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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 2: Chemical Exposure Index

Friends welcome to the second lecture on module 2 which is focused on accident modeling, risk assessment and management, in this lecture we will talk about chemical exposure index under the course of HSE in offshore and petroleum engineering which is being dealt at NPTEL IIT Madras.

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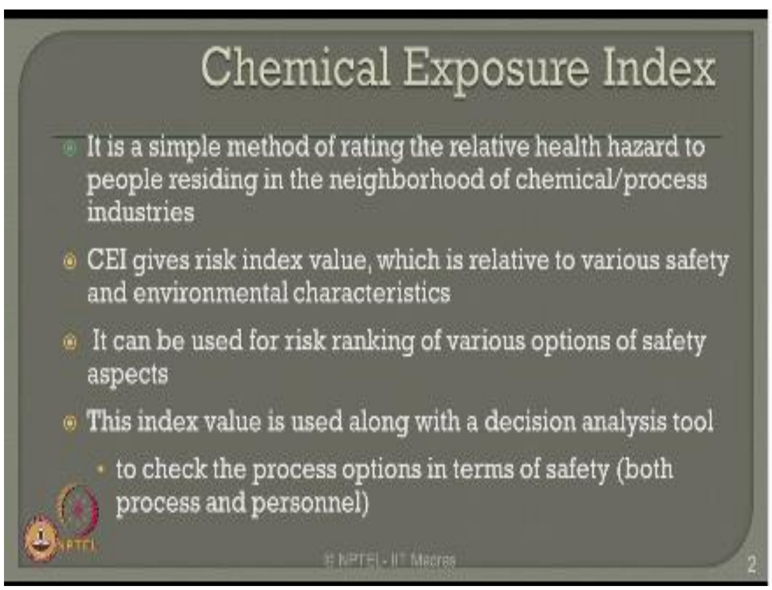

Chemical exposure index is a very simple method of rating the relative hazard to people residing in the neighborhood of chemical process industries, CEI abbreviated for chemical exposure index gives actually a risk index value which is relative to various safety and environmental characteristics of a given process industry, it can be used for risk ranking of various options of safety aspects in a process plant, nevertheless it can be applied to oil and gas industries as well.

This index value which is an outcome of CIE study is used along with the decision analysis tool it is very important the risk ranking which is derived as an outcome from the chemical exposure index cannot be applied because it is only applied locally to a given problem, know if you want take any decision based on the risk ranking derived from a chemical exposure index study then you have to apply addition analysis tool to check the process options in the terms of safety. Now the safety in this case is applicable to both personal and process.

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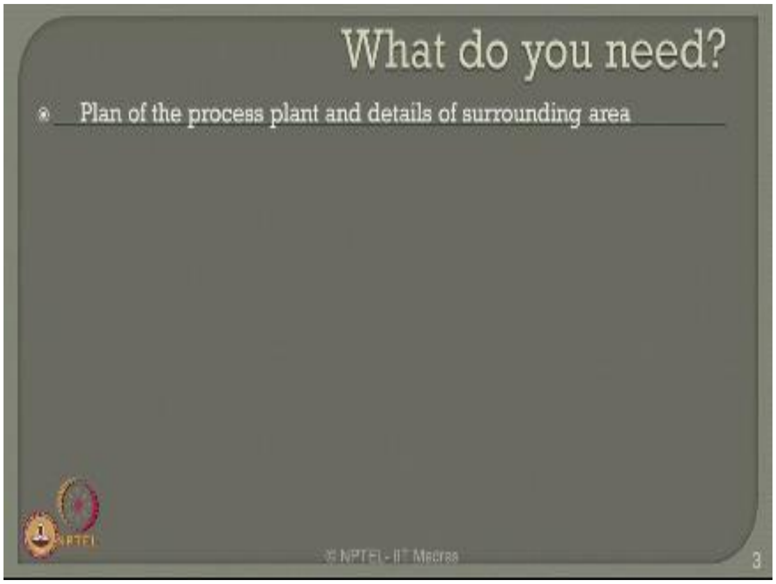

Now the question asked in mind is, to do a chemical risk analysis, what data do we require? The obvious should have the plan of the process plant and details of surrounding area because as I said chemical exposure index deals with the personal safety it also requires to arrive at the societal risk developed or imparted by the process plant in the neighborhood of the locality where the plant is situated.

Therefore we should have the complete job reveal details of the plant plus we should also have the climate weather conditions and the population of the surrounding area where the plant is situated.

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So you should have the detailed plan of the working process of the plant and also the details of other plants located in the surrounding area, obviously one should have the details of flow sheet which involves major piping in the process plant, containment vessels, chemical inventories which are located in the plant and also in the plant located in a neighborhood of the process industry.

We also have to look at the details of physical and chemical properties of the material which is being investigated, so there is chemical engineering handbook available in the open literature where the physical and chemical properties of various chemical inventories are available in a tabular form, most importantly friends one should also have something called ERPG values, ERPG stands for, emergency response Planning guide.

Which indicates an ERPG value associated with every chemical inventory which is applicable to any process plant, we should also follow the guidelines indicated by the chemical exposure index study and of course we are got to fill up what is called are the CI form which is standard format of reporting the chemical risk analysis of any process industry.

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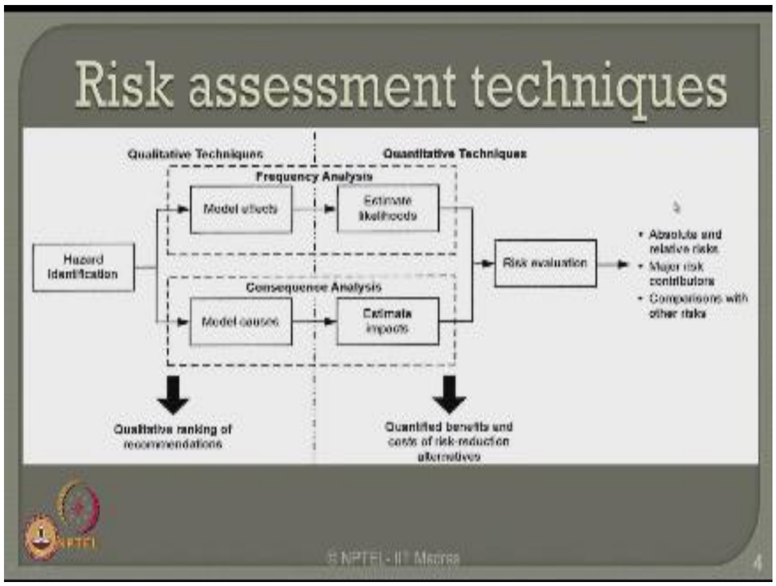

Before we look any detail of chemical risk analysis let us look at the way value of risk assessment techniques that are commonly practiced in offshore oil and gas industries, there are broadly two kinds of techniques which are practiced in oil and gas industry one is called qualitative other is called quantitative when you talk about frequency analysis you can also do the model effects and also estimate the likelihood of these effects.

You can also do something called consequence analysis which also gives the model causes and estimate impacts of these causes on the given body or on the given neighborhood both of them are techniques available which are essentially our allowed for identifying hazards in a given plant, friends we all remember that hazard is a situational scenario, so the identify hazard in a process industry is a most difficult task.

The fundamental reason being this is process changes at diverts under given operational temperature and pressure which cannot be expected unless otherwise that OTP is reached in a given plant. So to identify hazard in a given process while the processing operation is the most difficult task therefore people generally do either a frequency analysis or as a consequence analysis.

To estimate ultimately the risk, so one can see here hazard is getting materialized into a risk because you have effects and you have likelihoods which is frequency you have consequences so product of these two joined together will give you what is called risk evaluation. Now under this whole process there are certain segments which are qualitative there are certain segment of quantitative.

Now when we talk only about the model effects and model causes we address this as qualitative method that is why we call qualitative ranking of recommendations can be derived only from this, whereas when you look at the estimate of likelihoods and estimate of impacts which are reasons or end products of the cause and effects then one can also do the quantified benefits.

And cost of Risk Reduction alternatives because now you have a number by which you can do a risk ranking then you also know the cost justification towards this production effects which is otherwise an important factor in alert triangle. So the one when we talk about conversion of qualitative statements into a number.

We quantify them we call this as quantitative techniques therefore risk is a part of quantification of hazards whereas quantitatively also you can study hazards which is for example an HAZOP report. Now once you do a risk evaluation it will ultimately land up in absolute and relative risks of given departments are given process plants can also identify or rather one should be able to identify distinctly the major risk contributors in a given plant.

You should also be able to compare the contributors of the present risk of a given plant with that of the other risks which has been found in other plants or other segments of the plants. So risk evaluation gives an overall picture of the entire plant either the segment base of the plant or for the complete plant. So this will help people to really know where is or what are the factors or what are the common segments in the given process industry.

That contribute to the risk to the maximum, so if you really wanted to invest on Risk Reduction, risk mitigation or risk control etc then one should quantify them in terms of numbers. So one has interested in doing the risk analysis in detail hazard analysis will not help you to quantify or at least to find out the cost benefit of risk reduction methods if you do not quantify hazards into a risk forward.

Therefore both qualitative and quantitative or vital in an offshore industry, unfortunately both of them are adjectives as QRA, QRA can be addressed as qualitative risk analysis or quantitative, the moment they say risk analysis please understand it is always quantified, therefore if you see a literature talks about QRA it is very clear since RA refers to risk analysis the long Q refers and off to obviously refer to quantitative methods only.

That risk is quantification of Hazard please understand risk will try to give you a number which service called risk ranking which is very beneficial to identify the risk characterization locally and globally for the entire plant.

