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Oil Industry Safety Directorate
ISO 9001:2015 certified

सुरक्षा संवाद
Suraksha Samwad

An opportunity to learn from mistakes....

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He is a Chemical Engineering graduate from the L. D. College of Engineering, Ahmedabad. He has more than **25 years of diverse experience** in plant operation, technical service, commissioning, Quality & HSE Management Systems and Process Safety field across oil & gas industry, petrochemical, fertilizer & chemical industry. He is currently working in safety department of EWS division and responsible for leading various process safety studies like HAZID/ HAZOP/ SIL/ LOPA/ QRA/ Dispersion Analysis /Safety Audit during conceptual stage/ FEED/ EPC/ Operation stage of various projects in Refinery, Petrochemical, Fertilizer, oil & gas storage facility and cross country pipeline.

He has facilitated as **HAZOP/SIL Chairman** for various Indian clients like IOCL, BPCL, HPCL, MRPL, BORL, GAIL, ONGC, HMEL etc. and international client like SABIC Group company, ADNOC Group company, Dangote, Bangladesh petroleum corporation etc. He is **Process safety group leader** for Major projects like Dangote refinery, HMEL Petrochemical project, IOCL BS VI Project, IOCL Panipat Refinery Expansion project where various safety studies have been carried out . He has also imparted safety training on HAZOP /SIL/ QRA to various clients. He is a **TUV certified functional safety engineer** and also **certified Lead auditor for ISO 45001 system**

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QUANTITATIVE RISK ANALYSIS (QRA) OVERVIEW

04TH March,2022

EIL Capabilities in Process Safety Study

- EIL has carried out number of process safety studies like HAZID / HAZOP / SIL / LOPA / RRA / QRA / FERA / BRA / F & G Mapping etc. for many Indian and international client in Oil & Gas and Petrochemical & Fertilizer industry
- EIL has separate process safety dept .consisting of highly experienced person who are involved in various process safety studies
- EIL possess latest software tools like PHA Works, PHA Pro, Detect 3D, PHAST & SAFETI for performing various safety studies
- EIL has carried out number of QRA Study for most of the refinery & petrochemical complex set up by Oil PSU in India

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Content

- ✓ INTRODUCTION ON QRA
- ✓ PRESENT INDIAN REGULATION FOR QRA
- ✓ QRA OBJECTIVES AND APPLICATION
- ✓ QRA SCHEDULING DURING PROJECT LIFECYCLE
- ✓ QRA METHODOLOGY
- ✓ RISK CRITERIA
- ✓ QRA RESULT INTERPREATATION WITH CASE STUDY
- ✓ QRA LIMITATION
- ✓ CONCLUSION

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INTRODUCTION ON QRA

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Concept of Risk

Hazards

- A characteristics of the system / plant process that represents a potential for an accident causing damage to people, property or the environment.

Accident

- A specific unplanned event or sequence of events that has undesirable consequences.

Risk

- Risk is the probability that human, property or the environment may suffer harmful consequences as a result of exposure to a hazard.

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Risk = Frequency X Consequence

What is Quantitative Risk Analysis?

- When risk is quantified or presented in numerical term, it is known as Quantitative Risk Analysis(QRA).
- Typically QRA determines risk to people and it is expressed as no of death per year.

Need for Quantitative Risk Analysis?

- Traditional Hazard evaluation technique identifies hazards and provides measures for either eliminating or controlling hazard through different layer of protection.
- These methods typically provide qualitative information on hazard & risk.
- Hence there is a need to quantify risk for better understanding of risk and thereby managing risk in a better way.

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PRESENT REGULATION FOR QRA STUDY IN INDIA

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Petroleum Explosive Safety Organization (PESO)

- QRA is required under Petroleum Rules for bulk storage & handling of petroleum products.

Petroleum & Natural Gas Regulatory Board (PNGRB)

- QRA is required under various facility specific technical standards(TS) developed by PNGRB.

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QRA OBJECTIVES AND APPLICATION

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Objectives

Following are main objectives of QRA study for different stakeholders:

- To assess risk and manage it in better way for asset owner.
- To ensure that risk to society is acceptable as per risk acceptance criteria defined by regulatory body
- Identification of cost effective risk reduction measures for existing facility
- Evaluation and tracking of competitive process strategies considering impact to society

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Application

Apart from fulfilling statutory requirement of carrying out QRA study by asset owner, the study output can be used as follows.

- Sitting of Facilities during planning stage of facility development
- For deciding location of occupied building & other safety critical building
- Land use planning around facility by local authority
- Insurance company uses study output for deciding risk premium for coverage of risk to asset
- Provides input for developing onsite and offsite disaster management plan
- Future expansion of facility
- Provides input for deciding safe design philosophy
- Though QRA study can not prevent occurrence of Accident but sometime it helps in accident investigation if QRA study is carried out post accident.
- Major risk contributor to individual / societal risk can be identified & accordingly resources can be allocated for better risk management.

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QRA SCHEDULING DURING PROJECT LIFECYCLE

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QRA during Project Stages

Stage	Description
Conceptual Stage / Project Feasibility Stage	QRA during this stage helps in deciding site selection for project facilities. Even though sufficient process information is not available at this stage but still based on past data for similar facilities, QRA study can be carried out and output of study helps in deciding site suitability for proposed project facility.
Detailed Feasibility Stage / FEED Stage	QRA during this stage helps in facility sitting of overall project facilities. It helps in deciding safe design philosophy for bulk storage & handling facilities and deciding separation distance between various facilities in complex. It also provides certain mitigation measure which needs to be implemented during detail engineering stage for reducing risk further.
Detailed Engineering Stage / EPC Stage	QRA during this stage takes in to account risk arising due to changes made from DFR or FEED stage to detail engineering stage and ensures that overall risk due to installation of project facility remains acceptable as per risk acceptance criteria.

