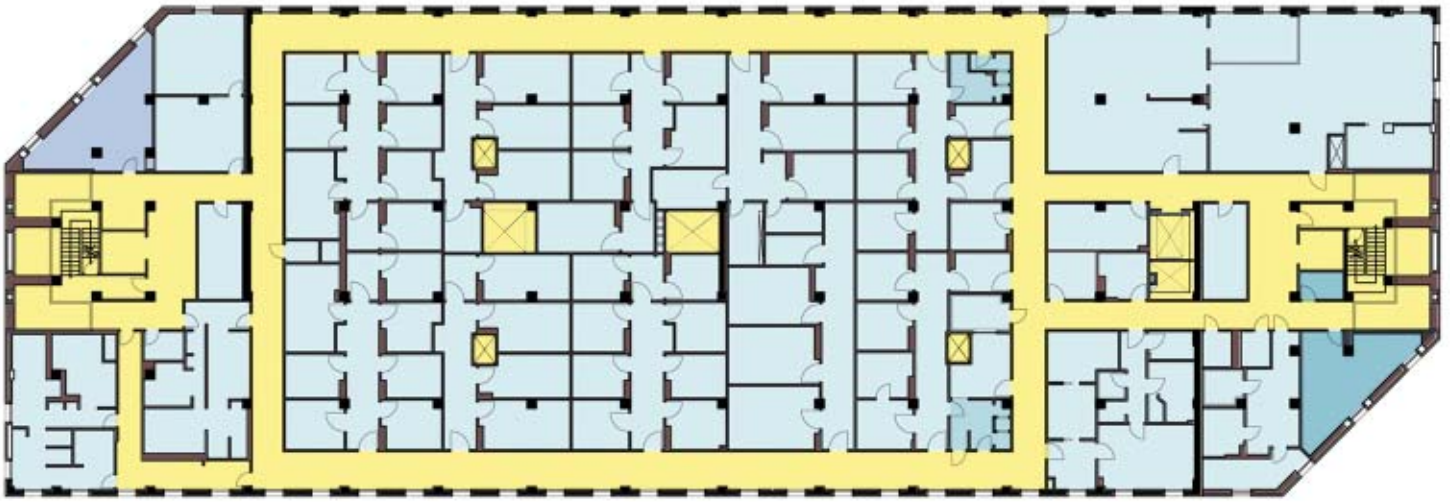


Figure 9: Fifth-Floor Plan and Space Use



Animal/LabSpace: 16,490 SF
Office Space : 443 SF
Storage/ Other : 513 SF
Corridor/ Public : 6,974 SF

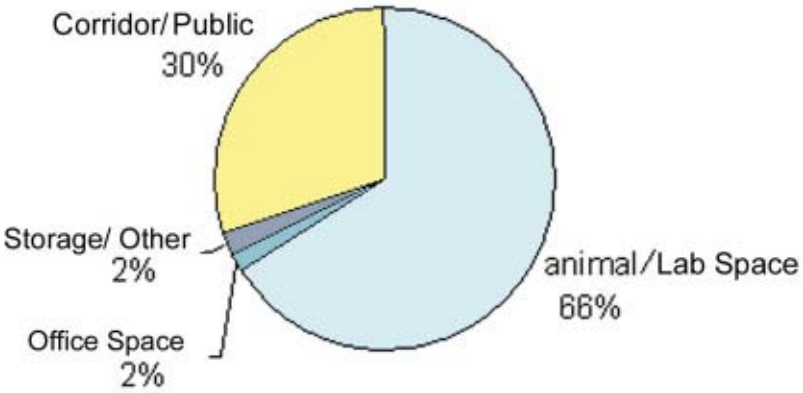
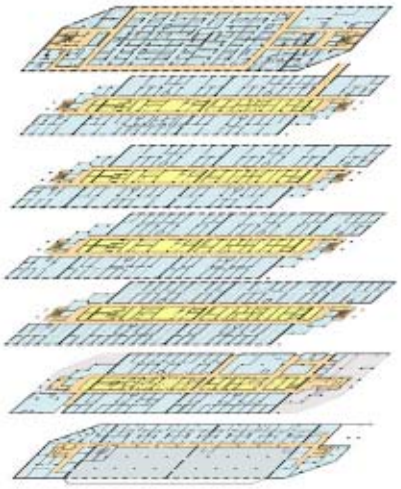
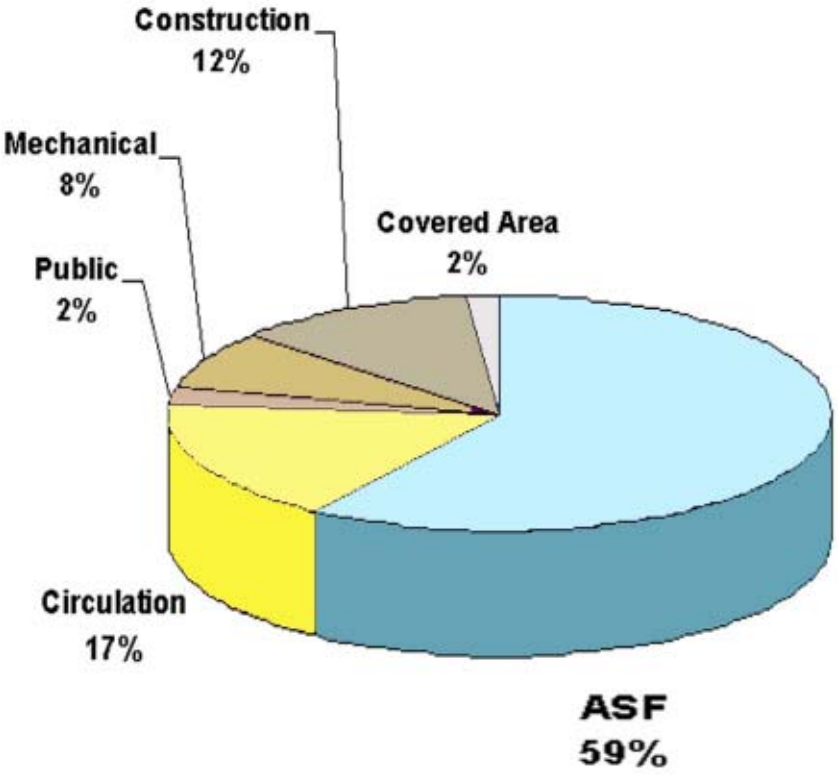


Figure 10: Sixth-Floor Plan and Space Use



Classroom:	1,211 s.f.
Research Lab:	50,822 s.f.
Research Activites:	22,533 s.f.
Office:	17,862 s.f.
Animal Space:	26,387 s.f.
Support/Other:	3,207 s.f.
ASF:	122,022 s.f.
Circulation:	34,155 s.f.
Custodial:	362 s.f.
Public:	5,016 s.f.
Mechanical:	16,720 s.f.
Construction:	23,909 s.f.



GSF: 202,184 s.f. *

OGSF: 203,787 s.f. *
(including covered outdooor space: 3,206 s.f.)

