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NPTEL ONLINE CERTIFICATION COURSE

Health, Safety & Environmental Management in Offshore and Petroleum engineering (HSE)

Module 2:
Accident modeling, Risk assessment & Management
Lecture 9: Risk assessment of pipeline failure

Friends in this ninth lecture in module 2 we will talk about risk assessment of pipeline failure I will also show you one example on chlorine gas release and ammonium gas release problems using a software. This is the Chennai and module 2 accident modeling, risk assessment and management.

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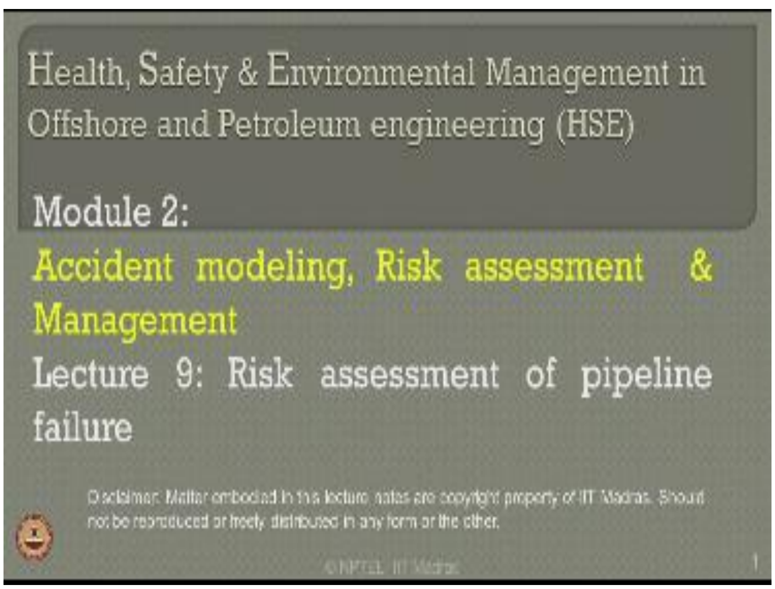

In HSE course under NPTEL IIT Madras.

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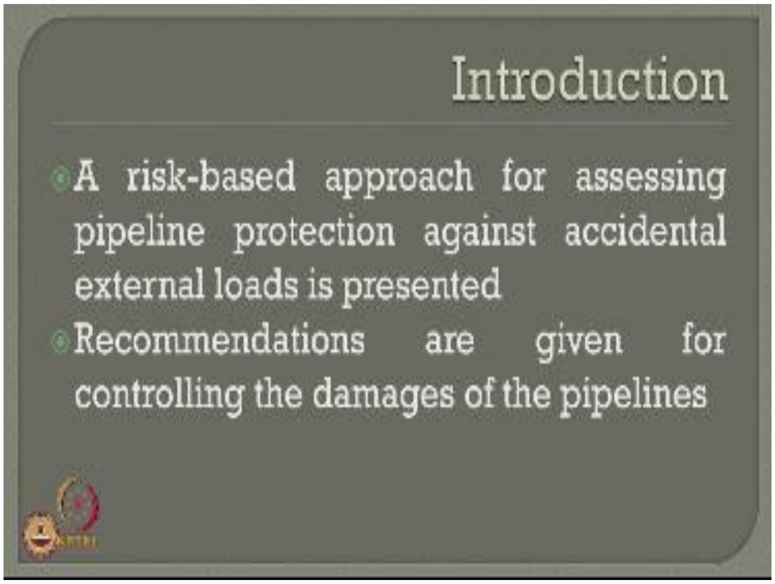

A risk based approach for assessing pipeline protection against accidental external loads is presented in this lecture for you. Recommendations are given for controlling the damages of the pipelines.

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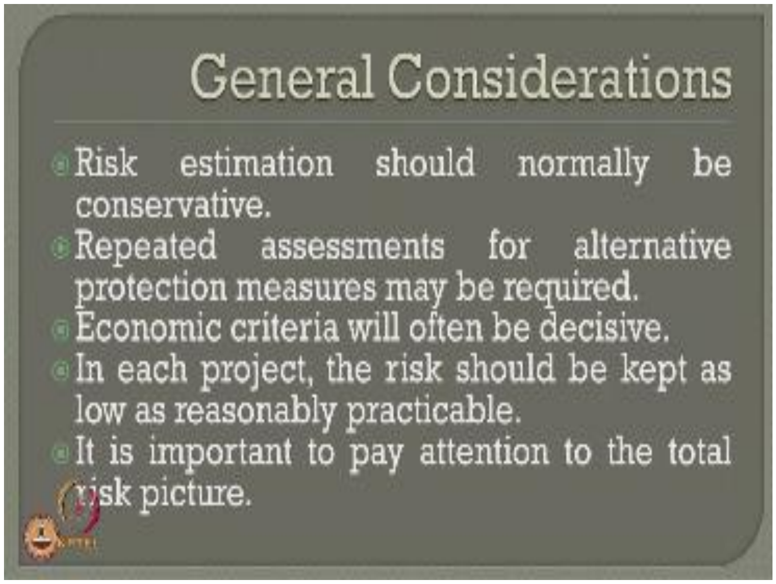

Let us quickly look at few general considerations which has been used in this analysis now. Risk estimation should normally be conservative. Repeated assessments for alternative protection measures may be required. Economic criteria will be often decisive in such problems. In each project, risk should be kept as low as reasonably practical, please understand friends in offshore projects it is clearly mentioned and it is understood that risk is can never be 0 there is always an acceptable level of risk which we call as ALARP level.

It is important to pay attention is the total risk picture instead of looking at one specific problem in a micro level.

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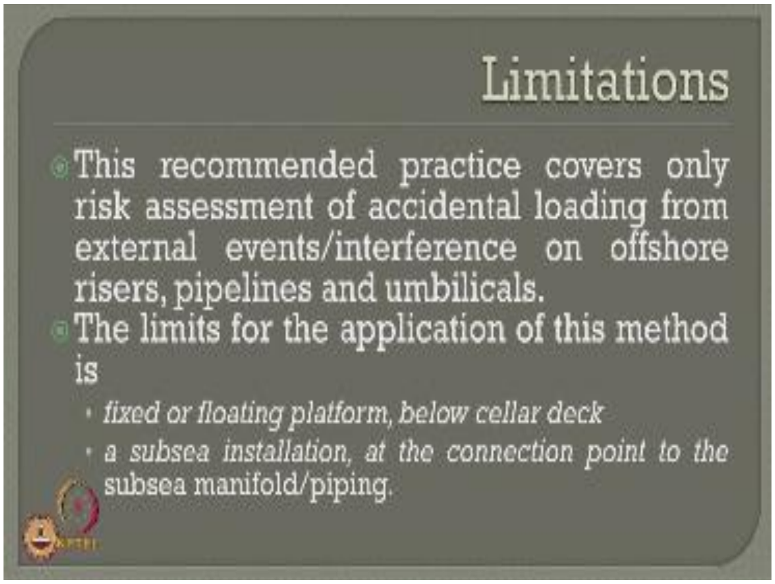

The study also has few limitations let us see what are they, this recommended practice covers only risk assessment of accidental loading from external events or interferences on offshore risers, pipelines and umbilicals. The limits for application of this method is limited to floating platform below the cellar deck, a subsea installation only at the connection point to the subsea manifold piping.

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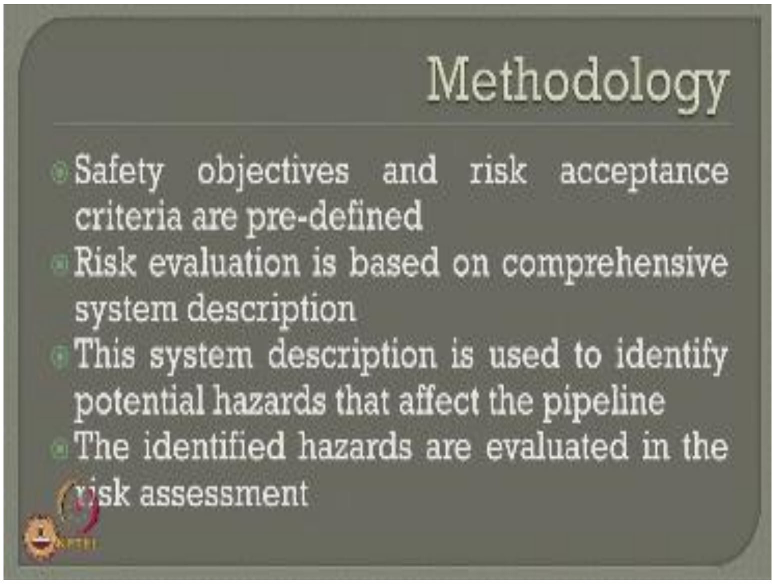

Let us briefly discuss the methodology how the study is now conducted. Safety objectives and risk acceptance criteria for the given problem are first predefined. Then risk evaluation is conducted based on comprehensive system description. This system description is used to identify the potential hazards that affect the pipeline flow. Then the perceived or identified hazards are evaluated under the braces of risk assessment.

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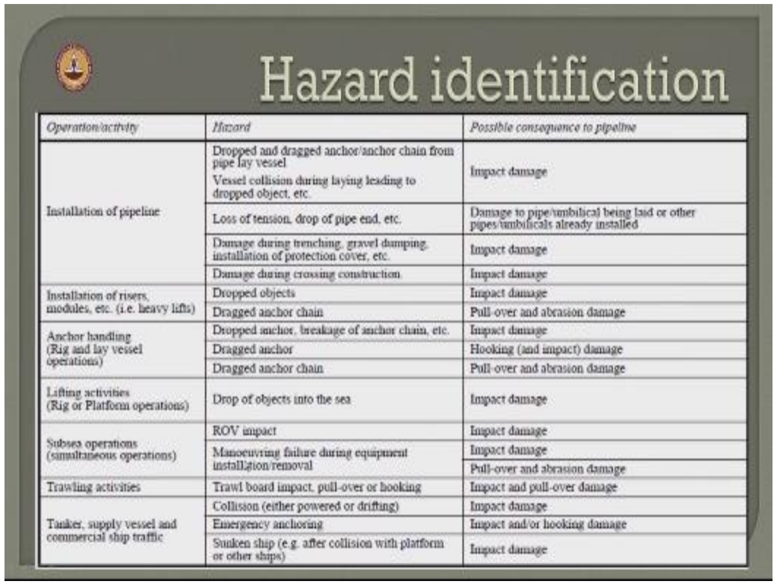

Hazard identification

Operation/activity	Hazard	Possible consequence to pipeline
Installation of pipeline	Dropped and dragged anchor/anchor chain from pipe lay vessel Vessel collision during laying leading to dropped object, etc.	Impact damage
	Loss of tension, drop of pipe end, etc.	Damage to pipe/umbilical being laid or other pipes/umbilicals already installed
	Damage during trenching, gravel dumping, installation of protection cover, etc.	Impact damage
	Damage during crossing construction	Impact damage
Installation of risers, modules, etc. (i.e. heavy lifts)	Dropped objects	Impact damage
	Dragged anchor chain	Pull-over and abrasion damage
Anchor handling (Rig and lay vessel operations)	Dropped anchor, breakage of anchor chain, etc.	Impact damage
	Dragged anchor	Hooking (and impact) damage
	Dragged anchor chain	Pull-over and abrasion damage
Lifting activities (Rig or Platform operations)	Drop of objects into the sea	Impact damage
Subsea operations (simultaneous operations)	ROV impact	Impact damage
	Manoeuvring failure during equipment installation/removal	Impact damage
		Pull-over and abrasion damage
Trawling activities	Trawl board impact, pull-over or hooking	Impact and pull-over damage
Tanker, supply vessel and commercial ship traffic	Collision (either powered or drifting)	Impact damage
	Emergency anchoring	Impact and/or hooking damage
	Sunken ship (e.g. after collision with platform or other ships)	Impact damage

So the foremost step is hazid which is hazard identification let us look at this table and try to understand in a given pipeline failure what are the possible hazards that can be identified. There is installation of pipeline one can look at the hazards in terms of dropped and dragged anchor or anchor change from the pipeline lay vessels, vessel collision which can also result in possible consequences which can cause an impact damaged to the pipeline can also have something a loss of tension drop of pipeline etc, which can damage the pipe, umbilicals when it is being laid.

Talk about installation of risers, it can hazards can arise from dropped objects, dragged anchor chains, it can result in impact damage and the pipeline can also cause abrasive damage to the material of the pipeline. Look at the anchor handling, anchor handling have hazards in terms of dropped anchor, breakage of anchor chain, dragged anchor and dragged anchor chain which can cause pull over and abrasion damage to the pipeline, impact damage, hooking damage and pull over and abrasion damage to the pipeline material.

You can also have operation activity in terms of lifting activities, subsea operations, trawling and tanker supply vessel extra, which can also result in impact damage on the pipeline. The major consequence as you see from this table is impact damage on the pipeline and the major hazard essentially come from the dropped and dragged objects or essentially dropped or dragged anchor breakage of anchor chains while laying etc.

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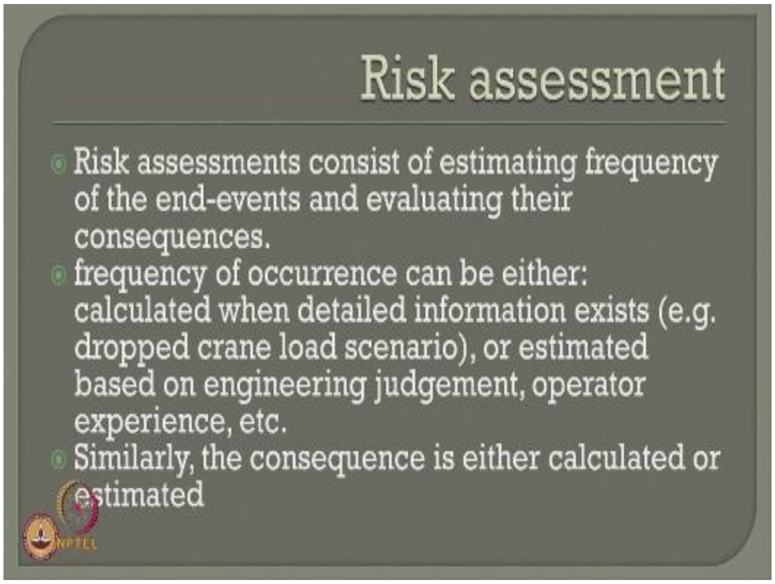

Once we identify the possible hazards in a given problem we do risk assessment. Risk assessments consist of estimating frequency of the end events and then evaluating their consequences. Frequency of occurrence can be either calculated when detailed information exists. For example, can be from dropped crane load scenario extra or on the other hand can estimate then based on engineering judgments, operator experience etc. Similarly, consequence can either be calculated or estimated based on experience.