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QRA during Project Stages

Stage	Description
Operation Stage	The QRA at this stage revalidates risk and also takes in to account new risk arising due to changes made in facility from last QRA study. Typically it is industry practice to carry out PHA study (HAZOP / SIL / QRA) at every 5 years. OISD GDN-206 also recommends to carry out PHA study at every 5 years and most of the downstream oil & gas industry carries out QRA study at every 5 years.
Major Revamp / Brownfield Expansion	QRA needs to be carried out after major revamp of facilities or brown field expansion to assess the risk and manage the risk. Also it helps in identifying measures to bring risk to acceptable level

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QRA METHODOLOGY

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Overview of QRA Methodology

There is no specific standard / code of practice / guideline available to follow for carrying out QRA study. However there are various international publication available which can be used as guideline for QRA study, some of the which are as follows:

- Guideline for Chemical Process QRA Study published by CCPS
- Purple Book published by CPR(Committee for prevention of Disaster), Netherland
- UK HSE Publication for using HC Release Data (HCRD) & Ignition Probability in QRA
- IOGP(International Association of Oil & Gas Producer) Publication for Failure rate data of various parts of Process unit

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Overview of QRA Methodology

- It is to be noted that NFPA 59A has provided some guideline for siting of LNG facility based on QRA study.
- Also major international oil & gas company like BP, Shell, ADNOC, KNPC, ORPIC, Saudi Aramco, Exxon Mobil has developed their own procedure / specification for QRA study.
- However in India, very few operating companies have developed their own procedure / guideline for carrying out QRA study.

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Major Steps Involved in QRA Study

Hazard Identification

- The hazard identification consists of a qualitative review of possible accidents that may occur, based on previous accident experience or judgement where necessary. There are several formal techniques like Hazard Identification (HAZID), Hazard and Operability studies (HAZOP) and Failure Mode and Effect Analysis (FMEA) which can be used to identify major hazard scenario. Sometimes brainstorming session with personnel involved in the design and operation of a process is effective in determining a list of top events.

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Major Steps Involved in QRA Study

Consequence Analysis

- Consequence analysis evaluates the resulting effects if the release occurs & their impact on personnel, equipment / structures, the environment or business. Estimation of the consequences of each possible event requires some form of computer modelling i.e. use of specific software. Physical effects from the release of hydrocarbons or toxic material such as dispersion, explosion over-pressures and heat radiation have to be calculated to assess whether escalation is a realistic possibility & the extent of the damage following the escalation.

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Major Steps Involved in QRA Study

Failure Frequency Estimation

- Once the potential accidental scenarios have been identified, frequency analysis estimates on how often such scenarios occurs.
- Generally the generic failure frequency for equipment and other component of plant is taken from different publication published by UK HSE or OGP or OREDA unless site specific or company specific data is available.

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Major Steps Involved in QRA Study

Risk Estimation

- Once the frequency and consequence for each scenario are determined as statistical quantities, potential loss for each scenario can be calculated as the product of the frequency and consequence values. In general, risks are expressed in terms of ñIndividual Riskò and risk to a group (ñSocietal Riskò).

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Major Steps Involved in QRA Study

Risk Assesment

- Up to this point, the process has been purely technical, and is known as risk analysis.
- The next stage is to introduce criteria, which are yardsticks to indicate whether the risks are acceptable, or to make some other judgement about their significance.
- Risk assessment is the process of comparing the level of risk against a set of criteria as well as the identification of major risk contributors.
- The purpose of risk assessment is to develop mitigation measures for unacceptable generators of risk, as well as to reduce the overall level of risk to As Low As Reasonably Practical (ALARP).
- It is important to note that quantification of risk is an engineering exercise, but evaluation of ALARP is a management exercise.

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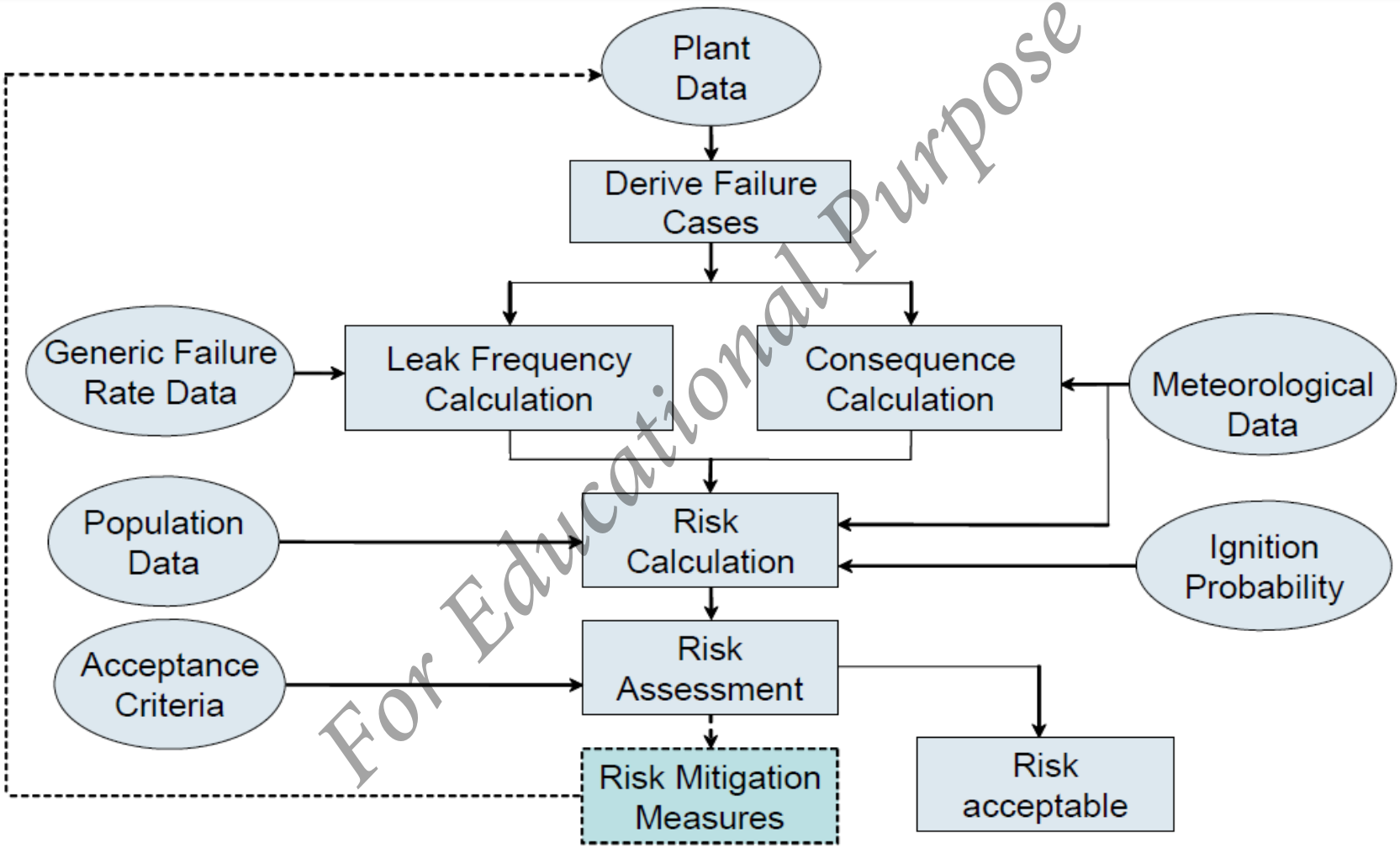
QRA Workflow



