Ammonia Refrigeration Processes & Equipment

OTI 3430

Objectives

This module will enable you to:

- Identify the hazards of ammonia
- Describe equipment and processes for ammonia refrigeration processes
- Describe common PSM findings and questions
- Identify possible violations of the PSM standard relative to the identified equipment and systems

Today's Focus

- Ammonia Refrigeration – not just general ammonia use
- Focus is prevention and process safety – not hard hat safety

NH_3 NAICS Codes from RMP Data

NAICS	NAICS_DESCRIPTION	Number	Process Type
49312	Refrigerated Warehousing and Storage	857	ammonia
311615	Poultry Processing	297	ammonia
311612	Meat Processed from Carcasses	164	ammonia
311411	Frozen Fruit, Juice, and Vegetable Manufacturing	123	ammonia
311511	Fluid Milk Manufacturing	111	ammonia
31152	Ice Cream and Frozen Dessert Manufacturing	99	ammonia
115114	Postharvest Crop Activities (except Cotton Ginning)	94	ammonia
311991	Perishable Prepared Food Manufacturing	89	ammonia
31141	Frozen Food Manufacturing	76	ammonia
311513	Cheese Manufacturing	71	ammonia
311611	Animal (except Poultry) Slaughtering	67	ammonia
31151	Dairy Product (except Frozen) Manufacturing	59	ammonia
42441	General Line Grocery Merchant Wholesalers	59	ammonia
311412	Frozen Specialty Food Manufacturing	56	ammonia
31161	Animal Slaughtering and Processing	54	ammonia
42491	Farm Supplies Merchant Wholesalers	51	ammonia

Does PSM Apply?

- Determine Coverage:
  - TQ for anhydrous ammonia is >10,000 pounds for entire interconnected systems (about 2,000 gallons) at ANY time
  - Most of inventory will likely be in the high and low pressure accumulators – start with largest vessels and include smaller ones if needed to establish inventory

Does PSM Apply?

7E FOIA EXEMPTION

Do PSM Exemptions Apply?

- NO!

- PSM Exemptions do not apply
- Anhydrous NH3 is listed as an HHC in Appendix A of 1910.119
- Not treated as a flammable for coverage
- Use as a working fluid in refrigeration systems is consistent with PSM definition of a covered process

What About NH3 Refrigeration Processes < 10,000 lbs.?

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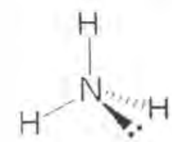
Typical Coverage Question

- Q: What if I have 3 separate 5,000 pound ammonia systems? Am I covered?
- A: Maybe
  - The definition of "process" includes co-located equipment (equipment that is not interconnected but could be affected if a release occurs).
  - Since NH3 properties include fire/explosion potential it is conceivable that a release resulting in a fire/explosion from one system could affect the other co-located systems (especially since the bulk of NH3 systems are located indoors)
  - If the systems are in separate areas of the facility and not interconnected, they are likely not covered

Properties of Ammonia

- Colorless gas at room temperature
- Boiling Point -28F
- Specific gravity 0.5970 (lighter than air)
- Pungent smell
- Very soluble in water
- Flammability limits 15-28%



Elsevier, Hazardous Chemicals Handbook, 1994

Properties of Ammonia (cont'd)

- Generally shipped and stored under pressure as a liquid
- Pure ammonia is called "anhydrous" meaning without water
- Refrigerant grade ammonia is 99.95% ammonia with less than 33 ppm water and less than 2 ppm oil

Health Effects of Ammonia

Concentration (ppm)	Effects
20	Perceptible odor
40	Slight eye irritation
50	OSHA PEL
100	Irritation of eyes and nasal passages after a few minutes exposure
300	IDLH
400	Severe irritation of the throat, nasal passages and upper respiratory tract
700	Severe eye irritation, no permanent effect if less than 30 minutes exposure
1700	Serious coughing, bronchial spasms, less than 30 minutes exposure may be fatal
5000	Serious edema, strangulation, asphyxia, fatal almost immediately

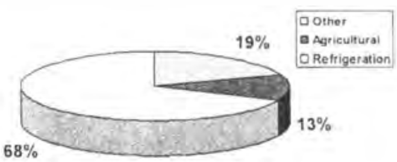
Elsevier, Hazardous Chemicals Handbook, 1994

Properties of Ammonia (cont'd)