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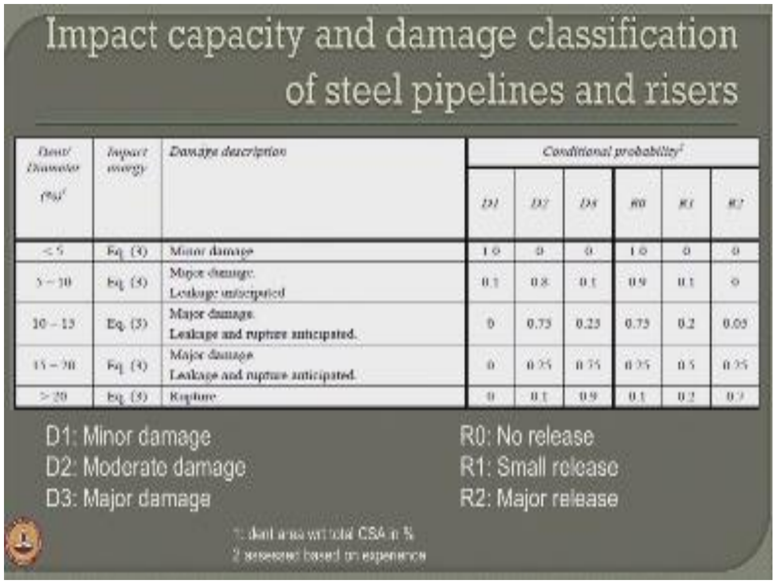

If you look at the impact capacity and damage classification generally applied to steel pipelines and risers as suggested by international codes. There are different dent diameter percentages whereas we classify the percentages dent area with respect to total cause fiction area in percentage. If it is less than 5% then the impact energy can be obtained separately changing the equation later.

It can result in the minor damage the condition probability for this kind of problems can be 1, 2 and so on where as $B_{1,}$ $B_{2,}$ $B_{3,}$ classified for minor damage moderate damage and major damage whereas R0, R1 and R2 can be no release small release and major release. On the other hand if the dent versus diameter ratio is less than 5% it can cause a minor damage to the pipeline which can result a minor damage whereas there is no possible major or moderate damage to the pipeline.

However, in such cases the release practically will not be there and therefore small and major releases are assigned to be 0. So you make a matrix which results in conditional probability which is derived based upon the kind of dent versus diameter ratio. As this ratio keeps on increasing you will see that the pipeline result in a major rupture, the moment I say major rupture can cause a moderate or a senior damage to the pipeline it can result in image a release of content from the pipeline.

So one can easily assist the impact capacity and the damage classification in terms of condition and probability that arrives from possible damage description applicable to steel pipelines and risers.

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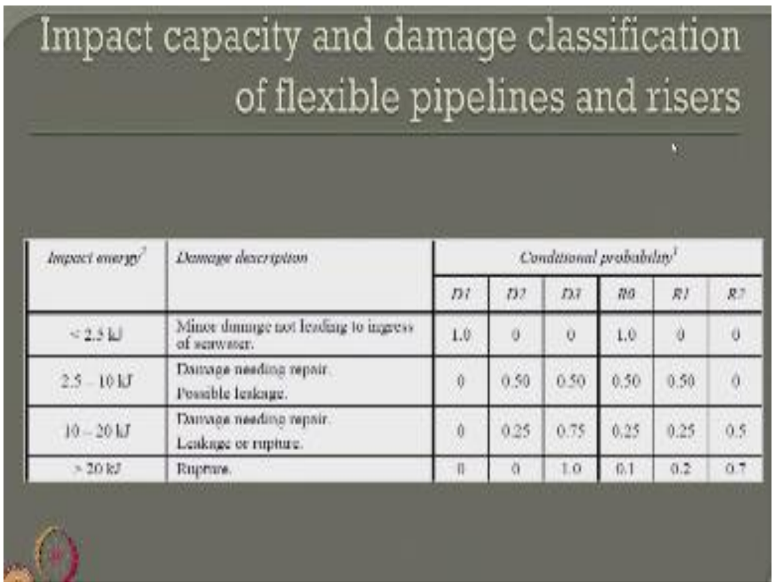

Impact energy[2]	Damage description	Conditional probability[1]					
		D1	D2	D3	R0	R1	R2
< 2.5 kJ	Minor damage not leading to ingress of seawater.	1.0	0	0	1.0	0	0
2.5 – 10 kJ	Damage needing repair. Possible leakage.	0	0.50	0.50	0.50	0.50	0
10 – 20 kJ	Damage needing repair. Leakage or rupture.	0	0.25	0.75	0.25	0.25	0.5
> 20 kJ	Rupture.	0	0	1.0	0.1	0.2	0.7

Similarly, one can also do this damage classification for flexible pipelines and risers whereas in this case the impact energy is discussed in terms of KJ of course, the legend of D_1, D_2, D_3, and R_0, R_1, R_2 are same asset of the previous slide. So you forgot an impact energy caused on a flexible pipeline which can lower than about 2.5KJ can result in a minor damage not even the ingression of seawater into the pipeline.

Therefore, it is going to be minor damage and no release from the pipeline and so on. So you prepare a condition probability matrix depending upon the damage description that can be cost because of impact energy arising on the flexible pipelines and risers.

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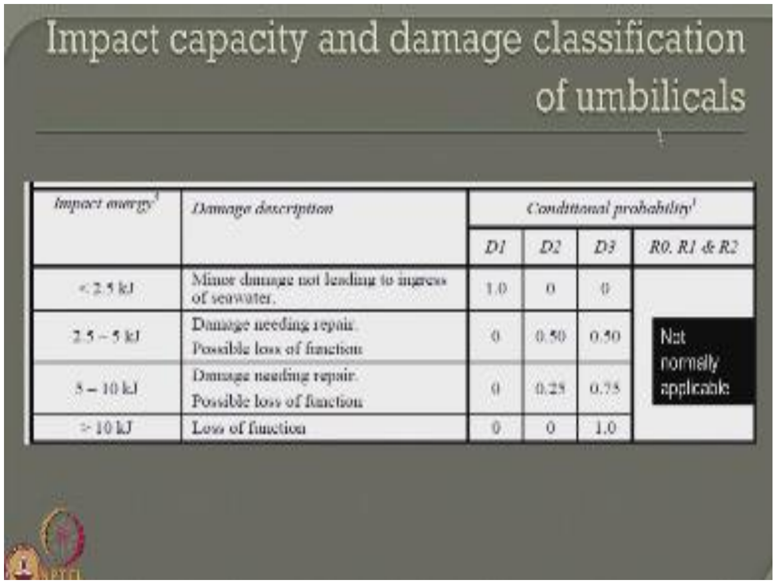

Impact energy[1]	Damage description	Conditional probability[1]			
		D1	D2	D3	R0, R1 & R2
< 2.5 kJ	Minor damage not leading to ingress of seawater.	1.0	0	0	Not normally applicable
2.5 – 5 kJ	Damage needing repair. Possible loss of function	0	0.50	0.50	
5 – 10 kJ	Damage needing repair. Possible loss of function	0	0.25	0.75	
> 10 kJ	Loss of function	0	0	1.0	

If we talk about the same application of umbilical generally again the impact energy classified from 2.5 to as higher than 10KJ. If the impact energy is very high can result in loss of function which can result in a damage probability in index of 1.0 which is causing a major or catastrophic damage to the pipeline. However, in case of umbilicals the releases from the umbilical does not arise because umbilicals may also carry cables.

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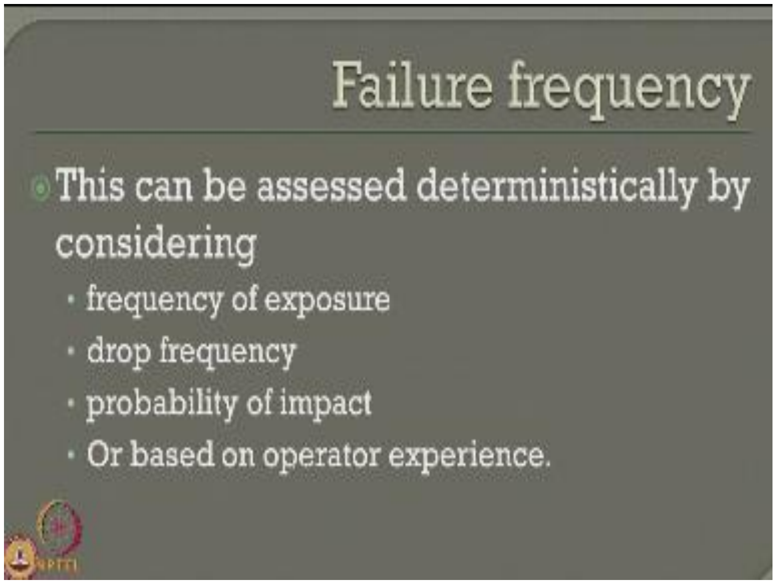

After assessing the hazard identification and after preparing the condition probability matrix one is interested to know what would be the failure frequency? As I told you in the previous slide failure frequency can be either based upon experience or based upon perceiving the data available in the similar case studies. This can be assessed deterministically by considering the frequency of exposure, drop frequency of the objects, probability of the impact which we said as D_0, D_1 and D_2 or of course based on operators experience.

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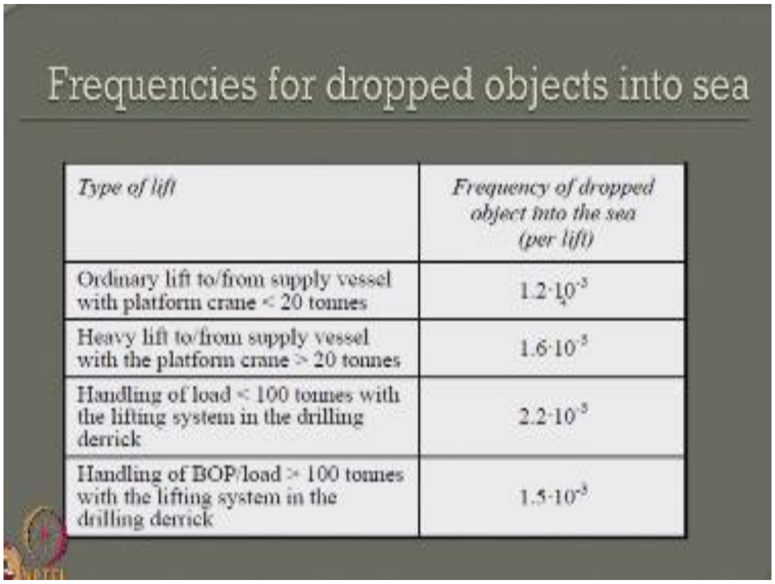

Frequencies for dropped objects into sea

Type of lift	*Frequency of dropped object into the sea (per lift)*
Ordinary lift to/from supply vessel with platform crane < 20 tonnes	$1.2 \cdot 10^{-5}$
Heavy lift to/from supply vessel with the platform crane > 20 tonnes	$1.6 \cdot 10^{-5}$
Handling of load < 100 tonnes with the lifting system in the drilling derrick	$2.2 \cdot 10^{-5}$
Handling of BOP/load > 100 tonnes with the lifting system in the drilling derrick	$1.5 \cdot 10^{-5}$

For a different types of lift frequency would drop objects into the sea are given in the literature which reproduce back for our reference. If it is the ordinary lift to or from the supply vessel where the lift is less than 20 tonne capacity the frequency of drop object in to the sea per lift is about 1.2 10^{-5} if the handing of BOP load is more than 100 tonnes then the frequency of dropped objects is 1.5 10^{-3} which is higher compared to this.

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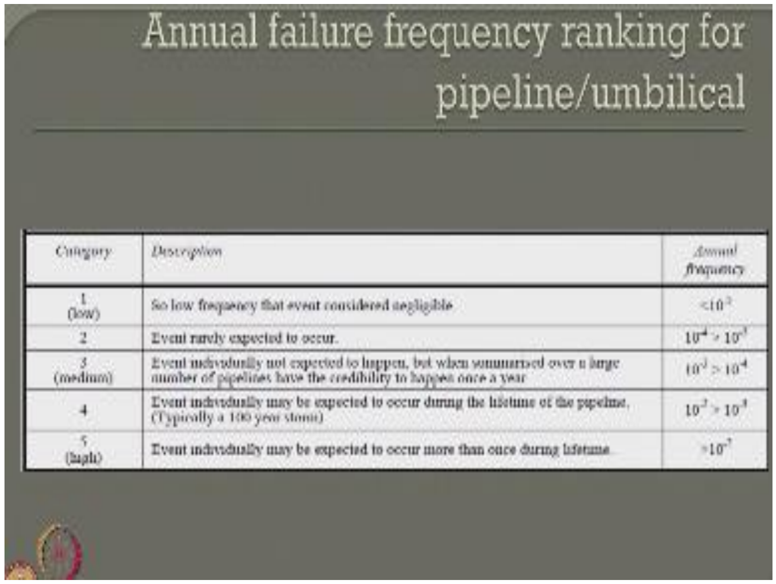

Similarly, look at the annual failure frequency ranking from the pipeline umbilical we categories them as a low, medium and high by giving a simple number where low stands for 1 and high stands for 5. The description for a low frequency ranking says that it is so low that the frequency event considered to be negligible, whereas if the event becomes very high then event individual will be expected to occur more than once during the life time.

In that case the annual frequency is very high which is higher than 10^{-2} whereas in case of low the frequency occurrence is less than 10^{-5}. So these are the guidelines available for preparing the annual failure frequency for pipeline and umbilical as discussed by the international course.