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RISK CRITERIA

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Risk Categories

Individual Risk

- It is defined as cumulative risk to a single person exposed to a Hazard. Normally it is expressed as Individual Risk per annum(IRPA).
- It is derived from location specific individual risk (LSIR) which is risk to a person at a particular location if unprotected person remains present there 24 hours a day and 365 days a year.

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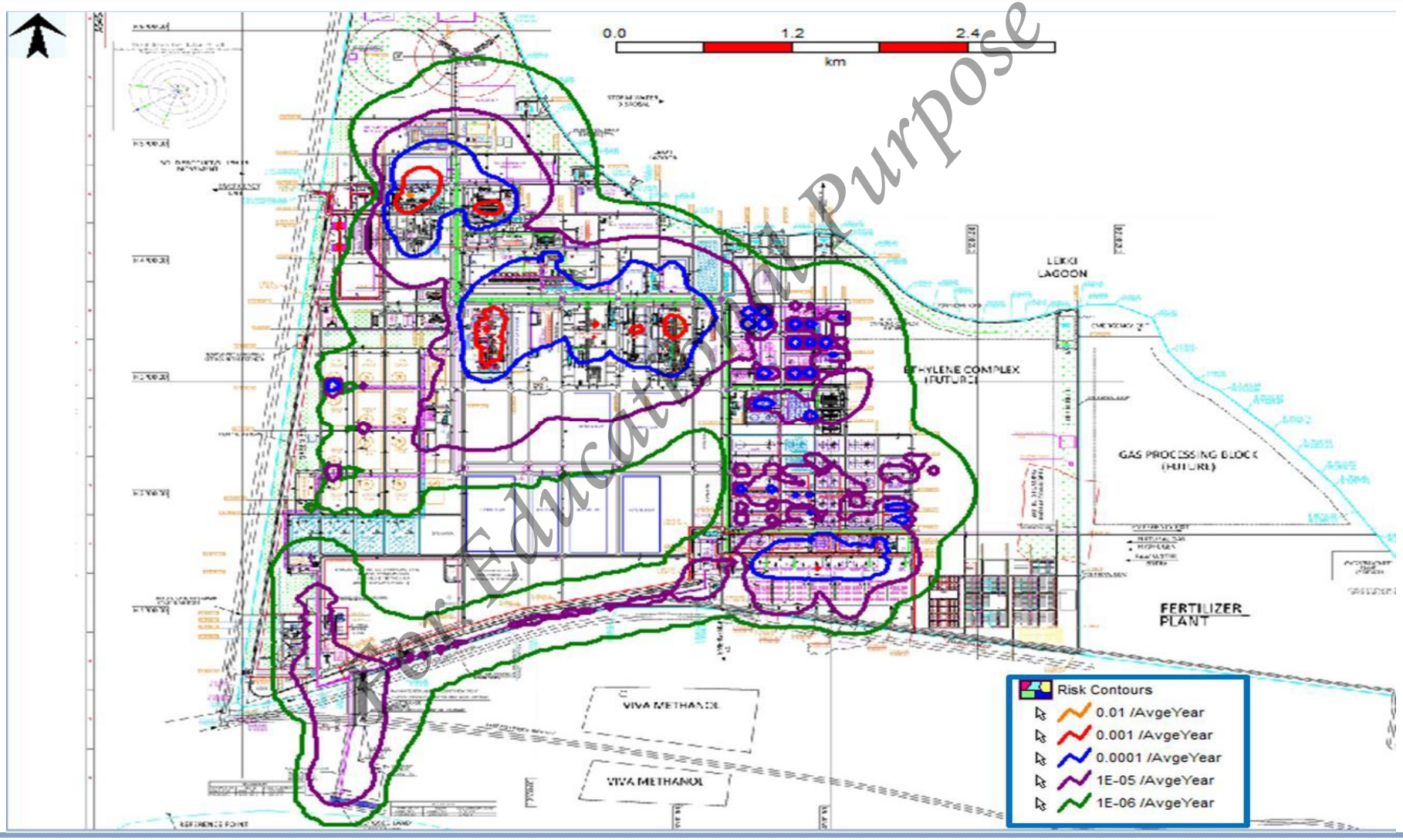
IRPA = LSIR X Occupancy of Person at that Location

ISO RISK CONTOUR SAMPLE



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Risk Categories

Societal Risk

- It is defined as the risk to a group of people due to all hazards arising from facility. Societal risk is typically represented in the form of F-N curve where F is the cumulative frequency of all hazardous events leading to N or more number of Fatalities. F-N Curve is Log-Log graph where X axis represents the number of deaths, and the Y-Axis represents the cumulative frequency of the accidents with the number of deaths equal or greater than N.

