Risk and Reliability of offshore structures
Prof. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module - 03
Risk assessment and Reliability applications
Lecture – 14
Consequence analysis

Friends, welcome to the fourteenth lecture in module 3 where we are going to talk about the consequence analysis.

(Refer Slide Time: 00:20)

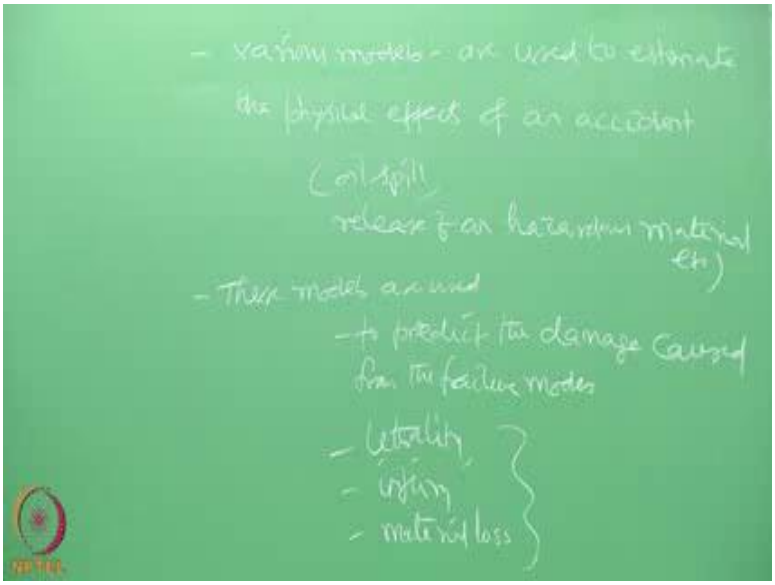
This is lecture in module 3 and we know that in module 3 we are focusing on risk assessment and reliability applications. Friends, we do agree that in case of reliability estimates it is important one should know the probability of failure and therefore, reliability index can be the converse of this, which can be seen as a safety of the system. While estimating the reliability, one is also indirectly interested, if the exceed limit may be of material strength or load capacity, what are way you may address this is reached what would be the sequence of failure.

What would be the mode or modes of failure? What would be the causes for such modes

of failure and ultimately what would be the effect or effects of those failures on the overall system? If I look at this effects or consequences in terms of economic perspective and quantify risk, in terms of economic perspective may be that we will complete the problem in total. So, we have already seen there are certain set of studies, what we understood in these lecture, module 3 FMA, ETA, FTA etcetera. There we understood how to get the sequence of failure? How to identify different modes of failure and how to diagnose the causes for such failure may be based on the experimental investigations or based on experience and expertise of dialogues or may be even doing a what if analysis?

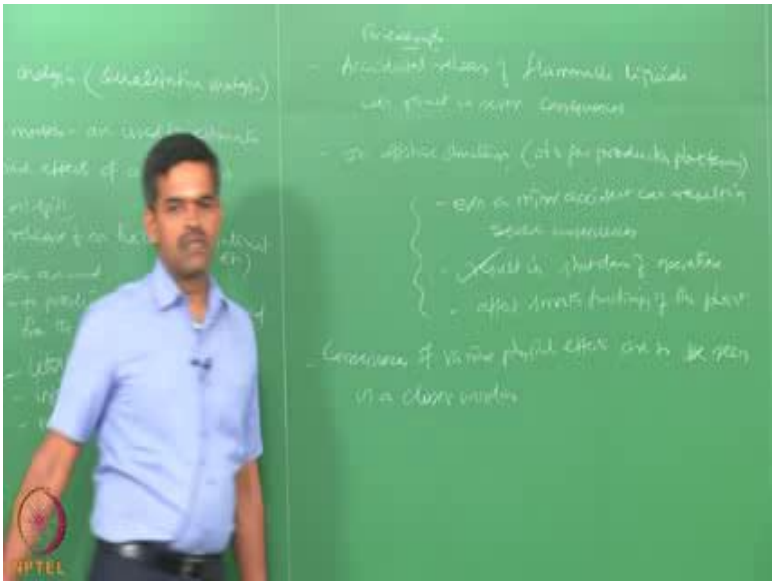
We have also focused. In fact, the risk priority in order purely not only based on the occurrence of modes of failure, but also on the effects caused by those failures, for example, if you look at the risk priority number which is an interesting quantitative outcome of an FMECA study, risk priority number also tells me the effects of those failure modes on the overall system. Anyway, we have been discussing this in different kinds of risk analysis methods, adding to this let us today talk about your consequence analysis, which is an explicit application of risk assessment, which can be very commonly used in any industry in general and in particular to offshore industries in a consequence analysis what we exactly do.