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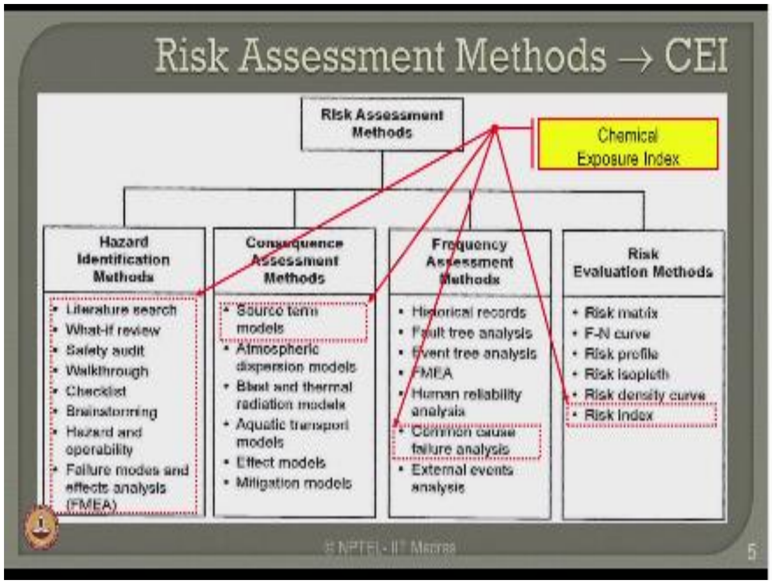

Once we understand risk methods or quantification of hazards then let us see what are the common methods of risk assessments and where chemical exposure index method do you like in these differences, if you talk about hazard identification methods one can do literature survey, one can do what if analysis, one can also perform safety audits, you can also conduct what is called walk through survey and prepare a checklist.

Or you can conduct a brainstorming workshop to identify the hazards present in a given plant of course more advantageously one can do HAZOP study and FMEA studies which we have seen in the previous module with examples in detail, all of them are called hazard identification methods however all of them mostly or qualitative but FMEA is converting a qualitative statement into a quantification by what is called risk priority number.

The moment the risk is associated in any study please understand it is getting quantified, followed by which the other method of risk assessment is consequent assessment methods we can also do a source term modeling, atmospheric dispersion modeling, blast and thermal radiation modeling, atomic transport modeling, effect models and mitigation methods available for modeling, all these when we talk about the consequence of a given source of an hazard, consequence alone will not help us we should also know what is the frequency of assessment one can do historical records, one can do fault tree and even Tree analysis, one can also do an FMEA please understand in frequency assessment methods which is getting quantified slowly.

FMEA which was an hazard method is also available in FAM that is frequency assess methods which is quantified, external event analysis can also be performed to do a frequency assessment methods, ultimately when you have the consequences when you have the frequency one can result in what is called risk evaluation which is an FM curve, development of risk matrix which we already saw.

Risk profile, risk isoflex, development of risk density curve and ultimately calculating risk index. So if you look at different methods of evaluation of risk assessment in terms of hazard identification, consequence assessment, frequency assessment and risk evaluation the one which is red bordered here are all part of chemical exposure index, so chemical exposure index do detailed hazard identification of a given process.

Pickup the source term modeling for consequence identify the common causes for the failure in a given system then ultimately land up in deriving what is called risk index or ERPG, therefore chemical exposure index is a quantified method of risk assessment which gives me ultimately a number based on which the risk ranking of the given process segments or the whole plant can be done.

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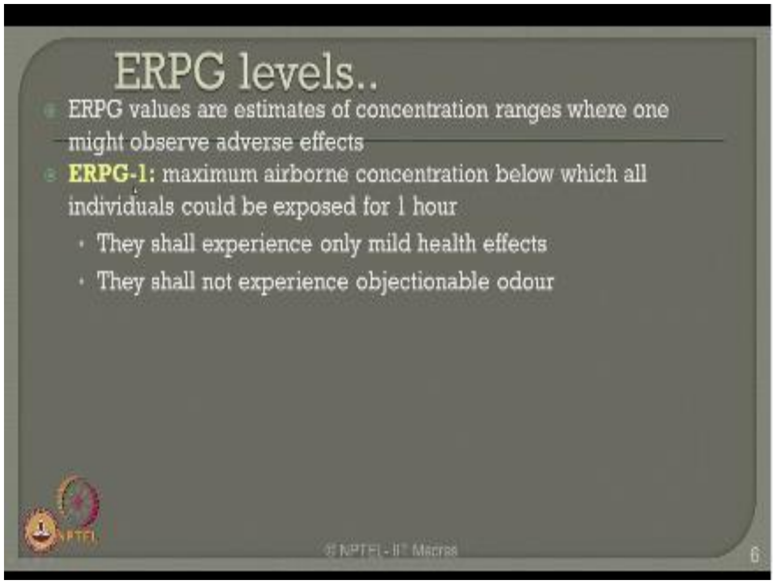

As I said chemical express index which is one of the quantified risk assessment methods which deals with chemical risk analysis the vital part of chemical risk analysis is ERPG emergency response planning guide it talks about different levels of emergency response planning, let us see what are these levels, ERPG values are estimates of concentration ranges where one might observe adverse effects of chemical or biological organisms.

ERPG level one is a maximum airborne concentration below which all individuals could be exposed to that concentration for a period of 1 hour, they shall experience only mild health effects they will not experience even objectionable odour, on the other hand friends please understand ERPG level is trying to quantify the concentration of the chemical for a specific duration of exposure for a period of let us say maximum of 1 hour.

And a consequence of this expression on the biological organism should not deal to mild or serious health effects should not even cause objectionable odour. So one thing easily realize that a chemical disposed environment with a very moderate or very mild concentration which will not cause serious health effects which will not even result in objectionable odour is what is called as ERPG level 1.

Provided the human being are biological organisms are exposed to that mild concentration which is airborne only for a maximum period of 1 hour. So please understand friends when you declare ERPG concentration levels.

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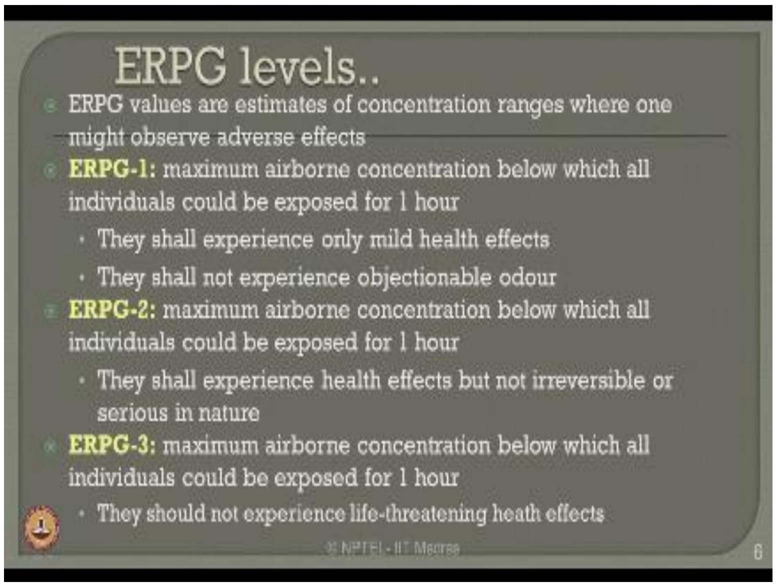

There are two important things here, one is a concentration itself second is duration of exposure and third important hidden in agenda in declaring ERPG level is, what is the consequence effects of this exposure and biological organism, if the exposure does not cause serious health effects does not even cause objectionable odour we can call that level of concentration as ERPG level 1. So for every chemical ERPG level 1concentration in parts per million or milligram per cubic meter is available in the standard data book of chemical engineering.

Similarly ERPG level 2 talks about maximum airborne concentration below which all individuals can be exposed to 1 hour but these individuals will experience health effects but are not irreversible or serious in nature. So they will undergo or experience certain serious health effects but they are not very serious in nature, so ERPG level 1, level 2 as well as the level 3 all the three ERPG levels only talk about the maximum airborne concentration.

Please understand chemical exposure analysis which deals with ERPG does not talk about concentration in water body, it is only on airborne concentration it means is a chemical is released in atmosphere when the chemical release becomes airborne what is that maximum concentration which will not cause serious health effects which will not result in irreversible effects which will not resultant in life threatening effects and to the maximum duration of exposure is 1 hour in all the three cases.

For all ERPG levels are 1, 2 and 3 the maximum permissible exposure to this concentration is only 1 hour. So this is common in all the three which is not common in all the three is the effect of this concentration on the human being for example ERPG level 1 does not cause even objectionable odour, ERPG level 2 will not cause irreversible effects. Whereas ERPG 3 will result in life-threatening health effects.

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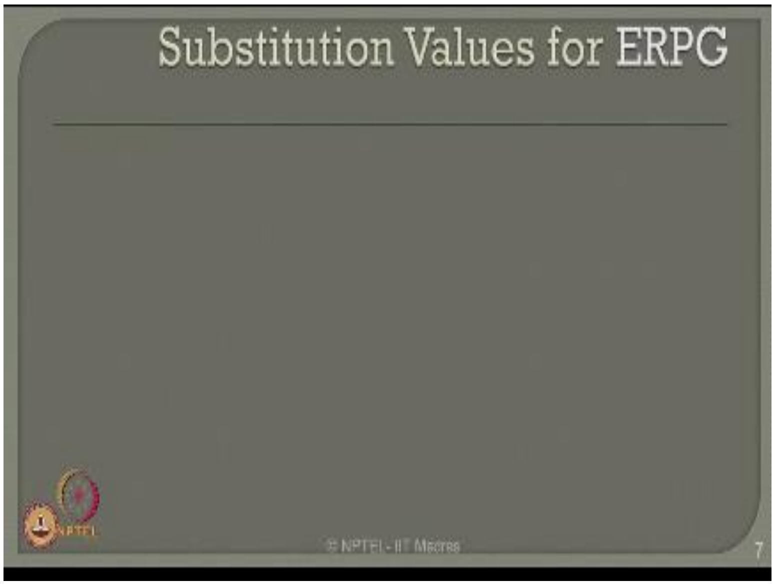

If it do not ERPG values for the giving chemical concentration in the chemical engineering handbook then there are substitution values available for ERPG also, when established ERPG values do not exist.