- Ammonia is a base.
- It is corrosive and can burn the skin and eyes
- Liquid ammonia can cause frostbite
- NH_3 reacts with and corrodes copper, zinc, and many of their alloys such as brass and bronze
- Combines with mercury to form explosive fulminate
- Carbon steel used for most piping and equipment
  - But note low temperature toughness issues!
  - Stress cracking of welds can be a problem

OSHA Accident Investigation Database 1995-2004

- 63 incidents as a result of ammonia releases
  - 43 involved ammonia refrigeration



Source: CSB Ammonia Presentation

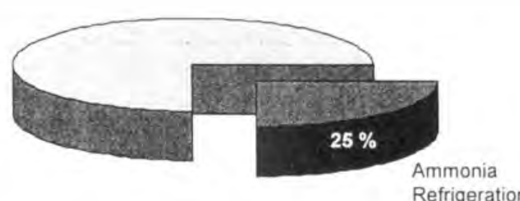
OSHA Database 1995-2004

Injury Type	Human Toll	Incidents
Fatality	19 (10)*	17 (10)
Injury – Hospitalized	85 (66)	29 (18)
Injury – Non-hospitalized	187 (165)	28 (21)

* () = Ammonia refrigeration incidents

Source: CSB Ammonia Presentation

8,300 RMP Ammonia Facilities

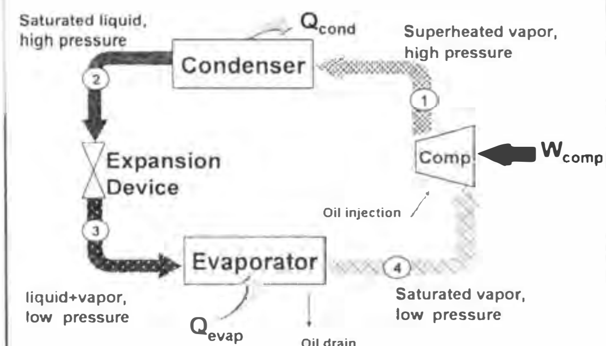


- Roughly 2,100 RMP NH_3 refrigeration facilities
- 1300 RMP ammonia incidents
- 50% involved ammonia refrigeration

Source: CSB Ammonia Presentation

Refrigeration Process Overview

Basic Refrigeration Cycle



From Reindl, 2006

Refrigerants

- Refrigerant fluids need to have appropriate properties to be useful
- Desirable properties:
  - Safe (low toxicity & flammability)
  - High heat of evaporation
  - Saturation pressure versus temperature curves giving:
    - reasonable pressures in the evaporator (not too low)
    - reasonable pressure in the condenser (not too high)
  - Low power consumption for compression
  - Low cost

Why Ammonia?

- Has good properties for a wide range of refrigeration applications:
  - 22 psig (27 psia) at 8 F
  - 256 psig (270 psia) at 116 F
  - High heat of evaporation of ~590 BTU/lb
  - Low cost, stable (doesn't decompose)
  - Low system and life-cycle costs
- Drawbacks
  - Toxic and potentially explosive in air
  - Slightly higher power consumption than HFCs (hydroflurocarbons - "Freons")

Why Ammonia? (cont.)

- NH3 not a persistent air pollutant
  - Readily "scrubbed" by rain
  - Low ozone depletion AND low global warming potential
  - HFC's developed for low ODP tend to have high to very high GWP
- Being promoted as a "green" refrigerant
- Can cause aquatic damage / act as a nutrient

Refrigeration Cycle Arrangements

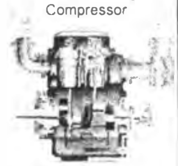
- High pressure / Low pressure "sides" to process
  - High pressure generally higher risk due to higher stresses, leak potential
- Single or multi-stage compression
- Evaporators:
  - Direct expansion
  - Flooded
  - Overfeed
- Condensers
- Transfer systems

Centrifugal Compressor

Compressors

- Wide range of ammonia compressor types in use
  - Reciprocating – small commercial / industrial loads. High vibration, positive displacement. Low first cost / high maintenance
  - Screw – medium to large commercial / industrial service. Smooth operation, pos displacement
  - Centrifugal – very large applications. Smooth operation, fixed discharge pressure, limited pressure range per stage

Reciprocating Compressor

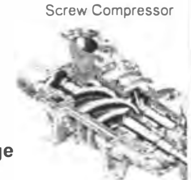


Mycom, Inc

Compressor Arrangements

- Parallel Compressors
  - Multiple compressors used to increase capacity (throughput) at same inlet / outlet conditions
- Multi-stage
  - Compression stages in series
  - Use to achieve a wider pressure range
  - Can accommodate a deeper (lower pressure) cold end, at a given (fixed) refrigerant throughput rate
  - Usually has cooling between stages to improve efficiency