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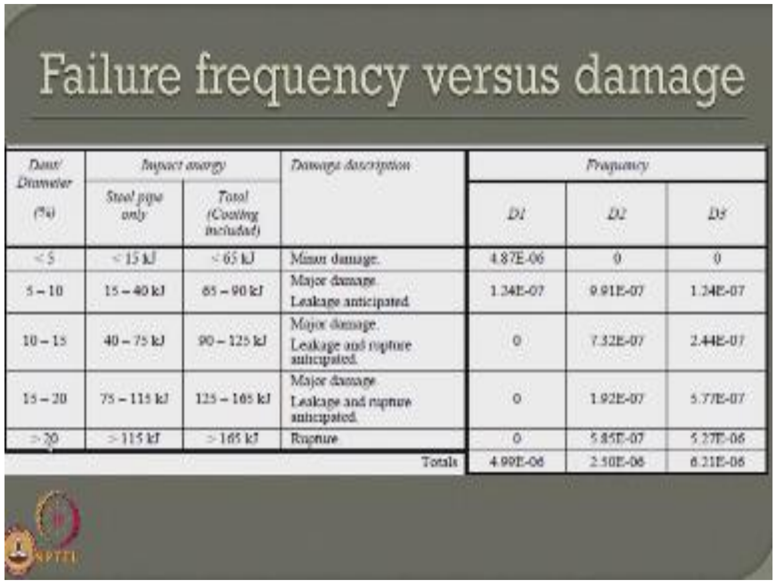

Failure frequency versus damage

Dent/ Diameter (%)	Impact energy		Damage description	Frequency		
	Steel pipe only	Total (Coating included)		D1	D2	D3
< 5	< 15 kJ	< 65 kJ	Minor damage.	4.87E-06	0	0
5 – 10	15 – 40 kJ	65 – 90 kJ	Major damage. Leakage anticipated.	1.24E-07	9.91E-07	1.24E-07
10 – 15	40 – 75 kJ	90 – 125 kJ	Major damage. Leakage and rupture anticipated.	0	7.32E-07	2.44E-07
15 – 20	75 – 115 kJ	125 – 165 kJ	Major damage. Leakage and rupture anticipated.	0	1.92E-07	5.77E-07
> 20	> 115 kJ	> 165 kJ	Rupture	0	5.85E-07	5.27E-06
			Totals	4.99E-06	2.50E-06	6.21E-06

We can also now compare the failure frequency versus the damage cost to the pipeline or the cables or the umbilicals. Again we get back to a dent versus diameter ratio if it is less than 5% and the impact energy on the steel pipeline or the coated pipeline in terms of KJ is expressed here, the damage description is classified based upon the minor damage to that of catastrophic rupture if the dent diameter is more than 20 % of to the diameter.

So the frequency of that occurrence is in terms of D1, D2 and D3 where they say minor, noticeable, and catastrophic rupture and damage will be given in terms of a failure frequency as you see from this table. So this table will help us to prepare a guideline what are the kinds of failure frequency for different kinds of impact energy caused on the steel pipeline as well as pipelines on the coated material describing the damage cost by the objects on the pipeline where the description is mechanically given depending upon the dent versus diameter ratio in terms of its percentage.

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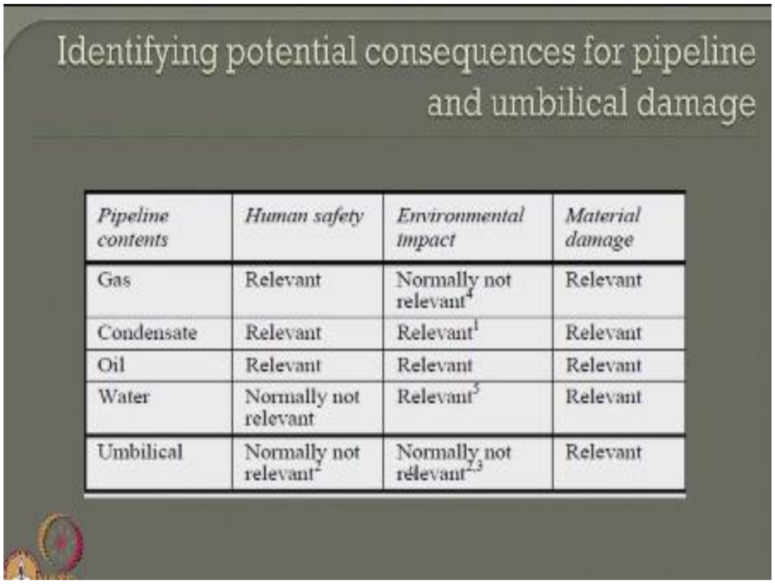

Pipeline contents	*Human safety*	*Environmental impact*	*Material damage*
Gas	Relevant	Normally not relevant[4]	Relevant
Condensate	Relevant	Relevant[1]	Relevant
Oil	Relevant	Relevant	Relevant
Water	Normally not relevant	Relevant[5]	Relevant
Umbilical	Normally not relevant[2]	Normally not relevant[2,3]	Relevant

Similarly, one can also identify the potential consequences for the pipeline umbilical damages for example if the pipe line carrying the contents like gas condensate, oil, water and cables then related to human safety, environmental impact and material damage we can always see which is relevant in the analysis which is not applicable in the analysis in the tabular form.

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If you look at the safety consequences ranking as described in terms of risk assessments it also being categorized as level low to 1 to level high as 5. The description for low level using the low person will be injured where is in the case of high more than 1 fatality is possible which can result in what we call as gas cloud ignition. So one can also do a safety consequences ranking depending upon the damage estimated on the pipe line caused to the dropping objects.

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Category	Description	Amount of release
1 (low)	Non, small or insignificant on the environment. Either due to no release of internal medium or only insignificant release.	~ 0
2	Minor release of polluting media. The released media will decompose or be neutralised rapidly by air or seawater.	<1000 tonnes
3 (medium)	Moderate release of polluting medium. The released media will use some time to decompose or neutralise by air or seawater, or can easily be removed.	<10000 tonnes
4	Large release of polluting medium which can be removed, or will after some time decompose or be neutralised by air or seawater.	<100000 tonnes
5 (high)	Large release of high polluting medium which can not be removed and will use long time to decompose or be neutralised by air or seawater.	> 100000 tonnes

We can also understand the release of the contents in the pipeline which is damage to that of the environment again we can categorize them with a simple index number varying from 1 to 5 where the descriptions available here whereas the amount of release is as high as 100,000 tonnes if the damage of the release cost is lying on the category of 5 which is very high.

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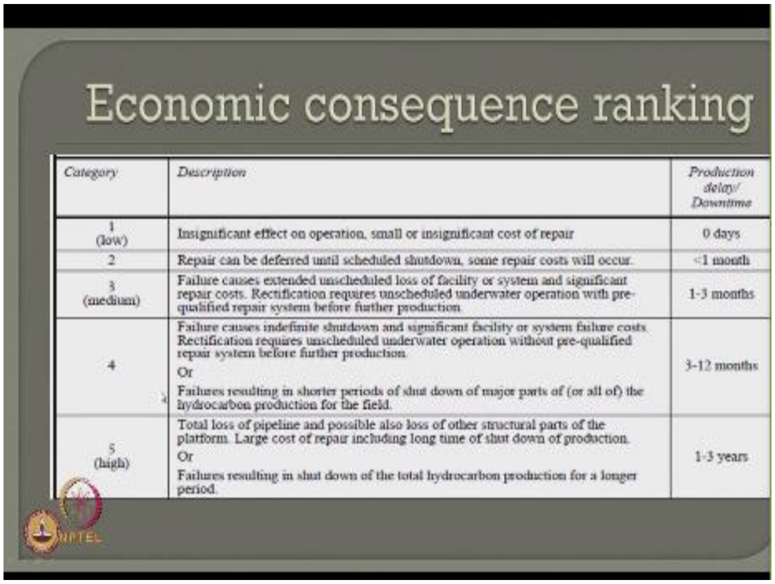

Economic consequence ranking

Category	Description	Production delay/ Downtime
1 (low)	Insignificant effect on operation, small or insignificant cost of repair	0 days
2	Repair can be deferred until scheduled shutdown, some repair costs will occur.	<1 month
3 (medium)	Failure causes extended unscheduled loss of facility or system and significant repair costs. Rectification requires unscheduled underwater operation with pre-qualified repair system before further production.	1-3 months
4	Failure causes indefinite shutdown and significant facility or system failure costs. Rectification requires unscheduled underwater operation without pre-qualified repair system before further production. Or Failures resulting in shorter periods of shut down of major parts of (or all of) the hydrocarbon production for the field.	3-12 months
5 (high)	Total loss of pipeline and possible also loss of other structural parts of the platform. Large cost of repair including long time of shut down of production. Or Failures resulting in shut down of the total hydrocarbon production for a longer period.	1-3 years

Similarly, one can also understand the economical consequences of such pipeline failure in a scale of 5 where the production delay a down time can vary anywhere from 0 days to 1 to 3 years depending upon the catastrophic damages cost on the by the pipeline because of the dropped objects or dent versus diameter ratio as high as more than 20%.

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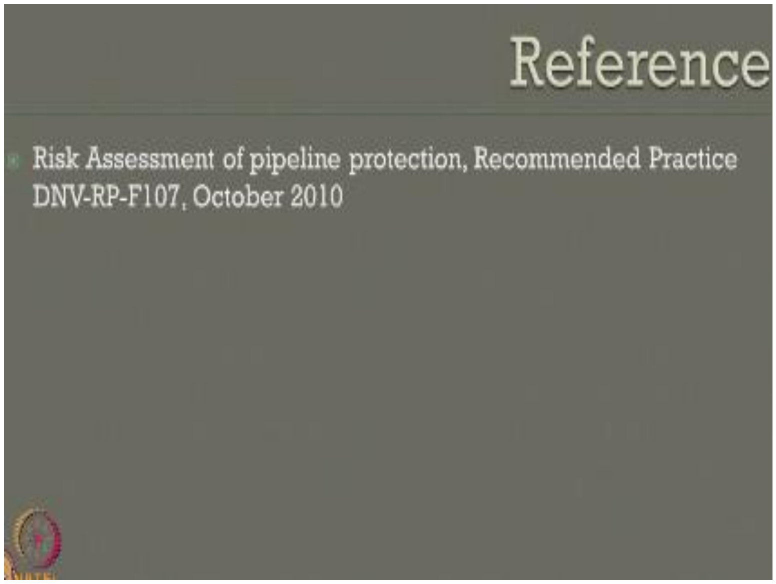

This specific table and the indications have a classical reference which is taken from the DNV-RP-F107, on October 2010 which discusses risk assessment of pipeline protection as a recommended practice. So using this one can identify the hazards present in a given scenario, one can also identify the failure frequencies and is easy for us to know a type of damage estimate not only on the pipeline as well as in the environmental impact cost with the release of the contents present in the pipeline.

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Subsequently the second part of the lecture will talk about the consequences and risk analysis of ammonia release. As I told you we can use the simple software to geographically locate the plant and content ammonia release in the plant and try find out the individual and societal risk caused by these kind of a gas release.

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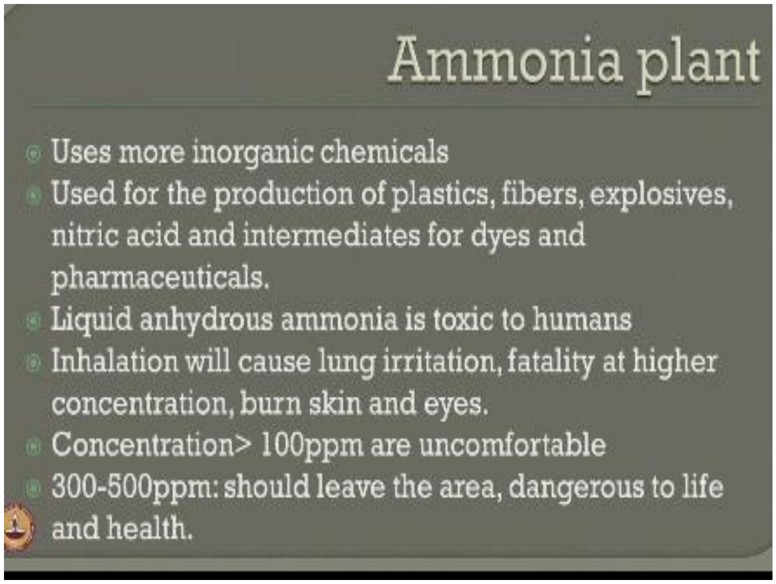

Let us understand the ammonia plant located at a specific location, ammonia plant uses more inorganic chemicals, it is used for production of plastics, fibers, explosives nitric acid and intermediates for dyes and pharmaceuticals. Liquid anhydrous ammonia is very toxic to humans, inhalation will cause lung irritation, fatality at higher concentration, burning skin, sensations and eye burning sensation are the results of ammonia release in the environment.

If the concentration exceeds 100ppm it results a lot of uncomfortable fatality for the societal public. If it is varying over from 300-500ppm then there is an alarm signal generated it indicates that person should leave the area because it will cause fatal to their life and health.

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Let us look at the case study now I have a ammonia plant located at specific geographic location we have mass location because of strategic reasons.

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It is an ammonia plant located. Now as we all understand for conducting risk analysis for a gaseous release I must know the ERPG that is emergency response planning guideline and the flammable limits of ammonia taken from the chemical engineering handbook for ERPG level 1 it is 25ppm, for level 2 it is 150, of the level 3 it is 750ppm as we all understand depending upon the release, depending upon the concentration respect to ERPG the hazard distance respectively varies from the computation as we saw in the lectures and chemical exposure index in the earlier module. The lower flammability limit for ammonia is 1.6 $^{10-5}$ ppm and so on.

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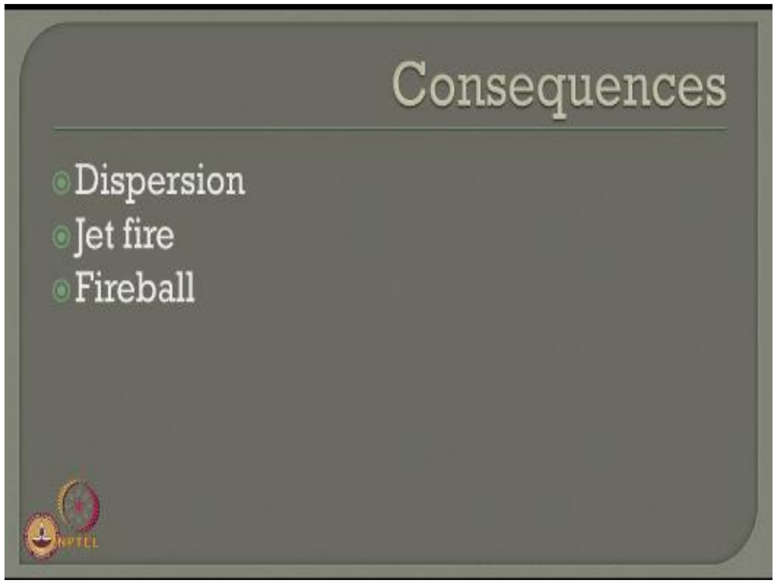

Let us look at the consequences now, it can result in dispersion, it can cause jet fire, it can cause a fireball.