*Source: UCB FDX

Figure 11: Net and Gross Space Use in the Building

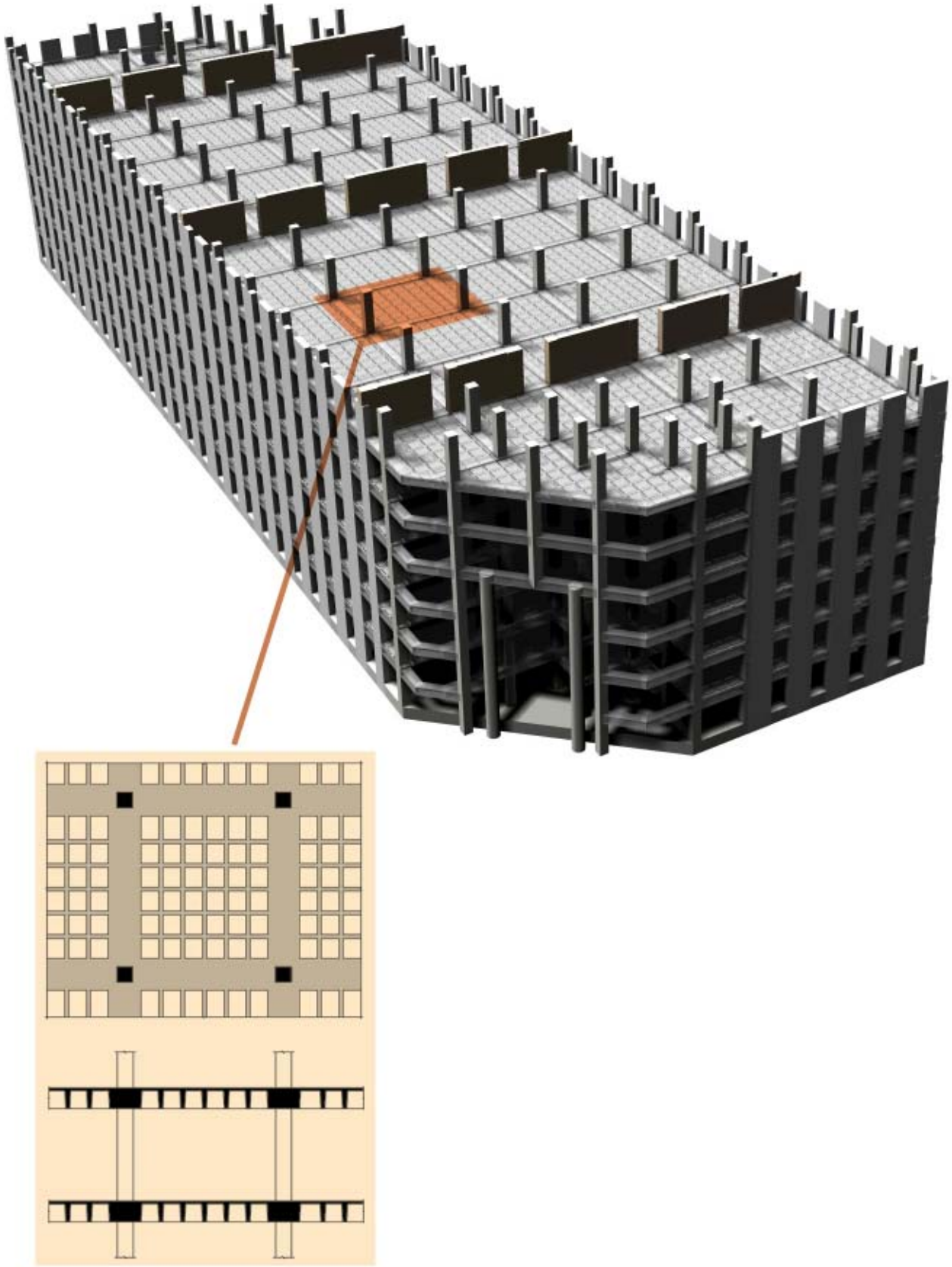


Figure 12: Diagram of Structural System

suspended air supply and cable tray

fume hood vent

laboratory support

lab vent and waste

Figure 13: Mechanical System Photos

typical corridor

lab hallway

conference room

typical office

Figure 14: Interior Conditions

equipment core

equipment core

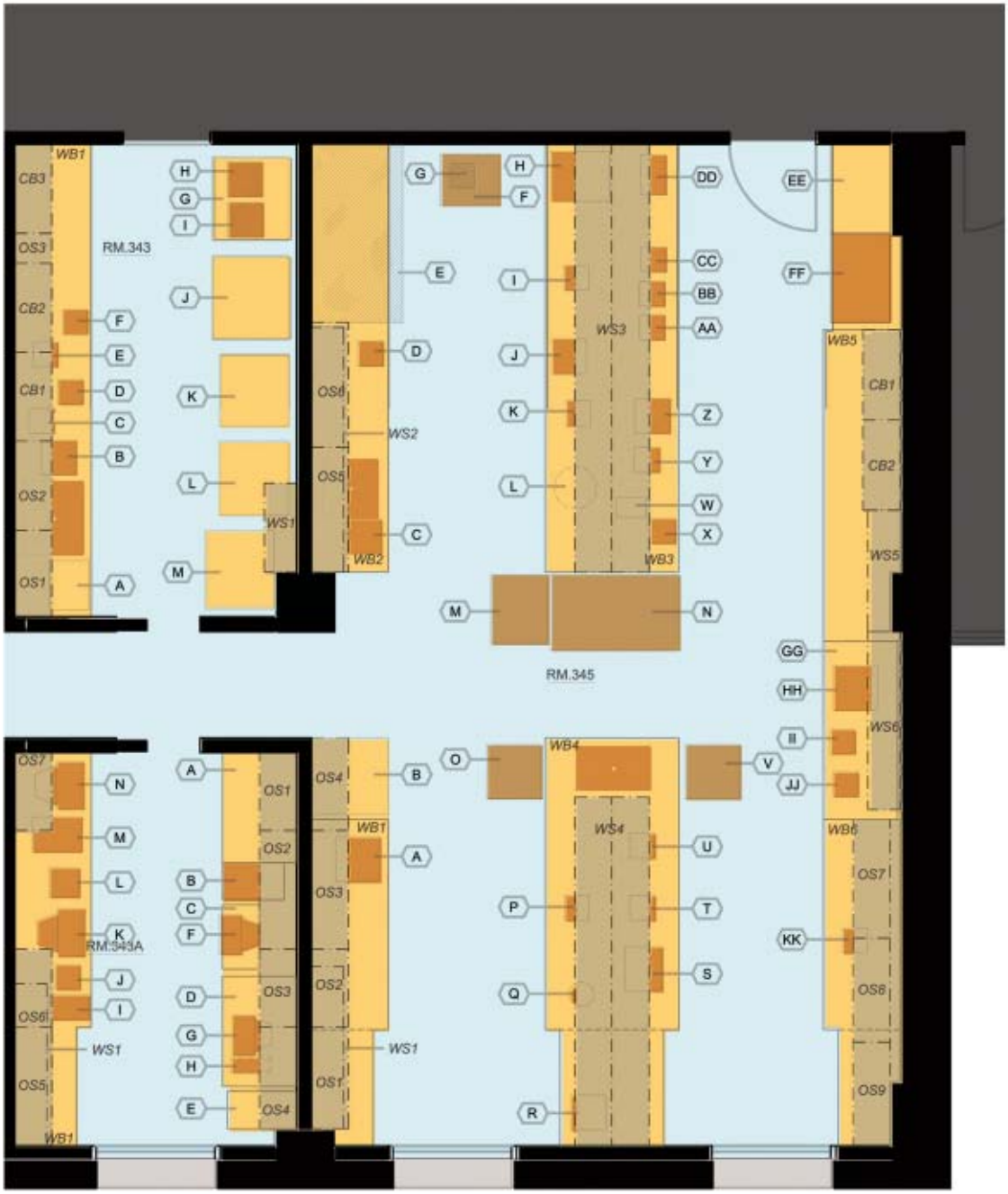
typical cold room

covered exterior lobby

fire stair

Figure 15: Interior/Exterior Conditions

Figure 16: Diagram of Typical Laboratory Layouts



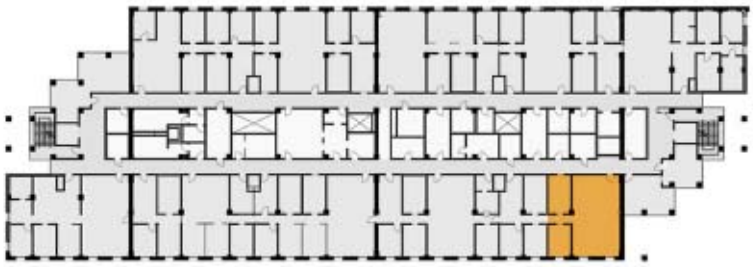


Figure 17a: Sample Lab #1, Floor Plan

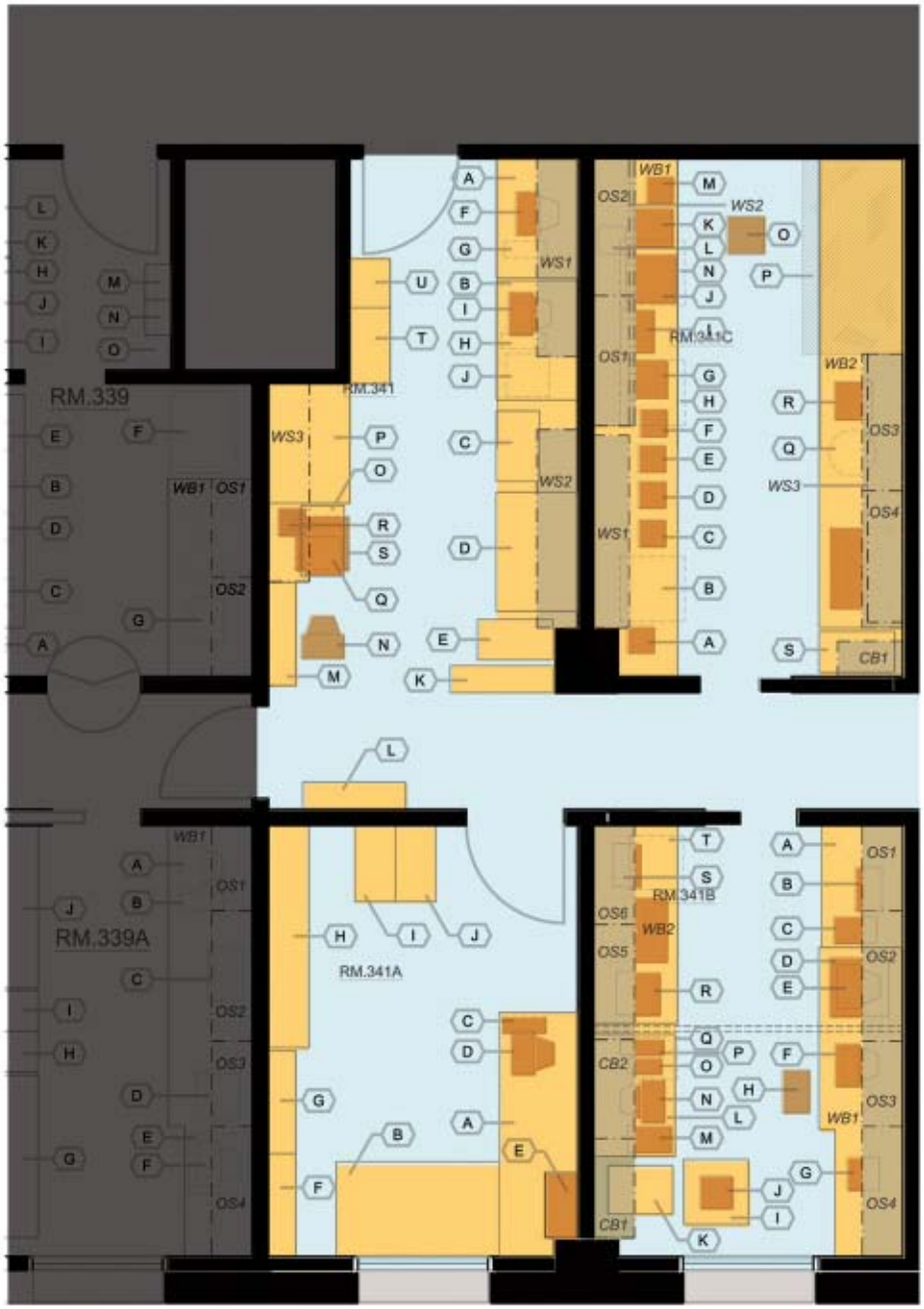


Figure 17b: Sample Lab #1, Floor Plan

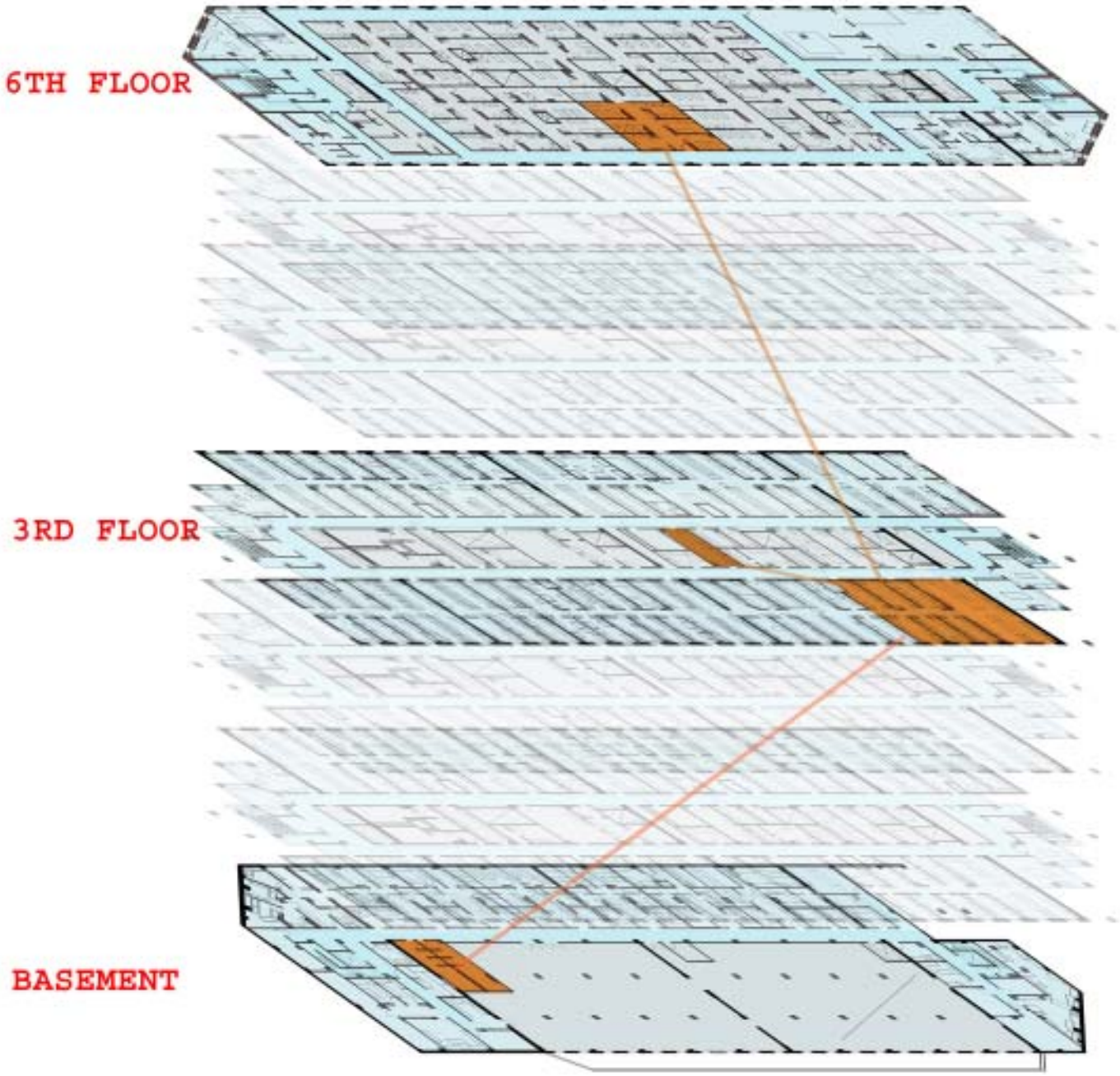


Figure 18: Sample Lab #1, Relationship Between Lab, Core, and Animal Space

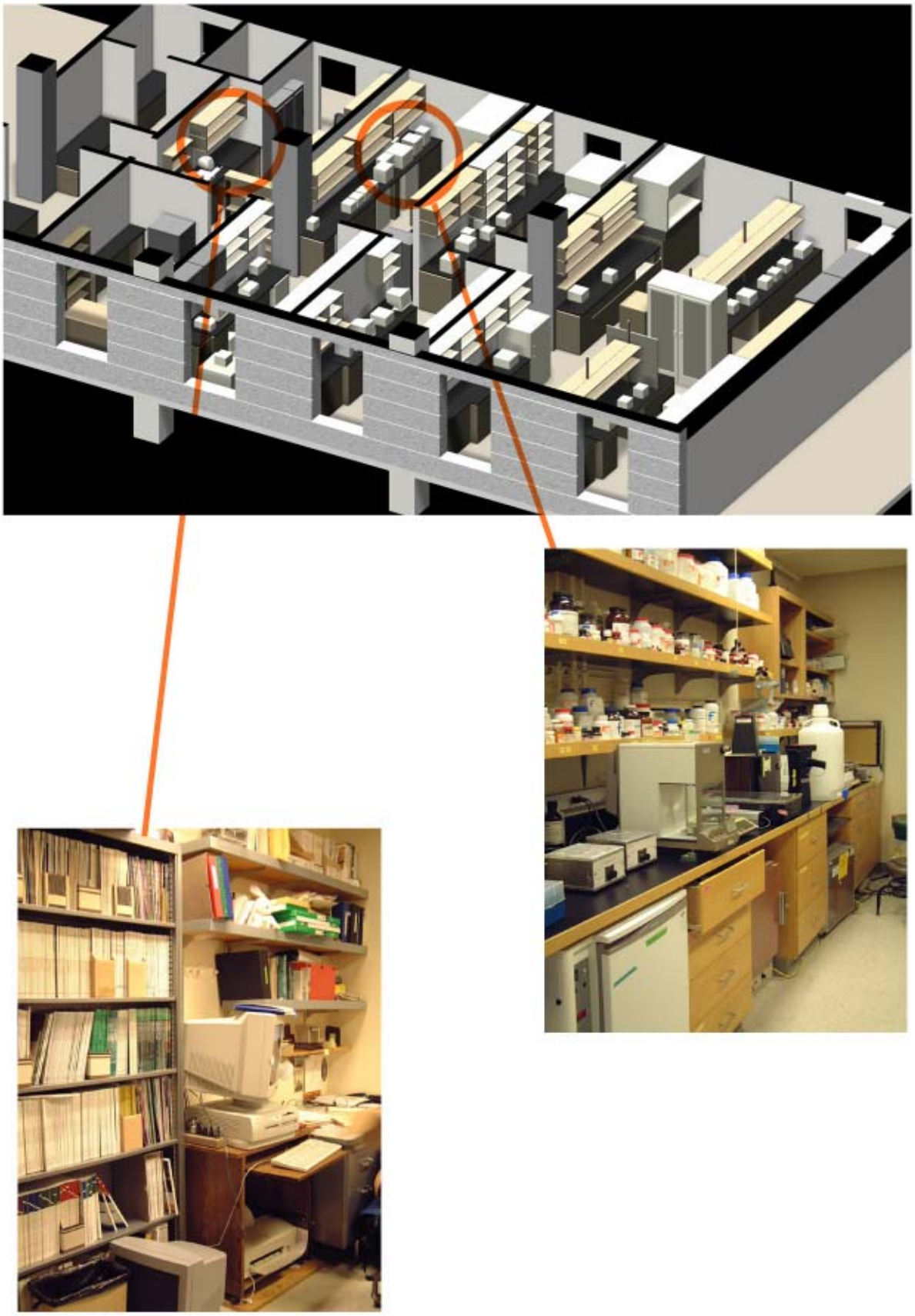


Figure 19: Sample Lab #1, 3-Dimensional Diagram with Photos (a)

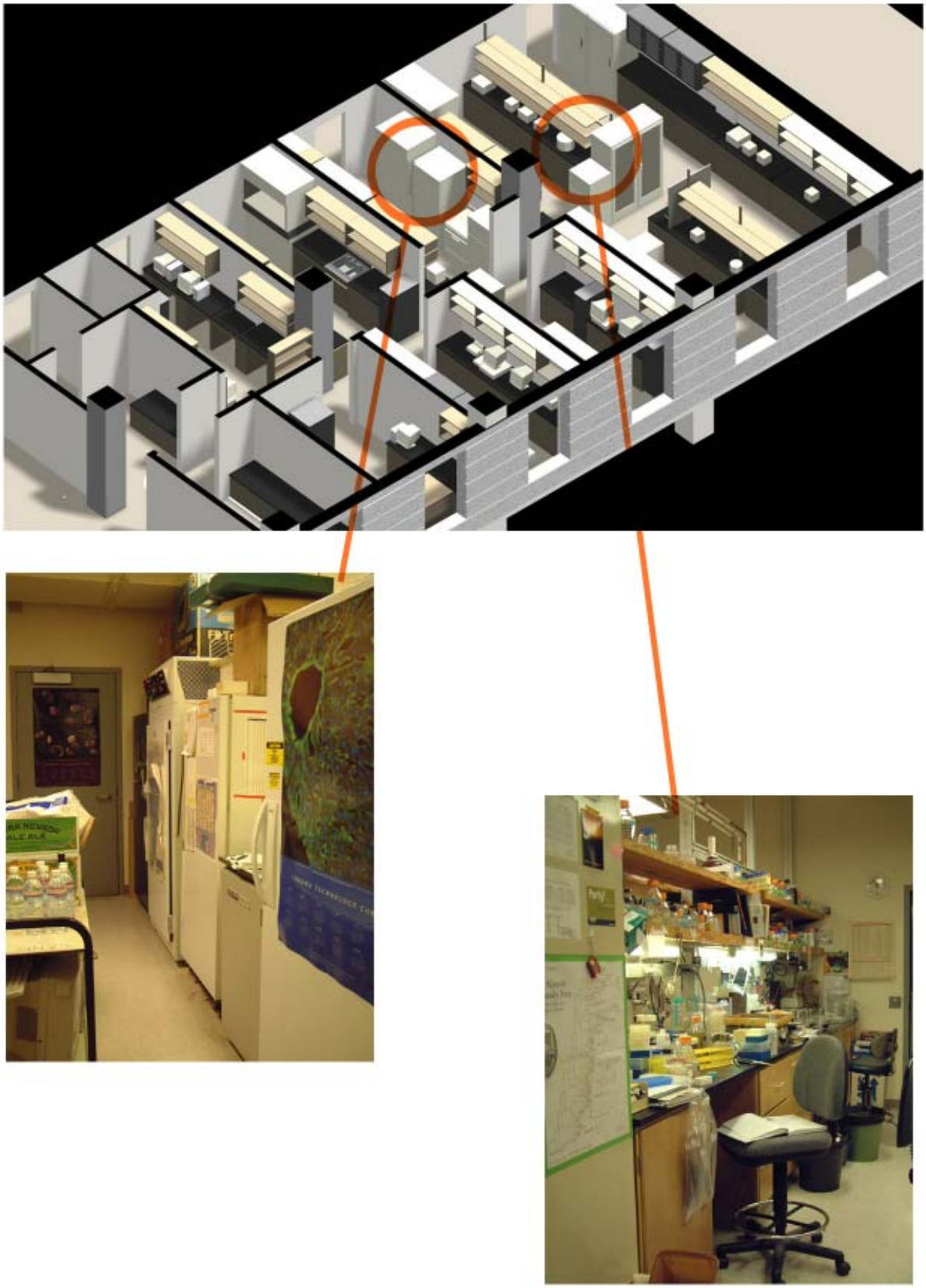
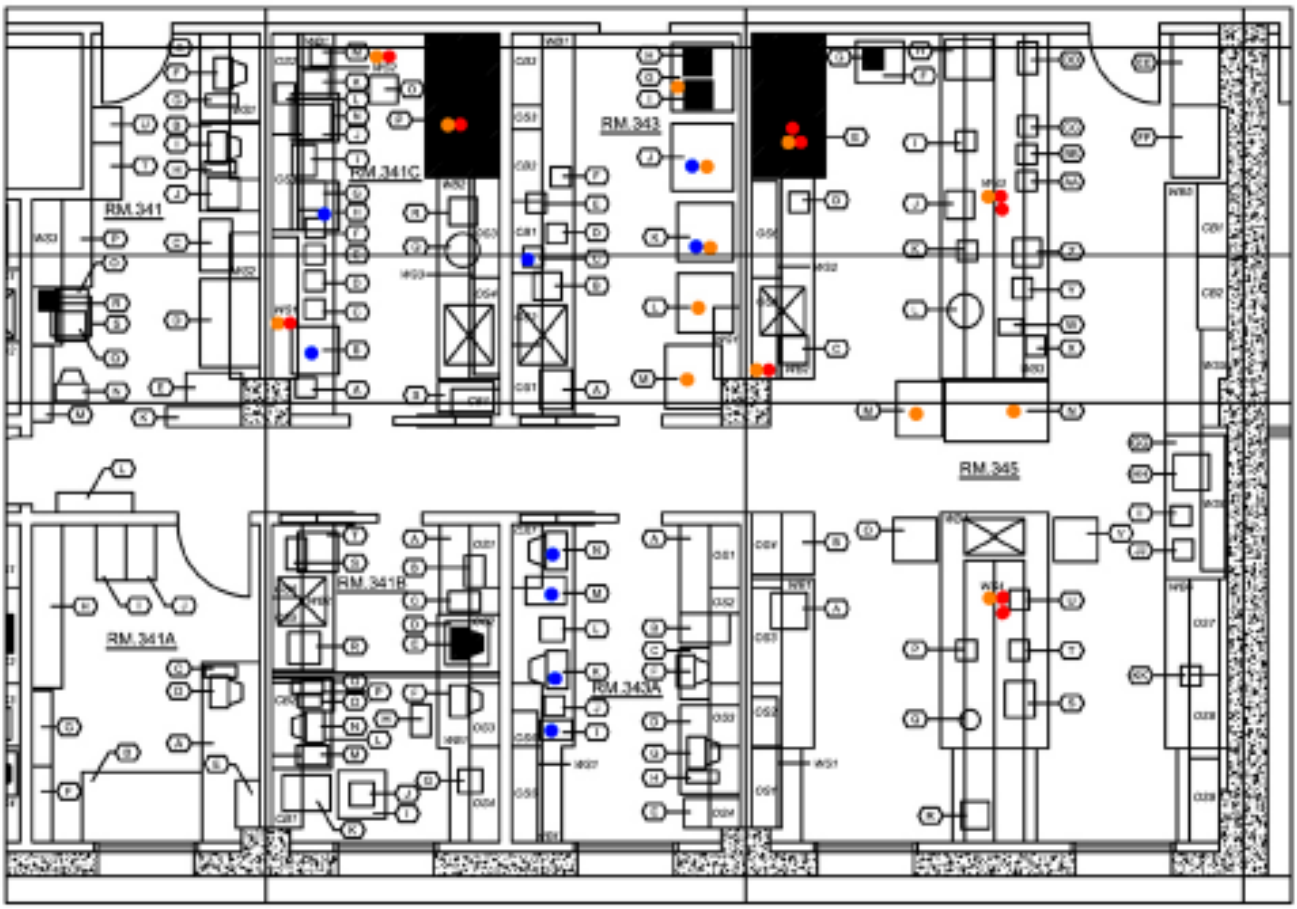


Figure 20: Sample Lab #1, 3-Dimensional Diagram with Photos (b)



importance

value

chemical

life safety 'D'

Figure 21: Sample Lab #1, Examples of Critical Items

Room	Sub	Key	Equipment	Life Safety	Value	Importance	Chem.
341	c	B	**Low Temp. Incubator**	B	1	Y	N
341	c	P	**Fume Hood**	C	2	N	CH/A
341	c	WS-1-2	**Open Shelving**	A/SL	1	N	CH/A
343	a	I	**CPU**	B	3	Y	N
343	a	K	**Monitor**	B	1	Y	N
343	a	M	**CPU**	B	3	Y	N
343	a	N	**Monitor**	B	1	Y	N
343		C	**Incubator**	C	1	Y	N
343		G	**Refrigerator**	D *	1	N	N
343		J	**Incubator**	D	1	Y	N
343		K	**Freezer**	D	2	Y	N
343		L	**Centrifuge**	D	3	N	N
343		M	**Refrigerator**	D	1	N	N
345		B	**Refrigerator**	D	1	N	N
345		E	**Fume Hood**	C	2	N	CH/A
345		E	**Fume Hood**	C	2	N	CH/A
345		M	**Refrigerator**	D	1	N	N
345		N	**Refrigerator**	D	2	N	N
345		WB-2	**Work Bench**	A	1	N	CH/A
345		WS-3	**Open Shelving**	A/SL	1	N	CH/A
345		WS-3	**Open Shelving**	A/SL	1	N	CH/A
345		WS-4	**Open Shelving**	A/SL	1	N	CH/A
345		WS-4	**Open Shelving**	A/SL	1	N	CH/A

Note: Items designated as life safety, valuable, important, and chemical hazard are **14%** of local lab contents. (Critical items may also be located in related spaces.)