Screw Compressor



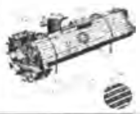
Mycom, Inc

Condensers

- Three major types:
  - Air cooled ("fin-fan")
  - Evaporative (e.g., BAC, Buffalo)
  - Shell & Tube (using cooling water from cooling tower or city water supplies)
- Air and evaporative coolers usually on roof or outside the compressor (mechanical) room
- Shell & Tube can be inside the mechanical room

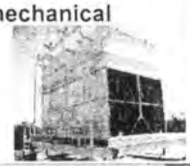
Fin-fan Condenser

Delta HX, Inc



Shell-and-tube Condenser

KVTI, Inc.



Evaporative Condenser

Baltimore Air Coil

High Pressure Receiver

- Pressure vessel storing condensed ammonia at high pressure
- Usually in or near the mechanical room
- Ammonia distributed to users from this point, using either storage pressure or pumps
- "High side" of process usually has ~1/3 of system NH_3 inventory

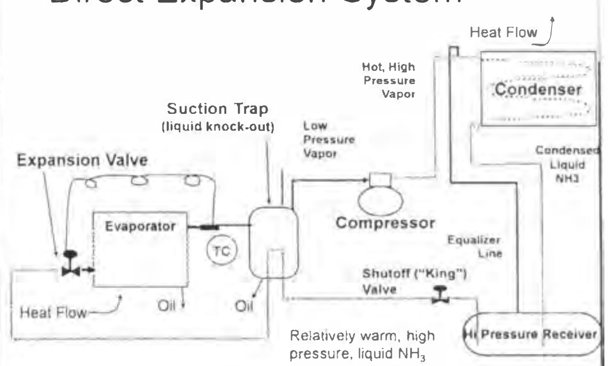
OSHA Intranet

Evaporator Arrangements

- Boiling of liquid ammonia in the evaporator is what actually accomplishes cooling – the removal of heat energy from the surroundings
- Evaporator pressure sets the lowest achievable temperature in the system – the lower the pressure, the colder the temperature!
- Evaporator set-up impacts the liquid ammonia inventory and its location
- Also impacts where compressor oil tends to accumulate, and thus must be drained – a potentially high risk activity

27

Direct Expansion System

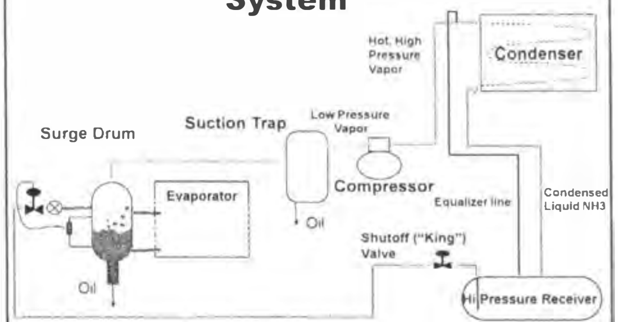


Direct Expansion System

- Simple - lowest first cost
- Oil drained from each evaporator – fouling a concern
- Generally low inventory in the plant
- Control can be an issue
- As with all systems, need a liquid / vapor separator (suction trap, knock-out) ahead of the compressor to protect it from liquid carryover
- Warm HP liquid NH_3 used to boil out the trap (or use heaters)
- All ASME vessels and the compressor will be equipped with relief valves, that must discharge to a safe location
- Relatively high maintenance

29

Gravity Feed (Thermosiphon) System



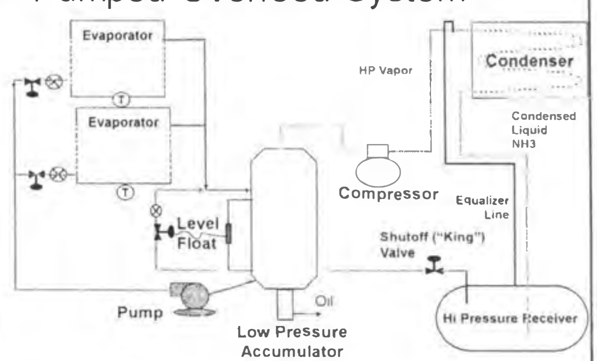
30

Gravity Feed (Thermosiphon) System

- Mixed vapor / liquid stream exits evaporator – surface is fully wetted for excellent heat transfer
- Surge drum for each evaporator
- Oil drained from each surge drum
- High inventory of ammonia, with much of it out in the plant at points-of-use, not centralized in the mechanical room area where it is easier to control.
- Can vaporize liquid out of suction trap as in direct expansion, or pump liquid back for recovery
- Relatively less oil in the compressor suction trap