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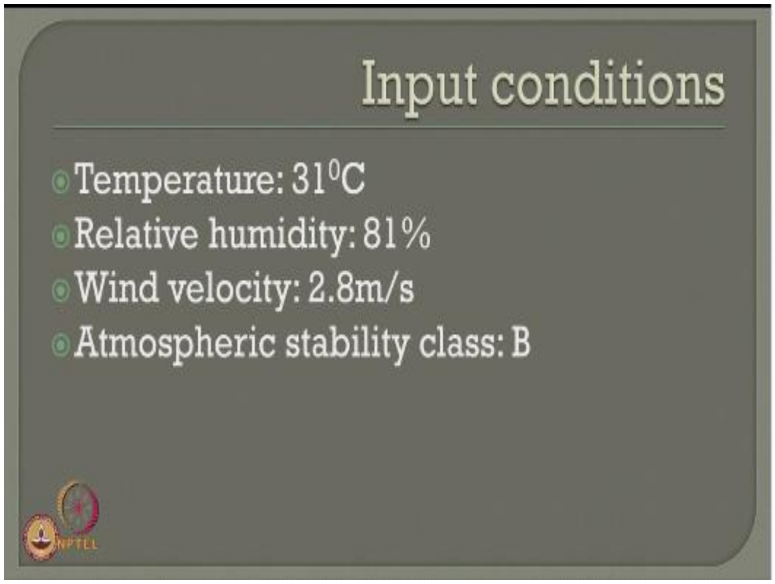

Result outcome from an ammonia release. Let us quickly see what are the input conditions defined for the given problem. Temperature is 31˚C in a specific site, relative humidity is about 81%, wind velocity is about 2.8m/s, atmospheric stability is class B.

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Let us look at the consequence assessments. In lower flammability region which specifies hazard distance for different kinds of scenario leaks varying from 25 mm to 100 mm, these are the diameter will leak arising from ammonia pipeline and the corresponding hazard distances has computed from the equation available to us in the previous presentations. So it has been estimated as 10.4 meter to that of 59.7 meter depending upon the leak rupture diameter varying from 25 mm to that as high as 100 mm which is been worked out depending up on the lower flammability of ammonia gas.

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ERPG

ERPG	Hazard distance (m)			
	25mm	50mm	75mm	100mm
ERPG-1	455.04	670.185	802.3	896.4
ERPG-2	356.284	501.257	597.5	668.3
ERPG-3	221.043	338.119	413.3	472.3

Based on the ERPG guidelines one can also worked out the hazard distances for different levels of ERPG 1, 2 and 3 respectively, for a 25 mm rupture the ERPG is about 221 meters for ERPG level 3 whereas this is as high as 455 meters for ERPG level 1, and as we keep on seeing the rupture diameter increases the emergency response guidelines values also change and therefore, the hazard distances specified by the ammonia gas released by the core also keeps on increasing significantly when compared to that of lower level diameter rupture release in case of ammonia gas.

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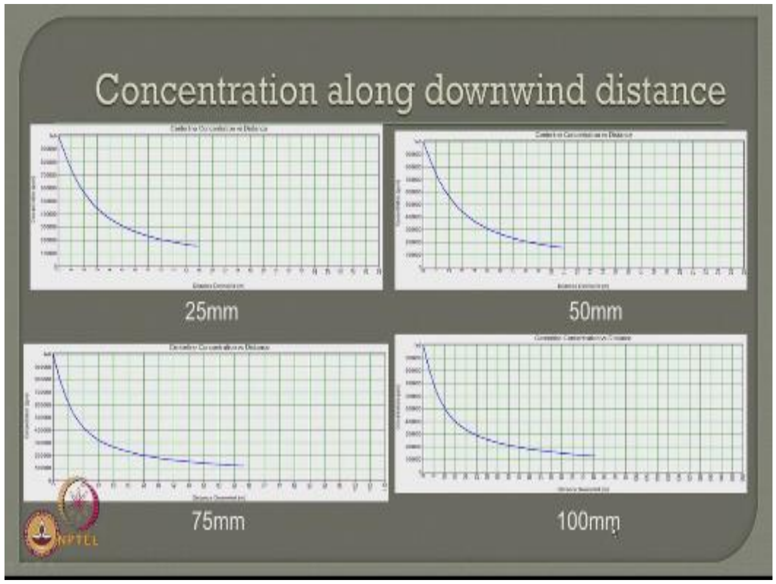

One is also interested to know the concentration along the downward distance for different velocity rupture. Let us see for 25, 50, 75 and 100 mm rupture diameter we have discussed about the concentration in parts per million keeps on decreasing at the downward distance increases which is a common scenario in all the cases but of course in case of saw 100 mm release diameter release you will see the downward distance extends as high as about 85 or 82 meters from the epicenter of the ammonia release whereas in 25 mm of the rupture the release extension is only as close as 11 meter.

It is obvious to understand that a central concentration was a distance keeps on increasing with respect to the concentration parts per million for different bore hole diameter rupture for an ammonia gas.

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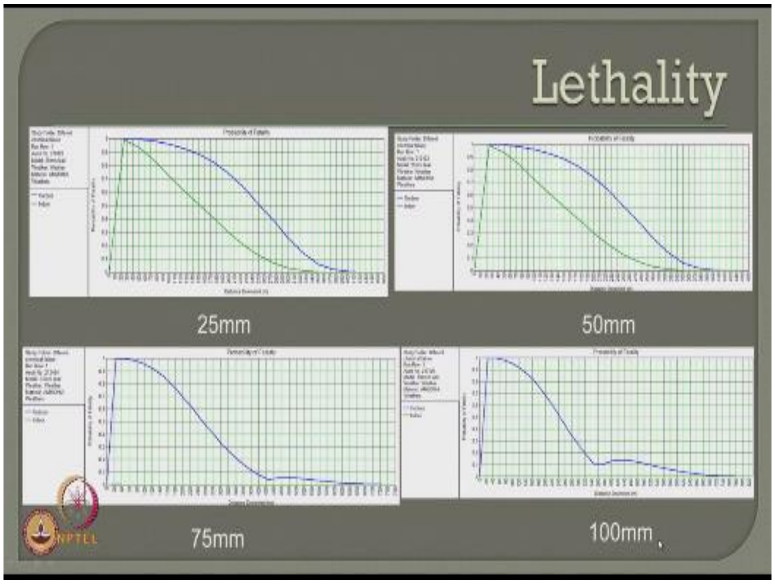

Once this is understood lethality influence is also studied in terms of probability of fatality which gives me the probability of fatality versus downward distance in meters, the green indicates is the indoor activity and of course the blue indicates it is a outdoor activity. We have plotted this for different rupture diameters varying from 25, 50, 75 and 100 mm diameter probably the diameter of rupture of the pipeline carrying ammonia you will see here very clearly that the weather condition, material, and the study conditions are taken as specified in the previous slides.

And the downward distance from the epicenter in terms of probability of fatality what we call lethality is we plotted and you see here for larger diameter of rupture even for outdoor activity the distance of influence of the release is as high as around 750 m whereas when we talk you the downward distance in there is a 25 mm diameter is influencing only about 400 meters.

Friends please understand whether it is outdoor or indoor we will always notice that the lethality influence in case of release is of course significantly high in both the cases, because it depends upon the stability class and the wind velocity and the release pressure and the diameter of rupture as you seen in the slides.

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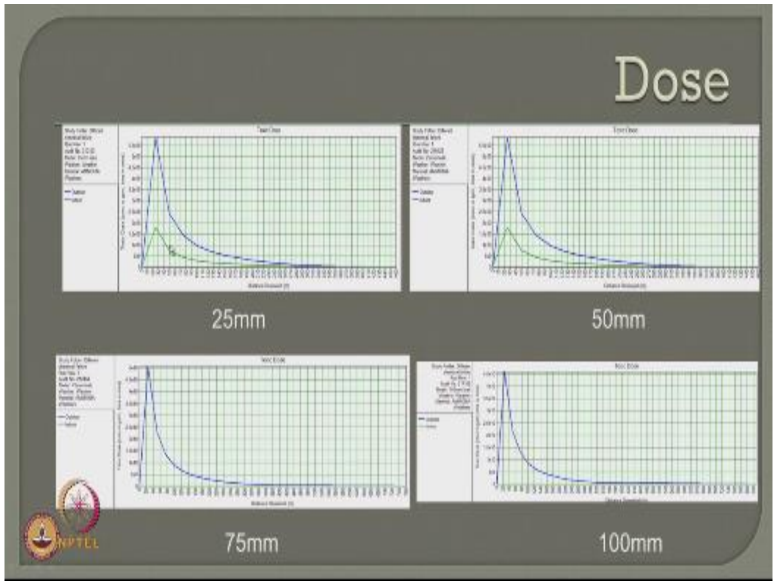

Let us now talk about the influence of dosage in terms of toxic dose of ammonia and the influence of that dose in terms of downward distance for different door hold rupture of ammonia gas release. The plot is available for both the activities of outdoor and indoor you will see that for a toxic dosage as high as 5.510^{10} in that case in terms of parts per million line in minutes you will see that for outdoor activity even though the rupture is 25 mm the toxic doors for higher value should set only for a smaller scalar distance and subsequently it reduces drastically as the distance goes forward.

It means the dosage influence in case of any types of diameter is only spiked for outdoor activity as well as indoor only for a smaller region of distance from the epicenter of the leak whereas when the leak is going to be even in large diameter the effect of dosage on the downward distance keeps on significantly declining as the distance increases with the decrease in toxic dosage.

It means in case of dosage influence of any rupture beat ammonia in the specific example, you will see that the downward distance is not influenced by the dosage in terms of rupture of any diameter.

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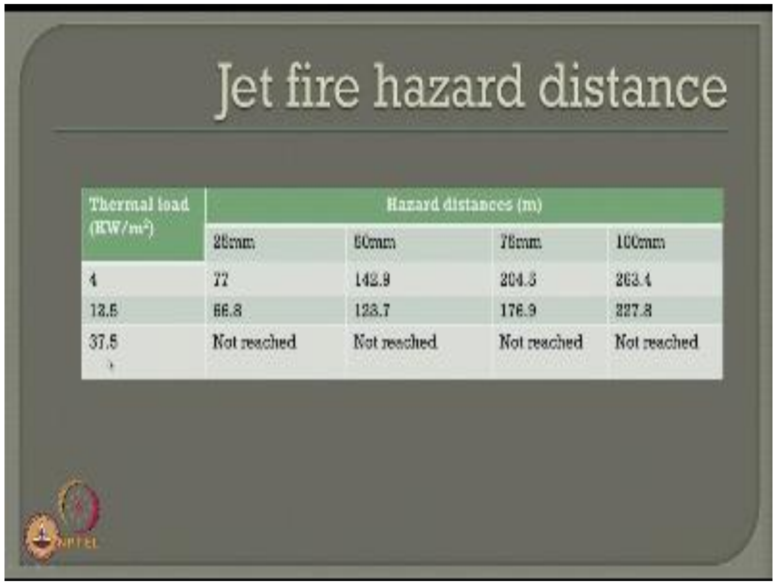
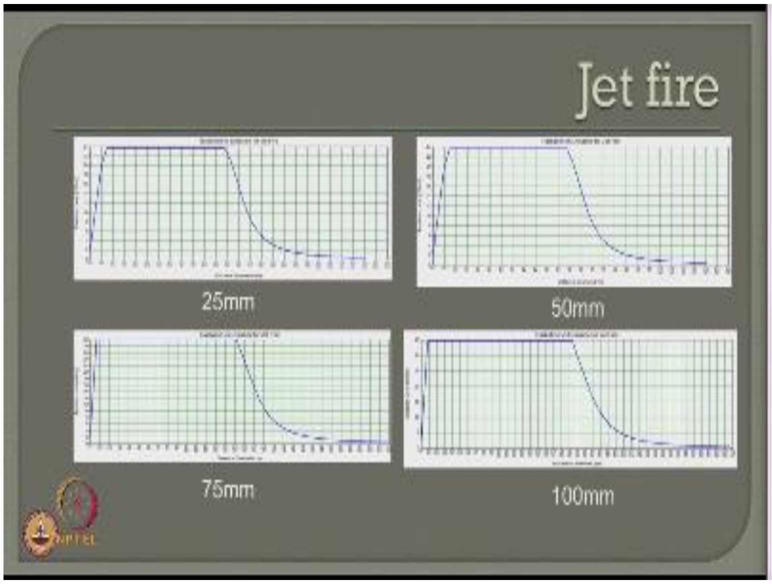


Thermal load (KW/m^2)	Hazard distances (m)			
	25mm	50mm	75mm	100mm
4	77	142.9	204.3	263.4
12.5	66.8	123.7	176.9	227.8
37.5	Not reached	Not reached	Not reached	Not reached

The second consequences from ammonia release is jet fire hazard distance which is computed for different thermal loads because as we understand in case of jet fire one has got to classify the thermal load in terms of 4, 4.5 and 37.5 kilo of the square meter which is very important categorization governed by the oil safety industry and directed. For different kinds of ruptures of 25, 50, 75 and 100 mm diameter we have found out hazard distances from the software depending upon the values has stated here in the temperature or for a given thermal load.

You can easily understand here for a larger thermal load concentration the hazard distances for even higher rupture as well as lower rupture is not reached at all. So that is why in literature you will see the reference value of thermal load computation is essentially taken as 12.5 and not 37.5kw per square meter, because influence of this radiation for larger distance now other distances even for larger up to diameter is not reachable at all.

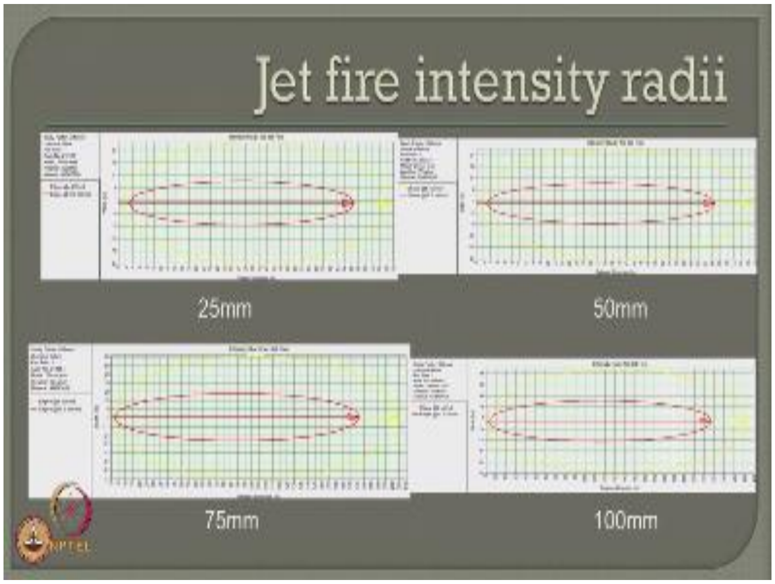
(Refer Slide Time: 21:37)



Similarly, for a jet fire one has found out the radiation versus distance for jet fire in terms of the download distance. You will see that influence of jet fire is high for larger diameter and smaller diameter rupture for a larger distance it means the significance of jet fire presents even the boreol rupture is small or larger is considerably there for over 80 meters in case of 80 meters here in this case is our 160 and is about 1200 meters.

