# PROCESS SAFETY
# AN TOÀN QUÁ TRÌNH

CHAPTER 1: INTRODUCTION

## AIMS & OBJECTIVE OF THIS COURSE

- introduce **fundamental principles** and **application** of chemical process safety
- theory backgrounds on toxicology
- source and dispersion models
- fire and explosion basics
- different methods to identify and estimate risk and safety level

## ASSESSMENT

- Homework and Assignment: 20%
- Midterm Test: 30%
- Final Examination: 50%

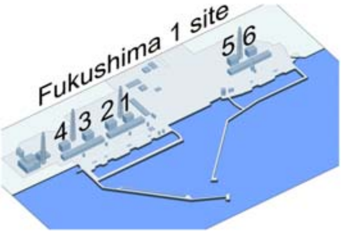
## TEXTBOOK & REFERENCES

- Daniel A. Crowl; Joseph F. Louvar, Chemical Process Safety: Fundamentals and Applications, 2nd edition, Prentince Hall PTR, 2002. (TEXTBOOK)
- Roy E. Sanders, Chemical Process Safety: Learning from Case Histories, Butterworth-Heinemann, 1999.
- Dow's Chemical Exposure Index Guide, New York: American Institute of Chemical Engineers, 1994.
- Dow's Fire and Explosion Index Hazard Classification Guide, 7th ed., New York: American Institute of Chemical Engineers, 1994.
- Frank P. Lees, Loss Prevention in the Process Industries, 2d ed., London: Butterworth-Heinemann, 1996

## SCHEDULE

- Introduction (W1)
- Toxicology and transport models (W2-4)
- Fire and Explosion (W5-8)
- Safety relief valve system (W9-11)
- Hazard identification and risk assessment (W12-13)
- Case Studies (W14)

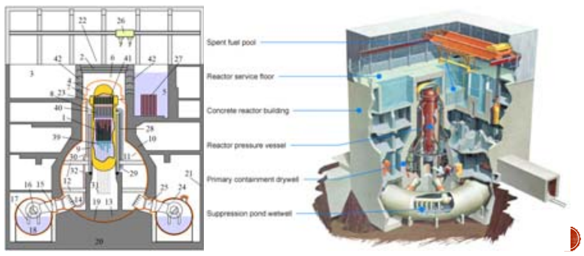
## FUKUSHIMA DISASTER



# THE FUKUSHIMA DAIICHI REACTORS

- Boiling water reactors (BWR) (1960s) 460 MWe
- Operation since 1971
- The fuel assemblies : 4 m long, 400 pcs
- 60 fuel rods containing the uranium oxide fuel within zirconium alloy cladding
- Normally at 286°C, 6930 kPa at core and 115-130 kPa dry containment
- Design base: 8240 kPa and 300°C at core , 500 kPa for containment (PCV)

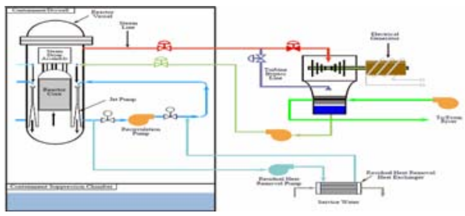
# REACTOR 1




# PHYSICAL PROTECTION LAYERS

- Control rods (39)
- Reactor Pressure Vessel (8)
- Biological Shield (9)
- Embedded shell region (19)
- Concrete embedment (13) & Secondary concrete shield wall (10)
- Reactor building (21)

# OPERATION



# WHAT WENT WRONG

- **Friday, 11 March**
- 14:46: 9.0 magnitude earthquake strikes off the Tohoku area
- 14:52: Reactor 1 emergency cooling system, running without external power, turns on automatically.
- 15:03: Reactor 1 emergency cooling system is manually shut down.
- 15:27: The first tsunami strikes the plant.
- 15:30: The emergency condenser designed to cool the steam inside the pressure vessel of the No. 1 reactor fails.
- 15:46 (approximate): A 14-metre (46 ft) tsunami
  - inundating the Fukushima facility
  - disabling the backup diesel
  - washing away their fuel tanks.
  - loss of all electrical power supply
  - most of the emergency core cooling system failed

# WHAT WENT WRONG

- 18:00: The falling water level and the core temperature starts climbing.
- 18:18: Reactor 1's emergency cooling system is once again back on.[6]
- 19:30: The fuel in reactor 1 becomes fully exposed
- 21:00: An evacuation within a radius of 3 kilometres
- 21:05: The pressure inside reactor unit 1 more than twice normal levels
- **Saturday, 12 March**
- 05:30: the decision is taken to vent some of the steam to reduce the pressure
- 06:50: the core of reactor 1 has now completely melted and falls to the bottom of the reactor pressure vessel
- 15:36: A massive explosion because of hydrogen