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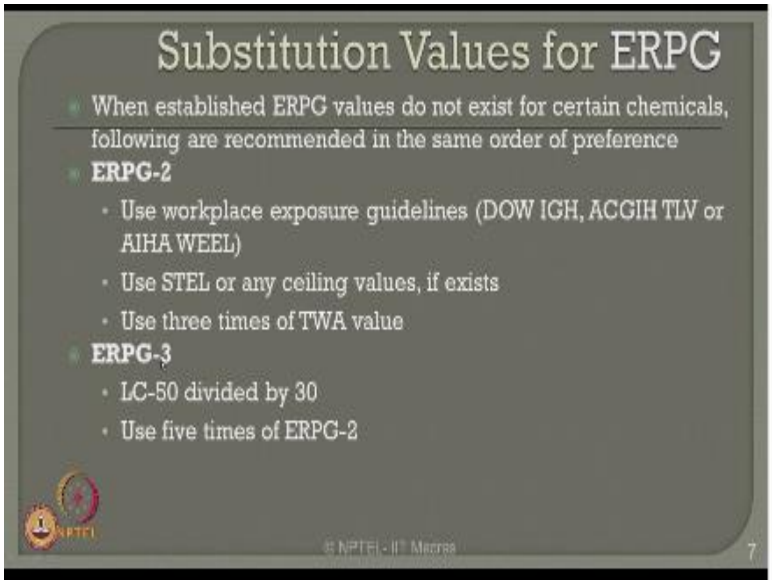

For certain chemicals following values are recommended in the same order of preference, instead of ERPG 2 you can use workplace exposure guidelines given by Dow IGH, ACGIH TLV or AIHA WHEEL other ways alternately one can use still which we already seen in the previous lecture of any ceiling value if it exists for the chemical or ultimately on alternatively you can use three times of time weighted average of the chemical concentration in place of ERPG 2 values.

For ERPG 3 can also look form little concentration 50 value of the chemical divided by a number simply 30, alternatively if you have ERPG 2 value for a given chemical concentration multiplied with value by five times you can take that as an ERPG 3 value, remember ERPG level 1 is a mildest concentration, ERPG 3 is a maximum concentration which will cause health effects which you can see from this slide.

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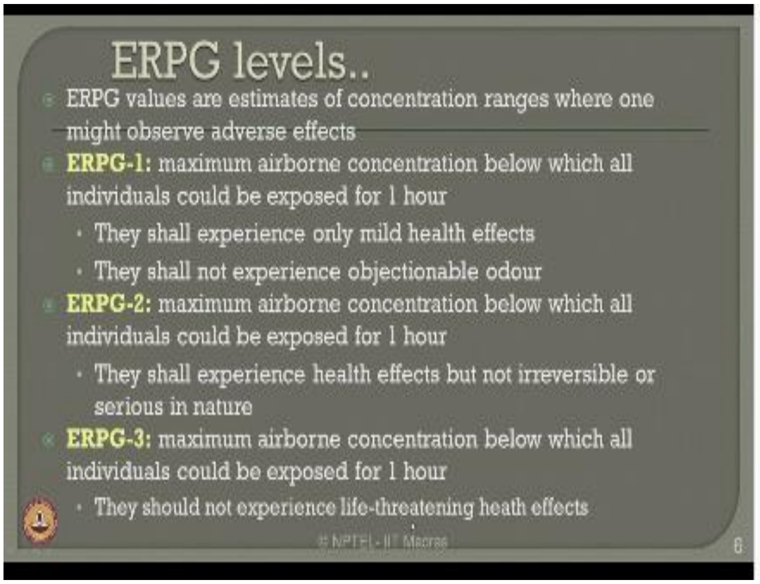

ERPG 1 is a mildest concentration because it cannot even have an objectionable odor, ERPG 3 can result in threatening health effects.

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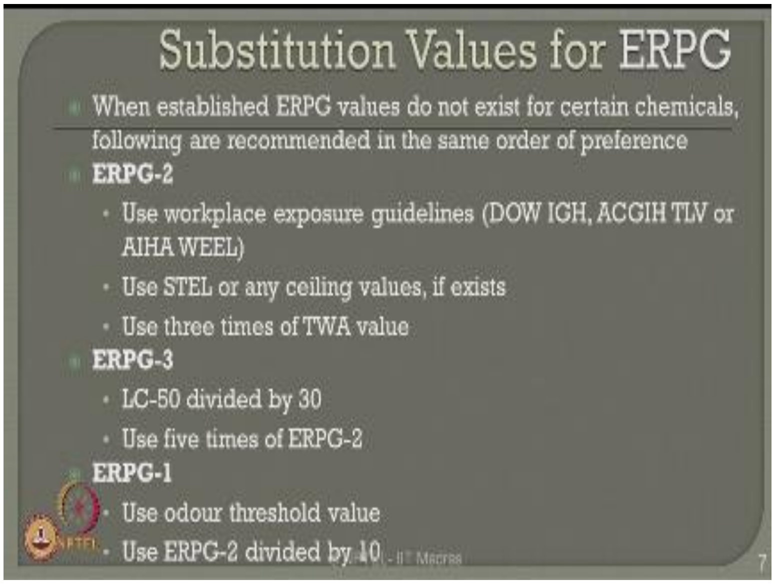

So here ERPG value is simply five times of that of approximately ERPG 2 value if ERPG 2 and ERPG 3 values are not available for a given chemical in the chemical engineering handbook, if you really wanted to find ERPG 1 value equivalency then you can use older threshold value or take ERPG 2 value from the literature below hat value by 10, so mild medium and severe, so why I am putting them in this order is.

This is how OSHA recommends substitution of values of ERPG for given chemical concentration if it is not available readily in the literature. Now let us see what are the different scenarios which we must estimate for the chemical risk analysis.

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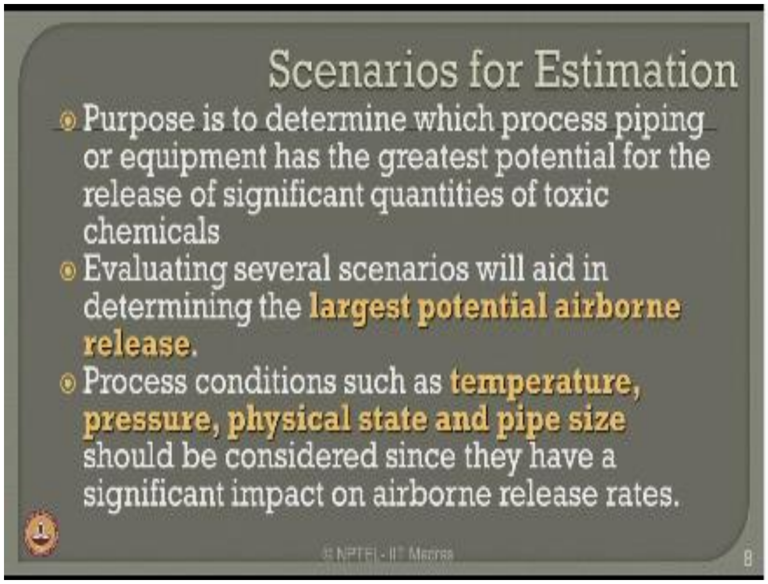

The very objective of doing chemical risk analysis is to determine which process piping or equipment has the greatest potential for release of significant quantities of toxic chemicals, we are interested in estimating the maximum release of chemical of or a toxic chemical in the airborne situation. So one should result in evaluating several scenarios where to compare them the chair gives me the maximum highest potential of release that should be considered for the scenario.

So evaluating several scenario swill aid in determining the largest potential airborne release, remember in chemical release analysis we speak only about airborne release of chemicals, process conditions such as temperature, pressure, physical state and pipe size are very important they should be considered as an important data or input for chemical exposure index because they have a significant impact on the airborne release rates.

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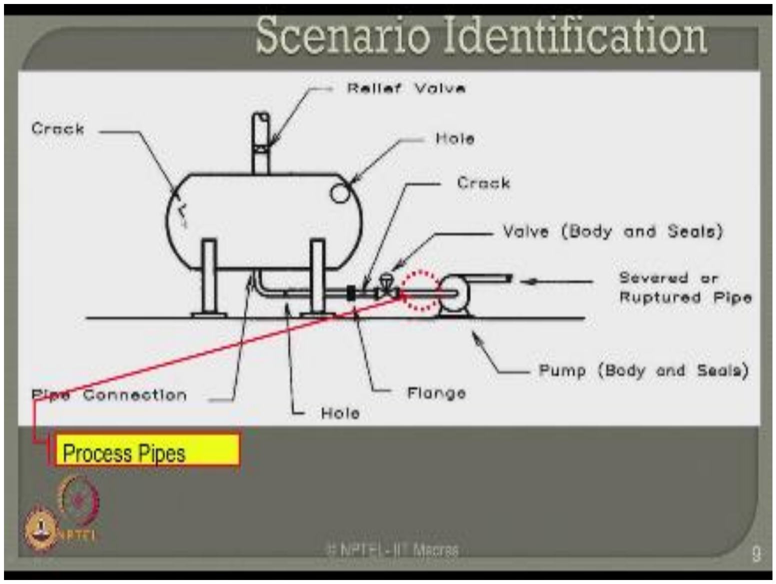

Whereas for example look at the scenario identification of the picture shown in the slide now, let us say there is a bullet which may have a hole for discharge which may develop a crack even on the bullet itself or the crack can be on another pipe line of the valves. Now this is not took on the process pipeline there can be a scenario where the process pipeline can rupture, for example this is a pipe connection which is taken away from the bullet.

This is the hole which is being used to draw or discharge or given diversification to the pipeline, this a flange connection which connects the primary a principal pipeline to the further process pipeline and there is a pump which actually pumps this chemical of this liquid further to any tank or anything, so one can see here this can be a ruptured pipeline the valve can be ruptured or cracked, the pipeline can rupture.

The whole can also release chemicals the relief for may not work properly or the entire bullet can also develop a crack or a physio because of over temperature and pressure present inside the bullet by the chemical.