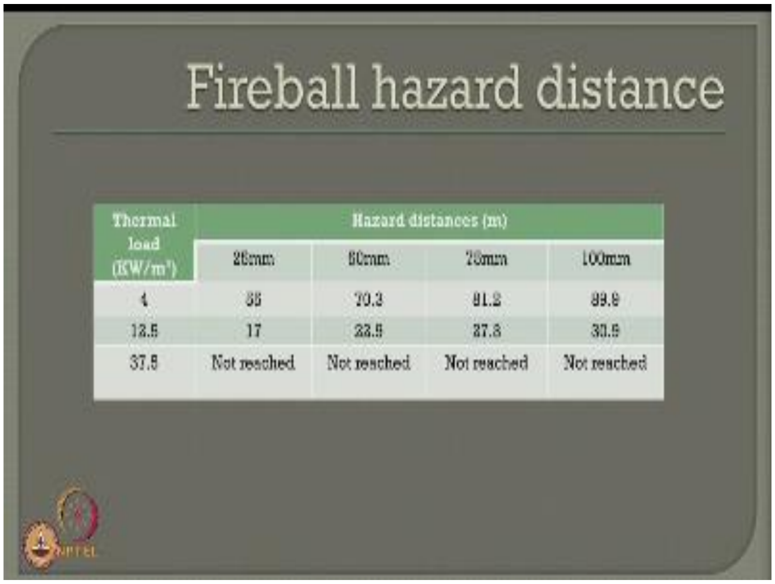
So as the diameter increases obviously one will notice that the influence of download distance of the jet fire is higher. However, one can notice compared to the discussion model in the last slide one can see here the jet fire influence is larger in terms of download distance caused by the radiation level compares still the discussion release what we had for different ruptures in the ammonia gas release.

(Refer Slide Time: 22:36)



One can also compute the jet fire intensity radii in terms of electrical intensities. The red one indicates the thermal load of 12.5kw per square meter, whereas the yellow will indicates radiate thermal intensity of 4kw per square meter from the epicenter of the problem for a given well velocity and for different ruptures varying from 25 to 100mm. You will see that as the diameter rupture increases the influence of the intensity radii object fire is very wide in terms of great release distance compared to the top is direction, compared to the top continue diameter rupture.

(Refer Slide Time: 23:20)



Thermal load (KW/m²)	Hazard distances (m)			
	25mm	50mm	75mm	100mm
4	55	70.3	81.2	89.9
12.5	17	23.5	27.8	30.9
37.5	Not reached	Not reached	Not reached	Not reached

The third consequence can be a fireball which can arise from ammonia release again the hazard distances for different thermal intensities for 4, 12.5, 37.5 are computed. As it can be seen from this table very clearly the higher thermal load intensity is not seen from influencing the hazard distances because they are not reachable at all.

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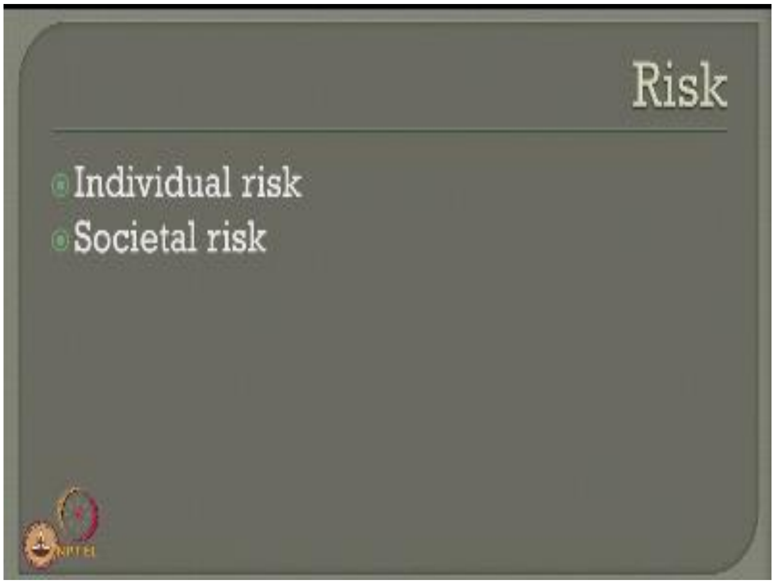
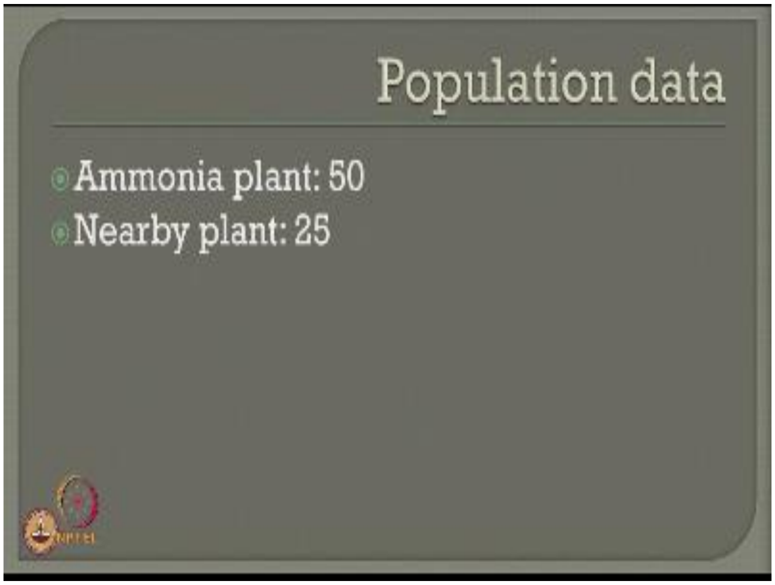
Based on the hazard identification done risk assessment is computed.

(Refer Slide Time: 23:48)



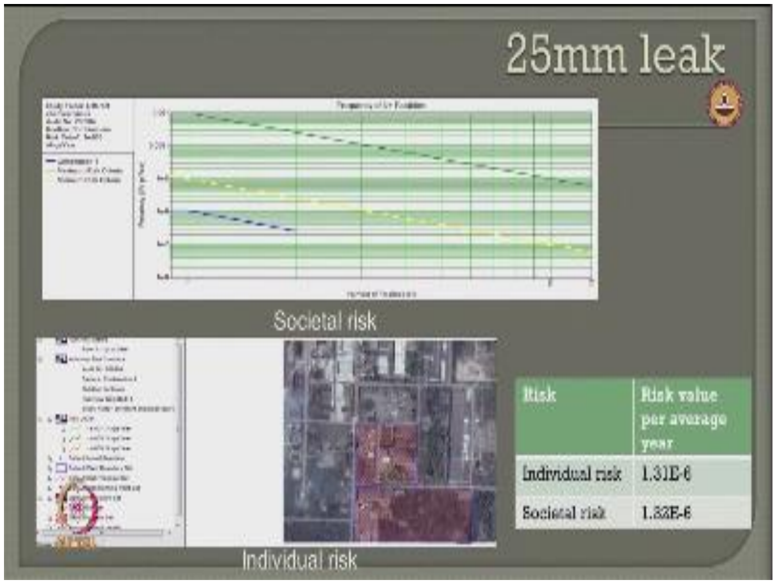
For both individual and societal risk.

(Refer Slide Time: 23:52)



To estimate the societal risk one has to have the population data, ammonia plant the population is estimated as 50, where the nearby plants the population is estimated as 25.

(Refer Slide Time: 24:04)



Then [indiscernible][00:24:05] are plotted for different leaks 25mm, 50, 75 and 100mm and for a different societal risk the contours are being plotted as you see here whereas the green one shows and risk level of 1 10^{-7} per average year, the red one shows 1 10^{-8} per average year, and the brown one shows 1 10^{-10} per average year as a risk level. Individual risk and societal risk for 25mm is being computed based upon their front curve as you see here as the values are 1.31 10^{-6} and 1.32 10^{-6}.

One can understand very clearly here that as far as societal risk a new risk is concerned for 25mm leak in case of ammonia release. The individual risk and societal risk in terms of estimates are almost similar for a given problem.

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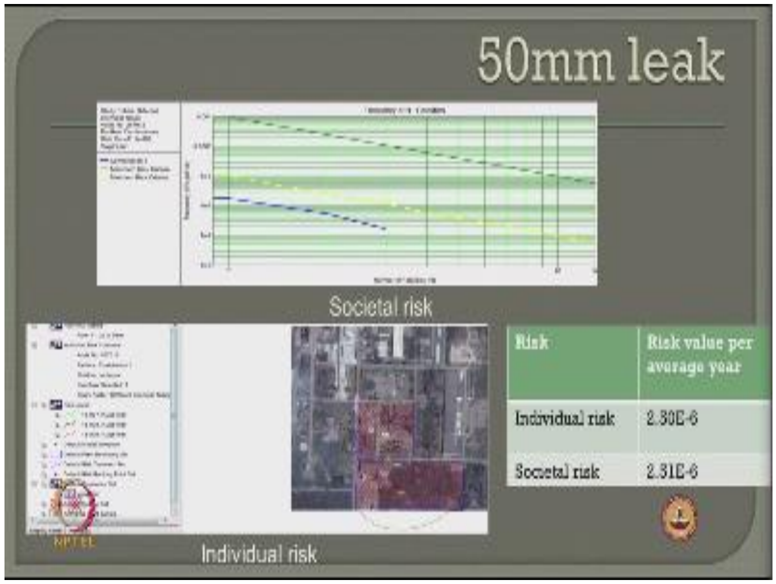
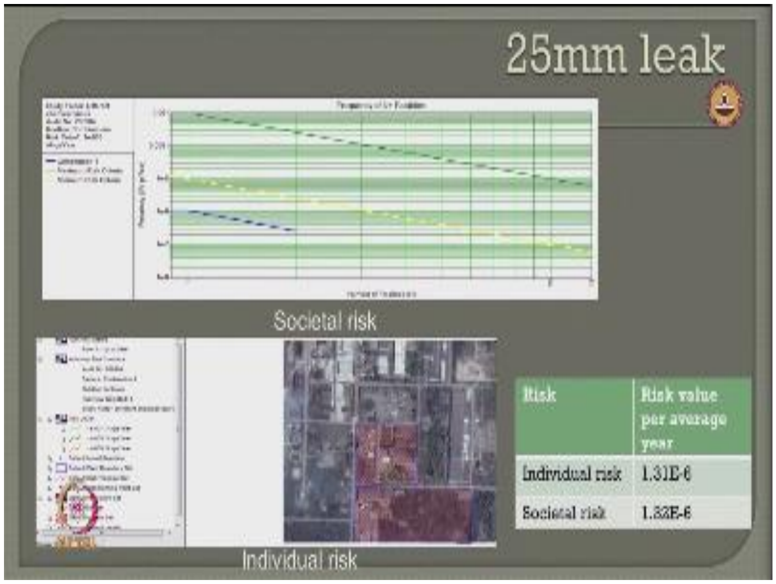


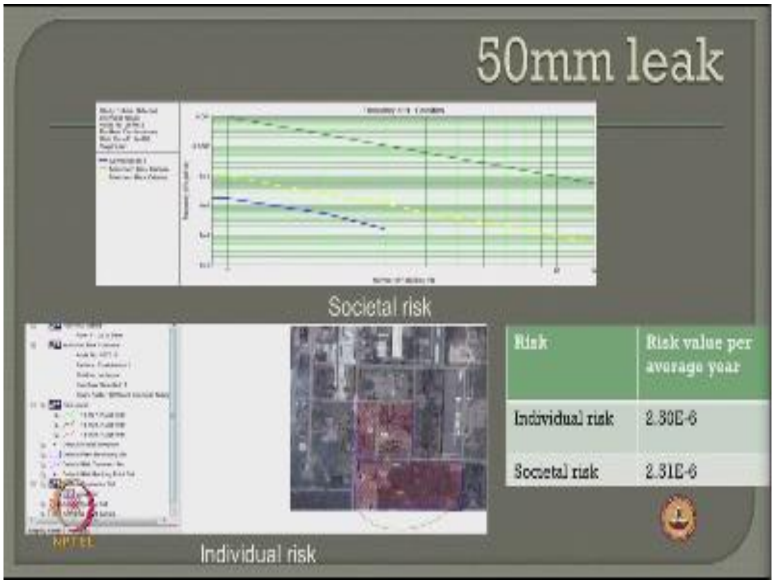
Same as we involved of 50mm leak you will see again the individual and societal risk does not differ much. However, the contour from the epicenter is enlarged you can see here the brown one compared to the previous one.

(Refer Slide Time: 25:12)



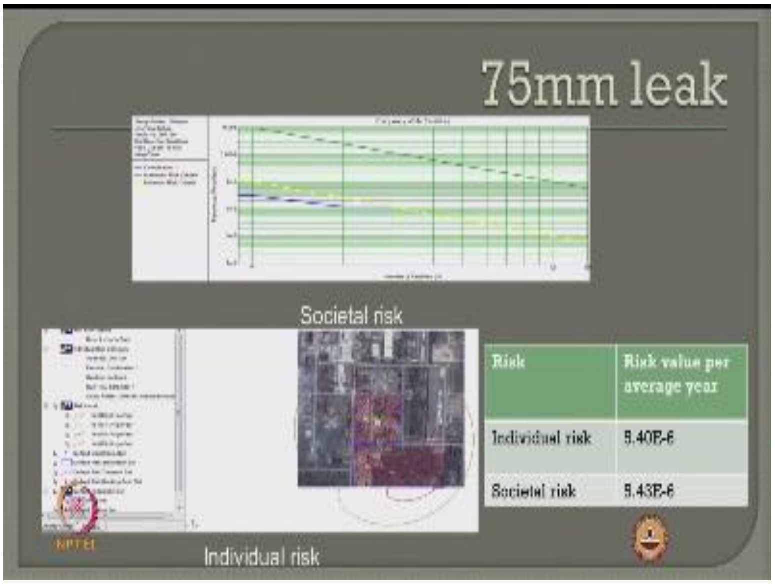
If you look at the previous one the intense radiations in terms of individual risk much lower from the epicenter.