(Refer Slide Time: 04:13)



So, in a consequence analysis, which is more or less a qualitative analysis a number of various models are used to estimate the physical effects of an accident. The accident can be an oil spill can be release of hazardous material etcetera now these models are used to predict the damage. So, these models are used to predict the damage caused or arise from the failures. So, the damage could be of different order. It can be lethality; it can be material loss varieties of effects can be. So, consequent analysis deliberately attempts to find out the effect or the consequences of the damage caused by different failure modes in particular to different perspective where risk assessment is also a part of it. So, accident release of flammable liquids.

(Refer Slide Time: 06:32)

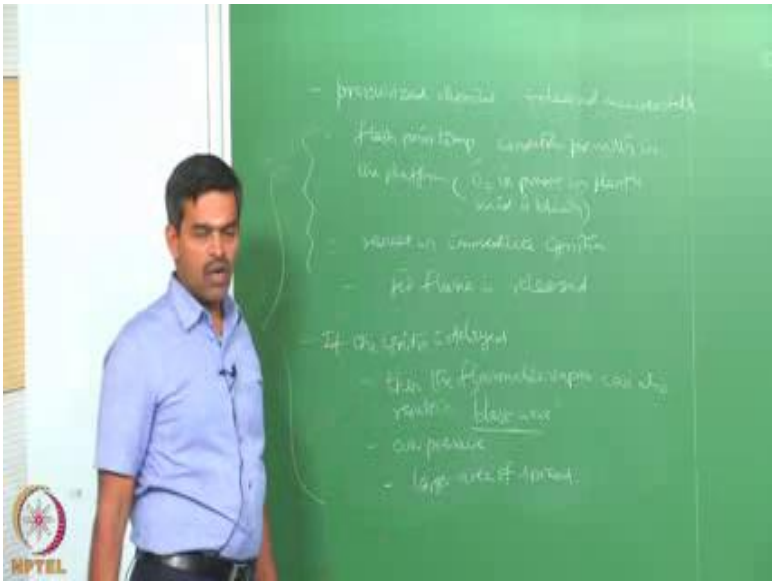


For example, if you consider, it is a accidental release of flammable liquids can result in severe consequences, I mean this is for example, I am just quoting only one example it is not necessary that hazardous release of gases do not cause severe consequences for example, but specifically in offshore structures. Let us say, oil and gas production platforms oil and gas production platforms, which are meant for exploration of production even minor accidents can cause very serious consequences that is unfortunate even a minor accident can result in severe consequences let us see why the consequence analysis is very important or primarily important offshore platforms or offshore structures because this may actually cause or result in shut down of operations it may

affect smooth functioning of the plant.

So, one has got the very clearly understand that the consequences alone need to be seen in a closer window. So, consequences of various physical effects are to be seen in a closer window. The reason is they can even result in shut down of the entire operation of the platform. Let us look at one series example let us say there is a pressurized chemical.

(Refer Slide Time: 09:19)



There is a pressurized chemical which is being released accidentally, the moment it is released depending upon the flash point temperature depending upon the flash point temperature and the conditions prevailing in the platform because the adverse effect is oxygen is present in plenty. There is one issue; wind is blowing which can set fire easily. So, if the flash point temperature is reached for the specific chemical it result in ignition this will result in what we call immediate ignition which will cause what we call as a jet flame as a result, suppose by any chance if we are able to delay this ignition, if the ignition is delayed by any chance then the flammable vapors can also result in what we call as a blast wave which causes also the over pressure.