*Only Life Safety Category 'D' is shown in Figure 21 & 22

Figure 22: Sample Lab #1, Critical Items Table

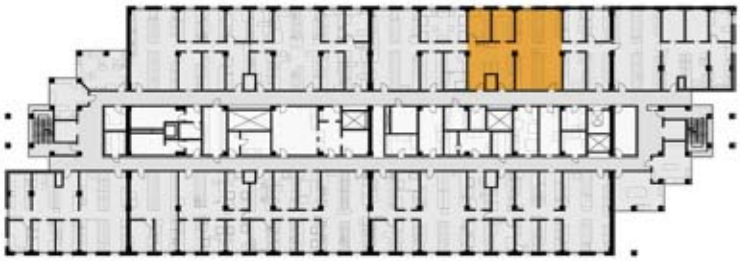
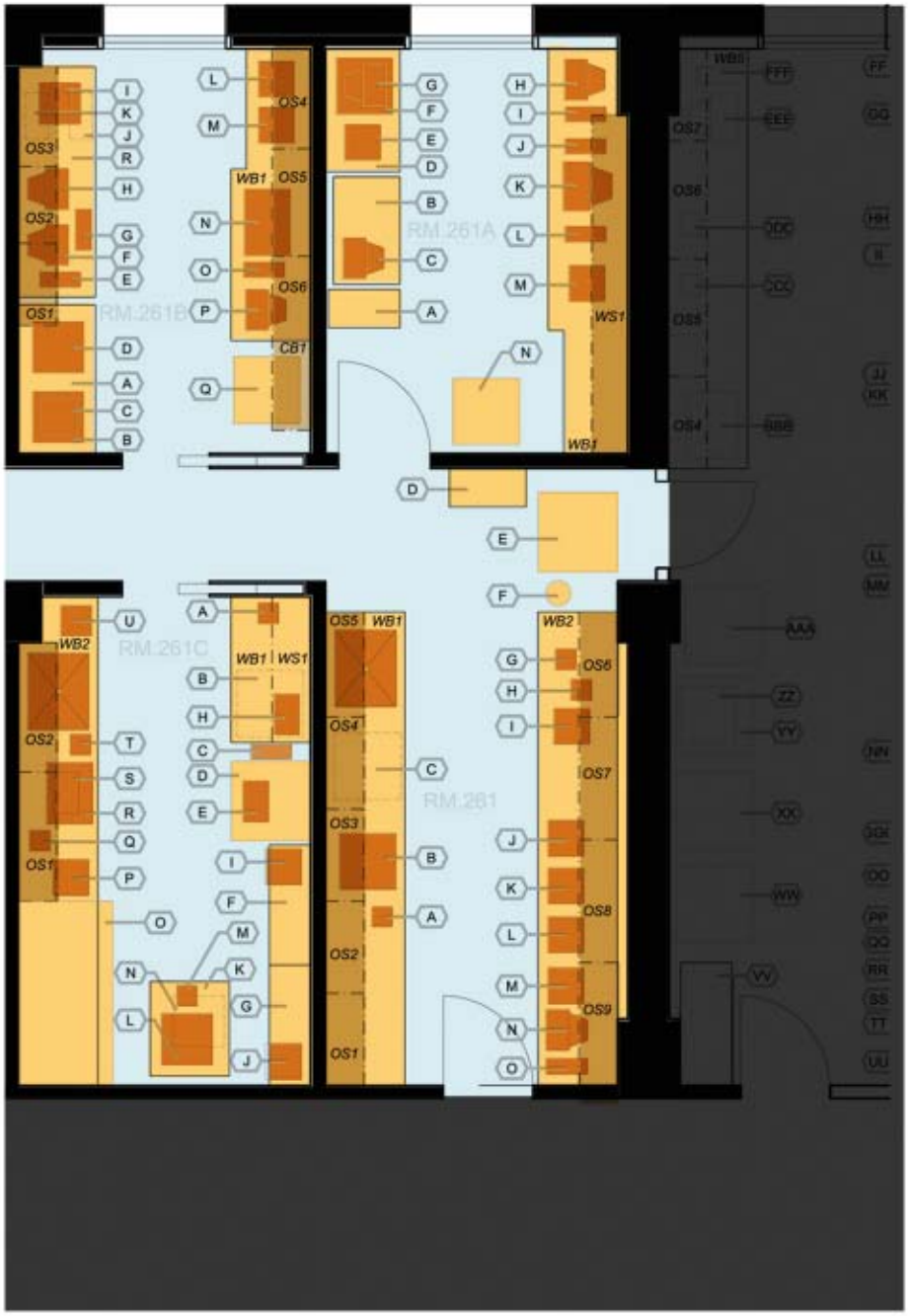


Figure 23a: Sample Lab #2, Floor Plan



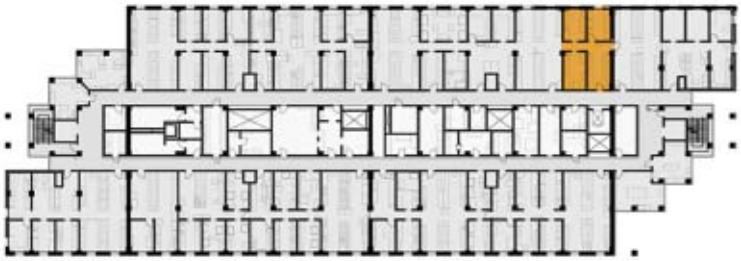


Figure 23b: Sample Lab #2, Floor Plan

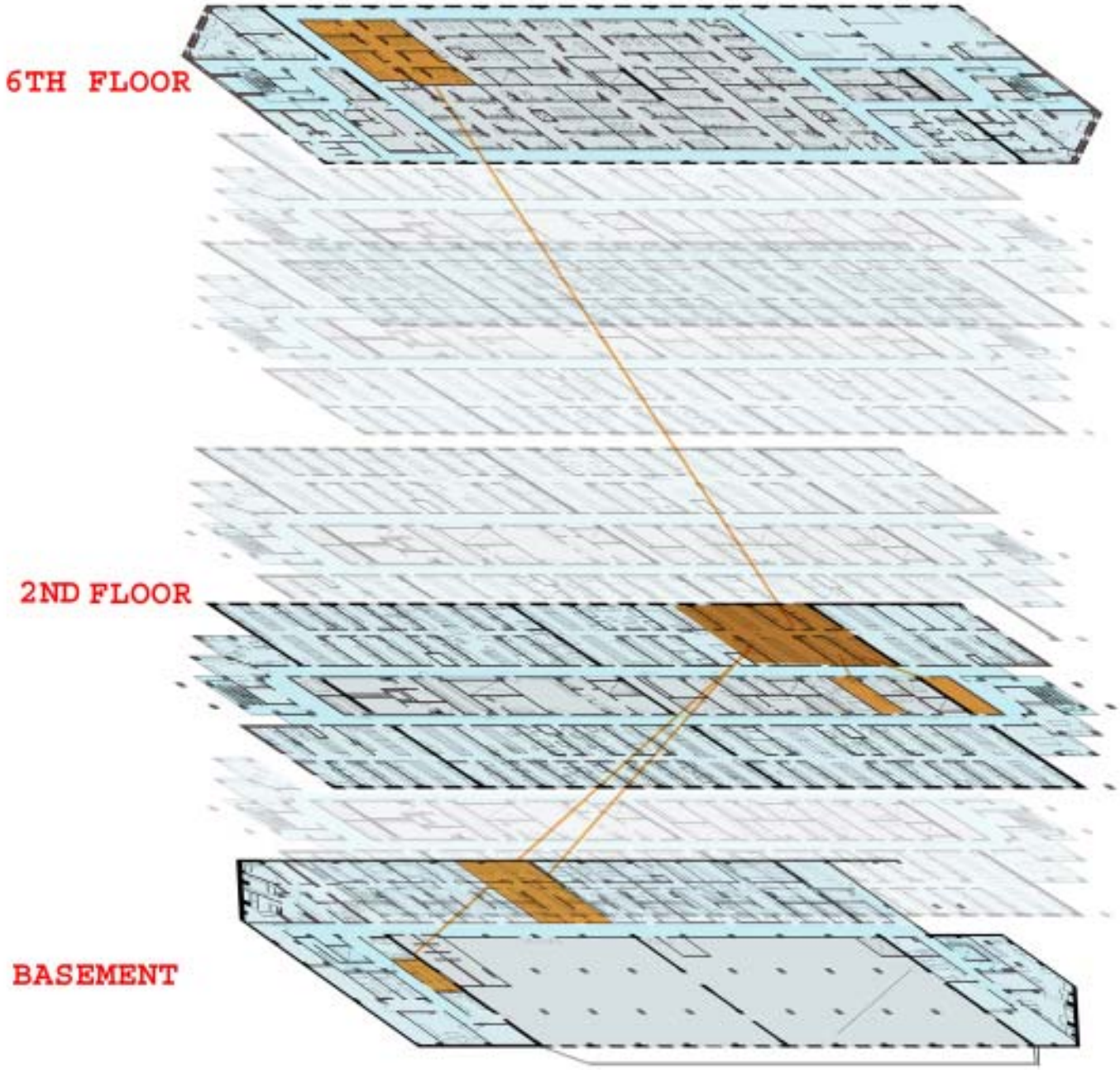
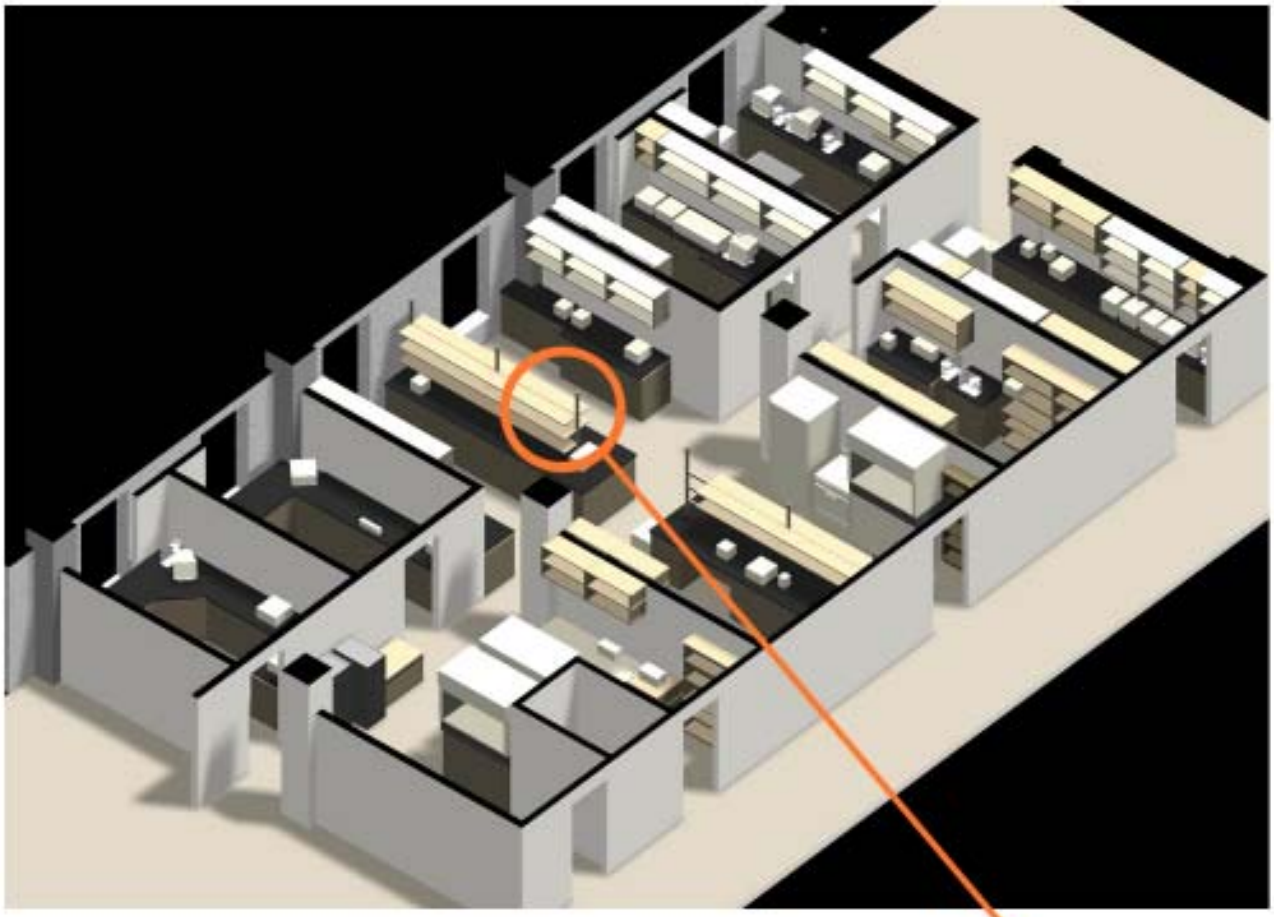


Figure 24: Sample Lab #2, Relationship Between Lab, Core, and Animal Space



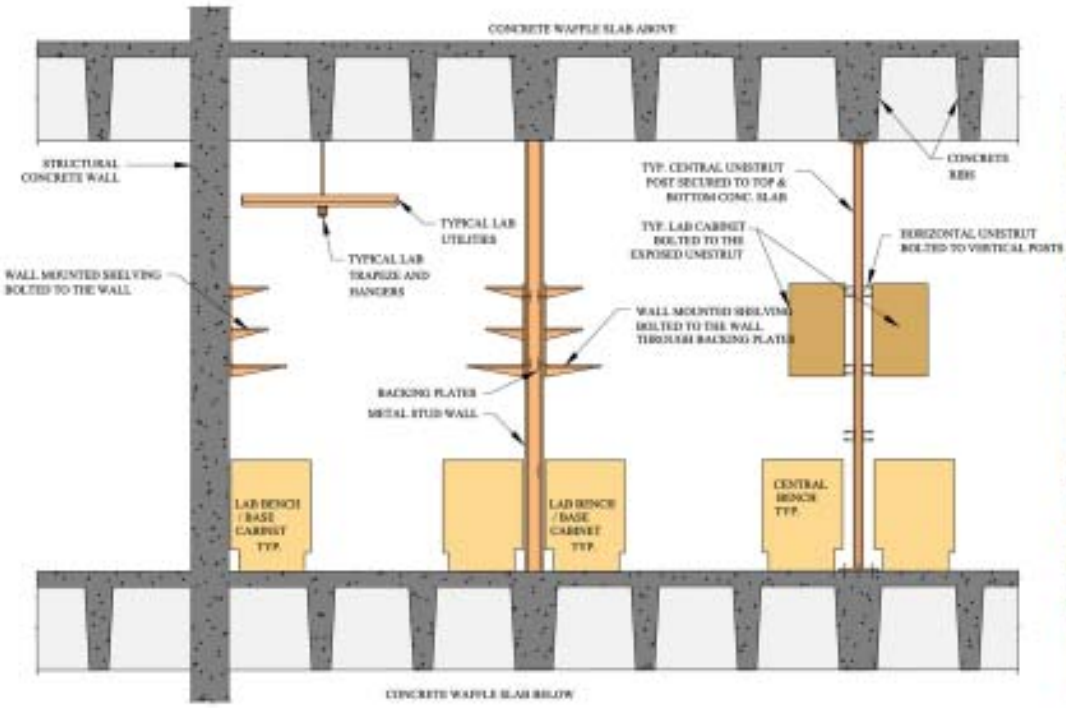


Figure 25: Sample Lab #2, 3-Dimensional Diagram with Photos (a)