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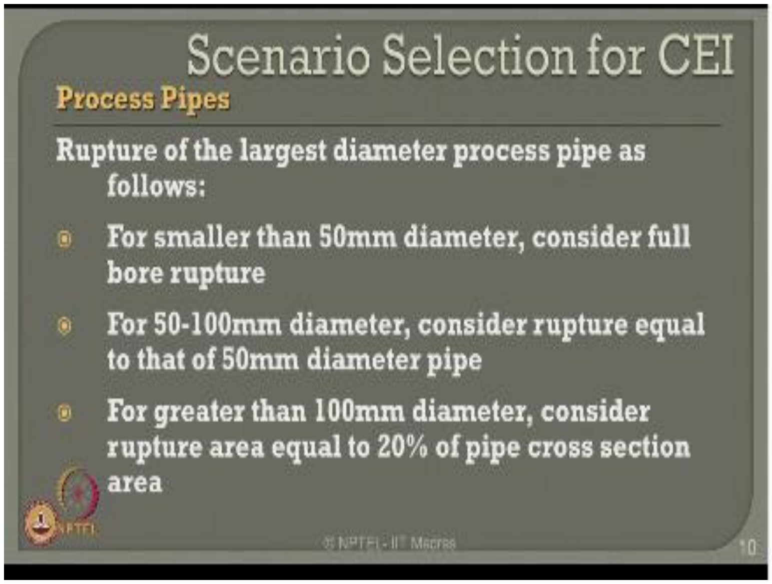

Now to given complexity of different scenarios what scenario should I select for a chemical exposure index study, if you talk about process pipelines is generally understood that rupture of the largest pipeline in a given process should be considered, first smaller than 50 mm diameter you must consider that the full pipe Bore is ruptured, for a diameter the pipeline varying from 50 to 100 mm.

You can consider rupture equal to that of 50 mm diameter pipe, for greater than 100 mm diameter pipe constitute a ruptured area equal to 20% of the pipe cross section area. So these are recommended by chemical exposure index study for conducting different scenarios in a given selection of CEI.

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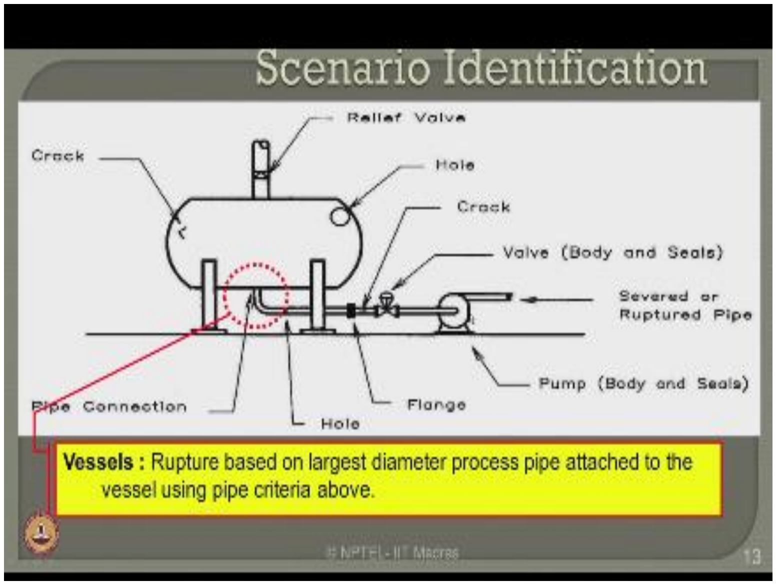

So the same picture back again, so one can now think of different scenario identification since the pipeline is now having a different diameter may be less than 50, 50 – 100, no the 100 mm different scenario can be now justified for doing the pipeline study, it can be full bore rupture, it can be a pressure relief valve device which is directly connected to the atmosphere you can calculate the total release rate at sit pressure and temperature.

All materials released is assumed to be 100% airborne because it is directly connected to the environment, the third scenario can be a vessel can rupture the rupture based on the largest diameter pipe process attached to the vessel is to be considered for the criteria. So for a given problem pipeline rupture the vessel rupture or the relief valve rupture can be different distinctly different scenarios for calculating Or identifying the chemical exposure index.

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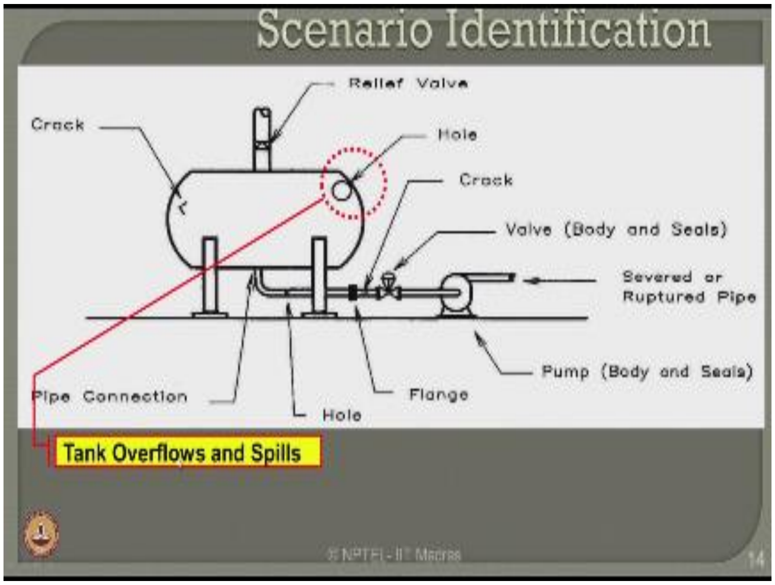

The fourth in the last can be your whole it is also a rupture from the vessel where through the tank and overflow and spill.

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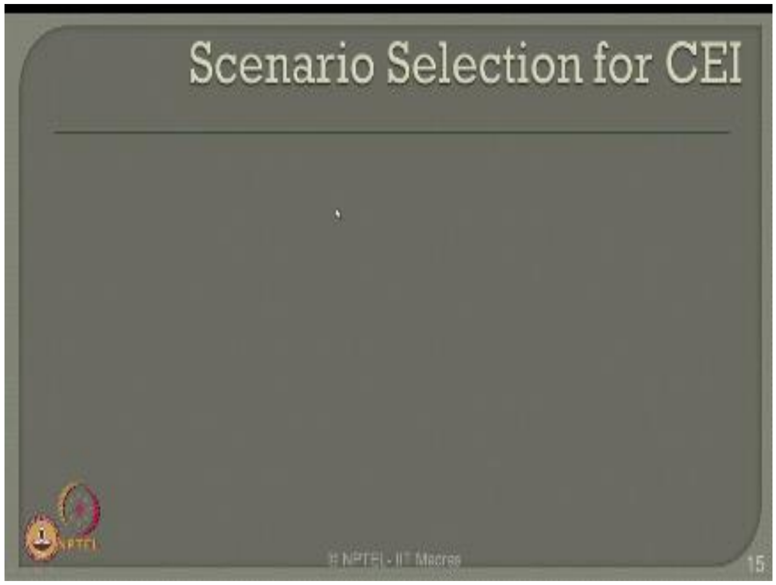

Once we know there are possible complexities of selection of scenario for chemical index study let us also see what are other scenarios percent.

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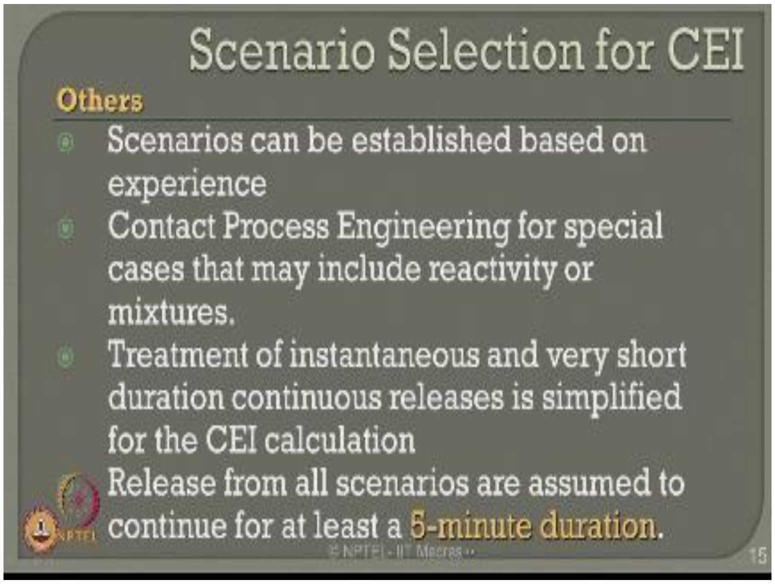

The scenarios can be established based on experience, the contact process engineering for special cases can also be identified because it can include reactivity or mixture of chemicals based on which the chemical can release or become airborne, treatment of instantaneous and very short duration continuous releases is simplified for the CEI calculation, release from all scenarios dear friends please know that are assumed to be continued only atleast for a period of five minutes duration.

So after five minutes it is considered that some fire factoring some emergency response methods will be available in the plant which will try to mitigate or at least reduce or control this release to a larger extent, so generally the scenario assumed to be at least for a five minute duration.

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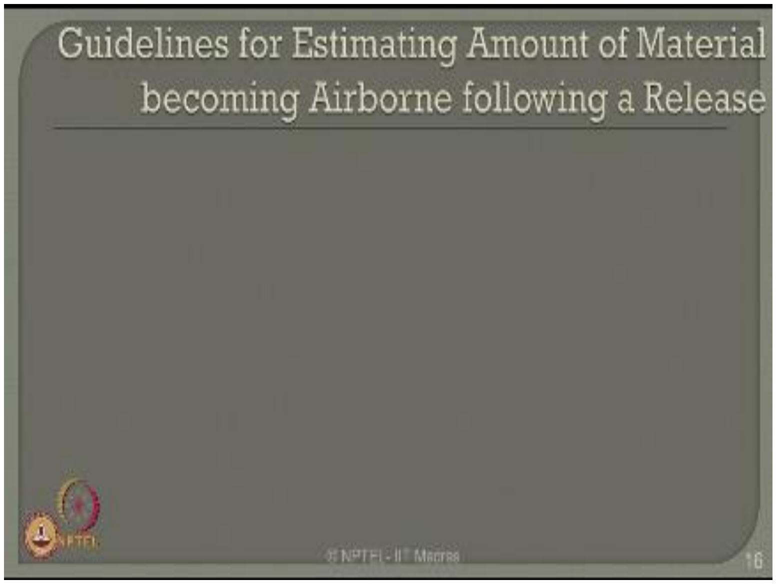

Let us now quickly see what are the guidelines for estimating amount of material which becomes airborne following a release, the moment I have a rupture either on the pipeline or the vessel or in the pressure relief valve these chemicals which are packed in a container or a vessel or a bullet will now become airborne. Now I understand the guidelines of estimating what is this quantity of the chemical which is becoming airborne.