31

Pumped Overfeed System



Pumped Overfeed System

- Liquid pumped to evaporators. Allows smaller piping
- Mixed vapor / liquid stream out of evaporator – heat transfer surface fully wetted, not susceptible to oil fouling.
- Excellent heat transfer
- One LP accumulator per plant area
- Good control
- Oil drained from accumulator, which also acts as knock-out suction drum
- Higher capital cost
- Pump cost, maintenance and leakage are considerations

33

Other Approaches

- Common for facilities to have grown incrementally over many years
- Many plants thus have multiple systems when a single, larger system might (now) make more sense
- Systems may, or may not, be interconnected
- Mixed / hybrid systems may be encountered
- Can be challenging to control – NH_3 can move around
- Equipment and tanks may be at various locations around the plant – not just in "the" mechanical room!
- Keep in mind that the different system types have their NH_3 inventory in different locations!

34

Transfer Systems

- Pumps are used to move liquid ammonia and oil out of the knock-out vessels
- Generally centrifugal pumps (shown) with mechanical seals, or "canned motor" types used
- Oil-rich refrigerant is returned to a central location for separation and recovery – reducing manual oil drainage

35

Ammonia Refrigeration Enforcement

What's Important

What to Look For

36

NH3 Refrigeration Fatalities - This IS PSM Stuff!!

#	Dead/ Hospital	Type Facility	Incident Description
1	1/0	NH3 Ref	Compressor housing blew out, struck refrigeration manager
2	2/0	NH3 Ref.	Draining oil from trap in NH3 refrigeration, system maintenance workers overcome
3	1/0	NH3 Ref	Floor collapsed while forklift operated on 2nd floor of cold warehouse storage Action caused NH3 lines to be severed Driver overcome by vapors
4	1/1	NH3 Ref	Oil separator on 2 stage NH3 refrigeration system overpressurized and exploded
5	1/2	NH3 Ref	NH3 release while maintenance crew unbolted flange from piece of cooling equipment
6	1/0	NH3 Ref	Overexposure to NH3 while opening a high pressure NH3 line
7	4/0	NH3 Ref	Pressure vessel in an ammonia refrigerator system ruptured under pressure The explosion caused extensive physical damage and released dense clouds of ammonia gas

37

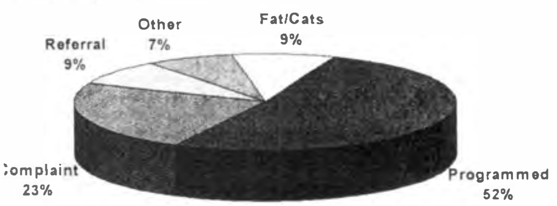
NH3 Refrigeration This IS PSM Stuff!! (cont'd)

#	Dead/ Hospital	Type Facility	Incident Description
8	1/2	NH3 Ref	Oil inside tank congealed after 7 down days Attempt to use steam to thin oil, over pressured tank causing explosion
9	1/0	NH3 Ref	Employee was asphyxiated by NH3 release
10	0/8	NH3 Ref	An NH3 liquid line catastrophically failed due to external corrosion 1500+ employees evacuated from plant

What themes do you see here?

38

Why Does OSHA Show Up at Facilities w/NH3 Refrigeration Processes??



For SICs 20 (Food and Kindred Products),
And 4222 (Refrig. Warehousing/Storage)

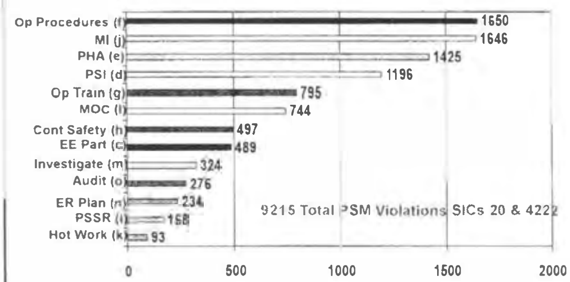
39

PSM Data for SICs 20 and 4222

- PSM inspections (May 26, 1992 to October 15, 2008)
  - Total Number of inspections 1638
  - Total number of violations......................6440
  - Total proposed penalty...........................$36.8 million
  - Total from all inspections (not just PSM)..$361.5 million