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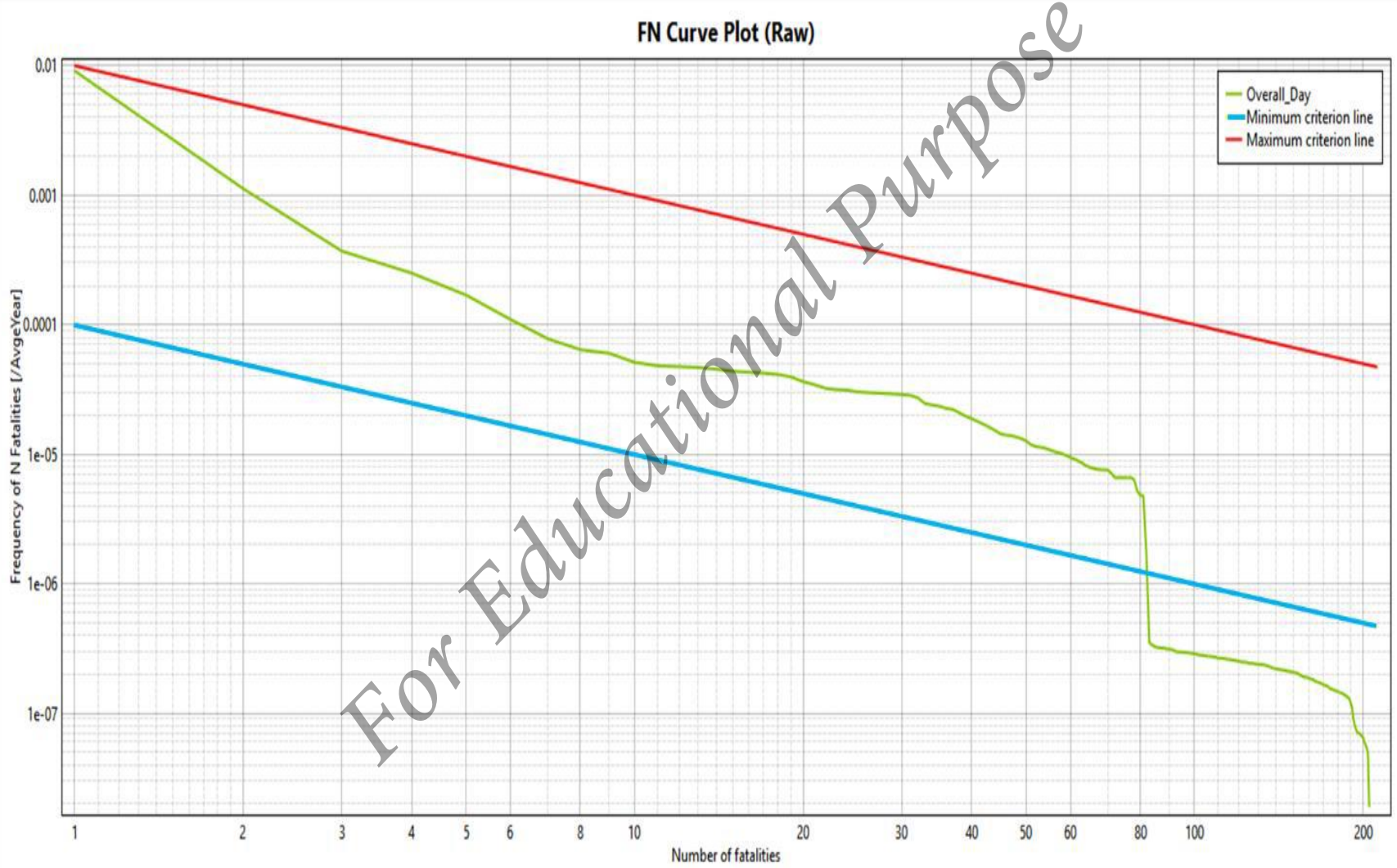
Typical FN Curve



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Risk Acceptance Criteria

- The risk acceptance criteria is most important aspect in any QRA study as it leads to better risk management.
- Typically this criteria is decided by regulatory body in various country. Hence this criteria varies across different country.
- The risk criteria used in various country is tabulated in next slide.

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Individual Risk Criteria In Different Countries

Country	Individual risk to employee per year		Individual risk to Public per year		Remark
	Max Tolerable Risk	Broadly Acceptable Risk	Max Tolerable Risk	Broadly Acceptable Risk	
Netherland			1 X 10^-6		
UK	1 X 10^-3	1 X 10^-6	1 X 10^-4	1 X 10^-6	
Hong Kong			1 X 10^-5		
Brazil			1 X 10^-4 to 1 X 10^-6 Depending on location and type of industry	1 X 10^-5 to 1 X 10^-6 Depending on type of industry	
Hungary			1 X 10^-5	1 X 10^-6	
Singapore			5 X 10^-5		
Malaysia			1 X 10^-6		
Australia	1 X 10^-3 to 5 X 10^-4 depending on location	1 X 10^-4	1 X 10^-5 to 1 X 10^-6 Depending on location of industry	1 X 10^-7 in some state of australia	
Canada			1 X 10^-5		
USA			1 X 10^-6 in some state of USA		
UAE	1 X 10^-3	1 X 10^-5	1 X 10^-4	1 X 10^-6	
India	1 X 10^-3				As per PNGRB guideline for ERDMP preparation

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Observation on Individual Risk Criteria In Different Countries

- It is observed from table, that very few countries including India have defined individual risk criteria for employees but most countries excluding India have defined individual risk criteria for general public.
- It is also observed that maximum tolerable risk criteria for individual risk to general public is more stringent than for employees. This is so because employees are aware of risk and being compensated for that.
- Maximum Tolerable Risk (MTR) criteria for general public lies in the range of 1×10^{-5} to 1×10^{-6} except few countries.
- Broadly Acceptable Risk(BAR) criteria for employees lie in the range of 1×10^{-4} to 1×10^{-6} for most countries.

