Making Sense of Laboratory Fire Codes

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Laboratory owners are faced with a difficult task when building a new lab or renovating an existing one — two fire-prevention codes specify different restrictions on the quantities of hazardous materials that can be used and stored in that facility.

The storage and handling of flammable, combustible, and toxic materials in laboratories may be subject to two standards: the National Fire Protection Association's (NFPA) NFPA 45 Fire Protection for Laboratories Using Chemicals, and the International Building Code (IBC) and its companion International Fire Code (IFC). Unfortunately, the two codes are very different, with different quantity limits and methods used to determine those quantities, as well as divergent advice on how to deal with fire prevention.

Determining which code to follow when constructing a new laboratory, or renovating or expanding an existing laboratory, can be difficult. This article provides an overview of the two codes and compares the quantity limits and design requirements imposed by those codes.

Laboratory codes for chemicals

NFPA 45 has been in existence since 1974 and is well-known and respected as the leading laboratory-specific fire code. It sets limits and restrictions on the amount of flammable and combustible materials that can be used and stored in a laboratory. The IBC (through its companion IFC) also sets limits on the amount of hazardous materials that can be stored and handled in a building, but it does not specifically address laboratories. Unfortunately, compliance is not as easy as simply deciding to follow one code or the other.

For instance, why not follow NFPA 45 when constructing a laboratory, since it specifically concerns laboratories? The problem is that most local fire departments will not waive the IBC requirements even though they were not specifically developed for, nor really address the unique requirements of, laboratories.

Then why not just follow IBC and ignore NFPA 45? The problem with this line of thinking is that the requirements in the IBC do not address laboratory requirements and many of the NFPA 45 requirements in other areas (aside from quantities) are not adequately addressed in the IBC. A lab designed based solely on the IBC limits will not be as safe.

Therefore, the best approach is to follow the quantity limits of the IBC and unilaterally follow the other (non-quantity) provisions of NFPA 45. This is not an ideal situation, but it will remain necessary until the discrepancies between the two codes are addressed. The IBC's recent decision to amend the 2018 IFC for higher-education laboratories is a promising start to bringing the two codes into agreement.

Comparing codes

NFPA 45's objectives are to:

- limit injury to the occupants at the point of fire origin
- limit injury to emergency response personnel
- limit property loss to a maximum of one laboratory unit.

NFPA 45 is focused on confining a fire to a single laboratory. Damage to the laboratory is acceptable as long

Table 1. NFPA and IBC classify flammable and combustible liquids based on flashpoint and boiling point.

Type	Class	Flashpoint	Boiling Point
Flammable	IA	<73°F	<100°F
	IB	<73°F	>100°F
	IC	≥73°F and <100°F	
Combustible	II	≥100°F and <140°F	
	IIIA	≥140°F and <200°F	
	IIIB	≥200°F	

as it does not spread beyond that laboratory.

The intent of the IFC (the fire portion of the IBC) is to establish the minimum requirements consistent with nationally recognized good practice for providing a reasonable level of life safety and property protection from the hazards of fire, explosion, or dangerous conditions in new and existing buildings, structures, and premises, and to provide a reasonable level of safety to firefighters and emergency responders during emergency operations.

Both codes limit the amount of hazardous materials, which are classified as flammable or combustible as shown in Table 1, that can be placed in a laboratory. Both require the owner to define a specific enclosed area (*i.e.*, the laboratory) for which the limits on hazardous material will apply.

Defining the enclosed area

The NFPA and the IBC/IFC each define an enclosed area for determining the quantity limits for storage and handling of hazardous materials. In NFPA 45, the enclosed area is the laboratory itself, which the code defines as "an enclosed space used for experiments or tests." In the IBC/IFC, the enclosed area is a control area defined as "spaces within a building where quantities of hazardous materials not exceeding the maximum allowable quantities per control area are stored, dispensed, used, or handled."

