Safe Machinery

Eugene Heil, P.E.

ABSTRACTION ENGINEERING

About the author

Biography of Eugene Heil

Education:

- BS Electrical Engineering, University of Vermont
- MS Engineering Management, Santa Clara University

Professional licenses:

- California registered Professional Electrical Engineer, stamp #E-09996
- California general, electrical, and landscape remodeling contractor #804994 with classifications B, C-7, C-10, C-27.
- California real estate broker, including property management, #01426162
- New Mexico registered Professional Electrical Engineer, stamp #21146, retired

Experience:

- July 2010 to present, Abstraction Engineering Inc, CEO and Principal
- 3 years with another field evaluation body, principal engineer and operations manager
- 10 years, buying, selling, managing, and renovating residential property.
- 26 years, Hewlett-Packard, Unisys, Shugart, and start-ups, developing computer memory systems, with senior management responsibility for quality and reliability.

Professional affiliations:

- ASSE – American Society of Safety Engineers
- BAESG – Bay Area Environmental Safety Group
- IAEI – International Association of Electrical Inspectors
- IEEE – Institute of Electrical and Electronics Engineers
- NFPA – National Fire Protection Association
- NAR & CAR – National and California Association of Realtors

Abstraction Engineering Inc

www.abstractionengineering.com

Abstraction Engineering Inc is professional engineering for safe machinery. We conduct essential safety evaluations for field label, CE Mark for Europe, SEMI S2, hazard analysis and risk assessment,

The Abstraction Engineering commitment to customer service is simple and no hassle:

Five o'clock and one less headache ™

Abstraction Engineering Inc
19072 Taylor Avenue
Morgan Hill, CA 95037-2719 USA

Eugene Heil, P.E.
408-726-1863 cell
eugeneheil@abstractionengineering.com

This book is sized for A4 international paper.

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I have worked 48+ years in Silicon Valley and these are my precepts.

- **Education.** Travel somewhere and read a book every day. Life-long learning (especially cultural) gives you a perspective not found with obedience (Milgram experiment). The book section 1.2 has dozens of examples of how bad public policy has caused the death of millions of people.
- **Courage.** There are two kinds of courage: Act when action is needed. Restraint when patience is needed. These are sometimes thought of as Western and Eastern thinking.
- **Manners.** Approach people with a smile, please and thank-you, you're welcome, how are you, how can I help? Timeshare training taught me about 3x personalities: visual, audible, emotional. How does this look to you? How does this sound to you? How do you feel about this? I wish to thank Jim W for teaching me to answer every phone call: "this is Eugene – how may I help you?"

With education, you can overcome fear. With courage, you can help yourself and others. With manners, other people will help you.

Registered Trademarks

- A2LA – American Association for Laboratory Accreditation
- ACES – American Council for Electrical Safety
- AMT – Association of Manufacturing Technology
- ANAB – ANSI National Accreditation Board
- ANSI – American National Standards Institute
- ASCE – American Society of Civil Engineers
- ASME – American Society of Mechanical Engineers
- ASSP – American Society of Safety Professionals, previously known as the American Society of Safety Engineers (ASSE)
- ASTM – American Society of Testing and Materials
- BAESG – Bay Area Environmental Safety Group
- Brady – Brady Corporation
- Clarion – Clarion Company Ltd
- CSA – Canadian Standards Association
- Eurofins – a trademark of Eurofins Scientific
- FM – FM Global - Factory Mutual
- IAEI – International Association of Electrical Inspectors
- IAMPO – International Association of Plumbing and Mechanical Officials
- IAS – International Accreditation Service, a subsidiary of ICC - International Code Council
- ICC – International Code Council
- IEC – International Electrotechnical Commission
- IEEE – Institute of Electrical and Electronics Engineers
- IFC – International Fire Code, a trademark of ICC - International Code Council
- Intertek – Intertek Group Plc., frequently using their original logo ETL
- ISO – International Standards Organization
- LIA – Laser Institute of America
- MET – is a trademark of MET Labs
- NAR & CAR – National and California Association of Realtors
- NEC – National Electrical code, a trademark of NFPA
- NEMA – National Electrical Manufacturers Association
- NFPA – National Fire Protection Association
- OSHA and Cal/OSHA – Occupational Safety and Health Administration
- RIA – Robotics Industries Association
- SEMI – Semiconductor Equipment and Materials International
- TUV – Technischer Überwachungsverein, organized into three large holding companies, TÜV Nord, TÜV Rheinland and TÜV SÜD.
- UL – Underwriters Laboratory

1 Safety

1.1 Who should read this book?

This book has two audiences. First, it is a **best practice guide** for people who design, manufacture, purchase, install, and maintain machinery in laboratories and industrial factories. Follow the recommendations and you will avoid trouble. Second, it is a **checklist and template** for people who inspect and write reports. The primary topics relate to the safety of operators and maintenance workers exposed to electrical equipment.

Why can't I just follow the code? Webster has two definitions for code:

- A set of laws, rules, regulations, and ideas about **how to behave.**
- A set of letters, numbers, and symbols used for **secret messages.**

Government code books are both – they explain how to behave but they do so with a secret message that average people can't figure out. And like the Bible, a single book can have many interpretations and religions.

Code books are ridiculously complicated. The California Vehicle Code is over 1000 pages and double column. Let's assume that California has 20 million drivers and assume that the average driver goes 10,000 miles per year and gets one ticket every 10 years. That's about 200 billion miles and 2 million tickets per year, and all of this driving without reading the vehicle code. How could this happen? Lesson #1: code is primarily for enforcement. It is not driving school.

This book provides a simple reasonable summary about how safe electrical machinery should behave. Engineers refer to a simple summary as an **abstraction**. We are taught in engineering school to write in a pyramid style, beginning with the point (often a recommendation), then the rationale (why it is necessary), and then the data and facts (tedium ad nauseam). This writing style makes it easy for someone to read only as far down as needed to form an opinion and decide what to do next. This writing style is the opposite of a joke or a novel, where the punchline comes at the end and the hero rescues the children.

Chinese characters are an abstraction. Conversation always starts with an abstraction. **Examples:** "let's go to the store" or "let's sit under the tree". Store and tree are abstractions. The conversation builds on trust, respect, and empathy, and develops into more detail. Doctors who understand this are said to have a good bed side manner. Engineers who don't understand this are said to be nerds.

1.2 Safety, risk, and fear

Webster defines safe as being cautious and secure from the threat of danger, harm, risk, loss, or difficulty. Safety begins by uncovering **foreseeable hazards** with a process of **due diligence.** Society then determines an **acceptable level of risk** based on **fear and consensus**. Society has decided that airplanes should be safer than cars, cancer has higher priority than drug addiction, marijuana has higher priority than tobacco, police brutality has higher priority than street crime, etc. Consider these public safety problems:

- Nicotine is more addictive than heroin or cocaine. The US has 44 million smokers. Combustible tobacco kills more people than AIDS, car accidents, illegal drugs, murder, and suicide combined. (Time magazine, Sept 30, 2013).
- In the US, ~300,000 people die every year from obesity, second only to smoking as a preventable cause of death. Foods that are high in sugar, fat, and salt can be very addictive.
- American drug laws originated with the San Francisco Opium Den Ordinance in 1875, primarily as discrimination against the Chinese community. 148 years later, heroin is still a criminal felony but prescription opiates are perfectly legal. The US has ~180 million opiate prescriptions per year.
- The opioid epidemic ravaging the United States is taking a grim and growing toll. The CDC said that 64,070 people died from drug overdose in 2016, up 21%. Three-fourths of all drug overdose

deaths are now caused by opioids — a class of drugs that includes prescription painkillers as well as heroin and potent synthetic versions like fentanyl. Drug overdoses (in 2016) killed more Americans than the Vietnam War (Ashley Welch, CBS News, October 17, 2017). 2023 update: >100,000 deaths per year.

- An average American youth will see 200,000 acts of violent on TV prior to 18 years old. {American Psychological Association. Violence & youth: psychology's response. Volume I: summary report of the American Psychological Association Commission on Violence and Youth. 1993}
- The California Tubbs Fire, October 2017, burned 5,643 structures including ~1300 homes in the Coffey Park neighborhood of Santa Rosa. The Hanly Fire burned in the same area in 1964, but back then, Coffey Park was farmland. Why build (and rebuild) homes in a fire corridor? (1) Hewlett Packard setting up a factory in the mid-70's. (2) Property taxes from 1300 million-dollar homes = $26 million per year. Will it burn again in 50 years?
- In the US, ~500 people are struck by lightning each year and ~100 are killed. Many of these deaths occur while talking on the telephone. Lightning kills more people than tornadoes and hurricanes combined. (Chaya Kurtz, networx.com, June 5, 2013)
- Radon causes 21,000 lung cancer deaths per year in the US. This is higher than drunk driving (17,400), falls in the home (8,000), drowning (3,900), and home fires (2,800). (Environmental Protection Agency http://www.epa.gov/radon/pubs/citguide.html)
- Postal? Think again. ~60% of all the workplace violence is against health care workers. (Kevin Pho, MD, in USA Today, February 2, 2011, and CBS 60 Minutes, Sept 29, 2013)
- Bees are the number one insect killer of workers. Bees kill more workers than spiders, wasps, and ants combined. Texas has ~3x more deaths than the next state Florida (Wall Street Journal, August 12, 2014, referring to a recent 16-page labor report)
- The state of California incarceration rate has steadily climbed from 0.1% (1980) to 0.5% (present). 7% of California's budget was spent on corrections during fiscal year 2013-2014. (Wikipedia)
- Thalidomide was prescribed to pregnant women for morning sickness in the 1950's. The drug caused >2,000 deaths and >10,000 birth defects. At the time, scientists believed that drugs taken by a pregnant woman could not pass across the placental barrier and harm the baby. (Wikipedia)
- Beverage alcohol was banned during US Prohibition (1920-1933), leaving only three ways to obtain it: (1) illegal distilleries, (2) smuggling from Canada, and (3) diversion of industrial ethanol. The federal government then required the industrial ethanol to be denatured (rendered un-drinkable) with additives to make it smell bad and taste bad. Clever chemists figured out how to re-distill the tainted alcohol. The government responded with poisonous additives such as kerosene, brucine (similar to strychnine), gasoline, benzene, cadmium, formaldehyde, chloroform, acetone, and methyl alcohol, the last one proving to be the deadliest. Just in New York City alone, 400 died in 1926 and 700 died in 1927. De-natured ethanol killed at least 10,000 people. (The Chemist's War by Deborah Blum, author of The Poisoner's Handbook)
- How likely is it that an American will be killed by a terrorist? In the 15 years following 9/11, more than 230,000 Americans have been murdered, mostly by their fellow Americans. Only 118 people in the United States have been killed by terror attacks perpetrated by Muslim-Americans. (Gregg Toppo, USA Today, September 22, 2016)
- Engine knocking – lead in gasoline. The 1922 Cadillac model 30 was the first car with an electric starter, and because of this, the engine could be more powerful, with a top speed of 45 MPH. But it suffered from engine knock. If you have used a bicycle pump, you know that compressing the air creates heat, and in the case of engine cylinders, sometimes the fuel would spontaneously detonate before the spark, resulting in noise and engine damage. Gasoline is a mixture. Octane (8 carbon atoms) can withstand more compression than Heptane (7 carbon atoms). The proportions of Octane and Heptane are known as an octane rating. On this scale, 100% Heptane has a rating of 0, 100% Octane has a rating of 100, and diesel has a rating of about 20. Charles Kettering and Thomas Migley Jr. determined that tetra ethyl lead was the cheapest way to raise the octane. This gasoline became known as "ethyl". Risks were well known. Frank Howard, President of Standard Oil, said *"We do not feel justified in giving up what has become a gift from heaven on the possibility that a hazard may be involved in it."* Lead poisoning has killed millions of people. Ethyl is still used

in airplane gas. Migley also created freon, another environmental disaster. Source: Wren Veritasium (YouTube video).

- Slavery? OMG don't get me started. Condoned in the Bible (Mosaid Law). Ignored in the US Constitution. Practiced by 12x US presidents. Sanctioned by the US Supreme Court. This must be the all-time worst-case example of bad public policy.

Safety can also be defined as the **inverse of risk**. More risk equals less safety and vice versa. Risk is fueled by fear – a very powerful motivator. Some fear is rational, but much is because of overwhelming (and self-serving) media hype. How much risk are we willing to tolerate? Society tolerates more risk (less demand for safety) when there is more training, education, disclosure, and control of the situation (eg. military & sports). Society tolerates less risk (more demand for safety) when there is involuntary participation, and with less training and control of the situation (eg. public transportation & medicine).

Consider the following list of risky activities from high to low tolerance:

1. Military (highest risk tolerated)
2. Sports
3. Vices (alcohol, tobacco, marijuana)
4. Private transportation
5. Personal (example: at home)
6. Employment
7. Attendance at public events (school, movie theaters, shopping malls)
8. Public utilities (gas, electricity, telephone, internet, privacy, credit and debit cards)
9. Public transportation
10. Medicine (lowest risk tolerated)

1.3 How safe is safe enough?

Safety requirements follow a hierarchy as follows:

1. **Cultural.** *"The West is a culture of emergency: twisters in Texas, earthquakes in California, wind chill in Chicago, drought, flood, famine, epidemics, drugs, wars on everything… If you didn't believe you could control everything, there wouldn't be an emergency."* (John Burdett, Bangkok 8)
2. **Will of the people.** Communities can and do decide which policies are important and which are not important. Some communities have million-dollar homes and others are desperate for jobs. One correlation extensively studied (Donahue & Levitt 2001) is the impact of legalized abortion on the crime rate two decades later. Popular safety campaigns have included alcohol, tobacco, firearms, Eugenics, vaccinations, asbestos, air pollution, toxic waste dumps, mold, autism, and more recently athlete concussions, sugary drinks, forest fires, global warming, carbon monoxide, Ebola, COVID, and fentanyl.
3. **National law**. Examples: US Department of Labor Occupational Safety and Health (OSHA) and the European Directives. Both have the mandate for the protection of workers.
4. **State law.** This is primarily through the implementation of OSHA national safety law (California title 8) and the adoption of model code books (California title 24). In the US, a standard is elevated to the status of a "code book" when there is widespread legal adoption and reasonably simple enforcement. Cal/OSHA has 30+ pages of regulations just for machine presses. In Europe, the model books are referred to as normal consensus standards, or "norms". European standards frequently begin with EN which stands for European Norm.
5. **Municipal law**. The fire department has the mandate for safe occupancy, including hazardous materials. The building department has the mandate for safe construction, including machinery. Fire and building officials can in fact trump the others because enforcement is the simplest. Without a permit, you don't have a place to live and work.
6. **Third party professional engineering opinions**. This includes nationally recognized testing laboratories (NRTL), regional field evaluation bodies (FEBs), professional engineers, industrial hygienists, etc.

7. **National code books and consensus standards**. Thousands of model code books and product standards are developed by volunteer consensus organizations (secretariats) in an effort to promote safety knowledge, standardization, consistency, economy, experience, and best practice. The organizations are sustained by membership dues, training classes, and the sale of books. American National Standards Institute (ANSI) acts as a librarian and referee for many of the consensus standards. However, third party opinions trump the codes and standards in the same way that physicians prescribe medications, not pharmacists.
8. **Hazard risk assessment.** A hazardous operations (hazop) study can confirm risks, probability, severity, detection, avoidance, and mitigations. There are several recognized techniques like MIL-STD-882, SEMI S10, FMEA, etc. Risk can be analyzed and measured. Less risk means more safety and vice versa. Hazard risk assessment is mandated in both SEMI and CE Mark.
9. **Insurance policy mandate.** This originates from general liability (if you are the seller) and workers compensation (if you are the buyer). Insurance refers to this as loss control. **Example:** Factory Mutual wants the plastic tools to have an FM4910 flammability rating.
10. **Best practice publications**. This includes books, magazines, trade group presentations, etc. that are subjected to peer review**.**
11. **Customer and personal experience.** How does this product compare to others? **Example:** first Chrysler cars had air bags and then all cars had air bags.
12. **Product liability (tort).** This originates from both statute law and case law. What would a "wise and prudent" professional have done?
13. **ALARP "as low as reasonably practical".** This is a popular concept in Europe that states that a company should continue to invest in safety until the "return on investment" is no longer practical. This means a price is placed on a finger, an eye, etc.

1.4 Safety education

Safety involves a lot of common knowledge, and behaviors are learned from an early age.

- Take care of your things.
- Be clean and neat.
- Trust a man in uniform.
- Ask for help.
- Look both ways before you cross the street.
- Read the directions.
- Don't touch a hot stove or a live wire.
- Avoid an unexpected start-up.
- Prepare for injuries and first aid.
- Periodically test your smoke detectors.

Examples of secretariats that develop the codes and standards:

- **ACES** – American Council for Electrical Safety, developed the field labeling procedures which evolved into NFPA 790 & 791.
- **AMT** – Association of Manufacturing Technology, developed the ANSI B11 standard for machinery.
- **ASCE** – American Society of Civil Engineers, developed the standards for construction and structural.
- **ASME** – American Society of Mechanical Engineers, developed the ANSI B30 standard for cranes and hoists, and the boiler and pressure vessel code.
- **ASSP** – American Society of Safety Professionals, previously known as the American Society of Safety Engineers, developed NFPA 70E and the LOTO procedures.
- **ASTM** – American Society of Testing and Materials, originating from the safety of railroad tracks, has now developed over 12,000 consensus standards.
- **CSA** – Canadian Standards Association.
- **EN** – European Norm (normalized technical standards) developed by CEN, CENELEC, and ETSI.
- **IAEI** – International Association of Electrical Inspectors.
- **IAMPO –** International Association of Plumbing and Mechanical Officials.

- **ICC** – International Code Council, developed the standards for residential building code, commercial building code, fire code, mechanical code, plumbing code, etc. Supersedes the 3x original regional building codes known as the Building Officials and Code Administrators International (BOCA), the International Conference of Building Officials (ICBO), and the Southern Building Code Congress International, Inc. (SBCCI).
- **IEC** – International Electrotechnical Commission, organized 1906, primarily concerned with manufacturing and testing of finished goods.
- **IEEE** – Institute of Electrical and Electronics Engineers, developed the standards for industrial wiring, also known as the color books (red book, orange book, etc.).
- **ISO** – International Standards Organization, organized 1946, primarily concerned with materials and process.
- **LIA** – Laser Institute of America, developed the ANSI Z136.1 standard and credentials for laser operation, with enforcement by the Food and Drug Administration (FDA).
- **NEMA** – National Electrical Manufacturers Association, developed the standards for enclosures, ANSI NEMA WD-6 for plugs, and ANSI Z535 for hazard warning labels.
- **NFPA** – National Fire Protection Association, developed the national electrical code, fire code, gas code, chemical code, etc.
- **OSHA and Cal/OSHA** – Occupational Safety and Health Administration, overall worker safety.
- **RIA** – Robotics Industries Association, developed the R15.06 standard for industrial robots.
- **SEMI** – Semiconductor Equipment and Materials International.
- **UL** – Underwriters Laboratory. The UL white book has ~1000 product categories and almost as many standards, which are used for testing and listing, as determined by the product category.

The National Technology Transfer and Advancement Act (1995) mandates that the government adopt privately developed consensus standards (and best practice) whenever possible.

The hierarchy of quality, reliability, and safety define how you invest your money:

1. **Prevention –** training, design, process capability, usability study.
2. **Appraisal –** testing, customer feedback.
3. **Scrap and rework –** fix it in the factory.
4. **Warranty –** fix it in the field.
5. **Insurance –** protects your investment.
6. **Lawsuit –** compensation for accidents, injuries, and defects due to negligence.

Principles of high reliability also apply to safety:

- Train the engineers in the discipline of quality, reliability, and safety.
- Carefully specify the entire system and all of the interacting components.
- Determine the weakness of the system and its components.
- Exacerbate the weakness through accelerated stress testing using factors such as temperature, humidity, altitude, start/stop, vibration, clock timing, and usability testing.
- Design and redesign reliability into a system by using robust parts, fault tolerance, cooling, maintenance, etc.
- Minimize the number of suppliers and treat them like family so problems are not covered up.
- Instrument every system with a “crash log” for forensic analysis.
- Operate a large rotating population of systems to predict what will happen in the field. Companies refer to this as “on-going reliability test” (ORT) and “eating your own dog food”.
- Promote excellent customer relationships so that the rare critical failures can be preserved for investigation.

- Treat customer complaints as epiphany.

1.5 How are US workers killed on the job?

In 2013, 4,585 workers were killed on the job in the United States, and an estimated 50,000 died from occupational diseases, resulting in a loss of 150 workers each day from hazardous working conditions. There are a total of 1882 federal and state OSHA inspectors, which is a ratio of one per 71,695 workers. Source: "Death on the Job, A National and State-by-State Profile of Worker Safety", AFL-CIO, April 2015

http://www.aflcio.org/content/download/154671/3868441/DOTJ2015Finalnobug.pdf

Statistics and time periods can vary. In the US, the top five worker deaths are caused by:

- Transportation 43%
- Machinery and excavation 18%
- Homicide 14% (in 2013, 475 homicides and 282 suicides, source AFL-CIO)
- Trip and fall 13% (~600,000 annual injuries and 670 deaths)
- Electrocution (primarily by accidental contact during construction)

Source: "CDC Fatal Occupational Injuries in the US", 2005, with some adjustment from AFL-CIO

http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5613a1.htm

The above is for **total deaths**. Using fatality **rate** as a measure, the 2015 top ten most dangerous jobs for men, excluding military service, are:

1. Logging workers: 132 deaths per 100,000 workers per year
2. Fishing workers: 55 deaths per 100,000 workers per year
3. Aircraft pilots and flight engineers: 40 deaths per 100,000 workers per year
4. Roofers: 40 deaths per 100,000 workers per year
5. Refuse and recyclable material collectors: 39 deaths per 100,000 workers per year
6. Structural iron and steel workers: 30 deaths per 100,000 workers per year
7. Truck drivers: 24 deaths per 100,000 workers per year
8. Farmers, ranchers, and agricultural managers: 22 deaths per 100,000 workers per year
9. Electrical power-line installation and repair: 21 deaths per 100,000 workers per year
10. Landscaping, lawn service, and grounds-keeping: 18 deaths per 100,000 workers per year

Source: Marguerite Ward, CNBC reporter, January 4, 2017.

http://www.cnbc.com/2017/01/04/the-10-most-dangerous-jobs-for-men.html

Machinery and electrocution account for ~20% of US worker deaths. Equipment safety depends on design, construction, documentation, labeling, inspection, training, and personal protection. This is critical to being compliant with regulations including the OSHA general duty to protect clause.

Examples (Northern California):

April 19, 2010. A 19-year-old man was **electrocuted at a Daly City gas station** while standing on a ladder changing a light bulb. The report said it was not clear if he died from the shock or from falling to the concrete.

March 17, 2010. Maximiliano Martinez, 26, was **electrocuted in Benicia** while installing a 12 KV transformer in an underground vault. Cal/OSHA issued 9 citations to PG&E totaling $176,165. The allegations include failure to protect workers from energized parts, lack of a high voltage warning sign, and lack of approved insulated handles, gloves, and safety equipment. Two more PG&E workers have died in similar accidents. Gerald "Jerry" Biedinger, 57, was killed in August 2010, in Tuolumne City, when his digging rig hit an electrical line. Jon Christensen, 30, was killed in June 2011, in Tracy, as he separated crossed wires without wearing the proper rubber gloves.

September 9. 2010. Gas line explosion burns a San Bruno neighborhood and kills 8 people. The accident was caused by an electrical problem that pumped in higher gas pressure, faulty welds that ruptured (because the 54-year-old pipe seams were welded only on the outside, not on the inside), inadequate inspections, lost records, and 95 minutes to turn off the gas after the rupture was detected. In April 2015, the California Public Utilities Commission (PUC) levied a $1.6 billion fine against PG&E.

July 27, 2012. A party bus picked up several passengers at Shoreline Amphitheater in Mountain View. While heading back to Santa Cruz, two drunken women started fighting and fell out through the door. One was injured and the other was crushed by the bus. The owner was **aware for five months that the door needed repair** and there was a history of suspended license and worker's comp insurance. The case went to trial for one month and ended with a guilty verdict in late May 2015, landing the owner four years in jail.

August 13, 2012. A man working on a fiber optic cable was **badly burned during an electrical explosion** Monday afternoon 4 PM north of Santa Cruz. The California Highway Patrol officer said the man was in his truck's bucket lift when a transformer apparently blew and caught the bucket on fire.

February 24, 2013. An electrical fire critically burned two men early Saturday as they were hooking up power to a circuit panel. San Jose firefighters were dispatched at 9 AM to the scene near Montague Expressway and North First Street to a report of two men unconscious after a flash fire. The San Jose fire captain commented: "The men had been doing some electrical work on the property, connecting the main building to the electrical panel. Some kind of flash fire occurred at the electrical box. I don't know if they crossed wires or what. **It set both of the workers on fire**."

June 11, 2013. A construction worker was killed at the new 49er stadium early Tuesday morning. A city spokesman said the person was working in the bottom of an elevator shaft when another worker took the elevator (up) and accidentally crushed the victim (with the counterweight coming down). **This is a classic LOTO violation.**

July 11, 2013. An employee of a Redwood City grocery store was found crushed to death in a machine used for compacting and bailing cardboard for recycling. Cal/OSHA later fined the company $84,530 for health and safety violations. The Cal/OSHA spokesman stated: **"Protections built into the bailer were either broken or defeated because of a lack of operational training measures."**

August 11, 2014. The owner and project manager of a Fremont construction company were both indicted for involuntary manslaughter due to a cave-in death of a trench worker at a Milpitas construction site January 28, 2012. The project did not have a permit for digging deeper than five feet. Three days before the accident, a Milpitas building inspector issued the first of two stop work notices over concern for cave-in due to recent heavy rain. Both stop work notices were ignored and there was no insurance policy for workers compensation. The Milpitas building official stated: **"The city has the final say when people can go back to work"**. Consequences to the company: Cal/OSHA fine of $168,175, contractor license suspended, and charges of criminal negligence. The case went to trial for 2.5 months and ended with a guilty verdict in early August 2015. The District Attorney stated: **"This wasn't an accident – it was a homicide."** The District Attorney also commented that this was the first time in over 30 years that a California jury had convicted an owner of involuntary manslaughter in a workplace death. The sentence was two years in jail.

February 26, 2018. In San Jose, a tree trimmer was electrocuted after cutting a branch that fell on to a high voltage power line. Wind and rain were a contributing factor.

1.6 Interesting word origins

Alkaline – Alkali (ashes). Potash originates from plant ashes, which can then be converted to lye. The German word for potassium, Kalium, element symbol K, originates from potash. (Arabic)

Acid – Acer (maple). The maple tree was used to make spears. An ace is a warrior who throws a spear and a pilot in a fighter jet. Acid means sharp or sour. Aceraceae (Latin).

Note regarding our sense of taste:

- **bitter** is alkaline (poisonous)
- **sour** is acidic (vitamin C)
- **sweet** is fruit (energy)
- **salty** is electrolytes (for muscle control etc.).

Chlorine – Khloros. Named for its pale green color. {Greek}

Corrosive – Corrodere (gnaw or chew). Strong acid or base. Corrosive is poisonous from the outside and toxic is poisonous from the inside. (Latin)

Electrical – Elektron (amber). Ancient Greeks considered amber to be the tears of the sun god Helios. As a party trick, the Greeks were able to create static electricity by rubbing amber on a piece of silk. Electrical hazards include fire, shock, blast, and burn. {Greek}

Energy – Energos (active). Similar to Ergon (work). Energy release hazards include explosion, arc flash, pneumatic, hydraulic, collapse, etc. { Greek and Latin). The engineer's job is to deal with energy:

- Chemical Engineering deals with **reactions** (especially fire)
- Civil Engineering deals with overcoming **gravity**
- Electrical Engineering deals with **electromagnetic force**
- Mechanical engineering deals with **pressure** (making something move)

Engineer – Ingenium and ingeniare. Devise and contrive through cleverness. Similar to engender, which means to beget (cause an offspring). Genetic engineering should be genetic engendering. (Latin)

Ergonomic – Ergon (work) and nomoi (natural law). Ergonomic means comfortable work. (Latin)

Fire – Pyr (fire). Pyro means fire, heat, and high temperature. Fire hazards originate from over-loaded wires, hot surfaces, sparks, friction, and exothermic reactions. (Greek)

Mechanical – Makhana. A device which enables. Mechanical hazards include pinch-point, entrapment, cutting, noise, burn, flailing gas line, etc. (Greek)

Oxygen – Oxys (sharp) and gene (creation). Oxygen was thought to be essential to acids. {Greek}

Toxic – Taxus (yew). The yew tree was used to make bows for shooting poisonous arrows. Toxic means damage to the organism – poisonous if absorbed, inhaled, injected, or swallowed. A Toxophilite is a lover of archery. (Greek and Latin). The word tax (Latin taxare) meaning to assess, is not related. Venom is a toxic created by an animal who injects it into the victim typically by biting or stinging.

1.7 Industrial machinery – electrical hazards

1.7.1 Fire

American homes are typically wood construction, half the voltage and double the current. Our code focus is based on preventing ignition from hot wires and sparks. European homes are typically masonry, double the voltage, and half the current. Their code focus is on preventing electrocution.

The International Association of Electrical Inspectors (IAEI) estimates there are 50,000 home fires annual in the US due to electrical malfunction.

Example: The deadly Paradise California "Camp" fire was caused by dry grass, high wind, and molten metal dripping from the transmission tower.

Protection: Combustion and explosion are prevented by separating the fire triangle: fuel, oxygen, and ignition. Circuit breakers and fuses prevent over-heated wires. Equipment must contain the spread of a fire and prevent ignition of nearby combustible material. Conduit will contain the burn and snuff out the oxygen. Purging will prevent infiltration of fumes.

1.7.2 Electric shock

In the US, electrocution is the fifth leading cause of worker death. Small amounts of electric current (milliamps) can cause serious injury or death. If the current of a 4 watt night light went through your hand (~33 mA), you would not be able to let go.

Living things run on a flow of ions similar to electricity. The EKG measures heart electricity. The EEG measures brain electricity. At 20 mA, your muscles contract like a painful cramp. At 40 ma, you can't breathe. At 60 mA, your heart won't beat right. With more electricity, the internal organs will cook like an egg in a frying pan or like a hot dog hooked up to jumper cables.

Two situations are especially dangerous:

- A worker falling into machinery will likely try to catch himself with an **open hand**. The sweaty palm is a good conductor, and the current may make it impossible to let go. The machine components must be guarded to prevent accidental contact.
- Below 400 volts, the sweat pores are the primary conductors. The skin has a natural layer of keratin dead skin callus that can act as a dielectric insulator. **Above 400 volts**, the current can break through the skin directly into the salty **bodily fluid**. This is especially dangerous.

Protection:

- **Insulation – Rubber** and plastic, including the dead skin callus on your fingers.
- **Chassis grounding –** If the machine conductors break down, the chassis ground would carry enough fault current to trip off the circuit breaker and kill the power.
- **Ground fault circuit interrupt (GFCI) –** GFCI senses the round trip current, and trips open if more than 5mA is leaking. GFCI is found in wet locations like kitchens, bathrooms, garages, and machinery "convenience" outlets.
- **Guarding –** Terminals >50 volts must be touch-proof or covered with plastic and rubber insulation.
- **Minimize or eliminate** working near energized conductors. Refer to NFPA 70E article 130.2 for the definition of electrically safe working conditions.
- **Hazard warning labels –** Appropriate labels must be in place next to the hazard.

1.7.3 Unexpected start-up

Guards, LOTO, and qualified workers are discussed in chapter 13.

- **Guards on & locks off.** Ordinary operators are protected by guards.
- **Guards off & locks on.** Maintenance workers are protected by LOTO (lockout tagout).
- **Guards off & locks off.** Qualified workers are protected with special training and PPE.

There are a variety of energy release hazards including unexpected start-up, electrical shock, blast, flash, capacitive discharge, mechanical collapse, pneumatic, hydraulic, corrosive, toxic, and explosion.

Protection:

- **Guarding.** Do not disable the door interlocks and open the doors unless the machine is LOTO.
- **Lockout tagout (LOTO).** A protocol for bringing a machine to a "zero energy" safe state prior to maintenance and repair.
- **Unambiguous labels and locks.** It is equally dangerous if locks are on the wrong switch or valve.

Example: arc flash hazard can be reduced by containing the components in a strong metal cabinet.

Example: chock the wheels before you work on a car.

1.7.4 Blast – lighting and thunder

A large fault current (short circuit) can cause:

- Plastic power components to turn into hand grenades.
- Copper vaporizing which creates a shock wave, slamming your head, eyes, and ears.
- Strong magnetic field.

Protection:

- Available fault current should not exceed the AIC rating marked on components and the SCCR marked on panels.
- Strong steel cabinet with venting.
- Rated tools and safety equipment. Hard hat, face mask, ear plugs, and leather gloves.

1.7.5 Heat and blinding light from the arc – welding

Fire (oxidation) is not the only way to burn. Arcing can also cause an extreme burn.

Protection: Face mask, balaclava, fire suit, leather gloves, cotton clothing (not polyester).

1.8 Industrial machinery – other hazards

1.8.1 Mechanical hazards

Machinery is the third leading cause of worker death in the US. Mechanical hazards include cutting, crushing, pinch point, high speed motion, ejected parts, loud noise, high temperature, etc. Earthquake and noise are discussed below. Emergency buttons are typically used for mechanical hazards.

Example: One time I was inspecting a power revolving door. These doors have multiple safety features such as folding flat with the fire alarm and stopping with the bump sensor. So, I asked the client if the bump had ever been tested. He started up the door and shoved in a nearby orange plastic barricade. The barricade was totally mangled and would have been a broken arm.

Example: One time I was inspecting a robot at a solar company in Fremont. We pushed the emergency stop at full speed. The robot stopped so quickly that the glass tubes let go, smashing violently into the wall, resulting in a shower of broken glass all over the work cell.

1.8.1.1 Mechanical hazard reduction

Mechanical hazards can be reduced by the six steps outlined in ANSI Z590:

1. **Elimination** of the hazard during design or re-design.
2. **Substitution** of less hazardous materials, processes, operations, or equipment.
3. **Engineering controls** are designed to minimize risk**. Examples:** guards, interlocks, pressure sensors, overload detectors, maintenance clocks, watch dog timers, ventilation, etc.
4. **Warning signs and labels** including automatic systems.
5. **Administrative controls** such as well-designed work methods, procedures, training, barricades, fire extinguishers, and the emergency button. Some of these are prevention and some are reaction.
6. **Personal protective equipment (PPE)** such as safety glasses, gloves, steel-toe boots, etc.

1.8.1.2 Noise reduction

OSHA 1910.95 covers occupational noise exposure:

- Noise is limited to 85 dBA over an 8-hour shift.
- Employees should receive annual audiograms to check for hearing loss.

The SEMI S2 standard has the following mandates for semiconductor equipment:

- Up to 70 dBA, test data must substantiate the claim. (27.3.2)

- Up to 75 dBA, test data must discuss the expected duration of the noise. (27.3.3)
- Over 75 dBA, the manual must document the sound level and locations. (27.3.4)

Machine noise is regulated in Europe by the EU-OSHA (similar to US OSHA), by the Machinery Directive (EH&S section 1.5.8), and by the 1989 Noise at Work Regulations.

- Emission of airborne noise (must be) reduced to the lowest level . . . comparative to similar machinery. (Machinery Directive EH&S 1.5.8 and 1.7.4.9)
- Instructions must disclose if the noise is >70 dBA at the workstation, or >80 dBA near the machine, so that suitable protection can be used. (Machinery Directive EH&S 1.7.4.2)

1.8.1.3 Earthquake

Refer to the chapter called Equipment Anchorage.

1.8.2 Corrosive & toxic

Corrosive chemicals (acids, bases, oxidizers) and toxic chemicals (compounds of arsenic, boron, cadmium, chlorine, gallium, lead, phosphorous, and selenium) are commonly found in the semiconductor manufacturing process. Material Safety Data Sheets (MSDS) have information on chemical properties, description, storage, health effects (exposure), and emergency response (first aid). Please refer to the section called **SEMI S6 ventilation** for more information.

Compared to older MSDS, the newer SDS is global and has 16x sections in a specific order.

Corrosive chemistry can hurt your skin, eyes, and lungs. Sometimes the exothermic reaction can create enough heat to start a fire. Corrosives like hydrofluoric, DMEA, and TMAH are very dangerous.

Toxic chemistry can enter the body by absorption, ingestion, inhalation, and injection. Toxicology depends on the dose and the duration.

1.8.3 Ergonomic hazards

Ergonomics should be a continuous improvement process to reduce musculoskeletal disorders (MSD). The primary factors are bad posture, high force heavy lifting, repetitive motion, and long duration. Refer to OSHA NIOSH and SEMI S8.

2 Product Liability

2.1 Safety definitions

Dangerous – the result of scientific method. **Examples:** Automobiles, knives, ladders, vaccines, hot coffee, etc. can be dangerous without necessarily being defective.

Defective – the result of a legal process. The jury trial has determined that the injury was caused by bad design, incorrect manufacturing, or inadequate warnings and explanation.

Foreseeability – correctly anticipating the danger, risk, and usage.

Negligence – irresponsible conduct. Failure to anticipate, foresee, design, test, or warn. In the US, the legal standard for negligence is primarily based on case law. In Europe, the legal standard is primarily based on a principle called ALARP (as low as reasonably practical), which means that safety is good enough when the cost of engineering improvement outweighs the cost of an accident, injury, facility, and loss of life.

Safe – a situation that has an acceptable risk. If there is an accident, a "safe" machine is the difference between an insurance payment (like worker's compensation) and a lawsuit for negligence.

Tort – compensation to make someone "whole" again. The seller of any property in defective condition, unreasonably dangerous, can be accused of liability for physical harm, even if the seller has exercised all possible care in the preparation and sale of the product. (Restatement of Torts 1965).

Warranty – a financial reserve for anticipated returns.

2.2 Product life cycle

New products and their corresponding tooling are usually developed in a process called the **product life cycle**. This process has seven stages, with each stage having very specific investment and release criteria. At my prior companies (Xerox, Unisys, Hewlett Packard), these stages were so significant that they were always accompanied by a major company party. The seven life cycle stages are:

1. **Business opportunity**, resulting in an investment plan.
2. **Concept models** with basic functionality, but lack many features that would affect cost, safety, quality, reliability, usability, documentation, etc.
3. **Release to pilot line**, resulting in units for testing and customer demonstration.
4. **Release to full production**, resulting in full specification units for revenue.
5. **High volume maturity**, resulting in cost, quality, and volume improvement, sometimes going offshore.
6. **End of production**, resulting in customers switching over to a newer model.
7. **End of service**, resulting in responsibility often transferred to a third party.

Just like professional athletes and soldiers, engineers can manage more risk than technicians, who can manage more risk than operators or consumers. The extremes of this would be like comparing a space shuttle to children's toys, with hazards such as choking, formaldehyde, lead in the paint, hover-board fires, etc. **A product that is not mature enough is said to be "thrown over the wall".**

2.3 Three key elements of a safe machine

There are three key elements of a safe machine. If there is a negligence case, at least one of these three elements must be proven **defective**.

- **Designed right –** The machine has been designed using appropriate engineering training, skill, experience, and knowledge of the various codes, standards, and best practice. Prototype models are subjected to rigorous design review and qualification testing.

- **Built right –** The manufacturing process is under rigorous engineering document control, change order control, and quality control, sometimes evidenced by ISO 9000 independent certification. Furthermore, products are tested by a competent third party as they are manufactured (if listed) or as they are installed (if field labeled).
- **Explained right –** Manuals and hazard warning labels are legally required to have certain content. Of the three key elements mentioned here, the failure to provide instructions and warnings would be the easiest claim to prove during a lawsuit.

2.3.1 Summary of basic product safety

One might think that basic safety is therefore very simple:

- Product design review and conformity testing.
- Production control to minimize variation.
- Adequate description so that products are used according to their rating (label), data sheet (one page), application note (one chapter), and manual (book).

However, all life is a balance of conformity and diversity, sometimes described as Yin and Yang.

- **The goal of conformity:** promote market acceptance, convenience, efficiency, lower cost, and lower risk. **Examples of conformity:** language and education, the measurement system (English or metric), currency, driving on the right side (or the left side), gasoline, electrical plugs, paper size, and of course, product and construction standards.
- **The goal of diversity:** promote adaptation to the natural changes in the world and tolerate the high risk. **Examples of diversity:** innovation, contingency plans and insurance to counter high risk, police to counter bad behavior, medicine, biological mating (classic Darwin), competition (retail stores), etc.

My former boss once said, "better than doing wrong things well is not doing them at all in the first place." Keep an open mind. Progress has a price. ~25,000 died building the Panama Canal and ~50,000 died at Bhopal India in a single accident.

2.3.2 How to determine if the product design is defective

Accidental –

- The specified part did not have adequate load rating, temperature rating, etc.

Conscious –

- An alternative design would have reasonably reduced the foreseeable risk of harm.
- The product is more dangerous than what a normal customer would appreciate.

Imputation of knowledge –

- Are you aware of your customer usage, the state of the art, and what the competition is doing?
- **Example:** would you sell a cup of scalding hot coffee and call it a beverage?

Risk utility test –

- After a hazard analysis (probability, severity, detection, avoidance), does the customer utility significantly outweigh the risk?
- After a market investigation, is there a lack of a reasonable substitute?
- Is there a high enough price to absorb loss?
- **Example:** Hypothetically, would you sell a rabies vaccine knowing that it kills 1% if the alternative (no vaccine) kills almost everyone infected?

Consumer expectation test –

- Did the product behave as a reasonable customer would expect?
- **Example:** A plywood sanding machine is ejecting thin sheets.

2.3.3 How to determine if the manufacturing is defective

- Did the product change from its intended design even though all possible care was exercised in the preparation and marketing of the product?
- **Example:** I opened a can of soup, and I found a dead mouse in it.

2.3.4 How to determine if the instructions and warning labels are defective

- Would reasonable instructions and labels have reduced the risk of harm?
- Did the absence of instructions and labels contribute to the injury?
- Numerous standards prescribe requirements for instructions and labels including ANSI standard Z535, ISO 3864, NFPA 70 & 79, UL 61010, SEMI S2 & S13, CE Machinery Directive, etc. Consequently, this is easier to prove compared to design and manufacturing defects.
- Kenneth Ross (attorney) and Geoffrey Peckham (Clarion) have an excellent series of articles published by In Compliance Magazine.
- **Example:** US farm equipment should have Spanish language instructions and warning labels.

2.4 Negligence

2.4.1 Common law of negligence

Negligence is conduct that falls below the standard established by law for protection against an unreasonable risk of harm. The common law of negligence states that the elements of **duty of care** and **breach** can be inferred from the very nature of the accident, even without direct evidence of how the defendant behaved, if the following conditions are all present:

- The defendant had a duty to act reasonably.
- The defendant breached this duty because he acted outside this duty, or unreasonably.
- If there had been no breach of duty, then no injury would have occurred.
- The plaintiff suffered actual damages although he did nothing wrong and did not contribute to the negligence.

2.4.2 Res ipsa loquitur – the thing speaks for itself

Res ipsa loquitur is a presumption or inference that the defendant was negligent, which arises upon proof that the situation causing the injury was in the defendant's **exclusive control**, and that the accident would **not normally occur** in the absence of negligence. The mere fact that an accident or injury occurred, with nothing more, is not evidence of negligence. (Farlex)

The plaintiff must establish a **preponderance of evidence** that the defendant's conduct was **unreasonable**, and that such negligent conduct caused the plaintiff's injury. The evidence can consist of direct testimony by eyewitnesses who observed the defendant's unreasonable conduct and its injurious result.

When no direct evidence exists, negligence can be established by **circumstantial evidence**, a logical conclusion that can be reasonably inferred from a set of known facts. **Example:** Skid marks at the scene of an accident are circumstantial evidence that a car was driven at an excessive speed. The reasoning process must be based upon the facts offered as evidence, together with a sufficient background of human experience, to justify the conclusion. Evidence that merely suggests the possibility of negligence is insufficient since negligence must appear **more likely than not** to have occurred. This inference must cover all the necessary elements of negligence: that the defendant owed the plaintiff a duty, which the defendant violated by failing to act according to the required standard of conduct, and that such negligent conduct injured the plaintiff.

Res ipsa loquitur is one form of circumstantial evidence that permits a reasonable person to surmise that the most probable cause of an accident was the defendant's negligence. This concept was first advanced in 1863 in a case in which a barrel of flour rolled out of a warehouse window and fell upon a passing pedestrian. Res ipsa loquitur was the reasonable conclusion because, under the circumstances, the defendant was probably culpable since no other explanation was likely. The concept has been applied often to mass transit injuries. Res ipsa loquitur is now widely accepted across the United States. Circumstantial evidence can be sufficient, and this simplifies the burden of proof in negligence cases.

2.4.3 Burden of proof in negligence cases

Dean Wade factors can be used to determine if a defect is unreasonably dangerous:

- Usefulness and desirability of the product.
- Probability and severity of an injury.
- Availability of safer products to meet the same function and purpose.
- Ability to eliminate danger without impacting usefulness or making it too expensive.
- Avoiding injury by careful use of the product. This includes making the danger obvious by the effect of instructions and warnings.
- Common knowledge and normal public expectation of the danger (particularly for established products).
- Adequate profit and insurance to spread the risk.

2.5 Examples of national injury lawsuits and other cases

Coca Cola exploding bottle. Escola hurt. 1944

Regarding the bottle filling and inspection, apparently the manufacturer acted in a reasonable manner. However, bottles of carbonated liquid would not ordinarily explode when carefully handled and are **not ordinarily defective without negligence**.

Caterpillar Tractor vs. Beck. Alaska. 1979

The consumer expectation test . . . provides no resolution for those cases in which the consumer would not know what to expect, because **the consumer would have no idea how safe the product could be made**.

Wiebe paper shredder without guards. Dart lost an arm. California. 1984.

There are two different bases of liability in design defect cases:

- The manufacturer could be liable if the product fails to perform as safely **as an ordinary consumer would expect**.
- Negligence is possible if the manufacturer could have feasibly made the product safer.

McDonalds hot coffee. Albuquerque, New Mexico. February 1992

Stella Liebeck, 79 years old, was sitting in the passenger seat at the drive-through window. She pulled off the lid to add cream and sugar and spilled the coffee into her lap. The coffee was scalding (~185ºF) and her sweatpants retained the heat, resulting in third degree burns, two years of disability, and $11,000 in medical bills. McDonalds offered $800 compensation. Liebeck then demanded $90,000, which led to a lawsuit and trial.

Evidence at trial:

- Coffee brewed at near boiling temperature (~200ºF) will extract the best taste and smell.
- Effect of water temperature vs. burn hazard: At 160ºF, the time to third degree burns is 20 seconds. At 180ºF, 12-15 seconds. At 190ºF, just 2-3 seconds.
- Scalding coffee is **not fit for consumption** and therefore cannot be a beverage.
- People are aware that coffee is hot. However, most people are **not aware of the hazardous consequence**, specifically that scalding coffee will cause third degree burns in three seconds.
- **Failure to warn**. Defendant stated there were more serious dangers in the restaurant.

- In the prior 10 years, McDonalds paid out $500,000 to settle over 700 claims. On a billion servings annually, the net loss is a tiny fraction of a penny per cup.

Result of trial:

- Jury awarded $200,000 compensation plus $2,700,000 punitive damages.
- Judge reduced the total award to $640,000.
- Coffee is still brewed near boiling and still served at 185ºF.
- Cups and lids are labeled hot. No mention of third degree burn consequences.

Scarangella vs. Thomas Built Buses. New York. 1999

Should a vehicle manufacturer offer a back-up alarm as an **optional safety device**? This case concluded that the absence of an optional safety device did not make the product defective, if the following **Scarangella factors** are met:

- Buyer is very familiar with the product and knows how to use it.
- Buyer knows about the availability of the safety device.
- Buyer understands the benefits and risks of the safety device.
- And in normal use without the safety device, the product is not unreasonably dangerous.

Peanut butter with salmonella food poisoning. Georgia. 2014 & 2015

A federal jury convicted the owner of a Georgia peanut butter plant and two others in connection with a 2008 salmonella outbreak that resulted in 9 deaths, 746 infected in 46 states, and the largest ever food recall in the United States. The plant is now bankrupt. The result was a 28 year prison sentence on September 21, 2015.

Alpo dog food was unintentionally contaminated with melamine. April 2007

Toys-R-Us crayons were unintentionally contaminated with lead. August 2007

Warehouse fire. One time I worked for a large computer company. After a warehouse fire, the fire investigator came on the scene, looked around, and concluded that the computer was the most likely cause. Insurance wanted their money back, known as subrogation. We set up two experiments to show that the fire could not have come from our computer. First, we put one computer in a thermal chamber and raised the temperature as high as we could get it. The chassis remained intact although the plastic melted. Second, we put a cup of gasoline inside the computer chassis and lit it on fire. **The chassis contained the fire**. We made the case for being non-culpable.

Cruise ship fire. One time I attended a presentation on a cruise ship fire, whose origin was thought to be a clothes dryer in the laundry room. Again, the insurance wanted their money back. The dryer manufacturer hired an expert to analyze the scene. Based on the burn marks, soot, and melting, the expert concluded the **fire was arson.** This occasionally happens on cruise ships because evacuation is the only way that many of the workers are permitted off the ship during deployment.

2.6 Liability of used and refurbished products

A used product is a product that has been sold to a buyer outside of the normal chain of commercial distribution. The product is presumed to be active and functional.

A business that sells or distributes products can be liable for accidents, injuries, and property damage caused by a defect in the product, if the defect is because:

- The seller fails to exercise reasonable care.
- The product is changed from its intended design even though all possible care was exercised in the preparation and marketing of the product.
- The product is manufactured incorrectly by the seller or a predecessor.
- The product is damaged during shipping and installation.
- The product does not comply with existing applicable product safety regulations.

A seller who discovers after the sale that their product was defective at the time of sale is generally not absolved of liability by issuing a warning or safety notice. The seller may need to **retrofit the product** to reduce the risk of injury to an acceptable level.

If a manufacturer decides that a safety notice should be sent or a retrofit be installed, the manufacturer has an obligation to find all owners of the affected equipment, even if they have disappeared into the secondary market. Inconsistent handling of a safety problem is one of the leading causes of product liability. The manufacturer's **obligation to inform** can last as long as the useful life of the tool.

The original equipment manufacturer can take steps to mitigate their product liability:

- Maintain a database of all systems.
- Provide a web site for product registration, manuals, spare parts, and safety critical information.
- Develop a network of authorized refurbishers.
- Offer a free start-up audit of equipment being refurbished by others.

Some liability will transfer from the manufacturer to the owner if it can be shown:

- Substantial and unauthorized modification of the tool.
- Inadequate maintenance.
- Unauthorized spare parts.
- Not following the operating instructions.
- Preventing access to a tool for the purpose of installing retrofit kits.
- Improper facility.

2.7 CE Mark for used and refurbished products

Placed on the market – The date when the machine first enters service inside Europe. When machinery comes from another country and enters Europe, as soon as the machine goes across the border, it is characterized as being "placed on the market" for the very first time, and the current directive applies. However, the current standards are not intended to be applied retroactively.

Machinery in service – Refers to machinery that is already in Europe and continues to be used. As long as the owner doesn't change, the machine status doesn't change.

Second-hand machinery – Refers to machinery that has been transferred to a subsidiary, or to another owner. The machine is now "placed on the market" (again) and the current rules apply.

Reconditioned machinery – Refers to machinery that has undergone technical work designed to modify its condition, performance, safety, etc.

The **Directives are the "law"** and the **standards are the "guidelines".** The Directives have more emphasis on hazard risk assessment and less emphasis on checklist regulation.

2.8 SEMI for used and refurbished products

SEMI S2 has a grandfather clause so that older equipment does not have to comply with the latest draft. The customer decides which version of SEMI S2 would apply. **Example:** Texas Instruments allows the use of SEMI S2-1993 (also known as SEMI S2 lite) as the basis of a safety evaluation for older fabrication tools with demonstrated safe history.

SEMI has two groups that are involved in refurbished equipment: (1) the Surplus Equipment Consortium Network (SEC/N) group and (2) the Secondary Equipment Services and Technology Group (SESTG).

SEMI has only one brief document for used machinery, and it's called the Equipment Condition Index (ECI). The ECI can be used to categorize the condition of a tool being resold. The ECI has numerous classifications. **Examples:** new, refurbished, used, operational, demonstrable, documentation available, clean of chemical residue, etc.

SEMI definition of safety: Compliance with design-based standards does not necessarily ensure adequate safety in complex or state-of-the-art systems. It often is necessary to perform hazard analyses to identify hazards that are specific within the system and develop hazard control measures that adequately control the associated risk beyond those that are covered in existing design-based standards.

Typical usage: IBM, Intel, and Sandia National Lab require a SEMI S2 on all equipment being commissioned within their labs and fabs. Sandia usually contracts one company to inspect and write the report, and another company to review the report.

2.9 Checklist for refurbished equipment

The risks of refurbished equipment (operating and servicing) are proportional to the age, prior maintenance, and care used for decommissioning, package, and shipment. Also, older machines were developed using less stringent codes and standards. **Example:** an older car without air bags, anti-lock brakes, etc. These risks are characterized below.

Electrical:

- Harness on automation equipment is subject to abrasion.
- Circuit breakers may have exceeded their useful life, especially if they have been subjected to short circuit. Circuit breakers should be periodically actuated to distribute the lubrication and to verify that they are not stuck shut.
- Loose connections can lead to hot spots and arcing. Many places have an annual torque check.
- Ground circuits can have increased resistance due to corrosion, loose connection, or missing wires.
- Spring loaded interlocks may have limited remaining life.
- Power supply electrolytic capacitors may fail.
- Power transformers may be over stressed which could result in poor insulation and dielectric integrity.
- Maintenance by unauthorized and untrained personnel which could result in bad replacement parts or wrong connections.
- Excessive current could cause the conductor leads to become bridle.
- Electrical code and standards are constantly changing.

Gas lines and gas boxes:

- Hazardous gas lines using worn Swagelok fittings.
- Hazardous gas lines using VCR fittings but without metal face seals.
- Burned out seals on gas lines due to adiabatic heating.
- Cracked stainless steel piping due to poor welding, inter-granular corrosion, and incomplete purging.
- MFCs have been improperly calibrated or the wrong MFCs have been installed.
- Check valves are defective.
- Gas box integrity has deteriorated. Poor air flow no longer sweeps out a gas leak.

Process chamber and vacuum system:

- Process wall deterioration.
- Defective vacuum gauges and electronics.
- Gate valves and slit valves not sealing.
- Contaminated pumps.
- Defective pump motors.

Robotics:

- Defective servomotors.
- Robotic arms bent or distorted.
- Electromechanical stops removed or defective.
- Defective servo amplifiers.

Mechanical:

- Bent or distorted frame.
- Legs damaged.
- Potentially sharp or abrasive corners or surfaces due to wear over time.

3 Special Inspections

3.1 Safety cops

As previously mentioned, there are many code writing and safety cop organizations. Requirements are prescribed in the codes for building, electrical, fire, mechanical, plumbing, and OSHA.

- Building department for construction permits and inspections.
- Fire department for occupancy and hazardous materials (hazmat).
- Nationally Recognized Testing Laboratories (example: UL) for consumer product safety.
- Contractor State License Board for contractors & electricians.
- Professional Engineers for blueprints and special inspections.
- Federal and state OSHA for worker safety.
- Environmental Protection Agency for discharges going up in the air, on the ground, down the sewer, and buried in the landfill.
- Food and Drug Administration (FDA) which includes x-ray, laser, and medical devices.
- Insurance companies (general liability and workers comp) for risk management and loss control.
- Trade organizations – ASCE, ASME, ASSE, IAEI, ICC, IEEE, IAEI, NEMA, NFPA, SEMI.
- Lawyers for tort compensation.
- Labor unions – especially in Europe.
- Contract specifications for equipment purchases.

Reasonable people can make an informed choice not to inspect. Some people do their own home construction, do their own tax returns, do their own medicine, and teach their own kids at home. Although the risk of an accident or injury may be low, the consequences could be painful and expensive. Negligence is presumed if unsafe equipment causes an accident or injury, and the insurance settlement may be difficult.

OSHA protects the safety of workers and consumers with OSHA regulations and guidebooks. Employers are responsible for preparing basic safety plans in areas such as accident prevention, hazard communication, hazardous materials management, trip and fall, energized work, lockout-tagout, etc.

OSHA regulations (29CFR 1910.303 and 1910.399) require that all electrical equipment in the workplace be certified or subjected to a complete and thorough evaluation before use. Certification is generally understood to be either an NRTL listing or a field evaluation label from a third-party field evaluation body approved by the Authority Having Jurisdiction (AHJ). Some cities have special arrangements. **Example:** San Jose had given IBM approval to do their own inspections. **Example:** University of Minnesota is their own jurisdiction.

The National Electrical Code (NEC) is rolled every three years (eg. 2002, 2005, 2008, 2011, 2014, 2017, 2020, 2023). The California electrical code follows the NEC by two years (eg. 2004, 2007, 2010, 2013, 2016, 2019, 2022, 2025). Local jurisdictions also need time to adopt the California code. Construction requirements take a few years before they are adopted into law.

The Standard for Industrial Machinery (NFPA 79) is rolled every few years (eg. 1997, 2002, 2007, 2012, 2015, 2018, 2021). NFPA 79 section 1.3.1 says that the standard is not intended to be applied retroactively. However, **changes** to the machine shall comply with the provisions of the latest standard.

3.2 Professional engineering inspectors

Many engineers are involved with special inspection. Examples of their scope of work include:

- **Chemical engineering:** fuels, consumer and industrial products, corrosive, flammable, and toxic gas, with specialization that includes fire safety and industrial hygiene.

- **Civil engineering:** soil, foundation, buildings, bridges, roads, airports, dams, and pipelines, with specialization that includes geological, structural, welding, and scaffolding.
- **Electrical engineering:** high voltage power and control circuits, with specialization that includes transmission line, machinery, robots, lasers, life safety, and sources of ignition.
- **Mechanical engineering:** product design, gas plumbing, pressure vessels, heat transfer, with specialization that includes planes, trains, and automobiles.

