Quantitative Risk Assessment Onshore LNG Regasification Unit (ORU)

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Abstract. This paper presents the assessment of risk levels of the worker categories on the onshore LNG terminal regasification facility. Quantitative Risk Assessment are applied to evaluate the process and non-process accidental events at Onshore Regasification Unit (ORU) during offloading and normal operation. Individual Risk Per Annum (IRPA) and Potential Loss of Life (PLL) are the parameters to measure the risk for an individual in a specific worker category on the ORU area. Estimation numerical are provided to allow understanding of the risk exposure and fatality amongst the whole worker category or other areas of interest. QRA studies is used to take into account potential releases of hazardous material, estimated frequency of occurrence and consequences. Major Accident Hazard (MAH) are identified by the hazard identification process to identify all incident possibilities which cause to extensive damage to company assets and severe impact to people. Frequency of hazard occurrences is quantified using Event Tree Analysis (ETA) and fire modelling is utilized to represent the consequence. Evaluation against a set of risk acceptance criteria is carried out to the risk level arising from operation of the ORU area. Finally, a set of Safety Operation Procedure (SOP) and Emergency Response Plan (ERP) are developed to ensure the safety operation of the facility.

I. Introduction
The need of gasses in East Java is increase in recent years while there are no supporting facilities in East Java. Therefore, one of National Gas Company plans to build a temporary LNG receiving terminal by using the existing facility of Port in East Java. The facility of Terminal LNG will consist of Floating Storage Unit (FSU) and Onshore Regasification Unit (ORU). Liquefied Natural Gas will be transferred from LNG carrier to Floating Storage Unit (FSU). Process of Ship to ship transfer consist of LNG transfer line and BOG return. While process of delivering LNG from FSU to Onshore Regasification Unit consist of Buffer Tank, BOG Compressor skid, LNG Booster Pump, Vaporizer, and Metering System. LNG transferred to Onshore Regasification Unit by using FSU pumps through the LNG unloading line along 2 km across the sea. BOG that produced in the FSU Tanks due to the presence of natural heat in leak will be delivered to ORU through BOG line which then recovered by BOG compressor. The capacity of ORU is 30 MMSDFD and will be in continuous operation to supply natural gas to East Java gas distribution system. Appropriate safety analysis on Onshore Regasification Unit (ORU) area is necessary to avoid the safety issues to personnel and damage issues to company property and environment. Quantitative Risk Assessment is one of the method to evaluate risk level of each worker categories on the LNG Terminal ORU during normal and offloading operation. This
paper aims to analyse Individual Risk Per Annum (IRPA) and Potential Loss of Life (PLL) against the Risk Acceptance Criteria for various worker category.

1. Manning Scenario and Area Definition
Various of ORU’s worker category have been grouped into four as show in Table 1. Working duration of each personnel and number of working shift also identified.

| Personnel Group          | Worker Category            | POB | Hour spent by Each Personnel (hour/day) | Shift |
|--------------------------|----------------------------|-----|----------------------------------------|-------|
| Management               | Plant Manager              | 1   | -                                      | 8     |
|                          | Supervisor ORU             | 1   | -                                      | 12    |
| Operator                 | Operator ORU               | 3   | 12                                     | -     |
|                          | Operator Filling Station   | 3   | -                                      | -     |
|                          | Maintenance & Inspection ORU| 2   | 8                                      | -     |
| General Worker           | Office Support             | 1   | -                                      | 8     |
|                          | Security Guard             | 3   | 1                                      | 6     |
|                          | Driver for ISO Tank Truck  | 3   | -                                      | -     |

ORU area is segregated into several areas to identify the hydrocarbon release events and location impairment. The relevant areas on the ORU is presented in figure 1 and figure 2. ORU area divided into 3 parts, i.e. Process Area of ORU, Filling Station and Office.