The definition of an enclosed area differs somewhat between the two codes. However, in both codes, an enclosed area may refer to a single laboratory or a group of laboratories, and may include other, non-laboratory areas, such as offices. In addition, the enclosed area in both codes must be isolated from other areas by fire-resistance-rated separations.

NFPA 45 quantity limits

NFPA 45 requires the laboratory owner to determine the fire hazard classification of the laboratory based on the anticipated quantities of flammable and combustible liquids that will be stored and used in that lab (Table 2).

To estimate the expected quantities of hazardous materials for a new laboratory, consider the proposed laboratory size along with information on the quantities stored and used in existing facilities or an analysis of the work envisioned in the new laboratory.

For an existing laboratory, review the fire hazard classification of the original design and determine whether this classification adequately covers envisioned future work in that laboratory. If the classification is inadequate, the laboratory must be upgraded to meet the higher fire hazard classification — an expensive and time-consuming endeavor that often requires adding sheetrock to walls and replacing doors and windows.

To avoid expensive renovations, many organizations either over-specify the fire hazard classification when the laboratory is initially designed, assuming it will then be adequate for all future needs, or specify a higher fire hazard classification for a small number of laboratories, with the intent that work requiring large quantities of hazardous materials will shift to those laboratories. Both approaches have drawbacks. Constructing laboratories with higher fire classifications than needed can incur unnecessary capital costs. And, specifying a higher hazard classification for a few laboratories can create a need in the future for expensive modifications. In general, over-specifying is less risky, as the costs to upgrade the laboratory during initial construction are usually much less than those of modifying it later.

It is important to understand that the higher the laboratory unit's fire hazard classification, the more restrictions on the laboratory's construction. This includes size, fire rating, and some height limitations (stories above grade).

As shown in Table 2, NFPA 45 identifies eight limits that must be met for the use and storage of hazardous chemicals in a lab. These consist of four requirements — quantity in use per 100 ft^2 of laboratory area; quantity in use per laboratory unit; total inventory in use and in approved storage per 100 ft^2 of laboratory area; and total inventory in use and in approved storage per laboratory unit — that must be satisfied for Class I liquids individually, and the same requirements for Class I, II, and IIIA liquids combined. The term "approved storage" in NFPA 45 refers to the liquids stored in Factory Mutual (FM)-approved, Underwriters Laboratory (UL)-approved, or equivalent listed safety cans or flammable storage cabinets.

Table 2. NFPA 45 limits the quantity of liquids that can be used and stored in a laboratory based on fire hazard class.

Fire Hazard Class	Material Class*	Maximum Quantity in Use, gal		Maximum Quantity in Use and Storage, gal	
		per 100 ft^2	per Lab	per 100 ft^2	per Lab
A — High Fire Hazard	I	10	480	20	480
	I, II, IIIA	20	800	40	1,600
B — Moderate Fire Hazard	I	5	300	10	480
	I, II, IIIA	10	400	20	800
C — Low Fire Hazard	I	2	150	4	300
	I, II, IIIA	4	200	8	400
D — Minimal Fire Hazard	I	1	75	2	150
	I, II, IIIA	1	75	2	150

*Material Class I encompasses Class IA, IB, and IC materials. NFPA 45 does not place limits on Class IIIB materials.

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Example. Consider a 500-ft^2 Class B laboratory. The following eight limits must be met for this laboratory to comply with NFPA 45:

1. Quantity of Class I liquids in use per 100 ft^2 of laboratory area:

$$500\ \text{ft}^2 \times \frac{5\ \text{gal}}{100\ \text{ft}^2} = 25\ \text{gal}$$

2. Quantity of Class I liquids in use per laboratory unit: 300 gal

3. Total inventory (in use and in storage) of Class I liquids per 100 ft^2 of laboratory area:

$$500\ \text{ft}^2 \times \frac{10\ \text{gal}}{100\ \text{ft}^2} = 50\ \text{gal}$$