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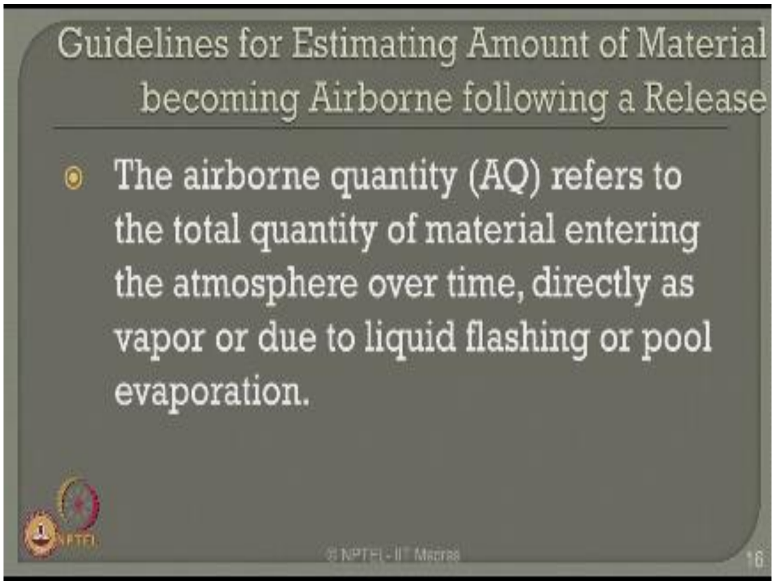

The airborne quantity refers as AQ is the total quantity of material entering the atmosphere overtime directly as vapor or due to liquid flashing or pool evaporation, friends please note the airborne quantity can arise from three sources, one the chemical can directly enter into the atmosphere.

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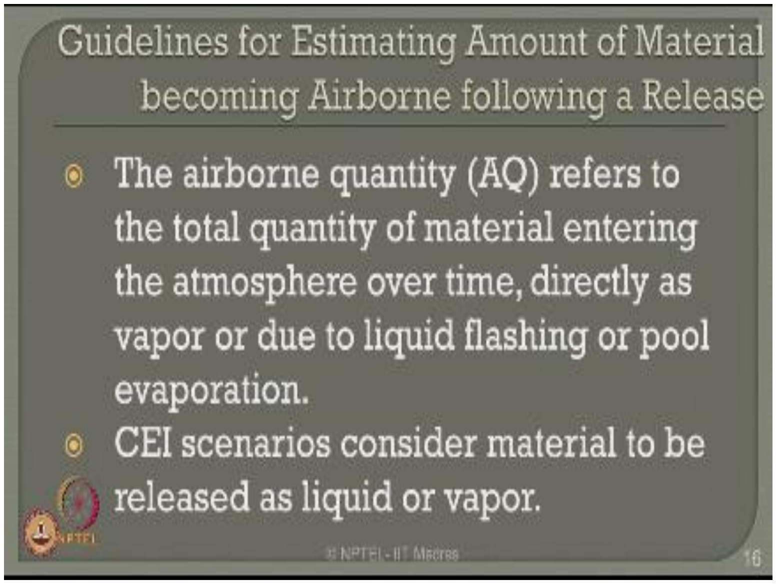

Two it can become later vapor it can also become the liquid which is flashing or can also evaporate after the pool formation near the dikes of the chemical storage, see a scenario is considered material to be released as liquid or vapor CI is not applicable for gaseous releases.

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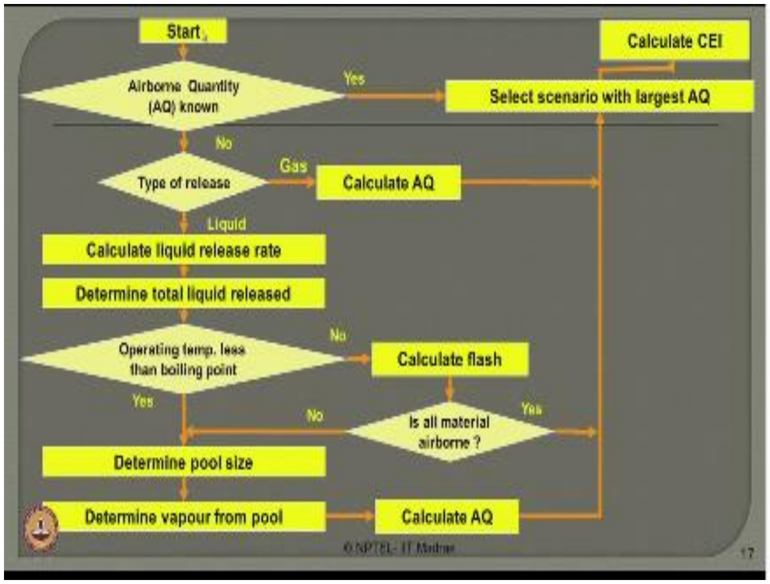

Let us quickly see how the float chart works for calculating the chemical as our index, let us say I identified a scenario or one can say I am not able to identify the worst scenario you can identify this for all scenarios and compare the best scenario in a given situation, so identify the scenario you have to calculate the airborne quantity if you know the airborne quantity directly select the scenario largest airborne quantity and calculate the CI.

If we do not know airborne quantity first identify what the type of release, if the type of release is gaseous calculate airborne quantity using a separate the equation then select the scenario with largest airborne quantity calculate the chemical exposure index, if the type of release is liquid calculate the liquid release rate then estimate the total liquid released during specific duration, if the operating temperature is lesser than the boiling point then identify the pool size.

If the operating temperature is higher than the boiling point of the liquid release then in that case calculate what is called flash, then estimate whether all material from the flashes is airborne, if all of them from the material flash is airborne then calculate the largest scenario and compute CI if it is not so determine the pool size, based on the pool size determine the vapor which is now getting evaporated from the pool.

Then based on that particular vapor concentration calculate the airborne quantity finally select the worst scenario and then compute CI for the worst scenario, so the comprehensive look out of the flowchart for calculating chemical exposure index which is essentially quantitative chemical risk analysis is available to you on the screen now. Now very interestingly one should know what are the equations available to compute the airborne quantity if a scenario is identified.

Let us quickly see now in the successive slides what are those equations available to compute different values of AQ liquid at least flash point and vapor or a pool size based on which a CI can be calculated, remember chemical exposure index is a simple number which will tell me which will help be to identify the risk based on a specific scenario.

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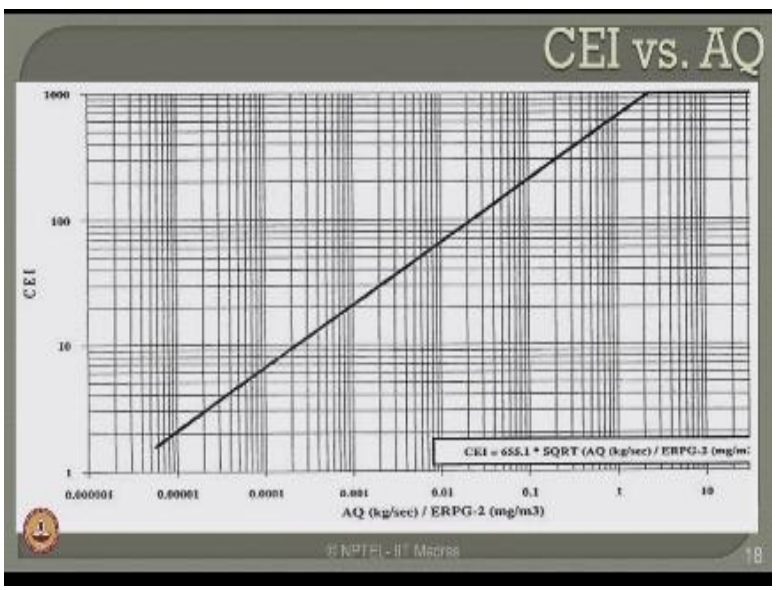

If you look at the CI verses airborne quantity there is a linear variation on a scale as shown here when plotted for ERPG values on a logarithmic scale, so CI keeps on increasing this set of increase in adverse quantity for an ERPG 2 guideline given a milligram per cubic meter concentration, whereas airborne quantity is so many kilogram in a second, please friends note that the minimum exposure of airborne quantity of chemical.

If is released is five minutes, let us talk about ammonia liquid release, as a problem one to understand how do we estimate CI for a ammonia liquid release from a container.

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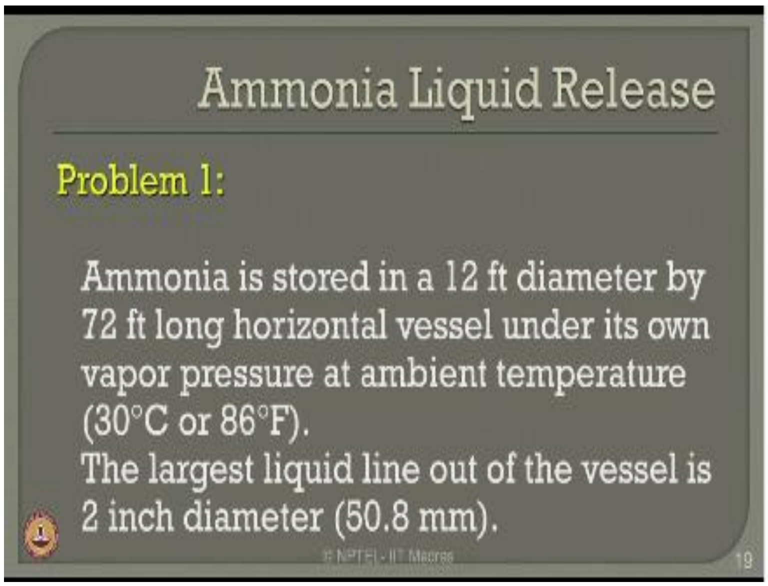

Let us say ammonia store in a 12 feet diameter of a 75 feet long horizontal vessels under its own vapor pressure at ambient temperature are about let us say 30 degree Celsius the largest liquid line which is extracting out from the vessel is about 2 inch in diameter which is 50.8 mm.

