UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	:	CEB4543 - HAZARD IDENTIFICATION & RISK ANALYSIS
DATE	:	5 AUGUST 2024 (MONDAY)
TIME	:	9.00 AM - 12.00 NOON (3 HOURS)

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **FIFTEEN (15)** pages in this Question Booklet including the cover page and appendices.

ii. **DOUBLE-SIDED** Question Booklet.

1. **FIGURE Q1** shows an X material storage tank equipped with relevant control systems. X material is pumped from a tank truck to tank T-301 every 4 days or about 90 times per year. Each unloading activity is carried out after the Inventory Control System (ICS) confirmed the availability of sufficient space in the tank to receive X material from the truck. The storage tank is equipped with a Basic Process Control System Level-Indicator-Control (BPCS LIC) system which consists of a level indicator (LI-80) and a high-level alarm (LAH-80) that annunciates in the control room. Two operators are typically involved in this operation; one who initiates the transfer with the truck driver and one in the control room who monitors various process functions from a computer interface. The driver is required to supervise the transfer. The tank is surrounded by a dike. From the Process Hazard Analysis (PHA) study conducted earlier, one of the scenarios identified was overflow of the storage tank and the spill is not contained by the dike. This would lead to the release of X material outside the dike due to tank overflow and failure of dike with potential ignition and fatality. It is assumed that the total overflow can be as large as 40,000 lb of X material. The PHA team also highlighted that the BPCS LIC failed once every 10 years and the ICS failed once a year.

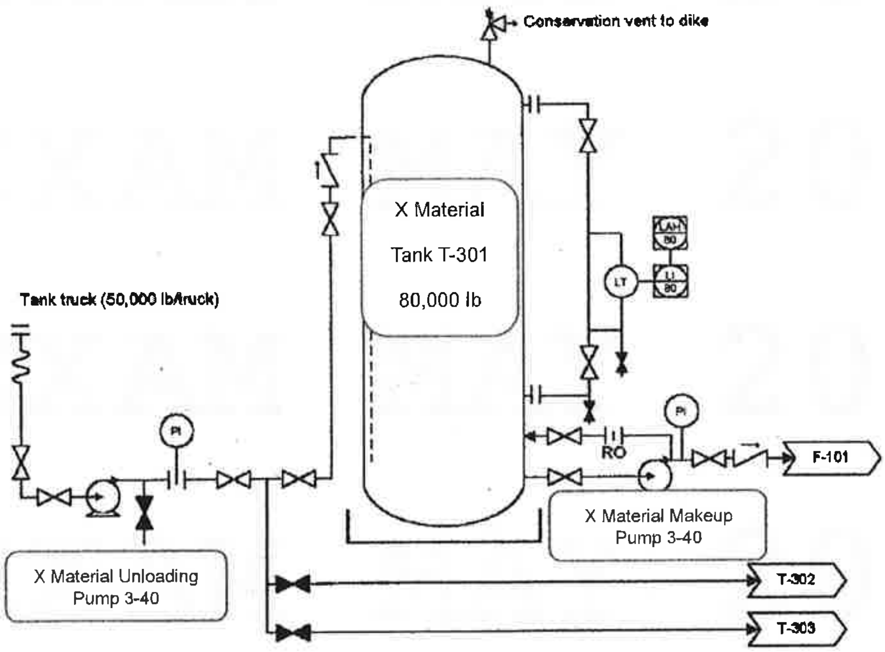

FIGURE Q1 : X Material Storage Tank

a. Based on the scenario, identify the initiating event of the incident, the appropriate candidate independent protection layers (IPLs) and subsequently, with proof of calculations, complete the Layer of Protection Analysis (LOPA) summary sheet provided in **APPENDIX I** as risk decision making method. Provide all the justifications. The relevant information is given in **TABLE Q1.** Attach **APPENDIX I** with your answer booklet.