40

Frequency of PSM Violations in SIC 20 and 4222
(May 1992 – October 15, 2008)



41

1910.119	Description
(j)(2)	Establish/implement MI procedures
(e)(1)	Conduct PHA/ *identify, evaluate and control*
(l)(1)	MOC not conducted
(c)(1)	Employee participation plan
(g)(1)	Initial operator training
(f)(1)	Develop and implement Op procedures
(e)(5)	PHA recommendation follow-up
(j)(5)	Correct deficiencies
(j)(4)(i)	Inspection/testing not conducted
(g)(3)	Document understanding operator training

42

Important Standards That Apply to NH3 Refrigeration

- 1910.119 – PSM
- 1910.147 – Lockout/Tagout
- Subpart I – PPE
- Subpart S – Electrical
  - Including 1910.307 Hazardous Locations
- 1910.38, Emergency Action Plans
  - As required by PSM
- 1910.120(q): HAZWOPER – Emergency Response
- Others
  - Subpart D: Walking/working surfaces
  - Subpart: O: Machinery and Machine Guarding
  - Egress

43

What Are Signs of a Poor NH3 Refrigeration PSM Program?

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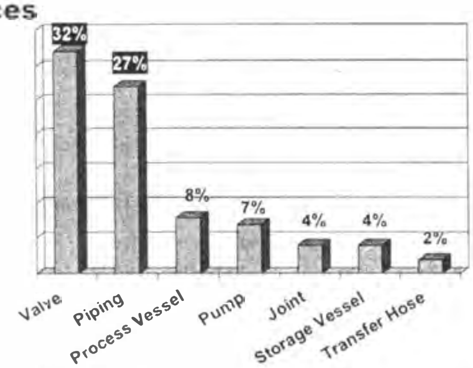
44

Refrigeration Equipment Release Sources



Total does not = 100% as 16% of release sources not identified
From CSB Presentation

Equipment / Line Opening

- Large percentage of NH3 releases occur during maintenance – **equipment opening**
  - Piping
  - Vessels
  - Pumps/Compressors
- Applicable Standards
  - LOTO (1910.147)
  - PSM safe work practices
    - 1910.119(f)(4)
    - 1910.119(h)(2)(iv)
    - 1910.119(h)(3)(iv)

Oil Draining

- Oil needs to be drained from NH3 systems
  - NH3 "chases" the oil from the system - NH3 sometimes gets released if proper procedures are not implemented or if equipment malfunctions
- IIAR Oil Draining Guidelines
- Important Standards
  - 1910.119(f)(1)(i)(B) – Normal operating procedures
  - 1910.119(f)(1)(iii) – Safety and health considerations
    - (B) – Precaution necessary to prevent exposure
    - (C) – Control measures if physical contact or airborne exposures occur.
  - 119(e)(3)(i) – PHA must identify hazards/deviations related to oil draining
  - 119(e)(3)(iii) – PHA must identify controls/safeguards

What Design Codes and Standards Could Be Expected in PSI*?

- PSM equipment "starting point" for design
  - 1910.119(d)(3)(i)(F):
    *Information pertaining to equipment in the process shall include **design codes and standards** employed*:
      - Vessels: ANSI/ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1
      - Piping: ANSI/ASME B31.5 *Refrigerant Piping and Heat Transfer Components*

* Remember - PSM is a performance standard! Employers may use other design codes or standards than those shown above if they can demonstrate that they provide equal or greater protection than the RAGAGEP which is recognized by users as the most relevant.

What Design Codes and Standards Could Be Expected in PSI**? (cont'd)

7E FOIA EXEMPTION

Facility Siting - Equipment

- Most NH3 refrigeration processes are in facilities that use material handling equipment, e.g. fork lifts
- Many releases have occurred when fork lifts have struck and ruptured equipment containing NH3
- This hazard must be *identified, evaluated, and controlled*
- Controls include:
  - Relocating process equipment
  - Barriers which prevent contact between handling equipment and process equipment
- Important standards
  - PHA facility siting 1910.119(e)(3)(v)
  - PHA 1910.119(e)(1) – PHA did not… *identify, evaluate, or control the hazard…*

Deficient Inspection Procedures and Inspections

- OSHA experience has shown that many industry employers have deficient:
  - inspection procedures
  - inspection implementation

Inadequate Inspection Procedures

- Look for "bare-bone" inspection procedures
- Written procedures that do not transmit employer's MI program guidance
  - Roles/responsibilities in MI program
  - Listing of equipment in program
  - Establishing standards for MI activities
    - IT / PM plans
    - Inspection standards, etc.