3.3 Jurisdictional approval

Jurisdictional approval is important to understand. **Examples:** Hewlett-Packard is in the City of Palo Alto. Stanford University is in the unincorporated County of Santa Clara. Stanford Linear Accelerator is under the US Department of Energy. California amusement parks are under Cal/OSHA state jurisdiction, same as elevators, and Cal/OSHA does their own inspections. Most California hospitals are under Cal/OSHPD. At a hospital, even a simple machine used to chop and burn needles needs to have an NRTL listing or an NRTL field label. PG&E is under the Cal/PUC.

The ASME pressure vessel code is adopted in 41 states. In California, Cal/OSHA does the inspection of non-code compliant pressure vessels: http://www.dir.ca.gov/dosh/PV-2006-4.pdf

In California, Arizona, and Texas, the cities and counties have electrical jurisdiction. However, in most of the western and rural states including Alaska, Washington, Oregon, Idaho, New Mexico, Minnesota, Kentucky, Tennessee, and others, the state has electrical jurisdiction. Unlisted electrical equipment (or modified listed electrical equipment) is beyond the knowledge of the average city inspector, so it's in a category called **special inspection**.

There are five credential levels that the jurisdiction may require for inspection of electrical equipment:

1. OSHA NRTL recognition. **Examples:** UL, CSA, Intertek, etc. https://www.osha.gov/dts/otpca/nrtl/
2. IAS FEB accreditation. **Example:** ETI. http://www.iasonline.org/Field_Evaluation_Bodies/
3. P.E. licensed in-state. **Example:** a California P.E. working in California.
4. P.E. licensed out-of-state. **Example:** a California P.E. working in Oregon.
5. Demonstrated education and experience but no professional engineer (P.E.) license needed. **Example:** this is the case with the SEMI and CE Mark reports.

There are two kinds of companies that inspect machinery: national labs (like UL) credentialed by OSHA, and regional field evaluation bodies (like Abstraction Engineering), credentialed one-by-one by the jurisdictions. California has ~500 jurisdictions. Most cities and counties accept a field evaluation body with three conditions:

- The principal is a licensed professional engineer.
- The firm is a legal entity (incorporated).
- The firm follows the Competency and Practice Guidelines defined by NFPA 790 & NFPA 791.

Arizona, Oregon, Washington, Minnesota, and some Utah cities (Salt Lake requires in-state PE license) will accept a California P.E. license for field labeling. Oregon is a simple application and has a one-time fee of ~$400.

Washington is modeled like an NRTL with approval based on UL product standards. It is a very complicated application which includes an on-site visit from the Washington representative.

Kentucky and Tennessee require an in-state P.E. license plus approval of the state chief electrical inspector. Note: All states have building and fire codes, but due to the cost, enforcement is often pushed up to the county or state level.

Idaho used to require NRTL or IAS FEB accreditation. The Idaho law changed in 2014 to permit industrial equipment (described in NFPA 79) to be inspected by a Field Evaluation Body if the engineer has an Idaho P.E. license. However, there is a local trade organization called "Southwest Idaho Manufacturers Alliance" that is pushing for a statue law that will exempt all industrial equipment from both listing and labeling. Oregon might already have this rule.

New Mexico requires IAS FEB accreditation or NRTL, but they will accept an in-state P.E. for the certification of electrical equipment that is not described in the UL White Book. This is subject to interpretation as the biggest factory is Intel and the White Book categories for semiconductor equipment are very general.

Large Texas cities (Dallas and Austin) require NRTL. Smaller Texas cities (Sherman) and Travis County (Tesla) will accept in-state P.E. Texas is perhaps the most restrictive to maintain a P.E. license. In Texas, “engineer” is a protected title. You cannot call yourself an engineer unless you are state licensed.

The jurisdictions maintain lists of approved special inspectors. A third-party inspector of electrical equipment is known as a **field evaluation body** (FEB). The FEB list is often changed. The old links (example below) might be working even though the list is out of date.

Santa Clara: http://santaclaraca.gov/home/showdocument?id=65946

Sunnyvale: https://www.sunnyvale.ca.gov/home/showpublisheddocument/870/637883960698070000

Authorities Having Jurisdiction (AHJs) sometimes have their own special requirements. **Examples:**

- Santa Clara, CA – (1) SO type power cord cannot be used as direct hook-up from a disconnect switch to a permanently installed tool. (2) Power cords and seal-tight flex cannot lay directly on a concrete floor. They need to be on Unistrut rails and covered with a floor cord cover kit. (3) Nameplates must clearly state the full load current and be wired accordingly. For example, do not wire a tool with a 200 amp feeder if the panel rating (full load current) is only 100 amps. (4) Conventional disconnect switches must be within arm’s reach.
- Livermore CA – A SEMI S2 report is as good as a field evaluation report.
- Fremont CA – If the machine is moved within the city, the old sticker is good enough. But if the machine comes from another city into Fremont, the machine must be re-inspected. Fremont requires the primary use of UL standards.
- Stockton CA – Machinery inspections must be done in two parts. First the grounding is checked, and the city gives approval. Then the machine can be energized for the rest of the inspection.
- Camarillo and Mission Viejo CA – The building department is contracted out to an independent company called Charles Abbott Associates. The rules are easy.
- Los Angeles is divided into: (1) cities affiliated with the City of LA (eg. Sylmar), (2), cities affiliated with the County of LA (eg. Carson, Westlake Village), and (3) cities with their own building department (eg. Palmdale). Each has their own rules. In Palmdale, only an NRTL is allowed to conduct field label evaluation.
- Unincorporated Santa Clara County (Stanford University) requires IAS FEB accreditation or NRTL.
- Hayward CA requires the firm to be in business for at least 5 years.
- Morgan Hill CA building department policy 2C allows a California licensed electrical engineer to do the evaluation and allows a prior report from a city in Santa Clara County.
- California title 24 requires lighting controls to be installed and inspected by a graduate of the California Advanced Lighting Controls Training Program https://www.CALCTP.org

3.4 FEB credentials vs. inspector credentials

This is like comparing a **hospital** to a **surgeon**. NFPA 790 & 791 focus only on the FEB credentials, not the inspector. Same with the cities: FEB credentials, not the inspector. However, many city inspectors have in fact gone to a specialized 2-year school (example: Diablo Valley College) and have passed a state exam.

Does a field evaluation body require a professional engineer? Yes. The California Board of Professional Engineers and the California business and professional code §6738 is very clear that unlicensed engineers must work under the direction of a licensed professional engineer.

https://law.justia.com/codes/california/2011/bpc/division-3/6730-6749/6738/

- An engineering consulting company must have a professional licensed engineer as the owner (sole proprietor), or as a partner (LLC), or as an officer (corporation).
- An unlicensed person cannot be the sole owner of an engineering business offering civil (including structural and geotechnical), electrical, or mechanical services.
- An unlicensed person may be a partner or officer, provided that a licensed engineer is also a partner or officer in charge of the engineering practice of the business.
- A licensed engineer who is . . . in responsible charge of professional engineering services offered or performed by a firm, partnership, or corporation must file an Organization Record with the Board within 30 days of such association.

A professional engineering consultant is someone who is:

- Educated (example: BS & MS engineering).
- Experienced (example: significant industrial experience and 10,000 inspections).
- Licensed (example: state licensed professional engineer and contractor).
- Insured (example: $1M general liability, $1M professional errors & omissions).
- Published (example: books, magazines, presentations, etc).

People involved in public safety are supposed to be licensed – architects, builders, doctors, nurses, dentists, lawyers, teachers, driving a car, cutting hair, etc.

Before you hire an FEB, check their web site for inspector credentials, and then check LinkedIn. Make sure the professional engineer is in fact working full time for the FEB and is not just moonlighting.

3.5 Listing and labeling

In the US, there are two jurisdictional groups involved with safe machinery.

One is the **US Department of Labor, who is responsible for OSHA** (occupational safety and health administration), who then recognizes the NRTL (Nationally Recognized Testing Laboratories) like UL. NRTL certification is primarily done in the production factory and primarily for consumer products like toasters.

NRTL originated in 1970 with two companies: UL and FM. Beginning in 1988, there was finally a process to approve additional labs. Now there are about 20x. OSHA requires NRTL certification on 35x fire protection products and 3x scaffolds. Electrical equipment is not included in this list. NRTLs have since expanded into consumer products, components, etc. and some industrial equipment. Except for fire safety, the US Government does NOT require NRTL certification on products. It is done for market and insurance reasons.

The other jurisdictional groups are the **city, county, and state building departments**, who adopt the construction codes and standards like NEC (National Electrical Code) and IFC (International Fire Code). The NEC and IFC require safety certification for most industrial equipment. In California, adoption of the construction codes (like the NEC & IFC) is known as title 24. Most cities permit the use of a city approved FEB (field evaluation body) to provide on-site inspection work. Abstraction Engineering is an FEB.

An NRTL listing is best for high volume consumer equipment with a broad distribution to unsophisticated consumers. An FEB field label is best for low volume industrial equipment with a narrow distribution to sophisticated consumers.

3.5.1 UL White Book and standards

UL has two roles. One role defines the White Book categories and develops the UL product safety standards. The other role conducts the conformity testing in competition with other OSHA recognized NRTLs (Nationally Recognized Testing Laboratories). There are ~21 NRTLs.

In Canada, the role of the Canadian Standards Association (CSA) is similar to UL. CSA maintains the standards but conducts the conformity testing in competition with other agencies such as UL & ETL. A product that is listed for both UL and CSA standards is marked **CSA, cUL, or cETL**. Canadian Provinces maintain their own **Electrical Safety Authority** (ESA) to inspect both construction and equipment.

The UL White Book (~1100 pages) has ~1000 product categories (coded with 4 digits) and includes a list of what standards go with each product category. Some product categories (like robots) are very specific. Some product categories (like industrial machinery) are generalized. The White Book also includes a cross-reference table between specific NEC sections and the various product categories.

UL standards (more than a thousand) cover **components** (eg. circuit breakers), **consumer products**, (eg. toasters), and **specific uses** (eg. data processing, laboratory, and explosive atmosphere).

A UL standard can cover a variety of products with only one common characteristic. **Example:** UL 499 covers **electric heating appliances** such as a large furnace for heat treatment. The standard also covers pottery kilns, water heaters, charcoal igniters, glue guns, egg incubators, wood burning pencils, pet heating pads, hot plates, soup kettles, and heat guns. But not hair dryers – that would be UL 1727.

3.5.2 Listed

The NEC (National Electric Code) says that electrical equipment needs a safety certification and gives two ways to do it, either in the production factory (NRTL listing) at the time it is built, or in the field (field label) after installation.

A **listed product** has national approval. The construction review is very formal and done before production. The production factory is under rigorous document and process control, with periodic auditing. In a UL listed product, 100% of the internal components are required to be UL listed. Listed products are typically for a **mass market** with broad application and limited skill operation.

A listed part (or assembly) has 3x aspects: **(1) Designed** by the manufacturer and used according to its **rating, cut sheet, data sheet, and installation manual.** Rating refers to maximum voltage, current, temperature, pressure, wet and oil location, indoors or outdoors, terminal torque, number of insertions, approved chemistry, duty cycle, etc. **(2) Sample tested** by an NRTL using a UL standard. **(3) Produced** on an NRTL supervised manufacturing line.

NEC 110.3(B) Installation and Use. Equipment that is listed, labeled, or both shall be installed and used in accordance with any instructions included in the listing or labeling.

Example: An outlet is a listed part, and it should be installed according to its rating. An outlet is also intended for portability. Therefore, the circuit voltage (eg. 208 3Φ+G), circuit breaker over current protection (eg. 30 amp), cord gauge (#10/4), and outlet type (NEMA L15-30) are a matched set. Wires can be larger, but outlets cannot be smaller. Adding unnecessary third legs and neutrals can sometimes be convenient but can sometimes cause confusion. A 30 amp circuit should not have a 20 amp outlet.

A UL listed assembly can incorporate either **UL listed parts** or **UL recognized parts** (backwards UR). UL listed parts (like molded case circuit breakers) can be installed or swapped in the field. UL recognized parts (power supplies, motors, chillers, etc.) must be installed in a UL supervised factory to maintain UL on the whole thing. On its own, the part would be considered restricted or incomplete. The European equivalent of this would be a Declaration of Incorporation.

3.5.3 Labeled

Companies that do field label evaluation are known as field evaluation bodies (FEB). FEBs need to be approved by the jurisdictions one by one. This can be complicated. For example, South San Francisco, Oakland, Lathrop, and Tracy CA require NRTL to do the field label. Sacramento, Phoenix, and New Mexico require IAS accreditation. Oregon and Minnesota are simple. Washington is complicated.

A **labeled product** has city, county, or state-wide approval. The construction review is less formal and done after installation. The product typically has a narrow market and application, and it is usually operated with a higher skill level. An example of this (narrow market and high skill) is a semiconductor production tool.

At some point, equipment manufacturers consider the cost/quantity value proposition for listing vs. field labeling. A listing is about $50,000 plus the cost of the regulatory manager, the product being sacrificed, and the factory overhead. Therefore, the breakeven point for listing vs. labeling is 50+ identical machines. Some **panel shops** have a special relationship with UL for assembly of a UL508A industrial control panel (ICP).

Once machines are field labeled, they can generally be moved without re-inspection if three conditions are met:

- The labeling company is approved by the city where the machine is moving to.
- The machine has not been disassembled and put back together.
- The machine has not been modified since the earlier inspection.

Earlier versions of NFPA 790 permitted **field labels to be used for a product series, same as a listing**. One or two products were reviewed for construction and test, and the rest receive a quality control inspection. However, NFPA 790 10.2.1 now requires the evaluation at the final installation site. This may affect machines that have been moved.

3.6 Understanding the Field Evaluation Body (FEB)

3.6.1 FEB operation

The FEB must maintain the necessary licenses, insurance, training, library, equipment, calibration, etc. Work must originate from a written proposal. Notes, reports, and stickers must be filed and cataloged.

Workflow is critical to a busy operation. FEBs use a job log “dashboard” that keeps track of proposals, back-log, inspections, reports, invoices, and payments. Most FEBs use cash-based accounting, meaning that revenue is recognized at the time the cash is received – the invoice does not create an asset. The **backlog** is the total of the purchase orders minus the invoices. The **accounts receivable** is the total of the invoices minus the cash received. Clients often reschedule their appointments. Proposals, backlog, reports, and cash are reviewed several times a day. Good workflow makes for a happy client.

3.6.2 FEB scope of work – independent third party or consultant

This topic can be complicated and requires good judgment to manage. Here are some of the issues.

- Does the professional engineer have a duty to public safety that conflicts with helping a client?
- Does a confidential professional services agreement (PSA) create a conflict of interest?
- Does the scope of work change if there is no building permit involved?
- Can the inspector show or tell a client how to fix something?
- Can the inspector suggest a better design, such as using a bus bar for ground distribution?
- Can the inspector make minor repairs, such as tightening a loose screw, creating a missing nameplate, tracing an unlabeled circuit back to the circuit breaker panel, or adding a yellow background to an EMO button?
- Can the client insist on a specialized insurance policy, and force a 50+ page consulting agreement, using a standard architectural contract, with the word architect crossed out and replaced with the word consultant, and then refuse to pay you if you don’t sign it?

- NFPA 790 (2024) 5.2.6.2 defines the conflicts of interest. (4) Measures to prevent individuals . . . **from acting as an advocate or consultant for that client.**

Many issues can be non-conforming but have no safety impact. Knowing the product, the people, and the situation, a FEB professional engineer might judge a concern same as the way a real estate broker might judge a disclosure during a property transaction.

3.6.3 FEB scope of work – adjunct to the electrical inspector or in-lieu of a listing

FEB professional engineers view their role as an **extension to the electrical inspector**. This includes the NEC feeder circuit (power and ground wires, transformers, circuit breakers, and disconnect switches), NEC article 409 Industrial Control Panels, and NEC article 670 Industrial Machinery. **FEB professional engineers** also consider the available fault current and arc flash.

- Electrical construction and electrical equipment have a similar purpose: "the practical safeguarding of persons and property from the hazards that arise due to the use of electricity". Reference: NEC.
- Most clients would rather work with a dedicated engineer than with a building inspector.
- Engineers see a lot of things to fix. **Examples:** missing "fed from" labels, incorrectly sized wires, missing disconnect switch, inadequate short circuit current rating, and transformers whose secondary neutrals are not properly bonded.
- The city accepts no liability for something missed in plan check or inspection.

Nationally Recognized Testing Laboratories view their role as **in-lieu of a listing**. This implies:

- More emphasis on conformity testing and less emphasis on construction and installation review.
- NRTLs believe that UL standards are for "certification" and NFPA standards are for "installation".

Example: Sizing a wire. NEC philosophy would be to size a wire according to a chart, and then go 125% for a continuous load (over 3 hours). UL standard philosophy would be to operate the full load for several hours, and then measure the temperature.

3.6.4 FEB scope of work – NRTL listed power and safety components

Several standards prescribe: (1) power and safety components must have NRTL listing, and (2) components must be used according to their rating. **Examples:** NFPA 79 4.2, NFPA 791 4.1.1(3), NFPA 791 4.2, NFPA 791 5.7(2)&(3), UL 508A table SA1, UL 61010 section 14, and SEMI S2 13.4.3. The implication is that **the component must be listed (NRTL tested) to confirm the rating (voltage, current, power, temperature, pressure, etc.).**

If an NRTL or IAS accredited FEB is doing the field label evaluation, which is required in some cities like Sacramento and Phoenix, then the power and safety components must be NRTL listed. No choice.

If another FEB is doing the field label evaluation, then the power and safety components are considered for NRTL (but not required). (1) Components without NRTL listing are not automatically bad. There can still be a demonstrated history of safe operation. (2) Brand name components, with or without the NRTL Mark, are often identical just made on different production lines. (3) Most equipment coming from Asia will not have NRTL components because of significantly higher cost and lead time.

Basically, it comes down to cost and lead time, and the issue is very similar to branded drugs vs generic.

3.6.5 FEB scope of work – basic hazards or just electrical

This is a very contentious debate. Some of the NRTLs, local FEBs, and at least one large semiconductor fab believe the scope of field labeling should be restricted to just hazards of electricity (shock and fire).

Predominant hazards from electricity:	Fire prevention:	Shock hazard guarding:
• Fires ignited by hot wires • Shock and electrocution • Arc flash burn • Blast, bludgeon, and noise • Unexpected start-up	• Circuit breakers and fuses • Wire gauge and conduit • Temperature rating of wires and terminals • Resistance at the terminals • Ambient temperature • Infiltration of vapors and dust	• Chassis equipment ground – trips the circuit breaker • Ground fault interrupter – measures current round trip • Barriers – plastic insulation, rubber gloves and mats, locked doors, touch-proof terminals • Disconnect and LOTO • Hazard warning labels • Minimize energized work

Rationale for the inspection to be just for the hazards of electricity:

- Field labeling originates in the National Electrical Code, and
- NFPA 79 & IEC 60204 prescribe only the electrical characteristics of machines.

However, some NRTLs and local FEBs (Abstraction Engineering) include additional machinery hazards such as mechanical, energy release, corrosive, toxic, and ergonomic.

- Intertek: http://www.intertek.com/field-labeling/process/
- MET Labs: http://www.metlabs.com/Services/On-Site-Field-Testing-and-Evaluation.aspx
- TUV: http://www.tuv.com/media/usa/aboutus_1/pressreleases/fieldevaluation/Guarding.pdf

Rationale for the inspection to include additional hazards:

- UL 61010, one of the more common standards for industrial equipment, includes sections for hazard warning labels, electric shock, mechanical, spread of fire, fluids, radiation, injurious gases, and explosion.
- UL 1740, for robots, includes an extensive review of mechanical and automation hazards.
- Federal and state OSHA requires inspection of machinery. Cal/OSHA has a lot of discussion on mechanical hazards.
- Safety inspections should confirm an **acceptable level of risk**, using judgment, conformance, best practice, and hazard risk assessment.

Rebuttal argument:

- The scope of UL 61010 states that it is only for analytical and laboratory equipment.
- NEMA enclosure standards are intended to enclose electrical parts, not mechanical parts.

Rebuttal counterargument:

- Standards are just guidance documents. Choice of standards depends on the judgment of the engineer, then by best practice, then as determined by the UL Whitebook, and finally as determined by the scope of the standard itself.
- UL 61010 is comprehensive and well written. UL 61010 is frequently used as the guidance document for industrial equipment where the **material is contained within the machine. Examples:** vacuum pump, chiller, abatement, wafer sorter, pick-and-place, dispenser, etc.
- If the standard itself were the only way to determine applicability, then NFPA 79 would be ruled out for some industrial equipment because Annex C states it applies to wood, metal, and plastic fabrication, assembly, and packaging, in other words, for **material outside the machine**.

3.6.6 FEB scope of work – choice of product standards

The FEB professional engineer has some discretion to select and apply the reference standard. Same thing in medicine – physicians prescribe medications, not the pharmacists.

The standard groups: UL 508/508A/61010, NFPA 70/79, IEC 60204, ICC/IFC, SEMI, and OSHA/Cal-OSHA have similar requirements, and they are moving closer together, a process known as harmonizing. The Abstraction Engineering checklist includes all of these groups.

These are the most common UL standards that relate to industrial equipment:

- UL standard 508, Industrial Control Equipment, for industrial motor controllers.
- UL standard 508A, Industrial Control Panels, specifically for the operation of motors. Something must be moving.
- UL outline 2011, Factory Automation Equipment. UL2011 is a very brief set of guideline notes.
- UL standard 61010, Electrical Equipment. UL61010 is the international version of UL 1262. UL 61010 is for stationary industrial equipment like chillers, metrology, analytical, etc. IEC 61010 is often used as the reference standard for the European CE Mark Low Voltage Directive (LVD).
- UL standard 499, Electric Heating Appliances, including industrial furnaces.
- UL standard 1740, Robotic Equipment, refers to RIA R15.06, NEC, and NFPA 79.
- UL standard 60950, Information Technology Equipment, includes office equipment like computers, cameras, printers, copiers, and equipment racks. UL 60950 has been used for the listing of industrial 3D printers and laser cutters.

So, what is the **essential characteristic** that relates equipment to a choice of over 1000 standards? Is it heat, motion, fixed or portable, hard wired or power cords, fluids, chemistry, measurement, etc?

NFPA 79 has several advantages over the UL standards:

- NFPA 79 is a direct extension to the NEC, referenced in NEC article 670, and the NEC is the law.
- NFPA 79 has been around longer than the UL standards, and it is more mature.
- NFPA 79 is reasonably complete, unlike UL where you would need a bundle of standards.
- NFPA 79 has well written requirements for collateral like nameplates, drawings, manuals, etc.
- NFPA 79 is more easily check-listed which makes for an easier interpretation and report.
- NFPA 79 is the basis of the European CE Mark for machinery, where it is known as IEC 60204.
- NFPA 79 is $50 vs. $800 each for UL 508, UL 508A, UL 60950, UL 61010, etc.
- NFPA 79 has been extended to a “handbook” version in 2015.

But there are limitations:

- NFPA 79 scope is only for machines that process material (cutting, forming, squeezing, etc.) Something must be moving.
- NFPA 79 scope is only for hazards of electricity (shock and fire). It does not address other hazards such as pinch point, toxic gas, laser, etc.
- NFPA 79 is not exactly clear about what situations require EMO buttons, door interlocks, etc.

3.7 Construction review

NFPA 791 chapter 5 describes the requirements for construction review.

- 5.2 Installation including nameplate, instructions, and wire space
- 5.3 Enclosures
- 5.4 Disconnect switch or plug
- 5.5 Feeder OCP to the front of the machine
- 5.6 Field terminations to land the wires
- 5.7 Critical components for power and safety
- 5.8 Branch OCP inside the machine
- 5.9 Outlets and lighting
- 5.10 Wiring
- 5.11 Markings including hazard warning labels
- 5.12 Grounding
- 5.13 Minimum distance between exposed energized parts

For a discussion of critical components, refer to the chapter **Technical File for CE and SEMI** and the section called **Power and safety components**.

3.8 Electrical testing

NFPA 791 chapter 6 describes the requirements for electrical testing:

- Insulation resistance (equivalent to a 500 VDC hi-pot)
- Dielectric withstand (equivalent to a 1500 VAC hi-pot)
- Ground bond (< 0.1 ohms, equivalent to 63 feet of #12 wire)
- Input power (voltage and full load current)
- Temperature rise of terminals and components
- Safety interlocks
- Emergency stop

Note: Refer to the section **Hi-pot testing and troubleshooting** near the end of next chapter.

Conditional approval:

Equipment sign-off (conditional release) originates from a Sematech procedure #98103579A-XFR.

Level 1 “conditional” release:

- Equipment grounds are correctly sized and landed.
- Power wires are correctly sized 125% of continuous full load and 100% of remaining load.
- Local disconnect switch or plug.
- Electrical circuits are labeled at both ends.
- Emergency buttons are hooked up and working.
- Seismic anchorage.
- Electronic signal interaction is working.
- Construction is neat, clean, and professional.
- Ok to turn-on for commissioning, but not ok for production.

Level 2 release:

- Leak check.
- Interlocks are hooked up and working.
- Ok to turn on the process gas and hazmat.

Level 3 release:

- Documentation, LOTO protocol, quality tolerances, etc.
- Ok for general use and production.

3.9 Permit and inspection

3.9.1 Typical permit procedure

1. The company has a budget for construction.
2. The architect draws up a construction plan.
3. The building contractor takes the plan to the City Hall to pull a permit.
4. The plan checker adds a condition for a third-party field label on “unlisted” machinery. Sometimes a city inspector does a walk-through and puts his own tags on the tools needing inspection.
5. The electrical contractor installs the wiring up to the machine disconnect (fit-up).
6. The equipment installer connects the wiring and utilities (hook-up).

7. A competent third party inspects the machinery and adds a field label.
8. The building official gets a report and signs off the permit.

3.9.2 Main reasons for inspection

The NEC, IFC, and Cal/OSHA all refer to listing and labeling as evidence of equipment safety (acceptable risk). Building and safety officials typically cite the following codes:

National Electrical Code (NEC) 90.7: Examination of Equipment for Safety. Certification agencies perform field evaluations to render an opinion of compliance with the code requirements along with applicable product standards.

National Electrical Code (NEC) 100:

- **Labeled –** Equipment to which has been attached a label, symbol, or other identifying mark of an organization acceptable to the authority having jurisdiction and concerned with product evaluation . . . (and) indicates compliance with appropriate standards or performance in a specified manner.
- **Listed –** Equipment, materials, or services included in a list published by an organization (nationally recognized testing laboratory) that is acceptable to the authority having jurisdiction and concerned with product evaluation.

National Electrical Code (NEC) 110.2 Approval. Listing or labeling is the most common method for establishing suitability.

National Electrical Code (NEC) 110.3. Examination, Identification, Installation, and Use of Equipment. Listed or labeled equipment shall be installed in accordance with any **instructions** included in the listing or labeling. Note: the instructions form a hierarchy: nameplate, data sheet (cut sheet), application notes, and manuals. Physical limits are commonly referred to as a "rating".

NFPA 70E (2018) 110.1(B): The electrical safety program shall include elements to verify that newly installed or modified electrical equipment or systems have been inspected to comply with applicable installation codes and standards prior to being placed into service.

International Fire Code (IFC) 605.7: Electrical appliances and fixtures shall be **tested and listed** in published reports of inspected electrical equipment by an approved agency and installed and maintained in accordance with all instructions included as part of such listing.

OSHA 29CFR 1910.303 and 1910.399: All electrical equipment in the workplace shall be certified or subjected to a complete and thorough evaluation before use. OSHA delegates safety enforcement to 22 of the 50 states including California (Cal/OSHA).

Cal/OSHA CCR title 8 section 3206: When the term approved is used in these orders, it shall refer to products, devices, systems, or installations that have been **approved, listed, labeled, or certified** as conforming to applicable governmental or other nationally recognized standards, or applicable scientific principles. The approval, listing, labeling, or certification of conformity shall be based upon an evaluation performed by a person, firm, or entity with appropriate registered engineering competence or by a person, firm, or entity, independent of the manufacturer or supplier of the product, with demonstrated competence in the field of such evaluation.

3.9.3 What equipment needs inspection?

NEC article 90.1 describes the purpose of the code: *"90.7 Examination of Equipment for Safety. For specific items of equipment and materials referred to in this Code, examinations for safety . . . provide a basis of approval . . . by organizations equipped and qualified. It is the intent of this Code that . . . the construction of equipment need not be inspected at the time of installation of the equipment, except to detect alternations or damage, if the equipment has been listed by a qualified electrical testing laboratory that has been recognized . . ."* NEC article 670 provides a definition of industrial machinery and specifically exempts handheld tools. Most would also agree to exempt low voltage equipment (<30 VAC) because that is the Cal-OSHA definition of hazardous voltage.

Regarding what needs an inspection, there are at least four safety agencies to consider: building permit (construction), fire permit (occupancy), Cal-OSHA (worker safety), and the workers compensation insurance carrier. They each have their own issues and timing. Building is involved only with new construction. Fire comes around once a year, but they are typically looking for fuel (stacks of paper) and sources of ignition (extension cords). Cal-OSHA requires everything to be certified safe, but it is vague about who should do it. Some companies want everything checked, including meters and microscopes. Some companies do the minimum, especially the family-oriented fabrication shops. Some companies do their own checklist inspection, or they ignore the situation until there is an accident.

Many companies have a policy to delegate inspections to a third party like Abstraction. Here is the delegation criteria for one company: (1) involves a building permit, (2) new on the floor, (3) includes heaters or moving parts, (4) over 30 volts AC, (5) not UL (NRTL) listed.

Equipment is often excluded from third party inspection if it is: (1) pre-existing on the floor, or (2) "off-the-shelf" analytical instrumentation like microscopes, power supplies, meters, etc. with no heaters and no moving parts, or (3) low voltage powered from an exterior UL listed "brick" power supply.

In the event of an accident or injury, inspection creates a presumption of diligence (the opposite of negligence). Cities are getting strict with listing, labeling, and inspection. Cities are overworked and they don't want any extra risk.

3.9.4 Consequences of not having an inspection

- Machinery cannot be used for production.
- Insurance might not pay in an accident.
- Building and fire inspectors might deny the occupancy permit or “red tag” the room or building.
- A negligence lawsuit instead of workers compensation.
- A disclosure lawsuit if the property is sold.

3.9.5 CE Mark is not the same as a listing or a field label

The CE Mark is the **manufacturer’s declaration** that it conforms to the European Union Directives and Standards. CE Mark safety assessment includes both a **conformity checklist** and a **hazard analysis** based on a well-known scientific method like SEMI S10 & S14. Done right, CE Mark is more extensive than field labeling, which sometimes restricts itself to hazards of electricity (shock and fire). The CE Mark includes other hazards such as mechanical guarding, loud noise, ventilation, etc.

The CE Mark is recognized in many countries outside of the EU. The primary standard for industrial machinery, IEC 60204, is nearly identical to the US NFPA 79. Europe has a **market surveillance** group that audits the CE Mark integrity of most products in their market.

However, in the US, the CE Mark carries **no legal jurisprudence** for two reasons:

1. Sometimes the manufacturer does their own quick safety investigation **without oversight** and traceability to a competent licensed third-party inspection agency.

CE Mark means the product conforms to the safety requirements of the EU Directives and Standards

2. The CE Mark and the China Export mark look almost the same and they are easily confused. Can you see the difference?

China Export mark means the product is manufactured in China for export

3.9.6 Typical inspection procedure

1. Relevant standards are abstracted down to a workable checklist.
2. Construction documents are reviewed:
   - Manual and schematic.

- Bill of material for parts critical to power and safety, with rating and regulatory.

3. Machinery is inspected on-site for construction:
   - Shipment damage.
   - Installation.
   - Name plate (make, model, serial, power, etc.)
   - Hazard warning labels (ANSI Z535.4)
   - Grounding, wire gauges, etc. (refer to checklist)
4. Machine is tested without power:
   - Hi-pot for insulation resistance. (as needed, optional in the NFPA 79 handbook)
   - Grounding on the metal surfaces.
5. Machine is tested with full power:
   - Full load current to confirm the correct rating of breakers, conductors, contactors, etc. This would be impossible if the client's electrical safety policy does not allow access to live wires.
   - Component and motor temperature.
   - Safety devices: EMO buttons, interlocks, GFCI, and proximity sensors like light curtains.
6. Field evaluation documentation:
   - Attach a field label.
   - Send the report to the client and a copy to the building official.

3.9.7 Is a UL listed industrial control panel (ICP) all that is needed?

Let's look at the scope of UL 508A (chapter 1).

UL 508A 1.3.1: "An ICP **does not include an evaluation of the controlled equipment such as motors, heaters, lighting, and other loads connected to power circuits.** Unless specifically noted on the wiring diagram of the ICP, an ICP does not include equipment mounted remotely from the panel and connected via a wiring system or equipment field installed on or within the industrial control panel."

Summary: If the UL listed ICP is the main complicated thing, and the rest of the machine is just a few simple listed components, like a brand name motor, then the tool probably does not need a field label. On the other hand, if the ICP is a simple thing but the rest of the machine is very complicated, like a semiconductor tool or a CNC milling machine, then the tool probably does need a field label.

3.9.8 Fit-up, hook-up, machine, and the typical corrective actions

There are three parts to the construction. (1) **Fit-up** is where all the utilities are landed in convenient locations on the floor. The city inspector checks it. (2) **Hook-up** is the final step of moving in (rigging) and connecting the machines. (3) The **machine itself**, whose inspection is sometimes called a "UL". Hook-up is the gray area in between, and it has the most problems such as small wires, bad power cords, incorrect plugs, missing ground, etc. **So, check the hook-up** even if the machine has a listing mark.

In deciding how good is good enough, building officials usually defer to the judgment of the professional engineer. Some tolerance is given for an older machine with a demonstrated history of safe operation, especially if the machine has solid documentation. Furthermore, the code book version can be ambiguous. Does the code book version apply to when the machine was designed or manufactured or refurbished, or when the permit is pulled, or when the tool is installed? Would you refer to the local code, the California code, the national code, or an international code?

Regardless of the age of the machine or the code book version, basic cost benefit analysis has led to a list of typical problems.

Examples of concerns disclosed but they are probably ok as is:

- The electrical components are a major brand, but they do not have a UL listing. They seem genuine, not counterfeit. This could happen with the circuit breaker, contactor, power cord, etc. If in doubt, ask for sourcing information.
- Manuals are incomplete but the owner has a standard operating procedure (SOP).
- Nameplate is stating an unrealistically high full load current.

Examples of concerns disclosed, and the client will help decide.

- There are no lockable on/off switch and valves. The factory will have to provide them.
- The overcurrent protection significantly exceeds the full load current. The factory may have to provide a fused disconnect switch.
- The SCCR (short circuit current rating) number is missing. This could be a problem if the tool is plugged directly into an overhead busway with a very high available fault current.
- The anchor method (L bracket or Z clip) is not clear. If using a Z clip, the foot needs to be able to handle the tension.
- The cabinet has very high component temperature which could affect product reliability.
- Some clients have their own requirements which may need to be reviewed. **Example:** the use of FM4910 rated plastic, especially if the insurance policy is from Factory Mutual.

Examples of concerns disclosed and should be fixed:

- Missing or incomplete nameplates. Easy to recreate with a label printer.
- All controls and lamps need labels. Fuse holders need labels for replacement fuse value.
- Residential circuits are labeled on the panel. Industrial circuits need to be labeled at both ends.
- A convenience outlet needs to be GFCI and needs a flip down cover in a wet location.
- Wet tools typically have ground fault protection.
- Facility wiring and power cords need to be sized for the maximum current.
- Hazard warning labels are missing, down-rev, or incomplete. The first thing is to identify every exposed hazard, and make sure there is a hazard label for each one. **Examples:** High voltage, hot surface, pinch point, noise, laser, etc. Then get new labels that conform to the latest ANSI Z535.4 standard. Refer to Clarion or Brady for good information.
  - Signal words: danger, warning, caution, notice.
  - Signal colors: red, orange, yellow, blue.
  - Pictogram and context message.
- The incoming ground needs to go under a main lug. Other grounds can be distributed from a bus bar. The incoming ground should not be tied down with a wire nut or sheet metal screw, and it should not be wrapped around a screw.
- The wire current rating needs to exceed the circuit breaker current rating.
- The power cord rating needs to exceed the full load current rating. If the full load is not known, size the power cord according to the circuit breaker.
- Make sure the circuit breaker, power cord, and plug type are a matched set. Make sure the power cord is in good condition and not lying on the floor.
- Emergency buttons need to be bright red on a bright yellow background.
- Emergency buttons and interlocks (PLC ladder) need to be reasonable. The fault detection priority is typically: (1) exhaust, (2) tool EMO, (3) remote EMO, (4) smoke detector, (5) UVIR detector, (6) gas leak, (7) spill leak, (8) door violation, (9) high temperature, etc. **Example:** I once saw a case such that when the door interlock was opened, the fire alarm circuit was disabled.
- Emergency and interlock circuits should work by holding up a voltage. Older tools sometimes connect the EMO button directly to a shunt trip circuit breaker (knocked down by asserting ground). This is ok for minor risk but not ok for high risk.
- Mechanical hazards should be guarded (high temperature, pinch point, robot motion, etc.)
- Power cabinets should implement one or more of the following three safety features:

- The cabinet door must be interlocked to automatically drop the power, or
- The cabinet door must have a key or special tool to open, or
- The interior must be completely guarded and touch proof for high voltage.

- Chassis should be clean, neat, cool, and secure. Do not store paper, trash, tools, and spare parts inside because this creates fire and shock hazard. Check for clearance, interlocks, dead fans, and overheated components. Plug any open holes to contain a flame, and to keep out small, dropped parts and curious fingers.
- Presses should conform to Cal-OSHA article 55. This could be a citation.

3.10 NFPA 790, NFPA 791, and FEB accreditation

3.10.1 FEB accreditation

There are several FEB accreditation services. IAS is perhaps the best known, like UL is for listing.

- IAS International Accreditation Service (part of the International Code Council)
- A2LA American Association for Laboratory Accreditation (independent)
- ANAB ANSI National Accreditation Board
- Eurofins

3.10.2 Prescription vs. performance

Prescription is a strict interpretation of the code or standard. Performance is a judgment of the intent of the code or standard, using the scoring of a conventional hazard analysis. An acceptable risk is ok.

Example: For the European CE Mark, the ground wire is supposed to be green with 30-70% yellow within a 15 mm segment. US manufacturers have a hard time finding this color and usually end up with a thin yellow stripe. This is generally acceptable because it is a very low risk.

Example: European machinery is often 230 VAC line-to-neutral (one hot leg) with a one or two pole switch. US would wire this tool as 208 VAC line-to-line (two hot legs). Both hot legs must be switched.

3.10.3 IAS FEB application

IAS FEB accreditation was mentioned in the prior section called Jurisdictional Approval. Some jurisdictions now require either NRTL status or IAS FEB accreditation including Oakland, Sacramento, Phoenix, and New Mexico. On the surface, having an IAS FEB credential would certainly simplify approvals. However, after going through the application process (and walking away), the author would like to point out the huge burden of this.

IAS FEB accreditation promotes all aspects of NFPA 790 & NFPA 791 from SHOULD conform (performance) to SHALL conform (prescription).

The effect of IAS FEB accreditation is to push the professional engineering FEBs towards becoming more like mini-NRTLs and away from being professional engineering consultants.

Motivation

The large trade organizations like ICC (International Code Council), NFPA (National Fire Protection Association), NEMA (National Electrical Manufacturers Association), and UL (Underwriters Laboratory) would like to maintain their dominance in the industry.

ICC is the parent company of the IAS (International Accreditation Service).

ICC has entered a partnership with the IAEI (International Association of Electrical Inspectors) with a possibility of taking over the training classes. ICC, IAS, NFPA, NEMA, UL, and IAEI are very influential with local building inspectors. They organize periodic meetings and host training classes.

ICC and NFPA have actively competed for Fire Code acceptance in the past. **Example:** In California, after Governor Davis (Democrat) was recalled and replaced with Governor Schwarzenegger (Republican), the fire code was changed from NFPA to ICC.

If a city requires **NRTL status** or IAS FEB accreditation, please be aware that NRTL status can be listing or labeling. NRTL listing and IAS FEB accreditation are required to operate according to very strict guidance. However, the **NRTL acting as a field evaluation body can do whatever they want,** from very reasonable to tolerable to difficult. The choice of an NRTL field label or an IAS FEB field label is not a level playing field.

IAS application process

- The applicant must prepare a complicated application that includes IAS forms and agreement, NFPA 790, NFPA 791, and a quality management system.
- All NFPA 790 and NFPA 791 requirements are promoted from **should conform** to **shall conform**.
- Office records will be reviewed. Field inspections will be witnessed.
- The application fee is $8500 USD plus expenses and there will be annual renewal.

NFPA 790 (Competency) and 791 (Recommended Practice and Procedures) evolved from the original standard developed by the American Council for Electrical Safety (ACES). Current editions are 2024.

- **NFPA 790** is the standard for competency of third-party field evaluation bodies.
- **NFPA 791** is the practice and procedures for evaluation of unlabeled electrical equipment.

In a related story, Incompliance Magazine, September 29, 2017, Andrew Bohan (of A2LA) comments:

- ACIL became ACES.
- ACES plus ISO/IEC 17020 became NFPA 790 (for inspection bodies).
- ACES plus ISO/IEC 17065 became NFPA 791 (for product certification).

3.10.4 NFPA 790 and NFPA 791

1.	**Nationally recognized standards.** In earlier versions of NFPA 790 and NFPA 791, the **primary standards** were adopted by the American National Standards Institute. The **supplemental standards** would include ones from manufacturing organizations such as the National Electrical Manufacturers Association or general safety bodies such as the National Fire Protection Association. **Effect:** When NFPA 791 was first developed, this clause might have prevented the use of NFPA standards as the primary standard. Later, in September 2015, the NFPA standards became ANSI standards.	✓ NFPA790 5.3.1 ✓ NFPA790 5.3.2 ✓ NFPA790 10.1 ✓ NFPA791 4.3
2.	**Confining the investigation.** **Effect:** Prevent the FEB from offering other services such as checking the facility wiring and labeling, available fault current, equipment anchors, hazard risk assessment, CE Mark, SEMI, and other consulting. Note: There is some contradiction here. NFPA790 5.2(9) states "Have policies and procedures that distinguish between field evaluation and **other activities** in which the FEB is engaged."	✓ NFPA790 5.1.4 ✓ NFPA790 5.2(9) ✓ NFPA790 5.2.9 ✓ NFPA790 5.5.3.2
3.	**Corrective actions.** **Effect:** Prevent the FEB from making minor corrections, such as fixing cable clamps and adding nameplates, warning labels, and the yellow ring to the emergency button.	✓ NFPA790 5.2.7

4.	**People needing an inspection are clients,** not applicants. **Effect:** Clients are not expected to know what they need, nor do they know what standards are applicable. **IAS comment:** "Applicant" is before doing business. "Client" is after doing business. If the applicant cannot determine the standard, the FEB and AHJ will then decide together.	✓ NFPA790 8.2
5.	**Conformance 100% to a standard** (is not practical). **Effect:** Temperature, humidity, and altitude cannot be done in the field. Hi-pot has the potential to damage equipment. **IAS comment:** Field evaluations have always been non-destructive and limited to the conditions of the environment and installation. FEB's usually have disclaimers in their reports regarding this.	✓ NFPA790 12 ✓ NFPA790 13
6.	**Statement of conformity.** The report shall state that the product "conforms" to a specific standard. **Effect:** The engineer is not allowed to use multiple standards, best practice, hazard risk analysis, and acceptable risk. **IAS comment:** The report must include a "statement of conformity" and can also reference the field label.	✓ NFPA790 12 ✓ NFPA791 7.1
7.	**The complete citations of the standards** used to complete the evaluation shall be included. **Effect:** There will be one tool per report, not multiple tools per report. Every report will have a citation list of ~400 line items and perhaps 40 pages. This is commonly done for the seller (low volume CE Mark and SEMI), but not for the buyer (high volume field labels). **Examples:** The author is privy to recent field label evaluation reports (single tool) from two major field evaluation bodies. One report (NRTL) is 15 pages. The other (non-NRTL IAS accredited) is 160 pages. **IAS comment:** FEBs typically issue a report for the field evaluation done at the same place in the same time period for that project. This can include multiple products.	✓ NFPA 791 7.6.1
8.	**Label control.** **Effect:** All inspection work must be done in person on site regardless of COVID or high security. This will prevent the use of virtual meetings (FaceTime, Zoom, etc) and stickers being sent by courier. **IAS comment:** Camera meetings are acceptable. Using an inside rep to apply the label can be acceptable if allowed by the AHJ and witnessed remotely by the FEB.	✓ NFPA791 8.4
9.	**Field label stock shall meet UL969.** **Effect:** Many print shops are not familiar with this.	✓
10.	**The FEB shall determine the adequacy of operation and maintenance manuals.** **Effect:** The client EHS manager should determine this.	✓ NFPA790 14.6

11.	**All power and safety components shall be NRTL listed.** **Effect:** Disqualify much of the equipment from Europe and Japan, and most of the equipment from China, Taiwan, and Korea. **IAS comment:** Agreed. Power and safety components should be NRTL. **Example:** A company has installed numerous car parking systems on the West Coast, consisting of a simple control panel and two small brand name motors (CE Mark) for the slider (in-out) and the hydraulic pump (up-down). The City of Los Angeles will typically arrange their own field label evaluation, but they now require NRTL on the components. An NRTL quoted more than $14,000 USD to provide a certificate for the two motors. After some bargaining, the NRTL agreed to cut the cost to just under $8,000 USD. The motors are not worth much, but they are unique to the equipment. There is no NRTL listed motor that will fit this application.	✓ NFPA791 5.7
12.	**Ground bond specialized testing.** There are many ways to check the ground bond. Specialized testing can include current injection (and measuring the voltage drop), milli-amp leakage from the sheet metal, and milli-ohm resistance measurement. **Effect:** Ground bond specialized testing is very difficult to set up. Ground bond is typically checked visually and with an ohmmeter. **IAS comment:** Ground bond specialized testing is not mandated. Both methods ok.	✓ NFPA791 5.12 ✓ NFPA791 6.1(2)
13.	**All equipment shall have power measured.** **Effect:** Power measurement is not difficult, but it often conflicts with the client's electrical safety policy based on NFPA 70E. Power measurement would require a full load operation and some sacrifice of material. **IAS comment:** Many FEBs measure voltage, current, and power.	✓ NFPA791 6.1 ✓ NFPA791 6.2 ✓ NFPA70E
14.	**All equipment shall be hi-pot tested.** **Effect:** Hi-pot testing should not be done in the field, and this includes the "insulation resistance testing" which is a 500 VDC hi-pot. NFPA 79 (2015) Handbook states that hi-pot is optional and depends on the situation. The risk reward has no practical benefit. Hi-pot has the potential to damage very expensive machinery. Some semiconductor tools are $100 million. Furthermore, hi-pot is very difficult to set up (disconnecting the neutral and certain components) and generates a lot of false failures. **Examples:** The author is privy to several examples of hi-pot destruction, including transformer coils, servo drives (having normal ground current leakage) and circuit boards having the AC power trace routed directly over the ground plane. **IAS comment:** Most FEBs are conducting either hi-pot or insulation resistance testing, and this includes FEBs specializing in machinery. Not conducting certain tests in the standard needs to be justified in the report.	✓ NFPA791 6.1 ✓ NFPA791 6.2 ✓ NFPA79 (2015) handbook

3.10.5 Quality Management System (QMS)

NFPA 790 (Competency) and NFPA 791 (Operation) have numerous QMS requirements. Unfortunately, there is no example of what the FEB QMS is supposed to look like.

IAS comment: The hardest part for small FEBs to get accredited is not technical issues (if an experienced FEB) but to have a Quality Management System that is thorough and addresses all items in NFPA 790.

Some of the clauses can be answered as a checklist response. Many of these requirements require a large, documented bureaucracy intended more for a hospital (FDA control) or a manufacturing business (ISO 9001), not for a small FEB. Here are just a few of the onerous examples.

15.	The management shall have a **management staff** with the authority and resources to discharge their duties.	✓ NFPA790 5.2.2.2
16.	The FEB shall have **policies and procedures** for the resolution of complaints (even if there are no complaints).	✓ NFPA790 5.2.10 ✓ NFPA790 5.5.3(10)
17.	The FEB shall have an individual with responsibility for the **management system** to ensure ongoing fulfillment.	✓ NFPA790 5.5.1
18.	The individual responsible for the **management system** shall report annually to the FEB's management.	✓ NFPA790 5.5.2.4 ✓ NFPA790 5.7.1
19.	The FEB shall insure that such audits are carried out by trained and qualified staff who are, whenever possible, **independent of the activity** to be audited. **Effect:** The QMS manager is separate and independent from the FEB technical manager. QMS would have to be outsourced like ISO 9001.	✓ NFPA790 5.7.1.1

3.10.6 Potential consequences and improvement needed

Consequences:

- Silicon Valley has a need of ~5000 stickers per year. If IAS FEB accreditation is required, the FEB capacity will be dramatically cut. There are only 6x IAS FEBs in all of California and they are being added at about one per year.
- Machines from China, Taiwan, and Korea will fail. Many machines from Japan and Europe will also fail. Components will need to be swapped out and the manuals rewritten. The cost of retrofit will double the machine cost and delay the machine commissioning by months.
- The average inspection time per piece will go from an hour to a day.
- For a typical group of 10x tools, the report will grow from a single report (15 pages) to a bundle of reports (hundreds of pages).
- Moving factories from overseas back to the US will necessarily reverse, especially Silicon Valley. However, pockets in the US, where factories have less regulation, may survive. For example, car manufacturing moving from Detroit down to Tennessee, etc.
- FEBs will not be viable unless the cost of additional administrative employees, longer inspections, larger reports, office, insurance, accreditation, etc. is passed on to the client.
- FEBs will become compliance clipboards. This contradicts the job and judgment of the professional engineer. You can have a doctor without a hospital, but you cannot have a hospital without a doctor. You can have a teacher without a school, but you cannot have a school without a teacher.
- **Example:** One time in China, the manufacturer hired an NRTL, and the client hired the author. I personally witnessed the NRTL with a team of 3x people on site for 3x days to complete their work, resulting in more than 100x non-conformances.
- **Example:** A European tool, which can be either 115 VAC or 230 VAC, was rejected by an NRTL because the nameplate stated watts instead of amps.
- **Example:** The cost of a new semiconductor fab in southeast Asia is $2-4 billion USD. Source: UC Berkeley technical report USB/EECS-2021-205. The cost of the new TSMC fab in Phoenix is $12-40 billion USD. TMSC Founder Morris Chang is quoted as saying "chip manufacturing costs in the US are about 50 percent higher than Taiwan". Source: Inside HPC. The cost of the new Intel fab in Ohio is $20-100 billion USD. Source: IEEE Spectrum January 2022.

Summary:

The NEC, adopted into California law as title 24, requires all electrical equipment to be certified safe. Different standards define the equipment, but generally it is something over 30 VAC, 45 VDC, and not a hand tool etc. Simple R&D stuff like meters, power supplies, etc are often exempt.

The NEC gives two ways for the equipment to be certified safe. They are not the same, but the city considers it to be equivalent. (1) In the factory at the time of production, known as an NRTL listing, primarily for consumer equipment (hair dryers etc) to a mass market. NRTLs are approved by OSHA. (2) In the field at the time of installation, known as a field label evaluation, primarily for industrial equipment in a factory. Field evaluation bodies (FEB) are approved by the building officials one by one. Some places are city by city jurisdiction (California, Arizona, Texas). Some places are state-wide jurisdiction (Oregon, Washington, New Mexico, Minnesota, etc).

Field label evaluation also applies to a NRTL listed assembly that has been modified, or taken apart and put back together, for example, after a move or a major repair.

NFPA 70 (NEC) added article 670 for machine tools in the early 1940's. Article 670 became NFPA 79 in 1961. FEBs were defined by the American Council for Electrical Safety (ACES) in 2005. ACES became the basis for NFPA 790 & 791 in 2008.

Using a "cake" as an analogy, the creation of the cake requires the product design, the recipe, and the kitchen. Field label evaluation is about checking the kitchen.

Silicon Valley is well known for product development and the pilot lines that do the manufacturing. The pilot line tooling is created with Pacific Rim partners including China, Japan, Korea, Singapore, Taiwan, etc., and most of this equipment is without an NRTL listing. Silicon Valley building officials and FEBs (like Abstraction Engineering) know how to deal with this. NRTLs cannot deal with it, and the economic consequences (Oakland vs Fremont) are very apparent.

Improvement needed:

The NEC mission statement is the practical safeguarding of hazards arising from electrical equipment. The focus of the FEB should be equipment installation. Credentials (education, licenses, experience, publications), engineering, safety, and hazard risk assessment are all important.

Although NFPA 790 & 791 can cover different kinds of equipment, the main opportunity is for industrial machinery. Long term, NFPA 790 & 791 need to be rewritten from the perspective of the factory, and with the goal of bringing good jobs back to the US.

NFPA 790 & 791 have too much policy and not enough judgment. NFPA 790 & 791 should be considered as a draft. They are not serving the NEC principle of practical safeguarding. More effort should be put into guidance documents and handbooks like this book "Safe Machinery".

IAS must change NFPA 790 & 791 requirements from "shall" (prescription) to "should" (performance). The Quality Management System policy must be flexible enough to accommodate small FEBs.

Standards used for listing should not be prescriptively applied to field evaluation. Thousands of standards used without interpretation and risk assessment are just plain insufficient.

4 Field Labeling Guideline

For this checklist, the following codes and standards have been cited. NFPA70 NEC Handbook (2020), CEC (2019), NFPA79 (2021), NFPA790 (2024), NFPA791 (2024), NFPA496 (2017), UL508 (2018), UL508A (2018), UL61010 (2012), ICC/IFC (2018). NFPA79 is similar to IEC60204 (CE Mark). To simplify this checklist, IEC60204 (2016) is not duplicated unless it is different from NFPA79.

California title 24 is the adoption of the model building codes. California Electrical Code (title 24 part 3) is 99% the same as the NFPA National Electrical Code, with minor changes typically for energy conservation. and two years behind. The CEC is free online at:

http://www.nfpa.org/codes-and-standards/all-codes-and-standards/codes-and-standards/free-access?mode=view

4.1 Documentation check (manuals and schematics)

1.	Manuals (or SOP): installation, operation, and maintenance.	✓ NFPA79-17 ✓ UL61010-5.4
2.	Electrical supply requirements (voltage, current, disconnect size).	✓ NFPA79-17.2 & 17.5
3.	Safeguarding (EMO, interlocks, etc) are easy to understand.	✓ NFPA79-17.2
4.	LOTO (lock-out tag-out) procedures are in the manuals. Six steps: • How to shut down the equipment in an orderly manner. • How to locate and operate all of the energy isolation devices. • How to install energy isolation devices. • How to relieve stored energy. • How to verify that equipment is isolated and deenergized. • How to release equipment from an isolated state.	✓ NFPA79-17.2
5.	Circuit diagrams (schematics) for the machine but not for commercially available or field replaceable components.	✓ NFPA79-17.7
6.	Standard symbols and notations per IEEE 315 (US) or IEC 60617 (CE).	✓ NFPA79-17.7
7.	Wire gauge and color identified for easy repair and evaluation.	✓ NFPA79-13.2
8.	The installation diagram should specify the OCP requirement.	✓ NFPA79-17.2
9.	The installation diagram should show the neutral, if it is used.	✓ NFPA79-17.5

4.2 Nameplate

10.	Nameplate information includes: • Manufacturer, model, and serial number • Voltage, frequency, and phases. The number of wires will help clarify if a neutral is needed. • Circuit breaker size and AIC rating, if provided. This should not be a recommendation for the incoming service. • Full load current (service is set 1.0-1.5x FLA) • Largest load current (see note) • Schematic diagram or main document number (see note) • Year of manufacturer (CE only)	✓ NFPA79-16.4 ✓ UL61010-5.1 ✓ UL508A-52 ✓ LVD-7.1

11.	Nameplate information includes: • SCCR (short circuit current rating). Refer to CB & fuse section.	✓ NEC 670.5 ✓ NFPA79-16.4 ✓ UL508A-SB
12.	Nameplate for each incoming supply service.	✓ NFPA79 16.4.3
13.	Nameplate is typically outside and near the incoming supply. NFPA79 states "visible after the equipment is installed". UL 508A table 52.1 states "or on the inside walls". UL 61010 5.1.1 states "after removing a cover or opening a door".	✓ NFPA79-16.4.1 ✓ UL508A-52 ✓ UL61010-5.1.1
14.	If the machine does not have its own main OCP, and it depends on the OCP of the branch circuit or the disconnect switch, then the nameplate should have a statement: "Supply conductor and machine overcurrent protection provided at machine supply terminals".	✓ NFPA79-16.4.5

Largest load: The portion of the full load that is **continuously on over 3 hours.** Wires are sized 125% of the continuous load and 100% of incremental non-continuous load.

Schematic diagram is a logical representation of a circuit. **Wiring diagram** is the actual construction point-to-point. Purpose of the diagram: (1) maintenance and repair (NFPA79), (2) installation of field wiring (UL 508A 52.1c), (3) including all components provided by the manufacturer (UL 508A 61.1).

- Make, model, and serial number.
- Voltage, frequency, and phases.
- Full load and largest load current.
- Circuit breaker size and AIC rating.
- Schematic drawing number.
- Date of manufacturing,
- Short circuit current rating (SCCR).