2. QRA Methodology
Quantitative Risk Assessment (QRA) is a study to assess risk level of a hazardous activity. QRA provides numerical estimates to support the understanding of exposure of risk to people or areas of interest. QRA studies explain the potential releases of hazardous material, their consequences and estimated frequency of occurrence. Generally, there are four main steps involved in this study i.e. hazard and scenario identification, consequence and effect analysis, probability and frequency estimations, and risk calculation leading to a quantitative risk assessment result against Risk Acceptance Criteria. The Risk Acceptance Criteria that used to evaluated ORU operation is shown in Figure 3.
The upper bound individual fatality risk for employee in the operation of the project facilities has been set at 1.0E-03 per year. The lower tier set at one in one hundred thousand per annum (1.0E-05 per year) and the risk exposure is considered “Broadly Acceptable” or “Acceptable Region”. Region between the upper and lower tiers is the intermediate tier. Risk exposures in the intermediate tier should be reduced to “As Low As Reasonably Practicable” (ALARP). As part of this QRA study, the total individual risk for each worker category is compared against the risk acceptance criteria, in order to assess whether the risks are in ALARP region, or whether any risk reduction measure is required.

3. Quantitative Risk Assessment Process and Results

4.1 Hazard Identification

The Major Accident Hazard are commonly identified by the Hazard Identification (HAZID) process. HAZID is the process to identify all the hazard possibilities that associated to the operations of the facility. The potential hazards on ORU facility are presented in Table 2. Major Accident Hazards is defined as a hazard that has potential to cause extensive damage to an asset, company reputation and / or severe or catastrophic consequences to people. These include:

- Fire, explosion or other dangerous substance release that impact death or serious injury to personnel
- Boat / ship collision
- Any event that impact major damage to the structure
- Any other work activity event involving death or serious injury to more than one person

| Type of Hazards Identified | Top Event | Source of Hazards |
|----------------------------|-----------|-------------------|
| LNG                        | Loss of containment (ORU) | Buffer tanks, piping, piping connection, manifold |
| Overhead Equipment         | Dropped Object            | Crane Activity    |
| Object Under Compression   | Structural Failure        | Dropped Object    |
| Boat Collision hazard to other vessels and offshore structures | Boat/Ship Collision | LNG carrier offloading activity and Other ship/boat |
4.2 Frequency Analysis

4.2.1 Individual Risk Per Annum (IRPA)

The Individual Risk Per Annum (IRPA) is the probability of individual fatality and IRPA takes the total of time an employee actually spends in a specific zone of the Onshore Regasification Unit in a single year. Therefore, IRPA can be represented as:

\[ IRPA = \sum LSIR \times \text{Presence Factor} \]  

Presence factor is the estimation of individual time proportion that spends his time in each location on the Onshore Regasification Unit area and is estimated according to the individual’s work. The LSIR represent the risk exposure to any personnel, if initially present, in a specific area for one entire year or for the full duration of the activity. Therefore, LSIR can be represented as:

\[ LSIR = \sum \text{Fatality Rate} \times \text{Event Frequency} \]  

Individual risk has been applied to different worker category. In the type of work and risk exposure there is a considerable difference and IRPA is often used to analyse the comparison of risk level between that various worker types. In this analysis, there are a few risks consideration in calculating IRPA including process hydrocarbon hazard, structural failure, ship collision, occupational hazard, helicopter accident and boat accident. The Individual Risk Per Annum (IRPA) for the ORU area is estimated and presented in Table 3.

| Group             | Position                        | Process Hydrocarbon | Occupational      | TOTAL          |
|-------------------|---------------------------------|---------------------|-------------------|---------------|
| Management        | Plant Manager                   | 1.82E-04            | 2.05E-08          | 1.82E-04      |
| Operator          | Supervisor ORU                  | 1.37E-04            | 3.08E-08          | 1.37E-04      |
| Operator          | Operator ORU                    | 1.98E-04            | 2.15E-07          | 1.98E-04      |
|                   | Operator Filling Station        | 1.50E-04            | 8.20E-08          | 1.50E-04      |
|                   | Maintenance & Inspection ORU    | 8.80E-05            | 1.44E-07          | 8.82E-05      |
| General Worker    | Office Support                  | 1.82E-04            | 2.05E-08          | 1.82E-04      |
| Security          | Security Guard                  | 6.14E-05            | 5.13E-08          | 6.15E-05      |
|                   | Driver for ISO Tank Truck       | 3.69E-06            | 1.79E-08          | 3.70E-06      |

The highest value of IRPA from worker category on ORU area is Operator ORU in the amount of 1.98E-04 per year followed by Plant Manager and Office Support with IRPA value i.e. 1.82E-04 per year.