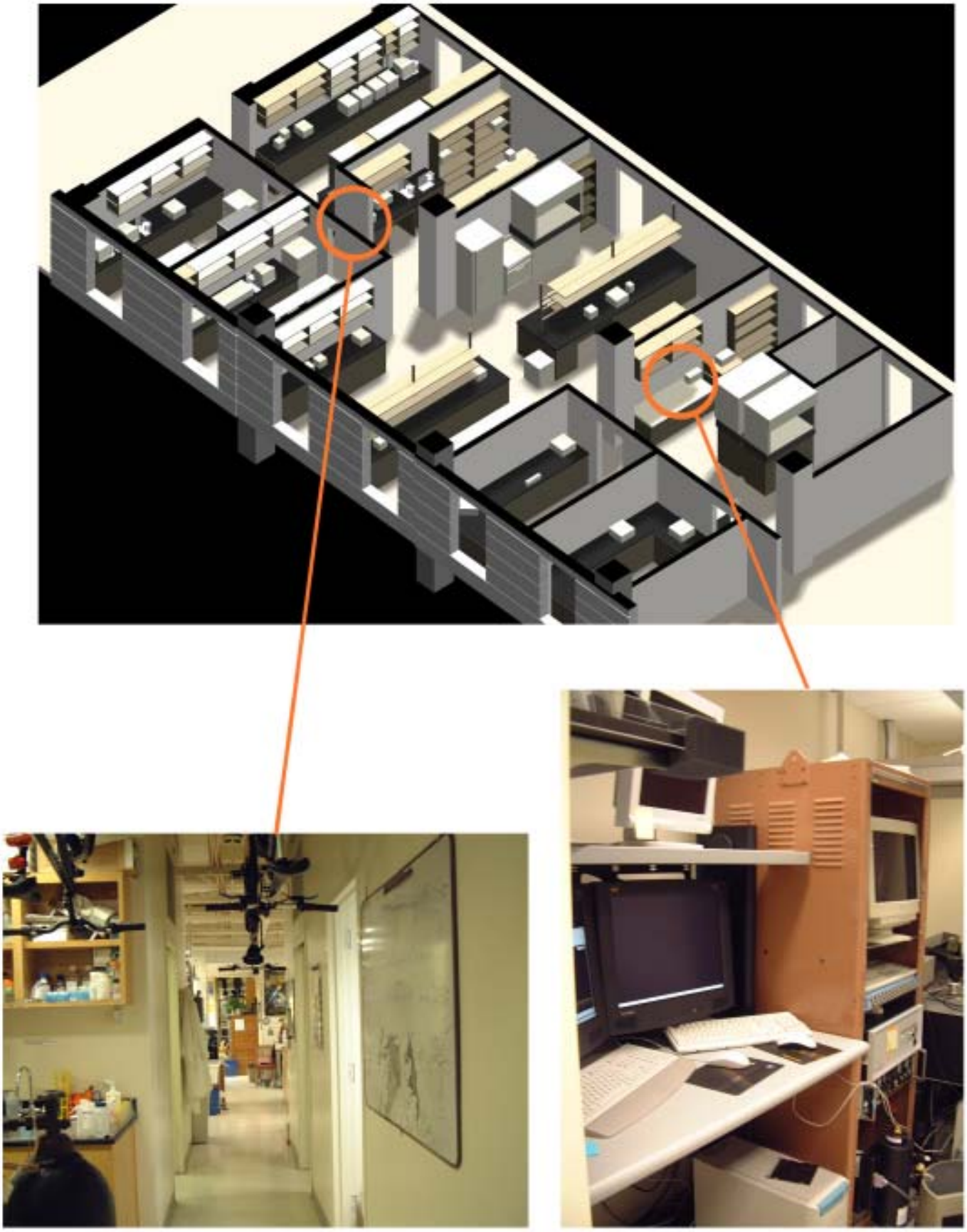
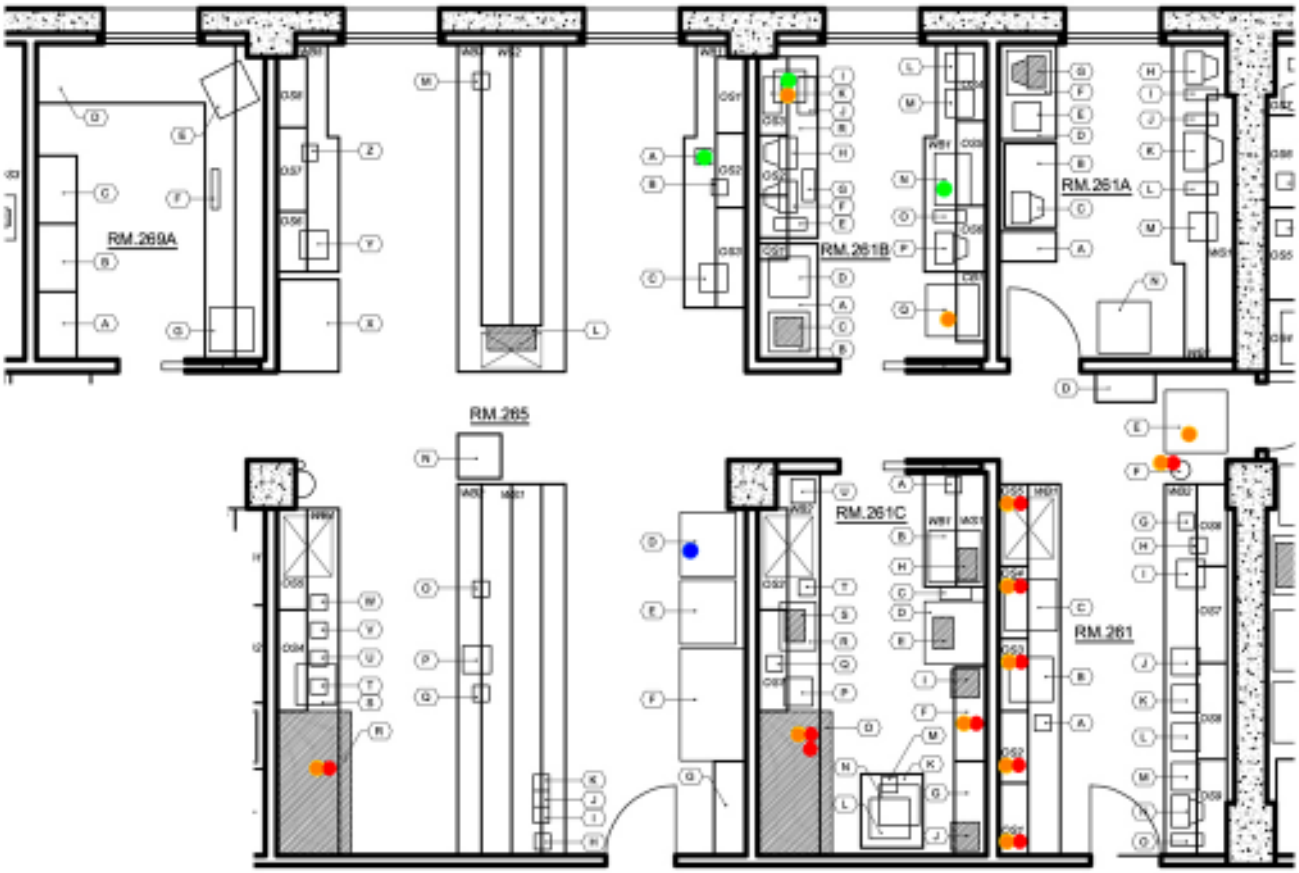
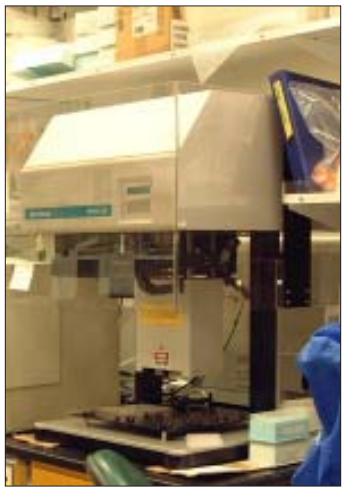


Figure 26: Sample Lab #2, 3-Dimensional Diagram with Photos (b)





importance

value

chemical

life safety 'D'

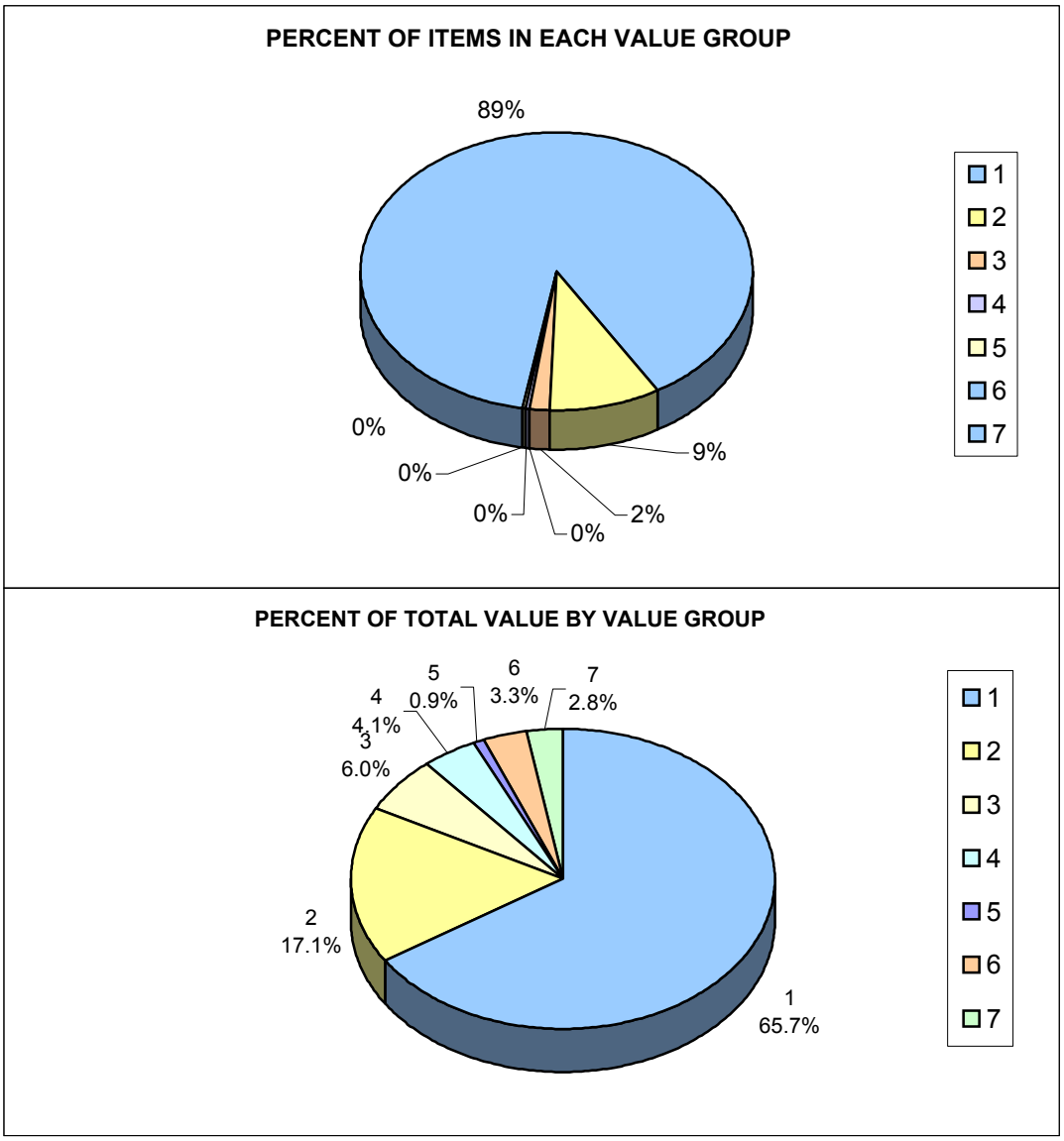
Figure 27: Sample Lab #2, Examples of Critical Items

Room	Sub	Key	Equipment	Life Safety	Value	Importance	Chem.
261	b	I	**Con-Focal Microscope**	D *	5	N	N
261	b	N	**DNA Sequencer**	C	6	N	N
261	b	Q	**Cyrotone**	D	1	N	N
261	c	F	**Cabinet**	B	1	N	CH/A
261	c	O	**Fume Hood**	C	2	N	CH/A
261	c	O	**Fume Hood**	C	2	N	CH/A
261		E	**Freezer**	D	2	N	N
261		F	**Gas Cylinder**	C	1	N	CH/R
261		OS-1-5	**Open Shelving**	A/SL	1	N	CH/A
265		A	**Centrifuge**	C	4	N	N
265		D	**Freezer (-20)**	C	2	Y	N
265		E	**Refrigerator**	D	2	N	N
265		F	**Refrigerator**	D	2	N	N
265		R	**Fume Hood**	C	2	N	CH/A
269/271		B	**Refrigerator**	D	1	N	N
269/271		C	**Refrigerator**	D	1	N	N
244	Core	H	**BioCabinet/Fume Hood**	C	2	Y	N
244	Core	J	**BioCabinet/Fume Hood**	C	2	Y	N
244	Core	K	**BioCabinet/Fume Hood**	C	2	Y	N
244	Core	I	**Freezer**	D	2	N	N
244	Core	L	**Freezer**	D	2	N	N
244	Core	B	**Incubator**	D	2	Y	N
244	Core	C	**Incubator**	D	2	Y	N
248	Core	G	**Centrifuge**	C	3	Y	N
248	Core	B	**Freezer**	D	2	Y	N
248	Core	C	**Freezer**	D	2	Y	N
248	Core	E	**Freezer**	D	2	Y	N
248	Core	K	**Freezer**	D	2	Y	N
248	Core	L	**Freezer**	D	2	Y	N
26	basement	B	**Water Tank**	B	1	Y	N
26	basement	F-H	**Water Tank**	B	1	Y	N
690	basement	A-C	**Racks**	C	1	Y	N
690	basement	A-C	**Racks**	C	1	Y	N
690	basement	A-C	**Racks**	C	1	Y	N
690	basement	A-E	**Racks**	C	1	Y	N
690	basement	A-B	**Racks**	C	1	Y	N
690	basement	A-B	**Racks**	C	1	Y	N

Note: Items designated as life safety, valuable, important, and chemical hazard are **13%** of local lab contents. (Critical items in related spaces are included below the line.)