Manufacturer	Easy Machine Company
Model	Gadget
Serial	1
Voltage	120 VAC
Frequency	50/60 hz
Phases & legs	1Φ + N + EG
Full load current	2 amp (~240 watts)
Largest load current	1 amp
Over current protection	CB (3 amp)
Electrical diagram	Gadget circuit
Date of manufacture	July 2018

4.3 Disconnect isolation switch for LOTO

15.	Disconnecting means: A device by which the conductors of a circuit can be disconnected from their source of supply. Refer to service equipment (230.70), fuses (240.40), appliances (422), industrial control panels (409.30), motors and controllers (430.75), industrial machinery (670.4).	✓ NEC Handbook page 15
16.	NEC Handbook: "The development of system isolation equipment comes from today's large and complex machines where repeated operation of disconnecting means for maintenance or service is inherent to the process and the risk of injury to personnel due to moving parts. Safety procedures include detailed LOTO protocol for all sources of mechanical and electrical energy. System isolation equipment helps simplify electrical LOTO procedures."	✓ NEC Handbook 430.109(7) page 521
17.	An individual disconnecting means shall be provided for each controller and shall disconnect the controller. The disconnecting means shall be located within line of sight from the controller location.	✓ NEC Handbook 430.102 page 519 ✓ UL508A-30.3.1 & 66.6.1

18.	Extensive discussion and numerous exhibits of conventional knife type safety disconnect switches. Three cases where a disconnect switch is not prescribed: • A stationary motor < 1/8 HP can go straight to a circuit breaker. • A stationary motor < 2 HP can go to a "snap" switch. • A portable motor can go to a plug and socket.	✓ NEC Handbook 430 section IX, pages 519-526
19.	Disconnect can be a CB, if convenient for LOTO, and if it is operated by an external handle.	✓ NFPA79-5.1.11.1
20.	Disconnect can be a CB if serving a stationary appliance up to 300 watts. Disconnect can be a CB, if serving a stationary appliance over 300 watts, if the CB is readily accessible.	✓ Cal/OSHA article 52 section 2522.23(a) & section 2522.23(b)
21.	Disconnect can be an attachment plug. NEC permits the load to be quite large. Cal/OSHA permits this on a portable motor up to 1/3 HP.	✓ NFPA79-5.1.11.2 ✓ Cal/OSHA article 56 section 2530.81(c)
22.	A machine is required to have a disconnecting means, but this device does not have to incorporate over current protection (OCP).	✓ NEC Handbook 670.4(B), page 875 ✓ UL61010-5.1.6 & 6.11.2.2
23.	Enclosure access options: • Automatic disconnect, or • Special key or tool to open, or • Touchproof interior. This is repeated in more detail in the section called "Enclosures".	✓ NFPA79-6.2.3.1
24.	Guard needed on the line side terminals. Automatic disconnect. "Live parts of electrical equipment operating at 50-1000 volts shall be guarded against accidental contact by an approved enclosure . . . by permanent substantial partitions or screens arranged so that only qualified persons have access to the space within reach of the live parts. Partitions or screens shall be sized and located so that persons (and tools) are not likely to have accidental contact." 2018 update. Regarding the lack of a guard on the line side of an open disconnect switch. My opinion had been NEC 110.27(A) combined with NFPA79 (a) automatic disconnect, or (b) special key or tool to open, or (c) touchproof. However, the electricians feel that in a disconnect switch box, **no guard** is needed on the line side if there are **no fuses** because there is no reason to open the box. Therefore, I think the best practice would be a tie-wrap on the hasp and an optional tag label "live wire". 2021 update. NFPA79-5.1.6. "All live parts on the line side of the disconnecting means shall be protected from intentional direct contact by use of insulation and obstacles" when both switch and door are open.	✓ NEC 110.27(A) ✓ NFPA79-5.1.6
25.	Enclosure should be labeled "Danger High Voltage".	✓ NFPA79-16.2.3
26.	Disconnect should be labeled to indicate the equipment.	✓ NFPA79-5.1.9.2
27.	Multiple disconnects shall be conveniently grouped together and cross-labeled.	✓ NFPA79-5.1.9.8 ✓ UL508A-30.3.4 & 55.4 ✓ Cal/OSHA article 56 section 2530.113

28.	Disconnect, if serving up to 2 HP, should be located within 20 feet, and within line of sight, and readily accessible to the operator. Note: NFPA implies 20 feet is equivalent to "line of sight". Cal/OSHA specifically states that 50 feet is equivalent to "line of sight".	✓ NFPA79-5.1.9.6 ✓ Cal/OSHA title 8 article 53 section 2524.65
29.	Disconnect, if serving a motor driven stationary appliance (over 1/8 HP) must be within line of sight from the motor controller.	✓ Cal/OSHA article 52 section 2522.26
30.	If not in line of sight, it needs the capability of being locked in the open position.	✓ Cal/OSHA article 56 section 2530.86
31.	Disconnect should be located on or near the tool's power cabinet.	✓ NFPA79-5.1.9.6
32.	Disconnect should be listed. (UL 98, IEC 947-3 & 60947)	✓ NEC Handbook 430.109(7), page 521 ✓ NFPA79-5.1.10
33.	Disconnect **sized by current** (1.15x of full load) or **rated by horsepower** (1.0x of the motor load horsepower). Note: CE requires the disconnect to be big enough to handle the **locked rotor current** for a stalled motor which is typically 3x full load.	✓ NFPA79-5.1.11.1 ✓ UL508A-30.2.2
34.	Open and closed plainly identified. CE requires I and **O.**	✓ NFPA79-5.1.11.1 ✓ UL508A-30.2.4 ✓ Cal/OSHA article 56 section 2530.104
35.	Disconnect requires no tools to operate.	✓ NFPA79-5.1.11.1
36.	Disconnect can be locked off, cannot be locked on.	✓ NFPA79-5.1.11.1 ✓ UL508A-30.4.4
37.	Disconnect simultaneously cuts all ungrounded conductors but does not cut the equipment ground. Neutral is normally not disconnected. European tools are often 230 VAC line-to-neutral (one hot leg). When these tools are installed in the US, they are typically 208 VAC line-to-line (two hot legs). The switch and OCP must protect both legs.	✓ NFPA79-5.1.9
38.	Handle not higher than 2 meters to the highest position. NEC says to the center of the grip of the operating handle, and this also applies to the circuit breaker toggles. CE states 1.9 meters.	✓ NEC 404.8 ✓ NFPA79-5.1.12.1 ✓ UL508A-30.4.5
39.	Readily accessible. Some cities interpret this as "within arm's reach".	✓ Cal/OSHA article 56 section 2530.107
40.	The handle is not blocked by a door either open or closed. **Example:** When the door opens, sometimes the disconnect handle is left on the door and the shaft is left sticking out from the switch. The shaft would then require a wrench to turn the switch on and off. An NRTL said this is non-conforming because the electrical disconnect should operate with the door open or closed, and **with no tools needed**. Abstraction believes the intent of the standard is to not **obstruct** the switch with the door open or closed, and there is no need to turn the switch on when the door is open.	✓ NFPA79-5.1.12.2
41.	Knife switches and circuit breakers shall be placed so that gravity will not close them. Up is closed (on) and down is open (off). If the spring breaks, gravity will not pull the switch closed and cause a start-up. CE no mention.	✓ UL508-16.2 ✓ UL508A-30.4.1 & 31.2.4 ✓ Cal/OSHA article 47 section 2480.5A
42.	Disconnect provided for each motor.	✓ Cal/OSHA article 56 section 2530.112

43.	Disconnect provided for an equipment transformer on the floor. And it needs to be conveniently located. **Example:** not in a locked room. This requirement does not apply to small class 2 & 3 transformers. Refer to the section below.	✓ NEC 450-14 ✓ Cal/OSHA article 20 section 2833 and article 27 section 2876
44.	Disconnect provided for a control transformer inside a machine.	✓ Cal/OSHA article 56 section 2530.74(b)
45.	Disconnect provided at the service entrance to the building.	✓ Cal/OSHA article 9 section 2380.1
46.	Disconnect provided on the supply side of all fuses in circuits over 150 volts to ground.	✓ Cal/OSHA article 10 section 2390.20
47.	Disconnects are not needed on both ends of the branch circuit.	✓ Cal/OSHA article 10 section 2390.20
48.	Knife switch blades are de-energized in the open position. Make sure the disconnect switch is connected forwards, not backwards.	✓ UL508A-30.3.5 ✓ Cal/OSHA article 47 section 2480.7
49.	Fuses are de-energized when the fuse holder is open (line side disconnect)	✓ UL508-39A.2
50.	Disconnect in the open position cuts all sources of supply, including the UPS and back-up generator. If this is not practical, then there should be good signage for turning off the UPS.	✓ Cal/OSHA-article 56 section 2530.74(a) ✓ SEMI S2-13.5.2
51.	Disconnect poles are ganged together and cannot operate independently.	✓ Cal/OSHA article 56 section 2530.103

4.3.1 Disconnect isolation switch – best practice

Disconnect method	Benefits	Concerns
5 star rating. Fused disconnect switch. **Recommended.**	• Fault current protection. • Full load current shut-off without damage. • Easily recognized shut-off, especially in an emergency. • Lockable in the off position.	• Moderate extra construction cost. However, large fuses are cheaper than a large circuit breaker. • Possible machine damage if one fuse blows and the other hot legs continue to provide power.
4 star rating. Regular disconnect switch without fuses.	• Full load current shut-off without damage. • Easily recognized shut-off. especially in an emergency. • Lockable in the off position.	• Slight extra cost.
3 star rating. Circuit breaker with a locking tab.	• Lowest cost if the circuit breaker is already included in the machine. • Lockable in the off position. Ok to prevent accidental turn-on.	• Should not be used for full load turn-off. Arcing will damage the contacts. The tool needs a heavy-duty contactor to drop the current. • Contact bounce can cause voltage transients that can damage inductive loads like transformers. • Much more difficult to actuate than a switch. • Some facilities require a flash suit for turning a CB LOTO on and off.
2 star rating. Circuit breaker with a temporary locking mechanism clip.	• Lockable in the off position. • Cal/OSHA says temporary locking mechanisms are acceptable. • But the NEC says no.	• NFPA 79 5.3 states that the disconnecting device should have an external handle, readily accessible with doors open or closed. • NEC Handbook 110.25 page 47 states the provision for locking shall remain in place without the lock installed. Portable locking mechanisms intended for temporary applications are not acceptable for LOTO compliance. The circuit breaker must have a loop for a padlock. • Using a CB as LOTO requires the worker to open the panel, turn off the breaker, and put on the clip. • Maintenance workers must avoid turning large circuit breakers on and off under a full load.
1 star rating. Non-locking switch or circuit breaker with a tag-out note.	• Easy, simple, and low cost.	• Tag should be line of sight. • Significantly more risk if the tag is violated or if the tag is put on the wrong switch.

Note 1: Local disconnect switches make it easier to do the **fit-up** first, followed by the machine **hook-up**.

Note 2: Unlike circuit breakers, cartridge fuses will significantly reduce the short circuit current.

Note 3: Knife switches are easily recognized as an emergency shut-off. I witnessed this in 2014 when a water-cooled laminator was turned on for the first time, and the water started coming out all over the floor. The worker's reaction was to hunt for the switch. The EMO buttons were ignored. The disconnect switch is the most obvious way to kill power in a panic.

Note 4: Circuit breaker contacts can bounce during opening and closing causing voltage transients.

4.3.2 Disconnect isolation switch on the primary side of a floor transformer

NEC and Cal/OSHA prescribe a transformer "disconnecting means". This has two interpretations. (1) If you disconnect the **transformer itself**, the switch will go on the primary side. (2) If you disconnect the **transformer load**, the switch will go on the secondary. Most electricians do this.

- Location marked on the transformer. (NEC 450.14)
- Lockable in the open position. (NEC 110.25 & 450.14)

4.3.3 Disconnect isolation switch – wired incorrectly

If line and load are wired backwards, the blades and fuses will be energized in the off position.

There is only one case where the disconnect switch should be wired backwards – when a photo-voltaic DC-AC inverter is feeding the utility. Both sides remain energized when the switch is off, however, the inverter side will automatically shut-off within one second. Therefore, it is safer to have the "utility" on the incoming side of the disconnect switch, which is typically guarded, and the inverter on the fuse side.

4.4 Circuit breakers and fuses for OCP overcurrent protection

52.	Power component ampere interrupt capacity (AIC) should be greater than the available fault current. Refer to terminology in next section. • For **120 VAC**: AIC = 1-5K amps. • For **208 VAC**: AIC = 2-12K amps. • For **277/480 VAC**: AIC = 4-32K amps.	✓ NEC 110.9 ✓ NFPA79-7.2.9 ✓ UL508A-SB ✓ IEC60947-2 (CE)
53.	OCP (CB or fuse) on hot legs should not exceed the rating of components and conductors. Exceptions: Tap rules and the "next size up circuit breaker" rule.	✓ NEC 240 ✓ NFPA79-7.2.1 & 7.2.8 ✓ UL61010-9.6
54.	NRTLs require UL listed. European and Japanese brand names (ABB, Fuji, Mitsubishi, Moeller, Schneider, Siemens) are ok with equivalent listing. Note: UL489 is for molded case. UL1066 is for electronics. UL1077 "pop type" circuit breakers are for appliances.	✓ NEC 110.10 ✓ NFPA79-7.2.1.3 ✓ UL508A-31.1.6
55.	Overcurrent protection: • "Listed products used within their rating" and "adequate short-circuit current rating . . . depending on the specific circuit and installation requirements." • "All protective devices shall be selected and applied with proper consideration being given to . . . fault current, interrupt rating, normal operating current." • "Supplemental overcurrent protective devices shall not be used as a substitute for branch-circuit overcurrent protective devices."	✓ NEC 110.10 ✓ NFPA79-7.2.1.2 ✓ NFPA79-7.2.1.3

56.	Overcurrent protection should be no bigger than: • 0.8x the rating of the downstream wire for a heater or machine load on continuously >3 hours. This is same as having the wire 125%. • 1.0x the rating of the downstream wire (excepting for the tap rule). • 1.00-1.5x the full load current for a resistive load. • 1.15-3.0x the full load current for a motor load. CE requires the overcurrent protection to be provided, adequate, and as low as possible (without nuisance tripping).	✓ NEC 430.31 ✓ NFPA79-7.2.11 & 7.3 ✓ UL508-18.1.3 ✓ UL508A-31.3 & 31.6
57.	If the CB supplies a motor load >2 HP, resetting the CB should not restart the motor. Therefore, a motor >2 HP requires a contactor start circuit.	✓ NFPA79-7.3.2
58.	Readily accessible (NEC): "capable of being reached quickly for operation, renewal, or inspections without requiring those to whom ready access is requisite to actions such as to use tools, to climb over or remove obstacles, or to resort to portable ladders and so forth."	✓ NEC

4.4.1 Circuit breakers have six major functions

- Trip open (if ground fault) to protect against a small amount of current leaking through your body.
- Trip open (if overload) to protect against a medium amount of current from heating up the wires, melting the insulation, short circuit, and starting a fire. **Example:** 20 amps to protect a #12 wire.
- Trip open (if short circuit) to protect against a large amount of current (thousands of amps) in a brief period, and not self-destruct with shrapnel, sparks, and welding the contacts together. Circuit breakers exposed to large currents could have internal damage and should be replaced.
- Trip open (if arc fault) to protect against damaged power cords plugged into residential outlets.
- Trip open (coordination) with a very predictable trip time so that the circuit breaker closest to the fault is the one that opens first.
- Trip open and close without excessive bouncing of the contacts which could create damaging voltage transients.

Example: Arc fault circuit breakers are electronic devices that sense the signature of an intermittent short circuit in a crushed power cord. They are subject to nuisance tripping. During holiday time, a home had several large indoor trees set-up with flashing LED lights. The outlet circuit breaker and the dishwasher circuit breaker were side-by-side in the panel. Every time the dishwasher was started, the dishwasher circuit breaker would trip open. The LED lights were interfering with the arc fault circuit breaker.

4.4.2 Circuit breaker and short circuit terminology

Bolt current is the theoretical maximum current available between two shorted conductors. Bolt currents can be 5000 amps in a residential home and 50,000 amps in a big factory. Bolt current is usually determined at the design and architecture stage, or it can be "reverse engineered" using a detailed knowledge of the building wiring and components combined with modeling software like ETAP or EasyPower.

Fault current is the practical maximum current available. It is typically limited by the upstream transformer and the inherent resistance of the wires and the arc. **Example:** 12 AWG wire has 1Ω per 630 feet. For 315 feet, the maximum fault current equals 120 VAC / 0.5Ω = 240 amps. Resistance will approximately double (current = half) if there is an arc in the circuit.

Ampere interrupt capability (AIC) is the maximum amount of fault current going through an **overcurrent protection device** (circuit breaker or fuse) such that the OCP would still function (open) and not self-destruct (shrapnel and sparks).

Short circuit current rating (SCCR) is the maximum short circuit current going through an **industrial control panel** (ICP, UL 508A) such that the panel would still function and not self-destruct (shrapnel and sparks). Refer to the next section for AIC and SCCR rules.

4.4.3 Circuit breakers – UL 489 vs UL 1077 and "slash" rating

UL 489 is the standard for **molded-case circuit breakers (MCCB),** ground-fault circuit-interrupters, fused circuit breakers, and accessory high-fault protectors. These circuit breakers protect the service entrance, feeders, and branch circuits. The primary application is fixed mounted panelboards and switchboards. UL 489 listed circuit breakers can break a large arc, resulting in AIC ratings of >=10KA. (UL website).

UL 1077 is the standard for **supplementary protectors** intended for use as over-current, or over-voltage, or under-voltage protection within an **appliance** or other electrical equipment where branch circuit overcurrent protection is already provided or is not required. This standard also covers accessory devices that may be installed in or on the protector to perform a secondary function. (UL website).

Slash rated circuit breakers, for example, 480/277Y, are intended for circuits with a neutral. The hot legs should not exceed 277 VAC L-N or 277 VAC L-G. Some delta transformers (no neutral) are wired to put out 480 VAC L_1-G, 480 VAC L_2-G, and 0 VAC L_3-G. An NRTL said that a "slash" circuit breaker cannot be used on any delta circuit (no neutral). Eaton says that a "slash" circuit breaker can be used on a delta circuit if the secondary voltages are in fact balanced so that no leg is higher than 277 VAC L-G.

4.4.4 Circuit breakers vs. fuses (and how to read a fuse chart)

Circuit breaker advantages:

- Easy to turn off and reset after an overload. Don't have to go and find replacement fuses.
- Poles ganged together to prevent possible equipment failure when just one leg trips off.

Fuse advantages:

- Fuses are more reliable. Circuit breakers can have problems with pitting, sticking, and black oxide.
- Fuses are faster. The fusible link is surrounded with sand. As the link melts, the sand contained in the cartridge will fill in the gap, knocking down the arc.
- Because of the sand, the fuse has a 4x better AIC rating compared to an equivalent circuit breaker.
- A disconnect switch with current limiting cartridge fuses will permit a connection to higher available fault current at an economical cost.

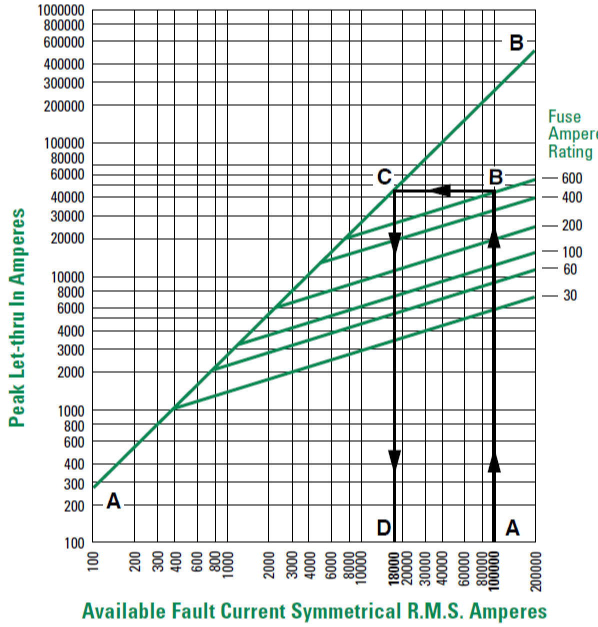
Best practice:

- Fused local disconnect switch box.
- Low voltage sensing that drops the contactor.

Reference: Littelfuse publication "Using Current-Limiting Fuses to Increase SCCR", form #PF992-C, ©2009, 16 pages.

Available fault current (facility) and short circuit current rating (equipment) are expressed as amps RMS. Figure 3 (on the right) shows RMS current into the fuse and RMS current out.

Example: A disconnect switch box has 600 amp cartridge fuses and 100,000 amps RMS of available fault current. Starting at "A", following up the chart to "B" 600 amp fuses, then left to "C" at the reduction line, then down to "D", arriving at the pass-through current of 18,000 amps RMS.



4.4.5 Circuit breaker coordination

Circuit breakers are wired like branches on a tree.

- Overload – the CB with the **lowest current rating** (eg. 20 amp) will trip open first.
- Short circuit – the CB with the **fastest trip speed** (eg. 1/10 second) will trip open first.

Circuit breakers do not trip open instantly. The fault clearing time depends on the circuit breaker type and the amount of fault current, up to the mechanical limit of the device. If the fault current is high enough, and the breakers have the same speed, it is possible that some or all of the circuit breakers (from beginning to end) may trip open. Therefore, circuit breakers are arranged regarding their current rating, speed rating, AIC rating, and available fault current. Coordination applies to ground faults (line to ground), not to bolt faults (line to line).

Example: A circuit breaker may open in 100 seconds at 1.5x OCP, 10 seconds at 3.5x OCP, 1 second at 10x OCP. Search: "circuit breaker characteristic trip curve".

There is an obvious **safety contradiction**. If upstream circuit breakers trip as fast as possible, they may bring down the entire building including essential services like operating rooms. If upstream circuit breakers are delayed (coordinated), the extended fault current time may cause a serious flash or fire.

Best practice: Model the network for short circuit current and circuit breaker speed. At the tool end, use fuses or fast circuit breakers. Use minimum size wires to limit the current. At the service end, carefully introduce some delay. Use GFCI to isolate local ground faults, especially in wet areas.

4.4.6 Circuit breaker induced damage

Circuits can store energy in the form of electrostatic charge (capacitance) or in the form of a magnetic field (inductance). The "conservation of energy" is dissipated by resistance in the wire and by vaporizing a small amount of metal on the contact of the switch pole.

Circuit breaker contacts can bounce during opening and closing. If the circuit breaker is "soft", there will be more vaporization, and it will wear out more quickly. If the circuit breaker is "hard", it will bounce at both opening and closing. There will be less vaporization, but the energy will then dissipate in the form of high voltage transients. The analogy is like solders marching across a bridge in lockstep or ringing a bell. The high voltage transients can be enough to punch through insulation and destroy the equipment. If transformer windings are shorted, not only is the transformer damaged, but the transformer secondary voltage could be significantly higher or lower, thus causing machine damage. Bottom line: avoid using a circuit breaker in place of a heavy-duty on-off switch.

Search: "Transformer Failure Due to Circuit-Breaker-Induced Switching Transients, by David Shipp et al, IEEE Transactions on Industrial Applications, volume 47, number 2, March/April 2011"

http://www.eaton.com/ecm/groups/public/@pub/@electrical/documents/content/pct_365633.pdf

4.4.7 Circuit breaker maintenance

Check annually for smooth mechanical operation and for hot spots that would indicate a high resistance connection (FLIR and Fluke infrared scan). Tighten screws according to the specified torque. The torque rating anticipates the expansion and contraction of the terminal. Over current protection can be confirmed with specialized current injection equipment (Megger PCIT & SCIT).

4.4.8 Circuit breaker counterfeit

The major manufacturers of circuit breakers (General Electric, Eaton/Cutler-Hammer/Westinghouse, Schneider/SquareD, and Siemens/Murray) have all published articles on how to detect a counterfeit circuit breaker. In some cases, the copies are virtually identical, and you must check the serial number online, just like dollar bills. If there is any doubt, ask for sourcing information.

The following paragraph is courtesy of Siemens.

Experts say a number of indicators can tell you if a component is counterfeit. Look for these suspicious characteristics:

- Markings and other features on the product or packaging look different or are missing, including:
  - Missing certification marks.
  - Incorrect colors on labels or packaging.
  - Incorrect shape or design of the product.
  - Missing components or product features.
- Words on the product or package are misspelled.
- The country of origin is different from the genuine source.
- The manufacturing locations or ports of entry are incorrect.
- Product defects or product performance are different from your typical experience.
- The price is unusually low.

Refer to the color illustrations for an example of a counterfeit circuit breaker.

4.5 Available fault current and short circuit current rating

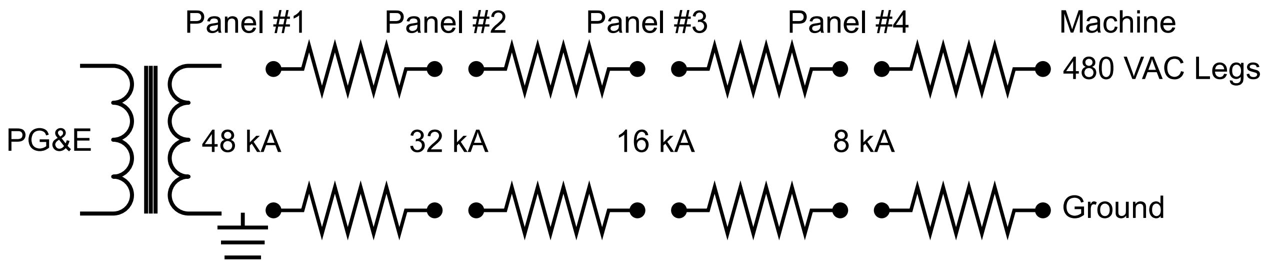
4.5.1 Available fault current

Available fault current = Ohm's Law

- **Voltage** is the electrical force created by the rotating magnetic field in a generator.
- **Current** is the voltage divided by the wire resistance. Starting at the feeder to an industrial factory, the fault current is ~48,000 amps (figure of merit). As you get further into the building, the available fault current is reduced because of the extra length and resistance of the wiring.
- **Time** is the time it takes to clear (open) a short circuit fault condition. Either a circuit breaker trips, or a fuse link melts, or a wire burns up.
- **Energy** is the product of power (voltage x current) and time. Energy can be measured in calories, joules, watt-hours, BTUs, etc. Energy = heat, light, and boom.
- **Arc flash energy** equals voltage x fault current x clearing time.

Analysis of available fault current

The following figure is a representation of a single line electrical distribution system from the utility connection on the left, through four panels to the final machine on the right. Each wire segment adds more resistance and reduces the available fault current. The fault current numbers (**example:** 48 KA at the building entrance) are representative of what you would see in a real factory.



There are two ways to calculate available fault current: approximate and precise. SEMI S22 approximates the available fault current in various situations using assumptions about wire gauge, wire length, and a bonded fault connect instead of an arc. Refer to the next table.

Example: A tool has a nominal power of 480 VAC and 48 amps full load current, and nominal wires that could sustain a short circuit current of ~13,000 amps. The tool's SCCR should be 14,000 amps.

SEMI S22	Available fault current			SEMI S22	Available fault current		
FLA rating	120 VAC	208 VAC	480 VAC	FLA rating	120 VAC	208 VAC	480 VAC
16 amp	1 KA	2 KA	4 KA	80 amp		8 KA	21 KA
24 amp	2 KA	2 KA	6 KA	88 amp		9 KA	24 KA
32 amp	3 KA	4 KA	9 KA	100 amp		10 KA	26 KA
40 amp	3 KA	4 KA	9 KA	120 amp		11 KA	28 KA
48 amp	4 KA	5 KA	13 KA	140 amp		11 KA	29 KA
56 amp	5 KA	7 KA	19 KA	160 amp		12 KA	30 KA
64 amp		7 KA	19 KA	180 amp		12 KA	31 KA
72 amp		8 KA	21 KA	200 amp		12 KA	32 KA

Available fault current at any given panel can be precisely calculated if the entire electrical distribution network is modeled in software such as ETAP or EasyPower. The electrical model is built using utility data, transformer impedance, feeder wire gauge (either by inspection or by code assumption), feeder wire length (estimated from the building floor plan), circuit breaker type, and fuse type.

After the model is built, you can get some useful information:

- **Maximum fault current** at a given panel. This will confirm if your panel SCCR is high enough.
- **Coordination** of circuit breakers. This will confirm if the circuit breaker closest to the fault is the one likely to open first. Otherwise, entire sections of the building could be blacked out. Coordination is assumed if, for a given fault current, the breaker closer to the fault is 4x faster than the one up-stream.
- **Hazard warning labels** for shock and arc flash. This will inform the Qualified Electrical Worker (QEW) about safe working boundaries and proper PPE.

4.5.2 Short circuit current rating

Short circuit current rating (SCCR) is determined by the ampere interrupt capacity (AIC) of the weakest part in the panel. Too much current through a weak part could cause it to self-destruct. Note: NFPA 79 refers to this as the "short-circuit interrupt rating".

59.	Electrical panels must be marked with the available fault current.	✓ NEC 110.24
60.	Industrial control panels (ICP) must be marked with their SCCR.	✓ NEC 409.110 ✓ NFPA79 16.4.1

61.	Industrial control panels must have SCCR that exceeds the available fault current.	✓ NEC 110.10 ✓ NFPA79 7.2.9
62.	Over-current protection devices (circuit breakers and fuses) must have an AIC that exceeds the available fault current.	✓ NEC 240.86 ✓ NFPA79 7.2.9

SCCR analysis method

1. Determine the single-line diagram of the industrial control panel.
2. Create a table of circuit description and rating.
3. Determine the SCCR for each component.
4. Put the "sweep 1" assessment into the SCCR analysis table.
5. Determine the SCCR for each engineered assembly.
6. Confirm if the weakest component can be improved.

Design and mitigation

Let's say that the calculation is done, and bad news, the available fault current exceeds the SCCR of the equipment. The next steps would be to **improve the SCCR** or **reduce the available fault current**.

- Analyze and fix the weakest components.
- Use engineered combinations. Fuses provide much higher short circuit protection than circuit breakers. A 200 KAIC fuse in front of a 10 KAIC component improves it to about 20 KAIC.
- Use heavy duty parts. If a component has no AIC rating, UL 508A table SB4.1 assigns a low default value of 5 KAIC. An AC receptacle has a default rating of only 2 KAIC.
- Use an isolation transformer.
- Use class J current limiting cartridge fuses in the disconnect switch box.
- Make the power and ground legs only as big as necessary. Don't automatically upsize long wires. Just keep the voltage drop <5%. Confirm the actual full load current (FLA) with a meter. The nameplate FLA is often overstated by 2x.

Example: A 208 VAC panel has a 25 KAIC circuit breaker at the front end. The contactors are rated 35 KAIC. After the contactor, there is a transformer feeding into the distribution circuit breakers rated 10 KAIC. The transformer is specified to reduce the available fault current by 45%. Since the SCCR is based on the worst-case component, the panel SCCR would be 10 KAIC/45% = 18,000 amps.

Example: High volume environmental testing is typically done in a large ballroom with overhead busways having 20,000 amps of available fault current. Hook-ups are made with tap boxes and drop-down power cords. One popular model of environmental test chamber has a Kuoyuh 98 series 25 amp "pop type" UL1077 supplemental circuit breakers (not UL489 molded case) mounted directly on the controller. UL permits a "pop type" circuit breaker in a heating appliance. However, this circuit breaker is rated only **1000 AIC** (125 VAC) and **200 AIC** (250 VAC). Because of high available fault current, these pop type CBs will not survive an internal short circuit, and if they go, the circuit board will likely be damaged.

- UL499 covers electric heating appliances. UL499-19.4 states "No overcurrent protective device is required as a part of the product if it is determined that equivalent or better protection will be obtained from the branch-circuit overcurrent protective device through which the product will be supplied." If you restrict field labeling to just the oven, and not the hook-up, and if the tap box is the branch, then the oven meets the code.
- NFPA79 states that the branch circuit breaker must be molded case and cannot be supplemental. Some inspectors interpret the "branch" circuit breaker as the last one prior to the controller and would fail the tool.
- NEC 110.10 and NFPA79 7.2.9 state that the equipment short circuit current rating (SCCR) must exceed the available fault current.
- NEC 409.110 requires the industrial control panel to be marked with the SCCR.

Summary and mitigation: AIC and SCCR are primarily about protecting cheap plastic power parts (circuit breakers and contactors) from self-destruction. Protection can be improved with cartridge fuses, isolation transformers, and higher resistance hook-up conductors. Safe machinery should be wrapped in a tough metal shell, which sometimes includes a chimney-like vent to direct the blast to the outside. Given that SCCR is not intended to prevent shock and arc flash, it could be treated as an acceptable risk. Keep spare parts available. Operate only with metal covers installed. Wear a full-face mask for occasional troubleshooting. Understand that smoke could trigger the smoke detector.

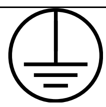
4.6 Conductors

4.6.1 Ground conductors – many kinds

There are many kinds of grounding conductors, and they are frequently mixed up. Let's review.

- **Equipment ground fault –** A path for fault current (many amps) from the equipment chassis back to the circuit breaker panel. Equipment ground is a safety device. The circuit breaker trips open.
- **Human ground fault –** A path for fault current (milli-amps), sometimes caused by accidental contact, worn-out extension cords, or corrosion breakdown of wet location lighting, pumps, and heaters. GFCI must be used in wet and outdoor locations.
- **Neutral –** A path for normal current back to the secondary of the transformer.
- **Electrode ground –** A path to the soil through a water pipe, copper rod, building frame, or rebar in the concrete foundation (Ufer). The electrode ground is for voltage stability. The equipment ground, neutral, and electrode ground are bonded together at the service entrance.
- **DC electronics ground –** A stable reference for DC voltage to digital circuits. Power supplies and circuit boards include some decoupling to the equipment ground.
- **Bonding –** Metal parts connected together for equipment grounding and to prevent sparks.
- **Shielding –** Provides "Faraday cage" immunity around sensitive wires, airplanes, ESD bags, etc.
- **Door panel ground strap –** Equipment ground to a door panel capable of being energized.
- **Wrist ground strap –** Prevents a build-up of electrostatic discharge (ESD) that could damage sensitive electronic components.

Note: UL508A 74 has obscure definitions for equipment grounding conductor, ground bus, grounded service conductor, grounding electrode conductor, main bonding jumper, neutral bus, and neutral conductor. Per figure 75.3, apparently it is common practice to connect the equipment ground, electrode ground, and neutral all together within the control panel. Best practice: don't do this except for a secondary derived service. Furthermore, UL508A 77.1.2 states "remove bonding means for test purposes only", but 77.2 then refers to an insulated neutral.

63.	Equipment ground (protective earth bond) is a grounding conductor (carries fault current) colored green (US) or green with yellow stripe (US & CE). CE requires the yellow portion to be 30-70% in a 15 mm segment.	✓ NFPA79-13.2.2
64.	Equipment ground coming into the machine must be tied down to a grounding terminal.	✓ NFPA79-5.1.7 & 8.2
65.	Equipment ground terminal identified. US: G, GND, GRD, GROUND, PE, symbol (on the right), green, or green/yellow. CE: PE or green/yellow. 	✓ NFPA79-8.2.1.3.3 ✓ UL61010-5.1.5.2
66.	CE and best practice: only one ground bond connection per terminal. US: one on one ground bond connection if subjected to modular replacement (devices, outlets, and lamps). This implies grounds can be stacked together for permanent construction.	✓ NEC 250.148 ✓ NFPA79- 8.2.3.2

67.	Terminals rated for more than one conductor shall be so identified. This is a common problem with ground lugs, circuit breaker lugs, and DIN rail terminals. Check the part data sheet. It will usually state one or two wires, and if two wires, they should be the same gauge. Avoid tuck-under. Crimp them together into a common ferrule.	✓ NEC 110.14 ✓ NFPA79-13.1.1.3
68.	Equipment ground to all metal panels capable of being energized. Fault path must be good enough to trip the CB. Maximum resistance end to end 0.1 Ω. Also refer to IAEI Soares textbook and UL467. Exceptions: (1) <= 30 VAC, (2) GFCI protected, (3) double insulated.	✓ NFPA79-8.2.1 & 18.2 ✓ UL508-28.1 ✓ UL508A-14 ✓ UL61010-6.5.2
69.	Chassis must be effectively grounded. Doors and covers with electrical devices need a ground strap. CE: a low resistance hinge or contact is ok but not recommended. No ground needed for a panel with just a push button (UL508). See note below for best practice.	✓ NFPA79-8.2 ✓ UL508-6.6 ✓ UL508A-14
70.	Ground can be copper or aluminum as long as the gauge and terminals are correct (NEC &, UL508). Ground wire must be copper due to concern for vibration (NFPA79). Ground wire should be copper (IEC60204). All internal conductors and bus bars must be copper (UL508A). Best practice: aluminum ok if there is no vibration.	✓ NEC 250.120 ✓ NFPA79-8.2.2 ✓ UL508-6.6.3 ✓ UL508A-29.1.1
71.	US: Equipment grounds are sized according to the circuit breaker. If hot legs are upsized, the ground must be upsized proportionally. CE: Equipment grounds are sized according to the power conductor cross-sectional area "S". Europe uses standard metric sized wire, not AWG. At higher current, the CE ground size (fixed 50% of load wire) is **significantly larger** than the US requirement (<20% of load wire). 1) If S <= 16 mm^2, the ground is the same size wire. 2) If 16 mm^2 < S <= 35 mm^2, the ground is 16 mm^2. 3) If S > 35 mm^2, the ground is half of S.	✓ NEC table 250.122 ✓ NFPA79-8.2.2.4 ✓ UL508-6.6.4 ✓ UL508A-15
72.	Swimming pool or hot tub. The equipment ground wire gauge is #8 gauge minimum and not smaller than the hot leg.	✓ NEC 680.2(B)(1)(b) ✓ NEC 680.2(B)(3)

73.

Breaker size (amps)	15	20	30	60	100	200	300	400	500	600	800
copper ground wire	#14	#12	#10	#10	#8	#6	#4	#3	#2	#1	#0
aluminum ground	#12	#10	#8	#8	#6	#4	#2	#1	#0	#00	#000

74.	Grounding electrode conductor (from the transformer to the building electrode) is sized according to the largest hot legs.	✓ NEC table 250.66

75.

GEC gauge for different hot legs	#2	#1 or #0	#00 or #000	#0000 to 350	351 to 600	601 to 1100	>1100
copper GEC gauge	#8	#6	#4	#2	#0	#00	#000
aluminum GEC gauge	#6	#4	#2	#0	#000	#0000	250

76.	The grounding electrode conductor (GEC) is not required to be in conduit if it is #6 gauge or larger and not exposed to physical damage.	✓ NEC 250.64(B)(3)
77.	The grounding electrode conductor (GEC) does not need to be larger than #6 copper (or #4 aluminum) if it is "point-to-point" and does not extend onward.	✓ NEC 250.66(A)

Dual feeders: If two sets of feeders, each needs a ground wire. Impedance is significantly reduced.

Grounding conduit: Can the metal conduit serve as the equipment ground wire? Look at the code.

- **NFPA 79 8.2.2.2** Conductors used for grounding and bonding shall be copper.
- **NFPA 79 8.2.3.1** The continuity of the equipment grounding **conductors** shall be ensured by effective connections.

- **NFPA 79 8.2.3.4** Separate wire-type equipment grounding conductor.
- **UL 508 6.6.3.** A separate bonding conductor . . . shall be copper . . . or other material acceptable for use as an electrical conductor. Ferrous metal parts in the grounding path shall be protected against corrosion.
- **UL 508A 14.3.** The grounding terminal shall have electrical continuity with all metal parts of the enclosure . . . by (either) metal-to-metal contact (or) an internal bonding conductor. UL508A 14.2 refers to UL 467 for grounding and bonding, the basis of the Soares text.
- **Soares Book of Grounding and Bonding** 10th edition page 138. NEC 250.96A requires that bonding be done around connections of metal raceways, cable tray, cable armor, cable sheath, enclosures, frames, fittings, and other metal non-current-carrying parts used as equipment grounding conductors where necessary . . . to ensure that the raceway will not become energized.
- **Soares Book of Grounding and Bonding** 10th edition page 140. UL examination of over 300 conduit fitting assemblies subjected to current test (and) 7 showed signs of arcing and welding. It was observed that if the fitting provides good electrical contact to both the enclosure and conduit, the fitting will provide a suitable equipment ground path for fault current.

Best practice for grounding: UL and NEC approve the use of **ferrous metal parts** (rated fittings and conduit) for the equipment ground path, but it must be tested. NEC permits **copper or aluminum** ground. NFPA 79 (machinery) requires **copper** conductors and ground wire. My professional colleagues have always expected to see a ground wire inside the conduit. The ground wire should be sized according to the upstream circuit breaker which would be tripping off. CB 20 amp would have a #12 ground. CB 60 amps would have a #10 ground. If the conduit serves as a ground **within the machine**, and if the supplier conducts ground bond testing (NFPA79-18.2) on each assembly prior to shipment, I will accept it.

Best practice for ground attachment: Goal is to minimize shunt path resistance and effectively trip the circuit breaker. Put the wires one-by-one under the screw points of a bus bar or put the wire into a flat ring ferrule under a screw head terminal. The screw itself should not be used as a conductor unless it is brass or copper. A bare solid wire or a tinned stranded wire can be wrapped under a screw head (UL508A-17.2 & 29.3.3), with two full threads and 20 foot-pounds torque (UL508A-20.2.3), but ferrules demonstrate better workmanship. Ground connection should avoid:

- Bare stranded wire wrapped under a screw head.
- Twist-on wire nut.
- "Sandwich" of two steel nuts on a steel screw if the circuit breaker is >20 amps.
- "Two-on-a-screw" if the grounds are for modular devices.

Example: A 240 VAC metrology tool was plugged into a small transformer on the floor, which was then plugged into a 120 VAC wall outlet. The ground check was ok. The tool was relocated at least once. A year later the client touched the tool chassis and was shocked. How could this happen? Turns out there was nothing wrong with the tool itself. The problem was in the transformer secondary. The ground wire (going to the tool) had snapped off (cold solder joint), flipped over, and landed on a hot leg. Now the tool chassis is energized with no ground path to trip open the circuit breaker and clear the fault. Perhaps the cord from the secondary had been jerked during the move. Lesson learned – cable clamp.

Grounding electrode: The **equipment grounding conductor** (green wire discussed above) should not be used for a **grounding electrode conductor** (wire that connects the neutral and ground bus bars to the electrode in the earth). The equipment ground is for **shock protection**. The grounding electrode is for **power stability**. In the context of machinery, the grounding electrode conductor is used to bond a neutral (from a separately derived system, coming out of the transformer secondary) to the building frame or to a copper rod in the earth. UL508A 16.2 has some confusing explanations about the secondary grounding (electrode, equipment ground, and neutral). Up to 1 KW, the electrode can be omitted. **Best practice:** If the transformer is on the floor, bond the neutral to the building electrode.

4.6.2 Ground current

The sum of the current in the hot legs and the neutral should be zero. Ground current indicates the equipment chassis is "floating" above the ground. If ground current is being measured, there could be several issues. Sometimes the mitigation is an extra-large ground wire.

- Clamp-on ammeters and ground wires are susceptible to interference from strong magnetic fields (transformers), especially if there are harmonics of the 60 Hz, or if a 50 Hz transformer is operating at 60 Hz. **Example:** I once measured 3 amps on a ground wire disconnected at one end. Test this by holding up the meter with no wire in the jaws and try different orientations.
- An isolation transformer is sometimes used to set up a secondary derived neutral bonded to the chassis ground. In this case, the current circulates on the secondary and not on the equipment ground coming into the tool. If the tool manufacturer requires an isolation transformer, put it in.
- Certain loads rapidly chop the AC wave form. When the load in non-linear, this can introduce harmonic current on the legs, especially the neutral bus. **Example:** A furnace using solid state relays (SSRs) to rapidly pulse the power into the quartz lamps. Also switching power supplies, electronic ballasts, variable-frequency drives, and uninterruptable power supplies (UPS). Test this by wrapping the current loop transformer around the three hot legs and the neutral together. If it is not zero, the current is leaking. Servo motors are reviewed in NFPA79 chapter 19.
  http://www.copper.org/applications/electrical/pq/issues.html

4.6.3 Neutral

78.	**Neutral color:** The neutral is a ground**ed** conductor that carries normal current back to a transformer. US: colored **white**, or **gray**, or black with **three white stripes**. Neutral and ground are tied at the service entrance. CE: neutral is colored light blue or black with light blue stripes visible at the access points.	✓ NEC 200.6(A) and 200.7 ✓ NFPA79-13.2.3
79.	**Neutral size for 1Φ:** Size the neutral same as the hot leg.	✓ NEC 220.61 ✓ NEC Annex D
80.	**Neutral size for 3Φ:** • If reasonably balanced, size the neutral according to its calculated load, or same as the grounding electrode conductor, whichever is bigger. Old rule of thumb: Two sizes smaller than the hot leg for example, #6 hot leg and #10 neutral. • If unbalanced, size the neutral same as the hot leg. • If unbalanced and non-linear (not a sine wave), size the neutral double the hot legs.	✓ NEC 220.61 ✓ NEC Annex D
81.	**Neutral circuit breaker:** • US: Neutral does not have its own circuit breaker. However, if two or three hot legs share a neutral, the CB hot legs must be tied for a common trip. • CE: Neutral **can be smaller** than the hot leg if the neutral has its own circuit breaker.	✓ NEC 225.7(B) ✓ IEC60204-7.2.3
82.	**Neutral CB and disconnect.** In the US, the neutral typically goes around the switch and circuit breaker. Some standards are different. • UL 61010-6.11.1 states the disconnecting means "shall disconnect all current-carrying conductors". • SEMI S22 permits the neutral to go through the disconnect switch (9.3.5) and through a circuit breaker (11.3) as long as it is ganged to the hot conductors. This is common practice in Europe.	✓ UL61010-6.11.1 ✓ SEMI S22-9.3.5 & 11.3
83.	**Lighting circuit** conductors must be hot and neutral (grounded).	✓ NFPA79-8.4.1

Neutral current > power leg current: With worst case 3Φ power factor, the neutral current can theoretically exceed the power leg current by up to 1.7x. Also, if the power sine wave is being "chopped" in the middle, typical with quartz heating lamps, switching power supplies, and UPS, the neutral current can be excessive and there could be significant power corruption (harmonic distortion) in the power distribution. Refer to the color illustrations for an example of a neutral burn-out.

Shared neutral. In the US, electricians sometimes save money by having 2 or 3 circuit breaker poles (separate loads) share the same neutral. In this case, the circuit breakers must have a common trip. There are two disadvantages: (1) One overloaded machine can take down two or three. (2) Difficult to determine which of the legs caused the overload.

Shared equipment ground. Like the shared neutral, the equipment ground wire can also be shared if the circuits originate from the same panel and bus. This is very unusual. NEC 250.130(C).

Grounding electrode conductor. Refer to the transformer section for bonding the neutral on isolation transformers and autotransformers.

4.6.4 Power legs

84.	**Power leg color:** Black. See note below. Use tags for identification.	✓ NFPA79-13.2.4.3 ✓ UL508A-66.9.1
85.	**Power leg gauge:** Adequate gauge (cross sectional area) and temperature rating to carry the current. See table in the next section.	✓ NFPA79 table 12.5.1 ✓ IEC60204 table 12.4 ✓ UL508A-31.4.3
86.	**Tap rule 10'** to a machine if: (1) conductors are protected from damage (enclosed or ducted), (2) conductors are rated at least 10% of the main, (3) conductors are rated for the full load, (4) rated OCP is at the end of the tap. • Power cords are not taps because they are not enclosed or ducted. • NFPA79 previously stated "conductors supplying additional OCP devices shall be considered as **branch circuits.** " In 2021, this appears to be deleted. Use your judgment.	✓ NEC 240.21(1) ✓ NFPA79 7.2.8 ✓ UL508-18.2
87.	**Tap rule 25'** to a machine if: (1) conductors are protected from damage (enclosed or ducted), (2) conductors are rated at least 33% of the main, (3) conductors are rated for the full load, (4) rated OCP is at the end of the tap.	✓ NEC 240.21(2) ✓ NEC Handbook exhibit 240.8 ✓ NFPA79-7.2.10.5
88.	**Tap rule 25'** round-trip to a transformer if: (1) conductors are protected from damage (enclosed or ducted), (2) feeder OCP does not exceed 3x the rating of the primary and secondary conductors, (3) secondary OCP does not exceed the rating of the secondary conductors	✓ NEC 240.21(3) ✓ NEC Handbook exhibit 240.9
89.	**Tap rule 25'** horizontal and 100' total to a machine if: (1) conductors are protected from damage (enclosed or ducted), (2) conductors are rated at least 33% of the main, (3) conductors are rated for the full load, (4) rated OCP is at the end of the tap. (4) High bay manufacturing building with walls at least 35' tall. (5) No splices.	✓ NEC 240.21(4) ✓ NEC Handbook exhibit 240.10
90.	**NEC 125% rule:** Supply circuit conductors are sized according to 125% of the continuous (largest) load (>3 hours on) and 100% of the intermittent load. **Example:** 17 amps FLA and 8 amps LL, size the wire = (1.25 x 8) + (17 - 8) = 19 amps. **UL 125% rule:** size 125% of the largest motor, heating, and lighting.	✓ NEC 210.19 ✓ UL508-25.5.1 ✓ UL508A-28.3.2
91.	Voltage drop should not exceed 5% (CE only)	✓ IEC60204-12.5

92.	Bending radius is 8x the diameter for bare wire, and 12x for insulated. UL defines wire bending space (volume), not the bending radius. **Example:** A ½" diameter insulated wire should be bent the size of a 12" dinner plate.	✓ NEC 300.34 ✓ UL508-6.14.4
93.	Service should go directly to the disconnect, avoiding terminals if practical. **Best practice:** disconnect is outside the electrical cabinet.	✓ NFPA79-5.1.1
94.	If subject to flexing, insulation 1/32 inch thick and 70°C rating minimum.	✓ UL2011-9.2
95.	Spacing between uninsulated live parts. • Creepage is the shortest distance over the surface of the insulation. • Clearance is the distance directly through air between two conductive parts. 120 VAC (0.125–0.75"). 208 VAC (0.25–1.25"). 480 VAC (0.375–2.0").	✓ UL508-34 ✓ UL508A-10

4.6.4.1 Feeder, branch, and supply circuits

The terms are somewhat interchangeable.

- A **feeder** circuit connects power to a circuit breaker panel.
- A **branch** circuit connects power from a circuit breaker panel or fused disconnect switch to an outlet, a resistive load, or a motor.
- A **supply** circuit connects power to a machine.

4.6.4.2 Sizing the disconnect for a motor circuit

Refer to the motor nameplate for the following information:

- Current (amps) = actual motor amp draw (each leg averaged)
- Horsepower (HP) = horsepower rating (motor nameplate)
- Voltage = actual line-to-line voltage (legs averaged)
- Motor efficiency (eff) = percent of electricity converted to torque (motor nameplate)
- Power factor (PF) = motor power factor (motor nameplate)
- Amps = (hp x 746) / (volts x efficiency x power factor x 1.73).
- Motors wires are sized 125% per NEC and UL.
- Locked rotor current (LRA) is similar to the start-up surge current.

Motor disconnects – three types:

- Sized based on horsepower only, or
- Sized based on amps only, or
- Sized based on **either** horsepower or amps.

Sizing the disconnect switch for a single motor:

- Ampere rating >= 115% of the rated motor full load current for a switch rated by full load current, **or**
- HP rating >= 100% of the rated motor HP (at applied voltage) if the switch is rated by horsepower.

4.6.4.3 Sizing the THHN wire

THHN (Thermoplastic High Heat-resistant Nylon coated) is a commonly used construction wire available in standard gauges. Let's compare American Wire Gauge (AWG) with European square millimeters.

- Line #1: American wire gauge (AWG).
- Line #2: THHN outer diameter (with jacket) which can be measured with a plastic caliper.
- Line #3: Cross sectional area in square millimeters of the conductor.

- Lines #4 & #5: NEC table 310.15(B)(16) ampere rating of copper, 75°C and 90°C up to 3 legs in a conduit, and with no other derating such as voltage drop and being on 3 hours continuous.

AWG	#12	#10	#8	#6	#4	#3	#2	#1	#0	#00	000	0000	250	300	350	400	500
THHN ODmm	3.1	4.1	5.6	6.4	8.0	9.0	10.0	11.0	12.4	13.2	14.4	15.8	17.2	18.5	19.7	20.9	22.9
copper mm^2	3.31 mm^2	5.26 mm^2	8.36 mm^2	13.3 mm^2	21.2 mm^2	26.7 mm^2	33.6 mm^2	42.4 mm^2	53.5 mm^2	67.4 mm^2	85.0 mm^2	107 mm^2	127 mm^2	152 mm^2	177 mm^2	203 mm^2	253 mm^2
current 75°C	25 amp	35 amp	50 amp	65 amp	85 amp	100 amp	115 amp	130 amp	150 amp	175 amp	200 amp	230 amp	255 amp	285 amp	310 amp	335 amp	380 amp
current 90°C	30 amp	40 amp	55 amp	75 amp	95 amp	115 amp	130 amp	145 amp	170 amp	195 amp	225 amp	260 amp	290 amp	320 amp	350 amp	380 amp	430 amp

Note: #0 gauge is also called #1/0 or "1 aught". #00 gauge is also called #2/0 or "2 aught". Wire gauge relates to the number of dies that the wire is pulled through to make it smaller and smaller.

After #0000 (#4/0) gauge, units change to kcmil (circular mils) 250, 300, 350 etc. 2 kcmil ~= 1 mm^2.

The chart is for copper. Aluminum has 60% of the conductivity of copper. So aluminum wires must be significantly larger than copper for the same current capacity.

Note: AC current is not uniform across a conductor. Due to the skin effect, the current is denser at the outer side and less dense at the center. And because of this effect, the AC current carrying capacity of a wire is not directly proportional to the cross-sectional area. Example: #6 gauge (13.3 mm^2) is rated **65 amp** (75°C) but #3 gauge (26.7 mm^2) is rated **100 amp** (75°C). Example: 250 KCMIL gauge (127 mm^2) is rated **255 amp** (75°C) but 500 KCMIL gauge (253 mm2) is rated **380 amp** (75°C).

4.6.4.4 Factors for sizing and derating the wires and terminals

- **Full load current** is just one of many factors used to size a wire.
- NEC 210.19 requires power conductors to be **sized 125% of the continuous** portion of the total full load. Continuous means on over 3 hours. This rule originates because: (1) If the load is on all the time, then wires never get a chance to cool down. (2) Warm wires have more resistance and cause more voltage drop. (3) For a given mechanical load, when the voltage drops, a motor draws more current, which in turn adds even more heat to the wires. This 125% oversizing has been extended to heaters, lighting, under a raised floor, and continuous loads (on over 3 hours). In addition, extra heat may cause a thermal-trip circuit breaker to trip with a current that's lower than its rating.
- NEC states that the 125% rule is applied after any other required de-rating such as ambient temperature and number of wires in the conduit. However, some state codes (e.g. 2008 CEC 8-104.6) state that you compare the first de-rating (ambient temperature etc) with the second de-rating (125%) and pick the larger wire. The 2017 NEC has changed to be the same as California.
- NEC has other ampacity derating rules for specialty equipment like air conditioning and welders.
- UL 508A requires terminals (66.4.1) and power conductors (66.5.3) to be **sized 125%** for **heaters** and for the **largest motor load**.
- The wire gauge should not be smaller than the **circuit breaker rating** except for the "tap" rules and the "next size up CB" rule. Power cords are sized according to the full load.
- Different wire insulations have different maximum temperature ratings. **Examples:** 60°C for TW, 75°C for THW, RHW, USE, and 90°C for THHN. Lower temperature rating means lower current rating.
- NEC 310.14(A)(C) describes how different terminals have different maximum temperature ratings. Circuit breaker terminals are assumed to be 60°C unless they are otherwise marked. For electrical equipment rated up to 600 volts, UL listed parts are never rated higher than 75°C. This also applies to lugs, contactors, line filters, etc.
- **Number of wires in the conduit**. Derate 20% current capacity for 4-6 current carrying wires, excluding the neutral if the loads are reasonably balanced. Refer to NEC table 310.15(B)(3)(a) for adjustment.

- **Ambient temperature**. Derate 5% current capacity for every 5°C above 30°C.
- **Wire length.** Voltage drop and power loss should not exceed 5% due to the length of the wire.
- **Conductor metal.** Copper or aluminum.

Additional reference for how to size a conductor: Mike Holt Enterprises

A wire will operate near its maximum temperature rating when it is at the maximum rated current and 30°C ambient. The insulation jacket protects from shock, short circuit, and fire hazard. But the insulation jacket and the conduit also hold in the heat. If too much heat builds up, the insulation melts. If there is extreme heat, the copper will melt at 1084°C just like a fuse.

Common problem: If a wire rated 90°C is at full load, and the wire is connected to a terminal rated 75°C at the **same full load**, the terminal may overheat and fail. Therefore, the THHN wire must be selected as if it were rated for 75°C. Or else you need to pick a **more heavy-duty terminal or switch**.

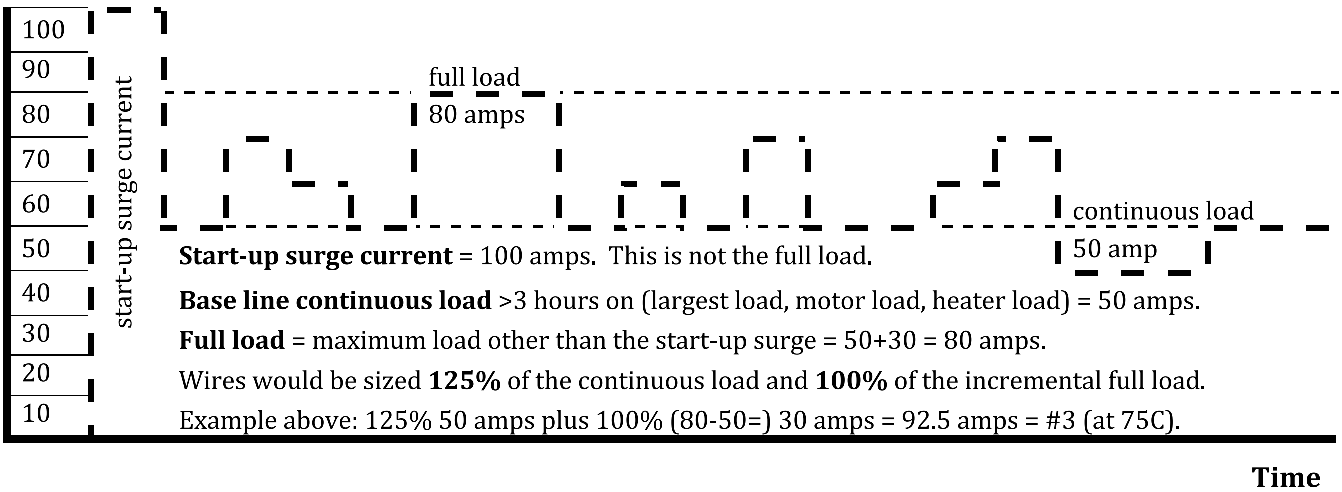
So what good is a 90°C rated wire? It gives you 10% more current rating in the following de-rating situations: (1) >3 hot legs in the conduit, (2) >30°C ambient temperature, and (3) meeting the 125% rule as long as the terminal is oversized.