4.2.2 Potential Loss of Life

The Potential Loss of Life (PLL) is the risk experienced by the entire group of personnel or employee in a given time period. It describes the hazard severity and the number of personnel in the proximity to it. PLL can be expressed mathematically as:

\[ PLL = \sum f \times N \]  

Where:

\[ \sum \] = Sum for all outcomes
\[ f \] = Frequency of an outcome per year
\[ N \] = Number of fatalities caused by the outcome
The Potential Loss of Life (PLL) for the ORU area is estimated and presented in Table 4. Based on calculation, Operator ORU have the highest PLL value i.e. 5.95E-04 per year from all worker category associated with the ORU area operations.

### Table 4. PLL Contribution for Each Worker Category of ORU

| Group            | Position                  | Process Hydrocarbon | Occupational | TOTAL     |
|------------------|---------------------------|---------------------|--------------|-----------|
| Management       | Plant Manager             | 1.82E-04            | 2.05E-08     | 1.82E-04  |
| Operator         | Supervisor ORU            | 1.37E-04            | 3.08E-08     | 1.37E-04  |
| Operator ORU     |                           | 5.94E-04            | 6.46E-07     | 5.95E-04  |
| Operator Filling Station |               | 4.50E-04            | 2.46E-07     | 4.50E-04  |
| Maintenance & Inspection ORU |             | 1.76E-04            | 2.87E-07     | 1.76E-04  |
| General Worker   | Office Support            | 1.82E-04            | 2.05E-08     | 1.82E-04  |
| Security         | Security Guard            | 1.84E-04            | 1.54E-07     | 1.84E-04  |
| Driver           | Driver for ISO Tank Truck | 1.11E-05            | 5.38E-08     | 1.11E-05  |

#### 4.2.3 Leak Frequency

The leak frequencies for each of the failure case for topside hydrocarbon release are estimated based on 'parts count' approach i.e. counting the leak points identified within the failure case boundaries on P&ID, such as valves, flanges, instrument connection, pumps, and vessel storage. The leak frequencies for different hole sizes are calculated based on generic leak frequency data adopted from OGP and presented in Table 5.

### Table 5. Leaks Size for Topside Release

| Topside Release Size | Representative Leak Size (mm) | Value taken |
|---------------------|-------------------------------|-------------|
| Small               | 1-10                          | 10          |
| Medium              | 10-50                         | 50          |
| Large               | 50-100                        | 100         |
| Rupture             | 100 to full bore              | Full bore   |

#### 4.2.4 Event Frequency

The leak frequencies for each failure case are used to calculate the frequency of a set of accident scenarios using the Event Tree Analysis (ETA). An event tree is a logic diagram that shows chain of possible successive events that can develop from hydrocarbon leak. The purpose of the event tree is to identify potential accident sequences for a leak and express a frequency for this sequence. The branch event tree probability used for the generic gas and liquid event tree are presented in Table 6.

### Table 6. Event Tree Probabilities

| Event Tree Branch            | Gas Leak Event Probability | Liquid Leak Event Probability |
|------------------------------|----------------------------|-------------------------------|
| Immediate Probability        | 0.001                      | 0.001                         |
| Successful fire detection    | 0.90                       | 0.90                          |
| Successful isolation         | 0.90                       | 0.90                          |
| Successful blow down         | 0.90                       | 0.90                          |
| Delay ignition                | Depend on release rate     | Depend on release rate        |
4.3 Consequence Analysis