Inadequate Inspection Procedures

- Written procedures need to be specific ("where to / when to / how to") and IT procedures must follow RAGAGEP
  - Provide specific instructions for performing tasks
- Important standards
  - 1910.119(j)(2): *ER shall develop and implement written mechanical integrity procedures*

Inadequate Inspections

- Typical deficient inspections (and associated standards)
  - not performed at all - 119(j)(4)(i)
  - not conducted per RAGAGEP or manufacturers' recommendations - 119(j)(4)(ii)
  - not performed on prescribed frequency - 119(j)(4)(iii)
  - inspection data missing -119(j)(4)(iv)
  - Inspectors not qualified to inspect pressure vessels and piping - 119(j)(2) and/or 119(j)(4)(ii)

54

Inspection RAGAGEP

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55

External Corrosion

- "*The loss of MI due to external corrosion is the single biggest concern in industrial ammonia refrigeration components*" IRC MI Guidebook
  - Corrosion proceeds w/electrolytes, e.g., free water
    - Sources: weather, condensation on cold surfaces
  - External corrosion most likely in high moisture areas, particularly on low temperature vessels and piping under failed insulation
    - Wet uninsulated equipment
    - Deceiving in equipment where insulation has failed – moisture can infiltrate even when the insulation appears dry
  - Insulation is part of the equipment system
    - Must be inspected

56

Unique Inspection RAGAGEP for NH3 Refrigeration Systems

- IIAR 110 provides inspection RAGAGEP which departs from refinery/chemical plant RAGAGEP
- **Vessels/Piping**
  - "Independent Full Inspection" (6.4.4)
    - At least every 5 years
    - Competent person independent of immediate commercial and production pressures of that installation
    - Carry out examinations and tests they consider necessary
    - Must take into account relevant regs/codes/standards
    - Specific guidance (RAGAGEP) given
  - If employer uses IIAR 110 inspection RAGAGEP, they must do ALL steps

57

Unique Inspection RAGAGEP for NH3 Refrigeration Systems

- IIAR 110 provides inspection RAGAGEP which departs from refinery/chemical plant RAGAGEP
- **Pressure relief devices** (6.5.4)
  - Shall be **replaced** every 5 years
  - Does NOT relieve employer from requirement to inspect PRVs under PSM - 119(j)(4)
  - Inspection may reveal need to increase inspection / replacement frequency

58

CUI Procedures and Inspections

- Employer's equipment inspection procedures must include CUI (corrosion under insulation)
  - Applicable Standard
    - 1910.119(j)(2) -- if procedures not developed or inadequate
    - 1910.119(j)(4)(ii) – if inspection conducted but didn't include CUI
  - CUI inspection RAGAGEP
    - Vessels: API 510, API 572, IIAR 110, NBIC* (NB 23)
    - Piping: API 570, API 574, IIAR 110, NBIC* (NB 23)

*National Board Inspection Code

59

Machine Room Electrical Classification

- Machine rooms have highest risk of large release of NH3 due to amount & types of equipment
  - Typically would require Class 1, Div 1 or 2 electrical equipment
  - NEC Article 500 refers to ANSI/ASHRE 15 which allows ordinary equipment if:
    - Continuous mechanical ventilation provided
      - Failure of ventilation system must initiate supervised alarm
    - Independent emergency ventilation system
      - Must activate system ≤ 40,000 ppm by NH3 detector (4%, or ~25% of LEL)
      - IH concerns at 40,000 ppm, therefore detector many times set lower

60

Evacuation and Response Programs Need to be Strong

- Employer's Emergency Action Plan (EAP) must comply with 1910.38
  - PSM is a standard that requires 1910.38
- Employer May Need to Comply with HAZWOPER 1910.120(q)
  - Usually dependent on size of facility
  - Employees respond from outside area
  - Is it a 38 "response" or a 120(q) response?
  - See Hudson LOI Requirements for emergency response and planning under PSM Standard - 06/24/2003
    - *limited actions, such as turning valves, taken by process operators during an emergency release of hazardous materials are regulated by 1910.120* - 120(q) CPL

61

References

A list of references can be found on OSHA's Ammonia Refrigeration eTool at:

http://www.osha.gov/SLTC/etools/ammonia_refrigeration/references/index.html

62