4.6.4.5 Next larger size circuit breaker rule

96.	OCP (CB or fuse) on hot legs should not exceed the rating of components and conductors. Exception: The **CB can be the next size up** if the maximum current falls between two circuit breaker sizes. NEC 240.6(A) defines the standard circuit breakers as 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300 etc. Accordingly, it would be ok for CB=70 amp to use #6 wire rated 65 amp and CB=90 amp to use #4 wire rated 85 amp.	✓ NEC 240.6(A) ✓ NFPA79-7.2.1 ✓ UL61010-9.6

Summary: There are many reasons for a wire to be bigger: distance, largest load, number of wires in conduit, ambient temperature, etc., but there is only one exception (CB upsizing) for wires to be smaller. The mistake can happen when the construction plan is wrong. Some electricians use this rule to run a #4/0 on a 250 amp. This rule should not be abused, and other derating factors should not be ignored.

4.6.4.6 Example of a machine current profile from 0–100 amps over time



4.7 Transformers

<table>
<tr><td>97.</td><td>Transformer over current protection is a % of full load current, and it depends on if the primary is the only side protected, or if both the primary and secondary sides are protected. Next highest standard fuse is allowed. CE: OCP follows manufacturer’s recommendation.
<table>
<tr><th rowspan="2">NEC table 450.3(B)</th><th colspan="3">Primary Protection</th><th colspan="2">Secondary Protection</th></tr>
<tr><th>current >9 amp</th><th>current <9 amp</th><th>current <2 amp</th><th>current >9 amp</th><th>current <9 amp</th></tr>
<tr><td>Only primary is protected</td><td>125%</td><td>167%</td><td>300%</td><td>X</td><td>X</td></tr>
<tr><td>Both primary and secondary are protected</td><td>250%</td><td>250%</td><td>250%</td><td>125%</td><td>167%</td></tr>
</table>
</td><td>✓ NEC 450.3
✓ UL508-18.3
✓ UL508A-35.2</td></tr>
<tr><td>98.</td><td>Isolation transformers often provide “secondary derived service”. Example: 208 VAC 3Φ stepdown to provide 120 VAC plus neutral. See note below for how to bond the secondary neutral.</td><td>✓ NEC 250.30</td></tr>
</table>

European industrial power is typically 400 VAC “Y” 3Φ+N. Tools often run 230 VAC line-to-ground single phase with a single pole circuit breaker. In the US, these same tools might run 208 VAC line-to-line. A problem can occur if someone is using the tool CB to turn off the tool – one leg remains energized. Make sure the tool switch and circuit breaker are configured for two hot legs.

Neutral bonding note: Machines can be configured with or without a service neutral. **Example:** 208 VAC 3Φ, 5-wire, with 120 VAC from a leg-to-neutral. The neutral is used to return ordinary current. The ground is used for fault current.

Isolation transformer: The primary and secondary share the magnetic circuit but have separate electrical coils. An isolation transformer creates a “derived” power source. The secondary neutral point (center of the Y) would normally be bonded to a grounding electrode conductor for voltage stability. This is the typical best practice for bonding the neutral on an isolation transformer:

- **Large power.** If the step-down transformer is **on the floor outside the machine**, the secondary neutral should be bonded to the building electrode. (NEC handbook exhibit 250.30)
- **Medium power.** If the step-down transformer is **inside the machine**, the secondary neutral can be bonded to the equipment frame in most jurisdictions. The frame needs excellent ground. Most of the neutral current will stay in the secondary and very little current will be in the parallel path of the equipment ground. Sometimes a supplemental wire will connect to a nearby water pipe or ground rod.
- **Small power.** If the step-down transformer is **<= 100 watts**, use a UL listed control power transformer to derive the 120 (or 24) VAC and neutral.
- **Convenience outlets.** Use a GFCI connected on a 120 VAC leg. This is similar to the retrofit of older homes where 2-prong outlets are converted to 3-prong outlets without rewiring.

Auto transformer: Autotransformers are commonly referred to as **buck** (step-down voltage) and **boost** (step-up voltage). The primary and secondary share the magnetic circuit and share the electrical coil. This is the typical best practice for bonding the neutral bus tap on an autotransformer.

- The autotransformer neutral bus tap does not promote voltage stability and it is often left disconnected.
- If the primary side 3Φ power is out-of-balance by >2%, then the facility should extend the neutral from the electrical panel (or disconnect switch) to the transformer “common” neutral bus tap. The reason is to prevent the transformer from overheating.
- The autotransformer neutral bus can be further extended to the load if L-N voltage is desired.
- If there is some concern with voltage surging, put an MOV type surge suppressor on the load.

4.8 Motors

The NEC has some ambiguity for over current protection on a motor circuit. Is it supposed to protect the wires, the motor, or both? Some electrical designers have used this to justify very large circuit breakers on very small wires.

<table>
<tr><td>99.</td><td>Wires outside a UL listed skid conform to NEC 310.15(B)(16) (if THHN) or various other tables for power cord (SJT, SOOW, TC, W etc.). The overcurrent protection must not exceed the current rating of the wire. There are additional derating factors such as ambient temperature, length of the run, number of wires in the conduit, load type (heater or motor), continuous load portion of the full load, etc.</td><td>✓ NEC 310.15(B)(16)
✓ power cord tables</td></tr>
<tr><td>100.</td><td>For a motor branch circuit, fuses can be up to 3x full load, and circuit breakers can be up to 11x full load. The "branch" circuit is the final circuit in front of the motor, not the circuit from the panel to the VFD.</td><td>✓ NEC table 430.52</td></tr>
<tr><td>101.</td><td>Circuit conductors supplying power to an adjustable speed drive (VFD) shall be at least 125% of the VFD rated input current.</td><td>✓ NEC 430.122</td></tr>
<tr><td>102.</td><td>The ultimate trip current cannot exceed 115% of the motor controller continuous current rating. This is intended to prevent nuisance tripping during spin-up.</td><td>✓ NEC 430.226</td></tr>
<tr><td>103.</td><td>Wires inside a UL listed skid conform to the various UL standards. UL will typically judge the wire gauge based on a table (same as NEC) or based on termination temperature at full load. UL listed motors typically have an integrated thermal sensing device.</td><td>✓ UL508 & UL61010</td></tr>
<tr><td>104.</td><td>Adequately protected and easily accessible.</td><td>✓ NFPA79-14.5.1</td></tr>
<tr><td>105.</td><td>Proper cooling.</td><td>✓ NFPA79-14.5.2</td></tr>
<tr><td>106.</td><td>Clean and dry compartment. Ventilation to the exterior, if required.</td><td>✓ NFPA79-14.5.3</td></tr>
<tr><td>107.</td><td>Sealed raceway between motor and other compartments. NEC refers to (undefined) motor compartment requirements. If the motor is big and dangerous, make sure the motor is mechanically isolated (not blowing heat and debris back into the enclosure) and that the wires are enclosed.</td><td>✓ NFPA79-14.5.4</td></tr>
<tr><td>108.</td><td>Direction arrow if required for safety. CE: no requirement.</td><td>✓ NFPA79-14.8</td></tr>
<tr><td>109.</td><td>Motor nameplate should be visible and readable. Nameplate should include manufacturer, voltage, current, RPM speed, temperature. Horsepower and/or KVA is usually included.</td><td>✓ NEC 430.7
✓ NFPA79-16.4.4 & 16.5.2</td></tr>
<tr><td>110.</td><td>Motors must have overload protection: over-current protection (OCP), thermal protection (TP), or impedance protection (ZP). If the rotor becomes locked, only the CB or fuse should activate. No smoke.
<table>
<tr><th>Motor Type</th><th>Non-time delay fuse</th><th>Time delay fuse</th><th>Instan-taneous trip CB</th><th>Inverse time CB</th></tr>
<tr><td>Single phase</td><td>300%</td><td>175%</td><td>800%</td><td>250%</td></tr>
<tr><td>AC polyphase</td><td>300%</td><td>175%</td><td>800%</td><td>250%</td></tr>
<tr><td>Squirrel cage</td><td>300%</td><td>175%</td><td>800%</td><td>250%</td></tr>
<tr><td>Energy efficient</td><td>300%</td><td>175%</td><td>1100%</td><td>250%</td></tr>
<tr><td>Synchronous</td><td>300%</td><td>175%</td><td>800%</td><td>250%</td></tr>
<tr><td>Wound rotor</td><td>150%</td><td>150%</td><td>800%</td><td>150%</td></tr>
<tr><td>Direct current</td><td>150%</td><td>150%</td><td>250%</td><td>150%</td></tr>
</table></td><td>✓ NEC table 430.52
✓ NFPA79 table 7.2.10.1
✓ UL508-18.1.3
✓ UL508A-26.2.4
✓ UL2011-7.1</td></tr>
</table>

4.9 Power cords – code interpretations for how to size

#	Interpretation	Reference
111.	NEC permits industrial point-to-point power cords in raceways up to 50 feet. Most jurisdictions permit "TC" tray cable of unlimited length same as conduit. Some jurisdictions restrict appliances cord "whips" to be 4-6'.	✓ NEC 400.10 (permitted)
112.	Most jurisdictions permit SO cord to be used just like flexible conduit (hard wired on both ends) as long as the entire cable is visible. NEC states a plug/receptacle is required on one end. UL61010 3.1.2 states the cord must be detachable without a tool.	✓ NEC 400.12 (not permitted) ✓ UL61010 3.1.2
113.	Most jurisdictions permit SO cord to pass through a hole in the wall as long as the entire cable is visible (not permanently covered). NEC states a cord is not a substitute for fixed wiring and cannot pass through a hole in the wall.	✓ NEC 400.12 (not permitted)
114.	Power cord type should be suitable for hard usage, typically "SO" or equivalent. CE requires that cables be of "adequate construction". IEC 60228 metric cords are typically 0.75, 1.0, 1.5, 2, 4, 6, 8, 10, 16, 20 mm^2. Full load current vs power cord gauge is below.	✓ NEC 400.5 ✓ NFPA79 table 12.8.2 ✓ IEC60204 12.6.1 ✓ UL508A-28.5.2

115.

SO cord gauge	#18	#16	#14	#12	#10	#8	#6	#4	#3	#2
copper mm^2	0.82 mm^2	1.31 mm^2	2.08 mm^2	3.31 mm^2	5.26 mm^2	8.36 mm^2	13.3 mm^2	21.2 mm^2	26.7 mm^2	33.6 mm^2
with 2 hot	10 amp	13 amp	18 amp	25 amp	30 amp	40 amp	55 amp	70 amp	no spec	95 amp
with 3 hot	7 amp	10 amp	15 amp	20 amp	25 amp	35 amp	45 amp	60 amp	no spec	80 amp

SJ cord (j = junior) is rated 300 volt. SO cord is rated 600 volt.

116.

TC cord gauge	#18	#16	#14	#12	#10	#8	#6	#4	#3	#2
copper mm^2	0.82 mm^2	1.31 mm^2	2.08 mm^2	3.31 mm^2	5.26 mm^2	8.36 mm^2	13.3 mm^2	21.2 mm^2	26.7 mm^2	33.6 mm^2
with 2 or 3 hot	no spec	no spec	20 amp	25 amp	35 amp	50 amp	65 amp	85 amp	no spec	100 amp

Tray cable is rated similar to THHN (75°C) in conduit. Compared to SOOW, tray cable has a thinner jacket, should not be on the floor, and must not be walked on.

117.

W cord gauge	#18	#16	#14	#12	#10	#8	#6	#4	#3	#2
copper mm^2	0.82 mm^2	1.31 mm^2	2.08 mm^2	3.31 mm^2	5.26 mm^2	8.36 mm^2	13.3 mm^2	21.2 mm^2	26.7 mm^2	33.6 mm^2
with 2 or 3 hot	no spec	no spec	no spec	no spec	no spec	65 amp	87 amp	114 amp	no spec	152 amp
with 3 hot plus neutral	no spec	no spec	no spec	no spec	no spec	52 amp	69 amp	91 amp	no spec	121 amp

W power cord is used in industrial, mining, motor, battery, and generator. 2000 volt rating.

118. There are conflicting prescriptions about how to size the power cord, including NEC, NFPA79, and various UL standards. Should they be sized:

- **100% of rated full load current.**
  - NFPA79 12.8.2 – The continuous current by cords shall not exceed the values given in table 12.8.2.
  - UL61010 (2012) 6.10.1 – Cords shall be rated for the maximum current for the equipment.
- **125% of rated full load continuous current.**
  - NEC 2017 210.19(A)(1): Size 125% of a continuous load and 100% of the incremental peak load. The entire circuit path needs to be over-rated including the circuit breaker, line side

References:
✓ NEC 240.5(B)(2)
✓ NEC table 400.6
✓ NFPA79 table 12.8.2
✓ UL508-25.6.1.2
✓ UL61010-6.10.3

	wires to the disconnect switch, and load side wires to the tool, including plugs and outlets. o NEC 2017 400.5: The important factor is that the load . . . minus the 25% increase for those loads considered to be continuous, supplied by the cable, does not cause the cable to operate at an ampacity greater than that specified in table 310.15(B). o NEC 2020: 210.19 has removed the wording “entire circuit path”. 400.5 has removed the wording “25% increase for loads considered to be continuous”. Apparently, the NEC no longer applies a 125% rule to power cords. o UL508 (2003) 25.6.1.2 – The cord ampacity, as specified in table 25.1, shall not be less than the ampacity required for the equipment. 100% of the ordinary load. 125% of continuous full load for motors and heaters. • **100% of the size of the upstream OCP (circuit breaker).** o NFPA79 7.2.3 Power Circuits – Feeder and branch circuit conductors shall be protected against over-current in accordance with their ampacities as specified in section 12.5. NEC 2020 has clarified some of this contradiction by making a distinction between “appliances” and “industrial equipment”. Appliances can have a “fixture” cord smaller than the outlet rating but industrial equipment cannot. The NEC defines an appliance as *“Utilization equipment, other than industrial, such as a clothes washer, air-conditioning, food mixing, deep frying, and so forth.”* Therefore, the cord must match the outlet.	
119.	The tool full load, feeder circuit breaker, power cord, and plug type should be matched. **Example** of a matched set: 208 VAC 3Φ full load 24 amp, circuit breaker 30 amp, power cord #10/4, and plug L15-30. If there is a mismatch, a CB that is too small might nuisance trip, and a cord that is too small might burn the plug. Matching is important in a large factory with lots of portable pumps and chillers moving around from tool to tool. For a single system, if the plug is oversized, or if it has an unused third hot leg or an unused neutral pin, add a label to the plug stating what the service is. This is a judgment call.	✓ NEMA WD6
120.	Cord wiring has strength requirements. (1) 10 pounds minimum to pull it out of an outlet; (2) 20 pounds minimum to detach the cord from the machine; (3) 35 pounds minimum to detach the plug. Reject old inferior power cords.	✓ UL508
121.	**Computer rooms** can have cables under the floor if: • Floor openings must have grommets. 15 feet max under the floor. • Cords that supply outlets, disconnects, sub-panels, etc (not directly attached to the machine) must be in conduit (plastic ok). • Conductors overrated 1.25x. **Equipment rooms** can also have cables under the floor but typically require sprinklers above and under the floor.	✓ NEC 645.5

Best practice (NEC 2020 update): Industrial equipment does not meet the definition of “appliance” whose “fixture” power cord can plug into a larger circuit. Therefore, judge both the upstream over-current protection and the full load current. In this context, it is common practice to have

- #14/4 SOOW (rated 15 amp) on a 15 or 20 amp circuit (if full load <15 amp)
- #10/4 SOOW (rated 25 amp) on a 30 amp circuit (if full load <25 amp)

- #8/4 SOOW (rated 35 amp) on a 40 amp circuit (if full load <35 amp)
- #6/4 SOOW (rated 45 amp) on a 50 amp circuit (if full load <45 amp).

Example: Flexing can crack the strands. After running full load for a while, run your hand up the power cord towards the plug end. If the plug attachment is worn out, or the cord is too small, you will feel a higher temperature near the plug.

Example: A chiller nameplate states 49.1 amps full load divided across 2x incoming 30 amp circuits with #10/4 SOOW power cords (rated 25 amp). One cord is drawing 10 amps. The cord temperature is the same as the room. The other cord is drawing 31 amps. The cord temperature is 40°C at the plug end (very warm). So respect the cord current ratings. Turns out this was an unanticipated malfunction.

Example: A vacuum pump is known to draw a power-on **surge** current (10 seconds), a **peak** dead-head load current of 20 amps pumping down the air (5 minutes), and a smaller **continuous** load current of 10 amps (>3 hours) holding the vacuum. Except for a **locked rotor**, the pump typically runs its peak for only a short amount of time. Size the cord for OCP and full load, ignore the continuous load.

Example: The pump states 208 VAC 3Φ 16 amp full load. The CB is 208 VAC 3Φ **20 amp**. The cord is #12/4 (ok). The plug is L15-30 (3Φ 30 amp). One thing doesn't match – the plug is too big. No chance of overheated wires. Fix: Add a label to the plug stating, "hook-up 208 VAC 3Φ 20 amp". For future portability, it is better if the plug and outlet are L15-20.

Example: The pump states 208 VAC 3Φ 16 amp full load. The CB is 208 VAC 3Φ **30 amp**. The cord is #12/3. The plug is L15-30. Now two things don't match – the CB is too big and the cord is too small. Fix: Upgrade the cord to #10/3.

Example: A chiller is known to draw a power-on **surge** current (10 seconds), a **peak** load current of 30 amps during heat exchange, and a smaller **continuous** load current of 20 amps (>3 hours) for circulating the water. Size the cord for OCP and full load, ignore the continuous load.

Example: THHN is hardwired inside walls or conduit where there's more of a heat problem. Cords have thick jackets, but the temperature is typically comfortable, and the cords remain visible.

4.10 Preventing oxidation

4.10.1 Ferrules to prevent oxidation

Copper and aluminum can have oxidation. A terminal is only suited for multi wire if: (1) the component data sheet says so and (2) the wires are the same gauge. Instead, crimp the wires together in a ferrule, and then put the ferrule into the terminal. Screw torque must be applied per the spec. Wires must be squeezed without any space for oxidation. Aluminum connections are typically coated with a zinc paste called Noalox (no aluminum oxide).

Electrical fires can be caused by **loose terminals**. **Example:** A portable heater is plugged into a wall outlet. The heater cycles from no load to full load. The wires heat up and cool down, expanding and contracting, over and over. Sometimes the wire becomes loose under the screw, building up oxidation and resistance, leading to a hot spot. Circuit breakers and GFCI will not prevent this. Best practice is: (1) ferrules on stranded wire, (2) torque check, and (3) periodic infrared scan at full load.

4.10.2 Terminal torque to prevent oxidation

The Color Illustrations chapter shows a photo of a burned-up circuit breaker. When a wire has current, it gets hot and expands. When the current goes off, the wire cools and shrinks. If not attached correctly, there could be a gap which allows air and oxidation. Then you get the equivalent of a heating element. Outlets, especially in cubicles, sometimes burn up when the outlets are cycled from full power to off, over and over, especially when people put space heaters under their desk, or coffee pots, etc.

As previously stated in section 3.5.2, a listed part (or assembly) has 3x aspects: (1) Designed by the manufacturer and used according to its rating, cut sheet, data sheet, and installation manual. Rating refers to maximum voltage, current, temperature, pressure, wet and oil location, indoors or outdoors, terminal torque, number of insertions, approved chemistry, duty cycle, etc. (2) Sample tested by an NRTL using a UL standard. (3) Produced on an NRTL supervised manufacturing line.

The wire terminals must be torqued according to their rating – too little torque and there might be a gap for oxidation, too much torque might stress or break the component.

- **City inspector** can inspect during a routine visit, typically not on a weekend or holiday.
- **Third party** field evaluation can inspect with a procedure, a form, detailed photos, and a report.
- **Electrical contractor** can do it and record it with a procedure and a form approved by the city.

122.	Many cities require torque witness for wires larger than a certain size, typically #2 (100 amp) or #3/0 (200 amp). There is no specific prescription except "installed according to the specification". All terminals should be torqued – even an outlet could burn-up.	✓ NEC 110.14 ✓ NEC annex I

The field label evaluation report should include:

- Panel name and location.
- Hot and neutral wire gauge (eg. 500 KCMIL) and the torque. Number of terminals.
- Ground wire gauge (eg. #1/0) and the torque. Number of terminals.
- Determine torque using either the component data sheet or UL486A table 1.3, which is reprinted in the NEC Handbook annex 1. UL486A specifies the following bit torque (inch-pounds):

Hex bit	1/8"	5/32"	3/16"	7/32"	1/4"	5/16"	3/8"	1/2"	9/16"
Torque (IP)	45	100	120	150	200	275	375	500	600

Flat head	1/8"	5/32"	3/16"	7/32"	1/4"	9/32"	5/16"	3/8"	1/2"
Torque (IP)	9	12	12	12	12	15	20	20	20

- Use a nearly new or calibrated torque wrench. Record the brand, model, and serial number.
- After torque, mark the terminals with red Loctite, and take representative photos.

4.11 24 VDC control circuits

Industrial control has been migrating from high voltage (120-240 VAC) to low voltage (24 VDC). There are several reasons for this.

- Philosophy has changed from protecting equipment to protecting people against shock hazard.
- Reduce exposure to hazardous voltage and current.
- Permit non-qualified electrical workers to work on the live controls.
- 24 VDC components (PLC, relays, contactors, motor starters) now have wide availability.
- 24 VDC components are smaller and permit tighter packaging.
- Components operating from a 24 VDC supply are less sensitive to voltage sags and drop-outs.
- AC circuits have line coupled capacitance that increases with the square of the voltage.
- DC power redundancy is relatively simple and does not require a transfer switch.

Reference: "24 VDC Control – An Emerging Alternative to Legacy 120 VAC Control Applications in North America", by John C. Thompson and David B. Durocher, 2002 IEEE IAS conference.

4.12 Wire colors internal to the machine

Do not confuse the wire colors for outside and inside the machine.

Facility wiring outside the machine:

- Wire colors in the US factory are black/red/blue for 208 VAC legs, white for neutral, and green for ground. And brown/orange/yellow for 480 VAC legs, gray for neutral, and green for ground.
- Wire colors in the EU factory are brown/black/gray for 400 VAC legs, blue for neutral, and green-yellow stripe for ground.
- Wire colors in the China factory are yellow/green/red for 400 VAC legs, blue for neutral, and green-yellow stripe for ground.

Wire colors inside the machine (NFPA 79 and IEC 60204 standards) are as follows.

Wiring can be thought of as three categories: power (AC), control (24 VDC), and logic (1-5 VDC). **Power** is a circuit for productive operation (heat, actuation, lighting, power supplies) including transformers. **Control** is the signal that directs the performance of a controller, including monitoring. The controller can be AC or DC. **Logic** is low voltage communication signal.

123.	**AC and DC power** wiring should be **black**, not red. Only the facility can have red for power.	✓ NFPA79-13.2.4.3(1)
124.	**AC control** wiring should be red.	✓ NFPA79-13.2.4.3(2)
125.	**DC control** wiring should be **bright blue.**	✓ NFPA79-13.2.4.3(3)
126.	**AC neutral** (US market) should be **white** (208 VAC), gray (480 VAC), or white stripes on black.	✓ NFPA79-13.2.3.1
127.	**DC neutral** (US market) should be **white with blue stripes.**	✓ NFPA79-13.2.3.2(1)
128.	**AC or DC neutral** (Europe) should be **light blue** if color is the only identification.	✓
129.	**Neutral for international:** make it white with 3 stripes of light blue continuously down the exposed wire, and label it.	✓ IEC 60204 13.2.3
130.	**Ground for international:** green and yellow. Variation permitted from 30-70%.	✓ IEC 60204 13.2.2(c)
131.	**Logic wiring** is typically bundled into cables and harnesses. Any color ok but avoid a reserved color. Note that some thermocouple wires are specifically colored solid green and solid yellow.	✓

Best practice: For non-standard colors, put a color code schedule on the inside of the door panel.

4.13 Button colors

132.	Start button cannot be red. Stop button cannot be green.	✓ NFPA79-10.2.2
133.	Start (or on) and stop (or off) buttons marked with icons: **I** & **O**	✓ IEC60204-10.2.2

4.14 Emergency button

134.	Red actuator on a yellow background. SEMI requires a **legend label** EMO or EMERGENCY (either ok) but the electrical code does not. Semiconductor equipment has multiple emergencies like main power off, gas off, automation jam, plumbing leak, door interlock, etc. Machines sometimes have **color coded** emergency stop buttons including red-on-yellow, blue-on-yellow, yellow-on-yellow, black-on-yellow, etc. Best practice: local signage to clarify the effect of the buttons.	✓ NFPA79-10.7.3 ✓ UL2011-6.2 ✓ SEMI S2-12.3 & 12.4

135.	EMO is for industrial machinery (not appliances and hand tools) with **mechanical** hazards such as jam, motion, pinch point, entrapment, power, fire, leaks, and smoke. See below for code interpretation. For CE: see ISO 12100 and ISO 13850. • Overrides all other functions and operations. • Removes power quickly without causing a hazard. • Resetting will not cause an automatic hazardous restart. SEMI S2 is stricter. "Resetting should not reenergize circuits or equipment". • Hardwired electromechanical. • Red-on-yellow. • Readily accessible. • Near the control console. • Self-latching • Single human action.	✓ NFPA79-9.2.5.4 ✓ SEMI S2-12.2.4
136.	EMO is exempted for machinery 2400 watts or less, or if the hazard is only electrical, or if it gets its power from the main system	✓ SEMI S2-12.1 exception 1 & 2
137.	EMO circuit must be fail safe, acting by direct opening (dropping a voltage), not by closing (asserting a ground). Shunt tripping circuit breakers (ground actuated) should be combined with a safety relay.	✓ NFPA79-10.7.2
138.	Continuously operable. Readily accessible. Near the control console. 10 feet max for operation and routine maintenance (SEMI S2). Accessible from any operating position (UL).	✓ NFPA79-10.7.1 ✓ SEMI S2-12.5.2 ✓ UL2011- 6.1
139.	Mushroom button, foot switch, pull cord, or push bar. A pull-cord must have 3 positions: normal tension (continue), tight (activated & stop), and loose (the cord is broken & stop).	✓ NFPA79-10.7.2.1 ✓ UL2011-6.2
140.	Push button must be self-latching. CE: self-latching is not required.	✓ NFPA79-10.7.2.2 ✓ UL2011-6.2
141.	A red-on-yellow disconnect switch or plug can serve as an EMO.	✓ NFPA79-10.7.4.1
142.	EMO height 21-55 inches.	✓ SEMI S8 (ergonomic, critical controls) 9.1.1
143.	**Gas cabinets and valve manifold boxes (VMBs)** Note: EMO on chemical delivery is common due to the interruption of NFPA 55.	✓ NFPA55 7.3.1
	Emergency shutdown for the following compressed gas types: • If health hazard is 3 or 4 • If fire hazard is 4 • If reactivity is 3 or 4	✓ NFPA55 7.3.1.12.1
	Emergency shutdown method can be one of the following: • Gas leak detection • Constant monitoring and **manual shutdown** by trained personnel • Constant monitoring and automatic remote shutdown • Excess flow valves (with automatic shutdown) at the bulk source	✓ NFPA55 7.3.1.12.2
	Emergency shutoff valves should be located: • At the point of use • At the tank, cylinder, or bulk source • At the point where the piping enters the building	✓ NFPA55 7.3.1.11

Red and yellow emergency buttons cause the most confusion of any topic in this book. Let's start with definitions. An **Emergency Stop** is for stopping **kinetic energy hazards** and applies to machines that move, actuate, and jam, like robots and conveyors, etc. An **Emergency Switching Off** is for turning off **potential energy hazards** such as voltage, pneumatic, hydraulic, corrosive, and toxic gas, high and low temperature. SEMI (not NFPA 79) defines an **Emergency Off (EMO)** as being a combination of both stop and off, originally for application in a clean room where much of the machine is inaccessible to the operator. EMO is now the common term.

A red and yellow device or switch is **more robust than a regular part**. They are often constructed for better reliability and fault tolerance with features like dual contacts, heavy duty contacts, high temperature rating, corrosion resistance, etc.

This is my understanding of how the code books prescribe the emergency button:

- **NEC** – no mention.
- **IFC** – no mention, although generally understood that the EMO should turn-off hazmat gas valves.
- **NFPA 79 9.2.5.3** – the "stop" category is determined by the **risk assessment and functional requirements** of the machine. The EMO requirements direct follow in NFPA 79 9.2.5.4. One could infer that the EMO prescription is also determined by the risk assessment, but some don't agree.
- **UL 73 Motor Operated Appliances (conveyors)** – this is the only UL standard I am aware of that prescribes an EMO.
- **SEMI S2 12.1** – Equipment should have an "emergency off" circuit. The EMO actuator (button) . . .
- **SEMI S2 12.5** – Emergency off buttons should be readily accessible from operating and regularly scheduled maintenance locations.
- **NFPA 55** – Emergency shutdown needed for toxic or flammable gas.

The emergency button is primarily for something broken, pinched, or jammed. **Activation requires well trained human behavior.** During an inspection, I often ask the operators about the hazards and what do they think the emergency button is for. The typical answers are:

- "I push in the button at the **end of the shift** before I go home."
- "I don't know what it is for and I've been **told not to touch it**."

EMO buttons require the operator to observe a hazard and then react to it by pushing the button. Since human behavior can be unpredictable, especially in a panic, my view of this is that they are supplemental to an engineering control. They are primarily for jammed up automation.

Over the course of 20,000 inspections, I have been on site during several "panics". The first response is to exit. The second response is to turn off the power switch or pull the plug.

The emergency button could be used to mitigate electrical shock during firefighting. This is similar to the way a fireman pulls off the meter head to kill power to a burning house before spraying the water. And by the way, future homes will be constructed with a disconnect switch. Semiconductor tools often have a chamber in the clean room and the AC distribution rack in the chase room. If the chamber is burning, pushing any EMO will drop power to the rack and the entire tool, thus mitigating the risk of electrocution when the sprinkler heads go off over the tool.

EMOs are sometimes imported and exported. EMOs on a large machine are sometimes ganged together for convenience. Tradeoff: stop the entire line with one button but waste all of the material.

Example: EMO on an environmental test chamber? Some ESPEC and Wisconsin chambers have emergency buttons, but none of the other major oven brands have it including AES, Despatch, Grieve, Lindberg-BlueM, Yamato, VWR, etc. The EMO has very little benefit on an environmental test chamber (oven). It is an acceptable risk. There is no jam hazard. Smoke is removed by ventilation. A fire would be contained within the sheet metal. The personnel should exit the room.

Example: Can the EMO be recessed (flat on the panel)? Yes. The emergency button should be guarded as necessary to prevent accidental activation (bumping). Normal test of a "single human action" is (1) the heal of the hand or (2) a karate chop, which is why some EMO buttons have shrouds with vertical slots.

For a very simple emergency shut-off, check out the **Woodstock D4151 paddle switch**.

Refer to the color illustrations for a red and yellow emergency button and an on/off switch.

4.15 Guarding and warning labels

144.	Live parts operating >= 50 VAC shall be guarded against accidental contact. Finger probe is defined in NFPA 79 figure 6.2.3. Pointed shaft 12.5 mm diameter by 80 mm long. UL states appropriate mechanical barriers, (light) curtains, or marking (labels). CE says “live” but does not define the voltages.	✓ NFPA79-6.2.3 ✓ UL508-6.17.1 ✓ UL2011-5.1 ✓ UL61010-6.2 (shock) & 7 (mechanical)
145.	Circuit breakers are labeled with their loads. Disconnects, outlets, and power cabinets must be labeled with their “fed from” source of supply.	✓ NEC 408.4
146.	If the disconnect plus the panel interlock does not de-energize all exposed live parts, the disconnect must be labeled with a safety warning: “switch does not turn off the internal UPS”.	✓ NFPA79-5.1.14.4 & 16.2.4
147.	If the disconnect is a plug, the enclosure door must be labeled with a safety warning to remind people to “pull the plug”.	✓ NFPA79-16.2.5
148.	If the disconnect is remote, the enclosure door must be labeled with a safety warning to remind people to “turn off the power before opening the door, and to close the door before turning the power back on”.	✓ NFPA79-16.2.6
149.	If an outlet is not turned off by the main disconnect, label the outlet.	✓ NFPA79-15.1.1(7)
150.	If the CB is less than the outlet rating (NEMA 5-15R = 15 amp, NEMA 5-20R = 20 amp), label the outlet. **Example:** “5 amps max”.	✓ UL508A-59.1
151.	If an **energized** control panel requires examination, adjustment, service, and maintenance, there should be labels for shock hazard (voltage identified) and arc flash (energy identified). From this information, the QEW can determine the shock and flash hazard boundaries and the appropriate PPE.	✓ NEC 110.16 ✓ NFPA79-6.6 ✓ NFPA70E & OSHA ✓ UL508A-55 & 67.4
152.	Fuse holder must be labeled with the replacement fuse value (UL 508A 40.3.4 & 56.1) unless the fuse holder is keyed not to accept a larger rated fuse). UL 61010 5.1.4 has no exemption. Best practice: Post a fuse chart next to fuse holders.	✓ UL508A-40.3.4 ✓ UL61010-5.1.4

Defeated guards and interlocks account for about 25% of all the machine injuries. Guards should be opened only with a key or special tool. If defending against a claim of negligence, the company will not be able to prove “employee willful intent” if the guard was bypassed with commonly available tools. According to the courts, this is considered “reasonably foreseeable misuse”. Source: Schmersal class.

Guarding can be separating and non-separating. A separating guard would be a cover or door panel. A non-separating guard (mat, light curtain, etc.) requires a safe setback, and there is no protection against flying objects. The US set-back distance rule of thumb is 63 inches (1.6 meters) per second, which is a brisk walking speed of 3.6 miles per hour. Europe ISO13855 has more details.

Fixed guards	**Moveable guards**
• Example: fence. • Captive fasteners. No sharp edges. • Opened with tools not commonly available to the operator. • Typically do not have interlocks.	• Example: door. • Captive fasteners. No sharp edges. • Swing, slide, counter balanced, and lift-off. • Typically have safety rated interlocks, and there are many kinds.

Guards and interlocks are less likely to be defeated if: (1) good viewing – for example, black fencing is easier to see through than bright shiny fencing. (2) mounted out of reach or concealed. (3) redundant. (4) permanently attached – for example, one-way screws. (5) hazard warning label at each interlock.

Process locking switch: The door is locked to prevent scrap and lost production.

Guard locking switch: The door is locked to protect people against energy or residual hazards. This guard must stay locked until it is safe to enter. Therefore, the situation may require monitoring such as time delay, motion sensing, pressure, temperature, etc.

Interlock switches have a scoring system of 1-4 to describe how easily they can be defeated. Low scoring interlock switches can be easily bypassed with a screwdriver, coin, tape, string, tie-wrap, screw, magnet, spare key, etc. ISO 14119 provides guidance on the choice of interlock switch.

Switches can be positive break or negative break.

- **Negative break:** When the guard is in place, the normally open switch is pushed closed (against a spring) for operation.
- **Positive break:** When the guard is in place, the normally closed switch is pushed open (against a spring) for operation.

Considerations: welded contacts, insulated contacts, and broken wires. A normally open switch will fail to a safe state if the wire breaks. A normally closed switch will fail to a safe state if the contacts are welded. Therefore, it is best to use a combination of positive and negative breaking switches.

Switch contact life depends on the number of cycles and the percent of rated full load current. Blue arc burning can cause "pitting" on the contacts, which makes them sticky like being welded. On the other hand, ozone can cause a "black oxide" insulation to build up. **Example:** a mechanical switch might be rated 1K cycles at 100% load, 10K cycles at 50% load, and 100K cycles at 10% load. A solid-state relay is much better for frequent on and off. **Example:** Can software cause a fire? Yes. I am aware of a case where a bug in the control software turned a contactor on and off at high speed. The arcing warmed up the contactor to the point that the plastic started to smoke, which triggered the smoke sensor in the tool exhaust.

Mats are used to disable, not to enable. The mat must be secured to the floor and not be easy to reach over. Normal operation is when there is nothing on the mat.

Bumpers are used to avoid a pinch from automatic doors (like an elevator). They can also be used on a moving gantry (like a router table). The equipment must stop instantly to avoid injury.

Two handed controls must prevent one side being tied down and must prevent accidentally leaning on the switch (forearm contact). This switch must be covered and small enough only for a single finger.

Light curtains come with various detection capabilities: (1) single beam (whole body, like when a garage door is closing), (2) leg, (3) arm, (4) hand, and (5) finger. Higher density equals higher cost.

Presence sensing device initiation (PSDI) is a very specific case of automatic restart after an obstruction is cleared.

Safety circuit is a series of hardwired fuses, switches, and control relays arranged for a safe start-up and shutdown. The circuit has three parts: the input sensors, the logic, and the output controls (contactors and valves). The logic can be hard wired (conventional relays) or programmable (PLC). ISO 13849 rates the safety circuits as category 1, 2, 3, 4 depending on the danger, with category 1 being the simplest. A well-designed safety circuit will protect against accidental start-up, short circuit, component failure, ground fault, over speed, over temperature, door violations, fault masking, etc.

Fault masking is the accidental clearing of a fault condition because of dumb sensors wired in series to save money. **Example:** Door "A" is violated but the fault is cleared by cycling door "B".

Guarding?	**or LOTO?**
• Normal routine operation – closed guards • Examples: adding raw material, refilling a tank, cylinder change, machine jam	• Repair and maintenance – open guards • Relieve hazardous energy

	• Prevent unexpected start-up • Example: changing a cutting tool or filter

Example: OSHA states that a tool change is a LOTO maintenance activity (control of hazardous energy) and not routine operation. https://www.osha.gov/laws-regs/standardinterpretations/2002-06-21

Example: Solvent tools sometimes have carbon dioxide fire suppression systems. A full-size cylinder will discharge 50 pounds of freezing gas in 15 seconds. UVIR (ultraviolet infrared) flame detectors can be very touchy. Some can be triggered with a flashlight or laser pointer. Is it ok for a worker to have his head under the discharge nozzle while changing a filter? An accidental discharge would slam the worker and cause injury to eyesight and hearing. A **minimal** approach is to dress like a ninja (head covered, nothing shiny). A **reasonable** approach would use a reliable UVIR detector with an alarm and a 10 second delay to get away. A **conservative** approach would require LOTO on the gas cylinder.

4.16 Lighting, outlets, and ground fault protection (GFCI)

153.	Lighting: 15 amps max. on a separate OCP. CE requires the lighting circuit to have OCP but does not state the size.	✓ NFPA79-7.2.6 & 15.2.3
154.	Lighting: 150 VAC max. (US). 250 VAC max (CE) but 50 VAC recommended. **Best practice:** 24 VDC LED lighting.	✓ NFPA79-15.2.2 ✓ UL508A-27.3.1
155.	Convenience outlet: 125 VAC max and 20 amp max. with a separate OCP not used for other machine circuits. CE requires the outlet circuit to have OCP but does not state the size.	✓ NFPA79-7.2.5 & 15.1 (2, 3, 6) ✓ UL508A-31.5
156.	Convenience outlet: Flip down cover if it is subject to splashing.	✓ NFPA79-15.1.1(8)
157.	Equipment outlet: If >20 amps, should be clipped or twist-and-lock.	✓ UL508A-28.6.5
158.	Outlet: 125 VAC max.	✓ NFPA79-15.1.1(2)
159.	Outlet: When pushing in the plug, ground must make before power. When pulling out the plug, power must break before ground.	✓ NFPA79-13.4.5.3
160.	Outlet: GFCI 5ma protects people using hand tools plugged into convenience outlets. NFPA 79 requires ground fault protection on: (1) wet location outlets, (2) external outlets, (3) internal outlets intended for maintenance, (4) industrial electric water heaters.	✓ NEC 590.6 & 647.7 ✓ NFPA79-15.1.1(1) & 15.1.2 ✓ NFPA 70E (OSHA)
161.	NEC 2017 590.6(B)(2) introduced SPGFCI special purpose ground fault circuit interruptor protection for personnel, intended for wet tools. Wet tools with water heaters and pumps are subject to corrosion. Class C, D, E for power up to 480 VAC. GFEPCI (ground fault equipment protection circuit interrupt) from 6-50ma. SPGFCI (special purpose ground fault circuit interrupt) 20ma with fast tripping. **NEC 2020 has removed this requirement.** NEC 2020 590.6(A) says GFCI not required if faulting the equipment would create a greater hazard.	✓ NEC (2017) 590.7(B)(2) ✓ NEC (2020) 590.6(A) ✓ UL943

There are arc fault circuit breakers and ground fault circuit breakers. Arc fault circuit breakers are relatively new in the US electrical code (residential). They are intended to detect minor short circuits in appliance power cords. However, it is well known that the arc fault CB electronics are very sensitive to LED lighting (Christmas trees) resulting in a lot of nuisance tripping..

5ma leakage is intended to prevent electrocution. These are found in residential wet locations such as kitchen, bathroom, garage, and outdoors. In the US, convenience outlets (on industrial tools) are 5ma ground fault because of the potential for plugging in bad hand tools or bad extension cords. Most factories require their construction contractors to plug their hand tools into GFCI outlets. 5ma ground fault protection is not a requirement in Europe. **Example:** I myself have been shocked on both an old kitchen mixer and an old metal power drill.

30ma leakage is intended to prevent "brown-out" of motors and heaters due to corrosion, for example, outdoor snow melting equipment. 30ma protection will not prevent electrocution. 30ma (or higher) ground fault detection is often installed at the building entrance. **Example:** I am aware of a large wet tool (panel washer) having a drip leak at the bottom. The technician put his finger on the leak and got rolled on the floor (277 VAC to ground).

Ground fault detection can be done two ways. (1) Use an integrated part. (2) Use a current transformer (CT) wrapped around the hot legs and the neutral such that the CT produces zero voltage unless there is an imbalance (current leaking through a ground path). The CT is wired to a safety relay (Banner etc), and the safety relay is wired to the PLC (or directly to a shunt trip main circuit breaker).

Most Japanese tools have a 30ma ground fault main circuit breaker. Maybe half of European tools have this, but not many US made tools.

4.17 Enclosures

162.	Power cabinets should implement one or more of the following three safety features to prevent shock hazard: • Cabinet doors must be interlocked to automatically drop power. • Cabinet doors must have a key or special tool to open. • The interior must be completely guarded and touch-proof. Wire terminations need sleeves. CE is very strict on this.	✓ NFPA79-6.2.3.1
163.	Reasonable accessibility and maintenance. UL requires a hinged door for access to circuit breakers and fuses that require **renewal** in connection with normal operation.	✓ NFPA79-11.2.1 ✓ UL508-6.4.2 ✓ UL508A-18.4
164.	Adequate clearance front and back, and for the doors to swing open. US: >90° opening. If >150 VAC line-to-ground (400 or 480 VAC L-L), 3.0' to a non-conducting wall, 3.5' to a grounded surface, 4.0' to exposed live parts. CE: >95° opening, 1-1.5 meters.	✓ NFPA79-11.4, 11.5 & table 11.5.1.1 ✓ UL508A-63.2.7 & 66.1.3
165.	NEMA rated type 1 or better. 19-gauge (0.045") minimum per UL. 17 gauge is more typical. NEMA type 1= indoor use, 2= drip tight, 3= rain and dust tight, 3R= rain proof, 4= watertight, 4X= corrosion resistant. Make sure the enclosure is suitable. Reject the "home brew" boxes without adequate strength and guarding. CE: "adequate" protection. **Example:** a box outdoors near the San Francisco Bay needs to be rated 4X due to salty moisture.	✓ NEC 110.28 ✓ NFPA79-11.3.2 ✓ UL508 section 6 table 6.1. ✓ UL508A-8 & 63.1.2 ✓ IEC 60529 ✓ NEMA 250-2003
166.	No burrs or sharp edges. Wiring holes should have a smooth bushing (strain relief or edge guard) to prevent abrasion.	✓ NFPA79-11.4.4 ✓ UL508-21.2.1 ✓ UL508A-11, 28.5.3, & 29.4 ✓ UL61010-6.10.2
167.	Top holes and vents should be guarded to prevent a screw or paper clip from falling down inside and causing a short circuit.	✓ UL508A-21.2.1
168.	Door panels and fan openings must provide fire containment. Holes <=2 mm. Ventilation holes >2 mm. should be guarded with a fan and filter.	✓ NEC and NEMA ✓ UL508A-26.5 ✓ UL61010-9.3
169.	The enclosure bottom can be open only if the bottom is < 6 inches off the floor and if exposed live parts are > 6" above the bottom. The enclosure should reduce the risk of unintentional contact (UL508). Metal flame baffle if necessary (UL61010).	✓ NEC ✓ NFPA79-11.4.10 ✓ UL508 ✓ UL508A-19.5 ✓ UL61010-9.3
170.	Door panels should have captive screws, latches, and fasteners.	✓ NFPA79-11.4.6 ✓ UL508A-63.2 ✓ UL61010-6.9.1

<table>
<tr><td>171.</td><td>Window glass:
If an electrical panel has window glass, it must be smaller than 12" x 12" or it must be UL 746C listed (wire in the glass). In this case, the wired window glass is trying to contain the blast from going into the room. UL 746C likely applies to fire doors, etc. like you see in a school or hospital.
Fume hoods (UL 1805) typically use tempered glass (no wire) with fire rated caulking. In this case, the tempered glass is trying to prevent the interior lights from being a source of ignition.</td><td>✓ UL508-6.12</td></tr>
<tr><td>172.</td><td>Schematic diagram is specified on the nameplate and kept in a “well identified location” which could be a print pocket, CD, PC, bookshelf, or document control library. CE has no requirement.</td><td>✓ NFPA79-11.4.8</td></tr>
<tr><td>173.</td><td><table><tr><td>Maximum surface temperature</td><td>Metal</td><td>Plastic</td></tr><tr><td>Handles for lifting</td><td>50°C</td><td>60°C</td></tr><tr><td>Knobs and handles</td><td>60°C</td><td>85°C</td></tr><tr><td>Accidental contact</td><td>70°C</td><td>95°C</td></tr></table></td><td>✓ UL2011-13.3
✓ SEMI S2 18.8 table 1</td></tr>
<tr><td>174.</td><td>No plumbing (air, gas, liquids) in the electrical panel unless separated by suitable barriers. This originates from hydraulic fluid. Air plumbing is common practice and there is no UL requirement, however, some inspection agencies would reject it.</td><td>✓ NFPA79-11.2.2.2</td></tr>
</table>

4.18 Heated chemical baths

175.	Heaters must have UL 499 listing.	✓ UL508A-26.4.1
176.	Heaters must have automatic shut-off for high temperature.	✓ IFC (fire code)
177.	Heaters must have automatic shut-off for low level or dry.	✓ IFC (fire code)

4.19 Gas leak detectors

<table>
<tr><td>178.</td><td>Some jurisdictions now require listing or field label on the gas detector, with evaluation according to the appropriate standards:
UL2075 for gas detectors,
UL864 for fire alarm panels, and
UL2017 for general purpose signaling devices and systems (non-fire life safety). The IFC citation incorrectly refers to UL 864 for toxic gas detection. UL2017 is more relevant because toxic gas leaks are generally not tied to the fire alarm.</td><td>✓ IFC 6004.2.2.10.1
✓ UL864
✓ UL2017
✓ UL2075</td></tr>
<tr><td>179.</td><td>Oxygen detectors might be required in small rooms with nitrogen gas plumbing. Normal air is 21% oxygen. Confined space detectors are set to 19.5%. Cryogenic nitrogen has more asphyxiation hazard than compressed nitrogen.</td><td>✓ OSHA 1910.146
✓ Cal/OSHA 5158</td></tr>
</table>

4.20 ANSI B11 machine tools and power presses

Machine shop tools have their own standard called ANSI B11. Many FEBs ignore these requirements during the field label construction review. However, there is prescription with both federal OSHA (CFR 1910.212) and Cal-OSHA (article 55 for power presses, 30 sections, 26 pages).

http://www.dir.ca.gov/title8/sb7g8a55.html

Example: With two handed controls for a single stroke, each hand controller shall be protected against unintended operation. To activate, both hands must let go and then both hands must push at the same time. In other words, one button cannot be taped down.

4.21 Testing

180.	**Ground bond.** <0.1 Ω equivalent to 63 feet of #12 wire. See next section "ground bond testing and troubleshooting".	✓ NFPA79-18.2
181.	**Outlet ground:** Grounding must be verified.	✓ NFPA79-15.1.1(5)
182.	**Ground leakage.** UL499 for heating appliances has a test that requires taping a conductive sheet to the chassis. Not practical in the field.	✓ UL499
183.	**Insulation resistance.** Equivalent to a 500 VDC hi-pot test. See next section.	✓ NFPA79-18.3
184.	**Dielectric withstand (AKA hi-pot or Megger).** Different voltages are prescribed in the various standards. • Traditional: 2x line voltage • NFPA79: 1500 VAC or 2121 VDC • IEC60204: 1000 V • UL508: 1000 plus 2x line voltage for **uninsulated** live parts. • UL61010: test voltage depends on clearance. Hi-pot is optional on insulated parts. Avoid going higher than the rating. **Example:** Fuji CB = 690 VAC. Components previously tested (UL listed) do not need to be retested. See next section.	✓ NFPA79-18.4 ✓ UL508-49.1.1 ✓ UL61010-6.8.3 ✓ UL2011-14 ✓ SEMI S9
185.	**Temperature.** Make sure components do not exceed their ambient rating. Typicall, 40C. Three successive readings at 10 minute intervals.	✓ NFPA79-A.3.3.7 ✓ UL508-43.25 ✓ UL2011-13
186.	**Safety devices.** EMOs, interlocks, light curtains, GFCI, detectors, etc.	✓ NFPA79-18.6 ✓ UL508A-79.2 ✓ UL61010-4.4.2.13 ✓ UL 2011-19
187.	**Single phasing** (if 2 or 3 hot legs). (1) Turn on full load and then disconnect one leg (smallest current). (2) Turn-off and turn back on again with one leg disconnected (one-by-one). Due to the potential for shock hazard and equipment damage, this test is not practical in the field. **Best practice:** equipment has voltage sensing that drops out the contactor.	✓ UL2011-15
188.	**Fan jam.** No risk of fire or electric shock. Not practical in the field.	✓ UL2011-16
189.	**Filter block.** No risk of fire or electric shock. Not practical in the field.	✓ UL2011-17
190.	**Motor jam.** Only the fuse should be damaged. No risk of fire or electric shock. Not practical in the field.	✓ UL2011-18

4.21.1 Hi-pot testing and troubleshooting

For testing called out in NFPA 79 18.3 (IR) and 18.4 (hi-pot), all machine power conductors (hots and neutral) are disconnected from the main power and connected to the hi-pot tester voltage lead. The machine ground bus bar is connected to the hi-pot tester ground.

First test – insulation resistance (IR): 500 VDC, resistance upper limit set to unlimited (typically zero), resistance lower limit set to 1 megohm, and 10 second dwell.

Second test – high potential dielectric withstand (hi-pot): 1500 VAC, 12 mA maximum leakage current, 30 second ramp-up, and 1 second dwell.

- Problem: NFPA 79 handbook (2015) page 144 prescribes hi-pot "only required where deemed necessary . . . components and machines can be severely damaged". NFPA 79 18.4 states "components that are not rated to withstand the test voltage shall be disconnected during testing". Since most construction wire is rated 600 VAC, and Fuji CBs are rated 690 VAC, hi-pot is typically not prescribed, which points to an apparent contradiction in the code. In addition, UL listed components have already had their testing done in their manufacturing facility and don't require hi-pot retesting. Note: An article I read states that the hi-pot test comes first and the IR test second, because the IR is used to confirm if the hi-pot did any damage.
- Problem: Some parts are normally disconnected from the tester. Solution: Turn on the tool circuit breakers and push in the contactor. Otherwise move the leads around and repeat.
- Problem: Equipment has neutral wired to ground. The only case for this is an isolation transformer that has one leg of the secondary bonded to ground. An isolation transformer is a special case that has enough wiring resistance to withstand a hi-pot and not break down internally. Solution: Hi-pot with the hot lead connected to both the power conductors and the neutral. If it fails, check the ground bus for white neutrals and check the neutral bus for green grounds. If it looks ok, pull off all the wires and make sure the two bus bars are not bonded together.
- Problem: Hi-pot current going back through the loads, then through the neutral all the way back to the ground in the panel. Solution: Disconnect the neutral between the tool and the panel board.
- Problem: Within the tool, sometimes the equipment ground is used to complete a circuit. See this with transformers. Solution: add a neutral.
- Problem: Power conditioning filters. Solution: Look at the schematic and then disable or remove any power conditioning filters. Or retest with DC, not AC. Sometimes DC will also fail.
- Problem: Most power strips (and some machines) have voltage spike protectors constructed of metal oxide varistors (MOV). See example at RK Electronics www.rke.com. They typically clamp at 3x the line voltage, AC or DC. They are often outside of the circuit breaker. Solution: On the machine, you can often shut off the CB and hi-pot on the inside or pull off the filter. Retest accessories one-by-one after they have been disconnected from the power strip.
- Problem: Relay sockets and distribution buses shorting to sheet metal. Solution: Insulate the sockets and buses with kapton tape or RTV.
- Problem: Toggle switches and lamp sockets sometimes break down due to age and high heat soldering. Solution: Replace with heavy duty switches and lamp sockets. Troubleshooting tip for old panels: After discussions with the customer, progressively turn up the current limit to 20 ma, turn off the room lights, and look for the arc flash, the popping sound, or the smoke.
- Problem: Damaged wire insulation due to age, bending radius too tight, or cable ties too tight. Solution: Cut the bundles loose. Add some insulation tape.
- Problem: Dust, solder balls, wire whiskers, nuts, washers, and other debris in the box causing arc flash. It goes all at once and typically at a high voltage. Solution: Vacuum or blow out the box.
- Problem: Sometimes a non-UL listed power supply has the circuit board power traces directly over the ground plane. A thousand volts will punch right through the fiberglass. The board is destroyed. Solution: Do not test hi-pot on power supplies or circuit boards.
- Problem: Cheap test leads are laid across a conductive floor or panel. Solution: Isolate the leads.
- Problem: GFEPCI circuit breaker monitors the current going out on a conductor and returning on a neutral or another conductor. Usually, they pop at 35mA but sometimes they pop as low as 5 mA. Solution: Connect on the tool side of the GFEPCI.
- Problem: Hi-pot tester is programmed for too low current. Solution: Double check the hi-pot tester to make sure it is set for 12 mA, not 1.2 mA or 0.12 mA maximum. Power cord capacitance gives you ~5 mA leakage.

Example: At a semiconductor fab in Silicon Valley, large wires were pulled through a conduit. The tool was hooked up and run for a few weeks, then the circuit breaker tripped. No cause was found. The circuit breaker was reset. After a few days, the CB tripped again, this time with smoke detected in the fab. The wires were pulled out of the conduit. A short section of the wiring had been sliced, shorted, and charred. The electrician should "Megger" his power wires after they are pulled in because this is the only way to check for a jacket that has been ripped open by a metal burr.

4.21.2 Ground bond testing and troubleshooting

Ground bond should be < 0.1 ohms, equivalent to **63 feet of #12 wire**. The ground within the machine is a much larger gauge and a shorter length. Therefore 0.1 ohms is practically irrelevant. Ground bond is difficult to test in the field because you have to bias off the leads and clips which can be 0.5 ohms. It's simpler to validate the grounding with construction review and with a conventional Fluke ohm-meter. Don't fight with the leads. **Concentrate on workmanship**. Make sure the ground wires are properly sized and screwed down tight.

Alternative view: In the event of a voltage fault to the chassis, the ground must be good enough to carry **double the OCP current for at least one minute**, because that is approximately how long it takes to trip open a circuit breaker. The wiring itself contributes a substantial heat sink to the circuit breaker.

Third test – ground conductivity (bond): move the leads on the hi-pot tester, set current = 100mADC, Rmin zero, **Rmax 0.1 ohms**, and 1 second test. Repeat the test on different metal surfaces.

Problem: Ground conductivity test is failing with the leads connected or passing with the leads disconnected. Solution: The resistance of the lead pair (typically 0.5 ohms) must be "zeroed out." But if you calibrate with the leads open, the tester will think there is an infinite bias and will then always pass. Procedure (Vitrek V4):

1. Connect the two ground conductivity leads together and include any extension wire.
2. From menu, select a ground conductivity test.
3. Hit the "utility" button.
4. Scroll three positions clockwise "calibration".
5. Hit "edit/save".
6. Hit "start"

5 Explosion Proof and Gases

5.1 Introduction to semiconductor gases and liquids

A semiconductor fabrication factory (fab) has many types of gas chemistry:

- **Inert gas** has a low chance of reaction with materials and corrosion of equipment. **Examples:** argon, helium, krypton, neon, and nitrogen.
- **Flammable gas** will burn if ignited. Cabinets must have fire suppression and sometimes have gas leak detectors. **Examples:** hydrogen, methane, and propane.
- **Pyrophoric gas** will burn in normal air without ignition. Lines must be purged before they are opened.
- **Silane** is an explosive pyrophoric gas with special requirements in the IFC and CGA G-13. Silane is especially dangerous because it can sometimes accumulate and then explode. CGA (Compressed Gas Association) standard G-13 requires 300:1 exhaust air dilution. A worst-case release depends on cylinder size, gas pressure, concentration, how full it is, and the size of the restricted flow orifice (RFO). Exhaust rates are calculated case-by-case. A standard gas cabinet design might not have enough exhaust for an application of high demand (large RFO) and long distance (high pressure). Bottle changes are very delicate because if air is introduced to the line, the silane will "dust the line" and ruin the wafers.
- **Toxic gas** will cause injury if absorbed or inhaled. Cabinets must have gas leak detectors. Many toxic gases can also be reactive, flammable, and pyrophoric. **Examples**: arsine and phosphine.
- **Corrosive gas** will cause injury upon contact, and can damage incompatible materials, especially in the presence of moisture. **Examples:** chlorine, fluorine, hydrogen bromide, hydrochloric, hydrofluoric, and silicon chloride.
- **Liquified gases** are liquid in the ampoule or cylinder and must be warmed up to create enough vapor pressure for delivery. Bottles have heated jackets. Lines have heat trace. If the temperatures are not maintained, the gas can condense (return to a liquid) in the line, which can cause corrosion. Purge is complicated because the introduction of nitrogen can cool the gas back to liquid. **Example:** ammonia requires the most heat.