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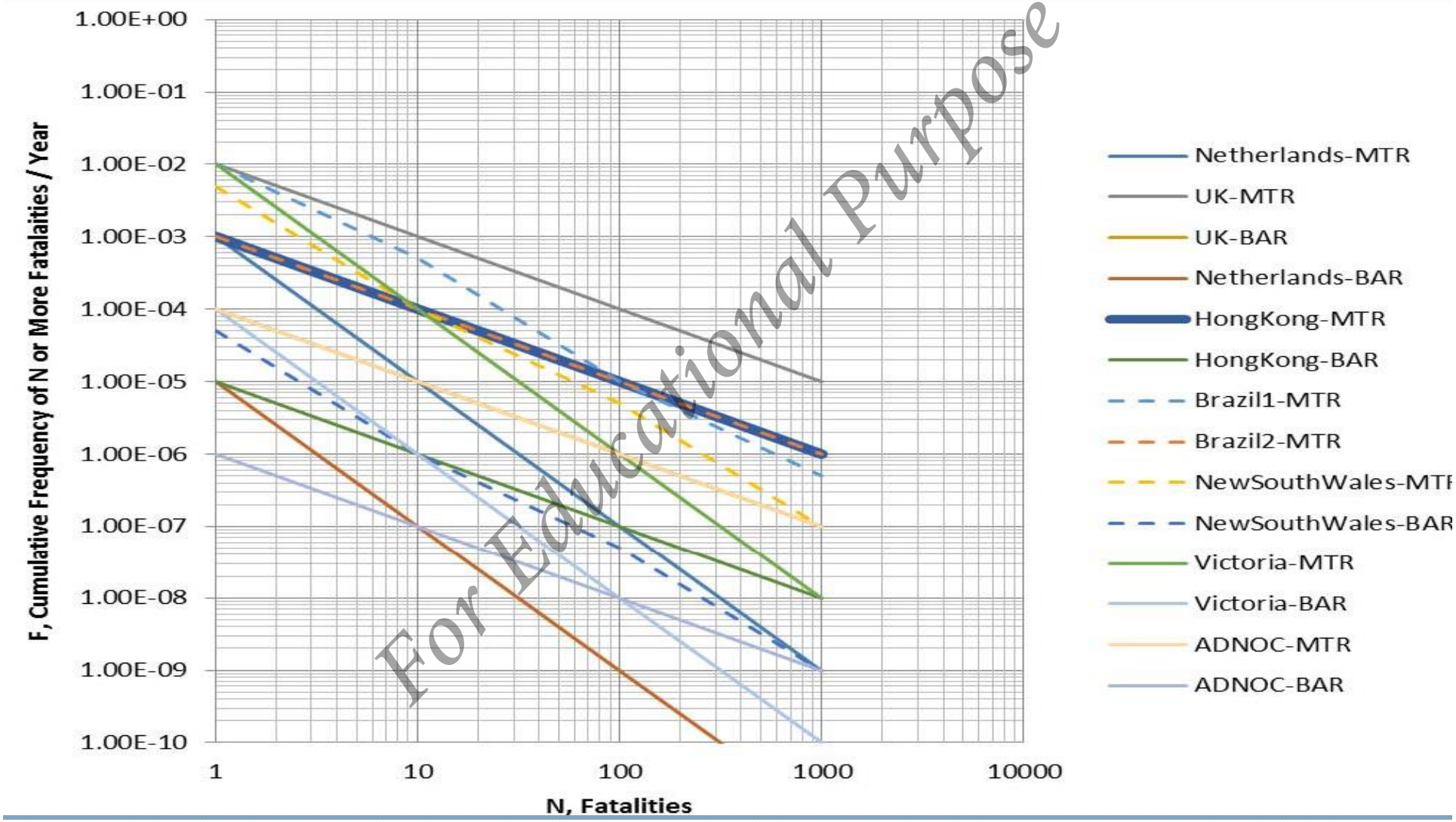
Societal Risk Criteria In Different Countries



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Observation on Societal Risk Criteria In Different Countries

- It is observed from figure, that few countries have defined maximum tolerable risk criteria(MTR) for society. India has not defined MTR for societal risk.
- It is also noted that few countries have also defined broadly acceptable risk criteria (BAR) for society. In India, PNGRB has prescribed 1×10^{-6} as broadly acceptable risk criteria for society which is in line with international practice.