TABLE Q1: Probability of Failure on Demand (PFD) data for IPLs and other relevant data

IPLs	PFD
Dike	1×10^{-2}
Safety Instrument Function	1×10^{-2}
Human Action (Operator checks through BPCS LIC)	1×10^{-1}
Relief valve	1×10^{-2}
Rupture disc	1×10^{-2}
Other Relevant Data	
Maximum tolerable risk of a serious fire	$< 1 \times 10^{-4}$
Maximum tolerable risk of a fatal injury	$< 1 \times 10^{-5}$
Probability of ignition	1
Probability of personnel in affected area	0.5
Probability of fatal injury	0.5

[18 marks]

b. Decide whether it is possible or not to consider the human action of checking on the level in the tank through the BPCS LIC by operators before the unloading activity as an IPL. Justify your decision.

[7 marks]

2. Commonly, a person loads the food into the cooker, closes the lid and then connects the electrical power to start the cooking process as presented in **FIGURE Q2** . The cooking takes place via heating by the electrical heating coil on which the temperature is controlled by the thermostat switch. The thermostat cuts off the current when the temperature inside the cooker is above 250°F. In addition, a pressure gage and a safety valve are installed to monitor and relieve the pressure accordingly. As a future engineer, you are required to develop a complete FMEA worksheet on the failure of the safety valve, pressure gage, thermostat switch and cooker lid clamp. The relevant ratings are provided in **APPENDIX II**.

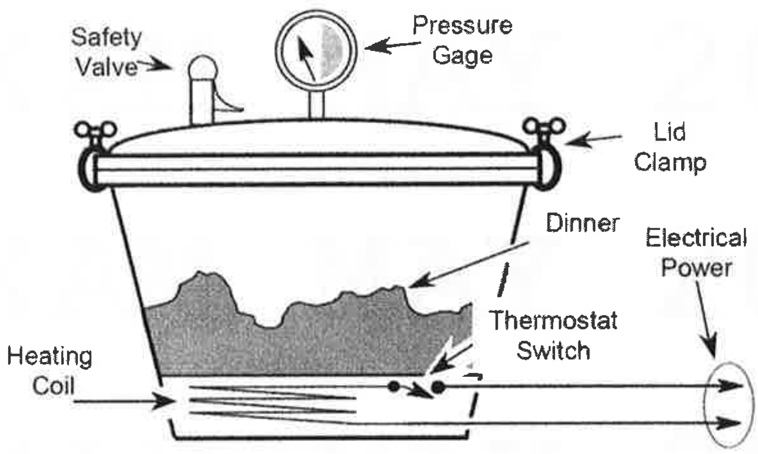

FIGURE Q2 : Pressure Cooker Unit

[25 marks]

3. You are required to study the consequence of releases from a storage tank containing 1000 kg chlorine at 50 barg. The molecular weight, heat capacity ratio and ERPG-1 value for chlorine are 70.9, 1.33 and 1 ppm, respectively. Based on your preliminary hazard study, there are several release scenarios that could affect a control room which is located at 300 m downwind distance from the storage tank.

   a. Assuming worst case scenario, evaluate the maximum size of leak (mm) in the tank that could reach the ERPG-1 concentration at the control room. State all other assumptions in your estimation.

   [15 marks]

   b. If the continuous release in **part (a)** occurs at 10 m above the ground level, predict the location (m) and maximum concentration (ppm) of the chlorine released with appropriate assumptions.

   [10 marks]

4. a. The hierarchy of control and defense in depth are the common concepts utilized to describe measures taken to reduce risk. Elaborate the details of the two concepts with appropriate examples and highlight any similarities or discrepancies between them.

[13 marks]

b. One of the measures to prevent or reduce risk is by the implementation of inherent safety principles. Typical inherent safety techniques used in the chemical industries are listed below:

- Change from large batch reactor to a smaller continuous reactor.
- Change the design of flanged pipe to welded pipe.
- Reduce storage inventory of raw materials.
- Reduce process temperatures and pressures.
- Use chemical with higher flash points & boiling points.
- Barricade control rooms and tanks.

Decide the relevant inherent safety principles for each of the techniques listed above and justify your decision.