Particulates must be filtered to prevent valve leakage and regulator creep (due to incorrect pressure differential).

A semiconductor fabrication factory (fab) has many types of liquid chemistry.

- **Non-flammable** liquids consumed in the process are known as operational chemistry.
- **Flammable** liquids consumed in the process are also known as operational chemistry. Examples: 4MS, 3DMAS, 4DMAS, BCHD, BTBAS, DEMS, DIPAS, DMPS, HMDSO, MDEOS, N-ZERO, pyridine, SAM24, SPARTA, TEB, TEOS, TEPO, TiCl4 (tickle), TMB, TMCTS, TMPI, and TMPO.
- **Pyrophoric** will burn without ignition. Examples: 3Si, DEZ, DMAH, DMEAA, TMA, TMAA, and TMG.
- **Solvents** are used to dissolve and carry away other chemicals. Solvents can be flammable, non-flammable, toxic, and corrosive. Solvent waste is collected and recycled. Examples: acetone, isopropyl, and Simple Green.
- **Corrosive liquid** in some cases (not hydrofluoric) can be pH neutralized and dumped down the sewer. Hydrofluoric and corrosive (with metal) must be collected and recycled same as solvent.
- **Exothermic** describes a release of thermal energy such as when something burns. Reactions can sometimes cause a gel plug in the waste pipe.
- **Endothermic** describes an absorption of thermal energy such as a tree producing wood.

MSDS summary

1. Common name (example: water) with typical concentration
2. Formula (example: H_2O)
3. CAS number (example: 7732-18-5)
4. Characteristics: C=corrosive, T=toxic, O=oxidizer, S=solvent, F=flammable, P=pyrophoric
5. NFPA 704 rating for H=health, F=fire, I=instability/reactivity (oxidizer) have some variations.

Name (operational solvents)	Formula	CAS	C	T	O	S	F	P	H	F	I
ABACUS • Pyraclostrobin 6% • Epoxiconazole 6% • Naptha <15% • Oxirane, Methyl <15% • Propane 1, 2-diol <5% • Polyethylene plycol <5%		 175013-18-0 133855-98-8 64742-94-5 none 91-20-3 25322-68-3		T		S	F				
Acetone	CH_3-CO-CH_3	67-64-1				S	F		1	3	0
AHEAD ruthenium tricarbonyl	$Si_2(NH_2C_5)_6$	532980-53-3	C			S	F				
Ammonia hydroxide 29%	NH_4OH	1336-21-6	C	T		S			3	1	0
CHORUS	$C_{10}H_{10}O_3Ru$	1015477-86-7		T		S	F				
CupraSelect	$C_{10}H_{13}CuF_6O_2Si$	139566-53-3 14781-45-4		T		S			1	0	0
Cyclohexanone	$C_6H_{10}O$	108-94-1				S	F		1	2	0
Dimethylamine	$C_4H_{11}N$	598-56-1		T		S	F		3	4	0
Dimethylaminoethanol	$C_4H_{11}NO$	108-01-1		T		S	F		3	2	0
Ethyl alcohol	C_2H_6O	64-17-5		T		S	F		2	3	0
HTB hafnium (IV) tert-butoxide	$HF[OC(CH_3)_3]_4$	2172-02-3		T	O	S			1	0	0
HyALD tris (dimethylamino) cyclopentadienyl Hafnium		proprietary		T	O	S	F				
PET tantalum pentaethoxytantalum	$Ta(OC_2H_5)_5$	6074-84-6	C		O	S	F		1	3	0
PET tanaalum(V) ethoxide 90% ethanol	$Ta(OC_2H_5)_5$	6074-84-6 64-17-5				S			1	3	0
Propanol	C_2H_8O	67-63-0				S	F		1	3	0
Tris (2,4-octanedionato)3 ruthenium	$Ru(OD)_3$					S					
Bis (ethylcyclopentadienyl) ruthenium II	$Ru(EtCp)_2$ $Ru(C_5H_4C_2H_5)_2$ or $C_{14}H_{18}Ru$	32992-96-4		T		S			2	0	0
Star Ti pentamethylcyclopentadienyl titanium trimethoxide	$[C_5(CH_3)_5]Ti(OCH_3)_3$ $Ti(CpMe_3)(OMe)_3$	123927-75-3				S					
Stoddard solvent		8052-41-3		T		S	F		2	2	0
TAT-DMAE tantalum tetraaethoxy dimethylaminoethoxide	$C1_2H_{30}NO_5Ta$	172901-22-3	C			S					
TBTDEN tertbutylimido) tris (dirthylamido) niobium	$[(CH_3)_6N]_3NbN(CH_3)_3$	210363-27-2		T		S	F		2	3	1
TBTDET (tert-butylimino) tris (diethylamino) tantalum	$C_{16}H_{39}N_4Ta$	169896-41-7				S			1	0	0
TDEAA tris (diethylamino) aluminium	$C_{32}H_{80}Al_2N_6$	352546-72-6				S					
TDEAH hafnium tetrakis (diethylamido)	$Hf[N(C_2H_5)_2]_4$	19824-55-6	C	T		S	F		2	3	1
TDEAT tetrakis (diethylamino) titanium	$Ti[N(C_2H_5)_2]_4$ or $C_{16}H_{40}N_4Ti$	4419-47-0	C	T		S	F		3	0	2
TDEAZ tetrakis (diethylamino) zirconium	$C_{16}H_{40}N_4Zr$	13801-49-5	C	T		S	F		3	0	2
TDMAH tetrakis (dimethylamido) hafnium	$[(CH_3)_2N]_4Hf$ or $C_8H_{24}HfN_4$	19782-68-4	C	T		S	F		3	0	2
TDMAT tetrakis (dimethylamido) titanium	$C_8H_{24}N_4Ti$	3275-24-9	C	T		S	F		3	3	2
TEMAZ zirconium tetrakis (dimethylamide)	$C_8H_{24}N_4Zr$	19756-04-8	C	T		S	F		3	0	2
TEMAH Tetrakis (ethylmethylamino) hafnium (IV)	$C_{12}H_{32}HFN_4$	352535-01-4	C			S	F		2	3	1
TEMAS tetrakis (ethylmethylamino) silane	$[(CH_3)_2N]_3SiH$	15112-89-7	C	T		S	F		3	0	2

Name (operational solvents)	Formula	CAS	C	T	O	S	F	P	H	F	I
TEMAT tetrakis (ethylmethylamino) titanium	$C_{12}H_{32}N_4Ti$	308103-54-0	C			S	F		4	4	2
TEMAZ tetrakis (ethylmethylamino) zirconium(IV)	$C_{12}H_{32}N_4Zr$	175923-04-3	C			S	F		3	2	0
TiPT tetraisopropoxytitanium	$Ti[OCH(CH_3)_2]_4$	546-68-9				S	F		1	3	0
TMPO trimethyl phosphate	$C_3H_9O_4P$	512-56-1		T		S	F				
TORUS • Ruthenium oxide .4-1.6% • Ethyl solvent mixture10-90% • Methyl solvent mix 10-90%		 20427-56-9 Proprietary Proprietary				S	F		0	3	0
Tert-Butoxyzirconium	$Zr(OC(CH_3)_3]_4)_4$	2081-12-1				S	F		1	0	0
ZyALD Tris (dimethylamino) Cyclopentadienyl Zirconium	$(C_5H_5)Zr[N(CH_3)_2]_3$ or $C_{11}H_{23}N_3Zr$	33271-88-4	C			S	F		3	2	1

Name (decommissioning solvents)	Formula	CAS	C	T	O	S	F	P	H	F	I
Ethanol	C_2H_5OH	64-17-5				S	F		2	3	1
Hexane	C_6H_{14}	110-54-3				S	F		2	3	0
Cyclohexane	C_6H_{12}	110-82-7		T		S	F		2	3	0
Octane	C_8H_{18}	111-65-9		T		S	F		2	3	0

Name (flammable)	Formula	CAS	C	T	O	S	F	P	H	F	I
4MS tetramethylsilane	$(CH_3)_4Si.$	75-76-3					F		0	4	0
3DMAS or triDMAS) tris (dimethylamido) silane	$C_6H_{19}N_3Si$	15112-89-7	C	T			F		3	0	2
4DMAS or tDMAS octamethylsilancetetramine	$C_8H_{24}N_4Si$	1624-01-7		T			F				
ATER (mixture) • alpha-mentha 90% • cineole 0-6% • p-cymene 0-4% • alpha-phellandrene 0-3%		 99-86-5 470-82-6 99-87-6 99-83-2		T			F		2	2	0
BCHD bicyclo 2.2.1-hepta-2,5-diene	C_7H_8	121-46-0					F				
BTBAS bis(terbutylamino)-silane	$C_8H_{22}N_2Si$	186598-40-3	C				F		4	4	2
Butyl acetate	$CH_3COO(CH_2)\ CH_3$	123-86-4					F		1	3	0
DEMS diethoxy-methyl-silane	$C_5H_{14}O_2Si$	2031-62-1					F				
DIPAS LTO520 • diisopropylaminosilane >95% • mdethanol <0.5%	$C_6H_{17}NSi$	908831-34-5 67-56-1	C				F				
DMDMOS dimethyldimethoxysilane	$C_4H_{12}O_2Si$	1112-39-6					F		2	4	1
DMPS dimethylphenylsilane	$C_6H_{12}Si$	776-77-8		T			F				
Ethylamine	$C_2H_5NH_2$	75-04-7					F				
HCDS hexachlorodisilane	Si_2Cl_6	13465-77-5	C				F		3	0	0
HMDSO hexamethyldisiloxane	$C_6H_{18}Osi_2$	107-46-0					F		1	3	0
Hydrogen	H_2	1333-74-0					F		0	4	0
MDEOS methyldiethoxysilane	$C_5H_{14}O_2Si$	2031-62-1					F				
Methane	CH_4	74-82-8					F		1	4	0
OMCTS octamethylcyclo-tetrasiloxane	$[(CH3)_2SiO]_4$	556-67-2		T			F		1	2	0
ORTHRUS diisopropylaminotrisilylamine		1632368-54-7									
N-Zero				T			F				
P-41 (mixture) halosilane	proprietary	proprietary	C				F				
Propylene glycol monomethyl ether acetate	$C_6H_{12}O_3$	108-65-6					F		1	2	0
Pyridine	C_5H_5N	110-86-1					F		2	3	0
SAM24 bis (diethylamino) silane / Silane diamine tetra ethyl	$C_8H_{22}N_2Si$	27804-64-4					F		1	4	3
SK7											

Name (flammable)	Formula	CAS	C	T	O	S	F	P	H	F	I
SPARTA 1-(trimethylsilyl) pyrrolidine	$C_7H_{17}NSi$	15097-49-1	C				F				
TEB triethoxyborate	$C_6H_{15}BO_3$	150-46-9					F				
TEOS tetraethylorthosilicate	$C_8H_{20}O_4Si$	78-10-4		T			F		2	2	1
TEPO triethylphosphate	$C_6H_{15}O_4P$	78-40-0		T			F		2	1	0
Titanium tetrachloride (tickle)	$TiCl_4$	7550-45-0	C	T			F		3	0	2
TMB trimethylborate	$C_3H_9BO_3$	121-43-7		T			F		3	3	1
TMCTS tetrametylcyclotetrasiloxane	$C_4H_{16}O_4Si_4$.	2370-88-9					F				
TMPI trimethylphosphite	$C_3H_9O_3P$	121-45-9		T			F		3	3	2
TMPO trimethylphosphate	$C_3H_9O_4P$	512-56-1		T			F		2	1	0
Trans-DCE trans-dichlorethylene	$C_2H_2Cl_2$	156-60-5		T			F		2	3	2

Name (pyrophoric)	Formula	CAS	C	T	O	S	F	P	H	F	I
4Si • n-Tetrasilane 75-90% • Isotetrasilane 10-25%	Si_4H_{10}	 7783-29-1 13597-87-0					F	P	0	4	1
Tetrasilane 100%	Si_4H_{10}	7783-29-1					F	P	0	4	1
DEAC diethylaluminium chloride	$(C_2H_5)_2AlCl$	96-10-6	C	T			F	P	3	4	3
DEZ diethylzinc	$(C_2H_5)_2Z_n$	557-20-0	C				F	P	3	4	2
DMAH dimethylaluminum hydride	$(CH_3)_2AlH$	865-37-2	C	T			F	P			
DMEAA dimethylethylamine alane	$C_2H_5N(CH_3)_2AlH_3$	124330-23-0	C	T			F		3	3	3
Silane	SiH_4	7803-62-5	C	T			F	P	4	5	3
TMA trimethylaluminum	$Al(CH_3)_3$	75-24-1	C	T			F	P	3	4	2
TMAA trimethylamine alane	$C_3H_{12}AlN$	16842-00-5	C				F	P	4	4	2
TMGa trimethylgallium	C_3H_9Ga	1445-79-0	C	T			F	P	2	4	2
Trisilylamine	Si_3H_9N	13862-16-3		T			F	P	2	4	3

Name (primarily health related)	Formula	CAS	C	T	O	S	F	P	H	F	R
Acetic (glacial acetic) acid 100%	$C_2H_4O_2$	64-19-7	C						3	2	0
Ammonia	NH_3	7784-41-7	C	T			F		3	1	0
Ammonium hydroxide	NH_4OH	1336-21-6	C						3	0	0
Ascorbic acid	$C_6H_8O_6$	50-81-7	C						1	1	0
B9003 polishing slurry		1344-28-1	C						1	0	0
BLU20-ELM H_2O_2 19%	H_2O_2	7722-84-1	C	T					3	0	1
Cabot 600Y75	AlO	1344-28-1							1	0	0
Copper sulfate pentahydrate	$CuSO_4.5H_2O$	7758-99-8		T					2	0	0
Hydrochloric acid 37%	HCl	7647-01-0	C	T					3	0	1
Hydrogen peroxide 30%	H_2O_2	7722-84-1	C	T	O				3	0	1
Hydrofluoric acid 35-50%	HF	7664-39-3	C	T					4	0	1
Nitric acid 70%	HNO_3	7697-37-2	C	T	O				4	0	0
Nitrogen liquid	N_2	7727-37-9		T					3	0	0
Nitrogen trifluoride	NF_3	7783-54-2							1	0	0
Phosphine	PH_3	7803-51-2		T			F		4	4	2
Phosphoric acid 80%	H_3PO_4	7664-38-4	C	T					3	0	0
Polyethylene glycol	$(C_2H_4O)\ n.H_2O$	25322-68-3							0	1	0
Potassium carbonate 47%	K_2CO_3	584-08-7	C						2	0	1
Potassium hydroxide solution 10-45%	KOH	1310-58-3	C	T					3	0	1
Sodium bisulfite 38%	$NaHSO_3$	7631-90-5		T					2	0	2
Sodium hypochlorite solution	NaOCl	7681-52-9	C	T					3	0	1
Sodium hydroxide 50%	NaOH	1310-73-2	C	T					3	0	1
Stannous chloride	$SnCl_2.2H_2O$	10025-69-1		T					3	0	1
Sulfuric acid 50% (3-0-2)	H_2SO_4	7664-93-9	C	T					3	0	1
Tetrahydrofuran	C_4H_8O	109-99-9		T			F		2	3	1
TMAH Tetramethylammonium hydroxide	$C_4H_{12}N.HO$	75-59-2		T					3	0	0
Tetramethyldisiloxane	$C_4H_{14}OSi_2$	3277-26-7					F		1	4	0

Name (primarily health related)	Formula	CAS	C	T	O	S	F	P	H	F	R
Texture A • Sodium hydroxide (NaOH) 0.2-.5% • Sodium benzoate 0.4-0.8% • Ascorbic acid 0.5-1% • Citric acid 2-3% • Hydrolytic polymaleic anhydride 2-4% • Urea <4%		 1310-73-2 532-32-1 50-81-7 77-92-9 26099-09-2 57-13-6 7732-18-5	C	T					3	0	1
Thiourea ISBC		none		T	O				3	1	0
Trimethyl phosphite	$C_3H_9O_3P$	121-45-9		T			F		3	3	2

Name (inert or non-hazmat)	Formula	CAS	C	T	O	S	F	P	H	F	R
Argon	Ar	7440-37-1							1	0	0
Nitrogen gas	N_2	7727-37-9							1	0	0
Nitrous oxide	N_2O	10024-97-2							1	0	0
Oxygen	O_2	7782-44-7			O				0	0	0
Water	H_2O	7732-18-5				S			0	0	0

5.2 Fire detection and suppression

For tools with flammable liquid, the choice of fire detection and suppression can be confusing. Some jurisdictions need overhead sprinklers, some need interior sprinklers (if the overhead sprinklers are blocked), some need FM4910 rated plastic, some need UV/IR detectors, some need VESDA early warning smoke detectors, and some need full carbon dioxide discharge. NFPA 49 provides fire suppression guidance on when to use water, foam, carbon dioxide, etc. There are a few cases where water is not a good choice:

- Light weight flammable liquid (flash points below 38°C) should use carbon dioxide because the water might spread the fire around the room. **Examples:** Acetone, isopropyl, and glacial acetic acid.
- A chemical that reacts violently with water.
- A chemical that would decompose into hazmat byproducts, making a mess to clean up.

In a factory, the fire code determines the allowable quantity of hazardous production materials (HPM) and the necessary fire protection.

In a tool, the **fire risk assessment determines how much isopropyl (or acetone) requires carbon dioxide.** Engineered fire protection is available from KFPI, Kidde, and others. Factors include:

- The maximum leak due to a spill or rupture.
- Other mitigation such as class 1 div 2 construction, air dilution, gas leak detection in the exhaust, liquid leak detection on the containment floor.
- Fire detection: Smoke detection, UV/IR flame detection, or a temperature switch.
- Fire suppression (gas or liquid): water, carbon dioxide, halon, foam, typically with a damper in the exhaust duct.
- Fire suppression (lithium): sand.
- Fire suppression (pyrophoric): Nitrogen quenching, typically with a damper in the exhaust duct.
- CGA standard G-13 requires silane gas cabinets to have UV/IR fire detectors. Often there is cardboard over the window. This prevents room light flashes from triggering a false alarm.

If the tool is in a chemical room with a potential for a large leak, does the tool need to be constructed as class 1 div 2 to prevent the tool from being a source of ignition? Do the cabinet penetrations (switches, buttons, lamps, meters, screens, etc.) need to be Ex rated? The prevailing opinion is yes in Europe but no in the US.

5.3 Chemical PPE (personal protective equipment) notes:

- PPE can be area specific (glasses, ear plugs, hard hat) or task specific (gloves, respirator).
- Cryogenic is a boiling temperature < -150°C. Cryogenic can cause frostbite.
- Pyrophoric spontaneously ignites in normal air at <54°C. Pyrophoric can cause explosions.
- Silane is pyrophoric if >1.5% concentration and >18°C.
- Ionizing radiation (x-ray etc) can cause genetic injury.
- Work plans are sometimes needed if you are bypassing a guard or safety interlock.

5.4 Class I Division 2 hazardous classified locations

Flammable liquids (more easily ignited and more dangerous) have a flash point 0-60°C. Combustible liquids (less easily ignited and less dangerous) have a flash point of 60-93°C. Flammable and inflammable mean the same thing. However, flammable is preferred for warning labels because inflammable (French) is sometimes misunderstood to mean not flammable, same as invisible (Latin) means not visible.

Explosion proof, hazardous classified locations, and atmospheric explosive (ATEX) mean the same thing.

Certain **gases and fumes** (alcohol, hydrogen, gasoline, oil-based paint, etc.), **dusts** (coal, flour, sugar), and **fibers** (cotton textile) are so explosive that they have special consideration in the code book. Requirements can be applied to components operating in the hazardous classified atmosphere, or to an entire work cell. Often the manufacturer will classify the work cell by defining what chemistry can be used within it.

The goal of the **NEC hazardous classified location** regulations is to prevent the fire by separating the three parts of the fire triangle: fuel, oxygen, and ignition. Common techniques to prevent combustion or explosion are:

- **Fuel.** Choose construction materials that contain or minimize the combustible load such as a metal chassis, FM4910 rated plastics, sheet rock on the walls, isolation barriers, continuous air dilution, water-based chemicals, etc.
- **Oxygen.** Purge out the oxygen using nitrogen cover gas or a carbon dioxide fire suppression. Pressurized cabinets will prevent the infiltration of flammable gas. A small steady injection of nitrogen can be as good as a larger amount of clean dry air (21% oxygen).
- **Ignition.** Minimize sources of ignition by using overcurrent protection (circuit breakers, temperature sensors), components with low electrical energy (IS intrinsically safe and PELV protected extra low voltage), components that don't spark or get too hot (explosion proof), and proper grounding.

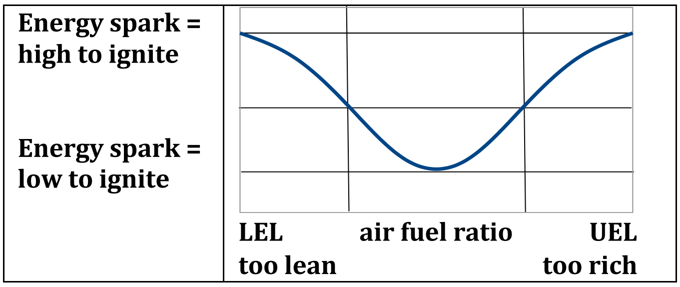
NEC definitions for hazardous classified locations:

- **Class I –** flammable gases, vapors, or combustible liquids, divided into two divisions: (1) **class I division 1 normally present** (**example:** spray paint booth) or (2) **class I division 2 normally confined** within a closed system, or prevented to accumulate by ventilation, and are hazardous only by malfunction (**examples:** solvent cabinet and gasoline filling station).
- **Class I** is further divided into three **flammable gas zones** (0, 1, 2). Zone 0 is continuously present and requires intrinsically safe. Zone 1 is likely to exist. Zone 2 is short duration.
- **Class I** is further divided into four **groups** (A, B, C, D) according to the explosion pressure. **Examples:** A = acetylene (worst case), B = hydrogen, C = ethylene, and D = propane.
- **Class II –** combustible dust (flour)
- **Class III –** combustible fibers (cotton)

Example: A large meat processing factory uses ammonia refrigeration. Ammonia is a large combustible load, easy to detect with leak sensors and difficult to ignite. The room is configured with gas leak detectors for automatic shutdown of unclassified electrical equipment (coolant pumps). After a leak, the remaining equipment that stays on (leak detectors, emergency lighting, ventilation fans) must be rated class 1 div 2 with conduit seal-offs, labeling, etc.

There are two ways to ignite: (1) a high temperature hot spot and (2) an electric spark. **Intrinsically safe equipment** is designed to reduce the **open circuit voltage** and the **short circuit current** to a low enough value so that there is not enough energy to cause ignition. Curves are available for various gas types which plot the ignition energy vs. the air fuel concentration.

The curve on the right shows the relationship between ignition spark energy (joules) and the optimal air fuel ratio. Required ignition energy is minimum at the best-case air fuel ratio. Ignition energy must increase for mixtures that are too lean or too rich. Intrinsically safe is below the curve, where the spark would not have enough energy to ignite the concentration.



5.5 Pyrophoric (self-igniting)

NEC article 500 takes precedence if the concern is the ignition source. Requirements might include installing seal-offs coming into the electrical cabinet, nitrogen purge with an interlocked pressure sensor, hard service power cords, tempered glass windows, etc. Fire code chapter 64 takes precedence if the concern is pyrophoric. The ignition source is irrelevant since the gas will react and burn in normal room air.

5.6 Paint spray booths

191.	Glass panels under the lamps need to be tempered and sealed with a gasket or fire caulk.	✓ NEC 516.6(C)(4) ✓ NFPA33-5.5.1
192.	Compressed air to the sprayer **interlocked to the ventilation**.	✓ IFC 2404.8 (2012)
193.	Fire extinguishers rated **4A:40B:C** within **30 feet** of the booth opening.	✓ IFC 2404.4.1 (2012)
194.	Filters must meet **UL900** evidenced by the data sheet or a listing mark on the product.	✓ NFPA33-5.1.1
195.	Metal thickness at least 0.05 inch.	✓ NFPA33-5.1.4
196.	Clearance to the wall at least 36 inches.	✓ NFPA33-5.3
197.	The class 1 div 2 zone is **3-foot radius** from the booth opening in any direction. There should be no non-explosion proof electrical equipment in this area, such as auxiliary lights.	✓ NEC 516.4
198.	Ventilation exhaust pipes must extend to at least 6 feet beyond any exterior wall or roof.	✓ IFC 2404.7.6

5.7 Vacuum dust collectors

Regular vacuum cleaners are found in UL white book category **DMDT**. Portable cleaning machines for use in hazardous locations are found in UL category **DMMR**. The standards are **UL73** motor operated appliance and the **NEC**. A vacuum cleaner rated **dust explosion proof** refers to the **motor not being the source of ignition.** UL certification will not prevent dust ignition from sucking up a spark or a broken tool bit. Therefore, the primary standard is NFPA 654 Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids.

NFPA 654 section 7.1.4 Explosion Protection for Equipment has six alternative construction techniques. Option (3) deflagration containment is typical. Best practice:

- The dust collector should be completely enclosed in sheet metal.
- The dust should accumulate in a metal can.
- Stainless steel vent pipe instead of plastic vent pipe.
- Straight pass through. Eliminate all sharp bends, low points, and rough surface.
- Spark arrestor (metal mesh screen) at the tool output going into the duct to the dust collector.
- Fire damper (fusable link shutdown) at the dust collector output. **Example:** Dayton 2TFZ5.
- Preventive maintenance for cleaning the dust collection can and the duct, as necessary.
- Cutter operation should be interlocked with the dust collector.
- Emergency buttons should be ganged together for the most convenient activation.
- Dust collectors typically use compressed air to periodically pop the dust out of the filters. During an emergency, air should not be blown into the fire containment. Therefore, the fire response (EMO button, temperature switch, etc.) should shut down the air supply.

5.8 Flammable dust environments (class 2, division 1 & 2)

Example: Imagine the difference between throwing a stick of firewood into a campfire (slow burn) vs throwing a bag of sugar (a big flash).

- Construction requirements for a room with flammable dust are less strict than gas because gas and fumes are sometimes pressurized, and they can flow more easily.
- Conduits and panels in a class 1 (gas) room must be sealed with rated seal-off fixtures (plaster-of-Paris). Conduits and panels in a class 2 room (dust) need only have ingress protection (rubber gaskets, putty in the holes).
- Construction drawings should have detailed construction notes, be reviewed, and stamped by a P.E., and be reviewed and stamped by city plan check.
- Construction keynotes should include sketches and cite relevant standards. (1) NEC article 500. (2) IAEI textbook "Hazardous Locations" for dust pages 119-125 (equipment) and pages 162-165 (wiring methods). (3) IFC chapter 22 (refers to NFPA 654). (4) NFPA 654 "Prevention of Fire and Dust Explosions . . . " 2020 edition. (5) NFPA 496 Purged Cabinet.

5.9 Explosion proof checklist

	Fire code ventilation exception	
199.	Class 1 Div 2 is required within 5 feet of flammable or pyrophoric gas.	✓ IFC 2703.7.2 (2015)
200.	Class 1 Div 2 is not required with adequate and continuous air dilution. Make sure fumes cannot be sucked up from a spill on the floor. The “adequate” air dilution **rule of thumb** is 2x air turns per minute for hazmat=2, 3x air turns per minute for hazmat=3, and 4x air turns per minute for hazmat=4. After some research, I have found no standards (IBC section 34, IFC sections 27 & 57, NFPA 30, SEMI, UL etc.) which prescribe air turns.	✓ IFC 2703.7.2 (2015)

	OSHA Subpart K Electrical § 1926.4xx	
201.	**Electrical installations.** Equipment, wiring methods, and installations of equipment in hazardous classified locations shall be intrinsically safe or rated (approved) for hazardous classified location.	✓ OSHA 1926.407(a)
202.	**Intrinsically safe.** Equipment and associated wiring approved as intrinsically safe is permitted in any hazardous classified location included in its listing or labeling.	✓ OSHA 1926.407(b)(1)
203.	**Approved** for the hazardous classified location.	✓ OSHA 1926.407(b)(2)

204.	**General.** Equipment shall be approved not only for the class of location but also for the ignitable or combustible properties of the specific gas, vapor, dust, or fiber that will be present.	✓ OSHA 1926.407(b)(2)(i)
205.	**Marking**. Equipment is typically marked to show the **rating** (class, group, and operating temperature) based on 40°C ambient. The temperature marking shall not exceed the ignition temperature of the specific gas, vapor, or dust to be encountered. However, the following provisions modify this marking requirement for specific equipment:	✓ OSHA 1926.407(b)(2)(ii)
206.	**Equipment of the non-heat-producing type** (such as junction boxes, conduit, and fitting) and equipment of the heat-producing type (motors) having a maximum temperature of not more than 100°C (212°F) do not need to be marked for operating temperature.	✓ OSHA 1926.407(b)(2)(ii) ✓ NEC handbook 500.8(C)(4) page 591 ✓ NFPA496-4.5.1
207.	**Fixed lighting fixtures** marked for use only in class I, division 2 locations do not need to be marked to indicate the group.	✓ OSHA 1926.407(b)(2)(ii)
208.	**Fixed general-purpose equipment** in class I locations, other than lighting fixtures, which is acceptable for use in class I, division 2 locations do not need to be marked with the class, group, division, or operating temperature.	✓ OSHA 1926.407(b)(2)(ii)
209.	**Fixed dust-tight equipment**, other than lighting fixtures, which is acceptable for use in class II, division 2 and class III locations, do not need to be marked with the class, group, division, or operating temperature.	✓ OSHA 1926.407(b)(2)(ii)
210.	**Safe for the hazardous classified location.** Equipment which is safe for the location shall be of a type and design which the employer demonstrates will provide protection from the hazards arising from the combustibility and flammability of vapors, liquids, gases, dusts, or fibers.	✓ OSHA 1926.407(b)(3)
211.	**Conduits.** All conduits shall be threaded and shall be made wrench tight. Bonding jumper if wrench tight is not practical.	✓ OSHA 1926.407(c)
	Class I Division 2 – Hazardous Locations	
	Grounding and bonding	
212.	The equipment ground should be intact and continuous all the way through multiple raceways, from the fault point all the way back to the service grounding point. The wire is sized according to 250.122	✓ NEC 250.102(D)
	Equipment	
213.	Components capable of causing ignition (contact switches, circuit breakers, push buttons, relays, alarm bells, horns, motors, lights, and heaters) must be listed for use in hazardous location.	✓ NEC 500.8(A) & 501.105-130
214.	Equipment shall not have any exposed surface hotter than the ignition temperature of the vapor.	✓ NEC 500.8(B)(1)
215.	General purpose equipment is ok if it is not a source of ignition under normal operating conditions.	✓ NEC 500.8(B)(3)
	NEC temperature code marking	
216.	Enclosure “T code” is the highest temperature of the outside surface, the inside components, or the vented purge gas. Note: NEC Handbook states that heat producing equipment <100°C does not need to be marked for temperature.	✓ NEC 500.8(C)(4) ✓ NFPA496-4.5.1

217.	Equipment shall be marked with class, division, and temperature. Components should indicate their maximum temperature produced. Enclosure "T code" either follows table below or it is shown in degrees Celsius. Enclosure "T codes" for class 1 div 2: T1=450°C, T2=300°C, T3=200°C, T4=135°C, T5=100°C, T6=85°C	✓ NEC 500.8(C) ✓ NFPA496-4.5.2 & 4.5.3
	Construction for Class I (flammable gas and vapor)	
218.	The cover on an explosion proof junction box is screwed on with at least five full turns.	✓ NEC 501.1
219.	Class I division 1 wiring: RMC, IMC, MI, MC-HL, ITC-HL, TC-ER-HL. Cables marked "HL" are rated for hazardous location.	✓ NEC 501.10(A)
220.	Class I division 2 wiring can be class I division 1 (above) or • gasketed busways or flexible metal conduit with listed fittings • heavy duty power cord (eg. MC, MV, SO, TC-ER)	✓ NEC 501.10(B)
221.	Avoid Teflon tape or joint compound on conduit threads, as this may weaken the seal fitting and interrupt the equipment ground path.	✓ NEC 501.15
222.	Conduits are sealed (plugged) to prevent infiltration of vapors and to prevent burning gas from blowing down the pipes.	✓ NEC 501.15
223.	If div 1 zone 1, the conduit is sealed within 18 inches of enclosure.	✓ NEC 501.15(A) ✓ NFPA496-4.2.3
224.	Fittings shall use approved sealing compounds. Conductor fill ratio <25%. Sealing compound thickness is same as pipe diameter but minimum 5/8 inch thick. Wires separated to prevent voids.	✓ NEC 501.15(C)
225.	Fluid pumps are sealed to prevent process fluid from entering the electrical enclosure.	✓ NEC 501.17
226.	Live parts (terminals) should have guards to prevent accidental contact with tools.	✓ NEC 501.25
227.	The equipment ground wire and the conduit are parallel paths. Therefore, metal connections must be low impedance to avoid sparks. Best practice: (1) bond all metal raceways, and (2) threaded joints must be wrenched tight.	✓ NEC 501.30
228.	Fittings must be suitable for bonding. Fittings typically have a screw for tying down the ground wire. Conduit lock nuts are not adequate for bonding.	✓ NEC 501.30(A)
229.	Flex (eg. liquid tight whips) must be < 6' length. • If div 1 must have bonding jumper wire. • If div 2, the bonding wire can be exempted if: listed fittings and 10 amp OCP to a non-power utilization load.	✓ NEC 501.30(B)
230.	Surge protection (example: RK Electronics) typically clamp at 3x the line voltage.	✓ NEC 501.35
231.	Flexible cords and plugs: • Rated heavy duty. • Listed for class I • Supported to prevent accidental disconnect	✓ NEC 502.10
	Intrinsically Safe (IS)	
232.	IS components are listed.	✓ NEC 504.4
233.	A control drawing defines the installation.	✓ NEC 504.10
234.	IS wiring does not share a raceway with non-IS wiring.	✓ NEC 504.30(A)
235.	IS wiring is supported to prevent accidental contact.	✓ NEC 504.30(B)

236.	Equipment safety ground and the service ground. If there are two: • Both electrodes should be located as close together as practical. • Both grounds terminate within the enclosure or control panel.	✓ NEC 504.50
237.	IS wiring and terminals have identity labels.	✓ NEC 504.80
	Meters, instruments, and relays	
238.	An attachment plug is not to be used as on/off. There should be an on/off switch.	✓ NEC 501.105(B)(6)
239.	Receptacles are provided only if necessary.	✓ NEC 501.105(B)(6)
240.	Receptacles are labeled with a warning not to unplug while loaded.	✓ NEC 501.105(B)(6)
241.	Good ESD control includes bonding, grounding, and humidity control. Avoid certain polymeric materials.	✓ NEC Handbook

5.10 X, Y, Z purging per NFPA 496

Purging uses a pressurized supply of clean dry air (CDA) or inert gas (nitrogen) inside of an enclosure or motor to prevent the infiltration of flammable gas, fumes, and dust. The water column is from 0.1 to 0.5 inches, as necessary for 4 air turns per minute. Alarm required (visual or audible).

- **X-purge** (for highest protection) allows a **division 1** environment to have **unclassified components** in the cabinet. Gas and fumes are kept outside the cabinet. Pressure switch interlock is required.
- **Y-purge** (for medium protection) allows a **division 1** environment to have **class 1 division 2 rated components** in the cabinet. There is no internal source of ignition. Pressure switch interlock is optional.
- **Z-purge** (for lower protection) allows a **division 2** environment to have **unclassified components** in the cabinet. There is a hazard only if the purge gas fails. Pressure switch interlock is optional.
- **No purge** needed for div 1 components in a div 1 zone or div 2 components in div 2 zone.

	Enclosure	
242.	Enclosure unlikely to be damaged (eg. window glass).	✓ NFPA496-4.2.1
243.	Protection from excessive protective gas pressure (screen bulging).	✓ NFPA496-4.2.1.1
244.	Pressure relieving blow-out devices do not spark.	✓ NFPA496-4.2.1.2
245.	Protective gas vents to an unclassified area.	✓ NFPA496-4.2.2
246.	Protective gas vents to div 2 zone 2 if equipment does not spark.	✓ NFPA496-4.2.2.1
247.	Protective gas vents to div 1 or 2 or zone 1 or 2 if outlet does not spark.	✓ NFPA496-4.2.2.2
	Pressurizing system	
248.	Protective gas pressure >25 Pa (0.0036 PSI).	✓ NFPA496-4.3.1
249.	Protective gas pressure interlocked.	✓ NFPA496-4.3.2
250.	If protective gas fails, all components which remain energized must be rated for hazardous location.	✓ NFPA496-4.3.3
251.	Instructions for maintaining protective gas pressure.	✓ NFPA496-4.3.4
	Protective gas system	
252.	Protective gas uncontaminated or unlikely to be contaminated.	✓ NFPA496-4.4.1
253.	Protective gas non-flammable (air or nitrogen).	✓ NFPA496-4.4.1.2
254.	Pipe protected from damage.	✓ NFPA496-4.4.2
255.	Compressor located in non-hazardous location.	✓ NFPA496-4.4.3

256.	Compressor intake lines prevent vapor ingress.	✓ NFPA496-4.4.4
257.	Compressor has power separate from enclosure.	✓ NFPA496-4.4.5
	Ventilated equipment	
258.	Protective gas helps to cool the equipment.	✓ NFPA496-4.6
	Power equipment	
259.	Tight metal enclosures for power equipment.	✓ NFPA496-4.7
	Type X purging	
260.	Pressure detection and alarm, plus a cut-off switch for automatic electrical shutdown. Switch must be flow or pressure activated, rated, no valves in between, and takes its signal from the enclosure.	✓ NFPA496-4.10.1
261.	Motors and transformers have overload shutdown.	✓ NFPA496-4.10.2
262.	Motors and transformers have cooling.	✓ NFPA496-4.10.3
263.	Automatic control – components will not energize until: • 4 air turns of protective gas (no motors), or • 10 air turns of protective gas (motors and generators) • Note: internal air should be diluted below 25% of LEL.	✓ NFPA496-5.5.1
264.	Automatic electrical shutdown is not required if the enclosure is properly labeled and has a lock or special tool to open.	✓ NFPA496-5.5.2
265.	Interlock switch must be rated for class I even if inside.	✓ NFPA496-5.5.2.1
266.	Key locked compartment if components require cool down.	✓ NFPA496-5.5.2.2
	Type Y purging	
267.	Components rated for division 2 or zone 2.	✓ NFPA496-4.9.2
268.	Pressure detection and alarm, plus automatic electrical shutdown if purge gas is need to keep components cool below their T code.	✓ NFPA496-4.9.3
	Type Z purging	
269.	Pressure detection and alarm, but does not require automatic electrical shutdown.	✓ NFPA496-4.8.1
270.	Pressure alarm takes its signal from the enclosure.	✓ NFPA496-4.8.2
271.	Alarm or indicator	✓ NFPA496-4.8.3
	Markings (warning labels)	
272.	Permanent and prominent.	✓ NFPA496-4.11.1
273.	"Warning – Pressurized Enclosure . . ."	✓ NFPA496-4.11.2
274.	"Warning – High Temperature Internal Parts . . ."	✓ NFPA496-4.11.4
275.	"Warning – Protective Gas Supply Valve . . ."	✓ NFPA496-4.11.5
276.	"Warning – Asphyxiation . . ."	✓ NFPA496-4.11.6
	Pressurized enclosures for class I (vapor)	
277.	Purge after opening.	✓ NFPA496-5.2.2
278.	Design avoids air pockets.	✓ NFPA496-5.2.3
279.	After high flow purging, the enclosure maintains a positive pressure >0.1 inches of water.	✓ NFPA496-5.2.4
280.	Purge pressure does not depend on flow rate.	✓ NFPA496-5.2.5
281.	Internal compartment(s) can be purged in series or separately according to best practice.	✓ NFPA496-5.2.6
	Pressurized enclosures for class I (vapor) – warning labels	
282.	Permanent and prominent.	✓ NFPA496-5.3

283.	"Warning – Power must not be restored until enclosure has been purged for TBD minutes at a TBD flow rate."	✓ NFPA496-5.3.1
	Pressurized enclosures for class I (vapor) – Y or Z requirements	
284.	Manual control – components will not energize until: • 4 air turns of protective gas (no motors), or • 10 air turns of protective gas (motors and generators) • Note: internal air should be diluted below 25% of LEL.	✓ NFPA496-5.4.1

6 Laser

6.1 Laser standards

Laser is an acronym that stands for light amplification by simulated emission of radiation. Laser light is non-ionizing, meaning below x-ray frequency, and coherent, meaning that the light waves have nearly identical frequency, phase, and polarization. For industrial application, lasers are primarily used for targeting, measuring, communication, spectroscopy, cutting, and sintering (additive manufacturing).

Laser safety requirements have been developed by:

- Laser Institute of America, Orlando, Florida
- Association for Manufacturing Technology, Laser Systems Product Group, McLean, Virginia

ANSI Z136.1 sections:

- ANSI Z136.1 – Safe Use of Lasers
- ANSI Z136.3 – Safe Use of Lasers in Health Care Facilities
- ANSI Z136.4 – Recommended Practice for Laser Safety Measurements for Hazard Evaluation
- ANSI Z136.5 – Safe Use of Lasers in Educational Institutions
- ANSI Z136.6 – Safe Use of Lasers Outdoors
- ANSI Z136.7 – Testing and Labeling of Laser Protective Equipment

6.2 Laser safety hazards

- **Glare.** Similar to staring into high beams.
- **Dazzle.** Temporary flash blindness.
- **After image.** Residual energy to the phosphorous may require a couple minutes to dissipate.
- **Burnt retina.** Lasers focus their energy on small spots. Retina photocells can be damaged with a brief temperature increase of just 10°C. Higher exposure and temperature will result in a blind spot. The eye lens and cornea can focus and intensify energy. Blue light is magnified by 100,000x. Blinking is not fast enough. The eye response takes up to ¼ second.
- **Burnt lens (cataracts).** Infrared is especially dangerous because there is no blink reflex.
- **Burnt skin.**
- **Fire.** 55 mw can burn a hole in a black plastic trash bag.
- **Shock.** Lasers have a relatively high voltage.
- **Fumes.** Lasers can generate air contaminants.

Maximum permissible exposure (MPE): The highest power (watts/cm^2) or energy (joules/cm^2) that is considered safe. MPE is defined as 10% of the dose that has a 50/50 chance of causing an injury.

Wikipedia reference: http://en.wikipedia.org/wiki/Laser_safety

OSHA 1801c laser safety requirements apply to construction, not to industrial machinery. **Example:** aligning sewer pipes.

Classifications: Lasers are classified by wavelength and power. Classification prior to 2002 is referred to as the "old system". Classification after 2002 is referred to as the "revised system". Laser safety after 2007 is regulated by the US Food and Drug Administration (FDA) and ANSI Z136.

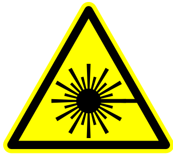
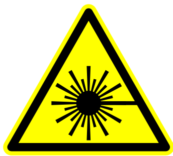
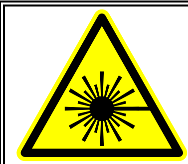
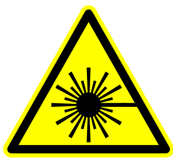
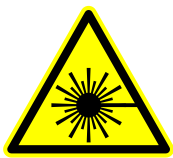
Laser safety officer (LSO) Training: The Laser Institute of America conducts two versions of the LSO training class. (1) The **on-line class** provides training in all areas except hazard analysis. (2) The **classroom** training is one week and includes hazard analysis. After the course, you can take an examination to become a "Certified Laser Safety Officer". $2000 total.

	Laser classification	
285.	A class 4 laser inside a properly guarded cabinet is **class 1 outside the cabinet**. Any laser, or laser system containing a laser, that cannot emit accessible laser radiation levels in excess of class 1 . . . is a class 1.	✓ ANSI Z136.1- 3.3.3.1
286.	Laser is properly classified (power and wavelength) for its operation. Refer to the label table at the end of the section.	✓ IEC 60825-8.2 ✓ ANSI Z136.1- 3.2
287.	Laser is used within a proper operating environment (temperature, humidity, altitude, shock, vibration).	✓ IEC 60825-4.13 ✓ ANSI Z136.1- 3.4
	Laser Safety Officer (specific responsibilities)	
288.	Classification (capability of injuring personnel), including the nominal hazard zone (NHZ).	✓ ANSI Z136.1- 1.3.2.1
289.	Hazard evaluation, including accident investigation and reporting.	✓ ANSI Z136.1- 1.3.2.2
290.	Control measures, including monitoring and enforcement of all aspects of laser operation, including authority to operate and shutdown.	✓ ANSI Z136.1- 1.3.2.3
291.	Development and approval of all laser policies, regulations, and standard operating procedures, including safety measures for routine maintenance.	✓ IEC 60825- 4.11 ✓ ANSI Z136.1- 1.3.2.4 ✓ ANSI Z136.1- 4.4.1
292.	Protective equipment (glasses, clothing, barriers, screens, etc).	✓ ANSI Z136.1- 1.3.2.5
293.	Signs and labels.	✓ ANSI Z136.1- 1.3.2.6
294.	Facility and equipment, including modifications.	✓ ANSI Z136.1- 1.3.2.7
295.	Proper use of indoor laser-controlled area (class 3B and class 4).	✓ ANSI Z136.1- 3.4.2 ✓ ANSI Z136.1- 4.3.10
296.	Emergency entryway provided and safety controls procedures.	✓ ANSI Z136.1- 4.3.10.2
297.	Safety feature audits.	✓ ANSI Z136.1- 1.3.2.8
298.	Employee training and record keeping, for operators, maintenance, and service personnel, including the LSO. Employees should have evidence of laser safety qualification in their personnel record.	✓ ANSI Z136.1- 1.3.2.9 ✓ ANSI Z136.1- 4.4.3 ✓ ANSI Z136.1- 5.3
299.	Medical surveillance. Base line annual eye exam. (class 3B or class 4)	✓ ANSI Z136.1- 1.3.2.10 & 6.3
	Laser documentation	
300.	Operation, maintenance and service manuals are available. **Best practice:** Each laser tool should have a standard operating procedure (SOP) that includes operation, maintenance, LOTO, periodic safety audit, and a sketch (or photo) showing the location and context meaning of the hazard warning labels.	✓ IEC 60825- 6.1 ✓ ANSI Z136.1- 4.1.1.1
301.	The schematic and BOM should be put into document control. The document reference number should be included in the nameplate label.	✓ NFPA79-16.4.1
	Laser administration	
302.	Laser operated only under the direct supervision of a qualified worker.	✓ ANSI Z136.1- 4.1.1.2
303.	Laser operated only if attended. This could be a special key (non-removable in the on position attached to a fob), a floor mat proximity sensor, or a push-to-hold "dead man" type button.	✓ ANSI Z136.1- 4.1.1.3
304.	Prevention against unauthorized access. The laser tools or the entire room must have lock-out capability. Control the power with a master key or a disconnect switch box. Easily accessible. Appropriate supervision. The LSO can decide the key policy. (class 3B or class 4)	✓ ANSI Z136.1- 4.3.4 ✓ ANSI Z136.1- 4.4.6 ✓ IEC 60825- 4.5

305.	Remove jewelry to avoid dangerous reflections. (class 3B or class 4)	✓
	Laser hazard warnings (labels and alarms)	
306.	The laser operation room must have a "laser on" visual alarm when any laser in the room is on. This is to warn all employees to have their glasses on. This alarm would be extended to the door entrance. The signs should state the class and the wavelength. (class 3R, class 3B, class 4). Typical: YAG 1064 nm, CO2 1060 nm, UV 355 nm.	✓ ANSI Z136.1- 4.3.9
307.	Hazard warning labels (per ANSI Z535): (1) signal word (DANGER for class 3B & class 4), (2) signal color (RED background for DANGER). (3) pictogram (sunburst), and (4) context message. **Examples:** See the table below for pictograms and context messages. Wavelength and power rating should be labeled.	✓ IEC 60825- 5.0 ✓ ANSI Z136.1- 4.3.14 ✓ ANSI Z136.1- 4.7
308.	Hazard warning label near each safety interlock.	✓ IEC 60825- 5.9.2
309.	Each laser tool must have an audible or visual alarm when the laser tool is on. This could originate from the power supply. (class 3B or class 4). **Best practice:** All the tools have a consistent (similar) alarm. **Example:** a red lamp directly over the tool.	✓ IEC 60825- 4.6.1 ✓ ANSI Z136.1- 4.3.9.4.1 & 4.3.9.4.2
	Access to hazardous areas	
310.	Protective housing provided. Operation without protective housing is very dangerous. The cover should be secured except for alignment and maintenance. Removing the housing requires special tools and eyeglasses.	✓ IEC 60825- 4.2.2 ✓ ANSI Z136.1- 4.3.1 ✓ ANSI Z136.1- 4.3.1.1
311.	High intensity beams should be contained within tubes to prevent fires, if appropriate.	✓ ANSI Z136.1- 4.3.6.3
312.	Alignment at low power requires the interlock to be bypassed. The low power setting must be tied to either an engineering control (production) or an administrative control (laboratory). Procedures and training must be approved by the LSO.	✓ IEC 60825- 4.3.2 ✓ ANSI Z136.1- 4.3.1
313.	Windows and curtains prevent the laser light from escaping the enclosure.	✓ ANSI Z136.1- 4.6.3 ✓ ANSI Z136.1- 4.6.4
314.	Viewing windows have adequate filters and attenuators.	✓ IEC 60825- 4.9 ✓ ANSI Z136.1- 4.3.5
315.	Guarding of access to beam paths. (class 3B or class 4)	✓ ANSI Z136.1- 4.3.6
316.	Permanently attached beam stop or attenuator. (class 3B or class 4)	✓ IEC 60825- 4.7 ✓ ANSI Z136.1- 4.3.8
	Laser interlocks and protective devices	
317.	Glasses provided as determined by the LSO. (class 3B or class 4)	✓ ANSI Z136.1- 4.1(3) ✓ ANSI Z136.1- 4.6.2
318.	Interlocks on removable panels and service access panels.	✓ IEC 60825- 4.3 ✓ ANSI Z136.1- 4.3.1, 4.3.2, 4.3.3
319.	Interlocks should fail to a safe state.	✓ IEC 60825- 4.3.1 ✓ ANSI Z136.1- 4.3.2
320.	Interlocks should not be easily defeated. Use a brand name like Omron, STI, Schmersal, Allen Bradley, etc. with a UL listing mark.	✓ IEC 60825- 4.3.2 ✓ ANSI Z136.1- 4.3.2
321.	Remote interlock connector to a master EMO. (class 3B or class 4)	✓ IEC 60825- 4.4 ✓ ANSI Z136.1- 4.3.7
322.	Controls are located so that adjustment and operation do not require exposure to the laser radiation. (class 3R, class 3B, class 4)	✓ IEC 60825- 4.8
323.	Emergency kill switch well labeled. This safety device would be used if: (1) the laser does not shut off, (2) the cabinet breaches, (3) the material starts to smoke, etc. (class 3B or class 4)	✓ ANSI Z136.1- 4.3.10.2.1

324.	Outdoor laser installations requirements.	✓ ANSI Z136.1- 4.3.11
325.	Protection against non-beam hazards (eg. high temperature).	✓ ANSI Z136.1- 7.1
326.	Protection against electrical hazards (eg. shock).	✓ ANSI Z136.1- 7.2
327.	Protection against ancillary hazards (eg. fire). Remove all paper and dust. Use metal duct tape for sealing.	✓ IEC 60825- 4.14 ✓ ANSI Z136.1- 7.3, 7.5, 7.13

6.3 Laser safety label examples per IEC 60825 section 5

Class	Description	Pictogram	Primary label context message
Class 1	Safe under all conditions of normal use	none	CLASS 1 LASER PRODUCT
Class 1M	Safe under all conditions of normal use except through a magnifier lens like a microscope or telescope.	none	CAUTION LASER RADIATION DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS CLASS 1M LASER PRODUCT
Class 2	Visible wavelength (400-700 nm) and up to 1 milliwatt. Laser pointers are typically class 2. The blink reflex would normally prevent eye injury.		CAUTION LASER RADIATION DO NOT STARE INTO BEAM CLASS 2 LASER PRODUCT
Class 2M	More dangerous than class 2 if there is a possibility of viewing the light through a magnifier lens.		WARNING LASER RADIATION DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS CLASS 2M LASER PRODUCT
Class 3R	More dangerous than class 2 because the beam exceeds the MPE. Low risk of injury. Up to 5 milliwatts.		WARNING LASER RADIATION AVOID DIRECT EYE EXPOSURE CLASS 3R LASER PRODUCT
Class 3B	Dangerous if viewed directly but not by matte reflection. Continuous, visible wavelength (400-700 nm) and up to 30 millijoules, or wavelength 315 nm to infrared, and up to 500 milliwatts.		DANGER LASER RADIATION AVOID EXPOSURE TO THE BEAM CLASS 3B LASER PRODUCT
Class 4	Able to burn skin. Fire risk. Permanent eye damage if viewed directly or reflected.		DANGER LASER RADIATION AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION CLASS 4 LASER PRODUCT

7 Robot

7.1 Robot safety requirements

Robotic safety requirements have been developed by:

- Robotic Industries Association, Ann Arbor, Michigan, RIA R15.06
- European Technical Committee (ISO/TC) 184, subcommittee SC 2
- US Canadian Technical Committee Z434 (2014)
- Safety requirements for industrial robots, ISO 10218 (2011), parts 1 and 2

ISO 10218-1 sections:

1. Scope
2. Normative references
3. Terms and definitions
4. Hazard identification and risk assessment
5. Design requirements and protective measures
6. Information for use

RIA R15.06 clauses (sections):

1. Introduction
2. Scope, purpose, application, and exclusions
3. Normative references
4. Definitions
5. Manufacturer, remanufacturer, and rebuild of robots
6. Performance requirements of safeguarding devices
7. Installation of robots and robot systems
8. Safeguarding of personnel – introduction
9. Safeguarding of personnel – prescribed method
10. Safeguarding of personnel – risk assessment method
11. Safeguarding of personnel – implementation
12. Safeguarding of personnel – application requirements
13. Maintenance of robots and robot systems
14. Testing and start-up of robots and robot systems
15. Safety training of personnel

RIA is now harmonized with international standard ISO 10218-1. In 2007, RIA adopted ISO 10218 to replace its section 4 (robot design requirements). ISO 10218 brings definition to the following areas:

- wireless teach pendants
- synchronized multiple robots
- collaborative robotic applications
- programmable safety controllers for limiting the envelope

Robot conformity report example – acronyms are the same as the CE and SEMI reports

	Robot Requirement	Comments	RIA R15.06	CSC	CPG	DNC	N/A
1.	**Manufacture, remanufacturer, and rebuild of robots.**		4				
2.	**Requirements**		4.1				
3.	**New and remanufactured robots** Anyone manufacturing, or remanufacturing, a robot shall meet all requirements contained in 4.2 – 4.16 of this standard.		4.1.1	X			

This line-by-line conformity assessment goes on for over 500 line items.

7.2 Robotic hazards and critical issues

- Robotic work cells can be surrounded by either a fixed barrier (with interlocked access) or with presence sensing safeguarding devices (PSSG). Physical barriers are more foolproof and provide additional safety in case the material is ejected.
- Compared to barriers, PSSGs are more convenient, but they need time to work. Calculations to guarantee a full stop assume that the person is moving at 63 inches per second, equivalent to a brisk walk. **Example:** If the robot takes one second to come to a full stop, the PSSGs must be set back at least 63 inches.
- Barriers and presence sensors need adequate coverage. Muting should be only for material, not for people. ISO 13857 has much more detail which includes the size and type of the openings (round, square, rectangle). **Example:** Can someone reach through a hole, over the top (with a ladder), or underneath, and be within the path of the robot? **Example:** Can material be added or removed (stocker activity) while the robot is operating at full speed?
- Safety devices sometimes fail. The severity of the risk determines the required category (reliability) of the safety device. The best-case safety device would use two completely redundant systems that are able to monitor their own health.
- Determine proper administrative controls. **Examples:** If someone enters the workspace, are they required to carry the LOTO key? If someone operates an amusement park ride or a gas pump handle, are the controls required to be handheld?
- Determine what kind of work requires access near a moving robot. Programming? Maintenance?

7.3 Robotic safety introduction (OSHA PUB 8-1.3)

Note: OSHA defines a robot as being “multifunctional”. The general consensus is that **wafer handlers and dispensers are not within the scope of a robot.**

7.3.1 Introduction

Robots are **reprogrammable, multifunctional, mechanical manipulators** that typically employ one or more means of power: electromechanical, hydraulic, or pneumatic. Industrial robots have been used chiefly for spray painting, spot-welding, and transfer and assembly tasks. A robot performs its tasks in a physical area known as the robot operating work envelope. This work envelope is the volume swept by all possible programmable robot movements. This includes the area where work is performed by robot tooling.