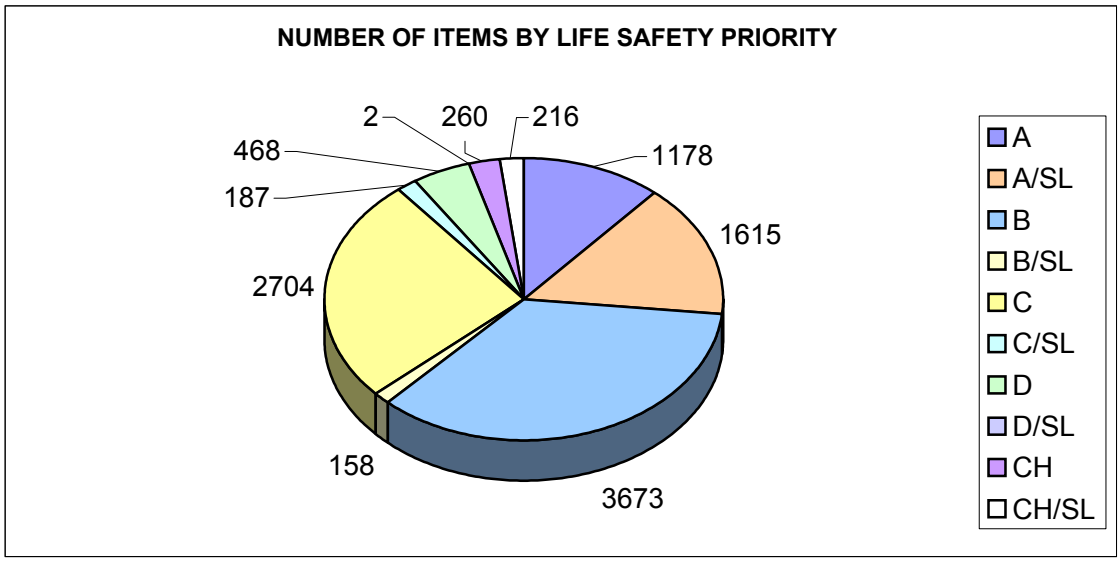
*Only Life Safety Category 'D' is shown in Figure 27 & 28

Figure 28: Sample Lab #2, Critical Items

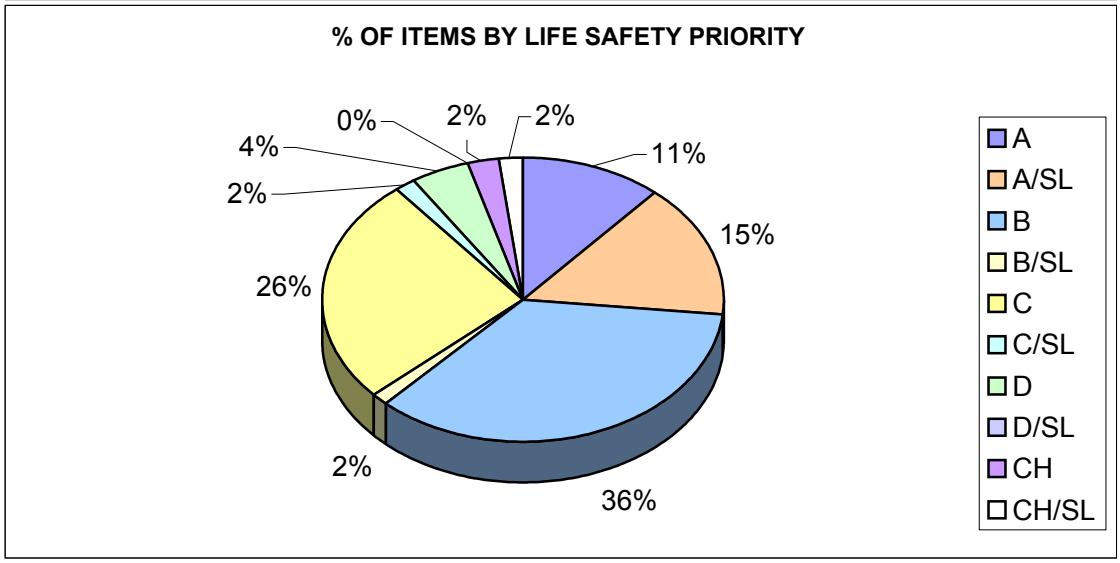


Value Group	Range of Value
1	$0-$5K
2	$5-$10K
3	$10-$20K
4	$20-$50K
5	$50-$100K
6	$100-$200K
7	$200-$1,000K

Figure 29: Number and Percentage in Each Value Group and Percentage of Total Value by Group



30a



30b

Designation	Translation
A	Low priority for anchorage
A/SL	Low priority + Shelf Lip
B	Moderate priority for anchorage
B/SL	Moderate priority + Shelf Lip
C	High Priority for Anchorage
C/SL	High Priority + Shelf Lip
D	Highest Priority for Anchorage
D/SL	Highest Priority + Shelf Lip
CH	Chemical Hazard
CH/SL	Chemical Hazard + Shelf Lip

Figure 30: Number and Percentage of Items by Life Safety Designation

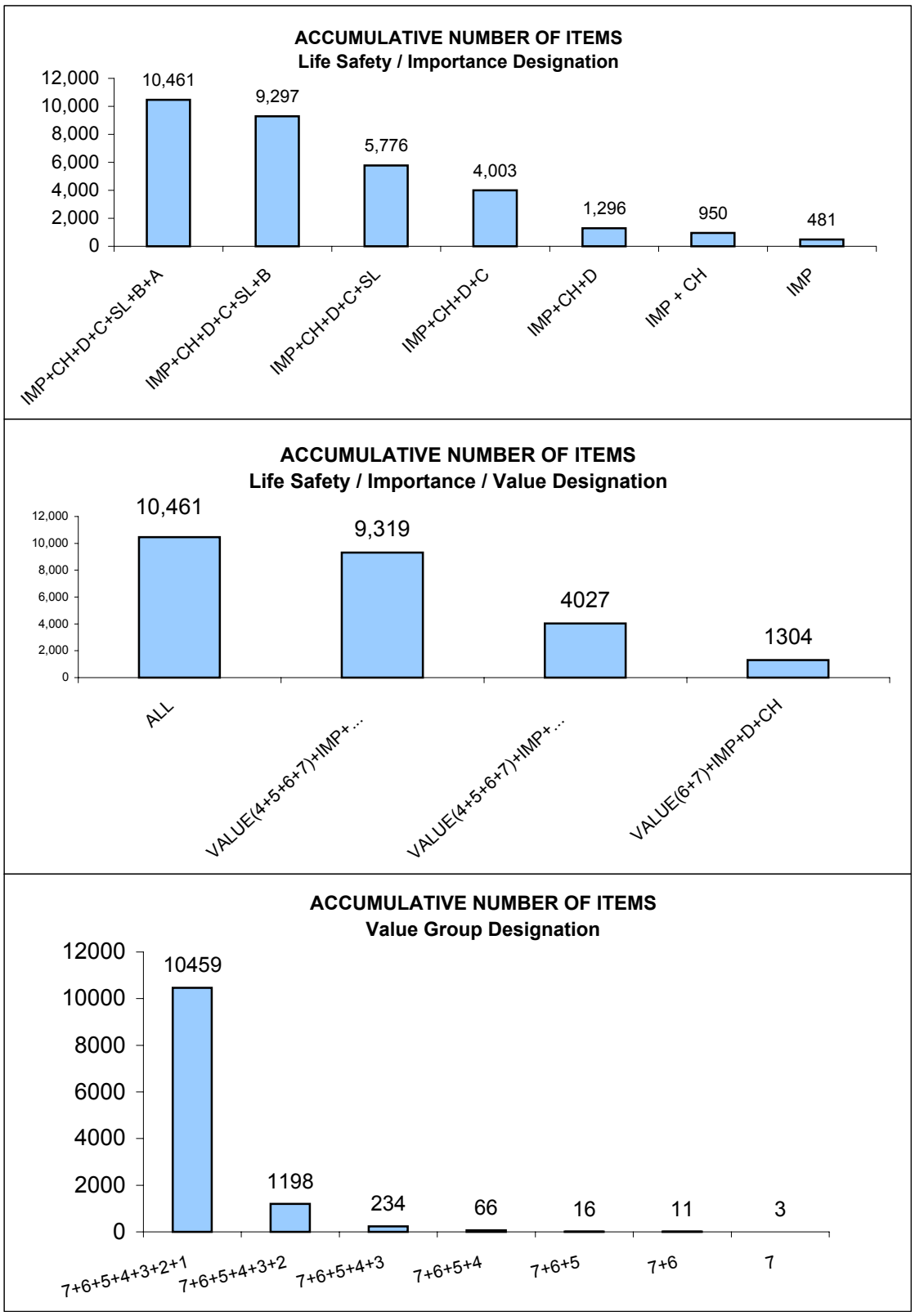
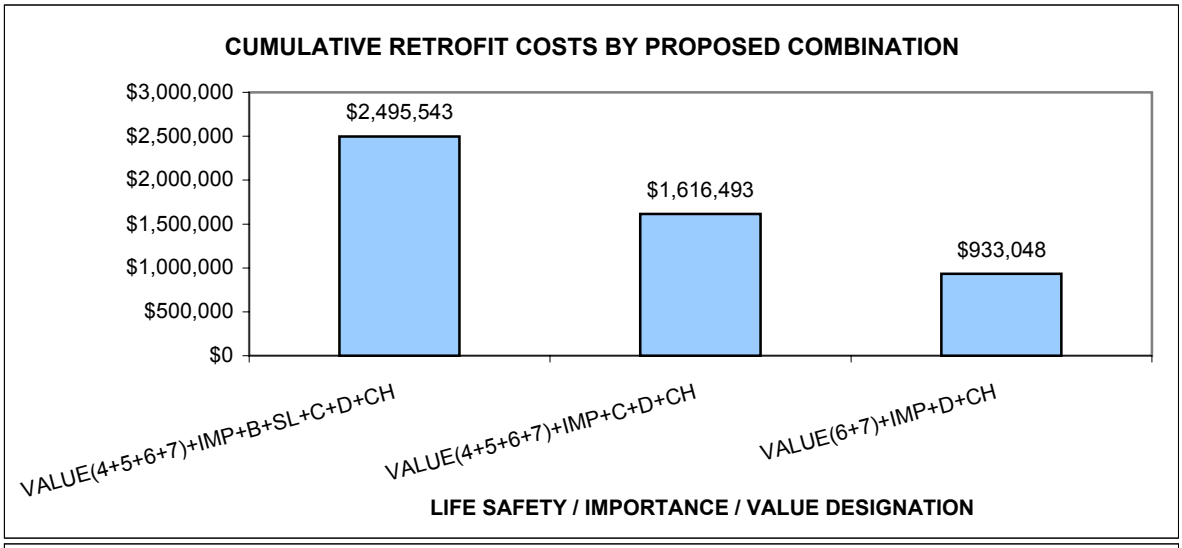
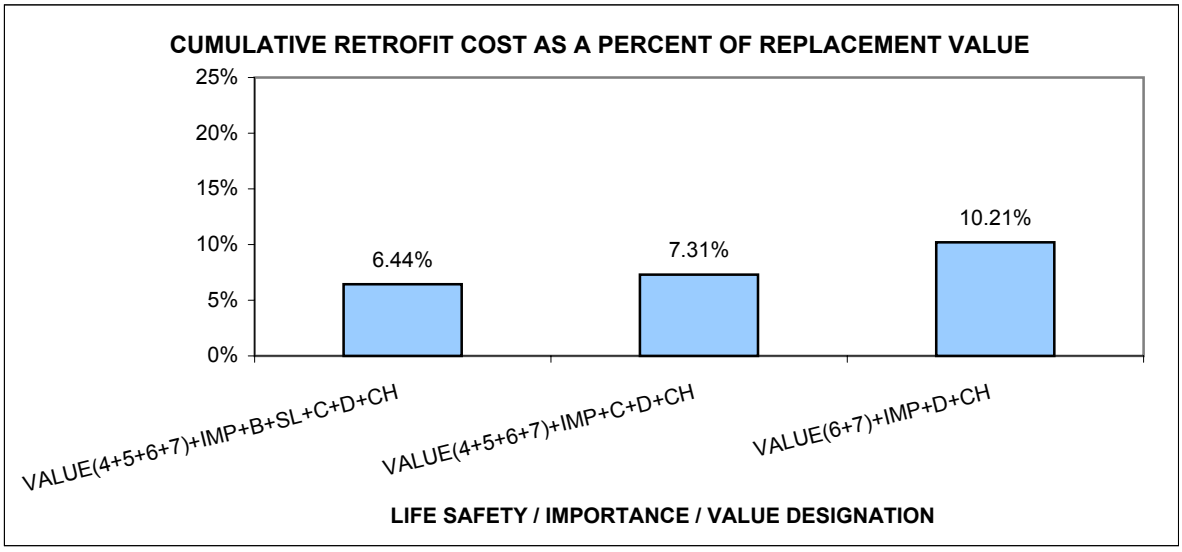


Figure 31: Accumulative Number of Items by Life Safety, Value, and Importance



32a

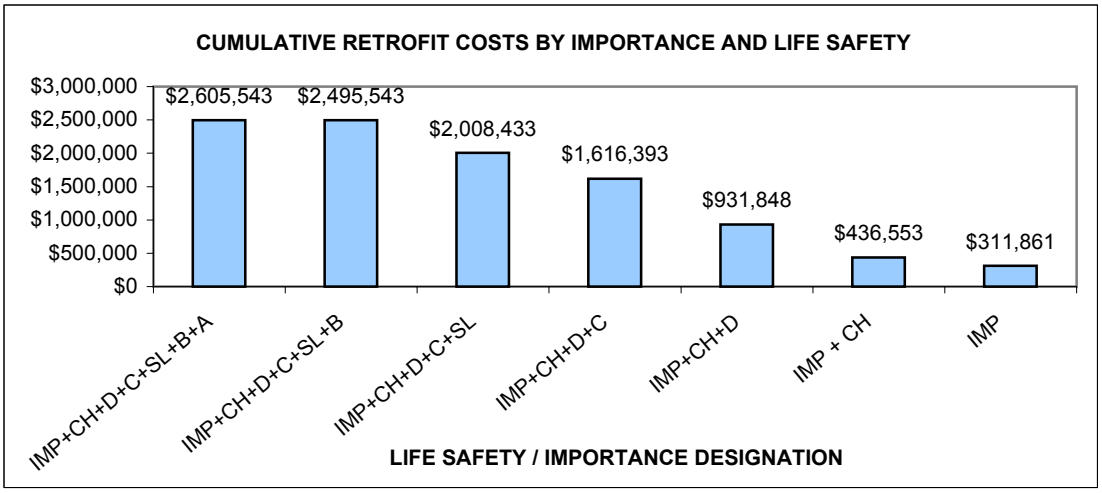


32b

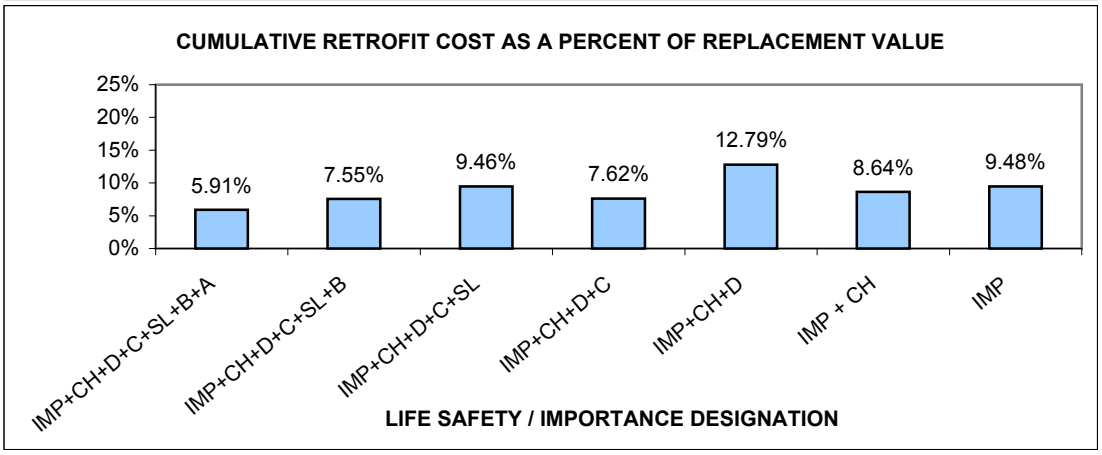
Research Laboratory	**=**	**50,822**	**s.f.**
Research Activities	**=**	**22,533**	**s.f.**
Animal Space	**=**	**26,387**	**s.f.**
Total Lab Space	**=**	**99,742**	**s.f.**
Total A.S.F	**=**	**122,022**	**s.f.**

Value (4+5+6+7)+IMP+B+SL+C+D+CH		
Total Retrofit Costs	**=**	**$2,495,543**
Cost per Lab s.f.	**=**	**$25**
Cost per A.S.F.	**=**	**$21**
Value (4+5+6+7)+IMP+C+D+CH		
Total Retrofit Costs	**=**	**$1,616,493**
Cost per Lab s.f.	**=**	**$16**
Cost per A.S.F.	**=**	**$13**
Value (6+7)+IMP+D+CH		
Total Retrofit Costs	**=**	**$933,048**
Cost per Lab s.f.	**=**	**$9**
Cost per A.S.F.	**=**	**$8**

Figure 32: Cumulative Retrofit Costs by Proposed Combination



33a



33b

Research Laboratory	**=**	**50,822 s.f.**
Research Activities	**=**	**22,533 s.f.**
Animal Space	**=**	**26,387 s.f.**
Total Lab Space	**=**	**99,742 s.f.**
Total A.S.F	**=**	**122,022 s.f.**

IMP+CH+D+C+SL+B+A

Total Retrofit Costs	**=**	**$2,605,543**
Cost per Lab s.f.	**=**	**$26**
Cost per A.S.F.	**=**	**$21.50**

IMP+CH+D+C+SL+B

Total Retrofit Costs	**=**	**$2,495,543**
Cost per Lab s.f.	**=**	**$25**
Cost per A.S.F.	**=**	**$21**

IMP+CH+D+C+SL

Total Retrofit Costs	**=**	**$2,008,433**
Cost per Lab s.f.	**=**	**$20**
Cost per A.S.F.	**=**	**$17**

IMP+CH+D+C

Total Retrofit Costs	**=**	**$1,616,393**
Cost per Lab s.f.	**=**	**$16**
Cost per A.S.F.	**=**	**$13**

IMP+CH+D

Total Retrofit Costs	**=**	**$931,848**
Cost per Lab s.f.	**=**	**$9**
Cost per A.S.F.	**=**	**$8**