[12 marks]

-END OF PAPER-

APPENDIX I

Detach the following LOPA summary sheet and attach with the answer booklet

Exam ID Number :

Scenario Number	**Scenario Title**	**Equipment Number**	
Date	Description	Probability	Frequency (per year)
Consequences Description/Category			
Risk Tolerance Criteria (category or frequency)			
Initiating Event (typically a frequency)			
Enabling Event or condition			
Condition Modifiers (if applicable)			
	Probability of ignition		
	Probability of personnel in affected area		
	Probability of fatal injury		
	Others		
Frequency of unmitigated consequence			
Independent Protection Layers			
Safeguards (non-IPLs)			
Total PFD for all IPLs			
Frequency of Mitigated Consequence			
Risk Tolerance Criteria Met? (Yes/No):			
Action Required to Meet Risk Tolerance Criteria:			
Notes:			
References (links to originating hazard review, PFD, P&ID, etc):			
LOPA analyst (and team members, if applicable):			

APPENDIX I

Independent Protection Layer (IPL) Credit Requirements

	Number of IPL Credits Required	
	Consequence Category IV	Consequence Category V
Adjusted Initiating Event Frequency	One Fatality	Multiple Fatalities
Frequency ^{3} 1 x 10^{-2}	2	2.5
1 x 10^{-2} > Frequency ^{3} 1 x 10^{-3}	1.5	2
1 x 10^{-3} > Frequency ^{3} 1 x 10^{-4}	1	1.5
1 x 10^{-4} > Frequency ^{3} 1 x 10^{-6}	0.5	1
1 x 10^{-6} > Frequency	0	0.5

APPENDIX II

Severability (SEV)

SEV	Severity	Product/Process Criteria
1	None	No effect
2	Very Minor	Defect would be noticed by most discriminating customers. A portion of the product may have to be reworked on line but out of station
3	Minor	Defect would be noticed by average customers. A portion of the product (<100%) may have to be reworked on line but out of station
4	Very Low	Defect would be noticed by most customers. 100% of the product may have to be sorted and a portion (<100%) reworked
5	Low	Comfort/convenience item(s) would be operable at a reduced level of performance. 100% of the product may have to be reworked
6	Moderate	Comfort/convenience item(s) would be inoperable. A portion (<100%) of the product may have to be scrapped
7	High	Product would be operable with reduced primary function. Product may have to be sorted and a portion (<100%) scrapped.
8	Very High	Product would experience complete loss of primary function. 100% of the product may have to be scrapped
9	Hazardous Warning	Failure would endanger machine or operator with a warning
10	Hazardous w/out Warning	Failure would endanger machine or operator without a warning

APPENDIX II

Occurrence (OCC) Rating

OCC	Occurrence	Criteria
1	Remote	1 in 1,500,000 Very unlikely to occur
2	Low	1 in 150,000
3	Low	1 in 15,000 Unlikely to occur
4	Moderate	1 in 2,000
5	Moderate	1 in 400 Moderate chance to occur
6	Moderate	1 in 80
7	High	1 in 20 High probability that the event will occur
8	High	1 in 8
9	Very High	1 in 3 Almost certain to occur
10	Very High	> 1 in 2

Detectability (DET) Rating

DET	Detection	Criteria
1	Almost Certain	Current Controls are almost certain to detect/prevent the failure mode
2	Very High	Very high likelihood that current controls will detect/prevent the failure mode
3	High	High Likelihood that current controls will detect/prevent the failure mode
4	Mod. High	Moderately High likelihood that current controls will detect/prevent the failure mode
5	Moderate	High Likelihood that current controls will detect/prevent the failure mode
6	Low	Low likelihood that current controls will detect/prevent failure mode
7	Very Low	Very Low likelihood that current controls will detect /prevent the failure mode
8	Remote	Remote likelihood that current controls will detect/prevent the failure mode
9	Very Remote	Very remote likelihood that current controls will detect/prevent the failure mode
10	Absolute Uncertainty	Absolute uncertainty likelihood that current controls will detect/prevent the failure mode

APPENDIX III

Data

Universal gas constant, R_g = 8.314 x 10^3 Nm/kg-mol.K
= 0.082057 m^3.atm/kg-mol.K
= 0.7302 ft^3.atm/lb-mol.°R
= 10.73 ft^3.psia /lb-mol.°R