A robot can have one or more arms which are interconnected sets of links and powered joints. Arms are comprised of manipulators which support or move wrists and end-effectors. An end-effector is an accessory tool specifically designed for attachment to a robot wrist to enable the robot to perform its intended task. **Examples** of end-effectors include grippers, spot-weld guns, and spray paint guns. The

ANSI R15.06 Standard defines an industrial robot system as that which includes industrial robots, end-effectors, and any equipment, devices and sensors required for the entire robot system to perform its tasks.

Most robots are set up for an operation by the **teach-and-repeat technique**. In this technique, a trained operator (programmer) typically uses a portable control device (commonly referred to as a teach pendant) to manually key a robot and its tasks. Program steps are of the up-down, left-right, in-out, and clockwise-counterclockwise variety. Robot speeds during these programming sessions are required to be slow. The ANSI Standard currently recommends that this slow speed should not exceed 10 in/sec (250 mm/sec).

The very nature of robotics systems operations has introduced a new type of employee into the industrial workplace, the corrective maintenance worker. This individual is normally present during all operations of a robotics system and is responsible for assuring continuing operation - adjusting speeds, correcting grips, and freeing jam-ups. The corrective maintenance worker may also be the trained programmer who guides a robot through the teach-and-repeat technique. It is necessary for this individual to be near the robot from time to time, which raises concerns about his or her safety and the safety of other workers who may also be exposed.

Recent studies in Sweden and Japan indicate that many robot accidents do not occur under normal operating conditions but rather during programming, adjustment, testing, cleaning, inspection, and repair periods. During many of these operations, the operator, programmer or corrective maintenance worker may temporarily be within the robot work envelope while power is available to moveable elements of the robot system.

This guideline describes some of the elements of good safety practices and techniques used in the section and installation of robots and robot safety systems, control devices, robot programming and employee training. A comprehensive list of safety requirements is provided in the ANSI R15.06 standard.

7.3.2 Safety systems

The proper selection of an effective robotics safety system must be based on hazard analysis of the operation involving a particular robot. Among the factors to be considered in such an analysis are the task a robot is programmed to perform, the start-up and the programming procedures, environmental conditions and location of the robot, requirements for corrective tasks to sustain normal operations, human errors, and possible robot malfunctions.

Sources of robot hazards include:

- Human errors
- Control errors
- Unauthorized access
- Mechanical hazards
- Environmental hazards
- Electric, hydraulic, and pneumatic power sources

An effective safety system protects operators, engineers, programmers, maintenance personnel, and others who could be exposed to hazards associated with a robot's operation. A combination of methods may be used to develop an effective safety system. Redundancy and backup systems are recommended, particularly if a robot can create serious hazardous conditions.

7.3.3 Guarding methods

Interlocked barrier guard – This is a physical barrier around a robot work envelope incorporating gates equipped with interlocks. These interlocks are designed so that all automatic operations of the robot and associated machinery will stop when any gate is opened. Restarting the operation requires closing the gate and reactivating a control switch located outside of the barrier. A typical practical barrier is an interlocked fence designed so that access through, over, under, or around the fence is not possible when the gate is closed.

Fixed barrier guard – A fixed barrier guard is a fence that requires tools for removal. Like the interlocked barrier guard, it prevents access through, over, under, or around the fence. It provides sufficient clearance for a worker between the guard and any robot reach, including parts held by an end-effector, to perform a specific task under controlled conditions.

Awareness barrier device – This is a device such as a low railing or suspended chain that defines a safety perimeter and is intended to prevent inadvertent entry into the work envelope but can be climbed over, crawled under, or stepped around. Such a device is acceptable only in situations where a hazard analysis indicates that the hazard is minimal and interlocked or fixed barrier guards are not feasible. Interlocked or fixed barrier guards provide a positive protection needed to prevent worker exposure to robotic systems hazards.

Presence sensing devices – The presence detectors used in robotics safety are pressure mats and light curtains. Floor mats (pressure sensitive mats) and light curtains (similar to arrays of photocells) can be used to detect a person stepping into a hazardous area near a robot. Proximity detectors operating on electrical capacitance, ultrasonics, radio frequency, laser, and television principles are currently undergoing reliability testing in research laboratories because of recognized limitations in their capability of detecting the presence of personnel. Although some of these devices are already available in the safety equipment marketplace, care must be used in their selection to ensure adequate safety and reliability. At this time, such proximity detectors are not recommended for such use unless a specific analysis confirms their acceptability for the intended use.

Effective presence sensing devices stop all motion of the robot if any part of a worker's body enters the protected zone. Also, they are designed to be fail-safe so that the occurrence of a failure within the device will leave it unaffected or convert it into a mode in which its failed state would not result in an accident. In some cases, this means deactivation of the robot. Factors which are considered in the selection of such devices include spatial limitations of the field, environmental conditions affecting the reliability of the field, and sensing field interference due to robot operation.

Emergency robot braking – Dangerous robot movement is arrested by dynamic braking systems rather than simple power cut-off. Such brakes will counteract the effects of robot arm inertia. Cutting off all power could create hazards such as a sudden dropping of a robot's arm or flinging of a work piece.

Audible and visible warning systems – Audible and visible warning systems are not acceptable safeguarding methods but may be used to enhance the effectiveness of positive safeguards. Audible and visible signals need to be easily recognizable.

7.3.4 Control devices

The following characteristics are essential for control devices:

- The main control panel is located outside the robot system work envelope in sight of the robot.
- Readily accessible emergency stops (palm buttons, pull cords, etc.) are in all zones where needed. These are clearly situated in easily located positions and the position identifications are a prominent part of personnel training. Emergency stops override all other controls.
- The portable programming control device contains an emergency stop.
- Automatic stop capabilities are provided for abnormal robot component speeds and robot traverses beyond the operating envelope.
- All control devices are clearly marked and labeled as to device purpose. Actuating controls are designed to indicate the robot's operating status.
- Controls that initiate power or motion are constructed and guarded against accidental operation.
- Each robot is equipped with a separate circuit breaker that can be locked only in the "off" position.
- User-prompt displays are used to minimize human errors.
- The control system for a robot with lengthy start-up time is designed to allow for the isolation of power to components having mechanical motion from the power required to energize the complete robot system.
- Control systems are selected and designed so that they prevent a robot from automatically restarting upon restoration of power after electrical power failure. The systems also prevent hazardous conditions in case of hydraulic, pneumatic, or vacuum loss or change.

- A robot system is designed so that it can be moved manually on any of its axes without using the system drive power.
- All control systems meet OSHA 29 CFR 1910 Subpart S standards for electrical grounding, wiring, hazardous locations, and related requirements.

7.3.5 Installation, maintenance, and programming

Good installation, maintenance, and programming practices include the following:

- The robot is installed in accordance with the manufacturer's guidelines and applicable codes. Robots are compatible with environmental conditions.
- The power to the robot conforms to the manufacturer's specifications.
- The robot is secured to prevent vibration movement and tip over.
- Installation is such that no additional hazards are created such as pinch points with fixed objects and robot components or energized conductor contact with robot components.
- Signs and markings indicating the zones of movement of the robot are displayed prominently on the robot itself and, if possible, on floors and walls.
- Stops are placed on the robot system's axes to limit its motions under rated load and maximum speed conditions.
- A lock-out procedure is established and enforced for preventive maintenance or repair operations.
- The robot manufacturer's preventive maintenance schedule is followed rigorously.
- A periodic check of all safety-critical equipment and connections is established.
- Stored energy devices, such as springs and accumulators, are neutralized before robot servicing.
- Only programmers have access to the work envelope and full control of the robot when it is in the teach mode.
- All robot motion initiated from a teach pendant used by a programmer located within the robot work envelope is subject to the current ANSI slow speed recommendation of 10 in/sec (250 mm/sec).

7.3.6 Training

Effective accident prevention programs include training. Some points to be considered in training programs include:

- Managers and supervisors in facilities that use robots are trained in the working aspects of robots so that they can set and enforce a robotics safety policy from an informed viewpoint.
- The employer ensures that his or her company has a written robotics safety policy that has been explained to all personnel who will be working with robots. This safety policy states by name which personnel are authorized to work with robots.
- Robot programming and maintenance operations are prohibited for persons other than those who have received adequate training in hazard recognition and the control of robots.
- Robot operators receive adequate training in hazard recognition and the control of robots and in the proper operating procedure of the robot and associated equipment.
- Training is commensurate with a trainee's needs and includes the safeguarding method(s) and the required safe work practices necessary for safe performance of the trainee's assigned job.
- If an authorized person needs to be within the work envelope while a robot is energized. **Example:** During a programming sequence, training is provided in the use of slow robot operation speeds and hazardous location avoidance until the work is completed. Such training also includes a review of emergency stops, and familiarization with the robot system's potentially hazardous energy sources.

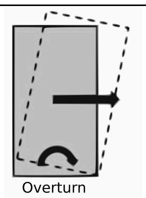
8 Equipment Anchorage

8.1 Seismic tie down calculation

An earthquake shakes the machine sideways. SEMI S2 seismic loading protection rules were derived from the Uniform Building Code (UBC) for places with earthquakes.

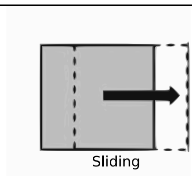
UBC rules have been superseded by ASCE standard 7-05 chapter 13 Seismic Design Requirements for Non-Structural Components. The ASCE standard has five seismic zones instead of four. Furthermore, the site address (coordinates) needs to be put into the US Geological database to obtain the soil amplification factor. The anchorage is drawn and stamped by a structural engineer.

There are three kinds of anchor bolts: epoxy rods, wedge anchors, and snake inserts with conventional bolts. There are three kinds of brackets: “L” brackets, “Z” clips, and ratchet straps. The bolts, brackets, and straps attach the equipment to the floor.



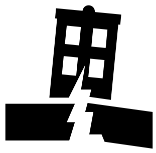
tension keeps feet on the floor

↑ ↑



bolt shear prevents sliding

X X



structural integrity

	Calculation of the bolts per SEMI S2	
328.	For equipment containing hazardous production materials (HPMs), the equipment should be designed to withstand a horizontal loading of **94%** of the weight of the equipment.	✓ SEMI S2 19.2.1
329.	For equipment not containing hazardous production materials (HPMs), the equipment should be designed to withstand a horizontal loading of **63%** of the weight of the equipment.	✓ SEMI S2 19.2.2
330.	Horizontal loads should be calculated independently on each of the X and Y axes, or on the axis that produces the largest loads on the anchorage points.	✓ SEMI S2 19.2.3
331.	When calculating for overturning, a maximum value of 85% of the weight of the equipment, acting at the center of mass, should be used to resist the overturning moment.	✓ SEMI S2 19.2.4

Example calculation:

A machine is 30 inches wide by 40 inches deep by 60 inches tall. The center of gravity is 50 inches above the floor and roughly centered over the footprint. The machine weighs 1000 pounds.

Overturning calculation (worst case direction):

- L1 = the shorter of either the width or the depth = 30 inches width
- L2 = the shorter horizontal distance to the center of gravity = 15 inches
- H = the height to the center of gravity = 50 inches
- W = weight = 1000 pounds

Because 94%H >= 85%L_2, there is a tension reaction “R” at the anchor bolts to resist overturning.

“R” = 1000 pounds * [(94%*50 inches) - (85%*15 inches)] / (2*30 inches) = **571 pounds.** If there are four bolts, and if they resist the overturn in pairs, each bolt needs a tension rating of at least 571/2 = 286 pounds.

Lateral force calculation: Lateral force “F_p” = 1000 * 63% = **630 pounds.** If there are four bolts, and if they resist the sliding as a group, each bolt must have a shear rating of at least 630/4 = 158 pounds.

Anchor bolt specification:

- The strength of the concrete floor must be known. **Example:** 5800 PSI (40 MPa).
- The torque on the wedge anchor is critical. **Example:** 40 foot-pounds (54 Nm).
- The bolt would have to go deep enough to prevent spalling (popping out) of the concrete.
- The structural drawing would recommend a common floor anchor (Hilti, Simpson, Red Head), galvanized or stainless steel, and with adequate shear and tension strength.

8.2 Anchor workmanship and inspection

Companies like Hilti submit their bolts to the ICC testing service, and they reply with an ESR document.

- The contractor should not hammer down the bolt so hard that the top (dog point) can't be read.
- The contractor should not cut off the dog point. Otherwise, the embed cannot be determined.
- The holes should be drilled straight and clean. The holes should be brushed with a rotary brush is a power drill, then vacuumed out with a HEPA. Brush and vacuum repeated 3x times. If the hole is drilled straight, the bolt will drop in perfect. If the hole is drilled crooked, the bolt would need to be hammered down.
- The contractor should have a "stud" finder type device that will locate the rebar before drilling. If they hit a stone or rebar, just move the bracket over maybe 4 inches, or around the corner.
- The attachment screws also come with an ESR-2196. It does no good to put in a heavy-duty anchor and then put a single sheet metal screw into the equipment.
- Epoxy dowels are typically used in foundation walls and thick slabs on the ground level. Epoxy dowels need more embedding than a wedge anchor. Before you use it in the existing hole, confirm the thickness of the slab and make sure the hole is deep enough.

The structural engineer’s drawing specifies the anchorage. This is typically confirmed at plan check. Wedge anchors and epoxy bolts are installed according to their ICC-ES (evaluation service) report.

- ESR-1771 is for Simpson Strong-Tie carbon and stainless-steel wedge anchor.
- ESR-1917 is for Hilti KWIK TZ carbon and stainless-steel wedge anchor.
- ESR-2196 is for Fastenal 1131818 sheet metal screws used to attach the “L” bracket.
- ESR-2251 is for ITW Red Head carbon and stainless-steel wedge anchor.
- ESR-2272 is for Power Fasteners “snake” model 6403SD.
- ESR-2322 is for Hilti HIT-RE epoxy adhesive anchors.
- ESR-2508 is for Hilti SET-XP epoxy adhesive anchors.
- ESR is unknown for the Rawl ThunderStud, a common wedge anchor used in Europe.

The inspecting agency should be either: (1) a licensed engineer, (2) a general contractor, or (3) on the approved list for concrete special inspector. The inspecting agency should be independent of the contractor who is installing the anchors. Many jurisdictions permit the “engineer of record” to sign for the inspection.

If the architectural contractor employee is relatively inexperienced at installing wedge anchors, then:

- Confirm that the floor is correctly marked with the layout of the holes. Unless otherwise specified, the brackets should be as close to the corners as practical.
- Confirm the holes are drilled for proper depth. If the rebar is contacted, the contractor would normally move the bracket. It is very difficult to drill through rebar.

- Confirm the holes are 3x brushed and cleaned out with a dust control vacuum.
- Confirm the wedge anchors are correct (plated or stainless steel, diameter, and length). **Example:** Hilti KB-TZ, 387513, 4½” length, 2” embed,
- Wedge anchors are then gently pounded down into the hole, being careful not to destroy the identification marking on the dog point.
- After brackets are attached, the bolts should be tightened with a proper torque wrench.

If the contractor employee is relatively experienced at installing wedge anchors, then:

- Sample audit the bolt types, making sure of correct diameter, and that they are not sticking out too far.
- Confirm the torque on a quarter of the bolts. If any are loose (one eighth turn short of full torque), check all the bolts.

The inspection report will include:

- Description of the project and the anchorage.
- List of equipment (bolts, brackets, torque wrench, etc).
- Brief sketch or photo.
- Signed affidavit.

Pull test: Anchor inspection usually involves only workmanship. However, sometimes the structural drawing specifies an actual “pull” test. In this case, a specialized jack is attached to the bolt top and several thousand pounds of tension are applied. **Example:** Big Ben or Com-Ten anchor tester.

Problems: The hole hits rebar or a hard loose stone in the concrete. Wedge anchors are not grabbing because of (1) soft concrete, (2) a joint in the concrete, or (3) the stone gouged out a hole. Sometimes there is obstruction from utilities under the raised floor. Workarounds: Use a metal detector to find the rebar. Move the bracket and try again. Or weld on a “kicker”. Or use an epoxy threaded rod. Some creativity is understood. One job I looked at had so much ducting under the raised floor that the worker ended up connecting the tension rods to Unistrut pieces which were clamped on to the steel girders.

9 Technical File for CE and SEMI

9.1 CE Mark and SEMI – introduction

The CE Mark and SEMI conformity reports are basically divided into three major sections.

1. **Technical File.** The first major section is the body of evidence to support a claim of conformity. This piece of the report includes the introduction, summary, equipment description, drawings, critical components, and recommendations. CE and SEMI reports are presented the same way with ~13 sections in common. Technical File is sometimes called the technical construction file.
2. **Conformity checklist.** The second major section is the line-by-line conformity checklist of appropriate code, directives, and standards. CE Directives are similar to OSHA regulations.
3. **Risk assessment.** The third major section is the hazard risk assessment. Risk assessment is required by both CE Mark and SEMI.

9.2 CE Mark and SEMI – sections in common

The CE Mark and SEMI conformity reports have the following sections in common. This is followed by an example of how sections would look in a report.

Information collected from the client:

1. Operating environment
2. Functional description
3. Summary of the material safety data sheets (MSDS)
4. Machine identification
5. Document catalog – drawings, schematics, test plans, data sheets, etc
6. Definitions of preferred and unique terminology
7. Interlock table – door switches, EMO, leak detection, alarm actions, lock-out tag-out, etc.
8. Power and safety components – brand, model, rating, listing
9. Photographs

Information developed during the investigation:

10. Recommendations
11. Hazard risk assessment – SEMI S10, FMEA, what if? etc
12. Fire risk assessment – SEMI S14
13. Inspection and test data – power, temperature, interlocks, etc

9.3 Operating environment

Example: The machine is intended to be operated in an H5 occupancy (semiconductor fab) with ancillary support such as emergency power for ventilation, automatic sprinklers, and life safety. Nearby combustible load and sources of ignition should be minimized. Or a class 1 division 2 gas room, or a chemical room, etc.

9.4 Functional description

Example: The machine is a process panel designed to supply high purity corrosives and solvents to the client tools utilizing one inlet line and eight outlet lines. The machine is suited for a situation that requires critical safety and uninterrupted delivery.

The key components include:

- programmable logic controller
- touch screen display
- alarm lights and buzzers
- gas shutdown button
- controller cabinet
- gas process enclosure

9.5 Summary of chemical hazards according to the MSDS

Toxic	CAS	NFPA 704	Description
Arsine AsH_3	7784-42-1	H=4 F=4 R=2	**Arsine** is a flammable, pyrophoric, and highly toxic gas composed of the simplest of arsenic compounds. At normal temperature and pressure, arsine is a colorless gas with a garlic-like odor. Arsine is the most toxic form of arsenic. Arsine can cause severe damage to red blood cells, lung, liver, kidney, and other organs. Symptoms include dark urine, weakness, shivering, decreased blood pressure, dizziness, headache, nausea, vomiting, and diarrhea. The victim may complain of thirst, have pain in the abdomen and flanks, and may collapse. Symptoms may be delayed. Concentrations of 250 ppm are rapidly fatal, 25–30 ppm are fatal with 30 minutes exposure, and 10 ppm can be fatal at longer exposure times. Reactions between arsine and halogens (e.g. bromine) can be explosive. Rescue workers must wear self-contained breathing apparatus and protective clothing. Skin and eye contact should be flushed with warm water for 15 minutes. Inhalation requires oxygen. Call 911 immediately. Hemodialysis and transfusion may be necessary.
Flammable	**CAS**	**NFPA 704**	**Description**
Hydrogen H_2	1333-74-0	H=0 F=4 R=0	**Hydrogen (H_2)** is a colorless, odorless explosive gas. The main danger for health would be difficulty in breathing. Hydrogen is easily flammable and explodes if exposed to oxidizers such as oxygen, air, and halogens. Ignition temperature depends on concentration, but it can be as low as 400°C. The lower explosive limit (LEL) is a concentration of 4%. Typical hydrogen gas detectors are calibrated to take action at 10-25% of the LEL. The MSDS does not define a permissible exposure limit (PEL).
Pyrophoric	**CAS**	**NFPA 704**	**Description**
Silane SiH_4 Disilane Si_2H_6	7803-62-5 1590-87-0	H=2 F=4 R=3	**Silane and disilane** are flammable, pyrophoric, and potentially explosive at higher concentrations. Silane is irritating to the eyes, skin, and mucous membranes. Silane hydrolysis inside the body may produce silicic acid. All lines and equipment should be bonded to earth ground to prevent sparking.
Corrosive oxidizer	**CAS**	**NFPA 704**	**Description**

Hydrogen peroxide H_2O_2	7722-84-1	H=3 F=0 R=1	Colorless aqueous solution. Used to bleach textiles and wood pulp, in chemical manufacturing and food processing. Vapors may irritate the eyes and mucous membranes. Contact with most common metals and their compounds may cause violent decomposition, especially in the higher concentrations. Contact with combustible materials may result in spontaneous ignition. Prolonged exposure to fire or heat may cause decomposition and rupturing of the container. The product is corrosive and will burn the skin, eyes, pulmonary and digestive tracts unless treated. If swallowed may produce nausea, vomiting, distention, and damage of the gastrointestinal tract. Inhaled vapors may produce delayed lung injury (chemical pneumonia). PPE includes chemical goggles, gloves, and apron.
Corrosive caustic	**CAS**	**NFPA 704**	**Description**
Potassium hydroxide KOH, 10-45%	1310-58-3	H=3 F=0 R=1	Clear aqueous solution. Density 12.8 lb / gal. Corrosive to metals and tissue. Noncombustible. Used in chemical manufacturing, petroleum refining, cleaning compounds. Poisonous and corrosive. The product will cause severe burns to skin, eyes, respiratory track, and gastrointestinal tract. KOH is extremely destructive to all body tissues. Harmful or fatal if swallowed or inhaled. PPE includes chemical goggles, gloves, and apron. NIOSH respirator type N95 (half face piece) or type N100 (full face piece).
Corrosive caustic	**CAS**	**NFPA 704**	**Description**
Tetramethyl-Ammonium Hydroxide TMAH, $(CH_3)_4NOH$ 2-25%	75-59-2	H=4 F=0 R=0	Colorless liquid with strong amine odor. Incompatible with strong oxidizing agents, strong acid, and polyvinylidene fluoride (PVDF). Avoid contact. Severe caustic burns to skin, eyes, mouth, throat, and stomach. Symptoms include burning pain, coughing, nausea, dizziness, and irregular heartbeat. May be fatal if absorbed, inhaled, or ingested. Large exposures can be fatal. The MSDS does not state the exposure limits.

Properties of hazardous materials – examples of alarm action

Gas	PEL	LEL	Monitor action (typical)
Hydrogen 100%	Not defined	4%	0.5 – 1.0% automatic ventilation 1.0 – 2.0% alarm

- ACGIH – American Conference of Governmental Industrial Hygienists
- LEL – lower explosive limit, a minimum concentration in normal air

NFPA 704 and ACA HMIS ratings have good definitions in Wikipedia:

- NFPA 704 ratings: http://en.wikipedia.org/wiki/NFPA_704
- ACA HMIS ratings: http://en.wikipedia.org/wiki/Hazardous_Materials_Identification_System

9.6 Machine identification

	Main tool	Remote box	Pendant	Valve box
Manufacturer	Acme	Acme	Acme	Acme

	Main tool	Remote box	Pendant	Valve box
Model numbers	A	B	C	D
Serial numbers	1	2	3	4
Power	100-240 VAC 1Φ+N+EG, 15A	24 VDC 1Φ+N, < 5 A full load	24 VDC 1Φ+N, < 5 A full load	Just sensors
Evaluation date	August 2013	August 2013	August 2013	August 2013

9.7 Document catalog

The CE Mark Directives refer to these documents as the **Technical File**. The safety report provides a catalog (or index) of the documents. The manufacturer keeps them in Engineering Document Control or in an archive like a notebook, compact disc, or flash memory stick. Refer to CE Mark for more detail.

Title	Drawing number	Date	Pages
Manual set – Installation, Operation, Maintenance	Doc1 revA	Jan 1, 2013	100
Electrical schematic	Doc2 revB	Jan 1, 2013	10
Piping & instrumentation diagram (P&ID)	Doc3 revC	Jan 1, 2013	1
Exhaust calculation (ventilation) study		Jan 1, 2013	1
Seismic tiedown calculation		Jan 1, 2013	1
Component data sheet, power supply, etc		Jan 1, 2013	1
MSDS for process chemistry		Jan 1, 2013	1
MSDS for maintenance chemistry		Jan 1, 2013	1

9.8 Definitions of preferred and unique terminology

Acronym	Meaning		Acronym	Meaning
A	aqueous or acid		AC or ac	alternating current
AI	analog input		AH	alarm horn
AH	alarm horn		AO	analog output
ASP	aspirator		AWD	acid wash drain
BAT	battery		BCDS	bulk chemical distribution system
BHD	bulkhead		BOE	buffered oxide etch
BOM	bill of materials		BPR	back pressure regulator

9.9 Interlock table

Item	Description	Yes/no	Notes
	Lock-out Tag-out		
	Electrical main disconnect	No	At the chemical dispenser
	Clean dry air for pneumatic	Yes	
	Nitrogen for pneumatic and/or purge	N/A	
	Chemical incoming (pressurized)	Yes	
	Chemical outgoing (plumbing)	Yes	
	Emergency Stop		
	EMO	Yes	Drops the valves
	Door open	Yes	

Item	Description	Yes/no	Notes
	EMO export (dry contact and SCADA)	Yes	SCADA network not available
	EMO import (dry contact)	N/A	This option imports the room EMO
	Ground fault	No	
	Cabinet temperature switch	No	
	Air flow interlocks		
	Exhaust pressure switch	Yes	
	Cabinet low Z-purge pressure	N/A	No purge on electrical
	CDA low pressure	Yes	
	Nitrogen low pressure	N/A	
	Fire protection		
	Sprinkler head	No	
	IR or UV flame sensor	No	
	Exhaust temperature switch	No	
	Leak sensing		
	Leak sensing in the secondary containment (SEMI S2 21.2.4.4)	Yes	Float switch, floor sensor, etc.
	Key lock access		
	Electrical compartment	No	
	Chemical pump compartment	No	

9.10 Power and safety components

Critical components for power and safety are identified in NFPA 791 A.3 and the Machinery Directive:

- Protective devices for interrupting current (circuit breakers, fuses, thermal relays)
- Emergency stop, programmable logic controller (PLC), power supply, contactor, push buttons
- Safety interlocks (hardware, firmware, wiring)
- Hazardous classified location (flammable gas or dust)
- Components with a risk of fire or shock
- Guards and proximity sensors
- Chemical pumps, valves, pressure regulators, leak sensors, etc

Description	Brand	Model	Rating	Listing
Actuator, mag reed sw	Hamlin			UL
Circuit breaker	ABB	S201U-K2	250 VAC, 2 A, 10 kA	UL489
Contactor	SquareD			
Control transformer	SOLA	CE2000TH	250 VAC, 25kVA, 2KVA	UL
Disconnect switch	ABB	OT30F3	600 VAC, 30A	UL
Enclosure	Rittal	WM303010NC	NEMA 4 & 12	UL
HMI touch screen	Omron		24VDC, 25W	UL, CE
EMO push button	Allen Bradley			UL, CSA, CCC, CE
Float switch (aqueous)			150 VAC, 0.7A	
Float switch (solvent)				
Fuse, slow blow, 1A	Mersen	ATQR12	600 VAC, 12A, 200kA	UL248

Description	Brand	Model	Rating	Listing
Magnehelic gauge	Dwyer			
Relay, DPDT	Phoenix		24 VDC	UL, CE
Valve, manual	Entegris			
Valve, pneumatic	Entegris			
Valve, solenoid 3-way	SMC		12 VDC	

9.11 Photographs

insert photo	insert photo	insert photo	insert photo
Main tool	**Remote box**	**Pendant**	**Valve box**

9.12 Recommendations

Item	Category	Recommendation	Status
1.	Manuals	Manual should discuss LOTO protocol for the electrical switches, gas and water valves, and ~12 chemical valves. LOTO protocol would include a method for confirming safe energy, such as switch in the off position, pressure relief, pH and conductivity testing. Also, PPE, tools, etc.	Under development.
2.	Labels	Nameplate should state electrical diagram number.	Fixed
3.	Labels	Nameplate should state the short circuit current rating (SCCR). This is the maximum amount of fault current that could go through the machine without self-destruction.	Refer to UL 508A supplement SB
4.	Electrical	Convenience outlet should convert to GFCI.	Disconnected.
5.	Mechanical	Chain and sprocket should have a guard.	
6.	Chemical	Valve stuck open (single point fault) could lead to exothermic reaction and gel plug.	Low probability. Under consideration.
7.	Ergonomic	Touch screen is 6” too high (SEMI S8 8.1.6).	Very low risk. Ok as is.
8.	Training	The manual should discuss the recommended training and skill level for electrical and chemical workers.	

Refer to the book section called **“Fit-up, hook-up, machine, and the typical corrective actions.”**

9.13 Construction requirements

Construction requirements are reviewed according to the respective standards. **CE Mark** will typically be check-listed against IEC 60204 (equivalent to NFPA 79), UL61010, and/or UL60950. **SEMI** will be check-listed against SEMI S2, S8, S13, and sometimes S22. **CE Mark** will include an **EMC test**. **SEMI** will include an **ergonomic** review, a **seismic** tie-down calculation, and a **ventilation** study. Please refer to the chapters called “CE Mark” and “SEMI” for these specifics.

If there are conflicting requirements between the US, Europe, and SEMI requirements, develop for the “lowest common denominator”. **Example:** in the US, the equipment ground wire is green or green/ yellow and sized (AWG) according to the feeder circuit breaker (60 amp = #10). In Europe, the equipment ground wire is colored 50/50 green/yellow and sized (metric) as a portion of the load wire gauge. Therefore, make the ground wire 50/50 green/yellow and large enough to satisfy both markets.

Compliant vs. not applicable. Sometimes there is confusion about a **requirement** being not applicable vs. an **equipment feature** being not applicable. Both the standard and the equipment must be judged, especially if there is conflict among multiple standards. **Example:** The SEMI S2 requirement for hi-pot testing is not reasonable and is therefore not applicable. **Example:** The SEMI S2 requirement for ionizing radiation is reasonable but the "equipment feature" is almost never applicable. **Example:** The NFPA 79 standard has almost no mention of mechanical safeguards.

9.14 Manuals and hazard warning labels

Manuals are reviewed according to the respective standards in the report, such as the Machinery Directive or SEMI S13. However, for best practice, manuals should be written to meet the requirements of several common industry standards including CE, NFPA, SEMI, and UL.

Hazard warning labels are reviewed according to ANSI Z535.4 but the results are not normally check listed. Recommendations would be noted. Refer to **Manuals and Hazard Warning Labels**.

10 CE Mark

10.1 What is the CE Mark?

CE is an abbreviation for *'Conformité Européenne'*, French for 'European Conformity'. The CE Mark for machinery is the manufacturer's guarantee that the machine meets the safety requirements for the European Union. The safety requirements are expressed in numerous **Directives** that have the force of law in Europe. Evidence of conformity can be satisfied by a direct assessment of the EH&S Annex (Environmental Health and Safety), and by doing a line-by-line review of appropriate normalized standards (European norms). A **normalized standard** is a harmonized reconciliation of numerous prior standards from different regions, countries, languages, and trade organizations.

In the US, the equivalent to Directives and Norms would be OSHA (Occupational Safety and Health) plus the consensus codes and standards originating from groups like UL, NFPA, ICC, IEEE, NEMA, SEMI, etc.

In Europe, the primary regulations for machinery are the Machinery Directive, the Low Voltage Directive, the EMC Directive, the Pressure Directive, and the WEEE/RoHS Directives.

There are two choices for exporting equipment into the European Union:

- If the product is going in **temporarily**, you provide a **Carnet** document to the customs officer. The officer will typically permit the product for a period, perhaps a year. Then you must take it back out. Sometimes a bond is posted.
- If the product is going in **permanent**, you need a CE Mark Declaration and CE on the product.

European standard organizations:

- ISO (International Standards Organization) is a management framework similar to ANSI.
- EN (European Normalized) standards are for the CE Mark market.
- IEC (International Electrotechnicial Commission) standards are typically for electrical and electronic equipment.

10.2 Hierarchy of CE Mark evidence

The hierarchy of CE Mark evidence of conformity can be thought of as four levels:

1. The Declaration that goes with the equipment manifest.
    - Declaration of Conformity or
    - Declaration of Incorporation
2. The CE Mark logo goes on or next to the nameplate.
3. The safety report – the index of technical documents and checklist review of the standards.
4. The Technical File or TF, sometimes referred to as technical construction file or TCF.

The **Declaration** gets the product past customs and into the European Union.

CE Mark means the product conforms to the safety requirements of the EU Directives and Standards. The CE Mark logo is like a visa stamp on a passport. It permits the product to freely transit the national borders of the European Union member countries. **Example:** from Germany to France.

10.3 Declarations of Conformity and Incorporation

The **Declaration of Conformity** (DoC) and **Declaration of Incorporation** (DoI) are typically a single page document that goes with the equipment manifest. The DoC is for a complete stand-alone product.

The DoI is for a product that is part of a larger assembly, such as a power supply, control panel, or spare part. It cannot stand alone. UL refers to this type of product as a “recognized component”.

The Declaration includes the manufacturer and model, a list of the appropriate European Directives and harmonized standards, and the name and signature of the responsible manager.

The Declaration also identifies the **authorized representative within the European Union**. This agency hosts the Technical File.

10.4 CE Mark safety report

The safety report includes a checklist assessment of the environmental health and safety (EH&S) sections of the relevant Directives, and a checklist assessment of any codes and standards that have direct applicability. Under the CE law, most products are “self-declared” to be CE conforming, but others must be certified by a European Notified Body (sometimes referred to as a No-Bo).

Examples of products that require certification by a Notified Body:

- Wood saws (Machinery Directive 2006/42/EC)
- Medical devices that touch or diagnose a patient (Medical Device Directive 2007/47/EC)
- Toys (Toy Safety Directive 2009/48/EC)
- Pressure vessels and plumbing above certain limits (Pressure Equipment Directive 2014/68/EU)
- Cranes and hoists (Lift Directive 2014/33/EU)
- ATEX category 1 (continuously present) and category 2 (electrical)

The Directive EH&S annexes are directly assessed. Manuals should be comprehensive. Standards (e.g., IEC 60204) are check-listed line-by-line. The electrical testing is conducted to the worst case of either the US or European standards. **Example:** The US has a higher hi-pot voltage (1500 VAC or 2121 VDC) compared to Europe (1000 VAC or VDC) but Europe sometimes has a larger ground wire.

Summary: In the case where the CE law permits a **self-declaration**, most companies engage a third party for an unbiased professional report. The overall report should look clean, neat, and completely detailed. The report is both a safety assessment and an excellent marketing tool.

Example: CE Mark conformity report

The following acronyms are used in the table below (same as the SEMI report):

- **Conforms to the Stated Criteria (CSC)** – equipment aspects that match the criteria stated in the text of the paragraph, also known as “prescriptive” conformance.
- **Conforms to the Performance Goal (CPG)** – equipment aspects that do not match the stated criteria, but do match the performance goal of the paragraph and present an acceptable risk according to the risk assessment method of SEMI S10.
- **Does Not Conform (DNC)** – equipment aspects that do not match the stated criteria and does not conform to the performance goal, or, for which there is insufficient information available to reach another conclusion.
- **Not Applicable (N/A)** – there are no equipment aspects to which the paragraph pertains.

	Machinery Directive 2006/42/EC Annex 1 Essential Health and Safety Requirements	**Comments**	**MD EHS**	**CSC**		**CPG**	**DNC**	**N/A**
1.	**General remarks**							
2.	**Principles of safety integration**							
3.	Machinery must be designed and constructed so that it is fitted for its function, and can be operated, adjusted and maintained without putting persons at risk when these operations are carried out under the	The system was evaluated to ensure that the system safety hierarchy was followed in design and	1.1.2 (a)	X				

	Machinery Directive 2006/42/EC Annex 1 Essential Health and Safety Requirements	Comments	MD EHS	CSC		CPG	DNC	N/A
	conditions foreseen but also taking into account any reasonably foreseeable misuse thereof. The aim of measures taken must be to eliminate any risk throughout the foreseeable lifetime of the machinery including the phases of transport, assembly, dismantling, disabling, and scrapping.	construction. First, design out all possible hazards, then guard against remaining hazards, then warn of residual risks. The tool is well suited to its primary task of circulating high purity chemicals through a series of particle filters.						
4.								
5.								

	Electrical Equipment for Measurement, Control, and Laboratory Use	Comments	61010	CSC	CPG	DNC	N/A
6.	**Marking and documentation**		5				
7.	**Marking**		5.1				
8.	General (readily visible)	Nameplate inside and outside.	5.1.1	X			

This line-by-line conformity assessment goes on for over 500 line items.

10.5 Technical File – Machinery Directive

The Machinery Directive Annex VII begins with: "The Technical File shall comprise the following: a) a construction file . . . " Both **Technical File (TF)** and **technical construction file (TCF)** are acceptable terminology but preference is moving towards Technical File.

The Technical File is the body of evidence that supports the claim of conformity stated in the Declaration. Each Directive has its own requirements for evidence. **Example:** The Machinery Directive Annex VII states the requirements (both stand alone and partially completed machinery) as follows:

- Instruction manuals.
- General and technical description, and an overall drawing of the machinery.
- Detailed explanation of the control circuits and safeguards.
- Drawings of electrical, mechanical, and plumbing (P&ID), both high level and detailed.
- Component data sheets and application notes, especially for parts critical to power and safety,
- Material safety data sheets (MSDS) for chemicals approved for operation and maintenance.
- Risk assessment, guards, residual risks, and hazard warning labels.
- Technical reports, quality control plan, calculations, notes, test results, certificates.
- Copy of the Declaration, which includes the Directives and Standards.

This information can be thought of as three levels:

1. Information typically provided with the machinery (eg. manuals and schematics).
2. The safety conformity report (checklist of standards, risk assessment).
3. Proprietary information (quality control, calculations, test procedures, source code, etc.)

The Technical File can be produced from an ISO 9000 document control system. The Technical File can also be a notebook or an archive compact disk.

10.6 Hosting the Technical File

The Technical File is hosted **within the European Union** by the manufacturer or the authorized representative. Whoever has the TF would produce it in response to a request from:

- **Market surveillance**, a national authority responsible for inspection and auditing, or
- **Subpoena discovery**, part of an investigation related to an accident, injury, or lawsuit.

The Technical File must be within the border at the time the product goes on the market. It doesn't matter where the product originates. If the manufacturer is not established in the EU, the Technical File would typically pass to the customer, an import broker, a law office, or a third party hosting site (which costs ~200 Euros/year). The person hosting the technical file:

- must have the Technical File in possession or know where it is located within the EU, and
- be able to produce the Technical File as soon as possible when requested by national authorities.

The Declaration includes the authorized representative. The Declaration is typically in the manual and attached to the equipment manifest. The Technical File must be kept 10 years from the last date of manufacture of the product, unless the directive expressly provides for some other duration.

10.7 Market surveillance

Market Surveillance is a national authority. Their role is to:

- Verify that only CE Marked products are on the market shelves.
- Challenge the product if it has been inappropriately CE Marked.
- Withdraw non-conforming products from the market.

The Technical File (TF) is the body of evidence that supports the Declaration. The TF is requested by inspection or audit, not systematically. Once requested, the TF part A should be made available as soon as possible. Extra time is reasonable for part B, considering the volume and format (written or computerized). Market surveillance procedures are coordinated to prevent repeated submission of the same Technical File to different inspection authorities.

The TF will be examined by technically competent agencies and, if found in order, the matter shall pass. If the manufacturer or the authorized representative cannot produce the TF, or if the TF is inadequate, then the manufacturer may be ordered to recall the product. The manufacturer may even be blacklisted from the entire European market.

The TF request is proportional to the requirements of the inspection carried out. The manufacturer or authorized representative should first respond by providing only a summary of the essential technical data (Technical File part A, in effect, the report). This will be reviewed. If there are still doubts about the conformity of the product, then specific points (Technical File part B) are then requested and provided. The full TF is requested only if reasonably necessary.

Reference: CE Marking Market Surveillance Mechanism: http://www.acebuiss.com/ce/mkt.htm

Note: Complaints often originate from a competitor. "Et tu, Brute?"

10.8 Risk assessment and risk reduction

CE Mark safety assessment includes a hazard analysis based on a well-known scientific method. Hazard analysis is primarily a system for identifying hazards and scoring them for probability, severity, detection, and avoidance. The goal is to produce a product with acceptable risk.

Recently, the CE Mark has introduced a new requirement, ISO 13849 (similar to the US standard ANSI B11.TR3.2000), which determines the probability of an accident due to the failure of a safety device. **Example:** What would happen if a circuit breaker fused shut and could not open during an overload?

The result is a performance level score of **dangerous failures per hour**. Highly dangerous environments must use safety components with intrinsically low failure rate.

10.9 CB Scheme – international equivalent of an NRTL listing

CE Marking is a mandatory regulation and not a test mark. It was created by the European Union to show that the product meets the essential health and safety requirements, and that the product may be traded freely within Europe. The CE Mark logo is attached to all products within the scope of the European Directives and therefore has no special marketing value, especially since the CE Mark safety reports are self-declared.

CB (certification body) is an international program for the exchange of product test results among **participating laboratories** around the world. A CB certificate indicates that the product test report has quality approval. The advantage to the manufacturer is:

- Minimum or no retesting for a certain regulatory region.
- Additional samples are not damaged or destroyed.
- Higher priority processing of the listing.
- Reduced time and effort.

European testing can be thought of as testing houses and testing certificates. **Example:** In Germany, the brand name testing house would be one of the various TUV organizations. Also in Germany, the most recognized voluntary test mark would be the **GS (Geprufte Sicherheit)** which translates to **approved safety**, a sticker that indicates that the product was tested and certified for safety according to the German Equipment Safety Law, by a "trustworthy, independent institute".

10.10 Directives and standards that apply to machinery

The EU Parliament has an extensive set (hundreds) of product requirement documents covering nearly every aspect of performance and safety for nearly every possible kind of product. The requirements are generally in a two tier structure called "Directives" and "harmonized (normalized) standards". The harmonized standards are sometimes referred to as "norms".

Harmonized standards form a hierarchy:

- Type "A" – Basic safety standards that cover design principles and concepts.
- Type "B1" – Group standards for general safety. (e.g. 13849)
- Type "B2" – Group standards for safety devices.
- Type "C" – Technical standards for the safety of specific machinery

The CE Mark process involves several steps:

1. Determine which Directives apply to the given product.
2. Determine whether to assess the general requirements in the Directives (the annex covering environmental health and safety), and/or by the specific requirements of an appropriate normalized standard.
3. Conduct the assessment and testing.
4. Conduct a risk analysis for both hazard and fire safety.
5. Produce a comprehensive safety report.
6. Assemble all reports into a Technical File.

Now we will get into the specific application of the six most common Directives.

- Low Voltage Directive, 2014/35/EU. Note: 2006/95/EC is retired April 20, 2016.
- Machinery Directive, 2006/42/EC
- Electromagnetic Directive, 2014/30/EU. Note: 2004/108/EC is retired April 20, 2016.

- Pressure Equipment Directive, 2014/68/EU. Note: 1997/23/EC is being retired.
- Atmospheric Explosive (ATEX) Directive, 2014/34/EU. Note: 1994/9/EC is retired April 20, 2016.
- Restrictions of the Use of Certain Hazardous Substances (RoHS) 2011/65/EU.

Example. Let's take the case of a plasma vacuum chamber and go through the selection of Directives:

- **Low Voltage Directive** applies because it is electrical equipment operating over 50 VAC.
- **Machinery Directive** applies because it is industrial with moving parts, and not a household appliance.
- **Information Technology Directive** does not apply because the tool is not office equipment.
- **Electromagnetic Compatibility Directive** apples, especially susceptibility, to make sure that the machine does not reset when someone starts talking on a handheld radio.
- **Pressure Directive** does not apply, because the PED refers to positive pressure (>1.5x over atmosphere), not to vacuum.
- **Atmospheric Explosive Directive** might apply, depending on the process gases described in the operating manual, and on the classification of the room at the factory.

10.11 Low Voltage Directive (LVD 2014/35/EU)

The LVD applies to electrical equipment operating between 50-1000 VAC, or 75-1500 VDC, and the risks are primarily electrical. The Directive itself is very thin. Therefore, conformity depends more on the relevant standard. There are three standards for consideration:

- Information Technology (office equipment), use IEC 60950 or UL 60950.
- Electrical Equipment (industrial without moving parts), use IEC 61010 or UL 61010.
- Machinery (industrial with moving parts), use IEC 60204, equivalent to NFPA 79.

UL 61010-1 vs. IEC 61010-1:

- Abstraction Engineering is currently using UL 61010-1 edition 3 (2012).
- IEC 61010-1 edition 3.1 (2016) is understood to be a minor amendment.
- UL 61010-1 (2019) is a proposal still identified as edition 3.0. Likely there is a minor amendment.

NFPA 79 vs. EN 60204-1 vs. IEC 60204-1:

- Abstraction Engineering is currently using IEC 60204-1 edition 6 (2016).
- IEC 60204-1 edition 6.1 (2021) 570 pages is an amendment to temporarily reconcile minor EMC and grounding differences between EN 60204-1 and IEC 60204-1.
- EN 60204-1 (2010) + amendment (2019) is similar.
- IEC/EN 60204-1 edition 7 is expected to "stabilize" around 2027.

10.12 Machinery Directive (MD 2006/42/EC)

The Machinery Directive defined a machine as "an assembly of linked parts or components, and at least one of which moves, with the appropriate actuators, control, and power circuits joined together for a specific application, in particular for the processing, treatment, moving, or packaging of a material." Below is a link for an excellent booklet from Allen-Bradley called "Understanding the Machinery Directive".

http://literature.rockwellautomation.com/idc/groups/literature/documents/rm/shb900-rm001-en-p.pdf

Can both Machinery and Low Voltage apply, or is it either/or? I have seen this interpretation both ways. **Example:** Machinery Directive would not strictly apply to a chemical cabinet with pumps. But Machinery Directive is often referenced because the documentation requirements are so well stated.

10.13 Electromagnetic Compatibility (EMC 2014/30/EU)

Contribution is recognized from Mark Montrose, EMC expert consultant.

10.13.1 EMC requirements

US emission testing is regulated by FCC part 18 which covers industrial machinery. FCC part 18 applies to a machine with "intentional" radiation such an RF plasma generator, X-ray, etc.

Europe emission testing is regulated by IEC/EN 55011 which covers industrial, scientific, and medical. IEC/EN 55011 covers both non-intentional radiation (part 1) and intentional radiation (part 2).

The EMC Directive states that equipment shall be designed and manufactured, having regard to the state of the art, as to ensure that:

1. The electromagnetic disturbance generated does not exceed the level above which radio and telecommunications systems or other equipment cannot operate as intended.
2. Equipment must have a level of immunity to electromagnetic disturbance expected for its intended use that allows it to operate without unacceptable degradation or performance.

EMC requires two types of compliance: emissions and immunity.

1. **Emissions** (causing interference) – Outgoing energy radiating through free space or conducted through wires. The radiated energy is measured with an antenna and a spectrum analyzer.
2. **Immunity** (susceptibility to interference) – Incoming energy that could disrupt the equipment, leading to a reset, shut-down, malfunction, or safety hazard. The interference comes from:
   - Radiated emissions from handheld radios and cell phones or commercial broadcast stations.
   - Electrostatic discharge, either direct contact or through the air.
   - Conducted disturbance that includes fast transients, power line surge and disruption, RF energy coupling into cables, and noise originating from the end use environment.

The EMC Directive classifies products into two groups: portable and fixed.

1. **Portable –** easily moved around. **Examples:** computers, cell phones, televisions.
2. **Fixed** – not easily moved around. Situation **examples:**
   - Permanently attached to the building such as computer rooms, boilers, printing presses, food processing equipment, large industrial tools, etc.
   - Complicated facilitation that requires a cleanroom environment, industrial power, clean water, compressed air, ventilation, air conditioning, process gas, safety alarms, etc.
   - A component that cannot operate by itself, but is part of a larger, more complete system.

Fixed equipment requires good engineering practice, knowledge of intended use, and awareness of the operating environment. Documentation needs to be kept for as long as the equipment is in operation.

10.13.2 EMC compliance – Standards route or Technical File route

10.13.2.1 Standards route

Certification by the Standards route is typical for small, high-volume, portable, digital consumer products that can be easily set-up in an ISO 17025 accredited test laboratory. Standards route can be applied to any product, either portable or fixed installation. Compliance requires a passing test report which is kept in the document control center. The EMC Declaration is simple. An EMC Technical File is not needed.

The Standards route requires testing to all **applicable European EMC standards,** both emissions and immunity, even if the tests are not appropriate for the end use environment. Test requirements cannot be modified or waived. Results are pass or fail. Immunity testing can sometimes be destructive. **Examples:** voltage surge and ESD.

EMC testing laboratories are time consuming and expensive – sold in time blocks. Failures must be analyzed, redesigned, and retested similar to trial and error. You must take the product back to the lab, wait for days or weeks depending on the backlog, pay the fee again, and hope for the best.

10.13.2.2 Technical File route

Certification by the Technical File route is typical for large, low volume, highly customized industrial tools. The EMC Technical File is the documented body of evidence that supports the claim of EMC conformity stated in the Declaration.

The Technical File route is used in the following situations:

- EMC standards don't exist or can't be applied to this type of product. **Example:** EMC immunity for vehicles, semiconductor manufacturing, large industrial machine tools, etc.
- EMC testing can't be done in an ISO 17025 EMC test laboratory because of facilitation. **Example:** size, weight, 3Φ power, compressed air, ventilation, life safety support, clean room, assembly with other machines in an industrial environment, etc. The EMC test must occur on site (in situ).

The EMC expert creates a custom **test program** by choosing only appropriate tests. Some immunity tests can be waived because:

- Not relevant for the intended environment of use. **Example:** fast transient, surge, conducted immunity, magnetic field disruption along with voltage dip and interruption.
- Relevant only for specialized products such as automotive electronics, intentional transmitters, and power generating subsystems.
- Extremely difficult for logistical reasons.

The EMC expert has knowledge of test requirements, applications, and end use. The EMC expert then creates the EMC test plan, Technical File, and professional opinion stating that some tests are done but others are waived for the reasons mentioned above. Compliance depends on a detailed report that describes the elements of the product and its use within a specific environment.

Combination of Standards route and Technical File route

In this case, the ISO 17205 EMC laboratory is packed up on a large truck and brought on site. The EMC expert does most testing under the credentials of the lab and generates a test report and a Technical File. Only some of the brand name labs are willing to go on site. The cost is similar to a trip to the lab.

10.13.3 EMC expert credential

The EMC testing agency must have a **Certificate of Assessment** issued by an official ISO 17025 assessor, someone affiliated with a Notified Body. This credential process is similar to ISO 9000 for quality control. The credential means you are certified to have the required competence, capabilities, and control systems in place. The process is subject to periodic auditing.

10.13.4 EMC Technical File vs. Machinery Technical File

Machinery and Low Voltage Directive issues are primarily about powerful, low speed electro-mechanical power parts such as switches, circuit breakers, motors, heaters, transformers, guards, etc. In contrast, the EMC issues are primarily about low voltage high-speed digital electronics. The Technical Files are different because they tell a different story.

Assemblies are analyzed to confirm if they can create RF energy, and if they can be disrupted by external electromagnetic effects. Product changes, such as upgrading to a faster processor, must be reviewed for EMC. Therefore, the product should be under rigorous engineering change control and quality control.

10.13.5 EMC statements of work – three levels

1. **EMC professional opinion letter.** This is a basic service for a control panel or spare part shipping with a Declaration of Incorporation. EMC is generally exempted for industrial equipment if there are only analog components or if the digital components are operating below 9 KHz. This letter states that the documentation was reviewed, and to the best judgment of the EMC expert, the panel should not be in violation of the essential requirements of the EMC Directive. It is possible (but unlikely) that the European Market Surveillance could complain in the course of an investigation. The product could be held up in customs.
2. **EMC Technical File.** This is a higher-level service for a complete stand-alone system in a closed metal cabinet, with slow speed analog power parts or moderate speed digital parts, and with no unshielded control cables exiting the cabinet. The EMC TF (10-20 pages) is the detailed body of evidence that supports the claim of EMC conformity stated in the Declaration of Conformity.
3. **EMC Technical File and testing.** This is a full service for a complex system with cables, controls, and motors etc. outside of the metal cabinet. Full service includes an on-site test for:
   - Radiated interference – signals coming out of the machine that typically interfere with other electrical equipment, including telecommunication networks.
   - Susceptibility – signals going into the machine that could cause safety hazards or system anomalies, typically from handheld radios and cell phones.
   - Electrostatic discharge – caused by environmental effects and electrical switching devices in the facility plus charge buildup on a person's body.

Emission testing is typically required for a semiconductor tool because of:

- High complexity.
- Large potential for yield loss (messed up wafers and circuits due to misalignment).
- High speed digital logic circuits.

Emission testing is typically not required for a power tool because of:

- Low complexity.
- Low potential for yield loss.
- Digital logic is generally low speed and contained within a chassis that has FCC compliance.

Electrostatic discharge could be excused if:

- the controller is hardened such as an Allen-Bradley or Siemens, and if
- all the control panels, etc. have some kind of regulatory mark (ESD tested), and if
- all the control panel cables, etc. are properly grounded and shielded.

Immunity is tested with common walkie-talkies (citizens band, police, fire) transmitting on bands 27/154/462 MHz from close range, plus a common cell phone, plus noise injected on the power mains.

10.13.6 EMC reference standards

EMC standards are divided into two groups: product family and generic. If there is no product family, then the generic standards apply. The two groups are further divided into emissions and immunity.

EMC product family standards – emissions

- EN55011, industrial scientific and medical equipment (ISM), radio disturbance
- EN55013, broadcast receivers and associated equipment, radio disturbance
- EN55014, household electrical appliances, portable tools, etc., radio disturbance
- EN55022, information technology equipment (ITE), radio disturbance
- EN55024, information technology equipment (ITE), immunity
- EN55032, multi-media equipment (CISPR 32), emission
- EN61000-3-2, harmonic currents, emission

- EN61000-3-3, voltage fluctuations and flicker in low voltage supply systems

EMC product family standards – immunity

There are very few products that fall into a pre-defined family for immunity. Therefore, generic standards are used. **Example:** IEC 61000-4-x series.

EMC generic standards – immunity and emissions

- EN61000-6-1, residential, commercial, and light industrial environments, immunity
- EN61000-6-2, industrial environments, immunity
- EN61000-6-3, residential, commercial, and light-industrial environments, emissions
- EN61000-6-4, industrial environments, emissions

EMC immunity standards (called out in the EMC generic standards)

- EN 61000-4-2, electrostatic discharge (ESD)
- EN 61000-4-3, radiated electromagnetic field
- EN 61000-4-4, electrical fast transient (EFT) burst
- EN 61000-4-5, surge
- EN 61000-4-6, conducted disturbance by RF fields
- EN 61000-4-8, magnetic field disturbance
- EN 61000-4-11, voltage dips and interruption

10.13.7 EMC summary

Portable products are tested in a commercial testing lab. Configurations are tested one-by-one. The lab is strictly third party. The ISO 17025 assessment credential considers troubleshooting to be a conflict of interest. An EMC Technical File is not needed.

Industrial products are tested on-site. Emission and immunity tests are rationalized according to the product and the operating environment. The EMC Technical File makes up for the waiver of certain tests. On-site testing is complete in one day. An EMC expert can diagnose and rework the product, as necessary. The Technical File route can certify many products. Reports are easily amended. The cost is about half compared to a lab, and there is much less administrative overhead.

Example: A company produces a high temperature, small footprint furnace for a lab environment. EMC testing was recommended because it was a new model, it had high speed logic, and it was going to a laboratory environment. The walkie-talkie test shut down the system. Investigation concluded that there was **inadequate grounding and shielding** on cables that tie the user interface into the equipment controller logic. This was easily fixed with a change of cables.

10.14 Pressure Equipment Directive (PED 2014/68/EU)

The Pressure Equipment Directive applies to a chamber with pressure of > 1.5x the normal atmosphere, and sometimes to the integration (plumbing, rupture disk, etc).

The Pressure Equipment Directive has two primary categories: vessel and plumbing. Within the categories, there are different requirements that depend on:

- Combination of pressure and volume.
- Diameter of the pipe (typically exempt up to 25 mm diameter).
- Compressed inert gas (air, nitrogen, steam, scuba, water heater, etc).
- Compressed hazardous gas (acetylene, hydrogen, propane, corrosive, etc).

Note: pressurized flammable liquid (**example:** cyclohexanone) can be treated with lower risk (like inert gas) if the maximum temperature is kept below the chemical flash point. Refer to Classification, Labeling, and Packaging (CLP) Regulation (EC) 1272/2008 for chemicals.

The PED prescribes increasing scrutiny based on where the product lands in the charts, such as pressure vs. volume, inert or hazardous gas, diameter of the plumbing, etc. Below is a simplified hierarchy:

1. Production control.
2. Production quality assurance (ISO 9000).
3. Design qualification by a mechanical engineer.
4. Design qualification by a NoBo approved mechanical engineer.
5. Weld coupon and welder qualification by a NoBo approved mechanical engineer.
6. Material assay by a NoBo approved laboratory.
7. Hydrostatic pressure test on every production unit by a NoBo approved mechanical engineer.
8. All documents submitted to the NoBo for a one-by-one PED Declaration.

10.15 Atmospheric Explosive Directive (ATEX 2014/34/EU)

10.15.1 ATEX applicability and requirements

In the US, the ATEX equivalent regulations are known as Explosion Proof or Hazardous Classified Locations. Requirements are defined in several standards including OSHA 1926.407, NEC article 500, NFPA 496, and a 2014/34/EU is relevant for:

- use of equipment in potentially explosive atmospheres (article 1-3 definitions), or to
- prevent formation of explosive atmospheres which may be produced or released by equipment (annex II 1.0.1).

The US has two "divisions" for normally present and normally confined. ATEX has three "categories". Manufacturers can self-certify category 2 non-electrical equipment and category 3 electrical equipment.