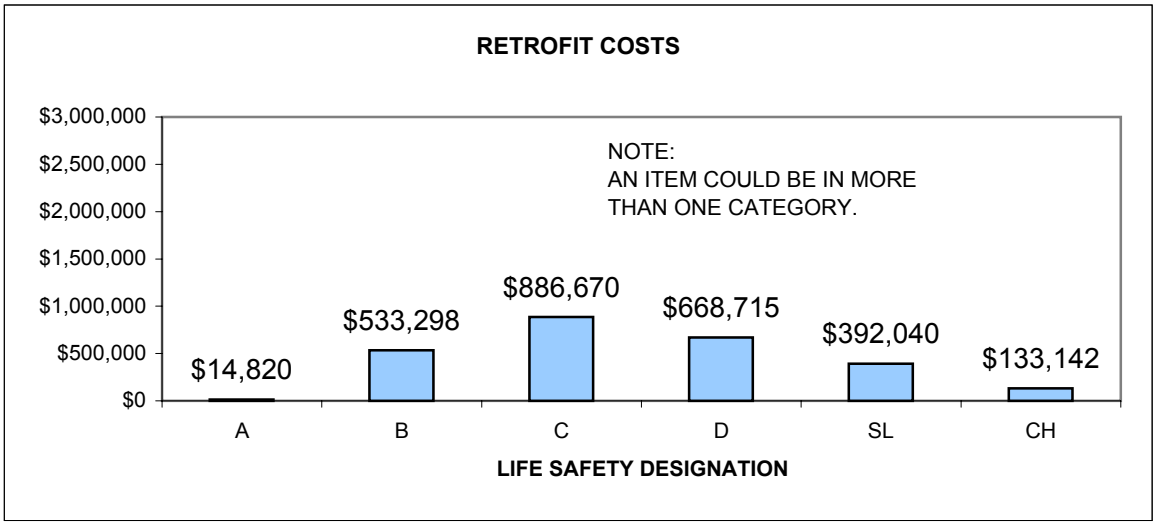
IMP+CH

Total Retrofit Costs	**=**	**$436,553**
Cost per Lab s.f.	**=**	**$4**
Cost per A.S.F.	**=**	**$3.50**

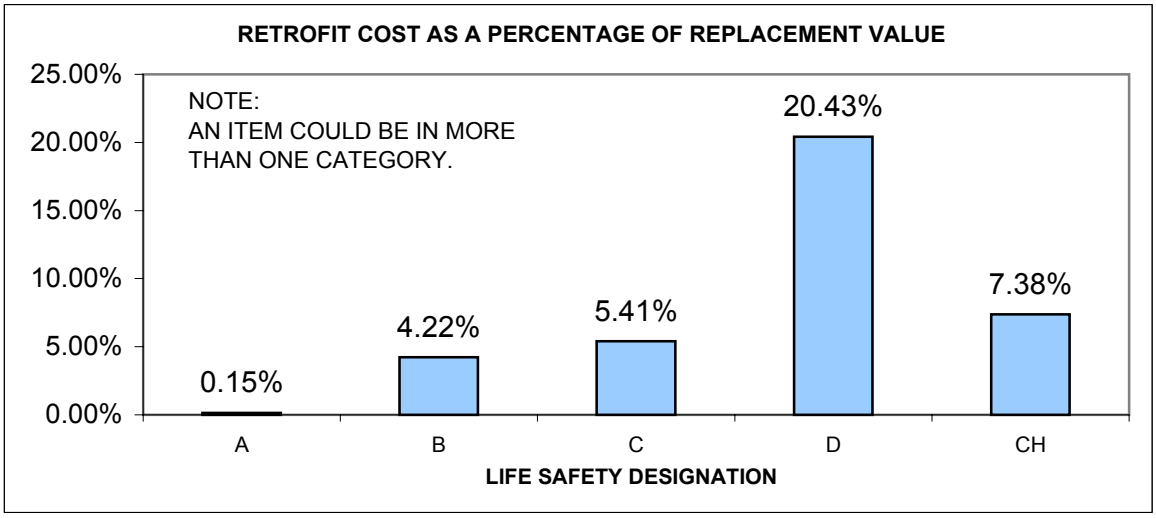
IMP

Total Retrofit Costs	**=**	**$311,861**
Cost per Lab s.f.	**=**	**$3**
Cost per A.S.F.	**=**	**$2.50**

Figure 33: Cumulative Retrofit Costs by Importance and Life Safety Designation



34a



34b

Research Laboratory	**=**	**50,822**	**s.f.**
Research Activities	**=**	**22,533**	**s.f.**
Animal Space	**=**	**26,387**	**s.f.**
Total Lab Space	**=**	**99,742**	**s.f.**
Total A.S.F	**=**	**122,022**	**s.f.**

Life Safety Designation 'A'

Total Retrofit Costs	**=**	**$14,820**
Cost per Lab s.f.	**=**	**<$1**
Cost per A.S.F.	**=**	**<$1**

Life Safety Designation 'B'

Total Retrofit Costs	**=**	**$533,298**
Cost per Lab s.f.	**=**	**$5**
Cost per A.S.F.	**=**	**$4**

Life Safety Designation 'C'

Total Retrofit Costs	**=**	**$886,670**
Cost per Lab s.f.	**=**	**$9**
Cost per A.S.F.	**=**	**$7**

Life Safety Designation 'D'

Total Retrofit Costs	**=**	**$668,715**
Cost per Lab s.f.	**=**	**$7**
Cost per A.S.F.	**=**	**$5**

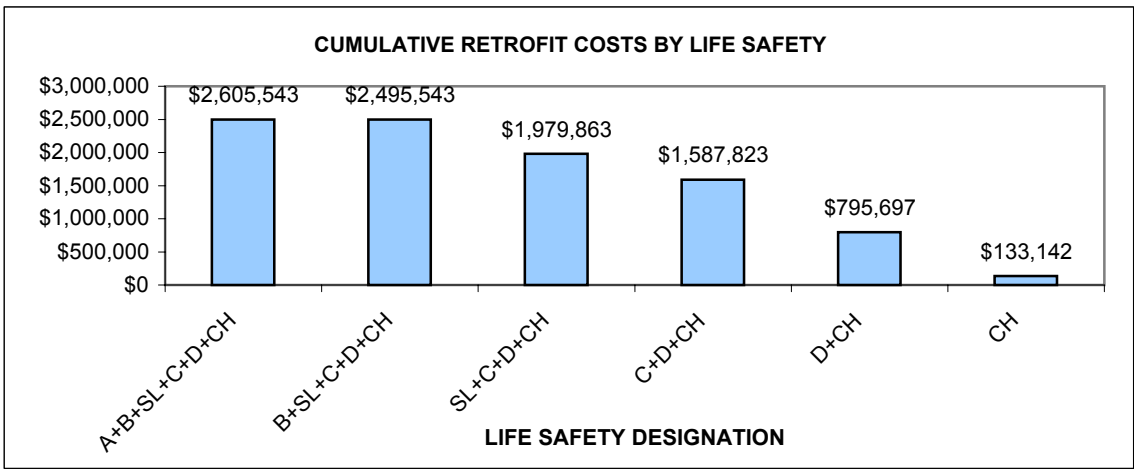
Life Safety Designation 'SL'

Total Retrofit Costs	**=**	**$392,040**
Cost per Lab s.f.	**=**	**$4**
Cost per A.S.F.	**=**	**$3**

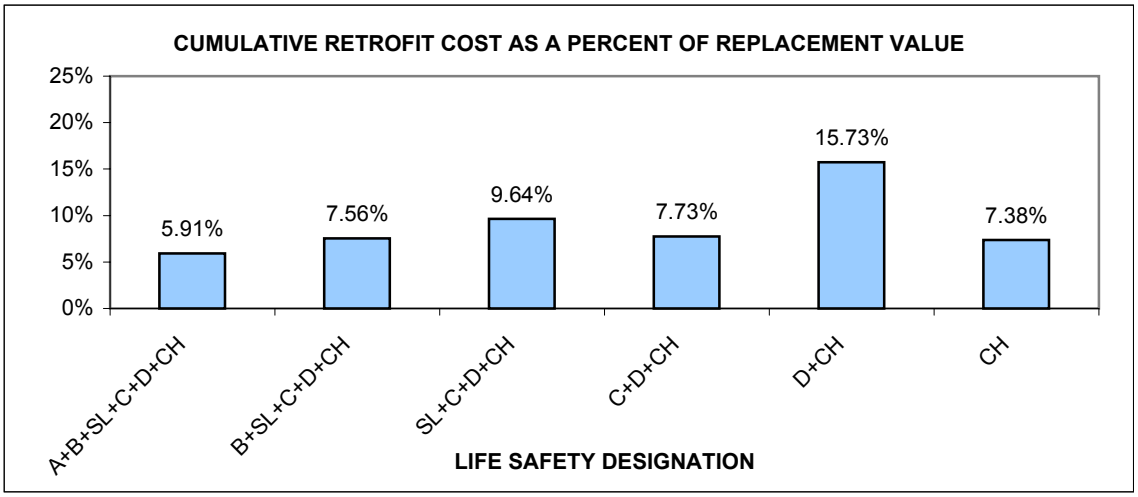
Life Safety Designation 'CH'

Total Retrofit Costs	**=**	**$133,142**
Cost per Lab s.f.	**=**	**$1**
Cost per A.S.F.	**=**	**$1**

Figure 34: Retrofit Costs for Life Safety Designations



35a



35b

Research Laboratory	**=**	**50,822**	**s.f.**
Research Activities	**=**	**22,533**	**s.f.**
Animal Space	**=**	**26,387**	**s.f.**
Total Lab Space	**=**	**99,742**	**s.f.**
Total A.S.F	**=**	**122,022**	**s.f.**

A+B+SL+C+D+CH

Total Retrofit Costs	**=**	**$2,605,543**
Cost per Lab s.f.	**=**	**$26**
Cost per A.S.F.	**=**	**$21.50**

B+SL+C+D+CH

Total Retrofit Costs	**=**	**$2,495,543**
Cost per Lab s.f.	**=**	**$25**
Cost per A.S.F.	**=**	**$21**

SL+C+D+CH

Total Retrofit Costs	**=**	**$1,979,863**
Cost per Lab s.f.	**=**	**$20**
Cost per A.S.F.	**=**	**$16**

D+CH

Total Retrofit Costs	**=**	**$795,697**
Cost per Lab s.f.	**=**	**$8**
Cost per A.S.F.	**=**	**$7**

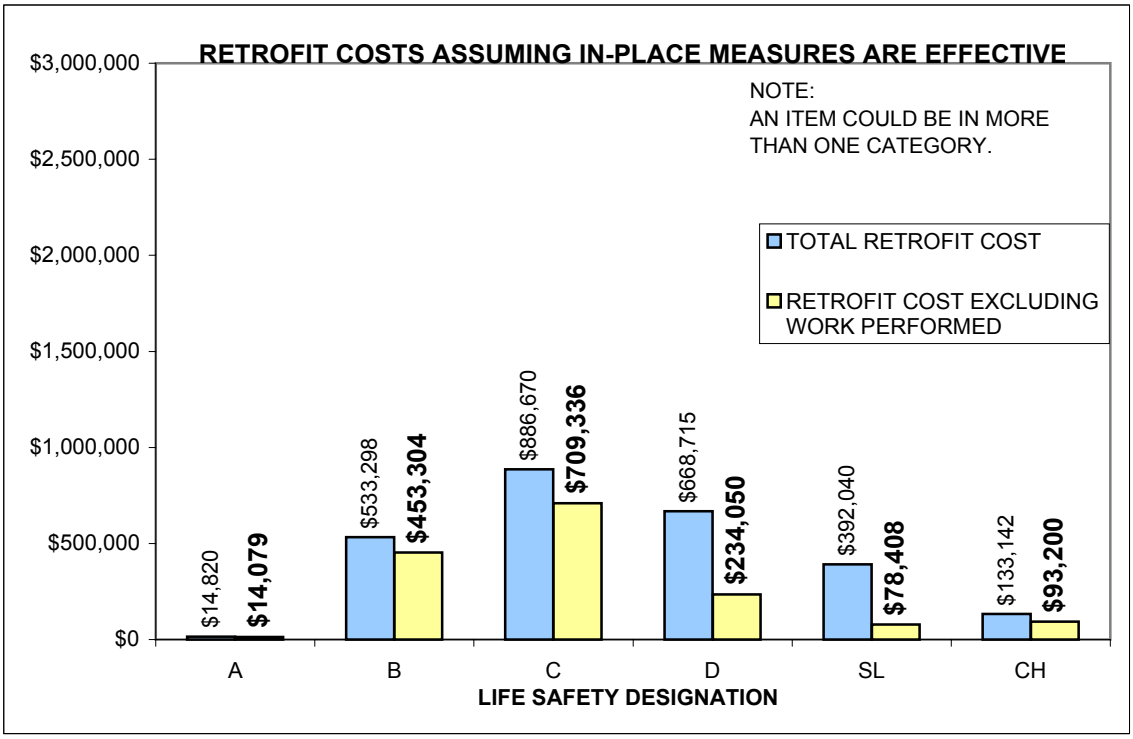
CH

Total Retrofit Costs	**=**	**$133,142**
Cost per Lab s.f.	**=**	**$1**
Cost per A.S.F.	**=**	**$1**

C+D+CH

Total Retrofit Costs	**=**	**$1,587,823**
Cost per Lab s.f.	**=**	**$16**
Cost per A.S.F.	**=**	**$13**

Figure 35: Cumulative Retrofit Costs by Life Safety Designation



Research Laboratory	**=**	**50,822**	**s.f.**
Research Activities	**=**	**22,533**	**s.f.**
Animal Space	**=**	**26,387**	**s.f.**
Total Lab Space	**=**	**99,742**	**s.f.**
Total A.S.F	**=**	**122,022**	**s.f.**

Life Safety Designation 'A'

Total Retrofit Costs	**=**	**$14,079**
Cost per Lab s.f.	**=**	**<$1**
Cost per A.S.F.	**=**	**<$1**

Life Safety Designation 'B'

Total Retrofit Costs	**=**	**$453,304**
Cost per Lab s.f.	**=**	**$5**
Cost per A.S.F.	**=**	**$4**

Life Safety Designation 'C'

Total Retrofit Costs	**=**	**$709,336**
Cost per Lab s.f.	**=**	**$7**
Cost per A.S.F.	**=**	**$6**

Life Safety Designation 'D'

Total Retrofit Costs	**=**	**$234,050**
Cost per Lab s.f.	**=**	**$2**
Cost per A.S.F.	**=**	**$2**

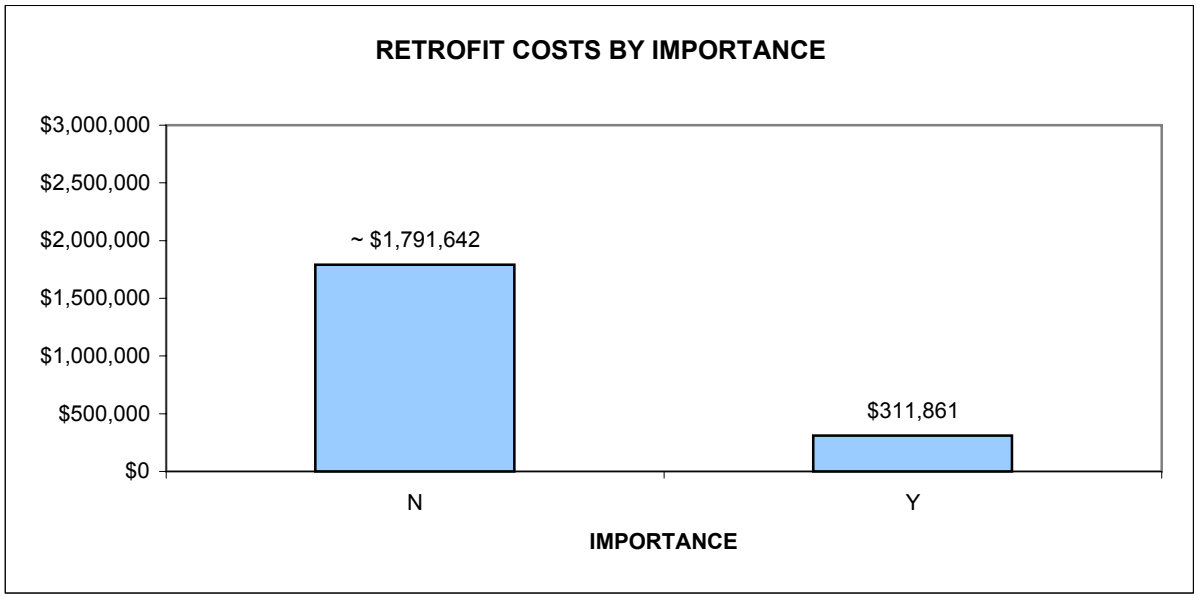
Life Safety Designation 'SL'

Total Retrofit Costs	**=**	**$78,408**
Cost per Lab s.f.	**=**	**$1**
Cost per A.S.F.	**=**	**$1**

Life Safety Designation 'CH'

Total Retrofit Costs	**=**	**$93,200**
Cost per Lab s.f.	**=**	**$1**
Cost per A.S.F.	**=**	**$1**

Figure 36: Retrofit Costs by Life Safety Assuming In-Place Measures are Effective