(Refer Slide Time: 25:20)



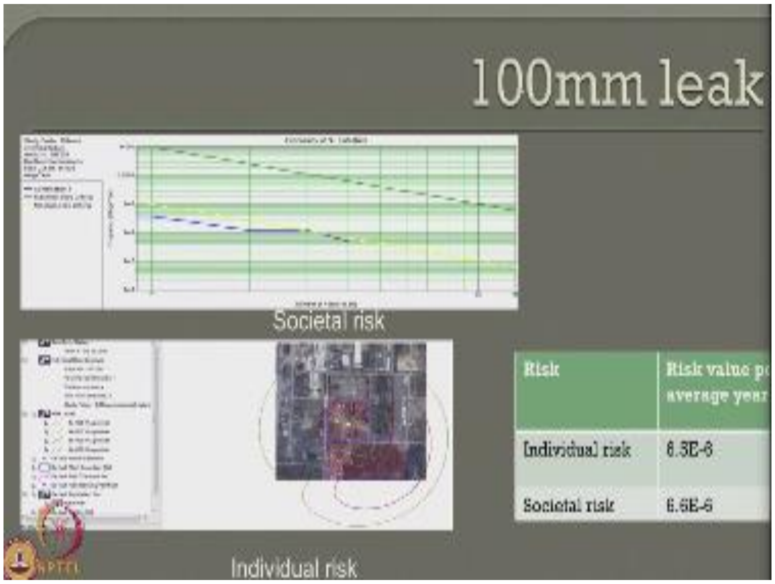
Whereas in this case is much higher as the leak diametric keeps on increasing you notice that the combination is also going to be changing the blue one indicates the combination of the present mixture, whereas the green one indicates the maximum risk criteria and the minimum risk criteria is given by the yellow one and you will see that 50mm leak it is lower than the minimum acceptable level of risk for oil and gas industries.

(Refer Slide Time: 25:46)



Similarly for 75mm leak release you will see the maximum and minimum are given as green and yellow, whereas the risk present in this specific case is blue which must be low rather than the yellow one which is acceptable risk level.

(Refer Slide Time: 26:01)



However for 100mm leak you will see that for a present scenario the congeal risk of the ammonia release is as close to the lower level it means it is in the border case. You will see compared to the previous case.

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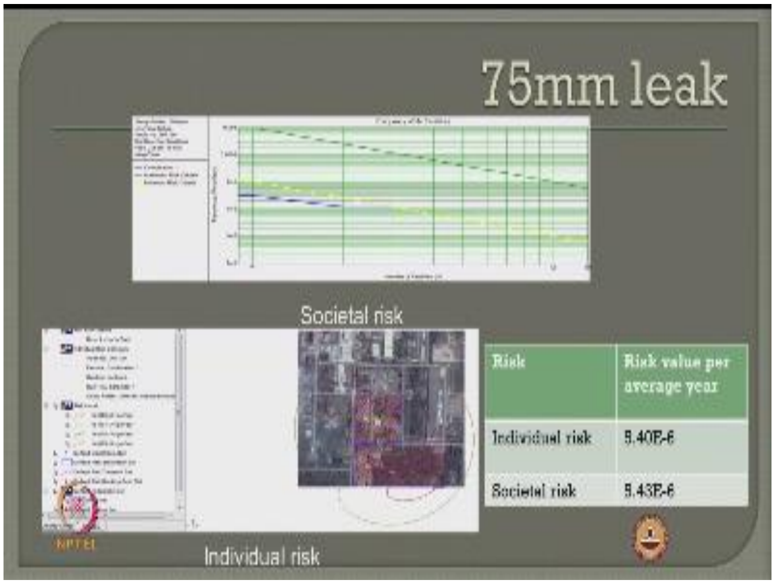

The previous case is much below the acceptable level.

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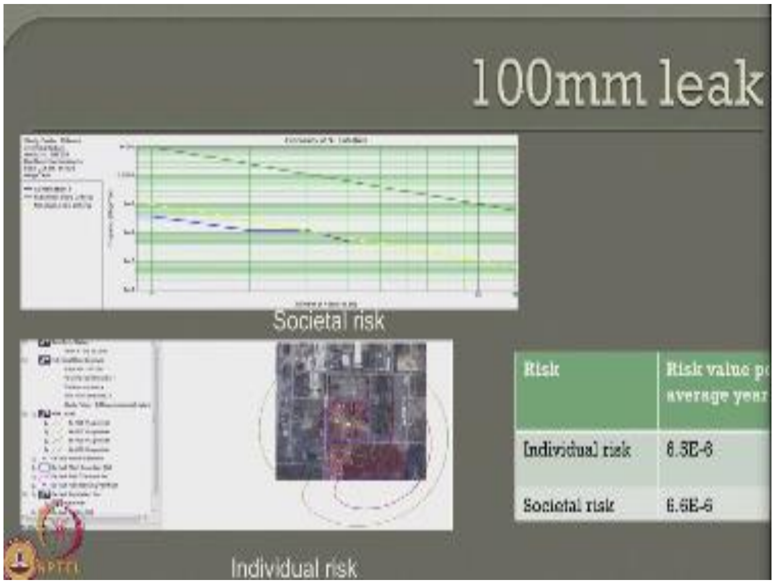

Whereas in this case it is touching the acceptable level for number of fatalities. So as the diameter will leak rupture releases increases you will see that the societal risk keeps on requiring more alarming.

(Refer Slide Time: 26:31)

Leak Diameter (mm)	Individual risk per average year	Societal risk per average year
25	1.31E-6	1.32E-6
50	2.50E-6	2.51E-6
75	5.40E-6	5.43E-6
100	6.5E-6	6.6E-6

Thus the risk values are compared individual and societal for different leak diameters as you see in this table.

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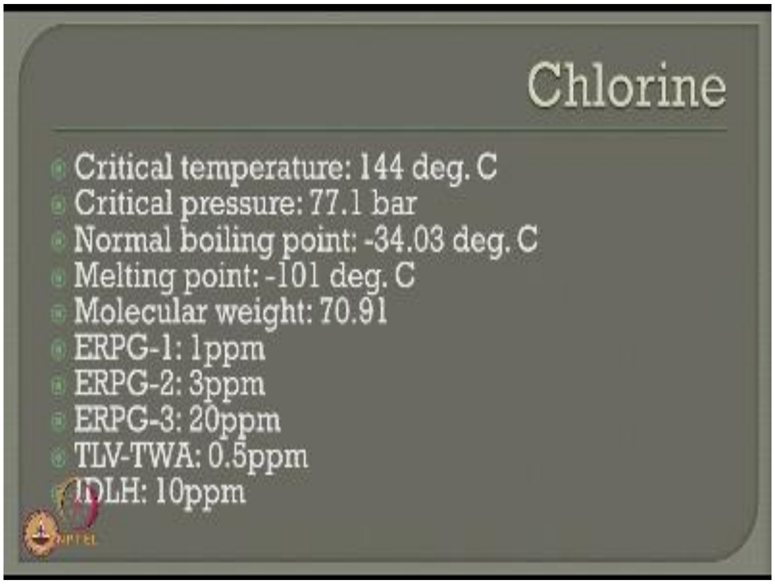
The next example now will be on chlorine release.

(Refer Slide Time: 26:45)



Chlorine of course has a critical temperature 144˚C, critical pressure is 77.1 bar, normal boiling point is -34.03˚C, melting point is -101˚C, molecular weight is 70.91, ERPG is 1:1 values are respectively 1, 3 and 20ppm. Friends please recollect time dated average of the lethal concentration of chlorine is about 0.5ppm and IDLH value for chlorine is about 10ppm.

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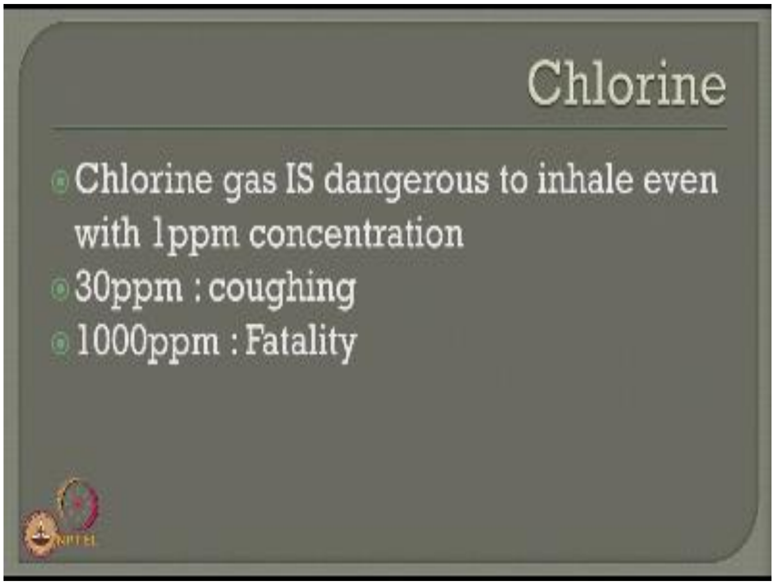

Chlorine gas is dangerous to inhale even with 1ppm concentration, 30ppm can result in coughing and 1000ppm will direct with the fatality immediately.

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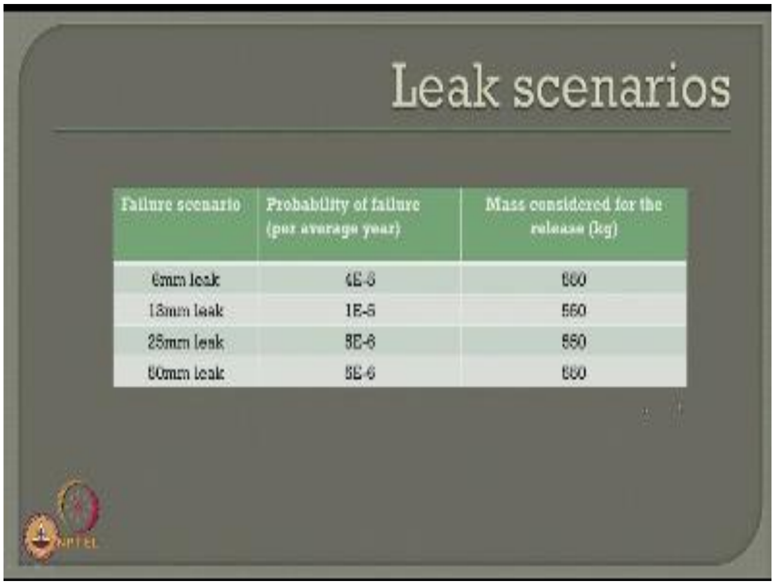
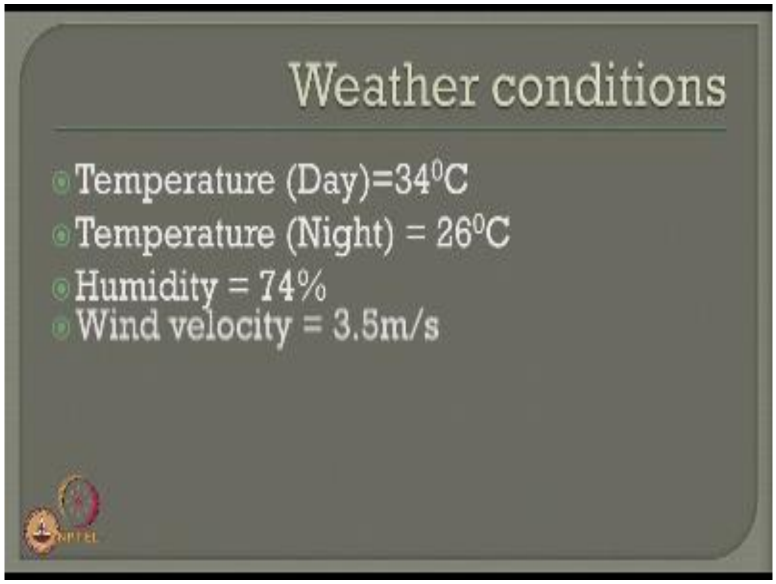
The case study is again picked up the location is masked again because of statistic reasons.

(Refer Slide Time: 27:42)



Now for chlorine release the leak scenarios are varying from 6 to 50mm as 6, 13 and 25 and 15 leak scenarios the probability of failure per average year is again worked out based upon the software calculations gives as an input. And the mass consider in almost say in all the leak scenarios is over 550kg.

(Refer Slide Time: 28:06)



Let us see what are the weather conditions used in this particular study. Temperature is over 34˚C, night temperature is 26˚C, humidity is 74%, wind velocity is 3.5m/s.

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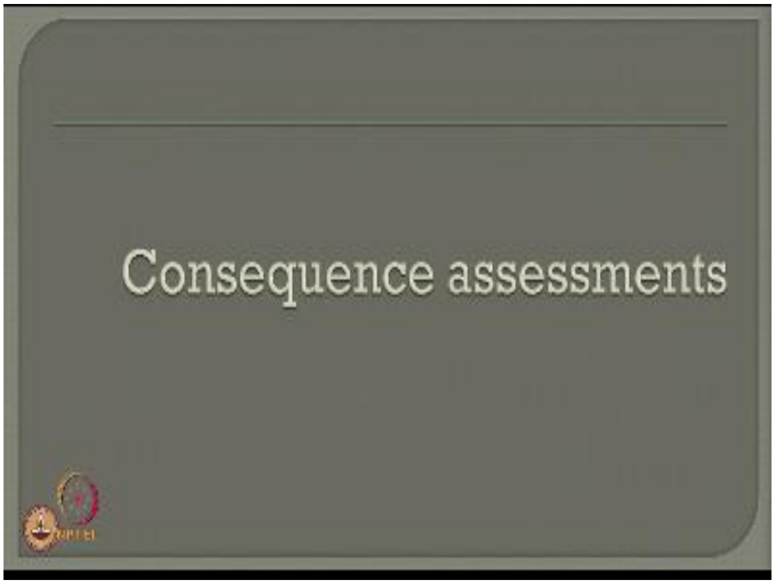
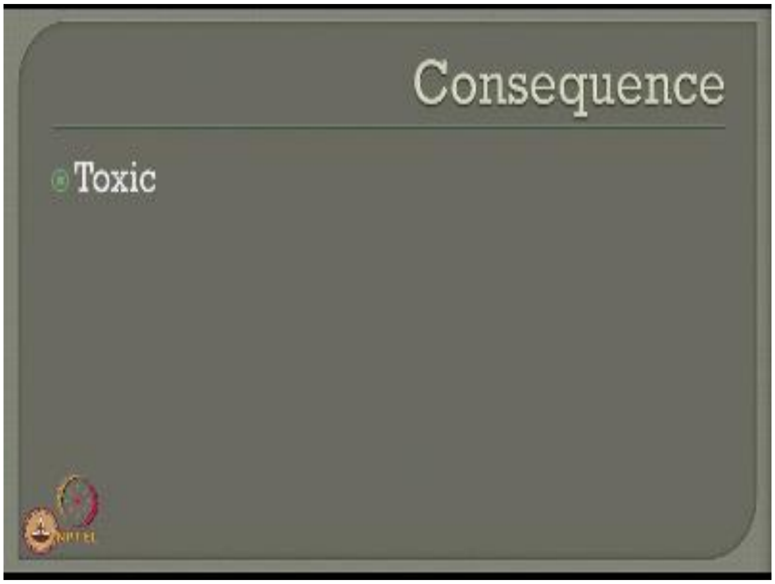


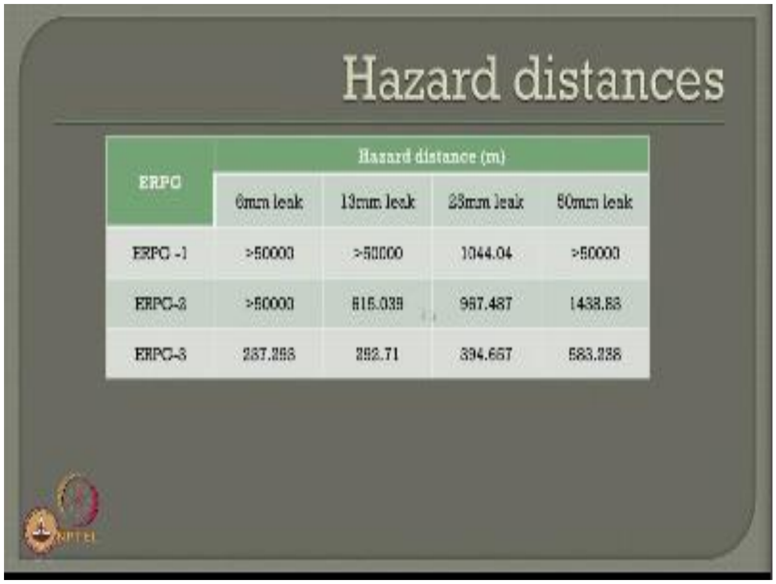
We have done consequence assessments for this particular problem.