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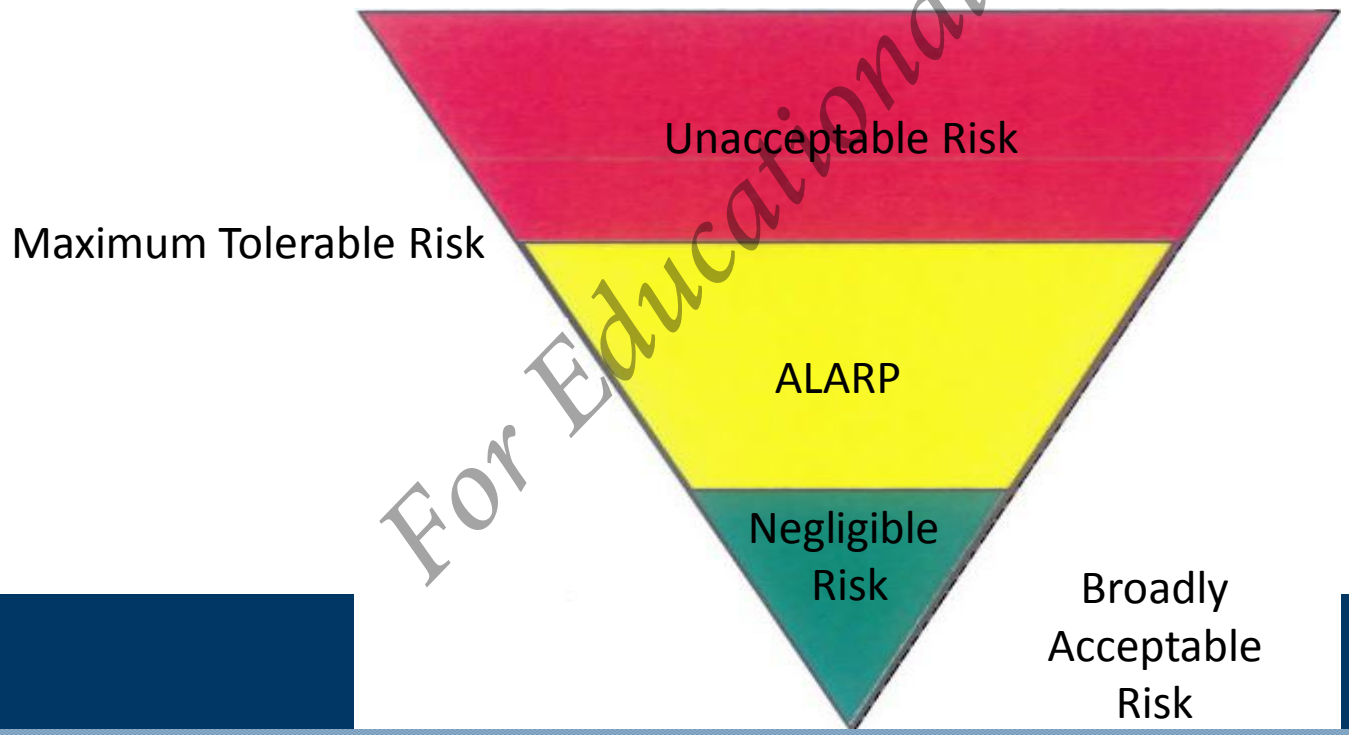
As Low As Reasonably Practicable (ALARP)

- The ALARP concept is defined as risk region between maximum tolerable risk(MTR) and broadly acceptable risk(BAR) and typically represented in triangle format as shown below.



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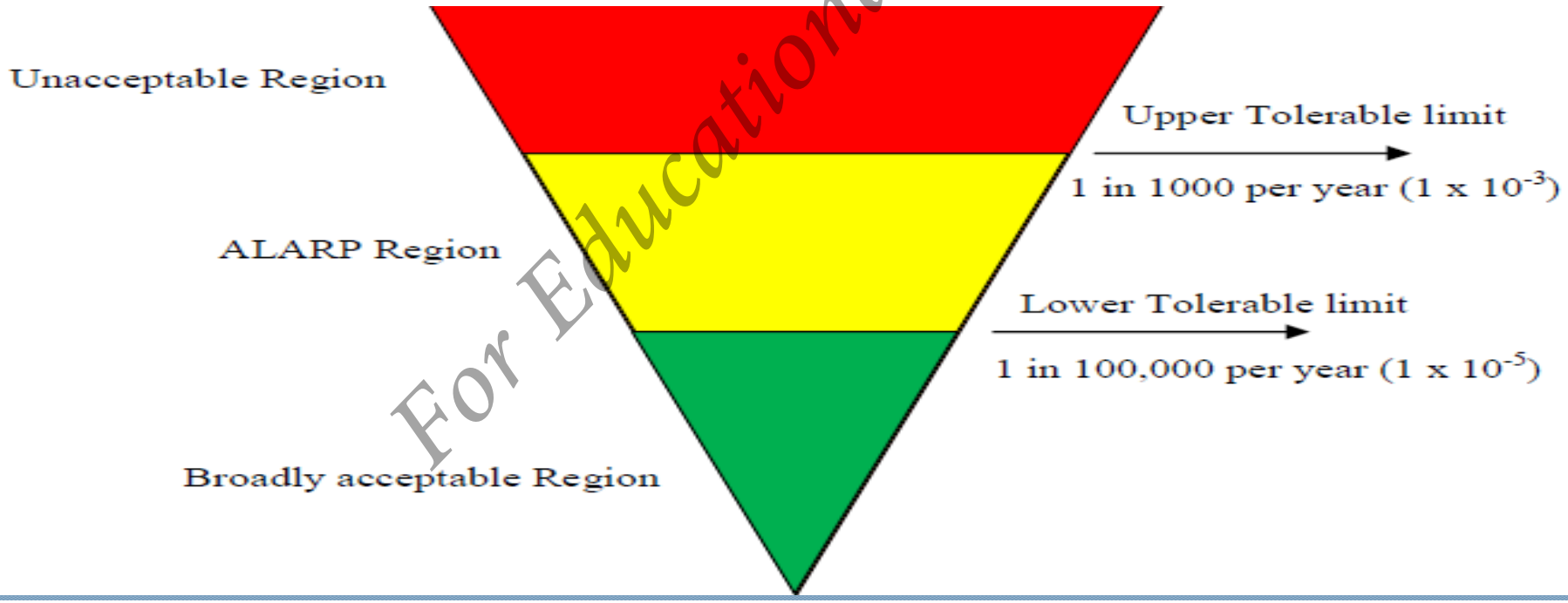
DEFINING ALARP FOR WORKERS IN INDIA

- Individual MTR Criteria for Workers ($1x10^{-3}$) is defined as per PNGRB Guideline. Whereas Broadly Acceptable Risk for workers is considered one level below maximum tolerable risk criteria(i.e. One level below $1x10^{-6}$) of societal risk as defined by Netherland