Gravitational constant, g_c = 1 (kg.m/s^2)/N = 32.174 ft-lb_m/lb_f-s^2

The energy of explosion of TNT is 1120 cal/g = 4686 kJ/kg = 2016 Btu/lb

For water;

Density, ρ_w = 1000 kg/m^3 = 62.4 lb_m/ft^3

Mass transfer coefficient, K_w = 0.83 cm/s

Unit conversion

1 atm = 101.3 kPa	1 kPa = 1000 N.m^{-2}	1Pa = 1 N.m^{-2}
1 atm = 14. 7 psia	1 mm Hg = 1.316 x 10^{-3} atm	
1 m = 3.2808 ft	1 ft = 12 in	
1 kg = 2.2 lb	1 lb_m = 453.6 g	
1 mile = 5280 ft	1 m^3 = 35.31 ft^3	1 gal = 0.1337 ft^3

Temperature conversion

°R = °F + 460 °R = 1.8 K °F = 1.8°C + 32

0°C + 273.15 = 273.15K

Conversion of concentration of vapours from mg.m^{-3} to ppm;

$$C_{ppm} = 0.08205\left(\frac{T}{PM}\right)\left(C_{mg/m^3}\right)$$

where;

M is the molecular weight in g/g-mol

T is the temperature in Kelvin

P is the pressure in atm

APPENDIX III

Flow of gas through a hole

Choked flow through a hole, P_{choked} is given by:

$$\frac{P_{choked}}{P_0} = \left(\frac{2}{\gamma + 1}\right)^{\gamma/(\gamma-1)}$$

The mass flow rate, $(Q_m)_{choked}$ resulting from a hole of area, A is given by:

$$(Q_m)_{choked} = C_o A P_0 \sqrt{\frac{\gamma g_c M}{R_g T_0}\left(\frac{2}{\gamma + 1}\right)^{(\gamma+1)/(\gamma-1)}}$$

where;

M	=	molecular weight of the escaping vapour or gas
A	=	leak cross sectional area
C_o	=	discharge coefficient
g_c	=	gravitational constant
P_0	=	upstream pressure (absolute)
T_0	=	temperature of the source
γ	=	heat capacity ratio
R_g	=	ideal gas constant

APPENDIX III

Pasquill-Gifford dispersion model

Model for puff for concentration on ground below puff center:

$$\langle C\rangle(0,0,0) = \frac{Q_m^*}{\sqrt{2}\pi^{3/2}\sigma_x\sigma_y\sigma_z} exp\left[-\frac{1}{2}\left(\frac{H_r}{\sigma_z}\right)^2\right]$$

The ground level concentration for puff model with $H_r = 0$:

$$\langle C\rangle(0,0,0) = \frac{Q_m^*}{\sqrt{2}(\pi)^{3/2}\sigma_x\sigma_y\sigma_z}$$

Model for plume for ground centerline concentration:

$$\langle C\rangle(x,0,0) = \frac{Q_m}{\pi\sigma_y\sigma_z u} exp\left[-\frac{1}{2}\left(\frac{H_r}{\sigma_z}\right)^2\right]$$

The centerline concentration centreline of plume model directly downwind with $H_r = 0$:

$$\langle \boldsymbol{C}\rangle(\boldsymbol{x},\boldsymbol{0},\boldsymbol{0}) = \frac{\boldsymbol{Q_m}}{\boldsymbol{\pi\sigma_x\sigma_y u}}$$

The maximum concentration on ground occurs downwind:

$$(\boldsymbol{\sigma_z})_{\boldsymbol{x,max}} = \frac{\boldsymbol{H_r}}{\sqrt{\boldsymbol{2}}}$$

$$\langle \boldsymbol{C}\rangle_{\boldsymbol{max}} = \frac{\boldsymbol{2Q_m(or\ Q_m^*)}}{\boldsymbol{e\pi u H_r^2}}\left(\frac{\boldsymbol{\sigma_z}}{\boldsymbol{\sigma_y}}\right)$$