## WHAT WENT WRONG

- 19:00: Sea water injection into reactor 1 is started.
- 21:40: The evacuation zone around Fukushima I is extended to 20 km
- **Sunday, 13 March**
- 11:01: The unit 3 reactor building explodes, injuring six workers
- **Monday, 14 March**
- 06:00 An explosion damaged the 4th floor rooftop area of the Unit 4 reactor

## SAFETY DATA

- 1967: Changing the layout of the emergency-cooling system
- 1976: Falsification of safety records by TEPCO
- 1991: Back-up generator of reactor 1 flooded
  - instead of moving the generators to higher ground, TEPCO installed doors to prevent leaking water
- 2006: the Japanese government opposed a court order to close a nuclear plant in the west part
- 2008: Tsunami study ignored
- Mar-2011: TEPCO submits a report to Japan's nuclear safety agency to reject the Tsunami study

## INTRODUCTION

- The recent processes
  - More complex
  - Higher pressure
  - More reactive chemicals, and exotic chemistry
- More complex processes require more complex safety technology
- Safety & Production are equally considered
- Safety has developed into a scientific discipline
- that includes many highly technical and complex theories and practices

## THE MEANING OF SAFETY

- The older strategy of "safety" emphasizes on worker safety
  - The use of hard hats, safety shoes
  - A variety of rules and regulations
- Recently, "safety" means "loss prevention" includes
  - Hazard identification,
  - Technical evaluation,
  - Design of new engineering features to prevent loss

## DETERMINATION

- Safety or loss prevention
  - the prevention of accidents through the use of appropriate technologies
  - to identify the hazards of a chemical plant and
  - eliminate them before an accident occurs.
- Hazard
  - a chemical or physical condition that has the potential to cause damage to people, property, or the environment.
- Risk
  - a measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the loss or injury.

## SAFETY PROGRAM

- Requires a SYSTEM
  - to record what needs to be done
  - to do what needs to be done
  - to record that the required tasks are done
- A positive ATTITUDE
  - the willingness to do some of the thankless work.
- Understand FUNDAMENTALS
  - chemical process safety in the design, construction, and operation.
- Learn from the EXPERIENCES of history
  - Understands case histories of past accidents
  - Ask colleagues for experiences and advices
- Safety takes TIME
  - to study, to do the work, to record, to share experiences, and to train or be trained
- YOU should take the responsibility to contribute the safety

# ACCIDENT & LOSS STATISTICS

- important measures of the effectiveness of safety programs.
- determining whether a process is safe
- or whether a safety procedure is working effectively
- these statistics must be used carefully.
- statistics only **averages** and do **NOT** reflect the potential for **single episodes**
- This course considers the following statistics
  - OSHA incidence rate,
  - fatal accident rate (FAR), and
  - fatality rate, or deaths per person per year

# OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA)

- The OSHA incidence rate is based on cases per 100 worker years.
- A worker year contains 2000 hours (50 work weeks year x 40 hours/week).
- Therefore it based on 200.000 hours of worker exposure to a hazard
- Calculation

$$\text{OSHA incidence rate (based on injuries and illness)} = \frac{\text{Number of injuries and illnesses} \times 200{,}000}{\text{Total hours worked by all employees during period covered.}}$$

# OSHA (CONT.)

- An incidence rate can also be based on lost workdays instead of injuries and illnesses

$$\text{OSHA incidence rate (based on lost workdays)} = \frac{\text{Number of lost workdays} \times 200{,}000}{\text{Total hours worked by all employees during period covered.}}$$

# FAR

- FAR is used mostly by the British chemical industry
- The FAR reports the number of fatalities based on 1000 employees working their entire lifetime
- The employees are assumed to work a total of 50 years.
- Thus the FAR is based on $10^8$ working hours.
- The resulting equation is

$$\text{FAR} = \frac{\text{Number of fatalities} \times 10^8}{\text{Total hours worked by all employees during period covered.}}$$

# FATALITY RATE

- The fatality rate or deaths per person per year
- This system is independent of the number of hours actually worked
- reports only the number of fatalities expected per person per year

$$\text{Fatality rate} = \frac{\text{Number of fatalities per year}}{\text{Total number of people in applicable population.}}$$

# COMPARISION OF STATISTICS

- OSHA and FAR depend on the number of exposed hours.
- A FAR can be converted to a fatality rate (or vice versa)
  - if the number of exposed hours is known.
- OSHA cannot be converted to a FAR or fatality rate because
  - it contains both injury and fatality information.