So, this will have a larger areas spread. So, the moment you have an hazardous chemical present in a plant, which is in evidently present in the offshore oil and production

platforms, if the chemical or gas is released even accidentally either it catches fire if the flash point temperature is reached and that will cause serious consequences. If the ignition is delayed by some process or by some conditions present in the platform, it will cause a blast wave and over pressure which will also create series consequence by spreading this over a large area around the platform. In both ways you can easily understand here, understanding the consequences of the failure modes or accidents are more interesting and more demanding than analyzing the risk based on the probability of occurrence and then the consequences.

Therefore, consequence analysis which plays a very vital role in offshore industry risk assessment because this is very important segment where people have to play, pay close attention in a micro window to really understand what would be the consequential effects caused by the failure of different modes and the overall functioning of the platform. Now, the consequence calculations can be divided; part one will talk about determination of the source strength parameters.

(Refer Slide Time: 13:00)

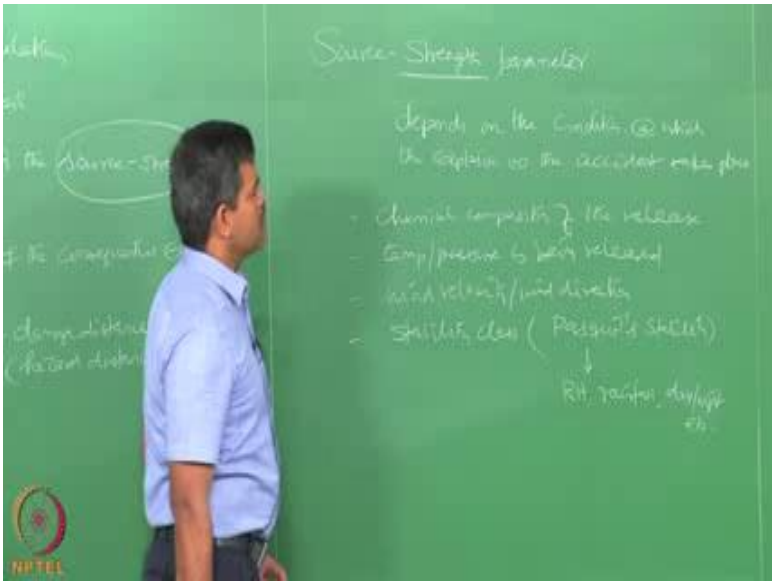
Part two talk about determination of the consequential effects and part three talks about determination of the damage or damage distances or what we call as hazard distances. So, kindly pay attention to these areas as explained in the specific example of chemical

release. We are bothered about two intensities of parameters here; one is what would be the devastating consequence caused when it catches fire or results in over pressure that is one, the second could be how far and how long it would be spread.

So, there are three stages; one is to determine the source strength whether the released chemical will catch fire or develops over pressure or a blast wave. So, that depends upon the source strength parameter and of course, the conditions prevailing in the platform which will also add to their strength or weakness of the source strength parameters. The moment I know this obviously, the second part of the calculation I must be able to estimate the consequence effects caused by this, will it cause a fire? If it causes the fire what would be the damage? If it causes on blast wave or an over pressure, what would be the damage? There are models available to estimate the physical damage caused by such effects on any system may be structural system, may be machinery equipment, may be human being etcetera.