- **Category 1** – Equipment in this category is intended for use in areas in which explosive atmospheres caused by gases, vapors, mists, or air/dust mixtures are **present continuously**, for long periods or frequently.
- **Category 2** – Equipment in this category is intended for use in areas in which explosive atmospheres caused by gases, vapors, mists, or air/dust mixtures are **likely to occur**.
- **Category 3** – Equipment in this category is intended for use in areas in which explosive atmospheres caused by gases, vapors, mists, or air/dust mixtures are **unlikely to occur** or, if they do occur, are likely to do so only infrequently and for a short period of time.

10.15.2 Summary of ATEX applicability

- **ATEX Directive** chapter 1, article 1, describes the application, both included and excluded from the scope. Annex 1 describes the classification of equipment. Annex II describes the environmental health and safety requirements.
- **ATEX Guidelines** (second edition, December 2017, 238 pages). This document has much more extensive discussions concerning the applicability. This replaces the fourth edition for 1994/9/EC.
- ATEX would apply if there is: (1) fuel present, (2) air at atmospheric pressure, and (3) a source of ignition from the equipment itself. ATEX would not apply if air is not present. {Guidelines page 25}
- **Example:** ATEX could apply to a machine that requires large amounts of undiluted IPA (with fumes), and the cleaning occurs while the machine is energized. ATEX could be excused if:
  - the IPA were in small amounts on wipes,
  - diluted to 30% concentration,
  - the clean-up occurred with adequate ventilation,
  - the machine was de-energized during the cleaning,
  - and with proper warning labels, etc.

- ATEX would not apply to machinery having a potentially explosive atmosphere inside under normal operating conditions but having no interface to external potentially explosive atmospheres . . . as an integrated whole. This situation falls under the Machinery Directive.
- ATEX would not apply if the only source of ignition is static electricity on moving plastic parts.
- ATEX would apply if an explosion could spread to the entire unburned mixture.
- ATEX would not apply if the unburned mixture is isolated within a tank. {Guidelines page 28}
- ATEX applies to normal operation and maintenance, and routine faults. ATEX would not apply to rare failures such as a burst line or a cracked vessel. In this context, the accidental leakage would be an unexpected event, not tolerated, and typically results in failure analysis.
- ATEX would not apply to mitigation equipment (eg. ventilation) unless that equipment is intended to operate within the explosive atmosphere.
- ATEX is primarily for components. Customers sometimes ask for ATEX because they are confused about what they need. The response should be: *"My equipment is considered to be ATEX category 3 (self-certified) because the purged electrical cabinet would normally prevent the infiltration of flammable vapors. All components outside the purged cabinet are rated intrinsically safe or explosion proof."*

2020 update: Prior to 2020, the CE Mark conformity reports were treating solvent tools as "ATEX not applicable" if the tool had a purged electrical compartment whose components were the only source of ignition. At a well-known fab in Europe, who is now relying on the opinion of a well-known engineering contractor, a purged cabinet is no longer adequate under certain conditions:

- If there is exposure to fumes during a worst-case leak (in the room);
- If there are certain components, capable of sparking, that are mounted on the outside of a panel or passing through the panel (switches, lamps, gauges, HMI flat panels, etc.);
- If there are customer add-on (particle counter, pH meter, conductivity meter, etc.).

A quick fix is to selectively swap the non-ATEX-compliant components or put them into small mini-purged cabinets. The CE Mark report will reference the opinion of a Notified Body or the vendor same as how the situation is handled for voltage corruption, ventilation, and structural.

How to read an ATEX label (from left to right):

- CE: complies with the ATEX European Directive
- xxxx: is the registration number of the notified body
- Explosion protection specific marking: (<Ex>)
- Equipment group: I = mines, II = other areas
- Equipment category: methane and dust (M1-M2), gas and vapor (1G-2G-3G), dust (1D-2D-3D)
- Environment: explosive gas and dust (group A-B-C-D-E-F-G), acetylene, hydrogen, etc
- Explosion protection included: (Ex)
- Protection concept type: dust (dA-dB-dC). ~25x categories
- Atmospheric group (hazard and zone): gas (class I), dust (II), fibers (III) and zone (A-B-C)
- Temperature class: T1=450°C, T2=300°C, T3=200°C, T4=135°C, T5=100°C, T6=85°C
- Equipment protection level: similar to protection concept ~25x categories

Reference: Intertek hazardous locations, hazloc-and-explosive-atmospheres-poster

10.16 Restriction on Hazardous Substances (RoHS-3 2015/873)

RoHS (restriction of the use of certain hazardous substances) and **WEEE** (waste electrical and electronic equipment) are companion documents. They originated as 2002/95/EC and 2002/96/EC, both published on January 27, 2003. RoHS is the law in Europe, China, Taiwan, Japan, and many states including California where it is known as proposition 65. Most products must meet RoHS.

Heavy metals: <0.01% cadmium, <0.1% chromium, <0.1% lead, <0.1% mercury, by weight, for a **homogenous assembly** where the separation of the materials is difficult, like an integrated circuit, or the plating on a connector. Some alloys are exempt but not circuit board solder.

- AISI 12L14 carbon steel (also known as sulfurized and phosphorated grade carbon steel, UNS G12144, and "lead" steel) is composed of (in weight percentage) 0.15% (max) carbon (C), 0.85-1.15% manganese (Mn), 0.04-0.09% phosphorus (P), 0.26-0.35% sulfur (S), 0.15-0.35% lead (Pb), and the base metal Iron (Fe). As an alloying element in steel . . . up to 0.35% lead by weight is exempted. RoHS Annex III section 6(a).
- Copper alloy (brass) can contain up to 4% lead by weight. RoHS Annex III section 6(c).

Halides and halogens: < 0.1% antimony, <0.09% bromine, <0.09% chlorine, and <0.15% combined bromine and chlorine. Antimony and halogens were commonly used as flame retardants in polymers.

Some suppliers have split their product lines into RoHS and non-RoHS compliant. Some suppliers claim their products to be non-RoHS just to avoid the liability. The main problem for RoHS is that non-lead alloys require a higher melting temperature.

There is an easy way and a hard way to confirm RoHS. Easy way: get a certificate from your component manufacturer. Hard way: check your parts with an X-ray fluorescence gun, commonly known as an XRF. Several companies make it. The XRF can be bought or rented.

- http://www.bergeng.com/rental-PMI-XRF-Analyzer-cat.html
- http://www.niton.com/en/niton-analyzers-products/which-xrf-analyzer-is-right-for-me?

10.17 Environmental Impact Dossier

Europe has approved the "EU Sustainable Development Strategy". This framework has seven areas: climate change and clean energy, transportation, production and consumption, resource conservation, public health, social inclusion, and global poverty. This is similar in scope to SEMI standard S23.

This is a relatively new addendum to the CE Mark compliance reports. The dossier sections discuss resource conservation, emissions, liquid and solid waste, and recycling. The air emissions include global warming gas (GAG), hazardous air pollutant (HAP), ozone depleting substance (ODS), volatile organic compound (VOC), organic dry solids (ODS), and halogens (bromine, chlorine, fluorine, etc).

10.18 US National Electrical Code vs. Europe IEC 60364

NEMA has a free article (about 100 pages) describing the differences between the NEC and IEC 60364.

Item	US	Europe
1. Primary electrical code	National Electric Code (NFPA 70)	IEC 60364, the Electrical Installations of Buildings (costs thousands of dollars)
2. Code cross-reference	NEC is a self-contained code.	IEC 60364 references dozens of standards (many countries, many situations).
3. Primary electric code for machinery	UL508, UL61010, and NFPA 79, an adjunct to NEC article 670. Note: the NEC extends into machinery.	Low Voltage Directive and IEC 60204. Note: IEC 60364 stops at the outlet or disconnect.
4. For the same power	Half the voltage and double the current. Hot wires.	Double the voltage and half the current. Shock hazard.
5. Primary construction	Wood	Masonry
6. Safety consequence	Fires caused by overheated wires	Shock and electrocution
7. Terminology examples	Receptacles, equipment	Socket-outlets, gear
8. Scope	Up to 600 VAC	Up to 1000 VAC

Item	US	Europe
9. Neutral	The neutral is white and typically grounded at the service entrance. If it comes from a floor transformer (separately derived system), it is grounded locally to the building electrode. In the US, the neutral is typically not opened by the disconnect switch or CB.	The neutral is light blue. 3 ground options: TN-S: the neutral comes from the utility step-down transformer outside the building, TN-C-S: the neutral comes from the main service entrance (same as the US), TN-C: neutral is ground (like old US wiring).
10. Equipment ground color	Solid green or green/yellow. The ground gauge is based on the size of the circuit breaker. If hot legs are upsized, the ground also needs to be upsized.	Green/yellow 50/50. The ground gauge is based on the gauge of the power conductor.
11. Equipment ground gauge	~25% of the hot leg	~50% of the hot leg
12. Wire issues in the machine	Power is a minimum of 18 gauge (0.82 sq mm). Wires are always stranded.	Power is a minimum of 0.75 sq mm. Wires are sometimes solid.
13. Lighting circuit	Up to 150 VAC	Up to 277 VAC
14. Maximum voltage drop	Not specified	NTE 5%
15. Disconnect overrating	15% oversized	Not specified
16. On/off icons	Not specified	On/off buttons must be marked I & O
17. Equipment clearance	Doors must open at least 90°. Clearance of 3-4 feet.	Doors must open at least 95°. Clearance of 1.0-1.5 meters.
18. Wire bending radius.	Wire bending radius must be **>8x** the overall wire diameter for bare wire and be **>12x** for insulated wire. So for a half inch diameter cable, the bending curve is the size of a dinner plate. NEC 300.34 and NFPA 79 5.1.5	Wire bending radius is not specified in either IEC 60364 or in IEC 60204-1. Note: Bending radius has two issues. The first is for reasonable installation. The second is to prevent the insulation from cracking over the years.
19. Hi-pot test	Up to 1500 VAC or 2121 VDC	Up to 1000 volts (AC/DC not specified) which is about half of the US standard.
20. Ground test	Four short paragraphs in NFPA 79.	Four pages in 60204-1

11 SEMI

11.1 Semiconductor equipment

There are five categories of semiconductor equipment:

- **Wafer preparation.** The silicon ingot is grown, rounded, sliced, and polished. There are only a few companies in the world making ingots in high volume. Worldwide wafer production is ~10 billion square inches per year.
- **Wafer fabrication.** This includes oxidation (a layer for insulation and protection), film deposition (typically from chemical vapor), metallization (aluminum, copper, gold, titanium, etc.), photolithography (photo resist, mask alignment, and exposure), dry etch (RF), wet etch (corrosive), diffusion (doping), and chemical mechanical planarization (CMP).
- **Test and sort.** This includes both wafer level and die level characterizations.
- **Assembly and packaging.** The wafer is scribed and diced. The chips are mounted into various package types. Wires are bonded from the chip to the lead frame.
- **Final test.**

11.2 What is SEMI?

Semiconductor Equipment and Materials International (SEMI®) is a trade organization whose members volunteer their time to develop consensus standards for equipment that is specific to the manufacturing of semiconductors. The standards are managed under the direction of ANSI to prevent favoritism.

Semiconductor machinery is sophisticated, expensive, and dangerous. Hazards can include high voltage, strong magnetic fields, hot and cold temperature, fire danger, explosion, compressed air, pneumatics, hydraulics, mechanical motion, poison gas, nasty chemicals, noise, vibration, laser, radiation, hazardous waste, etc.

The SEMI standards amount to hundreds of pages and cover all aspects of the machine including design, construction, installation, operation, maintenance, and decommissioning. The "S" standards apply to safe construction. The most popular SEMI standard is the SEMI S2 for Environmental, Health and Safety Guidelines for Semiconductor Manufacturing Equipment.

11.3 SEMI report benefits

SEMI assessment is good marketing collateral, and it is also a frequent condition on the customer's purchase order. If you sell a tool to IBM or Intel, you must provide a SEMI S2 report.

SEMI reports (with a P.E. stamp) are equivalent to field label reports in some jurisdictions like Sandia National Laboratory. The UL White Book references SEMI S2 for semiconductor manufacturing equipment (TWKH) and control panels for semiconductor equipment (TWRF).

If you are the facility manager, having a SEMI assessment provides an excellent overall safety review, and it could be the difference between a worker's comp injury and a claim of negligence.

SEMI reports are written for the benefit of the customer. The philosophy should be:

- **evaluate** the product against the standard;
- **disclose** anything significant that deviates from the standard,
- write an opinion as to the **risk of this deviation**, and
- **give the customer a choice**.

Sometimes a customer will look at the issue and say it is ok and sometimes they want a change.

Example: One time the author reviewed a TMAH cabinet (very toxic), and the customer requested an internal shower head so that a leak could be flushed without opening the door.

11.4 SEMI safety standards

The professional who produces the report must have machinery experience and a working knowledge of hazards that originate from electrical, mechanical, structural, and chemical.

A basic SEMI report is a review of five SEMI standards plus electrical machinery:

- SEMI S2 – Environmental Health & Safety Guideline
- SEMI S8 – Ergonomics Engineering
- SEMI S10 – Risk Assessment and Risk Evaluation
- SEMI S13 – EH&S Documents (manuals)
- SEMI S14 – Fire Risk Assessment and Mitigation
- NFPA 70 & 79 – electrical evaluation and field label

The report can also include the following standards:

- SEMI S1 – Equipment Safety Labels. Similar to Z535.4
- SEMI S6 – Exhaust ventilation using tracer gas.
- SEMI S22 – Electrical Design. This is the basic Design Verification Test and replaces SEMI S9 which is obsolete. SEMI S22 includes some requirements from NFPA 79, UL 508A, and UL 61010.
- SEMI S23 Guide for Conservation of Energy. SEMI S23 is similar to the CE Mark environmental impact dossier.
- International Fire Code (IFC) – chapter 27, Semiconductor Fabrication Facilities

SEMI reports are qualitative, not quantitative. The responses to issues should be descriptive, not yes or no. A complete SEMI report can run 100 pages. The summary is acceptable risk and recommendations.

11.5 SEMI S2 categories and report example

The SEMI S2 has 19 categories which are numbered from 9 to 27.

9. Documents provided to User – refer to the book chapter called **Manuals and Hazard Warning Labels**
10. Hazard warning labels – refer to the book chapter called **Manuals and Hazard Warning Labels**
11. Safety interlock systems
12. Emergency shutdown
13. Electrical design
14. Fire protection
15. Process liquid heating systems
16. Ergonomics and human factors
17. Hazardous energy isolation
18. Mechanical design
19. Seismic protection – refer to the book chapter called **Equipment Anchorage**
20. Automated material handlers
21. Environmental considerations
22. Exhaust ventilation – refer to the book section below called **Ventilation**
23. Chemicals
24. Ionizing radiation
25. Non-ionizing radiation and fields
26. Lasers – refer to the book chapter called **Laser**
27. Sound pressure level

SEMI conformity report example. Acronyms are the same as the CE Mark report.

	SEMI S2 Requirement	Comments	SEMI S2	CSC	CPG	DNC	N/A
1.	**Documents Provided to User**		9.6				
2.	Manuals Based on Original Intended Use The supplier should provide the user with manuals based on the originally intended use of the equipment. The manuals should describe the scope and normal use of the equipment and provide information to enable safe facilitation, operation, maintenance and service of the equipment.	Manuals describe the scope and normal use of the equipment and provide information for safe installation, operation, maintenance and service.	9.6.1	X			
3.	**Hazard Warning Labels**		10				
4.	Warning Labels Where it is impractical to eliminate hazards through design selection or to adequately reduce the associated risk with safety or warning devices, hazard alert labels should be provided to identify and warn against hazards.	Appropriate warning labels are in place.	10.1	X			

This line-by-line conformity assessment goes on for over 500 line items.

11.6 SEMI S6 ventilation for hazardous gases and fumes

Ventilation is a trade-off between safety and energy consumption. The safety issues are:

- Prevent **flammable vapor concentrations** from being higher than 25% of the LEL.
- Prevent **worker exposure** to toxic and corrosive chemicals during **normal operation** such as standing near an air vent.
- Prevent **worker exposure** during **routine maintenance** such as changing a bottle in a gas cabinet.
- Prevent **worker exposure** during a malfunction such as a **line break**, etc.
- Prevent **silane accumulation and explosion** with 300:1 air dilution against a worst-case leak through the restricted flow orifice per CGA standard G-13.

International Fire Code 2703.7 (semiconductor) states that electrical equipment within 5 feet of flammable gases or liquids must be rated class 1 div 2. There is an exception if **the equipment exhaust is sufficient to prevent accumulation** of flammable vapors and fumes. This code is frequently cited, and I think it applies to solvents as well. If there is ventilation to dilute the concentration below 25% of the LEL, no further work is necessary. Otherwise, the rules for class 1 div 2 and pyrophoric apply. Refer to the chapter Explosion Proof for construction detail.

Adequate **air dilution** (2-4 air volume changes per minute) will sweep out a leak and prevent it from entering the room through the normal vent. Adequate **face velocity** at the window openings (120–150 linear feet per minute) will prevent exposure to your hands and face.

SEMI S2 23.5.2: Chemical emissions during maintenance activities should be minimized. Conformance to this section can be shown by demonstrating ambient air concentrations to be less than 25% of the **Lower Explosion Limit (LEL)** or the **Occupational Exposure Limit (OEL)** in the anticipated worst-case condition. **SEMI gives you a choice** on how to measure LEL and OEL concentrations: **direct instrument reading** or **tracer gas**.

With **direct instrument reading**, you can either **sniff** it or **calculate** it. If you want to sniff it, you need to identify and rent the instrument specific to the chemical. Sniffing is more reliable because you can check the corners and dead space.

If you want to calculate it, then:

1. Calculate the worst-case spill or leak. **Example:** 100 ml of IPA before the leak detector shuts off the pump.
2. Calculate the entire volume of the chamber. **Example:** one cubic meter.
3. Determine how fast the chemical evaporates. **Example:** one minute.
4. Determine the air change rate. **Example:** 4 air changes (four cubic meters) per minute.
5. Estimate the concentration. **Example:** 100 ml in four cubic meter = 25 PPM.
6. If it is below 25% of the LEL or OEL, no worries.

SEMI S6 – exhaust ventilation. Tracer gas is for serious explosion and toxicology potential. There are several kinds of tracer gas. SF6 sulfur hexafluoride is commonly used because it is unique and non-toxic, but it is also ozone depleting. California uses PDCB paradichlorobenzene because SF6 is banned for this purpose. In a typical evaluation, the SF6 tracer gas (99.9% pure) is injected at 28 liters per minute through 0.25" tubing into areas with a possibility of breakage, such as fittings, valves, and gaskets. The SF6 is then measured outside the enclosure where an operator might be exposed. The SF6 measured concentration is then converted to an **Equivalent Release Concentration (ERC)** for the **Substance of Concern (SOC),** which is then compared to the **Lower Explosion Limit (LEL)** or the **Occupational Exposure Limit (OEL)**. The exhaust ventilation is considered adequate if the ERC is less than 25% of the LEL for an explosive SOC, or less than 25% of the OEL for a toxic SOC.

The ventilation study is conducted with several kinds of test equipment:

- A clean room rated fogger is used to study the air flow sweep pattern. Refer to the color illustrations.
- An air flow probe is used to determine the CFM needed for air turns and face velocity.
- Tracer gas bottle.
- Calibrated gas sniffer. Refer to the color illustrations.
- Cabinet needs exhaust ventilation hooked up to suck the used tracer gas to the outdoors.

11.7 SEMI S8 ergonomics

SEMI S8 has specifications for height, reach, weight, handle size, rotation and pull force, for controls, door panels, spare parts, etc. The goal is to prevent back injuries and repetitive motion injuries.

11.8 SEMI S23 energy conservation

SEMI S23 is the guide for how to measure the resource consumption of a semiconductor tool. All utilities cost money. The guide provides equivalent energy conversion for various utilities like air, water, and gas. SEMI S23 will likely replace the European "Environmental Impact Dossier" described earlier. The SEMI S23 standard assumes the following conversions for equivalent energy:

- Electricity: actual watt-hours
- Nitrogen: 250 watt-hours per cubic meter
- Clean dry air: 147 watt-hours per cubic meter
- Cooling water: 789 watt-hours per cubic meter
- Pure water: 9000 watt-hours per cubic meter
- Exhaust: 3.7 watt-hours per cubic meter

The S23 standard assumes that the tool has four modes: (1) full load operation, (2) idle, (3) sleep, and (4) no power (minimum load). Sleep timing should be documented. If the tool usage is unknown, SEMI assumes 70% operation, 25% idle, and 5% no power.

Utility consumption must be documented. Idle requires some electric power but not the flow of process gases. Power off would still require ventilation. All of this rolls up to a figure called Total Equivalent Energy (TEE). This figure can be used for estimated cost of operation and for competitive advantage.

12 Manuals & Hazard Warning Labels

To energize a circuit, why do technicians open a valve, but electricians close a switch? Why do we drive on a parkway and park on a driveway? Explanations and terminology are important.

12.1 Hazard warning labels – everything except chemicals

There are three predominant standards: ANSI Z535.4 (NEMA), SEMI S1, and Europe. The standards are similar. US safety warning labels have four required elements:

- **Signal word:** danger, warning, caution, and notice
- **Signal color:** red, orange, yellow, and blue
- **Pictogram:** an icon representation of the hazard
- **Context message:** a brief description of the actual hazard

ANSI Z535.4 4.14 defines the signal words as follows:

- **DANGER (red)** indicates a hazardous situation that, if not avoided, could result in serious permanent injury or death. This signal word is limited to the most extreme situations.
- **WARNING (orange)** indicates a hazardous situation that, if not avoided, could result in a moderate recoverable injury, a trip to the clinic, time-off from work, and reported to OSHA.
- **CAUTION (yellow)** indicates a hazardous situation that, if not avoided, could result in first-aid.
- **NOTICE (blue)** indicates important information that, if ignored, could result in damage to material, machinery, or facility. **Example:** critical maintenance. NOTICE is not related to injury.

ANSI Z535.4 Annex B describes how a label should communicate. Let's use two **examples** of a child reaching up to a hot stove and a child walking along the sidewalk. What message focus works best?

Emphasis	Hot stove message	Sidewalk message
• Detection	Light on	Crosswalk
• Avoidance	Stop – do not touch	Look both ways
• Hazard description	Hot surface	Moving car
• Consequence	Burned	Crushed
• Protection	Gloves	Orange vest

ANSI Z535.4 recommends a mix of description, consequence, and protection. Pictograms have some variations. The pictogram and the context message need to be tested for usability.

Europe requires only the pictogram within a triangle. The pictograms are standardized and free to use. (Directive 1999-45-EC, ISO 2972, ISO 3864, ISO 7000, ISO 45001, and DIN 4844-2)

Reference: "What do colors on signs stand for" by Sinoman Bernard, Chart Attack, September 9, 2019

- **Red denotes stop or prohibition.** Examples: emergency, fire alarm, fire extinguishers.
- **Yellow denotes caution.** Examples: machine parts that can hit or cut, door panels, guards, barriers, areas of trip and fall, construction equipment.
- **Green denotes a safe condition.** Examples: emergency exits, location of first aid kits, safety showers and eyewash, personal protection equipment.
- **Blue denotes obligation to proceed with caution.** Examples: safety glasses, gloves, boots, respirator, designated walkways, training.

12.2 Hazard warning labels – chemicals

In the US (before 2015), chemicals must comply with OSHA 1910.1200 which includes the RTK (right to know) HazCom label, the MSDS (material safety data sheet), a written hazard communication program, and appropriate training. An RTK HazCom label includes chemical identification, health hazard warnings (eg. PPE), and the effect on the body. In Canada, the label is called WHMIS (workplace hazardous material information system). In Europe, and in the US (beginning 2015), the label is called GHS (globally harmonized system) SDS (safety data sheet). http://www.rtklabels.com

The global SDS has two differences compared to the MSDS: there are 16x sections and they are in a specific order: (1) identification, (2) hazards, (3) composition, (4) first aid, (5) fire fighting, (6) clean-up, (7) handling and storage, (8) protection, (9) physical properties, (10) stability, (11) toxicological, (12) ecological, (13) disposal, (14) transportation, (15) regulatory, (16) other information.

12.3 Manuals

	General Requirements	**Reference**
332.	Primary references for documentation: • NFPA 79 (IEC60204-1) section 16 (safety warning labels) • NFPA 79 (IEC60204-1) section 17 (manuals and documentation) • UL 61010 section 5 (marking and documentation) • SEMI S2 section 9.6 and SEMI S13 (documentation) • Machinery Directive EH&S section 1.7.4 (instructions)	✓ NFPA79 section 16 ✓ NFPA79 section 17 ✓ UL61010 section 5 ✓ SEMI S2-9.6 ✓ SEMI S13 ✓ Machinery Directive
333.	Manuals should be identified as: • Installation • Operation • Maintenance Avoid the use of other designations such as “owner’s manual” and “user’s manual”.	✓ Same as above
334.	The three primary manuals can refer to other documentation for topics such as safety, inspection, instruction, adjustment, repair, service, decommissioning, etc. If the manual set does not compose the entire set of customer collateral, then be specific about what else there is. **Examples:** MSDS, P&ID, drawings, etc.	✓ NFPA79-17.3.2
335.	Documents should have document number and title. And they should be under engineering change order control.	✓ NFPA79-17.3.2
336.	Documents should include information on how the equipment owner can contact the equipment supplier.	✓ SEMI S13 section 15
337.	The manual wording and layout should be appropriate to the general education and technical level of the reader.	✓ Machinery Directive EH&S 1.7.4.1
338.	The manual must be in one of the European languages (typically English). If the country does not typically speak English, the manufacturer must provide a translation.	✓ Machinery Directive EH&S 1.7.4.1
339.	If the manual is translated, the manual should state “translation of the original instructions” and state the original language prior to translation.	✓ Machinery Directive EH&S 1.7.4.1
340.	The first chapter should describe the intended purpose of the machine and the primary audience.	✓ Machinery Directive EH&S 1.7.4.2 (g)
341.	Discuss inappropriate and prohibited use. This would include a practical discussion and warnings concerning ways in which the machinery must not be used based on the manufacturer’s experience of what might occur. **Example:** an environmental test chamber should not be used for pot-luck food because of contamination.	✓ Machinery Directive EH&S 1.7.4.2 (h) ✓ NFPA79-17.4 (3)

342.	Advertisements, brochures, data sheets, magazine articles, etc. should not contradict any information in the manuals, especially regarding safety. Make sure puffery does not lead to short-cuts. **Example:** "This machine will cut any material."	✓ Machinery Directive EH&S 1.7.4.3
343.	This first chapter of the manual should outline all of the information provided with the machine, including manuals, schematics, safety and training, MSDS, etc. General description of the machinery.	✓ Machinery Directive EH&S 1.7.4.2 (d)
344.	The manual should include drawings, diagrams, descriptions and explanations necessary for the use, maintenance and repair of the machinery and for checking its correct functioning.	✓ Machinery Directive EH&S 1.7.4.2 (e) ✓ NFPA79-17.2
345.	The manual should include the name and address of both the manufacturer and the authorized representative.	✓ Machinery Directive EH&S 1.7.4.2 (a)
346.	If the machine is ATEX rated, state this in the manual.	✓ Machinery Directive EH&S 1.7.4.2 (b)
347.	The manual should include the basic information from the Declaration of Conformity. **Examples:** make, model, Directives, Standards, etc.	✓ Machinery Directive EH&S 1.7.4.2 (c)
348.	Locations where noise exceeds 70 dBA and 80 dBA.	✓ Machinery Directive EH&S 1.7.4.2 (u)
349.	If appropriate, the manual should include a statement of harmful non-ionizing radiation. **Example**: strong magnetic fields that could affect pacemakers.	✓ Machinery Directive EH&S 1.7.4.2 (v)
	Installation Manual	**Reference**
350.	Assembly, installation and connection instructions, including drawings, diagrams and the means of attachment and the designations of the chassis or installation on which the machinery is to be mounted.	✓ Machinery Directive EH&S 1.7.4.2 (i)
351.	The installation diagram should provide a clear, comprehensive description of the equipment, installation and mounting, and the electrical supply requirements. The documentation should include block diagrams and interconnections. **Examples:** piping, plumbing, dry contacts, etc.	✓ NFPA79-17.2 (1)
352.	The installation manual should discuss any facility features that support the tool, including weights and dimensions of the tool, electric power, chilled water, UPS back-up, vibration, noise absorption, lighting, air conditioning, ventilation, effluent scrubbers, pumps, air lines, chemistry, dust collection, guarding around hazardous motion, fire suppression such as sprinklers, and daisy chaining of emergency signals from elsewhere in the factory.	
353.	The installation manual should discuss any tool features that support the facility, such as alarms, fire protection, seismic tie-down, etc.	✓ SEMI S2-9.7
354.	Power service should include supply voltage, range, and frequency. **Example:** 208–230 VAC 3Φ, 60 Hz. The manual and nameplate should indicate the maximum power rating of watts (active power) or volt-amperes (apparent power) or the maximum rated input current with all accessories or plug-in modules connected. Also include the size of the upstream circuit breaker and the size of the raceways and ducts.	✓ NFPA79-17.5.2 ✓ NFPA79-17.5.3 ✓ UL61010-5.1.3
355.	Define the electrical safety clearance around the machine. A floor plan drawing can show adequate clearance for service and maintenance. **Example:** Doors should open at least 90 degrees.	✓ NEC ✓ NFPA79-17.5
356.	Instructions relating to installation and assembly for reducing noise or vibration.	✓ Machinery Directive EH&S 1.7.4.2 (j)

357.	Instructions for the putting into service and use of the machinery and, if necessary, instructions for the training of operators.	✓ Machinery Directive EH&S 1.7.4.2 (k)
358.	The essential characteristics of tools which may be fitted to machinery. **Example:** Adapting conveyors to the machine.	✓ Machinery Directive EH&S 1.7.4.2 (n)
359.	The conditions in which the machinery meets the requirement of stability during use, transportation, assembly, dismantling when out of service, testing or foreseeable breakdowns.	✓ Machinery Directive EH&S 1.7.4.2 (o)
360.	Instructions with a view to ensuring that transport, handling and storage operations can be made safely, giving the mass of the machinery and of its various parts where these are regularly to be transported separately.	✓ Machinery Directive EH&S 1.7.4.2 (p)
361.	Describe how the machine is to be crated, shipped, unpacked, maximum tilt angle and stack height, etc.	✓ Machinery Directive EH&S 1.7.4.2 (p)
362.	Review the final check-out process for final inspection and commissioning.	
	Operation Manual	**Reference**
363.	The operation manual should start with a general introduction to safety precautions.	
364.	A description of the operator workstation.	✓ Machinery Directive EH&S 1.7.4.2 (f)
365.	Discuss the prevention of accidents by proper planning, training, and PPE. Review the required personal protection equipment (PPE) for environmental health and safety (EH&S). This is especially important for radiation.	
366.	Include requirements for specific skills, training, and qualification. In OSHA and NFPA 70E terminology, these credentials are known as **competent** person and **qualified** person.	
367.	Information about the residual risks that remain despite the inherent safe design measures, safeguarding and complementary protective measures adopted.	✓ Machinery Directive EH&S 1.7.4.2 (l)
368.	Provide a walk-around tour describing all of the hazard warning labels and safety devices. This should include an outline drawing that shows the location of all safety devices. **Examples:** on/off, interlocks, EMO, light curtains, GFCI, fuses, circuit breakers, temperature and pressure indicators, high/low limit switches, guards, sensors, alarms, etc.	✓ NFPA79-17.2 (6)
369.	Include a context discussion of each hazard, including hazards that are inherent in the task. **Example:** If there is a hot surface warning label, the context message should state "The exhaust pipe can reach 300°C maximum. Wear appropriate gloves."	✓ SEMI S13 section 9
370.	The documentation should include warning statements and a clear explanation of warning symbols marked on the equipment.	✓ UL61010-5.4.1
371.	The operation manual should include procedures for set-up, equipment use, and programming.	✓ NFPA79-17.8 ✓ UL61010
372.	The operating method to be followed in the event of accident or breakdown. **Example:** If a blockage is likely to occur, what operating method should be followed so that the equipment can be safely unblocked.	✓ Machinery Directive EH&S 1.7.4.2 (q)
	Maintenance Manual	**Reference**

373.	The maintenance manual should describe: • Procedures for adjustment, servicing, inspection, and repair. • Calibration, inspection, software test procedures. • Lock-out tag-out to bring the tool to a zero-energy state. • Description and periodic inspection of the safety devices including EMO and interlock. • Cleaning and lubrication, especially if it involves hazmat. • Solid waste including batteries, filters, etc. • Troubleshooting. • Safe use of lifting equipment. • Special tools and test equipment. • Spare parts list.	✓ NFPA79-17.2 ✓ NFPA79-17.9 ✓ NFPA79-17.10 ✓ SEMI S2-9.6.3
374.	Instructions for protection of the user. **Example:** Personal protective equipment (PPE).	✓ Machinery Directive EH&S 1.7.4.2 (m)
375.	If the service work is done while energized, make sure the procedures are consistent with NFPA 70E and OSHA 1910.331-335	✓ NFPA79-17.9.3
376.	Instructions and description for the operation, adjustment, and preventive maintenance, including protective measures.	✓ Machinery Directive EH&S 1.7.4.2 (r & s)
377.	Circuit diagrams (schematics) should be provided to help with safe repair and troubleshooting. They should be drawn using standard symbols and notations. They are required for the main system but not for field replaceable units (FRUs).	✓ NFPA79-17.7
378.	Spare parts specification, especially if it affects the health and safety of operators.	✓ Machinery Directive EH&S 1.7.4.2 (t)
379.	Dealing with hazardous materials • MSDS – how to read and understand them, both process and maintenance • Hazmat transported into the tool • Hazmat produced by the tool • Environmental impact and abatement • Effluent to the air, sewer, recycling, trash, and holding tanks • Decontamination procedures • Decommissioning	✓ SEMI S2-9.6.5

Manuals should go hand-in-hand with **good user interface design**, which would emphasize: (1) simplicity, (2) conciseness, (3) clarity, (4) consistency, and (5) comprehensibility. **Example:** Modern car dashboards run the extremes from reasonably simple (especially rental cars) to incredibly complicated (smart phone emulation). It should not take 10 minutes to figure out how to turn on the lights and adjust the mirrors.

Best practice: Even with a manual set, the tool owner should create a **standard operating procedure** (SOP) for every tool. There are two reasons for this. (1) This is the best way to train a "new" employee so that they do not pick up any bad habits from another employee. (2) This is the best way to start a disciplinary action against a "bad" employee who is doing something unsafe. There is case law that makes a distinction between **employee willful intent** vs. **reasonably foreseeable misuse**.

Example: Enclosed milling machines often have the door interlocks disabled. Employees do it for convenience (reasonably foreseeable misuse) but the tool owner should not tolerate it. Only “qualified workers” should operate a machine with the guards disabled.

13 Hazardous Facility

13.1 Hazardous facility introduction

This book now introduces hazard concepts divided into four sections. This chapter:

1. **Electrical Safety.** This section includes OSHA and NFPA 70E concepts such as lock-out tag-out (LOTO), qualified electrical worker (QEW), short circuit current rating (SCCR), and electrical hazards for maintenance workers, including arc flash and personal protective equipment (PPE).
2. **Hazardous Occupancy.** This section includes the IFC definitions for hazardous occupancy and the NFPA 704 definitions for hazardous production materials (hazmat).

Next chapter:

3. **Hazard Analysis and Risk Assessment.** This section includes the techniques for predicting consequences due to the failure of equipment. Risks are classified as very low (slight), low, medium, high, and very high (critical), based on the factors of probability, severity, detection, and avoidance. Note: SEMI changed slightly and critical to very low and very high for better translation.
4. **Hazardous Design.** This section introduces the relatively new ISO 13849 and IEC 62061 for predicting consequences due to the failure of a safety device, programmable logic controller, or human misbehavior. ISO 13849 is used for more simple programmable based systems. IEC 62061 is used for more complex systems. Performance (avoiding risk) is classified as SIL 1-4.

13.2 Operator (guards), Competent (LOTO), and Qualified (QEW)

Guards and simple PPE protect **operators** from accidental contact with hazardous energy.

During maintenance, with energy off and guards disabled, LOTO protocol protects **competent workers** from unexpected start-up. Hazardous energy must be identified, relieved, and locked off prior to work.

During test and troubleshooting, with energy on and guards disabled, only **qualified workers,** with special training and protective equipment, should be near the machine.

13.3 Lockout Tagout (LOTO)

Lockout Tagout (LOTO) is for someone working on non-energized equipment. Requirements are called out in OSHA 1910.147, Cal/OSHA, NFPA 70 (NEC), NFPA 70E, and NFPA 79.

Lockout Tagout – A documented process to bring equipment to a safe state for maintenance and repair. LOTO is the protocol for turning off sections of a machine or the entire machine. It includes energy relief and validation. LOTO is unique to each machine. LOTO protocol includes electrical cut-off, chemical and gas valves, cool-down, pressure relief, capacitor discharge, flushing and litmus testing, blocking something that could fall down, guarding a sharp blade, etc. LOTO protocol also includes worker credentials, training, PPE, and test equipment.

Lockout – Placement of a lockout device on an energy isolating device, in accordance with an established procedure. Confirmation that the device is working, and the equipment cannot be started.

Lockout device – Normally a **lock** (key or combination) applied to the safe position to prevent the energizing of a machine or equipment. It can also be a bolted cover, a blocking device, etc.

Tagout – The placement of a tagout device (tag) on an energy isolating device, in accordance with an established procedure, to indicate that the energy isolating device and the equipment being controlled may not be operated until the tagout device is removed.

Tagout device – A prominent **tag and attachment,** securely fastened to an energy isolating device in accordance with an established procedure, to indicate that the energy isolating device and the equipment being controlled may not be operated. Tagout is only used on devices that cannot accept a locking device and only in environments where there is a presumption that any person in the area is aware of the extreme hazards. Tagout is often used by the utilities, and typically with grounding equipment placed across the circuits.

OSHA 1910.147 – Covers the servicing and maintenance of machines and equipment in which the unexpected energizing or start-up of the machines or equipment, or release of stored energy, could harm employees. This standard establishes minimum performance requirements for the control of such hazardous energy.

Important note: There are three competing standards for LOTO:

- OSHA 29CFR1910.147 and the Cal-OSHA equivalent
- ASSE ANSI Z244.1
- NFPA 70E

A recent ASSE magazine article talks about the LOTO differences. The National Technology Transfer and Advancement Act (1995) requires federal agencies to use technical consensus standards unless they are "inconsistent with law or otherwise impractical". OSHA has been very slow to reconcile OSHA 1910.147 with the corresponding consensus standards (ASSE ANSI Z244.1 and NFPA 70E). Cal-OSHA tends to follow NFPA 70E.

Reference: Professional Safety, October 2017. "Hazardous Energy: The Battle for Control in the Standards Arena" by Bruce W Main and Edward V Grund.

Cal/OSHA requires each machine to have an individual written LOTO procedure unless the machine is a **cord plug** or if **all of the following are true:**

- Single energy source readily identified and isolated, such that when it is shut-off, it will completely de-energize and de-activate, with no residual energy.
- Isolation is achieved with a single lockout device under the exclusive control of one employee. **Example:** a LOTO procedure is required for a hard-wired machine (no plug) plus an incoming air line.
- There are no potential hazards created, such as shutting down an emergency system.
- There have been no prior accidents or injuries with the machine during service and maintenance.

NEC Handbook states the case for the disconnect switch as being **risk of injury** and **LOTO protocol**.

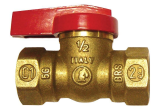
- Convenient disconnects are needed on all individual machines, including floor transformers.
- The disconnect switch must be simple. No tools needed to operate. Readily accessible. Not blocked by a door. Open and closed clearly marked. Interior blades and fuse holders de-energized. Lockable open. Not lockable closed. Overrated 1.15x of the full load. UL listed.
- The disconnect switch normally cuts all power including the UPS and back-up generator. If the main switch does not cut-off the UPS, then add a sign to both the main switch and the UPS cabinet.
- The disconnect switch can sometimes be a circuit breaker, snap switch, or plug.

LOTO basic six steps for non-energized work:

1. Preparation and training to shut down the equipment in an orderly manner.
2. Locate and operate all of the energy isolation devices. Notify workers.
3. Install energy isolation devices. Attach the lock and tag.
4. Relieve stored energy. Block motion. Ground the legs. Discharge capacitors.
5. Verify that the equipment is isolated with zero energy. Confirm the electrical proximity tester on a known live circuit, then the LOTO tool, then back again to the known live circuit.
6. Release equipment from an isolated state.

Example: A LOTO protocol card shows all of the hazardous energies which require relief, such as voltage, capacitor discharge, radiation, temperature, mechanical motion, purging of toxic or flammable gas, pneumatic or hydraulic pressure, corrosive, etc. There may be different cards for different maintenance activities, such as cleaning, valve change, filter change, lubrication, calibration, etc.

LOTO Protocol				**Developed by**	**Reviewed by**	**Revised by**
				Abstraction	Tool Manager	EHS Manager
Equipment:	Water heater			Date and revision:	January 1, 2018	Rev0
Building:	B-1	Room:	123	Next audit due:	January 1, 2019	

Energy	**Disconnect Location**	**Isolation Method**	**Locking Device**	**Check**	**Photo**
Electrical **120 VAC 1Φ**	Water heater main electrical disconnect	Flip the toggle disconnect switch to off	Padlock	Try to turn on before and after	
Gas valve	Gas valve next to the tool	Turn valve off.	Put a cap on the valve and lock the cap.	Try to turn on the gas igniter	
Water valve	Water valve next to the tool	Turn valve off.	Padlock	Try to turn on the water downstream	

Notes:

1. Shutdown sequence: (1) notify affected workers, (2) machine stop, (3) isolate, (4) attach LOTO devices, (5) relieve stored energy, (6) attempt restart.
2. Restart sequence: (1) clear the machine, (2) clear the workers, (3) neutralize the controls, (4) remove LOTO devices, (5) notified affected workers.

Best practice: When doing a large site, take all the LOTO protocol photos at once. Keep track of them in a photo-log. Make the thumbnails when you get back to the office.

Room	Tool ID	Description	Energy source	Photo ID	Thumbnail
Wet Lab	HCL-1	Acid wet bench	Panel A CB 1,3,5	P00001	T00001

Best practice: Protect the protocol cards with a Scotch TL906 laminator and 3 mil sleeves. Then you can punch a small hole, press in a metal eyelet snap stud, and hang the card right on the tool.

Best practice: The University of California at Davis (UC Davis) has a very well written LOTO SOP (standard operating procedure) which was adapted from the University of California base reference. Documents and procedures developed with tax-payer money are free use to the public. After editing, it is ~22 pages and includes sections for worker injury prevention, roles and responsibilities, different kinds of isolating devices (locks, blocks, tags, etc), how to put them on, and training requirements.

13.4 Qualified Electrical Worker (QEW)

Examples of qualified workers: energized electrical, chemical, school bus, taxi driver, fork lift, airplane pilot, ship captain, scuba diving, police, fire, medicine, asbestos, mold, respirator, confined space entry, lead solder, welding, etc. They have special training, equipment, and certification.

13.4.1 Unqualified electrical workers can get seriously hurt

Qualified Electrical Worker (QEW) is someone working on energized electrical equipment. Requirements are called out in OSHA 1926.32. Note: The equivalent for a chemical worker is called Hazardous Waste Operations and Emergency Response (HAZWOPER).

US electrical safety – shocking statistics:

- Average of 2 electrocution deaths per workday. (Consumer Product Safety)
- Average of ~8000 arc flash events per year and half involve burns.
- Incorrect LOTO procedure is a very common OSHA and Cal/OSHA citation.

Arc flash accidents – examples of human error and equipment breakdown:

- People bumping into you when you are working.
- Two electricians are installing a wire in a conduit connected to a live panel. The first electrician pushes the metal snake down the conduit and the second has his fingers over the connector in the panel to catch the snake. The snake goes through his fingers and makes contact within the live panel, causing an arc flash short circuit.
- Two power legs are accidentally connected during installation. The problem is discovered when the circuit breaker is turned on for the first time.
- A disconnect box is wired backwards. The open blades and fuses stay energized.
- Conduit has a burr that wasn't reamed out. The wire is pulled through the conduit and the jacket is sliced open. A small, short circuit begins to smoke and burn off the insulation.
- A screwdriver rolled off a main switch board down onto the live conductors coming from the utility. And boom – the fatal blast, recorded by a security camera, is now used as a training video.
- A live outlet is opened, and the wire pops off because the screw is loose.
- A machine shop tool is throwing metal chips on to the power cord plug. The plug is bumped. Chips fall down the crack. And boom – a soot spot on the wall the size of a dinner plate.
- A tool vendor needs to change the circuit breaker. He turns off the main switch and goes to lunch. Someone turns the switch back on. He comes back, puts on the bunny suit and rubber gloves, and then puts the ratchet to the lug. Rubber gloves prevent the shock. The ratchet handle is turned and contacts the chassis. And boom.
- A low-quality voltmeter (no fuse) is dropped on the floor, then used to probe a live circuit. The meter shorts out. And boom. Choose the correct meter category for the job. UL61010 categories: Cat I = electronic, Cat II = residential, Cat III = industrial, Cat IV = utility.

Extensive credentials to be an electrical contractor or electrician:

California C-10 electrical contractor:

- 0-2 years of college education
- 2-4 years of experience
- 4-hour trade exam and 4 hour law exam
- RME – responsible managing employee

California electrician:

- 720 hours education (union apprentice)
- 8000 hours on-the-job apprentice training
- Exam and license
- Always carry the card

Minimum credentials to be an OSHA "competent" or "qualified" employee:

Competent person – One who can identify existing and predictable hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has

authorization to take prompt corrective measures to eliminate them. OSHA 1926.32(f) and Cal/OSHA 1504.

Qualified person – One who, by possession of a recognized degree, certificate, or professional standing, or who by extensive knowledge, training, and experience, has successfully demonstrated his ability to solve or resolve problems relating to the subject matter, the work, or the project. OSHA 1926.32(l). Compared to a **competent** person, a **qualified** person is a higher level, with demonstrated skills and knowledge related to electrical equipment. The QEW has received safety training to recognize and avoid the hazards involved. The QEW understands the limitations of PPE and can perform a hazard risk analysis.

Industrial employees have significantly less training and experience than those with a state license.

Qualified Electrical Worker (QEW) duties:

- Recognize exposed electrical parts.
- Determine voltage.
- Approach restrictions – shock and flash boundaries will be discussed in the arc flash section.
- Precaution and personal protection equipment (PPE).
- Hazard risk assessment.
- and be the safety marshal on the floor.

Hazard risk assessment:

- Do I have to work with the power on?
- How high is the voltage?
- How high is the incident energy?
- How close will I be to the terminals?
- Do I have the right personal protection equipment (PPE)?
- Do I have the right tools?

Youtube videos – examples of real shock and arc flash caught on camera:

- Two electricians being shocked:
  http://www.youtube.com/watch?v=jY-_Jr3aqVw
- Arc flash interior substation racking a circuit breaker:
  http://www.youtube.com/watch?v=4bBvmPRqfmo
- Arc flash exterior substation accident:
  http://www.youtube.com/watch?v=dPJtknGmsys
- Arc flash test of a poly-cotton shirt:
  http://www.youtube.com/watch?v=W2Q_1usTkAg

13.4.2 Shock hazard

Our body produces voltage chemically, just like a battery or an eel. A small current down our nerves causes our muscles to contract. A large current through our body will cook the tissue.

Shock hazard current – it doesn't take much

- 2.5 mA– taser darts from law enforcement
- 5 mA– GFCI in kitchen and bath
- 3-10 mA– hurts like a cramp
- 10-40 mA– can't let go (same power as a night light)
- 30-75 mA– diaphragm paralysis
- 100 mA– heart paralysis
- 1500m A– tissue & organs cook (a car battery will cook a hot dog)

Conductor – yes or no?

- Blood & sweat – Yes. Your body is 60% water, ~1% saline.
- Skin – Yes. Callus is most of the resistance.
- Concrete floor – Yes. Concrete holds the building electrode, so stand on a rubber mat.
- Boots – Yes. The sole is often made with conductive carbon and a steel shank.
- Leather gloves – Yes. If contaminated.
- Cotton shirt – Yes. If thin and damp.
- Hard hat – Yes. If class C (aluminum). No if class G (plastic).
- Wood utility pole – Yes.
- Rubber gloves – No. Depends on the thickness. Class 0 = 1000 VAC.
- Rubber mat – No. I once saw someone with rubber boots demonstrate this by grabbing a 277 VAC hot leg bare handed. Of course, he would have been shocked if he had grabbed two legs, connecting through his hands.
- Wooden hot stick – No. 15 KV per foot typical rating.
- Air gap – No. 30 KV per cm typical rating.
- Plastic – No.

Shock hazard guarding

- Chassis ground – a path to trip the circuit breaker.
- Ground fault protection – trip open if there is leakage in the round trip current. GFCI 5 mA is typical for hand tools. GFEPCI 30 mA is typical for wet industrial equipment.
- Barriers – insulation, plastic guards, rubber gloves, locked doors, touch proof terminals.
- Minimize or eliminate energized work.
- Hazard warning labels.

13.4.3 Burn and blast hazard

Arc temperature is incredibly hot. Clothing fabric can char, melt, or burn. Heat can break through the clothing and burn the skin. The bright light can cause blindness. The arc vaporizes a substantial amount of copper and generates a pressure wave the same as lightning and thunder. Fault current can generate extremely strong magnetic fields which can throw metal parts. Plastic electrical components can disintegrate like a hand grenade. This is the reason for the AIC rating.

13.4.4 Electrical PPE summary

Electrical personal protection equipment (PPE) summary – what do I wear and use?

- **Prevent shock** – rubber gloves, boots, mats, insulated hand tools, test meters, etc.
- **Prevent burn** – leather gloves, heavy cotton clothes (like a potholder), balaclava, face shield.
- **Prevent bludgeon** – hard hat, face shield, ear plugs.

Refer to the color illustrations for examples of electrical personal protection equipment (PPE).

13.4.5 Arc flash labels

The purpose of the arc flash survey is:

- determine the **available fault current** (short circuit current) coming into each panel.
- determine the fault clearing time.
- provide hazard warning labels specific to each panel.

Arc flash – lightning and thunder

Arc flash is the explosive delivery of hot plasma energy, caused by a short circuit, with the effect being burns, bludgeoning, shrapnel, blindness, and death.

Arc flash energy equals voltage x fault current x clearing time.

- **Typical residential outlet:** 120 VAC x 200 amps x 0.1 sec = 2400 joules = a small shotgun shell.
- **Typical residential panel:** 240 VAC x 7000 amps x 0.1 sec = 168,000 joules = an M80 firecracker.
- **Typical industrial 3Φ panel:** 480 VAC x 20,000 amps x √3 X 0.1 sec = 1,663,000 joules = ¾ stick of dynamite. 4280 joules will vaporize one gram of copper. In this example, the arc flash energy (if it all went to the copper) would **vaporize ~388 grams of copper** (43 cm^3). And since **copper vapor expands 67,000x**, the hot copper vapor cloud would **explosively fill 2.9 cubic meters**.

Historically, OSHA has been more concerned with electrical shock than with arc flash. The NFPA 70E has an emphasis on both. Worker's Compensation insurance carriers (such as Chubb) are pushing to have the NFPA 70E standard adopted into OSHA 1910.

Arc flash regulations (NEC, NFPA 70E, and OSHA)

Our electrical regulations come from:

- Laws (written by the legislature)
- Consensus Standards (written by the engineers, adopted by reference)
- Enforcement (City and State Inspectors, also known as the Authority Having Jurisdiction)

The OSHA general duty clause makes the consensus safety standards applicable and enforceable by OSHA. The four standards that relate directly to arc flash safety and system protection are:

- NFPA 70, National Electrical Code (2023)
- NFPA 70E, Electrical Safety in the Workplace (2021), the practical reference for electrical safety. Earlier editions focused on shock and LOTO. The recent edition includes arc flash. Frequently cited by OSHA. The handbook includes both the code and the good advice.
- NFPA 79, Electrical Standard for Industrial Machinery (2021)
- IEEE 1584, Guide for Performing Arc Flash Calculations (2018). IEEE 1584 provides the scientific basis and the engineering guidelines for assessment and calculation.

Arc flash requirements

- Electrical equipment such as switchboards, panel boards, industrial control panels, meter socket enclosures, and motor control centers that are **likely to require examination, adjustment, servicing, or maintenance while energized**, shall be field marked to warn qualified persons of potential electrical arc flash hazards. The marking shall be located to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment. NEC 110.16.
- If service procedures require electrical work while equipment is energized, the technical documentation shall refer to appropriate safe work practice, such as the requirements of NFPA 70E, NFPA 79 17.9.3, and OSHA 1910.331-335.
- If the incident energy is > 1.2 cal/cm^2, the label must state either the incident energy or the required PPE hazard risk category. NFPA 70E 130.5(c)
- Arc flash must be re-evaluated every five years. NFPA 70E 130.5.
- Service equipment must be field marked with the amount of available short circuit current at the time of installation. NEC 110.24
- Employers must furnish PPE. OSHA ruling November 15, 2007.

Most companies today have an **Electrical Safety Program** for their facilities and equipment maintenance personnel. NFPA 70E defines in detail the requirements for procedures (LOTO, energized work permits) and hazard analysis (shock, arc flash, and blast). Unfortunately, due to the current economy, many safety managers have been tasked with more programs than they can handle. **Gap analysis** is a useful exercise to see how the facility compares to current requirements.

Arc flash mitigation

- **Reduce the available energy.** Minimize the capacity of the upstream transformer. Minimize the size of the wires. **Example:** #12 wire is about one ohm per 630 feet. So a typical 20 amp outlet with 315 feet of wire would have a maximum available fault current of about 120 VAC / 0.5 ohms = 240 amps.
- **Clear faults as fast as possible.** Circuit breakers should be selected based on adequate size and fastest possible clearing time. Fuses typically interrupt faster than circuit breakers.
- **Clear faults in a coordinated manner.** The goal is to trip only the circuit breaker closest to the fault and thus avoid tripping the entire building. Coordination is assured if the up-stream circuit breaker requires ~4x the amount of trip time, compared to the down-stream circuit breaker, for the expected fault current TBD. However, longer trip times conflict with the other goal of clearing faults as fast as possible.
- **Use higher rated Ampere Interrupt Capability (AIC).** Circuit breakers are typically rated 10KA to 65KA without self-destruction. Fuses are typically rated 200KA to 300KA.
- **Qualified Electrical Worker (QEW).** Training and experience.
- **Company policy.** Energized work permits are required for live voltage work >50 volts for any case other than diagnostic and testing. Avoid energized work.
- **Hazard warning labels.** Electrical shock and arc flash. Arc flash calculation requires site-wide analysis of available energy at every panel.
- **Wear protective clothing.** Note: arc flash calculation will usually prescribe a lower rated PPE (more comfortable) compared to the NFPA 70E generic table (less comfortable).
- **Blast proof cabinets** for the equipment.

Arc flash terminology (NFPA 70E)

Applicability – NFPA 70E has two approaches. **Complex analysis** is for voltages over 5000. The **generic table** is for voltages under 5000. This generic approach requires a simple calculation for the main feeder to verify the available fault current. If the system meets the requirements, then the risk categories and PPE are determined by table values. This generic approach is applicable to most small manufacturing facilities with a 480 VAC distribution system of less than 5000 amps. This method may not apply to older systems with antiquated protection devices and with very high fault currents.

Hazard Risk Category Classifications (NFPA 70E table 130.7-C-15) – Assigns a hazard risk category (0, 1, 2, 3, 4) to ~80 situations for electrical workers.

Incident energy – The amount of energy at a certain distance, produced by an electric arc, and specified as calories per square centimeter. The incident energy and the hazard risk category determine the required PPE.

Arc flash protection boundary – Within this distance to an exposed live part, an unprotected person could receive a **second-degree burn**. If working within this boundary, the worker **must wear appropriate flame resistant (FR) PPE**. Some labels refer to this as the flash hazard boundary.

Limited approach boundary – Within this distance to an exposed live part, the worker must wear appropriate flame resistant (FR) PPE **and be qualified.**

Restricted approach boundary – Within this distance to an exposed live part, there is an increased hazard of shock and arc flash, especially with inadvertent movement, like being surprised or bumped. The worker must wear appropriate flame-resistant PPE, must be qualified, **and in addition**:

- Specific training.
- Documented plan.
- Perform a risk analysis.
- Approved by management.
- Avoid contact by keeping back as much as possible.

Prohibited approach boundary – Within this distance to an exposed live part, shock is inevitable. If working within this boundary, the electricity must be turned off. This definition has been deleted from the 2015 edition of NFPA 70E.

Shock hazard boundaries and arc flash boundaries are not the same.

Shock and arc flash are different hazards with different boundaries. Shock hazard is rubber gloves, rubber boots, rubber mats, plastic guards, etc. Arc flash is burn and blast. Both are deadly. If the victim was compared to fried chicken, then shock is like **original recipe** and arc flash is like **extra crispy**.

Arc flash PPE depends on activity and available energy (NFPA 70E).

NFPA 70E has both detailed PPE (table 130.7-C) and simplified PPE (annex H) based on categories 0, 1, 2, 3, 4. Below are two examples for simplified PPE.

- Simplified PPE **example:** If you apply a **clamp-on current meter to a live 480 VAC conductor**, this is a category 2 activity. You would wear flame resistant (FR) clothing with a rating of 8 cal/cm^2 plus a hard hat, safety glasses, hearing protection inserts, leather gloves and shoes.
- Simplified PPE **example:** If you apply a **clamp-on current meter to a dead 480 VAC conductor**, then back away and turn-on power, you could approach to the point of the limited approach boundary to read the meter, and wear only basic PPE like glasses and cotton shirt.

Category	Energy Level	Personal Protection Equipment
0	2 cal/cm^2	Hard hat, face and hearing protection, leather gloves over rubber gloves, and cotton shirt and pants.
1	4 cal/cm^2	Hard hat, face and hearing protection, leather gloves over rubber gloves, leather work boots, and fire resistant shirt and pants.
2	8 cal/cm^2	Hard hat, face and hearing protection, leather gloves over rubber gloves, leather work boots, fire resistant shirt and pants, and cotton underwear.
3	25 cal/cm^2	Hard hat, face and hearing protection, leather gloves over rubber gloves, leather work boots, double layer of fire resistant shirt and pants, and cotton underwear.
4	40 cal/cm^2	Hard hat, face and hearing protection, leather gloves over rubber gloves, leather work boots, multi-layer flash suit over fire resistant shirt and pants, and cotton underwear.