Consequence analysis presents the risk analysis of process hydrocarbon hazards to measure the risks to worker from fires and explosions resulting from the ignited hydrocarbon inventories of equipment at ORU Area. The mean ambient temperature and relative humidity of 28.78°C and 80.12% respectively are adopted in this study. There are two types of wind condition used in the consequence modelling

- Wind speed of 1.5 m/s and Pasquill stability Class F, to represent the most moderate wind condition in ORU field
- Wind speed of 5 m/s and Pasquill stability Class D, to represent the most turbulence wind condition in ORU field

The topsides hydrocarbon release events have been assessed for each “Isolatable Section”. Isolation of a section will provide a limited hydrocarbon release inventory. The isolatable sections are defined and bounded by the location of the following:

- Emergency Shutdown Valves (ESDVs)
- Blowdown Valves (BDVs) or Emergency Depressurization Valves
- Normally Closed Valves with positive isolation
- Pressure Relief Valves (PRVs)

The inventory for fire and blast will be the inventory within the isolatable segment, namely the inventory between the two ESDVs if the isolation is successful. The built piping isometrics and vessel drawings will be taken into consideration of isolatable section inventories.

\[
\text{Total Release Inventory} = \text{Vol. in isolatable section} + \text{Vol. discharged before SDV closed}
\]

\[
\text{Vol. discharged before SDV closed} = \frac{\text{mass Release rate} \times \text{time delay between initiation & isolation}}{\text{density}}
\]

After 30 minutes, unignited leaks are stopped in the event of unsuccessful isolation. Fire and gas detection system followed by successful emergency shutdown will detect any flammable. There is difference in the time delay between leak initiation and isolation for small, medium and large releases. Time delay were assumed to be based on information obtained for FSU and LNGC as follow:

- For a small leak is 5 minutes
- For a medium leak is 3 minutes
- For large and full bore leak is 1 minute

4.3.1 Jet Fire Fatality

Release of high pressure gas impact in a turbulent jet mixing between gas and air. Upon immediate ignition, a jet fire will occur. Wind speed is strongly effect on the flame length of the jet fire. The calculation of jet fire fraction is formulated as follows:

\[
\text{Immediate Fatality} = [\text{Fatality at 35 kW/m}^2 + 0.7 \times \text{Fatality at 12.5 kW/m}^2]
\]

Where:
\[
\text{Fatality at 35 kW/m}^2 = \text{Fatality Fraction} \times \text{Directional Probability} \times \text{Shielding Factor}
\]
\[
\text{Fatality at 12.5 kW/m}^2 = \text{Fatality Fraction} \times \text{Directional Probability} \times \text{Shielding Factor}
\]

The jet fire analysis result is shown in Table 7, personnel at any location may affected by directional factor, where the directional factor is the factor on the 360° full rotation of the Jet Fire flame length. For this study, the direction of jet fire flame can be pointed to 6 directions which are North, South, East,
West, Vertical Up and Vertical down. Any time there is 1/6th of a chance that the Jet Fire will be pointed to one of the directions. Shielding factor is utilized to consider the shielding benefit provided by the decks below and above the jet fire source. People located on these deck receive less heat radiation than people located on jet fire decks.

4.3.2 Flash Fire Fatality
In this analysis, condensate of the hydrocarbon can be flashing upon leaks and forms a hydrocarbon gas cloud. A Flash fire occurs within a hydrocarbon cloud of hydrocarbon gas that is not close to stoichiometric concentration, accumulated in an uncongested area. Formula of Flash Fire Fatality Fraction are as follows:

\[
\text{Immediate Fatality} = \text{Fatality at LFL Distance}
\]

Where:
Fatality at LFL Distance = Fatality Fraction \times Directional Probability

The consequence modelling result of flash fire are presented in Table 8 for wind speed of 1.5 m/s. The extent of the LFL gas cloud can effect on directional factor for flash fire and personnel who are within the LFL distance will suffer from immediate fatality.