4. Total inventory (in use and in storage) of Class I liquids per laboratory unit: 480 gal

5. Quantity of Class I, II, and IIIA liquids in use per 100 ft^2 of laboratory area:

$$500\ \text{ft}^2 \times \frac{10\ \text{gal}}{100\ \text{ft}^2} = 50\ \text{gal}$$

6. Quantity of Class I, II, and IIIA liquids in use per laboratory unit: 400 gal

7. Total inventory (in use and in storage) of Class I, II, and IIIA liquids per 100 ft^2 of laboratory area:

$$500\ \text{ft}^2 \times \frac{20\ \text{gal}}{100\ \text{ft}^2} = 100\ \text{gal}$$

8. Total inventory (in use and in storage) of Class I, II, and IIIA liquids per laboratory unit: 800 gal.

As this example shows, the maximum quantity per 100 ft^2 of laboratory area limits the total amount of hazardous liquids that can be used and stored in the lab. Thus, conditions 1, 3, 5, and 7 limit the 500-ft^2 laboratory to the following quantities:

- 25 gal of Class I liquids in use
- 50 gal of Class I liquids in use and storage
- 50 gal of Class I, II, and IIIA liquids in use
- 100 gal of Class I, II, and IIIA liquids in use and storage

Conditions 2, 4, 6, and 8 can also limit the quantities in use and storage in a lab in some cases, such as very large laboratories.

IBC/IFC quantity limits

The IBC/IFC requires that the storage of flammable and combustible liquids in any control area not exceed the maximum allowable quantity (MAQ) given in Table 307.1 of the code. Table 3 provides a portion of that table.

In addition to the hazardous material categories listed in Table 3, the IBC/IFC provides MAQs for many other hazardous materials, including cryogenics, organic peroxides, and oxidizers.

As long as the MAQ is not exceeded inside any control area, the IBC allows normal construction in accordance with standard Type B occupancy requirements. If the MAQ is exceeded inside any control area, the building must be constructed to high-hazard (Type H) occupancy requirements, since quantities of flammable and combustible liquids greater than the MAQ require significantly more fire protection.

The IBC/IFC does allow the MAQ quantities to be doubled if the entire building is equipped with an automatic sprinkler system and allows the MAQ to be doubled again if the higher quantities are contained in approved storage cabinets, day boxes, gas cabinets, gas rooms, or exhausted enclosures, or in listed safety cans.

The IBC/IFC limits the number of control areas per floor (Table 4). The maximum number of allowed control areas decreases for floors above and below the first (*i.e.*, ground level) floor. The MAQ also decreases by a specified percentage for each floor above or below the first floor.

The maximum inventory of allowable hazardous materials can be determined by dividing the floor area by the maximum number of control areas (assuming that the entire floor is the laboratory). For example, for the first floor, the floor area is divided by 4; for the second floor, the floor area is divided by 3; and so on.

What are the practical impacts of the differences?

NFPA 45 does not place any restrictions on the number of laboratory units in a laboratory building. Hence, owners can, with proper construction for each laboratory, continue to add as many laboratories as they need to accommodate the quantity of material they intend to handle.

The IBC/IFC limits the number of control areas based on the number of floors above grade (Table 4). While you can

Table 3. The IBC/IFC sets building requirements based on maximum allowable quantities (MAQs) of flammable and combustible liquids in a designated control area.

Material	Material Class	Storage, gal	Use (Closed Systems), gal	Use (Open Systems), gal
Combustible Liquid	II	120	120	30
	IIIA	330	330	80
	IIIB	13,200	13,200	3,300
Flammable Liquid	IA	30	30	10
	IB and IC	120	120	30
Combination Flammable Liquid	IA and IB and IC	120	120	30

still have as many laboratories as needed, those laboratories must be grouped into a specified number of control areas, which in effect limits the quantities of flammable and combustible materials. The limits of the IBC/IFC are significantly more restrictive than those of the NFPA 45.

NFPA 45 limits the size of laboratories with Class A and Class B fire hazard classification to 10,000 ft^2. The code does not limit the size of Class C or Class D laboratories. (The current review cycle of NFPA 45 is recommending removing this size restriction.)

