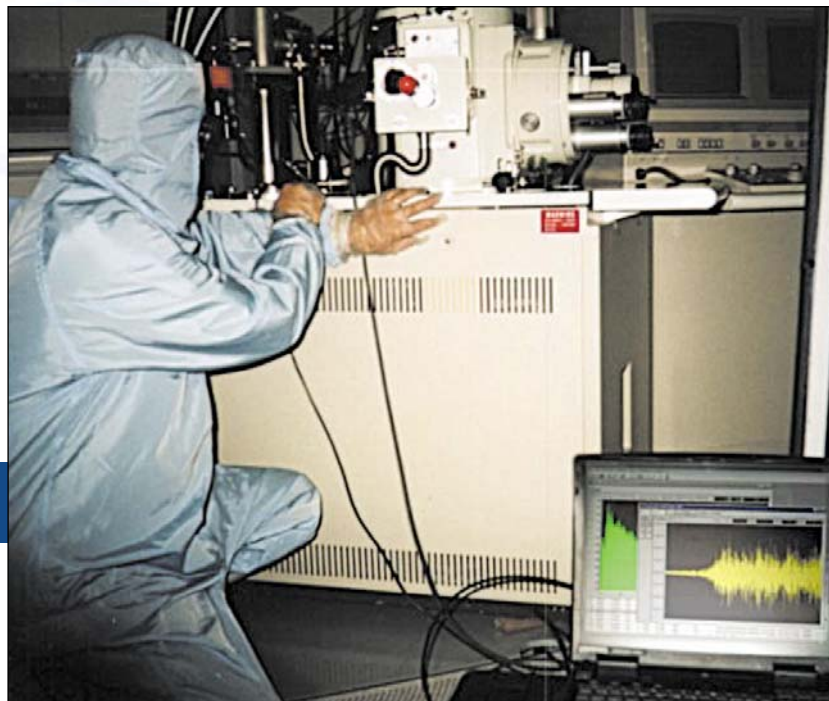


VIBRATION CONSIDERATIONS IN LABORATORIES

By Darron Chin-Quee, Project Director

Laboratories house a variety of highly vibration-sensitive equipment used for research and production in fields such as metrology, biotechnology, medicine and micro/opto-electronics. Inserting probes into nuclei of single living cells, or etching lines less than 1 micron on micro-electronic circuits requires environments to have vibration levels well below human perception thresholds. Vibration at the equipment base can cause internal components, study specimens, or items being produced, to move relative to each other. How much this relative motion disrupts equipment operations depends on the vibration frequency and amplitude.

Site survey of environmental noise and vibration.



What Equipment Requires Consideration?

The list of vibration-sensitive uses continues to grow as technological improvements demand increasing miniaturization and higher resolutions in microscopy. Typical equipment and processes requiring consideration include: electron microscopes, magnetic resonance imaging, silicon wafer production, and opto-electronics.

What Causes Vibration?

External sources, including road and rail traffic, construction activity, and heavy industry (e.g., metal stamping plants) are best controlled by appropriate site selection. See Figure 1.

Internal sources include walking, in-lab traffic, building services (HVAC, MEP) and other lab equipment. They can generate higher vibration levels than external sources and can be addressed by appropriate structural design (e.g., floors with adequate natural frequencies, stiffness, and mass), proper location of sensitive uses within the lab, and isolating building services and vibrating lab equipment (e.g., pumps).

How Is Vibration Accounted for in Design?

Functional facilities result from properly controlling external and internal vibration sources to meet well-accepted criteria. But what criteria? Manufacturers' criteria are often not available, lack sufficient frequency sensitivity detail, or are overly conservative. Furthermore, specific equipment to be used is often unknown prior to key building design decisions.

Over the last 20 years, generic vibration criteria have been developed. These provide frequency sensitivities for wide classes of equipment and are used extensively within high-tech industries. See Figures 2 and 3.