| Industry | OSHA incident rate (cases involving days away from work and deaths) 1985[1] | 1998[2] | FAR (deaths) 1986[3] | 1990[4] |
|---|---|---|---|---|
| Chemicals and allied products | 0.49 | 0.35 | 4.0 | 1.2 |
| Motor vehicles | 1.08 | 6.07 | 1.3 | 0.6 |
| Steel | 1.54 | 1.28 | 8.0 | |
| Paper | 2.06 | 0.81 | | |
| Coal mining | 2.22 | 0.26 | 40 | 7.3 |
| Food | 3.28 | 1.35 | | |
| Construction | 3.88 | 0.6 | 67 | 5.0 |
| Agricultural | 4.53 | 0.89 | 10 | 3.7 |
| Meat products | 5.27 | 0.96 | | |
| Trucking | 7.28 | 2.10 | | |
| All manufacturing | | 1.68 | | 1.2 |

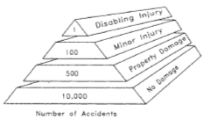
[1] *Accident Facts*, 1985 ed. (Chicago: National Safety Council, 1985), p. 30.
[2] *Injury Facts*, 1999 ed. (Chicago: National Safety Council, 1999), p. 66.
[3] Frank P. Lees, *Loss Prevention in the Process Industries* (London: Butterworths, 1986), p. 177.
[4] Frank P. Lees, *Loss Prevention in the Process Industries*, 2d ed. (London: Butterworths, 1996), p. 2/9.

# EXAMPLE 1

- Example 1-1: A process has a reported FAR of 2. If an employee works a standard 8-hr shift 300 days per year compute the deaths per person per year.
- **Solution**
- Deaths per person per year =
- (8hrs/day) x (300days/yr) x (2 deaths/$10^8$hr)=$4.8 \times 10^{-5}$

# ACCEPTABLE RISK

- Cannot eliminate risk entirely.
- Every chemical process has a certain amount of risk
- the design stage needs to decide if the risks are "acceptable"
- Engineers must make every effort to minimize risks within the economic constraints of the process




| Type of death | 1998 Deaths |
|---|---|
| Motor-vehicle | |
| Public nonwork | 38,900 |
| Work | 2,100 |
| Home | 200 |
| Subtotal | 41,200 (43.5%) |
| Work | |
| Nonmotor-vehicle | 3,000 |
| Motor-vehicle | 2,100 |
| Subtotal | 5,100 (5.4%) |
| Home | |
| Nonmotor-vehicle | 28,200 |
| Motor-vehicle | 200 |
| Subtotal | 28,400 (30.0%) |
| Public[2] | 20,000 |
| Subtotal | 20,000 (21.1%) |
| Total accidental deaths | 92,200[3] |

# NATURE OF ACCIDENT PROCESS

- Most accidents follow a three-step sequence:
- initiation (the event that starts the accident),
- propagation (the event or events that maintain or expand the accident), and
- termination (the event or events that stop the accident or diminish it in size).

| Step | Desired effect | Procedure |
|---|---|---|
| Initiation | Diminish | Grounding and bonding<br>Inerting<br>Explosion proof electrical<br>Guardrails and guards<br>Maintenance procedures<br>Hot work permits<br>Human factors design<br>Process design<br>Awareness of dangerous properties of chemicals |
| Propagation | Diminish | Emergency material transfer<br>Reduce inventories of flammable materials<br>Equipment spacing and layout<br>Nonflammable construction materials<br>Installation of check and emergency shutoff valves |
| Termination | Increase | Firefighting equipment and procedures<br>Relief systems<br>Sprinkler systems<br>Installation of check and emergency shutoff valves |

# THREE TYPES OF ACCIDENTS

| Type of accident | Probability of occurrence | Potential for fatalities | Potential for economic loss |
|---|---|---|---|
| Fire | High | Low | Intermediate |
| Explosion | Intermediate | Intermediate | High |
| Toxic release | Low | High | Low |


# INHERENT SAFETY

- Inherent safety mentions chemistry and physics to prevent accidents
- The major approaches to inherently safer process designs
- Intensification
  - Reducing the amount of hazardous material present at any one time
  - e.g. by using smaller batches
- Substitution
  - Replacing one material with another of less hazard
  - e.g. cleaning with water and detergent rather than a flammable solvent
- Attenuation
  - Reducing the strength of an effect,
  - e.g. having a cold liquid instead of a gas at high pressure,
  - or using material in a dilute rather than concentrated for
- Limitation of effects
  - Designing and locating equipment so that the worst possible condition gives less danger,
  - e.g. gravity will take a leak to a safe place
- Simplification/error tolerance
  - Keep piping systems neat and visually easy to follow
  - Design control panels that are easy to comprehend
  - Design plants for easy and safe maintenance

# INDEPENDENT PROTECTION LAYER

- process design
- process control system
- critical alarms and operator supervision/response
- automatic shutdown and interlocks (SIS)
- physical protection
  - (e.g. pressure relief valve, containment)
- plant emergency response
  - (e.g. fire fighting)
- community emergency response (e.g. notification, evacuation)