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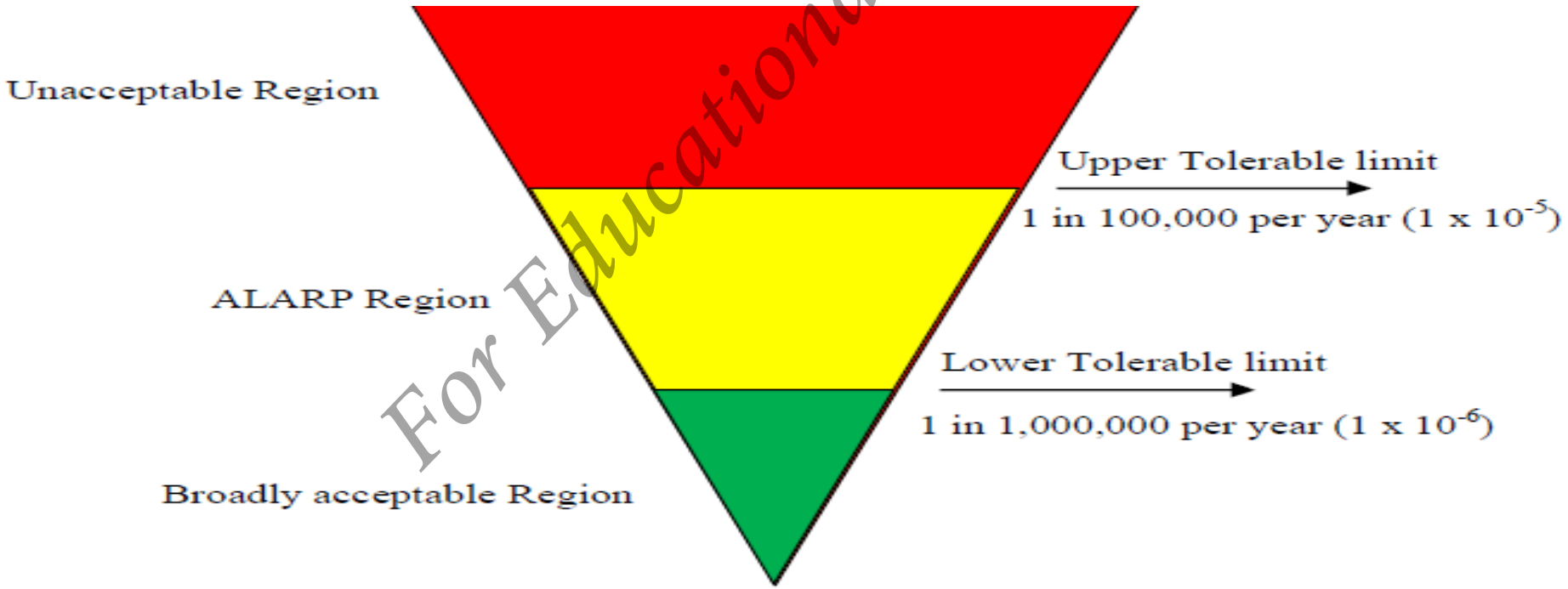
DEFINING ALARP FOR PUBLIC / SOCIETY IN INDIA

- Societal MTR Criteria ($1x10^{-5}$) is considered as per Netherland country which is more stringent than UK HSE MTR Criteria (1×10^{-4}). Whereas Broadly Acceptable Risk for society is considered $1x10^{-6}$ as per PNGRB guideline.



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IMPORTANCE OF RISK CRITERIA

- As mentioned earlier, the numerical risk value arrived from QRA study is to be compared with risk acceptance criteria so it is essential that asset owner defines proper risk acceptance criteria (ALARP) which shall be used uniformly across organisation.
- It is to be noted that all recommendation of QRA study depends on gap between actual risk and risk acceptance criteria.

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QRA RESULT INTERPRETATION WITH CASE STUDY

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INDIVIDUAL RISK PER ANNUM

- Normally IRPA is calculated for each risk ranking point (RRP). Typically RRP is assigned to all occupied building in facility as occupancy will be higher in building compare to plant area. Hence all occupied building should fall in ALARP zone or otherwise some protection measure like blast resistant design or positive pressurisation of building should be provided to bring risk to occupant of building in ALARP zone.
- Safety critical building like fire station shall fall outside the lower limit of risk acceptance criteria.
- Typically IRPA is arrived as follows:

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IRPA = LSIR X Occupancy of Person at that Location

POTENTIAL LOSS OF LIFE

- Sometimes PLL is reported in QRA report which indicate statistical fatality profile over the expected lifetime of facility. It is derived as follows:

PLL = No. of person affected by risk X Frequency of Risk

- Typically PLL is used for cost benefit analysis when risk is already in ALARP zone and some recommendation is to be implemented to reduce risk further based on cost benefit analysis.

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CASE STUDY FOR INDIVIDUAL RISK

Sl. No	Type of Building	Location	Individual Risk		
			Flammable & Explosion	Toxic	Total
1.	Canteen	Near Main Gate	-	2.31 E-06	2.31 E-06
2.	Admin Building	Near Main Gate	-	1.46 E-06	1.46 E-06
3.	Main Gate security/OHC/ medical centre	Near Main Gate	-	3.34 E-06	3.34 E-06
4.	O&M Store	Near Main Gate	-	1.26E-05	1.26E-05

- Here Canteen, Admin Building, Main Gate, OHC & Medical center fall in broadly acceptable risk but O & M store is in ALARP Zone. Hence if risk in O&M store is to be reduced further then major risk contributor to this building is to be identified and appropriate recommendation is to be provided for further risk reduction.

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SOCIETAL RISK (FN Curve)

- Where the risk is outside ALARP zone then major risk contributor to overall risk needs to be determined and suitable recommendation is to be provided to reduce risk to acceptable level.
- The major risk contributor may be fatality/damage due to fire, explosion or toxic effect.
- It is to be noted that F-N curve is again need to be redrawn based on implementation of recommendation for ensuring the risk remains within ALARP zone.