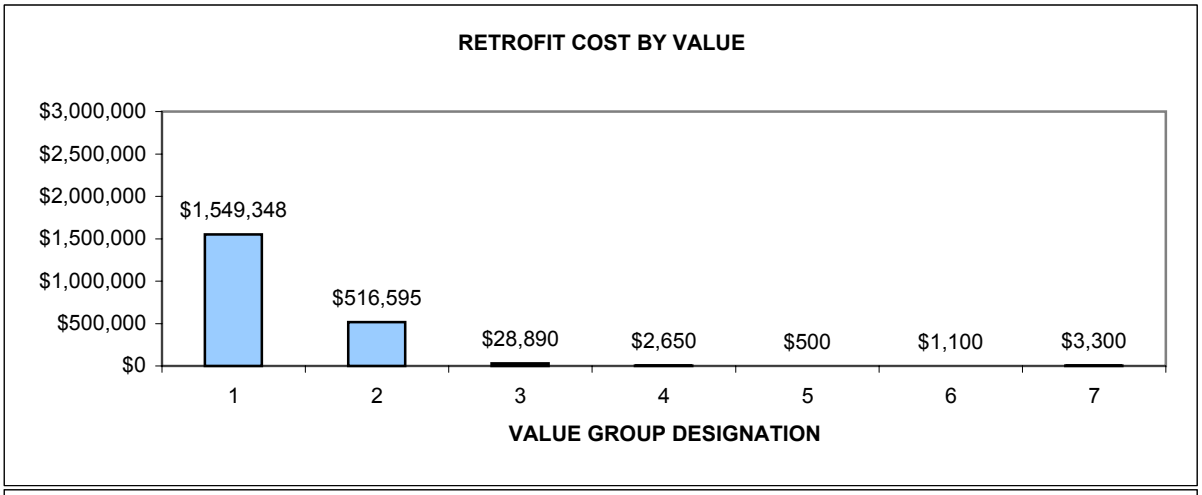


Research Laboratory	**=**	**50,822**	**s.f.**
Research Activities	**=**	**22,533**	**s.f.**
Animal Space	**=**	**26,387**	**s.f.**
Total Lab Space	**=**	**99,742**	**s.f.**
Total A.S.F	**=**	**122,022**	**s.f.**

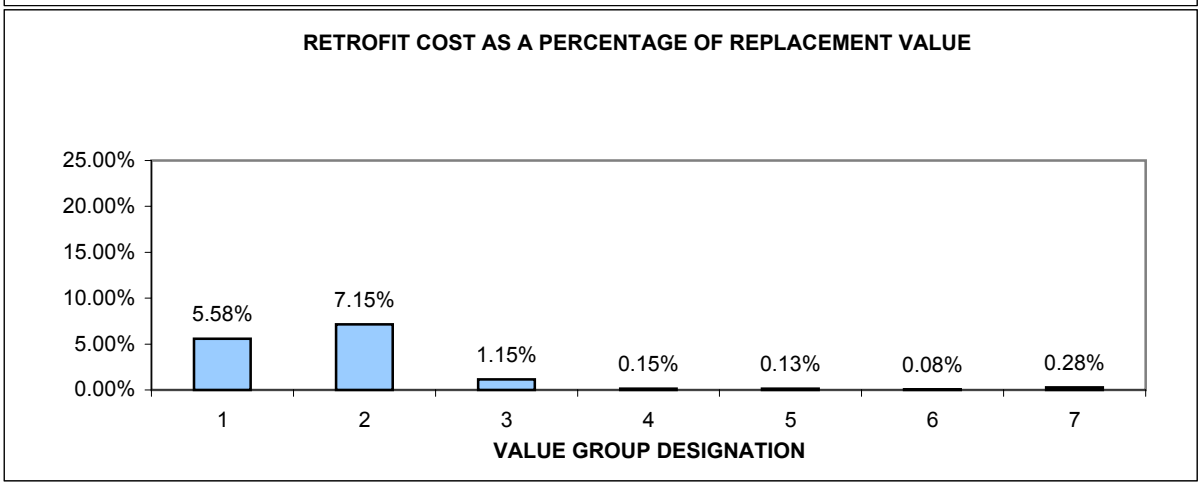
Importance 'Y'

Total Retrofit Costs	**=**	**$311,861**
Cost per Lab s.f.	**=**	**$3**
Cost per A.S.F.	**=**	**$3**

Figure 37: Retrofit Costs by Importance



38a



38b

Research Laboratory	**=**	**50,822**	**s.f.**
Research Activities	**=**	**22,533**	**s.f.**
Animal Space	**=**	**26,387**	**s.f.**
Total Lab Space	**=**	**99,742**	**s.f.**
Total A.S.F	**=**	**122,022**	**s.f.**

Value '1'

Total Retrofit Costs	**=**	**$1,549,348**
Cost per Lab s.f.	**=**	**$16**
Cost per A.S.F.	**=**	**$13**

Value '2'

Total Retrofit Costs	**=**	**$516,595**
Cost per Lab s.f.	**=**	**$5**
Cost per A.S.F.	**=**	**$4**

Value '3'

Total Retrofit Costs	**=**	**$28,890**
Cost per Lab s.f.	**=**	**<$1**
Cost per A.S.F.	**=**	**<$1**

Value '4'

Total Retrofit Costs	**=**	**$2,650**
Cost per Lab s.f.	**=**	**<$1**
Cost per A.S.F.	**=**	**<$1**

Value '5'

Total Retrofit	**=**	**$500**
Cost per Lab	**=**	**<$1**
Cost per A.S	**=**	**<$1**

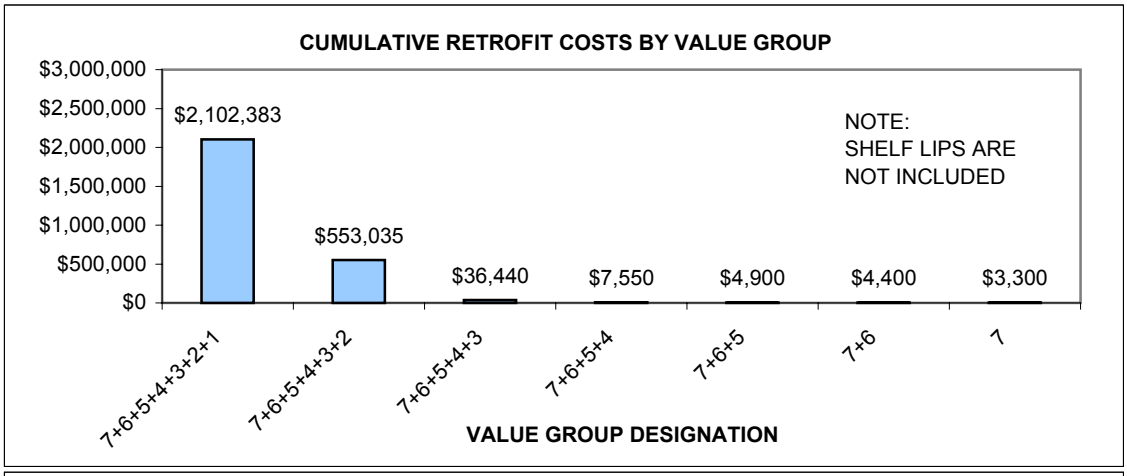
Value '6'

Total Retrofit	**=**	**$1,100**
Cost per Lab	**=**	**<$1**
Cost per A.S	**=**	**<$1**

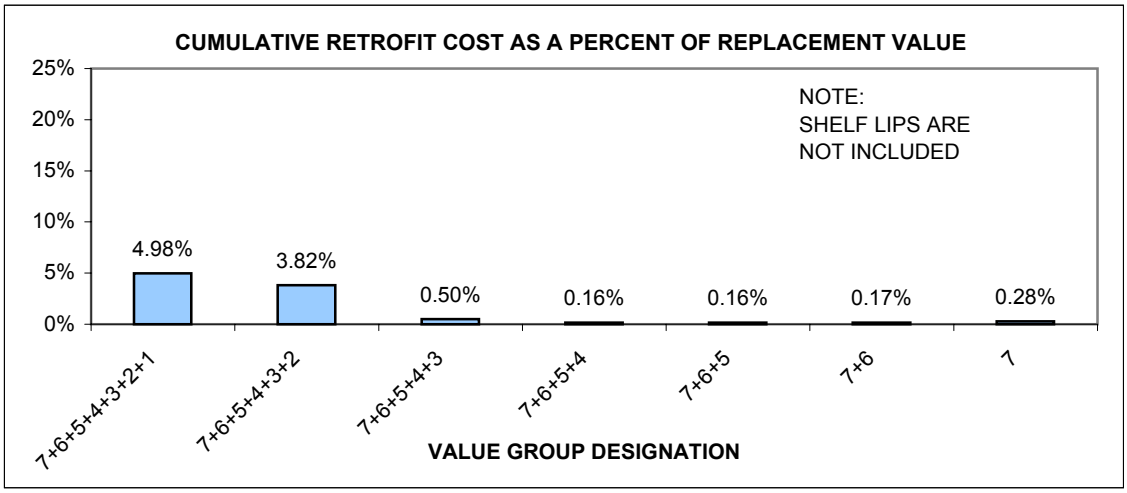
Value '7'

Total Retrofit	**=**	**$3,300**
Cost per Lab	**=**	**<$1**
Cost per A.S	**=**	**<$1**

Figure 38: Retrofit Costs by Value Designation



39a



39b

Research Laboratory	**=**	**50,822**	**s.f.**
Research Activities	**=**	**22,533**	**s.f.**
Animal Space	**=**	**26,387**	**s.f.**
Total Lab Space	**=**	**99,742**	**s.f.**
Total A.S.F	**=**	**122,022**	**s.f.**

7+6+5+4+3+2+1

Total Retrofit Costs	**=**	**$2,101,383**
Cost per Lab s.f.	**=**	**$21**
Cost per A.S.F.	**=**	**$17**

7+6+5+4+3+2

Total Retrofit Costs	**=**	**$553,035**
Cost per Lab s.f.	**=**	**$6**
Cost per A.S.F.	**=**	**$5**

7+6+5+4+3

Total Retrofit Costs	**=**	**$36,440**
Cost per Lab s.f.	**=**	**<$1**
Cost per A.S.F.	**=**	**<$1**

7+6+5+4

Total Retrofit Costs	**=**	**$7,550**
Cost per Lab s.f.	**=**	**<$1**
Cost per A.S.F.	**=**	**<$1**

7+6+5

Total Retrofit Costs	**=**	**$4,900**
Cost per Lab s.f.	**=**	**<$1**
Cost per A.S.F.	**=**	**<$1**

7+6

Total Retrofit Costs	**=**	**$4,400**
Cost per Lab s.f.	**=**	**<$1**
Cost per A.S.F.	**=**	**<$1**

7

Total Retrofit Costs	**=**	**$3,300**
Cost per Lab s.f.	**=**	**<$1**
Cost per A.S.F.	**=**	**<$1**

Figure 39: Cumulative Retrofit Costs by Value Groups

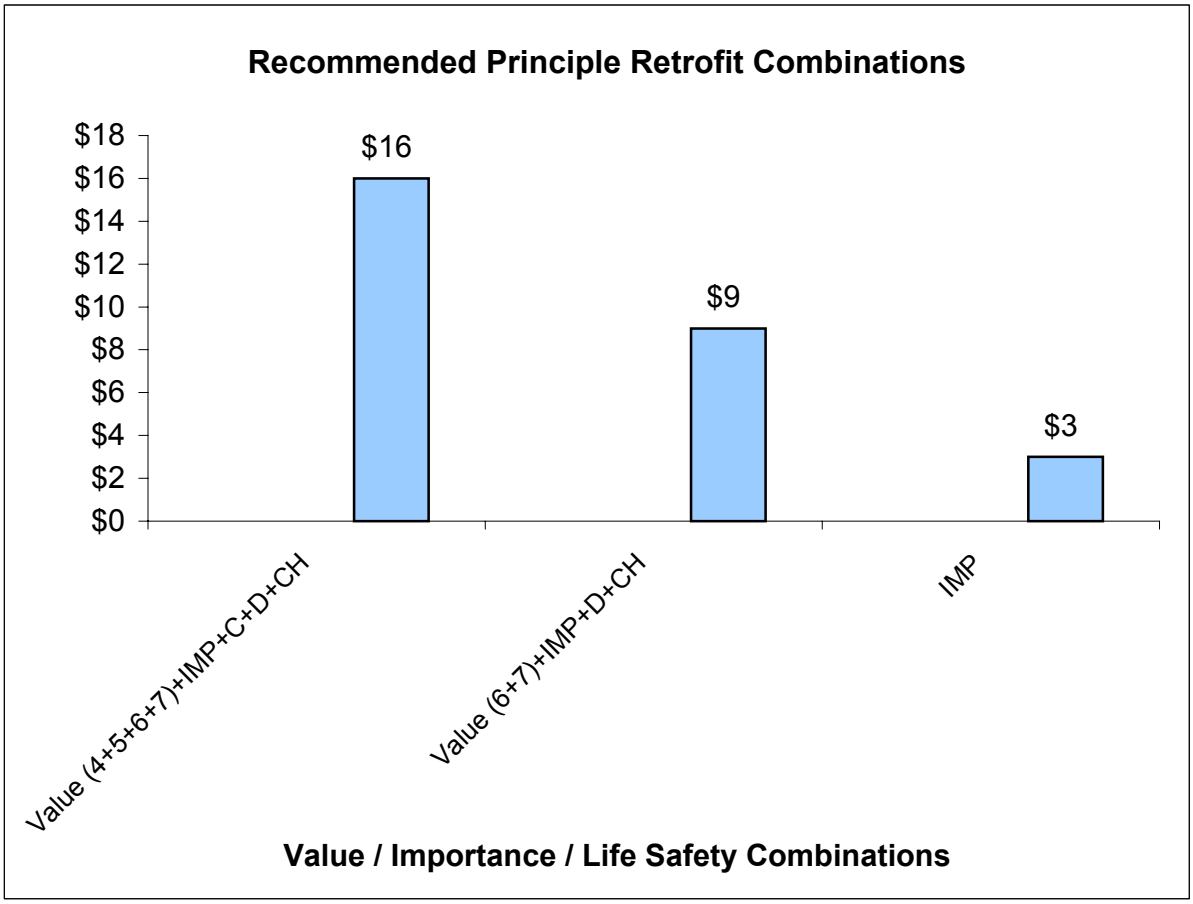


Figure 40: Retrofit Costs by Recommended Combination without Existing Measures

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APPENDIX A

Evaluation of the Seismic Vulnerability of the Existing Mechanical/Electrical Systems

June 2002

Background

As part of the Pilot Project for Nonstructural Seismic Hazard Mitigation focusing on the case study building, a detailed inventory of the contents of laboratory spaces has been collected. These contents generally consist of furniture, equipment, and supplies not normally considered part of the building and therefore not covered by code requirements for seismic protection. In the case of laboratories, the contents form the bulk of the value of the building and are the primary focus of the Pilot Project. These findings will form the basis of a comprehensive itemized inventory and analysis that will determine retrofit measures needed for various performance objectives.

Although not the main target of the study, the traditional nonstructural systems of the building, such as mechanical, electrical, and plumbing, also have an important influence on post-earthquake usability of the building. A visual survey of these systems was performed in February 2002 to determine if they were, in general, installed in accordance to seismic requirements of the building code. The responsibility to assure such compliance is shared and often unclear, typically leading to poor or incomplete seismic installations.

The purpose of this evaluation of existing nonstructural building systems is to determine if severe seismic deficiencies exist that would override any consideration of performance of the laboratory contents. Such a tendency would require detailed collection of building system inventory and installation of additional seismic protection to enable a realistic improvement to the performance of the lab spaces.

The building includes the normal systems associated with initial construction of a laboratory building. They can be categorized as follows:

- Ducts and piping, including HVAC, plumbing, and chemical, both in functional spaces and in mechanical rooms.
- Rooftop mechanical equipment, including chillers.
- Floor mounted mechanical equipment, including HVAC and other mechanical.

- Floor mounted electrical equipment, including cabinets and transformers.
- Tanks, including single and multiple compressed gases and water tanks.
- Suspended equipment, including HVAC and electrical.

The usual evaluation revealed that the building systems feature an unusually high level of compliance with code seismic anchorage and bracing requirements.

Figure A.1: Typical piping support

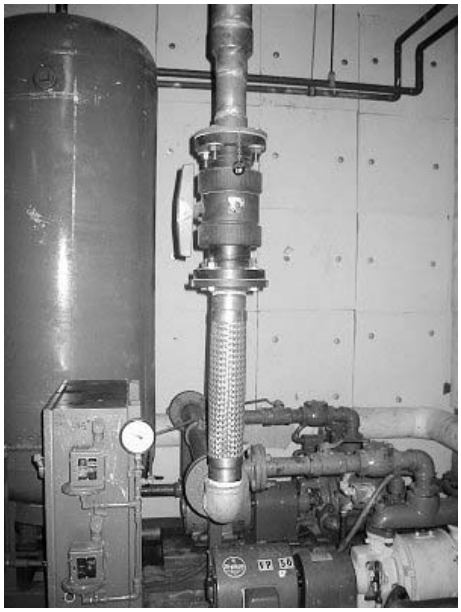

Figure A.2: Flexible piping connection

Ducts and Piping

Piping and ducts for the building's HVAC systems are extensive throughout the building on every floor. Most appear to have been restrained during installation from the ceiling level with diagonal cable braces. Issues regarding the effectiveness of the existing conditions include:

- Adequacy and condition of lateral seismic bracing (Figure A.1). Lateral bracing often consists of cables attached diagonally to sleeves used for vertical support. The attachment of the sleeves to the piping appears inadequate for lateral forces.
- Adequacy of flexible seismic connections (Figure A.2) between stationary floor-mounted equipment and ceiling-supported piping.
- Adequacy of strength of piping joints and connections to resist lateral forces where unrestrained.
- Adequacy of trapezes carrying laboratory utilities.