The IBC/IFC places no limits on the size of a laboratory, but does limit the number of potential control areas. This indirectly limits the size of a laboratory. Depending on the floor size, the IBC/IFC may be more or less restrictive in terms of laboratory size than NFPA 45.

The IBC/IFC effectively limits the height of a laboratory building to about three floors unless only very small quantities of flammable and combustible liquids are required on the fourth and higher floors, since the percent of the MAQ allowed decreases above the first floor and rapidly decreases above the third floor.

NFPA 45 also reduces the maximum amount of hazardous materials on floors above the first floor and depending on the laboratory fire hazard classification (Table 5). However, the reductions are not nearly as significant as those mandated by the IBC/IFC.

Hence, NFPA 45 allows taller laboratory buildings and, more importantly, laboratories on higher floors. This can be critical in congested areas, such as large cities.

Example. Let's work through the numbers for a Class I flammable liquid. For a Class A laboratory, NFPA 45 would allow 480 gal of Class I flammable liquid to be in use and storage. The IBC/IFC would allow 120 gal per control area and a maximum of four control areas for the first floor, or 480 gal of Class I flammable liquids. If the building is outfitted with a sprinkler system and the hazardous liquid is stored in approved containers, the IBC/IFC allows the MAQ to be doubled and then doubled again, to 1,920 gal. This is the same amount that the NFPA 45 would allow for four laboratories. However, the amount that could be stored on higher floors differs depending on which code is followed (Table 6).

In reality, this is not a fair comparison for several reasons.

First, NFPA 45 does not restrict the number of laboratory units on most floors. Thus, by increasing the number of individual laboratories, the total quantities of hazardous materials allowed by NFPA 45 can exceed the total quantities per floor allowed by the IBC/IFC.

Second, NFPA 45 limits the quantity of flammable and combustible liquids stored per 100 ft^2 of lab space. In smaller laboratories, this condition is often the determining quantity. In a small building, constructing four laboratory units (as was done in the example) would make each of the labs quite small, which in effect reduces the maximum storage quantity allowed by NFPA 45.

Third, the IBC/IFC allows Group H construction, which removes any limitations but at a much higher initial building cost. NFPA 45 does specify slightly more stringent laboratory fire rating than the IBC/IFC, but does not require the other construction requirements of Type H construction, making it much less expensive to comply with NFPA 45.

In addition to quantity limits, other requirements of the two codes also differ.

NFPA 45 has several other requirements that are important for laboratory safety. These include requirements for heating, ventilation, and air conditioning (HVAC) and duct construction, routing and fire rating, and equipment usage. If a municipality requires a laboratory owner to follow the IBC/IFC, the owner will generally ignore all NFPA 45 requirements (instead of just ignoring NFPA 45's quantity limits and following the other, non-quantity requirements).

The NFPA 45 committee recognized that many municipalities are going to insist on the IBC/IFC quantity limits. In Section 8.2.4.1, NFPA 45 specifically acknowledges this,

Table 4. IBC/IFC MAQ restrictions by floor.

Floor	Maximum Control Areas per Floor	Maximum Percent of MAQ per Control Area	Maximum MAQ Increase per Floor
1	4	100%	400%
2	3	75%	225%
3	2	50%	100%
4	2	12.5%	25%
5	2	12.5%	25%
6	2	5%	10%
7–9	2	5%	10%
>9	1	5%	5%

Table 5. NFPA 45 also reduces the maximum quantities that can be used and stored in a laboratory above a bulding's third floor.

	Laboratory Fire Hazard Classification			
Floor	Class A	Class B	Class C	Class D
1	100%	100%	100%	100%
2	100%	100%	100%	100%
3	100%	100%	100%	100%
4	Not Permitted	50%	75%	75%
5	Not Permitted	50%	75%	75%
6	Not Permitted	50%	75%	75%
7–9	Not Permitted	Not Permitted	50%	50%
>9	Not Permitted	Not Permitted	50%	50%

stating: Chemical inventories in each laboratory unit shall be maintained within the maximum allowable quantities specified in the applicable fire code or building code.