PEAK GROUND VELOCITY (in/sec)	RICHTER MAGNITUDE	EARTHQUAKE	TRANSPORTATION SOURCES	CONSTRUCTION SOURCES	BUILDING DAMAGE	HUMAN PERCEPTION	SENSITIVE EQUIPMENT	HUMAN EXPOSURE LIMITS
1000								
	9							
100	8	SAN FRANCISCO, 1906						
	7	KOBE, 1995						
		NORTHRIDGE, 1994						
10	6				STRUCTURAL DAMAGE	INTOLERABLE		
	5			BLASTING AT 50 FT.	MINOR DAMAGE	EXTREMELY UNPLEASANT		1 MINUTE
1.0	4	LOWER LIMIT OF BUILDING DAMAGE			LOW PROBABILITY OF DAMAGE	VERY UNPLEASANT		1 HOUR
	3			PILE DRIVING AT 50 FT.	VERY SAFE TO BUILDINGS	UNPLEASANT		8 HOURS
.1	2	NOT FELT EXCEPT BY A FEW PEOPLE UNDER CERTAIN CIRCUMSTANCES	SUBWAY TRAIN (MEAS. ABOVE TUNNEL)			STRONGLY NOTICEABLE	COMPUTERS	
	1		MOTOR VEHICLE TRAFFIC AT 50 FT. FROM ROUGH ROADWAYS AND ELEVATED HIGHWAYS	BULL DOZER AT 50 FT.		EASILY NOTICEABLE	OFFICE	
.01			MOTOR VEHICLE TRAFFIC AT 50 FT. FROM SMOOTH AT GRADE ROADWAYS	JACKHAMMER AT 50 FT.		BARELY NOTICEABLE		
.001			TRUCK AT 200 FT. ON A ROUGH ROAD	BLASTING AT 500 FT.		IMPERCEPTIBLE	OPTICAL MICROSCOPES	
.0001				PILE DRIVING AT 500 FT.			ELECTRON MICROSCOPES	

Figure 1: Overview of External Vibration Sources

Figure adapted from original BBN Laboratories material courtesy of Acentech Inc., reprinted herein.

These vibration criteria curves (Ungar, Gordon, Sturtz, Amich, 1983-1998) while very useful, tend to be conservative and are not a substitute for specific end-user frequency sensitivity limits.

Site Selection and Building Location: Evaluating external vibration sources in relation to the location of a building site is an important basic design consideration. It is important to avoid high vibration locales (See Figure 1) and allow for future development. For example, on a recent project, pile driving activity on-site and off-site was considered, resulting in early installation of future building expansion piles. A vibration survey is recommended when selecting a site. Where marginal vibration conditions exist, isolation of the foundation and equipment mountings may be needed.

Sensitive Equipment Placement: Equipment is best located slab-on-grade to limit transmission and amplification of vibration from building services and footfalls. It is often difficult to achieve better than VC-B (Figure 1) levels above grade. Placement of more sensitive equipment should be limited accordingly. High-mass controls (e.g., inertia bases) are more readily incorporated at grade than on supported structure. Some equipment (e.g., NMRs) should be located away from exterior facades due to susceptibility to high background noise and wind-induced vibrations on lightweight building elements (e.g., windows). Distances from mechanical/electrical equipment and building service spaces should be maximized.

Structural Considerations: Equipment supported on structure requires special consideration. Vibration generated by footfalls decreases with increased floor stiffness (K) and natural frequency (Fn). Figure 3

gives recommended values of $K F_n$ products. Long span floor systems are to be avoided, especially in lightweight steel/concrete composite construction, a practical limit being 25 - 30 ft to avoid excessive footfall vibrations. Spans longer than 35 ft. are usually impractical for vibration-sensitive uses. To limit induced vibration, some facilities use separate structures to support floors and equipment mounts.

Building Services: All building services require a high degree of vibration isolation. Major pieces of equipment (chillers, fans, stand-by/UPS diesel generator sets, etc.) should be located in a separate utility building wherever possible. Stiff, massive support structures are preferred to enhance vibration isolation of mechanical equipment.