$\langle C\rangle\ (x, y, z)$	=	Ave. concentration
Q_m	=	Release rate (mass/time)
Q^*_m	=	Fixed mass (mass)
$\sigma_x, \sigma_y, \sigma_z$	=	Dispersion coefficients = f(stability class, downwind distance)
u	=	Wind speed (length/time)
x, y, z	=	Coordinates (length)
H_r	=	Release height (length)

APPENDIX III

Equations for Pasquill-Gifford dispersion coefficient for plume dispersion

Pasquill-Gifford stability class	σ_y (m)	σ_z (m)
Rural conditions		
A	$0.22x(1 + 0.0001x)^{-1/2}$	$0.20x$
B	$0.16x(1 + 0.0001x)^{-1/2}$	$0.12x$
C	$0.11x(1 + 0.0001x)^{-1/2}$	$0.08x(1 + 0.0002x)^{-1/2}$
D	$0.08x(1 + 0.0001x)^{-1/2}$	$0.06x(1 + 0.0015x)^{-1/2}$
E	$0.06x(1 + 0.0001x)^{-1/2}$	$0.03x(1 + 0.0003x)^{-1}$
F	$0.04x(1 + 0.0001x)^{-1/2}$	$0.016x(1 + 0.0003x)^{-1}$
Urban conditions		
A–B	$0.32x(1 + 0.0004x)^{-1/2}$	$0.24x(1 + 0.0001x)^{+1/2}$
C	$0.22x(1 + 0.0004x)^{-1/2}$	$0.20x$
D	$0.16x(1 + 0.0004x)^{-1/2}$	$0.14x(1 + 0.0003x)^{-1/2}$
E–F	$0.11x(1 + 0.0004x)^{-1/2}$	$0.08x(1 + 0.0015x)^{-1/2}$

A–F are defined in Table 5-1.

[1] R. F. Griffiths, "Errors in the Use of the Briggs Parameterization for Atmospheric Dispersion Coefficients," *Atmospheric Environment* (1994), 28(17): 2861–2865.

[2] G. A. Briggs, *Diffusion Estimation for Small Emissions*, Report ATDL-106 (Washington, DC: Air Resources, Atmospheric Turbulence, and Diffusion Laboratory, Environmental Research Laboratories, 1974)

Equations for Pasquill-Gifford dispersion coefficients for puff dispersion

Pasquill-Gifford stability class	σ_y (m) or σ_x (m)	σ_z (m)
A	$0.18x^{0.92}$	$0.60x^{0.75}$
B	$0.14x^{0.92}$	$0.53x^{0.73}$
C	$0.10x^{0.92}$	$0.34x^{0.71}$
D	$0.06x^{0.92}$	$0.15x^{0.70}$
E	$0.04x^{0.92}$	$0.10x^{0.65}$
F	$0.02x^{0.89}$	$0.05x^{0.61}$

A–F are defined in Table 5-1.

[1] R. F. Griffiths, "Errors in the Use of the Briggs Parameterization for Atmospheric Dispersion Coefficients," *Atmospheric Environment* (1994), 28(17): 2861–2865.

[2] G. A. Briggs, *Diffusion Estimation for Small Emissions*, Report ATDL-106 (Washington, DC: Air Resources, Atmospheric Turbulence, and Diffusion Laboratory, Environmental Research Laboratories, 1974).

APPENDIX III

Atmospheric Stability Classes use with the Pasquill-Guifford Dispersion Model

Table 5-1 Atmospheric Stability Classes for Use with the Pasquill-Gifford Dispersion Model[1,2]

Surface wind speed (m/s)	Daytime insolation[3]			Nighttime conditions[4]	
	Strong	Moderate	Slight	Thin overcast or >4/8 low cloud	≤3/8 cloudiness
<2	A	A–B	B	F[5]	F[5]
2–3	A–B	B	C	E	F
3–4	B	B–C	C	D[6]	E
4–6	C	C–D	D[6]	D[6]	D[6]
>6	C	D[6]	D[6]	D[6]	D[6]