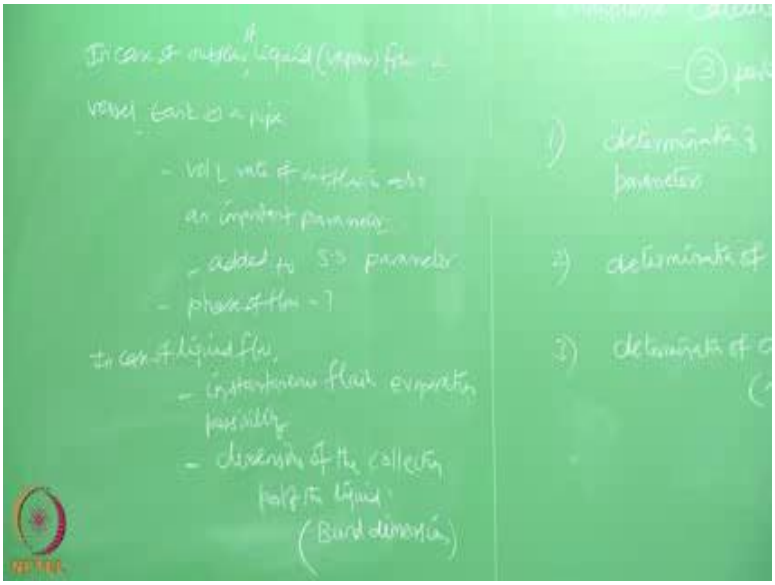
Of course the third and vital part of the calculation should also indicate, what would be the hazard distance? It means how far and how circumferentially this damage would spread. So, therefore, friends risk assessment alone which gives me consequence as a multiplier will not be able to throw a broader window in terms of consequence analysis separately. Therefore, in offshore industry risk assessment also being estimated by a separate QRA, which is also talking about purely on consequences alone because they have lot of parameter to be indicated and they have lot of serious effects to be diagnosed as a part of the consequence analysis cause by release of any chemical or a gas which may be purely accidental non intentional. So, let us talk about each parameter separately and elaborate them what is store source strength parameter.

(Refer Slide Time: 16:26)



The source strength parameter depends on the condition at which an accident or explosion takes place at which the explosion or the accident takes place. It depends on the chemical composition of the release it depends also on the temperature and pressure at which the chemical or the gas is being released what we call as operational temperature and pressure it also of course, depends on wind velocity and wind direction. It also depends on stability class usually given by pasquils stability, pasquils stability will give highlighted figures about whether what is the relative humidity in that area what is the rainfall what is the day and night temperature etcetera it covers all and tries to give me a stability class based on which the strength parameter of the source can be estimated.

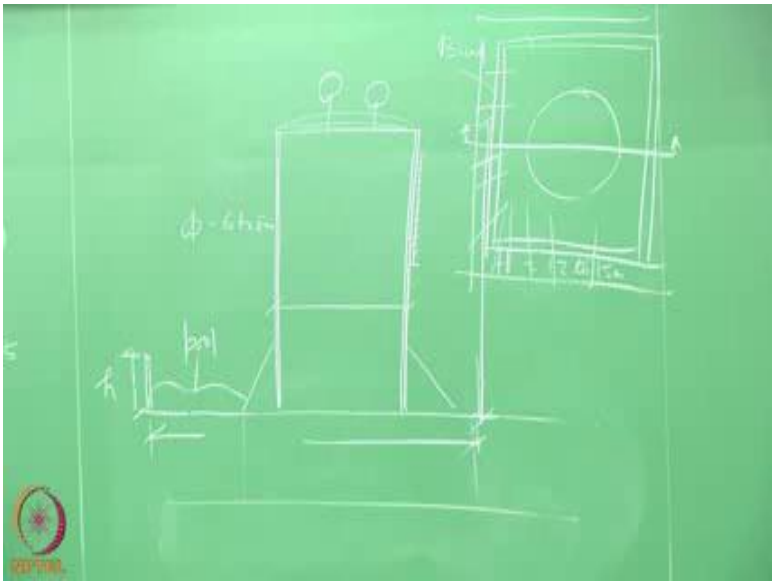
(Refer Slide Time: 18:28)



Let say for example, in case of an out flow liquid in case of an out flow liquid of liquid out flow of liquid. It may be in a vaporized form from a vessel liquid or a vapor from a vessel or a tank or a pipe as the case may be the volume and rate of out flow is also useful, the volume and rate of out flow is also an important parameter which is added to the source strength parameter also their phase of flow in what phase. It flows that is also important in case of only liquid flow. Then one is interested to know, what is the possibility of instantaneous flash evaporation possibility? One should be interested to know depending upon the chemical engineering handbook data available for every kind of liquid or chemical being released the flash point temperature and the temperature at which the flash or evaporation is possible will be indicated.