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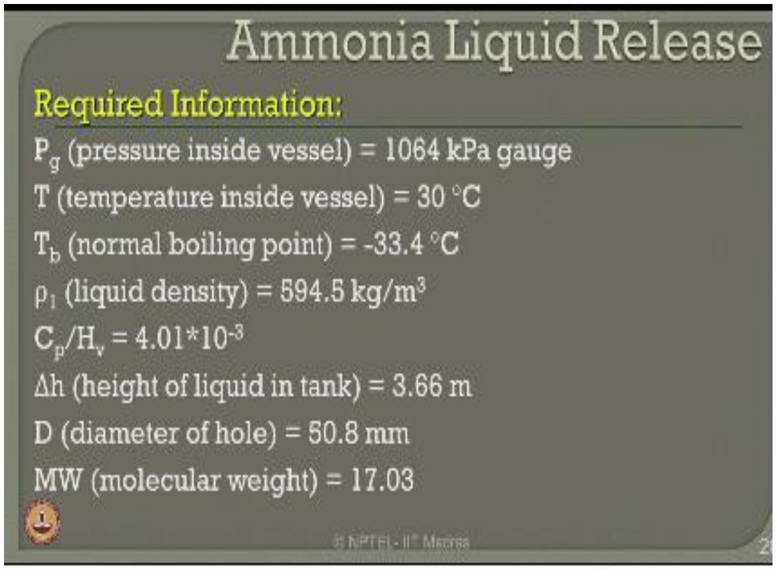

Now the required information to be chemical exposure index or chemical risk analysis of the following, one must know what is the pressure inside the vessel which is a given data which is 160 1064 kilo Pascal gauge pressure the temperature inside the vessel as we read from the problem is 30degree Celsius, the normal boiling point of ammonia liquid is minus 33.4 degree Celsius taken from the chemical engineering handbook.

The liquid density of ammonia is 594.5 kg per cubic meter Cp/Hv is a ratio as a available for all the chemicals available in the chemical engineering handbook for ammonia this value is 4.01 x 10^{-3} height of liquid in the tank is about 3.6 6 meter below the tank height is given as so many feet is 12 feet, the diameter of rupture of a hole which is extracting ammonia from the vessel is 2 inch diameter which is 50.8 mm.

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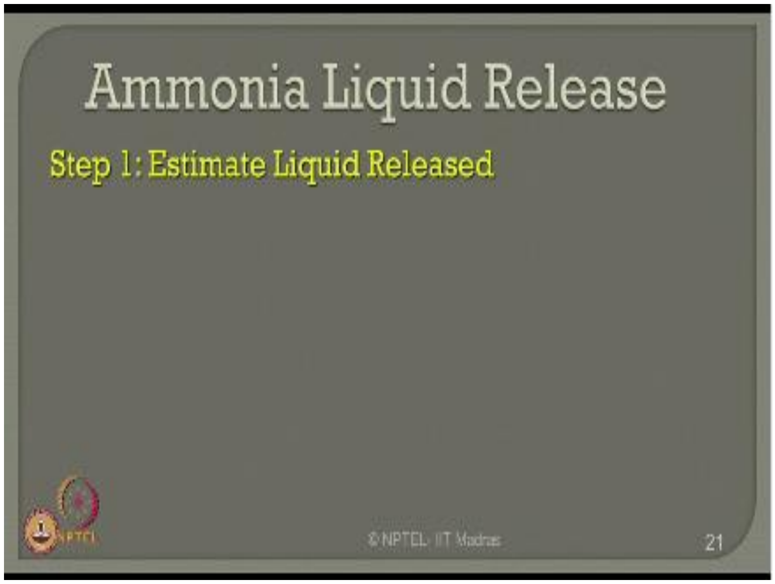

The molecular weight of ammonia is 17.03 which we know from the chemical engineering handbook, let us see where the strip one in estimating CI, now in the scenario there is a liquid release it is not gas therefore I must compute a queue so estimate the liquid release first.

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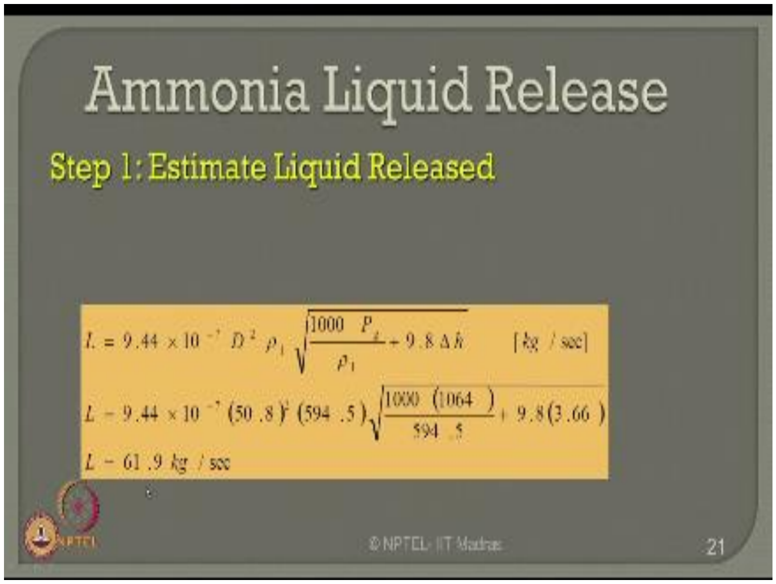

The liquid release can be given by a simple expression as shown here substitute the values of the diameter D 50.8 density which is given gage pressure is available to me delta h is the height of the liquid column of the ammonia being stored in the vessel which is 3.66 meter, so all of them are unit compatible therefore if you substitute them in respective units then I will get L which is the liquid released ammonia in kg per second. For this problem 61.9 kg per second.

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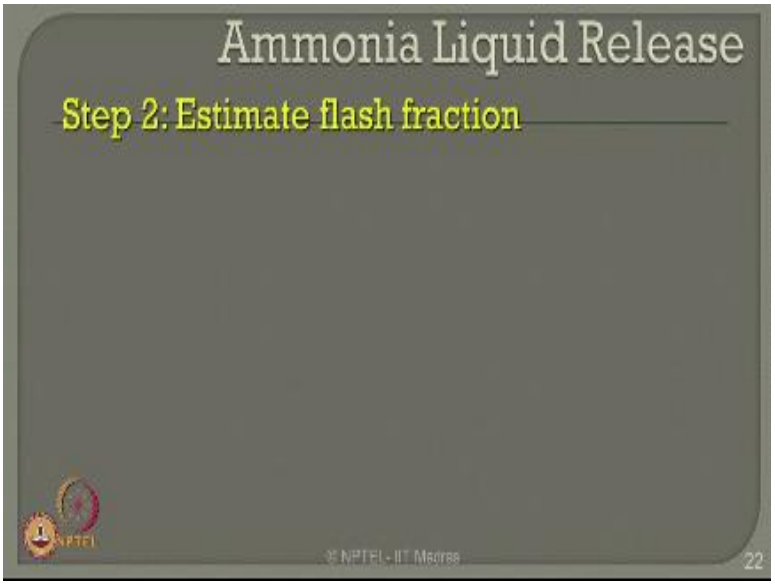

Once I know this I would also like to know what that is a flash fraction of this ammonia getting evaporated the flash fraction is given by an equation Fv.

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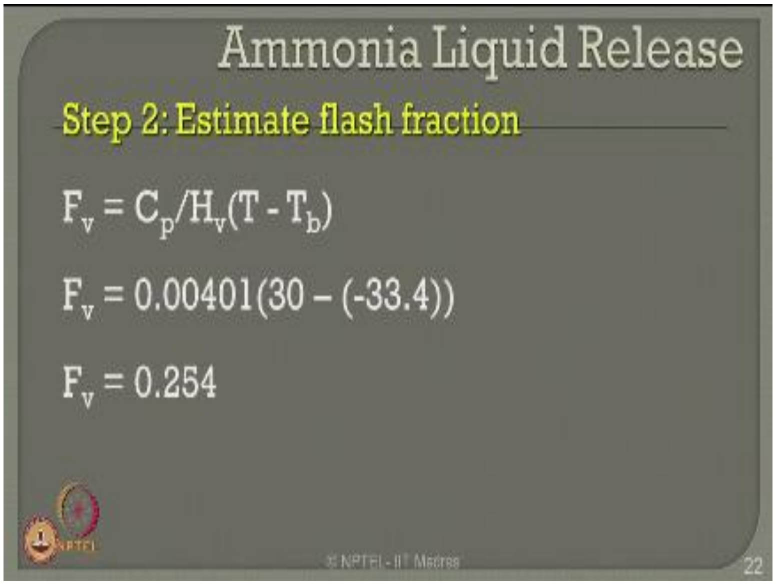

Which is CP/HV (T-Tb) boiling temperature Fv is now obtained by substituting the values of the equation and we know the operational temperature is specific problem is 30 degree Celsius and the boiling point of ammonia taken from chemical engineer handbook is minus 33.4 therefore the volume of flash fraction in the specific problem comes to be 0.254, now if this value exceeds 0.Q 0.2.

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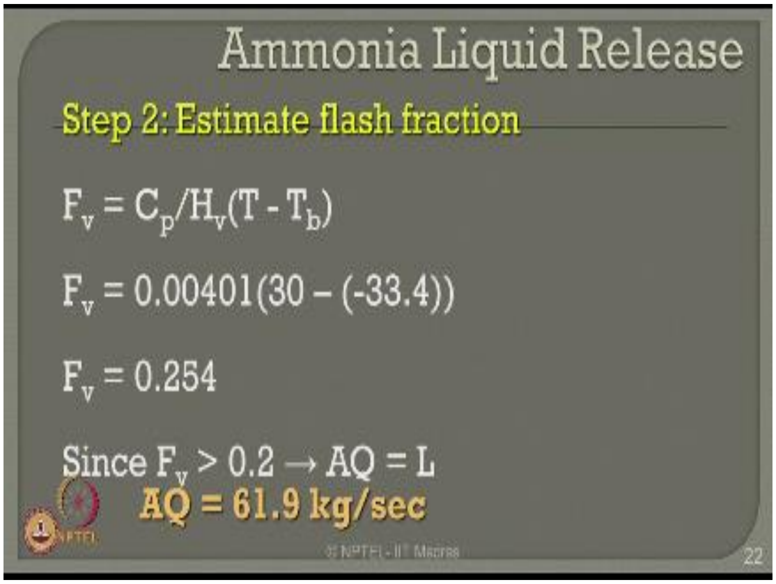

Then airborne quantity is completely assumed to be the liquid since then this value FV exceeds 0.2 that is 0.254 then the airborne quantity will be exactly equal to the value of L which we computed from the last slide, therefore airborne quantity now will be 6 1.9 kg per second which is computed from the last equation.