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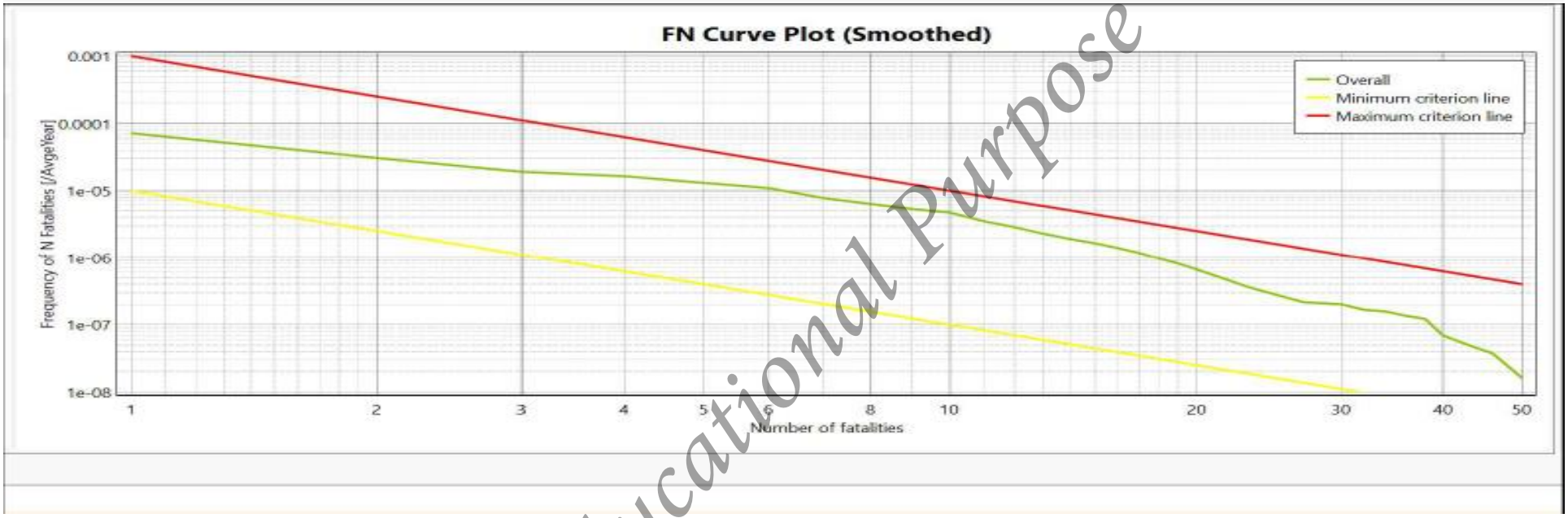
CASE STUDY FOR SOCIETAL RISK (FN Curve)



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- Here F-N curve remains in ALARP zone. However 6-10 person fatality frequency is near to upper limit of ALARP Zone so some risk reduction measure is required to be Implemented for reducing risk further.

QRA STUDY LIMITATION

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OVERVIEW OF LIMITATION

The uncertainty is major limitation in QRA . However CCPS has categorised limitation in two categories.

Technical Limitations

- These limitations arise due to incomplete enumeration (listing) of incident, improper selection of incident, unavailability of required data, consequence or frequency model assumption and validity of software.

Management Limitations

- These limitations arise due to unavailability of resources, skill and adequate time for carrying out QRA study.

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SOURCE OF UNCERTAINITY

System Description

- Process description or drawings are incorrect or out of date Procedures do not represent actual operation
- Site area maps and population data may be incorrect or out of date
- Weather data from nearest available site may be inappropriate

Hazard Identification

- Recognition of major hazards may be incomplete (inexperienced analyst)
- Screening techniques employed for selection of hazards for further evaluation may omit important cases.

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SOURCE OF UNCERTAINITY

Consequence Techniques

- Uncertainties in physical modeling
  - Inappropriate model selection
  - Incorrect or inadequate physical basis for model
  - Inadequate validation
  - Inaccurate model parameters
- Uncertainties in physical model data
  - Input data (composition, temperature, pressure)
  - Source terms for dispersion and other models
- Uncertainties in effects modeling
  - Animal data inappropriate for humans (especially toxicity)
  - Mitigating effects may be omitted

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SOURCE OF UNCERTAINITY

Frequency Techniques

- Uncertainties in modeling
  - Extrapolation of historical data to larger scale operations may overlook hazards introduced by scale up to larger equipment
  - Limitation of fault tree theory requires system simplification
  - Incompleteness in fault and event tree analysis
- Uncertainties in data
  - Data may be inaccurate, incomplete, or inappropriate
  - Data from related activities might not be directly applicable
  - Data generated by expert judgment may be inaccurate

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SOURCE OF UNCERTAINITY

Risk Estimation

- Assumption of symmetry
  - Uniform wind rose is rare
  - Uniform ignition sources may be inaccurate
- Assumptions to reduce the depth of treatment
  - A single condition of wind speed and stability may be too restrictive
  - A limited number of ignition cases will reduce accuracy

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APPROACH FOR OVERCOMING QRA LIMITATION

- Need for developing standard guideline/procedure by either industry association or standard developing body for carrying out QRA study.
- Developing site specific or company specific failure data.
- Need for defining uniform risk acceptance criteria by regulatory body/government authority

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CONCLUSION

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SUMMARY

- In spite of all the limitation in QRA study, it is useful tool to assess risk and manage risk in a better way as not knowing quantum of risk is more dangerous.
- The study helps in efficient allocation of resources based on level of risk
- The study only helps in decision making as it is a probabilistic study and predictive tool for risk management
- The user of report should judiciously interpret the results of QRA study and take decision based on his own judgement, experience and skill as well as knowing all the limitation of study

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