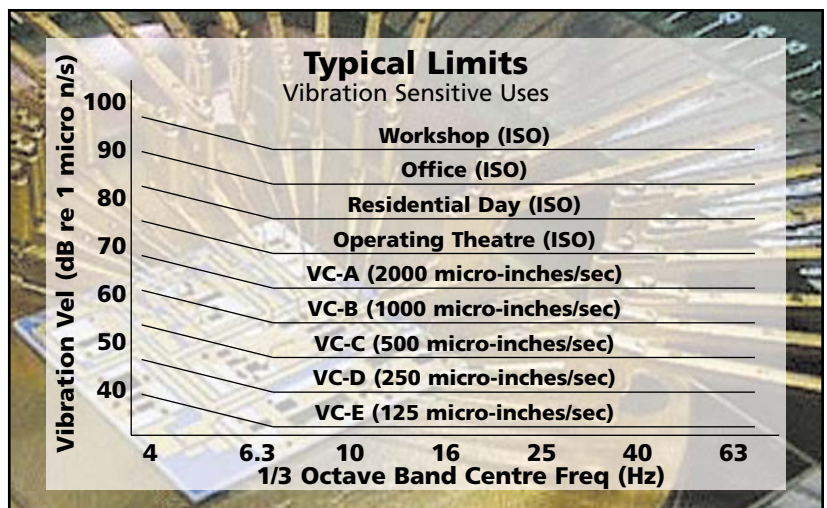


Figure 2: Generic Vibration Criteria

Criterion Curve	Max Level ⁽¹⁾ µin/sec (dB)	Detail Size ⁽²⁾ (µm)	Description of Use	Floor Stiffness KF ⁽³⁾ (kips/in-sec)
Residential Day (ISO)	8000 (78)	75	Barely felt vibration. Adequate for computer equipment, probe test equipment and low-power (to 20X) microscopes.	500 - 3,000
Op. Theatre (ISO)	4000 (72)	25	Vibration not felt. Suitable for sensitive sleep areas, microscopes to 100X and for other equipment of low sensitivity.	1,000 - 6,000
VC-A	2000 (66)	8	Usually adequate for optical microscopes to 400X, micro-balances, optical balances, proximity and projection aligners, etc.	2,000 - 12,000
VC-B	1000 (60)	3	An appropriate standard for optical microscopes to 1000X, inspection of lithography equipment (including steppers)	4,000 - 25,000
VC-C	500 (54)	1	Applies to most lithography and inspection equipment to 1 micron detail.	8,000 - 50,000
VC-D	250 (48)	0.3	Usually suitable for electron microscopes (TEMs & SEMs) and E-Beam systems, operation to their capacity limits.	16,000-100,000
VC-E	125 (42)	0.1	Difficult to achieve. Assumed adequate for the most demanding of sensitive systems - long path, laser-based, small target and other systems.	35,000-200,000

- 1) Value of constant velocity region as measured in one-third octave bands of frequency range 8 to 100 Hz. The dB scale is referenced to 1 micro-inch/sec.
- 2) The detail size refers to the line widths for micro-electronics fabrication, the particle (cell) size for medical and pharmaceutical research, etc.
- 3) KF_n depends on walker weight and gait. Ranges indicated reflect average to conservative designs. Average walker (150 lbs, 75 steps/min). Conservative walker (185 lbs, 100 steps/min).

Figure 3: Generic Criteria, Uses and Recommended Floor Stiffness

ACOUSTICAL CONSIDERATIONS IN LABORATORY SPACES

Spaces used for instruction in academic settings require a high degree of speech intelligibility. In teaching laboratories, all occupants must be able to hear properly in order to assimilate the information being presented. For non-academic facilities, communications are equally important. In addition to possible lapses in communication, long hours spent in noisy spaces produce higher fatigue levels compared to quieter spaces, adversely affecting the level of efficiency and quality of the work.

What Facility Design Aspects Should be Considered?