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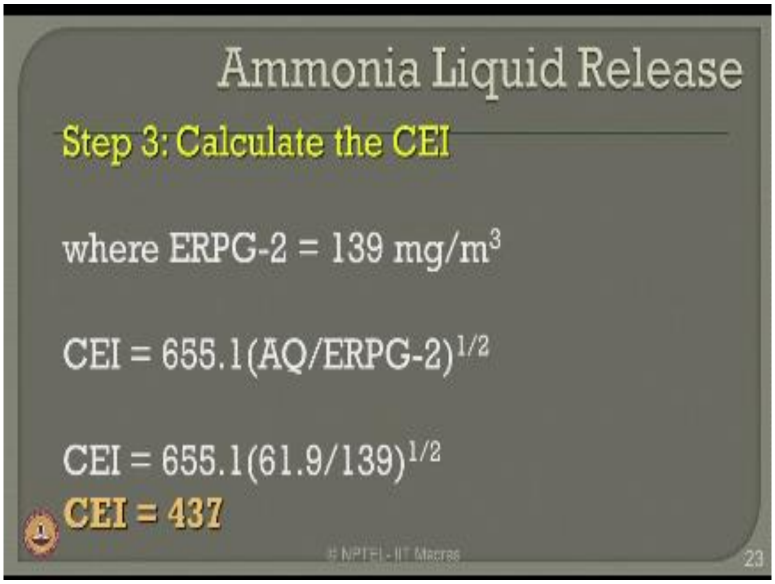

Once you know this I can now directly compute the chemical exposure index number but chemical exposure index number is relevant to detail difference of ERPG values for ammonia from the chemical engineering handbook one can find the ERPG 2 concentration is 139 mg/m^3 therefore CEI will be nothing but the equation as 655.1 x AQ/ERPG -2 ^{½} if is substitute the values because AQ is 61.9 which it got from the last slide.

ERPG 2 for ammonia is 139 I substitute in this equation get CEI value as 437 please understand CEI is simply a number,

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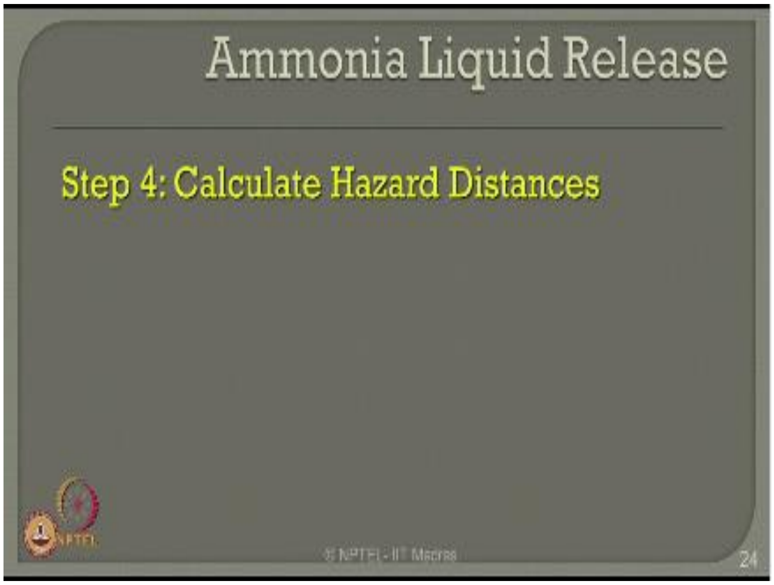

Once again CI one will be interpret to know how on converting this into term of societal risk so I compute what is called hazard distance, hazard distance is a quantitative figure which stays public that up to what distance your life can be a threat, one can ask me a question how we relate the life threatening to that of our distance, it all depends on what ERPG level you are estimating if it is estimated around distance for ERPG level 3 then is like that.

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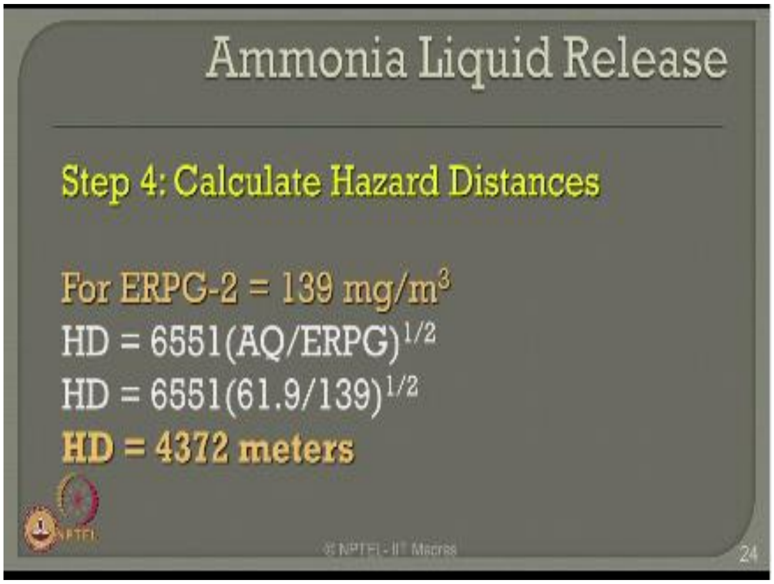

Let us see for ERPG 2 of 139 milli gram per cubic meter Hazard distance given to this equation I substitute the values I get the rod distance in 4372 meters on the other hand up to 4.372 kilometers if ammonia liquid is discharged from this vessel at a boiling temperature off so ands so then it will not cause irreversible effect on human being because ERPG dual concentration team says on states that it should not cause irreversible effect on human organism.

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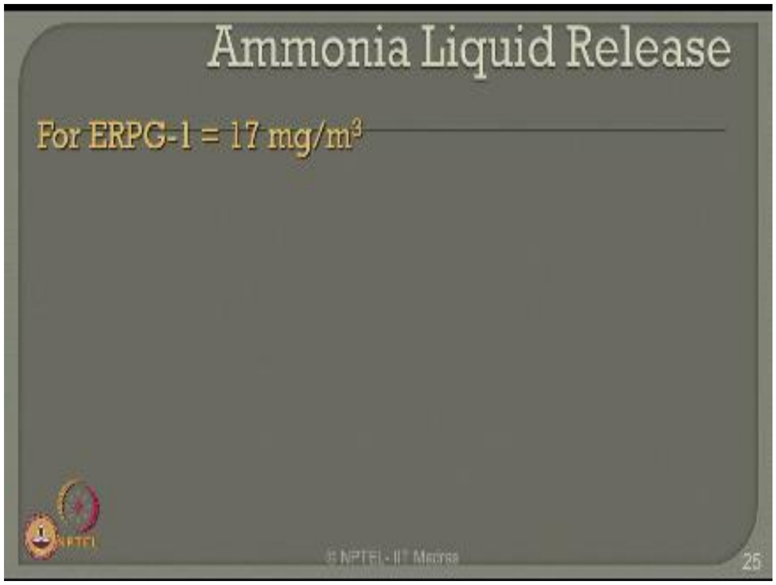

Similarly one can compute hazard distances for ERPG 1 level, ERPG one level is the mildest possible concentration for hazard distance.

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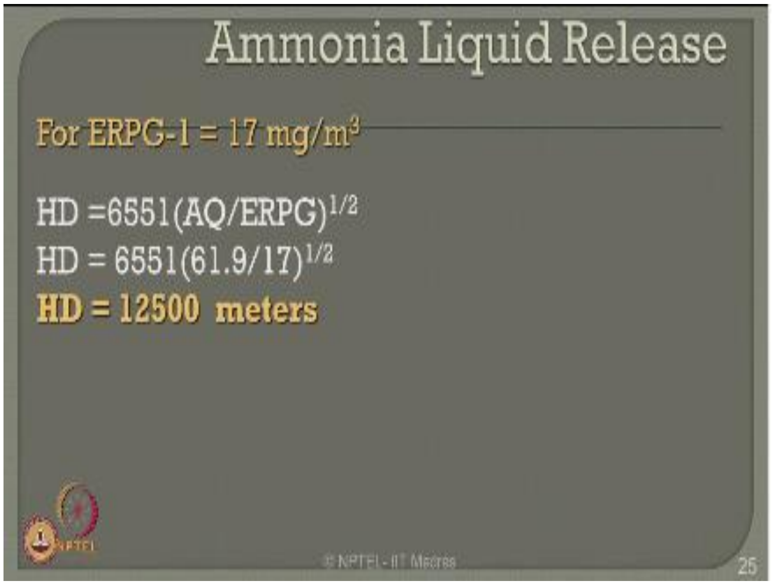

Will be 12.5 km so it is very evident for upto 12.5 kilometers if you stay beyond 4.375 kilometers that is from 2 level to 1 level you will not even get objectionable to wither, on the other hand if you are staying beyond 10.5 kilometers will have no effect of this liquid released in airborne contain apart on the societal risk.

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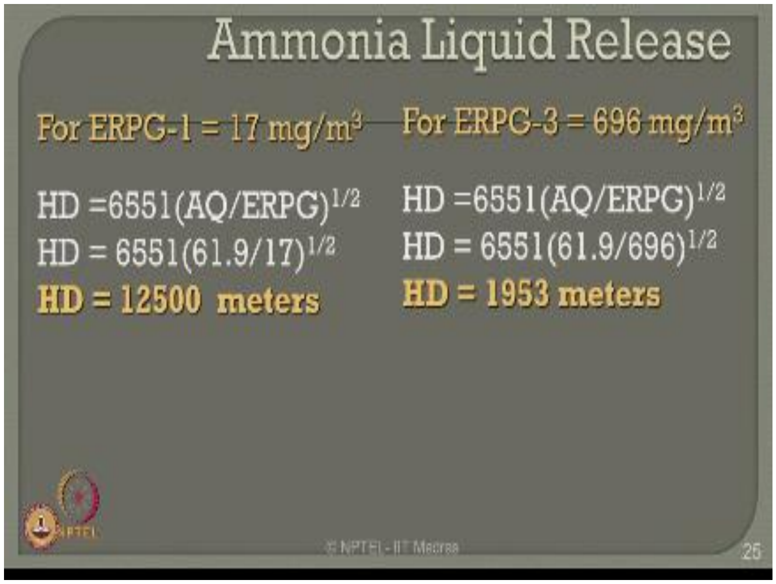

For ERPG 3 which is the little concentration which is very high 696 milligram per cubic meter the hazard distance comes to be 1.953 kilometers. So if you are staying less than 1.5 kilometers from the plant where the liquid is released or discharged as a given rate then this show that you will have a reversible effect in your body which may end up in fatal also.