4.3.3 Explosion Fatality
Vapour Cloud Explosion is defined as a rapid release of energy that causes a significant pressure pulse capable of causing damage. An explosion will occur if a hydrocarbon vapour cloud mixes with air to produce a mixture that is close to the stoichiometric concentration and there is a degree of congestion due to objects (equipment or structure). Explosion Fatality Fraction is calculated based on the following formula:

\[
\text{Immediate Fatality} = \text{Fatality at 0.2 bar}
\]

Where:
Fatality at 0.2 Bar = Fatality Fraction \times Directional Probability

The result of explosion consequence is shown in Table 9, the explosion overpressure depends on total number of hydrocarbon gas in the cloud and is hypersensitive to the degree of confinement / congestion of the vapour cloud.

4. Conclusion
The risk levels of personnel caused by process hydrocarbon hazard and non-hazard events on Onshore Regasification Unit area has been quantified by Quantitative Risk Assessment. The Individual Risk Per Annum (IRPA) and Potential Loss of Life (PLL) was calculated for each worker category. Operator ORU was found to have the highest IRPA and PLL value, i.e. 1.98E-04 per year and 5.95E-04 per year. Generally, the entire worker has the value of IRPA that within the ALARP region of the Risk Acceptance Criterias, which is mainly contributed by Process Hazard. As the all IRPA result present that all personnel risk is below than acceptable criteria 1E-03, it can be concluded that ORU operation is acceptably safe.
### Table 7. Total Jet Fire Analysis Result at Process Area

| Scenarios     | Jet Fire Flame Length (m) | 12kW/m² Thermal Radiation Length | 37.5kW/m² Thermal Radiation Length | JF Event Frequency |
|---------------|---------------------------|----------------------------------|------------------------------------|-------------------|
|               | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   |
| ORU-PA_ISO1a_GAS | 2     | 10     | 18    | 18   | 0     | 9      | 21    | 21   | 0    | 0     | 17    | 17    | 2.74E-05 | 2.24E-06 | 1.33E-06 | 1.09E-07 |
| ORU-PA_ISO1b_GAS | 7     | 29     | 54    | 54   | 0     | 37     | 73    | 73   | 0    | 31    | 60    | 60    | 3.34E-05 | 2.97E-06 | 1.33E-06 | 1.09E-07 |
| ORU-PA_ISO2a_LIQ | 15    | 59     | 105   | 149  | 19    | 82     | 151   | 219  | 17   | 64    | 118   | 170   | 7.19E-06 | 4.64E-07 | 2.62E-07 | 2.92E-07 |
| ORU-PA_ISO2b_LIQ | 15    | 59     | 105   | 149  | 19    | 82     | 151   | 219  | 17   | 64    | 118   | 170   | 1.34E-05 | 8.68E-07 | 5.35E-07 | 2.92E-07 |
| ORU-PA_ISO2c_LIQ | 20    | 77     | 139   | 197  | 27    | 112    | 207   | 300  | 21   | 88    | 163   | 236   | 1.34E-05 | 8.68E-07 | 5.35E-07 | 2.92E-07 |
| ORU-PA_ISO3_GAS  | 7     | 31     | 57    | 81   | 6     | 39     | 76    | 111  | 0    | 32    | 62    | 89    | 2.92E-05 | 3.81E-06 | 2.18E-06 | 3.31E-07 |
| ORU-PA_ISO4_GAS  | 7     | 31     | 57    | 81   | 6     | 39     | 76    | 111  | 0    | 32    | 62    | 89    | 2.92E-05 | 3.81E-06 | 2.18E-06 | 3.31E-07 |