(Refer Slide Time: 28:24)



The consequence arising from chlorine release can be toxic.

(Refer Slide Time: 28:27)



The hazard distances for different ERPG levels are worked out based upon the type of release varying from the rupture to 650m, we have discussed that the ERPG 1 is more than 50 kilometers, whereas for 25mm leak is about 1044.04 m. It varies depending upon the ERPG levels as we keep on increasing the ERPG level, you will see the hazard distance comes closer to 237 meters for 6mm leak, whereas 583 meters for a 50mm leak.

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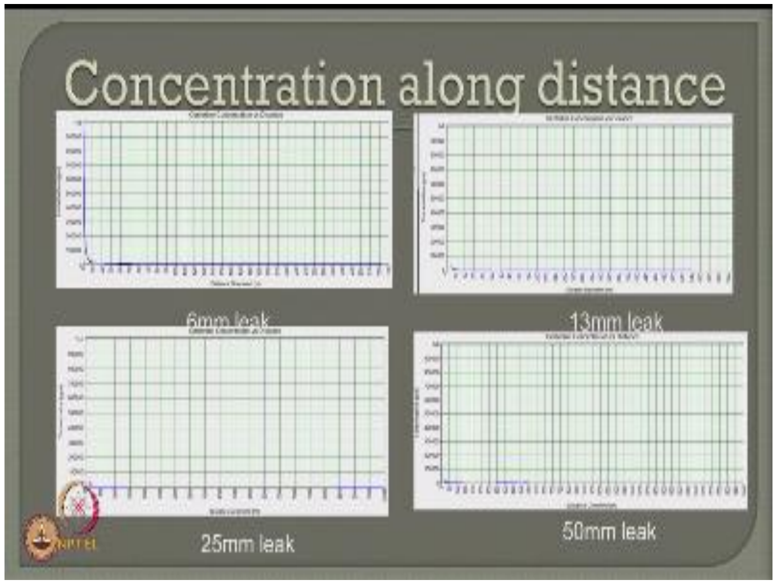
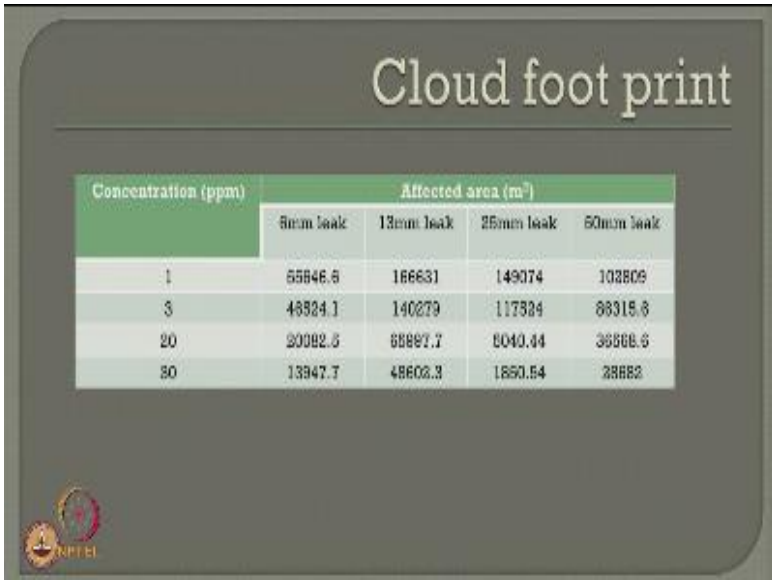


Let us now look at the concentration of release along the distance, we will see that the chlorine release unlike ammonia has got a spike at the initial concentration and subsequently the concentration of the release declines drastically for the downward distance which is true in all the cases of release 6mm, 13, 25 and 50mm respectively.

(Refer Slide Time: 29:27)



Concentration (ppm)	Affected area (m^2)			
	5mm leak	13mm leak	25mm leak	50mm leak
1	55846.6	166631	149074	102809
3	48524.1	140279	117524	88315.6
20	20082.5	65887.7	6040.44	36568.6
30	13947.7	48602.3	1850.54	28682

We also worked out the cloud foot print based upon the concentration in terms of 1 to 30 part familiar for different leak scenarios computing the affected area in terms of the square meter which is epicenter from the point of release in the given plant.

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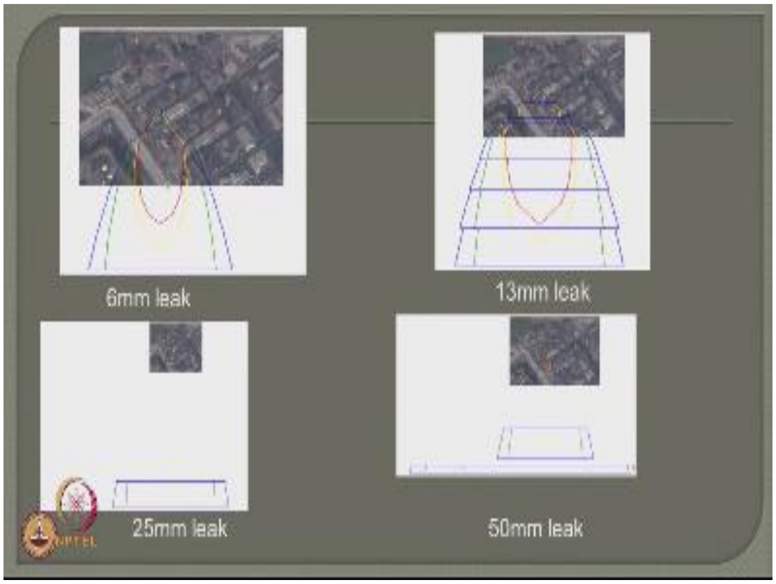
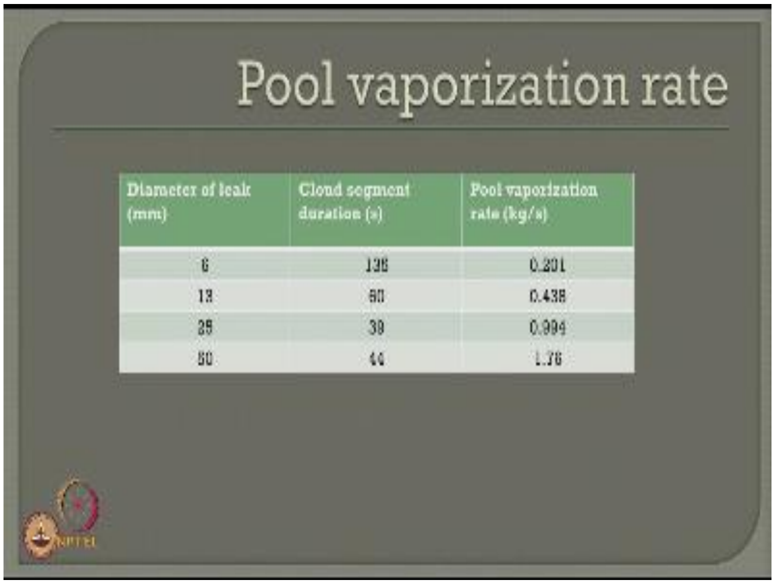


We have also plotted what we call as a cloud foot print depe3nding upon the point of observation for a different scenario as you see here.

(Refer Slide Time: 29:53)



Diameter of leak (mm)	Cloud segment duration (s)	Pool vaporization rate (kg/s)
6	135	0.201
13	60	0.438
25	38	0.994
50	44	1.76

We have also worked out pool vaporization rate depending upon the diameter of leak for a given cloud segment duration. The pool vaporization rate is given as kg/s as see in the presentation for different leak scenarios.

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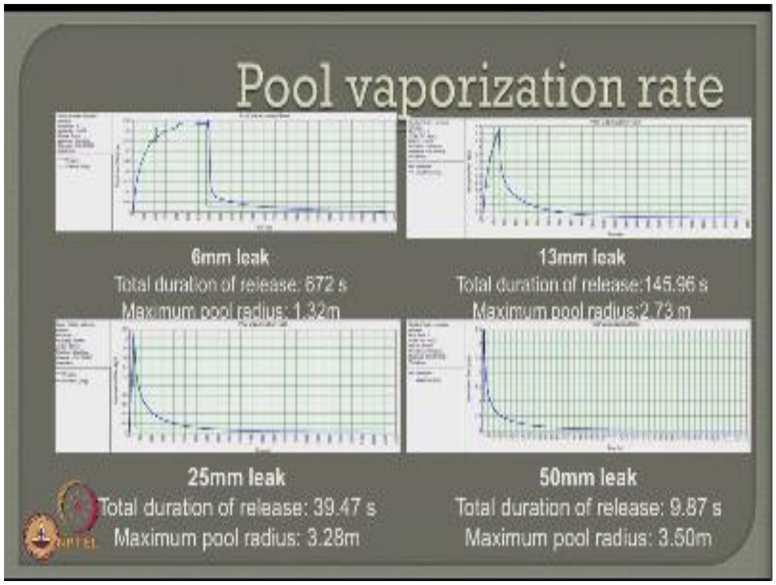
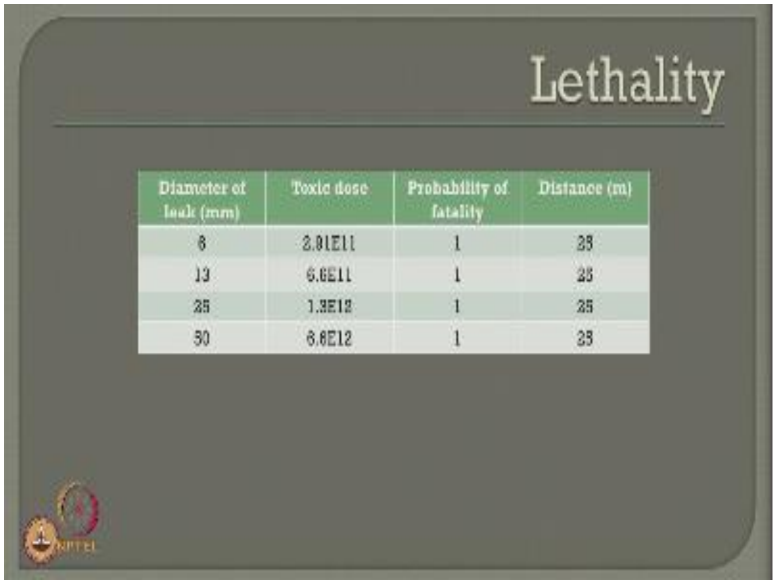


Based on this we have computed and plotted the pool vaporization for different leak scenarios the total duration is being computed from the software which is varying from 672 seconds to the as low as 9.87 seconds. You will see unfortunately that for a larger diameter leak release the vaporization is spiked and significantly decreases with respect to time.

However, for smaller leak release the vaporization spikes and sustains for sometime which is about 672 seconds and the pool diameter radius is about 132 meters whereas in case of larger release this pool radius increases to 3.5 meters. So the influence of the leak in terms of vaporization is spiked up and then declines respected time.

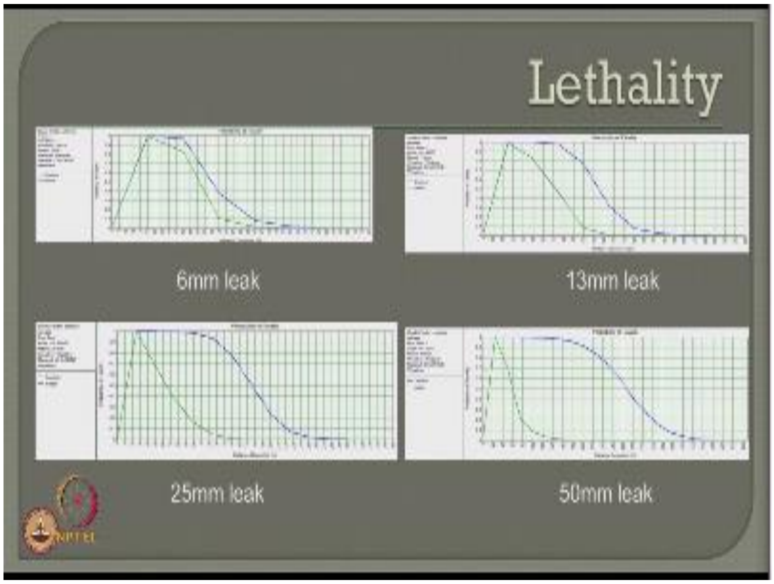
However, the pool radius increases respectively diameter of the leak rupture in terms of chlorine release gas.