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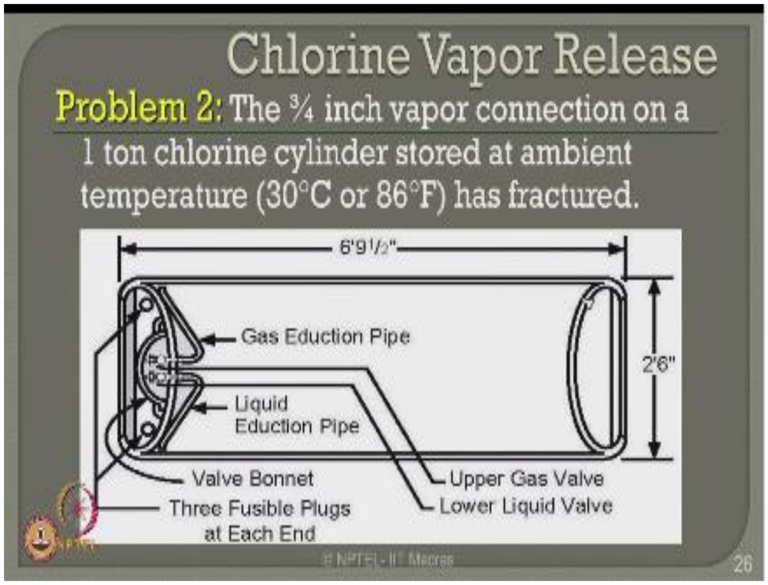

Let us take up another example which the chlorine vapor release, the first example problem was on ammonia liquid release. Now I am working a problem on chlorine vapor release let us say I have an object or a vessel which has got a gas ejection pipe we are having a liquid ejection pipe is a valve bullet which controls the chlorine vapor release completely there are three fusible plugs at each end of this container.

The container is about approximately 7 feet long and the diameter is about 2 feet 6 inches where upper and lower gas valves and liquid valves seen in the figure respectively. Now a $3/4^{th}$ inch vapor connection on a given vessel which is 110 plane cylinder stated ambient temperature as fracture. Now the temperature is about 30 degree Celsius which is fractured and the cave capacity available is 110m chlorine.

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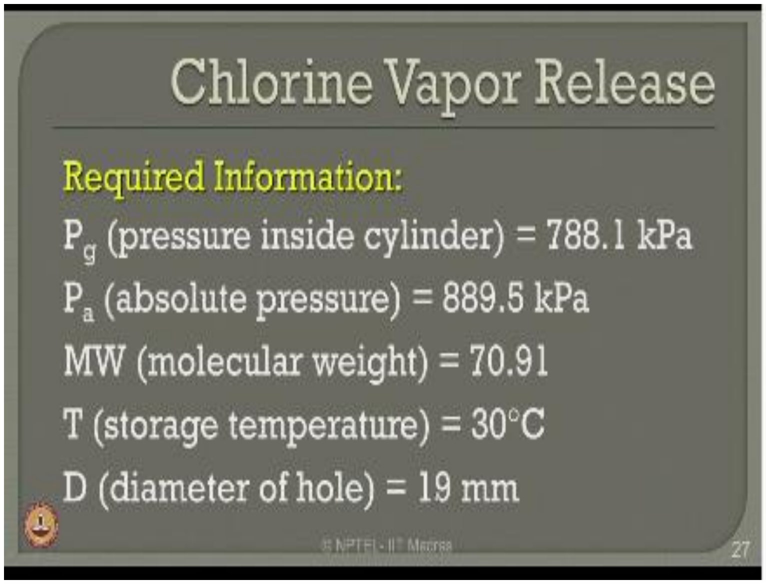

Let us see what are the required information for solving this problem, pressure inside the vessel 788.1 kilo pascal which is given in the problem with the gauge pressure the absolute pressure is of course 899.5 kilo pascal molecular weight of chlorine vapor is 17.91 the temperature of storage is 30 degree Celsius given in the problem diameter of hole is 3/4th inch which is about 19mm.

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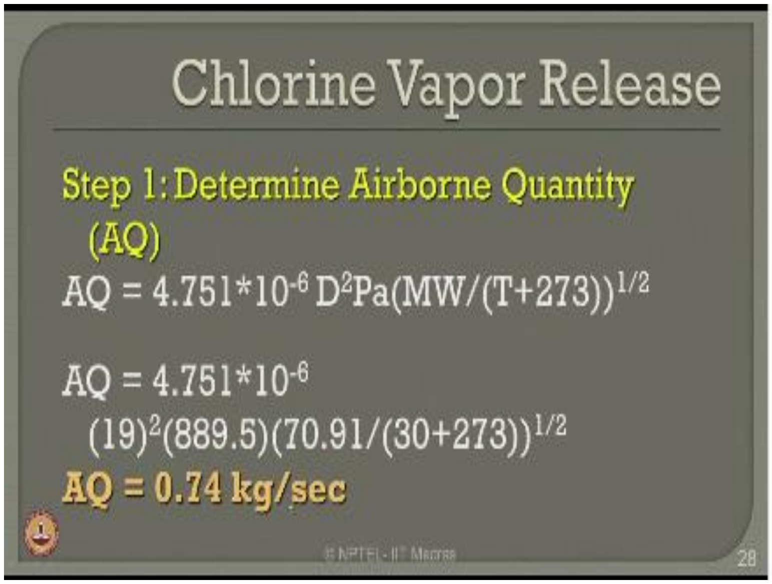

Step one determine airborne quantity of the square invertors given by this equation I know the values substitute them I am converting them into Kelvin’s substitute them I am adding to 73 here substitute them and get along quantity as 0.74 kg per second.

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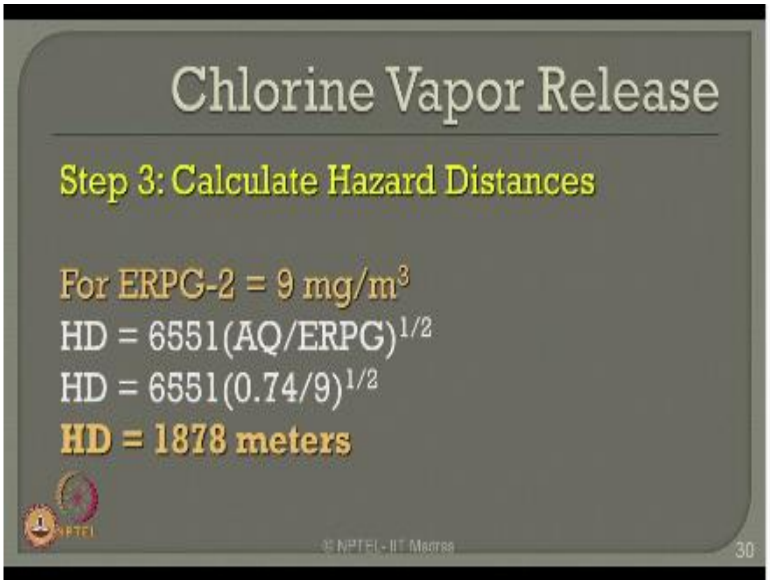

Now I want to compute directly the CEI the ERPG level 2 for clearance vapor is 9 mg cubic meter I substitute the value I get CEI as 188 then I compute a hard distance ERPG 2 I get the hard distance as 1.878 km.

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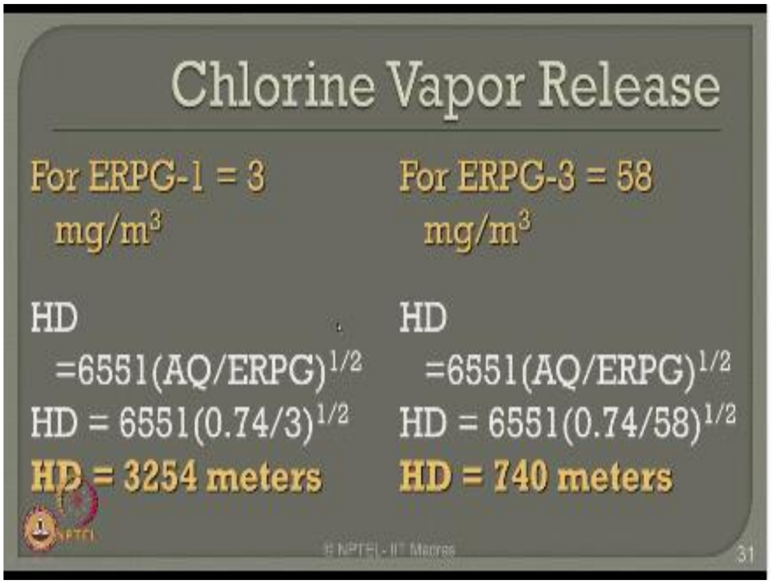

For ERPG 2 you can also do this for ERPG 1 and ERPG 3 which gives me the respective values shown on the screen. So ERPG 3 is as close as 0.75 kilometers from the plant source whereas ERPG 1 is as far as 3.254 kilometers from the plant source. So any human being or biological organism living beyond 3.25 kilometres from the source will not be affected even buy a odour of chemical release like chlorine vapor in the airborne concentration as shown in this example.

So hazard distance gives a physical interpretation of how chemical release will affect the societal risk in terms of Public Health, this lecture has given you two examples enable you to work out the chemical risk analysis for two different type of concentration one on a liquid concentration other on a vapor one should be able to work out chemical risk analysis using the equations shown in the presentation, thank you.

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