### Table 8. Total Flash Fire Analysis

| Failure Case | LFI Distance (m) | Flash Fire Event Frequency |
|--------------|------------------|---------------------------|
|              | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   |
| ORU-PA_ISO1a_GAS | 0     | 0      | 0     | 0    | 0.00E+00 | 2.69E-07 | 7.99E-07 | 6.54E-08 |
| ORU-PA_ISO1b_GAS | 0     | 0      | 16    | 16   | 4.01E-06 | 2.30E-05 | 2.95E-05 | 2.41E-06 |
| ORU-PA_ISO2a_LIQ | 38    | 53     | 52    | 61   | 5.17E-06 | 5.85E-06 | 5.80E-06 | 8.06E-06 |
| ORU-PA_ISO2b_LIQ | 38    | 53     | 52    | 61   | 9.67E-06 | 1.04E-05 | 1.18E-05 | 8.06E-06 |
| ORU-PA_ISO2c_LIQ | 35    | 66     | 73    | 74   | 3.22E-05 | 1.92E-05 | 1.48E-05 | 8.06E-06 |
| ORU-PA_ISO3_GAS  | 0     | 19     | 31    | 33   | 3.50E-06 | 2.95E-05 | 4.83E-05 | 1.45E-05 |
| ORU-PA_ISO4_GAS  | 0     | 19     | 31    | 33   | 3.50E-06 | 2.95E-05 | 4.83E-05 | 1.45E-05 |

### Table 9. Total Explosion Analysis Result at Process Area

| Scenarios     | 0.1 bar (distance in meter) | 0.2 bar (distance in meter) | 0.35 bar (distance in meter) | Event Frequency |
|---------------|-----------------------------|-----------------------------|-----------------------------|----------------|
|               | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   | Small | Medium | Large | FB   |
| ORU-PA_ISO1a_GAS | 0     | 0      | 28    | 28   | 0     | 0      | 25    | 25   | 0    | 0      | 23    | 23    | 0.00E+00 | 4.03E-07 | 1.20E-06 | 9.80E-07 |
| ORU-PA_ISO1b_GAS | 0     | 34     | 37    | 37   | 0     | 28     | 30    | 30   | 0    | 26     | 27    | 27    | 6.01E-06 | 3.46E-05 | 4.43E-05 | 3.62E-06 |
| ORU-PA_ISO2a_LIQ | 84    | 103    | 90    | 69   | 74    | 86     | 78    | 61   | 70    | 78    | 73    | 58    | 7.76E-06 | 8.37E-06 | 8.70E-06 | 1.21E-05 |
| ORU-PA_ISO2b_LIQ | 84    | 103    | 90    | 69   | 74    | 86     | 78    | 61   | 70    | 78    | 73    | 58    | 1.45E-05 | 1.57E-05 | 1.77E-05 | 1.21E-05 |
| ORU-PA_ISO2c_LIQ | 81    | 115    | 114   | 126  | 72    | 97     | 101   | 112  | 69    | 89     | 94    | 105   | 4.83E-05 | 2.88E-05 | 2.21E-05 | 1.21E-05 |
| ORU-PA_ISO3_GAS  | 0     | 52     | 68    | 70   | 0     | 47     | 57    | 58   | 0    | 45     | 52    | 53    | 5.25E-06 | 4.43E-05 | 7.24E-05 | 2.18E-05 |
| ORU-PA_ISO4_GAS  | 0     | 52     | 68    | 70   | 0     | 47     | 57    | 58   | 0    | 45     | 52    | 53    | 5.25E-06 | 4.43E-05 | 7.24E-05 | 2.18E+00 |
References
[1] Oil and Gas Producers (OGP) 2010 Risk Assessment Data Directory, Report No. 434-6.1 Ignition Probabilities
[2] Oil and Gas Producers (OGP) 2010 Risk Assessment Data Directory, Report No. 434-1 Process release frequencies
[3] Oil and Gas Producers (OGP) 2010 Risk Assessment Data Directory, Report No. 434-7 Consequence modelling
[4] Oil and Gas Producers (OGP) 2010 Risk Assessment Data Directory, Report No. 434-14.1 Vulnerability of humans
[5] Oil and Gas Producers (OGP) 2010 Risk Assessment Data Directory, Report No. 434-14.5 Vulnerability of Plant/Structure
[6] Assumption Register of Fire and Explosion Analysis (FEA) Rev. B
[7] Spouge.J 1999 Guide to Quantitative Risk Assessment for Offshore Installation (Centre for Marine and Petroleum Technology)
[8] UK HSE 2001 Reducing risks, HSE’s decision-making process protecting people