(Refer Slide Time: 31:14)



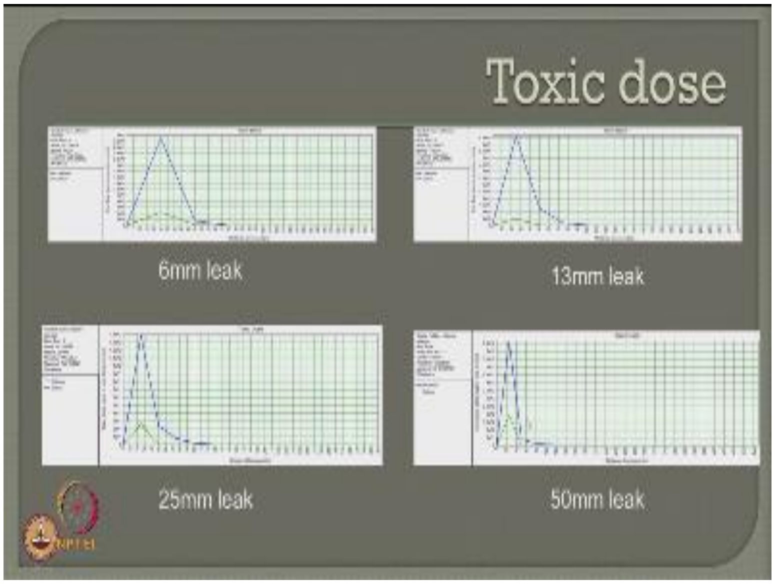
Lethality is also studied depending upon the diameter of leak for a given toxic dose, the probability of fatality is taken as 1 in this case and estimated distances are shown in the table now for a given toxic dose.

(Refer Slide Time: 31:28)



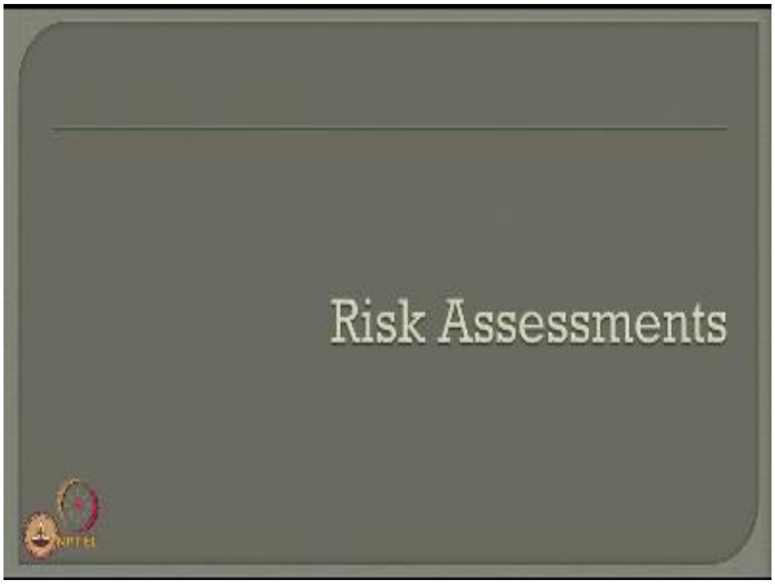
They have been also plotted for different types of release as you see here the plots available for both [indiscernible][00:31:33] unlike ammonia gas, you will see that as the diameter of the rupture increases the outdoor activity having larger influence on the distance downward compared to that of the indoor activity.

(Refer Slide Time: 31:29)



Toxic dose release is also done same way you will see that toxic doses keeps on influencing up to 50m or approximately 50 to 60 m which is case is common in all the four. Therefore, the diameter of rupture does not influence the toxic dose concentration in terms of distances. However, the toxic dose concentration value in terms of the exposure is higher for a different types of leak scenarios as seen in the plots here.

(Refer Slide Time: 32:23)



Based on this risk assessment is computed.

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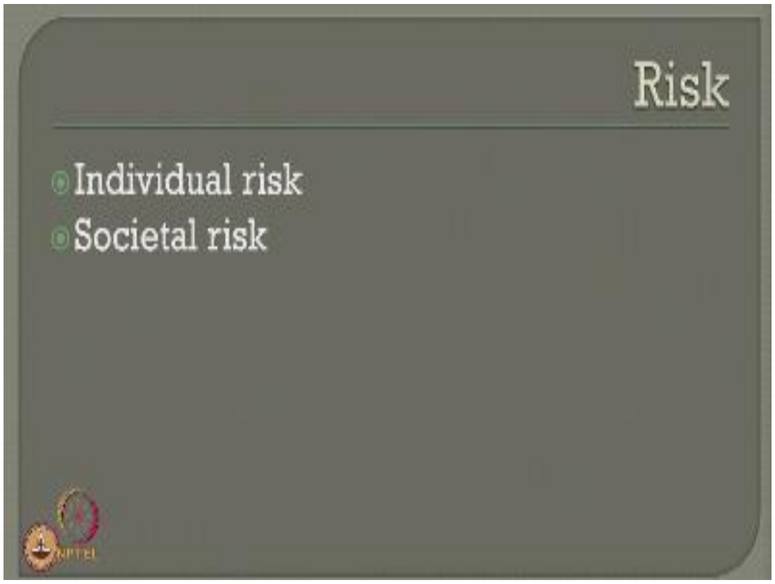

For both societal and individual risks for different leak scenarios.

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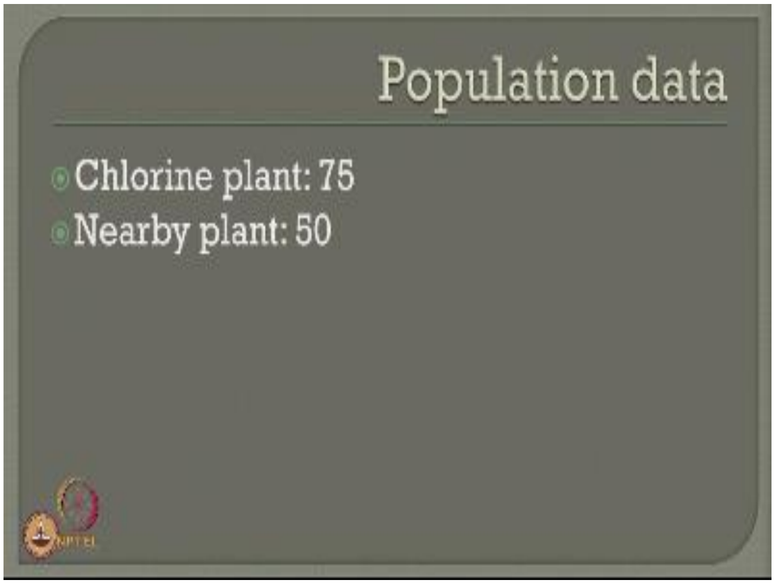

Population data is very important the plant is constitute of 75 people, whereas the nearby plant has got 50 people.

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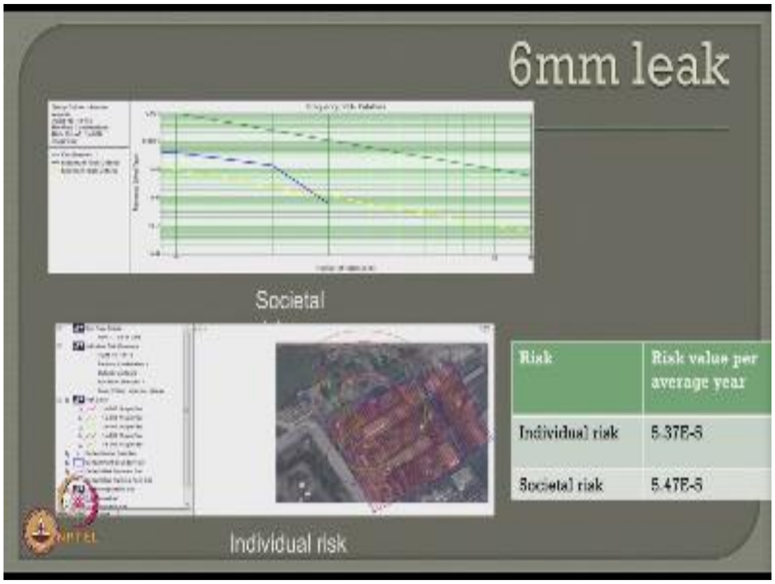

Now the leak scenario is 6mm, 14, 25 and 50mm considered and individual risk and societal risk are plotted. Individual risk is plotted in terms of the contours, societal risk is plotted in terms of the front curve as you see here the green one is a maximum and the yellow one is acceptable, whereas the blue one is a present combination, you will see that the blue one exceeds the minimum acceptable risk criteria even for 6mm leak release, because the risk value per average here is gone very high compared to the top of ammonia release.

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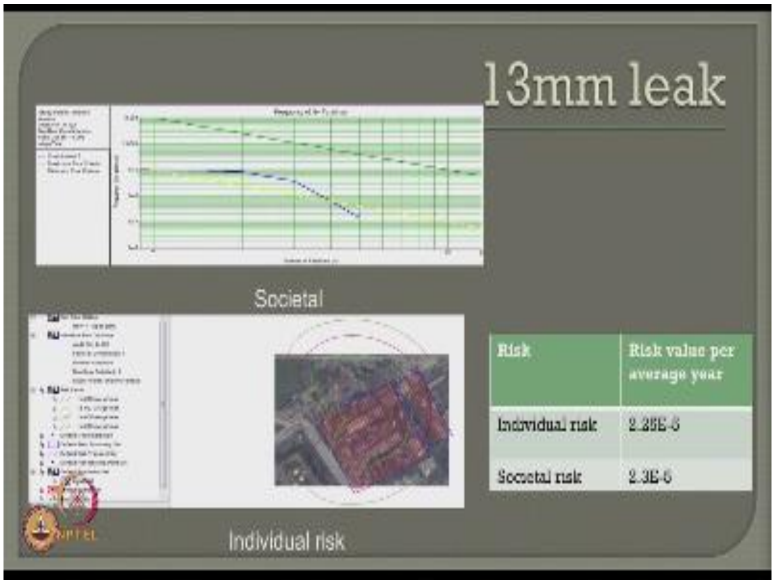
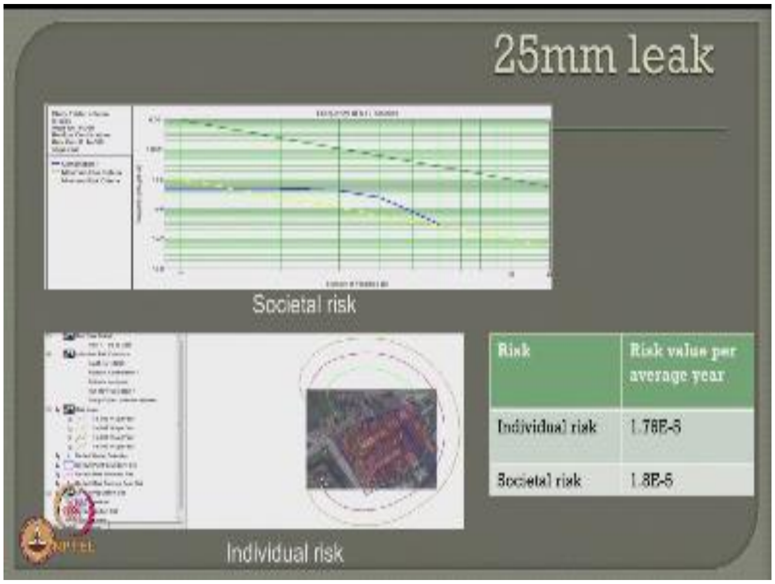


The same is 2 for 13mm leak.

(Refer Slide Time: 33:19)



For 25mm leak.

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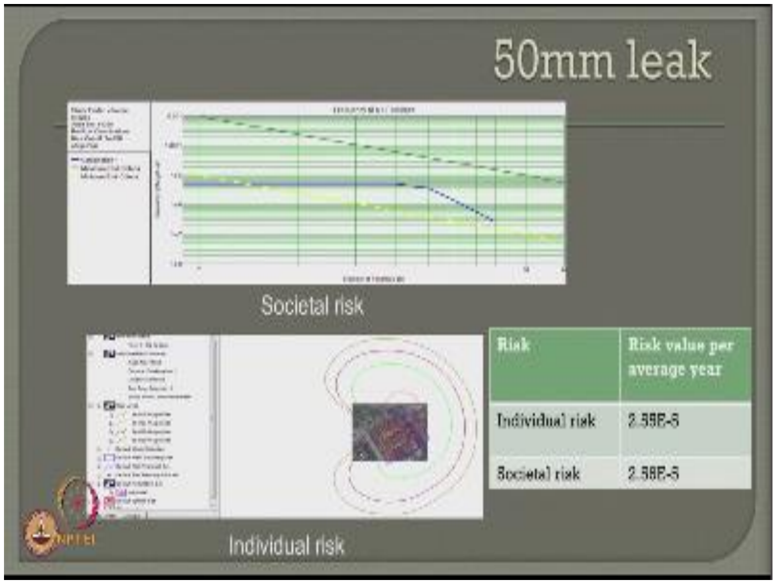

As well as 50mm leak respectively friends. You will always see that the risk of contour in terms of individual risk keeps on broadening for different risk levels as you see in this legend here depending upon the type of rupture which is being studied in the specific case.

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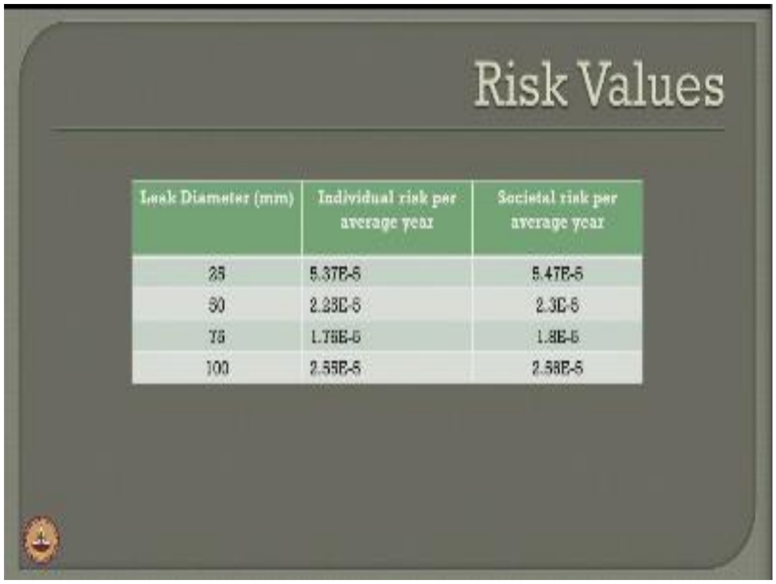

Based on this risk values are tabulated and summarized for different leak diameters. In this present study we have understood three release models, one is the pipeline failure depending upon the contents in the pipeline, second can be ammonia case failure, third can be chlorine release failure which gives you a clear picture how to do risk estimates for a given problem using a software, thank you very much.

(Refer Slide Time: 34:02)

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