Figure A.3: Rooftop cabinet support

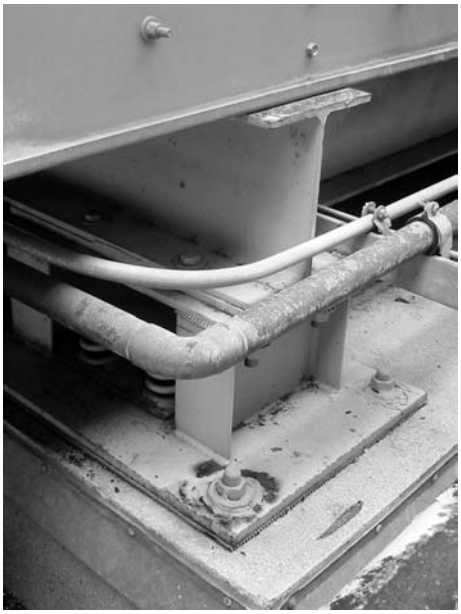

Figure A.4: Chiller support

Rooftop Mechanical Equipment

Many large pieces of equipment, including chillers, have been restrained with specially designed connections for vibration reduction in addition to seismic isolation. Most of the installation has been apparently been performed to code.

Issues regarding the effectiveness of the existing conditions include:

- Increased loading (over old code requirements) at roof (Figures A.3 and A.4).
- Installation of emergency generator (apparently as an addition).
- Effectiveness of cable bracing for piping.

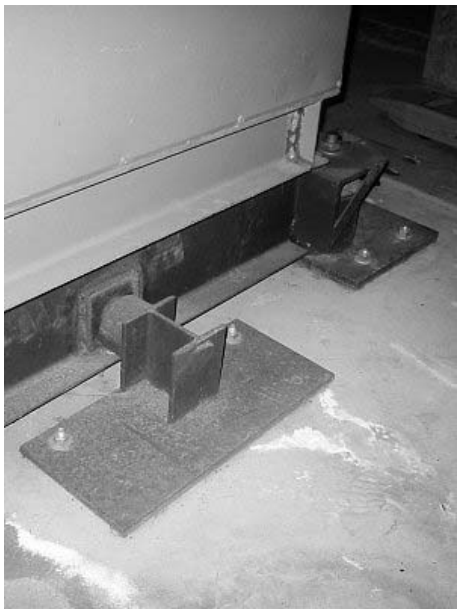

Figure A.5: Seismic bracing

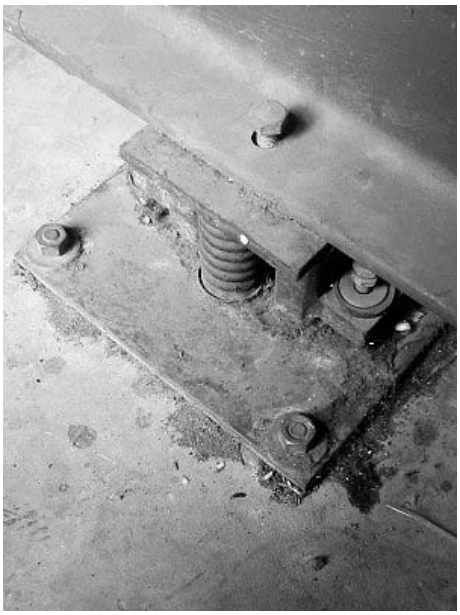

Figure A.6: Support detail

Floor Mounted Mechanical Equipment

Some of the larger pieces of mechanical equipment are located at the basement level. Most of these are installed on concrete pads and restrained independently in the vertical and horizontal directions. The floor mounted equipment appeared to be adequately anchored to the concrete slab. Issues regarding the effectiveness of the existing conditions include:

- Adequacy of vertical supports at ground level, including the interaction with vibration damping springs (Figure A.6).
- Ability of independent seismic bracing to resist lateral loads (Figure A.5).
- Condition of existing connections, including potential water damage from prior leaks or flooding.

Figure A.7: Typical electrical cabinet

Figure A.8: Detail of bolted connection

Floor Mounted Electrical Equipment

Most electrical equipment is confined to small rooms at the center of each floor and to the basement level of the building. Floor mounted equipment appeared to be adequately anchored and restrained. Issues regarding the effectiveness of the current conditions include:

- Adequacy of existing bolt attachments and conditions, including added washers (Figure A.8) and bolt tightness.
- Confirmation of the existence of proper restraints on cabinets where connection to the floor is not visible.

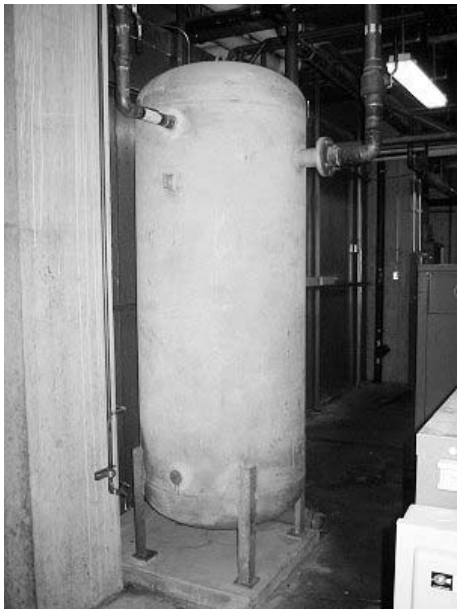

Figure A.9: Vertically oriented tank

Figure A.10: Multiple tanks

Tanks

Most tanks are restrained by various methods, depending on size and portability requirements. Larger tanks are permanently restrained to concrete pads at the basement level. Issues regarding the effectiveness of these existing conditions include:

- Adequacy of restraints for vertically oriented tanks (Figure A.9), which rely on ground level attachments to overcome the moment induced by lateral forces.
- Adequacy of multiple tank restraints (Figure A.10).

Figure A.11: Typical suspended cabinet

Figure A.12: Typical strongbacks

Suspended Equipment

Some mechanical equipment other than piping has been suspended from concrete slabs. Issues regarding the effectiveness of these existing conditions include:

- Adequacy of the vertical connections at the ceiling level (Figure A.11)
- Adequacy of horizontal restraints, particularly those that restrain the object in compression from a far distance.
- Adequacy of restraints of items from vertical strongbacks (Figure A.12).

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APPENDIX B

Evaluation of Equipment With Existing Seismic Restraints

June 2002

Background

As part of the Pilot Project for Nonstructural Hazard Mitigation focusing on the case study building, a detailed inventory of nonstructural components and contents has been collected. A somewhat unanticipated characteristic of some of the inventoried items is various seismic restraints added by the occupants or building management as an extension of the UC Berkeley Q-Brace program. Some of the restraints are commercially available "tethers," some, such as shelf lips, are considered "standard of practice," and some are one-off solutions developed for specific cases in this building. The restraints have apparently not been formally designed or tested and, in general, their efficacy is difficult to determine by calculation. This white paper is intended to document the types and extent of seismic restraints found in the case study building.

Laboratories in the case study building were visually examined during the month of October 2001 in order to identify seismic risks from nonstructural components and contents. These findings will form the basis of a comprehensive itemized inventory and analysis that will determine retrofit measures needed for various performance objectives.

The observations revealed a number of existing non-structural seismic restraints. Most of these were provided by the Quake-Bracing Assistance Program (Q-Brace), which allowed individual labs to reinforce non-structural items at their discretion. This program provided funds to campus buildings to anchor bookshelves, file cabinets, and other heavy equipment that could pose a life safety risk during an earthquake. The effectiveness of these existing restraints needs to be evaluated in context of the goals of the project.

General Observations

Most of the existing non-structural seismic restraints consist of the following:

- Some refrigerators, incubators, racks, and other large and heavy equipment have been attached to walls, strongbacks, or each other with chains. Manual latches have also been added to some refrigerators or cabinets to prevent doors from opening during earthquake motions.
- Lips, elastic cords, or metal plates have been added to some cabinet or open shelves in order to prevent chemicals, lab samples, or books from falling. Also, some floor mounted bookcases and cabinets have been attached directly to shear walls or partitions with screws, nails, or bolts.
- Commercial fabric tethers have been attached with adhesive to some computers, microscopes, microwave ovens, and other small items to secure them to desks or shelves.

Figure B.1: Refrigerator latch

Figure B.2: Adhesive connections

Large / HeavyEequipment

Many large pieces of equipment, such as refrigerators or incubators, have been braced with chains attached to walls, strongbacks, or to other pieces of equipment. This includes approximately 80% of large incubators or freezers and about 70% of refrigerators. The typical restraint assembly includes two chains, each placed at opposing 45 degree angles in the horizontal plane, and 45 degrees in the vertical plane. The chains are linked to metal plates, which are secured to the equipment with epoxy (Figure B.2). The other ends are attached directly to the adjacent wall, which is sometimes a structural concrete wall and sometimes a steel stud partition. In cases where large equipment is stacked, some of the equipment is restrained directly to the building structure and some to adjacent restrained equipment. In other cases, equipment is secured with chains at a 90-degree angle to the ceiling with no lateral support.

Large items, such as refrigerators and incubators, are sometimes secured directly to concrete shear walls with (usually four) expansion anchors or screws attached to metal plates (Figure B.4). Items secured to metal stud partitions are attached with smaller screws to the same metal plates. In some cases at the core of the building, a Unistrut brace is runs along a partition wall to distribute the heavy load, especially if more than one heavy object needs to be restrained. The brace spans between two interior concrete columns and is attached to them with expansion bolts,

although the partition is likely carrying most of the load due to the long span.

Original cabinets or bookshelves over lab benches that aren't attached to walls are attached instead to vertical strongbacks. This usually consists of a pair of Unistrut channels back-to-back attached to the floor and ceiling. In cases where large equipment is nearby, the equipment has been restrained by being chained to these vertical strongbacks (Figure B.3). The methods of attachment vary. Connections at the ceiling for strongbacks and other chained restraints consist of expansion anchors or sleeve anchors cast into the original concrete.

Few, if any, of these "tethered" systems are statically stable and the dynamic effectiveness of the configurations need confirmation. In addition, the capacity of the connections is unknown, particularly the epoxied plate-to-equipment connection and the plate-to-stud wall connection.

Mechanical latches have also been added to prevent doors from opening during an earthquake (Figure B.1) on approximately 50% of refrigerators. Although these haven't been tested, they are most likely adequate for restraining the doors. Further consideration should be given, however, to the condition of the contents after strong shaking.

Issues raised by existing heavy equipment restraints include:

- The effectiveness of statically unstable restraint cables is unknown.
- The effectiveness of the partitions to restrain the heavy loads is uncertain, since the partitions appear to be discontinuous at the core of the building. This is a particular concern at the core of the building, where many refrigerators are restrained by the partitions.
- Where four screws are used to connect metal plates to partition walls, the effectiveness in resisting loads is unknown. If the attachment is to drywall only and not to braced metal framing, very limited restraint is provided.

Figure B.3: Connection to strongbacks

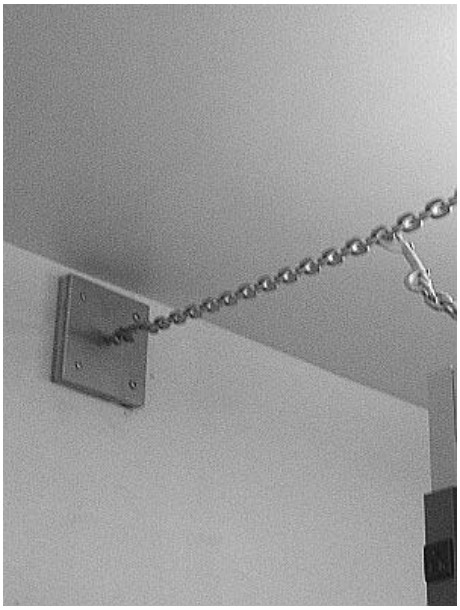

Figure B.4: Chain connection to wall

- Where expansion anchors are used to connect metal plates to concrete, the effectiveness in resisting the required loads is unknown and may vary due to discrepancies in installation and materials.
- Withdrawal forces from existing ceiling connections are unknown. Some chained restraints for heavy objects are attached only to the ceiling overhead, providing limited lateral support.
- There is significant variation in the application of epoxy and plates. In some cases, the metal plates are attached to 1-inch wide areas of the equipment. In other cases, the epoxy is peeling. Other areas appear to have too little epoxy applied. More importantly, the strength and type of epoxy is unknown.
- In cases where heavy equipment is attached to each other (stacked or adjacent) for seismic restraint, the effectiveness of the connections needs to be determined.

Figure B.5: Smaller tank restraint

Figure B.6: Larger tank restraint

Tanks

The two major types of tanks used in the case study building are compressed gas cylinder storage tanks (approximately 3-4 feet high and 6-10 inches in diameter) and larger liquid nitrogen storage tanks (about 3-4 feet high and 18-24 inches in diameter). Nearly all tanks in the building have had provisions made for seismic restraint. These consist of one to three chains wrapped around a vertically positioned tank restrained to a wall, desk, or column (Figure B.5). The chains are usually attached to a small Unistrut segment that is bolted to the wall or, in some cases, directly to cabinets or strongbacks. In other cases, chains are attached loosely or not at all (Figure B.6, bottom).

Issues raised by existing tank restraints include:

- Adequacy of chain to restrain tank, including clasp connection and tautness of chain.
- Adequacy of connection between chain restraint and building structure, including additional Unistruts or connection to tables or strongbacks instead of walls.
- Risk of damage from movement, even when restrained, to pressurized valves, pipe connections, or any area of tank where chemicals could escape.

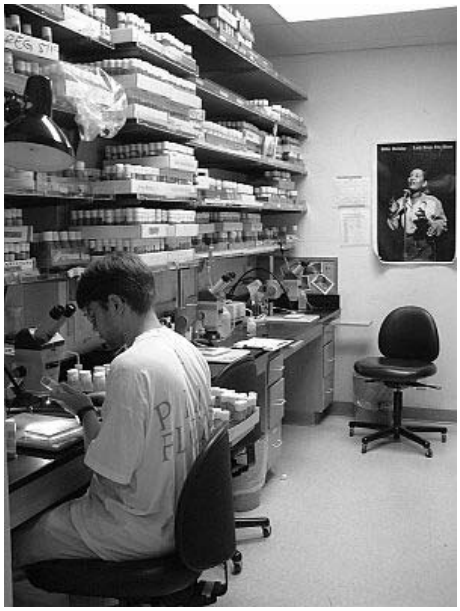

Figure B.7: Lips on lab sample shelves

Figure B.8: Lips on chemical shelves

Shelves

On many shelves holding chemicals or lab samples, plastic or wood "lips" have been added to provide seismic restraint (Figure B.8) up to a height of about 2 inches above the shelf. In other areas, elastic cords have been placed in front of chemical bottles to restrain them to the shelves. The location of the elastic cords varies, but is usually 2-3 inches above the shelf.

One concern with both the lips and elastic cords is the weight and center of gravity of the chemical bottles. The restraints may not be high enough to prevent the bottles from falling over the lips or pushing the elastic cords out far enough to allow the bottles to fall. In some cases, bottles can slip under the elastic cords as well. Also, reactions between chemicals in the event of simultaneous bottle breakage are an issue of concern.

In some cases, the added lips are taller than the center of gravity of lab samples (Figure B.7), which may be a more effective application. Unlike some of the chemical storage applications, many lab samples are stored in small, lightweight plastic containers behind the taller Plexiglas lips. The weight and size of the lab samples allow them to be restrained more easily.

Figure B.9: Shelves with bungee restraints

Figure B.10: Shelves with metal restraints (top)

Bookcases or open shelves may be secured to walls or strongbacks with bolts or screws, but that provides little or no seismic restraint to contents without additional protection at the front of the shelves. In some cases, elastic cords or shelf lips have been added to these shelves (Figure B.9), but lip additions can be more effective than elastic cords. Lip additions have a greater ability than cords to restrain heavy loads.

Retractable metal plates have been added to some top shelves (Figure B.10), which restrain contents through gravity forces acting against wood screws. These plates may pose a serious life safety risk due to their position and weight, and the insufficient length of the screws and size of their heads.

Issues raised by existing shelf restraints include:

- Effectiveness of shelf lips against center of gravity of shelf contents, especially chemical bottles and glassware.
- Effectiveness of metal face plate connections under torsional stress due to the limited area of resistance (screw heads). Life safety risk of falling metal plates.
- Effectiveness of bookcase restraints to walls or other heavy equipment.

Figure B.11: Microwave with fabric tethers

Figure B.12: Computers w/fabric tethers

Fabric Tethers

Off-the-shelf fabric tethers from one or two manufacturers have been added to several small pieces of equipment, including computers, monitors, microscopes, and microwave ovens (Figure B.11). These tethers consist of adhesive pads attached to hard surfaces, with a fabric strap (and buckle) connecting them. Usually, a pair of tethers is placed on either side of the object at a 45-degree angle to provide resistance against both vertical and lateral loads (Figure B.12). In some cases, the tethers are attached incorrectly (adhesive poorly connected or loose, poor location of anchor, etc.) to the tables or equipment or are unbuckled.

Issues raised by existing fabric tethers include:

- Allowable load as demonstrated or determined by the tether manufacturer for the angle of placement of the adhesive pads.
- Effectiveness and consistency of installation, including whether angle of attachment of the tethers is optimal.
- Effectiveness of adhesive over time, under stress, or on different surfaces.