The design considerations that determine the quality of the acoustics in laboratory spaces are:

- Room Acoustics** - particularly with respect to control of excessive reverberation and unwanted echoes which reduce speech intelligibility and result in propagation of noise throughout the space;
- Sound Isolation of Architectural Room Boundaries** - to achieve suitable indoor sound levels, noise intrusions via the room architectural boundaries must be minimized. This typically involves isolating the room from sources such as major mechanical equipment located in adjacent spaces, but can also include outdoor noise such as from road and rail traffic, or aircraft sources;
- Noise from Building Services** - such as fans, dampers, and diffusers associated with the supply and return air system within the space, as well as fume hood exhaust fans and dampers. Piped gas and water lines and

valves must also be considered. Higher indoor noise levels due to these sources reduces speech intelligibility, as well as the overall comfort level for the occupants.

What Are Some of the Control Measures Available?

Surface Finishes: The room shape and amount of sound absorptive finishes within a space are important factors in obtaining proper interior acoustics. These factors also affect the reverberation within the space. In a reverberant space, the same sound arrives at a listener from a multitude of directions, with varying time delays and causes a blurring effect. This interferes with intelligibility even though the sound level at the listener is more than adequate. For optimum communications within a space, there must be adequate acoustical (sound absorbing) treatment as part of the room finishes.

Boundary Partitions: Sound energy created by human activity (e.g. talking) or radiated through the air by equipment (e.g., pumps, chillers) is known as airborne sound transmission. Vibration from rotating machines (such as fans or pumps, etc.) acting directly on the building structure cause the structure to vibrate. Acoustical energy is then re-radiated as airborne sound (noise) at other parts of the building. This is known as structure borne noise transmission. Unlike airborne noise transmission, the degree of structure borne noise transmission to other parts of the building is very difficult to predict.



Space	Noise Criteria (NC) Level
Small Teaching Laboratories with few or no fume hoods (up to 750 ft ²)	35-40 (lecture mode) 40-45 (lab demo mode)
Large Teaching Laboratories with few or no fume hoods (over 750 ft ² or more than 50 people)	30-35 (lecture mode) 35-40 (lab demo mode)
Teaching Laboratories with multiple fume hoods	40-45 (instructional mode) 45-50 (lab mode)
Research Labs, Auxiliary Support ≤ 5 occupants	45-55

Recommended Background Noise Criterion (NC) Levels

The type of construction needed will be dependent upon the level of noise reduction necessary. Concrete block or poured concrete is generally preferred. For very noisy spaces such as mechanical rooms, cavity wall construction is often needed. Floating concrete slabs on resilient isolators may be necessary for mechanical rooms immediately above laboratories. A resiliently suspended solid gypsum board ceiling might be needed in the mechanical room if located below the lab space. Ensuring all vibrating mechanical or electrical equipment is supported on proper vibration isolators is the best way to minimize noise transmitted by the building structure.

Ventilation System: The interior background noise levels from building services such as heating and ventilating systems must be adequately low where speech intelligibility is important. The chart above gives recommended background Noise Criteria (NC) levels for laboratory and associated spaces. Where fume hoods are present, the specified NC levels are a compromise between the limitations of practical noise reduction and the intended use of the space.

Fan and equipment noise is usually best controlled by selection and proper placement of duct silencers to adequately attenuate sound of fans. In some cases, acoustical (internal) lining of ductwork itself is appropriate. However, depending on the spaces serviced, use of duct lining is subject to considerations with respect to fibre entrainment in the air-stream, microbial growth, and durability of the lining in corrosive environments.

Airspeeds within supply and return air ductwork must be limited in order to avoid noise from air diffusers, grills and the ductwork itself. Without acoustical lining, maximum airspeeds in supply ducts should not exceed about 425 fpm (for NC 30) to 630 fpm (for NC 40). Slightly higher speeds are acceptable if lined duct is used prior to each diffuser. For example, the speed can be increased by about 20% if the duct is terminated with at least 10 feet of internal acoustical lining. Airspeeds about 100 fpm higher are permissible within exhaust ducts, for a given condition.

Ensuring the laboratory space is optimal requires equal attention to all the aspects noted here. In addition, aspects such as vibration may also need to be considered, depending upon the sensitivity of the equipment or research being done.



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