So NFPA 45's other provisions can still be followed to improve safety even if one has to accept lower flammable and combustible liquids limits to comply with local building codes.

The IBC/IFC restrictions are particularly onerous in larger cities, where urban laboratories are most desirable on the higher floors (as the lower floors are more valuable for parking or retail). One could argue that placing laboratories higher in a building would prevent other non-laboratory building occupants from having to exit through floors with higher limits of hazardous materials in an emergency. However, the difficulty in fighting a fire on higher floors, the requirement for fire-rated emergency exits, and the concern that other occupancies would be allowed above the laboratories creates a counterpoint to this argument. I see prudent safety concerns in both arguments and wonder if the IBC/IFC restrictions could be relaxed by allowing laboratories on higher floors with no other occupancies above them.

The IBC/IFC reductions in the MAQ on higher floors requires a larger first floor plan in most cases, which is more expensive than adding higher floors. A way to relax this requirement while maintaining safety with the proper NFPA 45 safeguards could be allowing 100% MAQ up to a reasonable height (*e.g.*, 4–6 floors).

Proponents of the IBC/IFC point out that by constructing numerous individual laboratories as is allowed by NFPA 45, very large quantities of flammable and combustible materials can be stored in a laboratory building, since there is effectively no limit on the number of laboratories that may be constructed in a new building. While theoretically correct, NFPA 45's other provisions work to ensure that any fire will be limited to a single laboratory and not spread. Hence, I would argue that the total volume of flammable and combustible materials is not the issue if the fire is contained within one laboratory.

Most laboratory facilities have a small number of laboratories with large quantities of flammable and combustible materials and a large number of laboratories with much smaller quantities of flammable and combustible materials. For long-term flexibility, most organizations want to have the ability to shift work between different laboratories depending on their current and ever-changing needs. Hence, they will likely construct all of the laboratories such that they are capable of storing large amounts of flammable and combustible materials, but will actually only operate a few of those laboratories with quantities anywhere near the theoretical maximums. But they need the flexibility to change the inventory as soon as their needs change without repermitting and without modifications. In my 40 years of experience in petrochemical research laboratory facilities (which are probably the highest inventory users), I have never seen any facilities that are close to Class A limits in any but a small number of their laboratories.

Table 6. Comparison of NFPA 45 and IBC/IFC for a laboratory storing Class I flammable liquids.

	Maximum Quantities Allowed by Floor, gal							
Floor	**1**	**2**	**3**	**4**	**5**	**6**	**7–9**	**10+**
NFPA 45								
Class A	1,920	1,440	960	N/A				
Class B	1,600	1,200	800	400	400	400	N/A	
Class C	600	450	300	225	225	225	150	75
Class D	300	225	150	113	113	113	75	38
IBC/IFC								
Class A, B, and C	1,920	1,080	480	120	120	48	48	24

NFPA 45 also has a long history of successfully limiting fires to a single laboratory. While any fire is certainly undesirable in the base case, it supports the argument that the totality of all of NFPA 45's requirements are adequate to meet its intent of limiting a fire to one laboratory. This is very much like the intent behind an automatic sprinkler system, *i.e.*, limiting damage to one area.

The new IBC higher-education laboratory occupancy addition to the IBC/IFC scheduled to appear in 2018 is a great start toward resolving the differences between the two codes. The new section will allow for much higher percentages of the MAQ on higher floors and incorporates a variant of NFPA 45's density provisions (gal/100 ft^2). Colleges and universities, feeling the difficulty of complying with the more-restrictive IBC/IFC and supported by local fire officials, pushed the effort forward. While members of NFPA 45 were represented, the effort was limited to those parties driving the effort. The hope is that with this "foot in the door," other groups will drive further efforts to reconcile the two codes. CEP

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