Field investigation work – five steps

Step 1: Obtain an up-to-date single line diagram of the electrical distribution system.

Step 2: Contact the supplying utility (PG&E) and request the line side available fault current and the utility transformer specification. Let-through (load side) fault current would also serve the purpose.

Step 3: On the line drawing, identify the size, type, and length of the feeder conductors from the utility transformer to the main switch gear. Length can be estimated to within 10%. Since the conductors are on the utility side of the meter, they may not be readily accessible, but it is usually safe to assume that they are copper and they are correctly sized according to the NEC tables.

Step 4: For sub-panels that are fed from a main panel, obtain information for the feeder circuit breaker (make, model, type, size) and the feeder conductors (type, gauge, and approximate length). The circuit breaker information provides the fault clearing time.

Step 5: For sub-panels that are fed from a transformer, obtain the following information: (1) KVA or MVA rating, (2) %Z impedance rating, (3) primary and secondary voltages, (4) primary and secondary conductor type, gauge, and length.

Arc flash calculation examples (NFPA 70E)

Example: Bolt (short circuit) current (NFPA 70E annex D.4):

- 3Φ transformer rated 10 megawatts, voltage = 4160, transformer impedance = 5.5%
- **I_{SC} =** [transformer rating] x [100 ÷ %Z] ÷ [√3 x V] **= 25,000 amps**

Example: Arc power (NFPA 70E annex D.4):

- 3Φ voltage = 4160, bolt current = 25,000 amps
- **P =** I_{SC} x [√3 x V] x $(0.707)^2$ **= 91 mega-watts**

Example: Flash protection boundary (NFPA 70E annex D.2):

- 3Φ transformer rated 10 megawatts, arc time = 0.1 seconds
- **D_C =** [transformer rating] x 53 x t **= 7.28 feet**

Example: Incident energy (NFPA 70E annex D.5.1):

- 18 inches distant, arc time = 0.2 seconds, bolt current = 20,000 amps
- **E_{MB} =** 5271 x $[D_{INCHES}]^{-1.9593}$ x [arc time] x [0.0016 x I_{SC}^2 – 0.0076 I_{SC} + 0.9838]
- **E_{MB} =** 5.098 calories/cm^2 Therefore, **flash rating = 5.**

NFPA 70E allows the hazard warning label to specify either the incident energy or the PPE rating.

13.5 Summary – important but simple

If you do your work **OFF –** that's Competent Electrical Worker and LOTO. If you do your work **ON –** that's Qualified Electrical Worker and consideration for shock, arc flash, risk assessment, PPE, etc.

LOTO is important because:

- Machinery and electrocution account for 20% of US worker deaths.
- OSHA 29 CFR 1910.147 requires it, with NFPA 70E being frequently cited.
- Expensive to ignore it.

Avoid the following examples of LOTO citations:

- The factory requires complex LOTO if there is more than one maintenance worker.
- Different maintenance activities require different LOTO procedures.
- Hydraulic press requires power LOTO and the ram to be blocked.
- A tool with 3 operator stations must have the compressed air supply locked off.
- **Example (Cal/OSHA reporter 2012):** Repeat LOTO Violations Trigger Cal/OSHA Willful Action. Despite being on "full notice" by Cal/OSHA of deficiencies in its lockout tagout program, a Southern California employer failed to take adequate precautions, leading to a second serious injury within three months, and a second willful violation in a little over six months. Total penalties **~$180,000.**

Typical LOTO scope of work:

- Review existing equipment descriptions and procedures.
- Review energy sources (electrical, mechanical, pneumatic, hydraulic, corrosive, etc.)
- Site survey. Take photos. Prepare the protocol cards one-by-one.
- Deliver a customized LOTO package. Standard operating procedure and a card for each machine.

Arc flash is important because:

- OSHA general duty clause requires a safe work environment.
- Coordination will prevent a major shutdown of the building.
- Maintenance workers need protection.
- In the US, ~8000 arc flash events per year with many resulting in crippling burns and death.

Typical arc flash scope of work:

- Review existing training, procedures, equipment, PPE, and labels.
- Collect information from the existing electrical equipment including the single-line, transformers, panels, circuit breakers, fuses, etc. in the power network.
- Determine wire length based on the floor plan.
- Determine wire gauge based on inspection or CB rating.
- Develop the computer model for short circuit current, clearing time, and coordination.
- Calculate the available fault current at each panel.
- Based on predicted current, calculate the fault clearing times. Confirm the coordination of the circuit breakers and fuses.
- Calculate incident energy based on appropriate method (NFPA 70E table or IEEE 1584).
- Determine the boundaries and PPE required for safe energized maintenance.
- Print and apply a customized arc flash hazard warning label to each electrical panel.
- Deliver an up-to-date single line drawing.
- Deliver the entire model in an ETAP data file for easy future maintenance.
- QEW training, LOTO, PPE, and risk assessments.

13.6 Hazardous occupancy and the semiconductor fab

Property ownership is a misnomer. Instead, you have a deed to a bundle of rights. Some rights are retained by the government including:

1. **Imminent domain –** the public right to buy your property for the public good.
2. **Zoning –** the public right to tell you how your property can be used (land use plan). Zoning might include agriculture (ranch), industrial (factory), residential (housing), and commercial (retail stores and offices). Zoning has a big impact on the value of the land. Typical monthly rents might be $0.10/sq.ft. for agriculture, $1/sq.ft. for industrial, $2/sq.ft. for residential, and $10/sq.ft. for commercial. The municipality might prefer more agriculture (better home value, less traffic) and more industrial (jobs and property taxes without the schools). Getting the city to "up-zone" a property can be like winning the lottery. **Example:** converting agricultural land to a housing development. **Example:** increasing the ratio of the house size to the lot size (floor area ratio).
3. **Building code –** the public right to enforce construction regulations, licensed contractors and electricians, workers compensation insurance, permits, and inspections.
4. **Fire code –** the public right to tell you how the building can be occupied**. Example:** a restaurant has a sign that says 60 people maximum.
5. **Public safety –** the public right to enter your property due to an immediate threat of fire or violence, or to investigate a crime (with a warrant).

The fire department permits the use of a property according to its occupancy classification. The US has two predominant fire codes available: the ICC International Fire Code (IFC) and the NFPA National Fire Code. California at one time used the NFPA fire code but now uses the IFC. Chapter 2 defines the following codes for occupancy:

A = assembly (A-1 theaters, A-2 restaurants, A-3 churches, A-4 indoor stadiums, A-5 outdoor stadiums)

B = business (office and professional)

E = educational (schools)

F = factory (F-1 moderate hazard, F-2 low hazard)

H = high hazard (H-1 explosive, H-2 accelerated burning, H-3 combustible, H-4 corrosive and toxic, H-5 semiconductor)

I = institution (day care, hospitals)

M = mercantile (stores)

R = residential (R-1 hotels, R-2 apartments, R-3 homes & condos, R-4 assisted care)

S = storage (warehouses, etc)

Different occupancy classifications have different construction requirements. Semiconductor fabrication facilities (H-5) use large quantities of hazardous production materials (HPM). Refer to the ICC Fire Code (IFC) chapter 18 and the ICC Building Code (IBC) section 415.8. **Examples** of construction requirements:

- HPM maximum quantity defined by IFC table 2703.1.1.
- Fire, smoke, and gas detection (with alarms) in continuous operation.
- Approved locations for emergency controls and equipment.
- Service corridors for the transport of hazardous production materials (HPM).
- Trained personnel at emergency controls.
- Automatic fire extinguishing systems.
- HPM piping shall be welded except within a ventilated enclosure.
- Emergency power for alarm systems, ventilation, valves, etc.

13.7 Hazardous production materials (HPM)

NFPA 704 rates materials for the hazards of health (blue), fire (red), and instability (yellow), as follows:

Rating	Health hazard	Fire hazard	Instability hazard
4	Can be lethal.	Will vaporize and readily burn at normal temperature.	May explode at normal temperatures and pressures.
3	Can cause serious or permanent injury.	Can be ignited under almost all ambient temperatures.	May explode at high temperature or shock.
2	Can cause temporary incapacitation or residual injury.	Must be heated or high ambient temperature to burn.	Violent chemical change at high temperature or pressure.
1	Can cause significant irritation.	Must be preheated before ignition can occur.	Normally stable. High temperature can make unstable.
0	No hazard.	Will not burn.	Stable.

According to the IFC definitions, an HPM is a material having a rating of 3 or 4 in any of the categories. **Examples** of MSDS abstractions can be found in the **Technical File** chapter.

13.8 Hazardous classified location

Hazardous classified location is a construction requirement intended to prevent explosion by separating the fire triangle – fuel, oxygen, and ignition. The **US hazardous classified location** (NEC article 500) requirements and **X, Y, Z purging** are found in the chapter called **Explosion Proof**. The European **Atmospheric Explosion Directive (ATEX)** is found in the chapter called **CE Mark**.

14 Hazard Analysis & Risk Assessment

14.1 Hazard analysis and risk assessment

ASSE Professional Safety November 2014 has an op-ed article by Patricia Ennis on preventing fatalities. In 2013, approximately 4405 US workers lost their lives. The US construction death rate is 4x what it is in the United Kingdom. The primary difference is believed to be the European practice of hazard risk assessment and safety by design. The article states: “ASSE believes that a greater focus on the use of risk assessments . . . is key to . . . reducing work-related fatalities.” The article refers to ANSI Z690 and ISO 31000 standards for risk assessment and risk management.

14.1.1 Code conformance vs. hazard analysis

Civil engineering (construction) is a mature discipline. Castles, cathedrals, and pyramids have been around for thousands of years. Electrical code can be traced to the Niagara Falls Power Company and the Chicago World’s Fair (1893) which featured a large display of electric power and lighting, and concern for fire and insurance. Out of this came Underwriters Laboratory (1894) and the National Fire Protection Association (1896). Industrial Machinery (NFPA 79) originated at the beginning of World War II (1941). Chemical and environmental regulations are more recent. Some would trace this to the book **Silent Spring** by Rachel Carson (1962), then the Santa Barbara oil spill (1969), followed by Earth Day (1970).

A machine is presumed to be safe if the machine is: (1) built according to a model code, and (2) certified by a competent third party. Most construction requirements are covered by a code. For a situation not covered in a code book, you apply a scientific method called hazard analysis.

Civil (structural) **Electrical** **Mechanical** **Chemical**

Code books and certification “prescribe” right and wrong.

Hazard analysis and insurance “qualify” right and wrong.

14.1.2 Hazard analysis introduction

The US Department of Defense originated the study of system safety in MIL-STD-882 driven by the space rocket program. The goal is to apply engineering techniques for the protection of personnel, equipment, facility, and the environment. MIL-STD-882 has evolved into numerous analysis techniques:

- Preliminary Hazard Analysis (PHA)
- Fault Tree Analysis (FTA)
- Failure Mode and Effects Analysis (FMEA)
- Hazard and Operational study (HazOp)
- Markov analysis
- What if? analysis

In commercial industry, especially in semiconductor and solar cell factories using flammable, explosive, and toxic chemistry, the fire department, and the insurance carrier sometimes request a hazard analysis by a third party. Their goal is to maximize safety and minimize financial risk.

CE Mark and SEMI S2 also promote hazard analysis, but with more emphasis on conformance of the machinery.

14.1.3 Hazard analysis techniques

Analysis techniques can be thought of as either a deductive (top down) or an inductive (bottom up) logical method.

Deductive reasoning is where the future behavior is drawn from a set of premises, true or false. Deductive reasoning is a prediction of consequences. Quoting Sir Author Conan Doyle (Sherlock Holmes): "when you have eliminated the impossible, whatever remains, however improbable, must be the truth".

Deductive reasoning example:

- Premise #1 – Ohm's law. Voltage = current x resistance.
- Premise #2 – Voltage remains the same but the resistance is doubled.

Prediction – Current will be half.

Inductive reasoning is where future behavior is based on broad generalizations (hypothetical experience) from specific observations. The conclusion is based on the sum of the observations.

Inductive reasoning example:

- Observation #1 – first coin pulled is a penny.
- Observation #2 – second coin pulled is a penny.
- Observation #3 – third coin pulled is a penny.

Hypothesis created – all the coins in the purse are pennies. The hypothesis could be right or wrong.

Preliminary Hazard Analysis (PHA) – Preliminary is a clue that this is inductive reasoning. PHA is the favorite technique for identifying hazards, causal factors, probability, severity, and mitigating safeguards. PHA is first choice in situations where the hazards are primarily **electrical, mechanical, and fire.** SEMI S10 and S14 are based on PHA.

Fault Tree Analysis (FTA) – FTA is a deductive approach that postulates an undesired "top event" and then takes it down through the numerous chains of events that would logically have to occur. An example of a single "top event" would be a hydrogen explosion.

Failure Mode and Effects Analysis (FMEA) – FMEA is an inductive approach that postulates the effects of various sub-system failures. Classic reliability budgeting is based on component failure rates and redundancy modeling. **Example:** This kind of analysis could predict that there was a 1% chance of a space shuttle mission failure. In fact, the actual failure rate would be 2 out of 135.

Hazard and operability study (HazOp) – HazOp is a structured and systematic examination of a planned or existing process or operation to identify and evaluate problems that may represent risks to personnel or equipment or prevent efficient operation. The HazOp technique was initially developed to analyze chemical process systems but has later been extended to other types of systems and also to complex operations and to software systems. A HazOp is a qualitative technique based on guidewords and is carried out by a multi-disciplinary team (HazOp team) during a set of meetings. (source: Wikipedia)

Markov Analysis – Markov is an inductive approach for modeling the probability of complex system performance over time. The result would be a prediction of system performance attributes including availability (up time and down time), lead time, queuing, reliability, safety, maintenance, etc.

What if? Analysis – This inductive method of analysis is based on the book "Guidelines for Hazard Evaluation Procedures" by the Center for Chemical Process Safety, American Institute for Chemical Engineers. This book is currently in the third edition, published 2008. The analysis is used to postulate and analyze how certain deviations (human error, mechanical failure, etc) can lead to an increase of risk. The analysis is a review of the most likely hazards, and what safeguards are in place (or should be in place) to prevent the hazard from becoming an accident. What if? Analysis is first choice in situations where **the hazards are primarily flammable, explosive, and toxic chemistry.**

14.1.4 SEMI S10 and S14 Preliminary Hazard Analysis (PHA)

SEMI S10 (general hazard risk) and SEMI S14 (fire risk) are the best-known examples of preliminary hazard analysis (PHA). A typical PHA report has the following outline:

- Definition of risk factors
- An inventory of apparent hazards
- A finished table that includes:
  a. Hazards by category (electrical, mechanical, etc.)
  b. Hazards by sub-system (main chamber, control panel, conveyor, etc.)
  c. Consequences of a mishap.
  d. Existing probability, severity, and safeguards as it stands.
  e. Future probability, severity, and safeguards after improvements.

Risk factors:

SEMI S10 and ISO 14121 (supersedes EN 1050) are an internationally accepted methodology for defining acceptable risk, cataloging system elements, and determining if the hazards require further mitigation so that risk is reduced to an acceptable level.

Factors influencing risk include:

- **Severity** of the effect of the hazard, ranging from first aid to multiple deaths.
- **Frequency and duration** of the exposure to the hazard within the danger zone.
- **Probability of occurrence** of an event which can cause harm. The probability of occurrence can be defined for one system or for a whole product line and can be evaluated over the entire product life cycle. Analysis is confined to hazards to operators and maintenance personnel only and would be limited to the information in the available manuals and by inspection of the equipment. The probability of an event such as the failure of a part that could cause harm is estimated by taking into account:
  a. reliability and other statistical data
  b. accident history
  c. risk comparison
- **Avoid or limit the harm** (technical and human factors such as awareness of the hazard, reduced speed, properly located emergency stop devices)

Risk factors can be technical or of human origin. When the machinery is equipped with protection devices (engineering controls) the probability of occurrence describes the efficiency of the controls and accounts for human factors considerations. The probability of occurrence is also dependent upon the **possibility of avoidance** which considers:

- **operator:** skilled, unskilled, or unmanned operation.
- **speed of appearance** of the event: sudden, fast, or slow.
- **awareness off the hazard:** general information (training, instructions), direct observation, or through indicating devices.
- **human possibility of avoidance:** possible (reflex, agility, escape exit), possible under certain conditions (rescue), or impossible.
- **practical experience and knowledge of similar machinery:** experience or no experience.

SEMI S10 defines a 5-tiered rating system for probability. The Hazard Probability Definitions including likelihood groupings and expected rate of occurrence are provided in Table 3.

The results of the risk assessment are summarized in Table 5.

Table 1 – Hazard Severity Definitions

Severity Group	Effect on People	Effect on Equipment and Facility	Effect on Property
1. Catastrophic	One or more fatalities.	System or facility loss.	Chemical release with acute, lasting environmental or public health impact.
2. Severe	Disabling injury/illness.	Major subsystem loss or facility damage.	Chemical release with temporary environmental or public health impact.
3. Moderate	Medical treatment or restricted work activity (OSHA recordable).	Minor subsystem loss or facility damage.	Chemical release triggering external reporting requirements.
4. Minor	First aid only.	Non-serious equipment or facility damage.	Chemical release requiring only routine cleanup without reporting.

Table 2 – Hazard Probability Definitions

Likelihood Group	Expected Rate of Occurrence
A – Frequent	More than 1% chance in a year
B – Likely	More than 0.2% chance in a year but not more than 1%
C – Possible	More than 0.04% chance in a year but not more than 0.2%
D – Rare	More than 0.02% chance in a year but not more than 0.0%
E – Unlikely	More than 0.002% chance in a year but not more than 0.02%
F – Unforeseeable	Not more than 0.002% chance in a year
Likelihood Group	**Expected Rate of Occurrence (alternate definition)**
A – Very high	At least once per year, perhaps multiple times
B – High	Once every five to ten years
C – Medium	Once every twenty years, about once over the life of the tool
D – Low	Could possibly occur, but not expected over twenty years or more
E – Negligible	Not expected to ever occur

Table 3 – Risk Assessment Matrix

Risk Ranking Matrix	Likelihood					
Severity	A – Frequent	B – Likely	C – Possible	D – Rare	E – Unlikely	F – Unforeseen
1. Catastrophic	very high	very high	high	medium	low	very low
2. Severe	very high	high	medium	low	low	very low
3. Moderate	high	medium	low	low	very low	very low
4. Minor	medium	low	low	very low	very low	very low

Table 4 – Hazard Categories

1	**Mechanical hazards**	7	**Hazards due to materials and substances**
	☐ crushing		☐ contact of substances or inhalation of gases, fluids, mists, fumes and dust with harmful, toxic, corrosive
	☐ shearing		☐ fire and explosion
	☐ cutting or severing		☐ biological and micro-biological hazards
	☐ entanglement	8	**Ergonomic**
	☐ trapping or drawing in		☐ unhealthy posture or excessive effort
	☐ impact		☐ hands, arms, legs, & feet
	☐ stabbing or puncture		☐ personal protection equipment
	☐ friction or abrasion		☐ inadequate local lighting
	☐ high pressure fluid injection or ejection		☐ mental stress
2	**Electrical hazards**		☐ human behavior and training
X	☐ shock direct contact		☐ manual controls
	☐ shock indirect contact		☐ visual displays
	☐ shock high voltage	9	**Combination of hazards**
	☐ electrostatic	10	**Unexpected start-up**
	☐ thermal radiation		☐ control system failure
3	**Thermal hazards (hot or cold)**		☐ energy supply restoration
	☐ burns and scald		☐ electrical disturbance
	☐ hot or cold working environment		☐ other outside factors (gravity, wind)
4	**Noise hazards**		☐ software
	☐ permanent hearing loss		☐ operator error
	☐ speech impairment	11	**Impossible to stop machine**
5	**Vibration hazards**	12	**Variations in rotational speed**
	☐ vascular disorder	13	**Power supply failure**
	☐ whole body	14	**Control circuit failure**
6	**Radiation hazards**	15	**Fittings error**
	☐ low frequency, radio, microwave	16	**Break-up during operation**
	☐ infra-red, visible, ultraviolet	17	**Ejected objects or fluids**
	☐ X ray and gamma ray	18	**Overturning**
	☐ other ionization (alpha, beta)	19	**Slip, trip, and fall**
	☐ laser		

Table 5 – Hazard Identification and Summary

Electrical						
Sub-system	Hazard identification	Existing controls	Present risk level	Recommendation	Risk after recom.	Status
Electronics Enclosure	Contact with exposed line voltage causing electrical shock	Hazardous voltage terminals are touch-proof. Hazard labels posted.	3C	Convert outlet to GFCI.	3D	closed
Mechanical						
Chemical						

14.1.5 SEMI S14 Fire Risk Assessment

A separate fire risk assessment is usually conducted in addition to the general risk assessment. The following topics are reviewed:

- Construction materials, both combustible and non-combustible.
- Component rating and listing.
- Process materials like substrates, chemicals, and gases.
- Potential sources for ignition like overheated wires, furnace chambers, etc.
- Fire detection and suppression.
- Smoke containment.

The overall fire risk is assessed by examination of all fire sources, by evaluating the probability of each source, and by evaluating the consequence in terms of severity. Safeguards are improvements are considered and discussed. The probability and severity rating tables are the same as SEMI S10.

14.1.6 Failure Mode and Effects Analysis (FMEA)

FMEA is the process of reviewing as many components, assemblies, and subsystems as possible to identify potential failure modes in a system and their causes and effects. For each component, the failure modes and their resulting effects on the rest of the system are recorded in a specific FMEA worksheet. There are numerous variations of such worksheets. An FMEA can be a qualitative analysis but may be put on a quantitative basis when mathematical failure rate models are combined with a statistical failure mode ratio database.

FMEA is often used for machines involving chemicals, whose operation is described by a P&ID (piping & instrumentation diagram). The failure modes are identified from the P&ID such as valve stuck open, valve stuck closed, valve stuck halfway, regulator too high or too low, a leak at a fitting, etc. Using an Excel spreadsheet, the rows describe the failure modes and the columns describe the consequence, probability, severity, etc. There are many YouTube tutorials that describe this, with software available.

14.1.7 What if? analysis

A typical what if? analysis report has the following outline:

- Executive Summary
- System Description, including a brief review of the machinery and the chemistry
- Scope of Review Activities
- Analysis Test Methodology
- Safety Assessment
    d. Risk and hazard inventory similar to PHA
    e. Properties of hazardous materials (MSDS abstractions)
    f. Subsystems and hazard scenarios
- What if? Analysis worksheet

Examples of subsystems and hazard scenarios:

Fire: In the event of a catastrophic failure of the piping, a release of hydrogen gas could be ignited by (yet unidentified) ignition sources. The hydrogen pipes come down from the ceiling, and the hydrogen gas goes straight up. So, it is unlikely that the gas would collect around the floor except at the direct connection to the machine. The release of pyrophoric chemicals would also cause a fire. The volume of chemicals on hand is small.

Gas tanks: The most likely place for a gas release would be either at the gas tank connection or at the fittings on the line. The risks associated with this release are mitigated primarily by proper construction, automatic shutoff, and ventilation.

Ignition sources: Hydrogen serves as a carrier gas inside the tool. There are several ways that the safety of hydrogen is controlled . . .

Earthquake: Lateral and vertical accelerations can cause sliding, rollover, and collapse of the equipment, and broken gas lines. Mitigation is handled with anchoring and seismic motion detectors.

	Mishap – what if?	Concern	Mitigation
1.	Accidental contact with high voltage	Shock.	208 VAC max voltage, touch-proof terminals
2.	Accidental loss or restoration of electrical power.	Unexpected stop or start-up.	Valves automatically dropped to a closed state.
3.	Loss of CDA or nitrogen.	Valve stuck open or closed, inadequate purge.	Process would eventually alarm.
4.	Residual hydrogen accumulates because it is not burned off with igniters.	Explosion	Rapid dispersion into the exhaust duct.
5.	Sensors malfunction. Oxygen infiltration.	Explosion	
6.	Hot parts are not adequately cooled.	Component failure	
7.	Employee training.	Cleaning solvents are spilled	
8.	Vessel rupture.	Spill.	Secondary containment. Sump. Exhaust always on. PPE.
9.	Drainage problems.	Exposure.	Secondary containment. Sump. Exhaust always on. PPE.
10.	Chemical valves: stuck open, stuck closed, diaphragm hole leak, and valve seat leak. Incompatible chemicals interact.	Exposure	Secondary containment. Sump. Exhaust always on. PPE.
11.	Chemical pumps: open, closed, high temperature, high current, leaking, etc.	Exposure	Secondary containment. Sump. Exhaust always on. PPE.
12.	Pressure regulators: pressure too high, too low, etc.	Exposure	Secondary containment. Sump. Exhaust always on. PPE.
13.	Electrical components: short circuit, open circuit, intermittent	Sparks. Blast unlikely.	Door panels and rated parts.
14.	Sensors (leak detectors, capacitor, pressure, flow meter): in various failure modes	Exposure	Secondary containment. Sump. Exhaust always on. PPE.

A typical What if? analysis work sheet abstracts from a catalog of hundreds of items.

14.2 Hazardous Design – Safety Categories

The term "safety category" has multiple meanings. Here are some common definitions.

14.2.1 NFPA 79 and IEC 60204

NFPA 79 (and its companion document IEC 60204) section 9.2.2 defines three stop categories (0, 1, 2) that relate to the emergency stop of machine actuators. NFPA 79 does not mandate one or another.

- Category 0 is an uncontrolled stop by cutting off the power.
- Category 1 is a controlled stop using power on the actuators, then cut the power. This is needed by variable frequency drives (VFD) and turbo molecular pumps to avoid damage.
- Category 2 is a controlled stop using power on the actuators, and the power stays on.

14.2.2 PHA and traditional hazard analysis

PHA defines five safety categories as being very low (slight), low, medium, high, and very high (critical). This assessment drives the investment and urgency of the corrective action.

14.2.3 EN 954

EN 954-1 defines five safety categories as being B, 1, 2, 3, and 4. The categories represent a classification of the safety-related parts of a control system with respect to their ability to withstand faults, and the behavioral consequences of the fault. Categories B & 1 are determined primarily by the selection of components. Categories 2, 3, & 4 are determined primarily by the structure of the system.

Category	System behavior	Requirements
B	A fault can lead to the loss of the safety function.	Safety-related parts of control systems and/or their safety devices and their components must be designed, constructed, selected, assembled and combined in accordance with the relevant standards such that they can withstand the expected influence.
1	A fault can lead to the loss of the safety function. Probability of a fault is lower than in category B.	Requirements of B plus the use of well-tried components and safety principles. Characteristics of a well-tried component: • Widely and successfully used in the past with successful results in similar applications. • Manufactured and verified by applying principles which demonstrate its suitability and reliability for safety-related applications. • At least 10 different applications. • At least 10,000 hours of expected life. • At least one year of service history with enough samples to achieve 95% confidence. Characteristics of well-tried safety principles: • Fault detection. **Example:** a safety circuit that has a minimum current loop. • Fault avoidance. **Example:** construction. • Fault probability reduction. **Examples:** by using a heavy-duty part or by redundancy. • Fault direction and consequence. **Example:** a blow-out pressure disk diaphragm.

Category	System behavior	Requirements
2	A fault can lead to the loss of the safety function between the checks. The loss of the safety function is detected by the check.	Requirements of 1 plus the safety function shall be checked at start-up and periodically during operation, as necessary. When a fault is detected, the machine will go into a "safe" state. A single event fault must not cause the fault sensor and the PLC to both fail at the same time.
3	If the single fault occurs, the safety function is still maintained. Some but not all faults are detected. Accumulation of undetected faults can lead to the loss of the safety function.	Requirements of 2 plus the safety-related parts shall be designed such that: • A single fault in any of these parts does not lead to the loss of the safety function, and • The single fault is detected whenever reasonably practicable.
4	If faults occur, the safety function is still maintained. Faults are detected in good time to prevent the loss of the safety function.	Requirements of 3 plus the safety related parts shall be designed such that: • A single fault in any of these parts does not lead to the loss of the safety function, and • The single fault is detected before or during the next demand on the safety function, or, if this is not possible, an accumulation of faults should result in a loss of the safety function.

The earlier discussion talks about the traditional hazards caused by the physical world such as electrical, mechanical, chemical, radiation, normal human behavior, etc. Another discussion is needed to include hazards caused by the failure of safety devices and human misbehavior. This is the basis of:

- IEC 61058 – categories for system integrity level (SIL)
- ISO 13849 – functional safety of simple systems, with emphasis on performance level (PL)
- IEC 62061 – functional safety of complex systems

14.2.3.1 IEC 61058 SIL categories

IEC 61058 introduces a concept called System Integrity Level (SIL). SIL is defined as a relative level of risk reduction provided by a safety function. SIL is a measurement of performance required for a Safety Instrumented Function (SIF). SIF are implemented as part of an overall risk reduction strategy which is intended to eliminate the likelihood of a Safety, Health, and Environmental (SH&E) event that could range from minor equipment damage up to an event involving an uncontrolled catastrophic release of energy and material.

Four SILs are defined, with SIL=1 being the least dependable and SIL=4 being the most dependable. A SIL is determined based on both quantitative (failure rates and redundancy) and qualitative factors (development process and safety life cycle management).

Low demand. Example: air bag			**High demand. Example: brakes**	
SIL	**Failures per demand**		**SIL**	**Failures per hour of continuous operation**
1	1 failure per 100 demands		1	1 failure per 1 million hours
2	1 failure per 1,000 demands		2	1 failure per 10 million hours
3	1 failure per 10,000 demands		3	1 failure per 100 million hours
4	1 failure per 100,000 demands		4	1 failure per 1000 million hours

Example: Let's say that brakes fail once per year on a population of 100,000 cars driven an hour per day. The SIL category is high demand. The failure rate per hour is 1 per 36,500,000 (365 hours per year x 100,000 cars). Therefore, in this case, the SIL=2.

SIL targets can be defined based on consequences:

- SIL=1 avoid minor injury (machinery)
- SIL=2 avoid severe injury (automobile)
- SIL=3 avoid multiple deaths (train wreak)
- SIL=4 avoid many deaths (airplane crash)

14.2.3.2 ISO 13849 – functional safety of simple systems

ISO 13849 has replaced EN 954 as the primary means to provide presumption of conformity to the machinery directive for the safety-related parts of the control system.

ISO 13849 performance levels (PL) have five elements:

- The category of circuit structure and architecture.
- The mean time to dangerous failure.
- The number of cycles such that 10% of the components have a dangerous failure.
- Diagnostic coverage.
- Common cause failure.

ISO 13894 performance levels (PL) are divided into five categories: a, b, c, d, e, from low risk (a) to high risk (e). The score is based on a combination of three factors: severity, frequency, and avoidance. Add up the number of points (a simplification) as follows:

- 8 points for serious injury (permanent) or 4 points for slight injury (reversible).
- 2 points for frequent or continuous exposure or 1 point for seldom or short exposure time.
- 1 point for no avoidance or 0 point for avoidance under specific conditions.

PL=a if 5 points. **PL=b** if 6 points. **PL=c** if 7-9 points. **PL=d** if 10 points. **PL=e** if 11 points.

ISO 13894 performance levels (PL) can also correspond to the probability of dangerous failures per hour (PFHD). These indicate how likely it is that a dangerous failure could occur over a period of one hour.

ISO 13894 performance levels (PL) define both risk and reliability. PL=e has the highest risk and therefore requires the best safety function reliability. The reliability is based on the following factors:

- The system's structure (EN 954 categories B, 1, 2, 3, 4).
- The mean time to dangerous failure (MTTFd) of the safety component.
- The diagnostic coverage (DC) of the system.

It is also necessary to:

- Protect the system against a common cause failure (CCF) that knocks out both channels.
- Protect the system from systematic errors built into the design.
- Follow certain rules to ensure software can be developed and validated in the right way.

ISO 13849 has major difficulties. Component reliability data is just becoming available. The method is complicated to analyze and expensive to implement. And there has not been a significant overall improvement to system safety. The main tools for calculating PL are SISTEMA (from German OSHA) and the Pilz calculator.

14.2.3.3 IEC 62061 – functional safety of complex systems

IEC 62061 is used to specifically implement IEC 61058 for machinery. It has the design requirements for safety related control systems and for the respective subsystems and component devices.

Architectural constraint and fault tolerance – A "zero" fault tolerance means that the subsystem faults with a single component failure. A "one" fault tolerance means that the subsystem can still function with a single component failure, but not with two. **Example:** airplanes can tolerate a single engine failure or a single flat tire but cars cannot.

Common cause failure – This is when a single cause creates multiple faults and a dangerous failure. **Example:** airplanes flying through a flock of birds, knocking out all the engines, or contaminated fuel. Annex F has six factors that can help to mitigate common cause failures. **Example:** using redundant sensors from different manufacturers.

Diagnostic coverage – The ratio (probability) of detecting a dangerous failure against all possible dangerous failures. **Example:** a car has 20 light bulbs. Two of the bulbs cannot be diagnosed unless you happen to be looking at them. Therefore, in this case, the diagnostic coverage is 18/20 = 90%.

Probability of dangerous failures per hour (PFH_D) – The failure rate per hour of a subsystem. **Example:** Car brakes mentioned above, hypothetical 1 failure per 36,500,000 hours.

Proof test – a periodic test to check for faults, diagnostic coverage, and degradation.

Subsystem – The first subdivision of a system, such that a failure of a safety component would cause a failure of a safety function. **Example:** redundant sensors would be in separate subsystems by definition.

Systematic failure – Generally speaking, parts can fail due to infant mortality (early life), normal operation, and wear-out (end-of-life). Systematic failures are those caused by poor engineering. **Examples:** heat, over-voltage, vibration, workmanship, etc.

14.2.4 Summary

Our discussion was separated into hazardous facility, traditional hazard analysis, and functional safety. The first is the language of the fire department. The second is an engineering method that originated from the early space program. The third is a relatively new technique that takes into account the failure of components and humans to do what they are supposed to do.

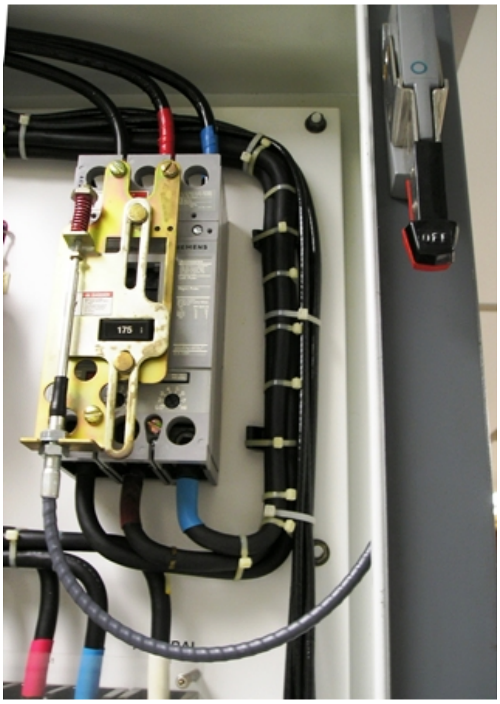
Hazard analysis is often used in situations driven by:

- A lack of coverage in a code book.
- A request by the insurance carrier (factory and workers comp).
- A requirement from the local fire department.
- A need for an OSHA workplace safety program.
- A desire by management for an independent assessment by a third party.
- A requirement for CE Mark and for SEMI.

PHA is typically used for electrical, mechanical, and fire hazard. A report is attached to SEMI S2 and CE Mark safety analysis. The emphasis is machine safety.

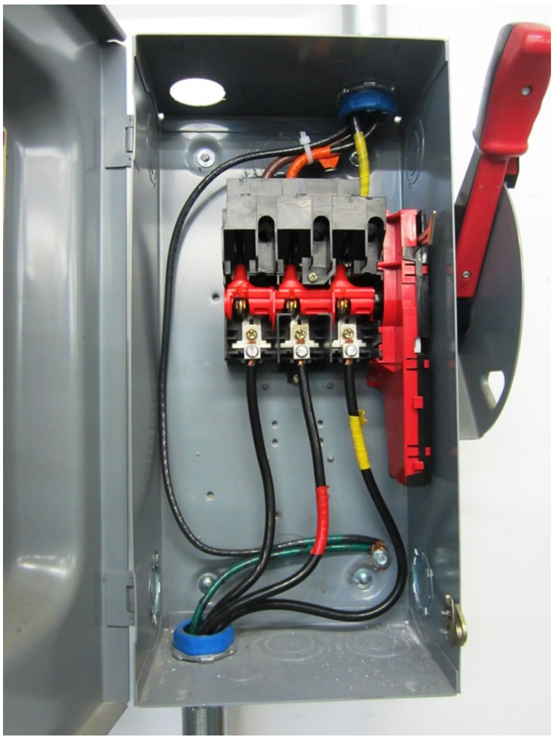
What if? Analysis is typically used for flammable, explosive, and toxic chemistry hazards. A report is sometimes requested by the fire department or the insurance carrier, with emphasis on facility safety.

15 Color Illustrations



Disconnect can be a circuit breaker handle

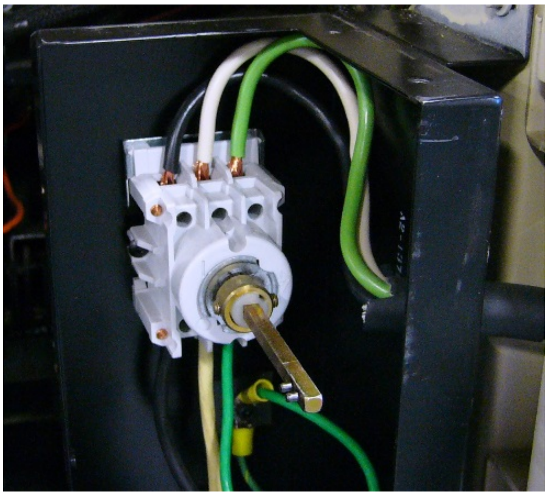
Disconnect can be red & yellow rotary switch



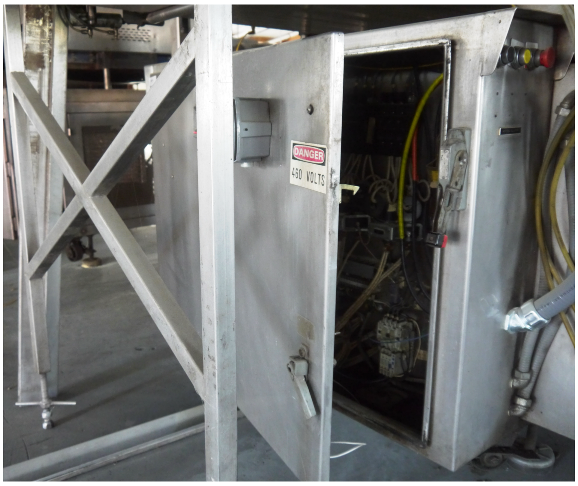
This disconnect switch is wired backwards. Line side into the bottom means terminals and blades staying energized when the switch is off. 480 VAC should be brown-orange-yellow.

This disconnect switch is too high. It should be “readily accessible” and not require a ladder.

Ground wire should be connected to the cord

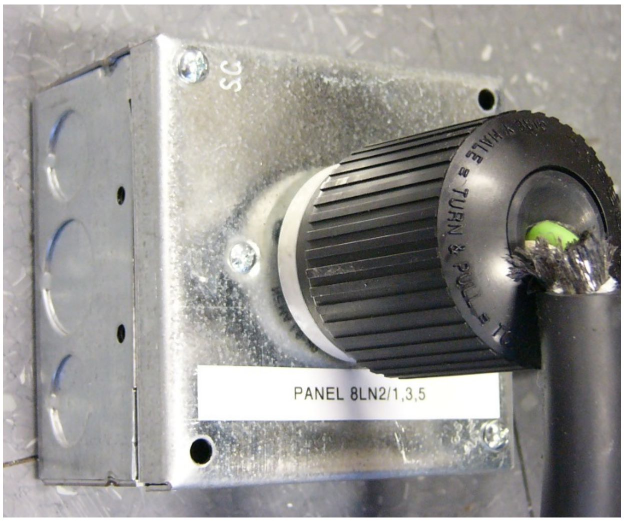


Ground wire should be permanent not switched



Inadequate clearance – door must swing 90°

Inadequate clearance – must be 36 inches



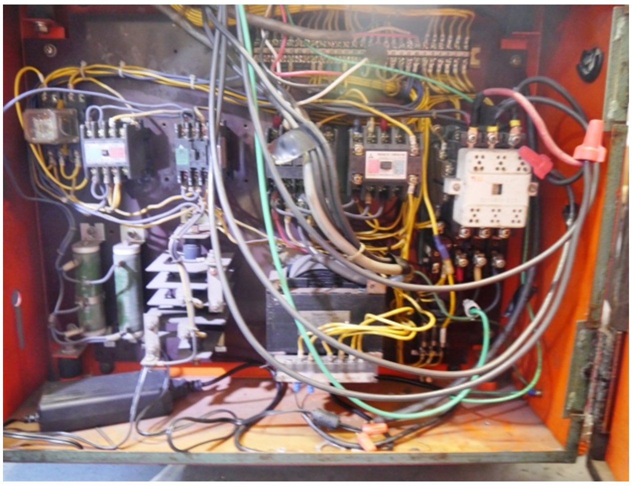
Cord cap needs repair and strain relief

Hydra cords – call Hercules

Red EMO on yellow with interlock bypass key

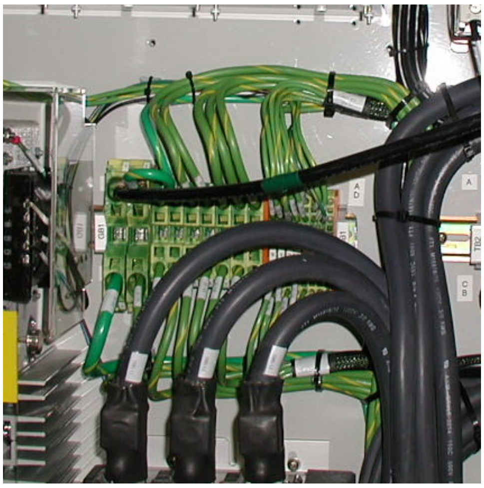
Door interlock should not be easily defeated

Neat and safe wiring with touchproof guard



Messy and dangerous wiring

Hook-up across a sharp edge needs a grommet



Bending radius should be >12x cable diameter

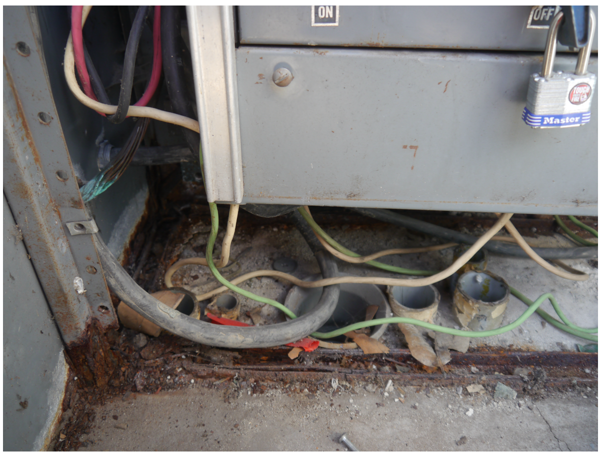
Check for dead and missing fans

Counterfeit circuit breaker on the right

Do not mix power and signal in same raceway

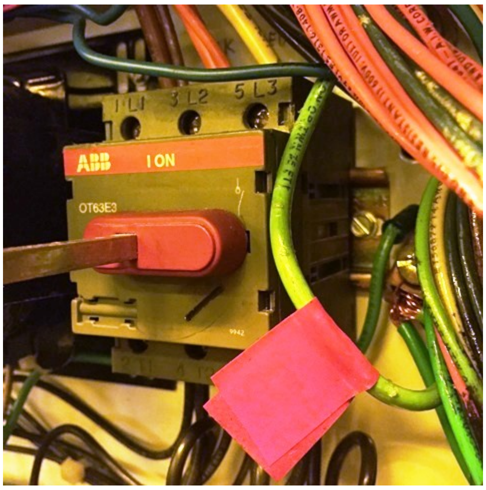
Electric water heater in a shower stall

Splattered chemical on a control panel



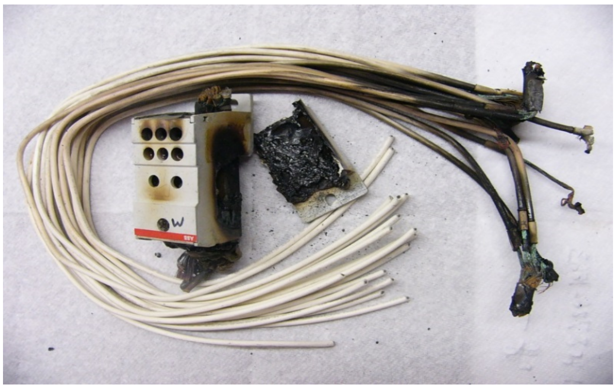
Corrosion on the floor of an outdoor panel

Good: wiring terminals torqued to spec



Bad: multi-wire should be crimped in a ferrule

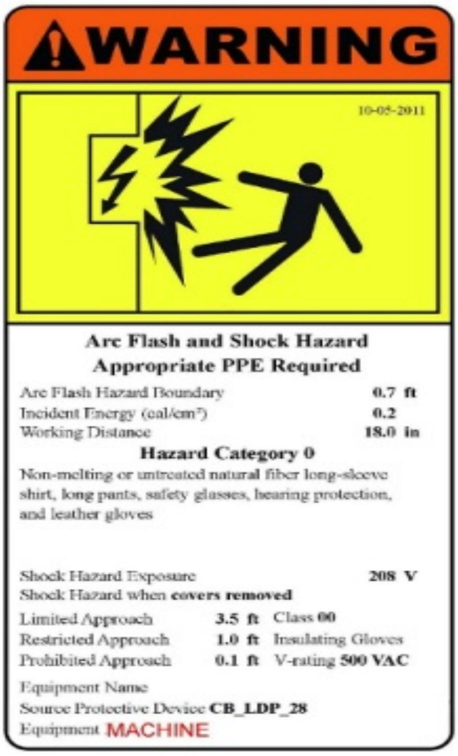
Loose terminals, then oxidation, then burn-out



Short circuit on the neutral bus

Circuit breaker with hasp – courtesy of Eaton. NEC 110.25 states that the provisions for locking shall remain in place with or without the lock installed.

Cal-OSHA permits temporary clips for LOTO. NEC 110.25 states that portable locking mechanisms intended for temporary application are not acceptable for LOTO.



Arc flash hazard warning label

Toxic pictogram (Wikipedia)

Airport baggage conveyor

On the cover of an air ionizer

Nomex flash rated suit

Balaclava

Face shield

Gloves

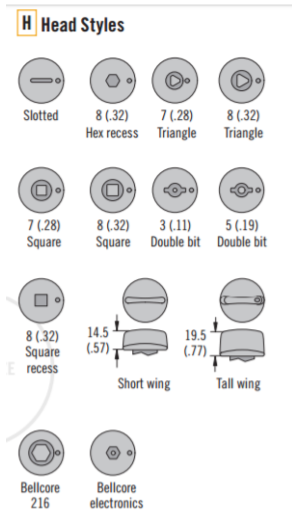
Insulated tools

Voltage tester

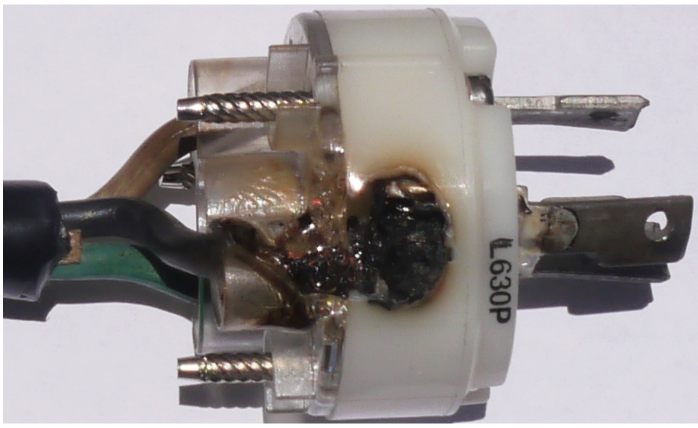
Personal protective equipment for the qualified electrical worker (QEW)

Disconnect switch with line side guard courtesy of Schneider

Paddle switch for a simple emergency off courtesy of Woodstock

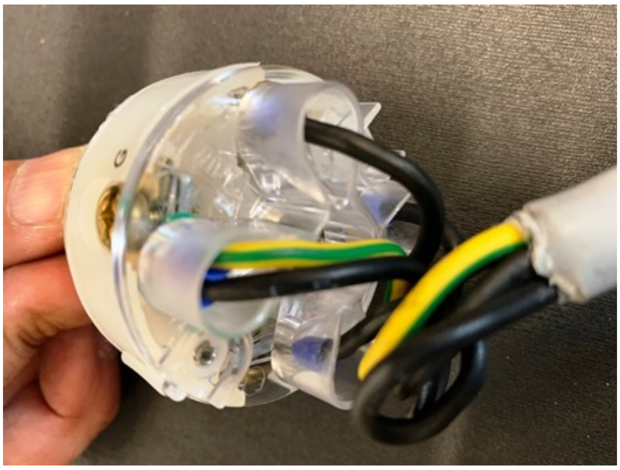


Examples of special tool to open

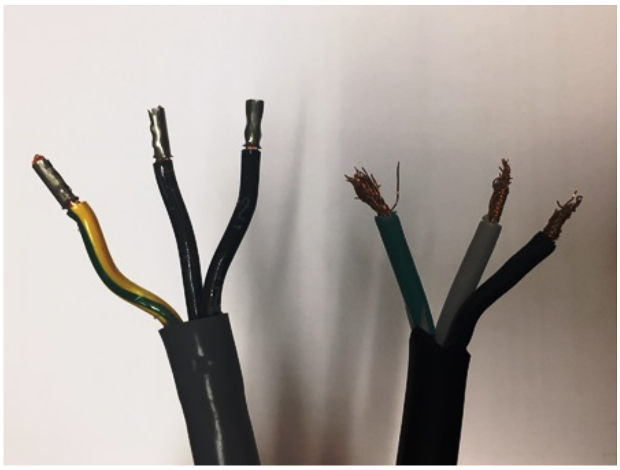


L6-30 plug overloaded and burned

Wire whisker short circuit



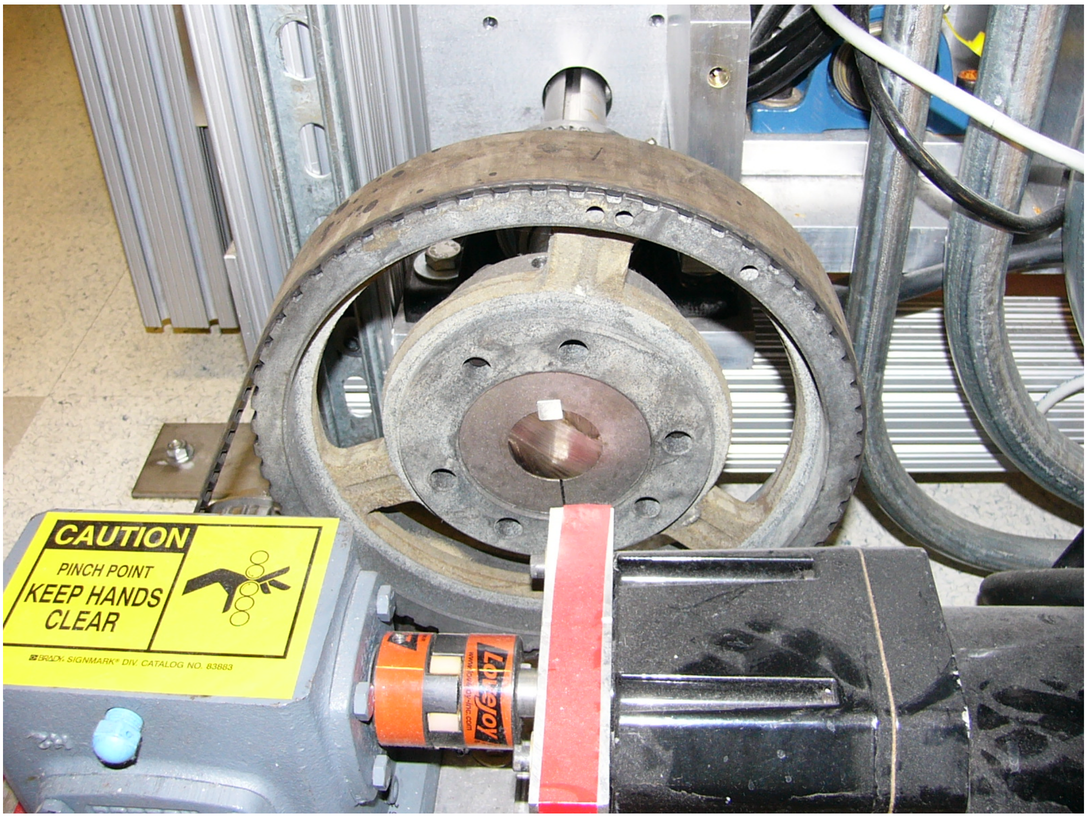
Neutral and ground connected



Ferrules on a power cord

Gas cab ventilation sweep test

Gas cab tracer gas test

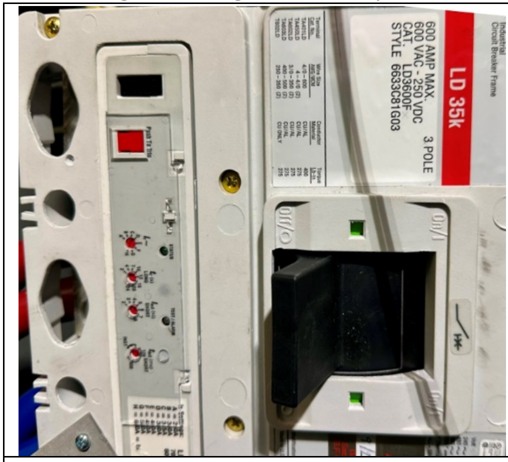


Guard needed – a warning label is not enough

Torque witness example

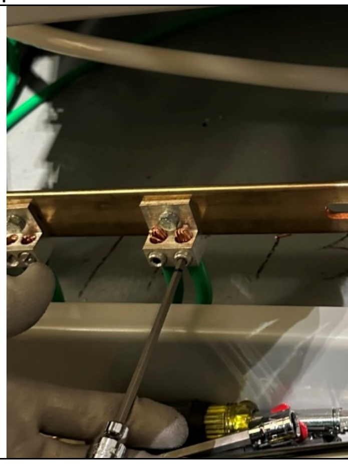
Torque witness – panel xxxx CB #x, x, x outgoing to xxxx disconnect switch

- Date and time xxxx. Location xxxx.
- The torque wrench is a xxxx wrench model xxxx, serial xxxx, 10-100 foot-pounds, calibrated September 2023.
- Outgoing circuit breaker is an Eaton LD35K, 600 amp, 65 KA 3Φ, with 2x 350 KCMIL hot legs and 2x #1 ground.
- The 3Φ hot legs were torqued with a 5/16” hex bit set to 275 inch-pounds per the circuit breaker data plate.
- The ground legs were torqued with a 3/16” hex bit set to 120 inch-pounds per the NEC.



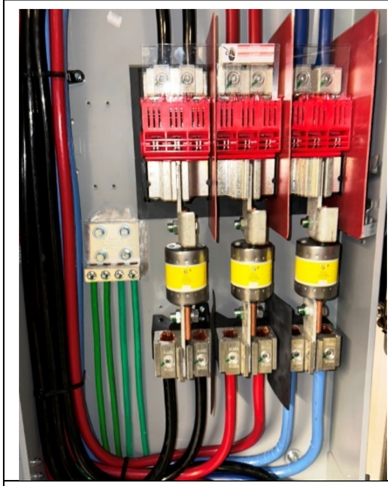
disconnect switch


outgoing hot legs


outgoing grounds

Torque witness –disconnect switch incoming

- Date and time xxxx. Location xxxx
- The torque wrench is a xxxx wrench model xxxx, serial xxxx, 10-100 foot-pounds, calibrated September 2023.
- Incoming terminals 3Φ, with 2x 350 KCMIL hot legs and 2x #1 ground.
- The 3Φ hot legs were torqued with a 5/16” hex bit set to 275 inch-pounds per the NEC.
- The ground legs were torqued with a 5/16” hex bit set to 275 inch-pounds per the NEC.


disconnect switch


incoming hot legs

incoming grounds

Arc flash accident in Texas

16 References

Basic codes, standards, and text books for electrical:

1. NFPA 70 National Electrical Code (NEC) Handbook
2. NFPA 79 Electrical Standard for Industrial Machinery Handbook
3. NFPA 790 Standard for Competency of Third-Party Field Evaluation Bodies
4. NFPA 791 Recommended Practice for Unlabeled Electrical Equipment Evaluation
5. NFPA 70E Electrical Safety in the Workplace Handbook
6. "Electrical Safety Code Manual, a Plain Language Guide to National Electrical Code (2008), OSHA, and NFPA 70E" by Kimberley Keller, 2010, ~300 pages
7. "Safety Basics – Handbook for Electrical Safety", Cooper Bussman, 2001, 66 pages
8. "Molded Case Circuit Breakers and their Application", ANSI/NEMA AB 3-2013 58 pages, free download at www.NEMA.org

Product liability:

9. "Acceptable Risk" by Fred A. Manuele, ASSE Professional Safety magazine, May 2010.
10. "Unknowing Dangers" by Ellen Wertheimer, Villanova School of Law, Year 2005, paper #27
11. "The McDonald's Coffee Lawsuit" by Kevin G. Cain, Journal of Consumer and Commercial Law, ~1998
12. "Optional Safety Equipment and the Savvy Purchaser" by Michael Hoeing, New York Law Journal, May 2009
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