So, if you operate in temperature matches with that. So, one can estimate what would be the volume of flash which can happen as an evaporation when the liquid is being released as an outflow of course, we all agree and understand that all the liquid getting out flow is not going to be evaporated some will remain in liquid state therefore, one should also be in interested to know what are the possible dimensions of the collecting pool of the liquid in. In fact, we call this as bund dimensions or bund volume. So, let us see what is the bund quickly?

(Refer Slide Time: 21:14)



Let say I have a tank where the chemical is being stored which is hazardous of course, the tank will have a base. The tank will be resting it be founded properly that is the base where there are hazard plates which are provided the wall thickness of the tank is also shown here. Generally the tank will also have a calibrator which is indicated on the side to indicate the liquid level it may be an electronic float. There will be again pressure release valves, there will be again safety valves, etcetera which will indicate some safety arrangements present in the tank the height of the tank is usually, let us say the height of the tank above the ground usually where the crude oil or any chemical process industries like oil and gas is about, let us say 12 to 15 meters, the diameters about 6 to 8 meters. It is a diameter can be about 6 to 8 meters tall tanks very large in diameter.

Obviously, you know whenever there is a liquid possible outflow from this tank because of accident because of crack or over pressure etcetera, obviously, part of the liquid exiting out from the tank will get evaporated depending upon the flash point temperature of that liquid stored inside the tank, but remaining will have to stay will have to stay as a liquid. So, the liquid has got spread all around the tank, if you look at the plan obviously, if this is the tank all around essentially there will be a protective system if I cut a section here let say that is what I see the tank here. So, I will also have a wall and will also have a wall we call this as bund.

So, I have to estimate the pool volume based on that I must fix up the dimensions of the bund and the height. So, this is possible only when you do a consequence analysis in detail to estimate how much quantity will be now released as an outflow liquid, out of which how much will get evaporated and how much will remain still as a liquid for sometime because that liquid should not be allowed to flow further. It should be contained around the tank one may ask the question why should be contained around the tank because around the tank generally we have a provision of running fire fighting devices like sprinklers and wet raisers.

So, in case it catches fire, these sprinklers can spray water and the fire can be contained in that specific segment and so the spread of this fire can be stopped. So, therefore, I need to construct a bund, I need to know the volume of the bund, to know the volume of the bund I must know what is the input data available, how much liquid will fall on the bund because that practically depends upon how much volume of liquid you have in the tank. Out of which how much percentage can be evaporated because of the flash point remaining, how much pool will be formed the one the liquid which is staying here is what we call as the pool and we need to know this.

So, these are all important data which forms a source strength parameter in consequence analysis. In addition to that, one should also look at the evaporation rate as a function of volatility of material based on which the pool dimensions can be fixed and then the sprinkler design should be done in such a manner so that the wind velocity on the wind direction should be taken care of while designing the layout of the sprinkler system. So, that the fire does not spread in the windward direction, but it is contained within the pool area.

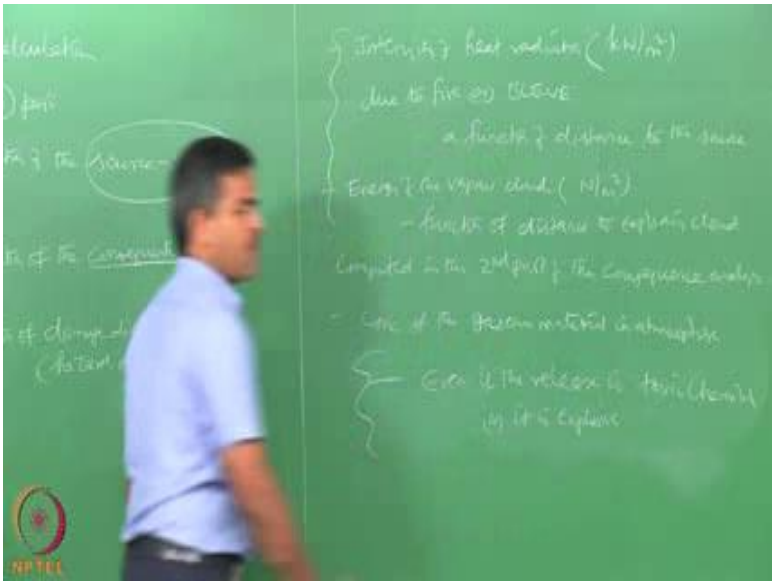
So, let us look at the second issue in consequence calculation what is called consequential effects consequential effects depends on various parameters.

(Refer Slide Time: 25:28)

It depends upon the dispersion relation of the gas in atmosphere of course we all know the dispersion relation is a function of the source strength parameter. It also depends on relative density of the gas. It also of course, depends on Pasquil's stability class and it also depends on topology topological data of the surrounding area because I am talking about the consequential effects not only to the plant, but also to the public near the plant. So, I look only also the societal risk, societal risk is that risk caused by the accident or the consequent of the accident on the plant individual risk is the effect caused by the failure on the plant itself or the personal working in the plant.

So, societal risk is much more important larger and dimension compared to that of individual risk who are working in the plant. Therefore, I must also know what is the topological data of the surrounding area? What is the population density? What is the age group of the population? How far the spread of the residential area is there how far away they are located from the plant all these should be accounted for in the consequential effects which is the second step or the second path of the calculation of the consequence analysis interestingly intensity of heat radiation which is usually expressed in kilo watt a square meter due to fire or bleve is actually a function of distance to the source where the accident has occurred.

(Refer Slide Time: 27:54)



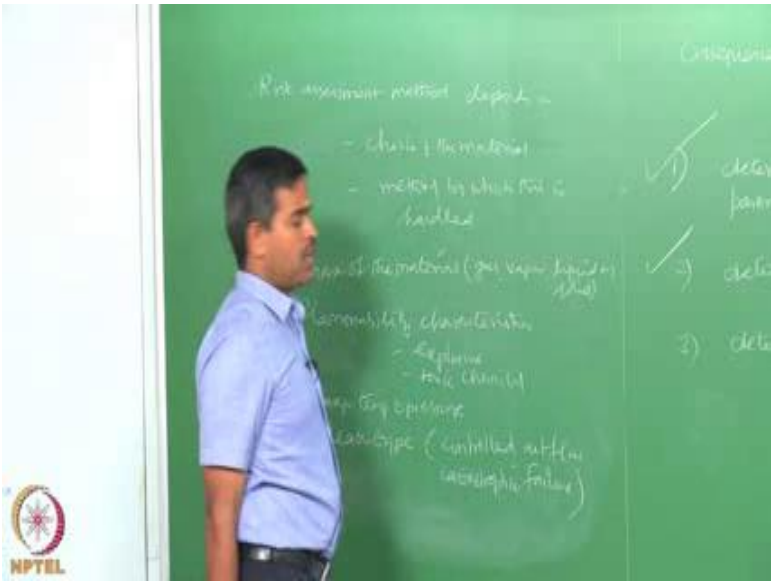
It also depends on the energy of the vapor cloud, which usually expressed again in newton per square meter which is now going to be the function of distance to exploding cloud.

So, these values need to be computed in the second part of the consequence analysis further friends it is also important to know the concentration of the gaseous material in the atmosphere due to the dispersion of the evaporated chemical which is also an important parameter in estimating the consequences of course, the concentration of the gaseous material in atmosphere because this will tell me what would be the effect caused by this dispersed gas to the society or to the public around the plant. So, these are all true whether the accident remaining going to be either explosive or simply a toxic release. So, these are true even if even if the release is a simple toxic chemical or it is explosive.

So, the consequential effects throw a brighter window in understanding many parameters which are otherwise not looked upon in detail, when you do a risk assessment alone here consequence only becomes the multiplier in terms of estimating quantified values of risk because we know risk is a product of probability of occurrence of an even with the consequence of that event if it is occurred. So, varieties types of models are used in risk analysis they all depends on what is the type of material being released and what the way

the material is being handled. Therefore, properties of materials in handling methods definitely govern the choice of risk analysis. What are those properties? So, risk assessment method through consequence analysis depends on essentially on the choice of the material which is being released.

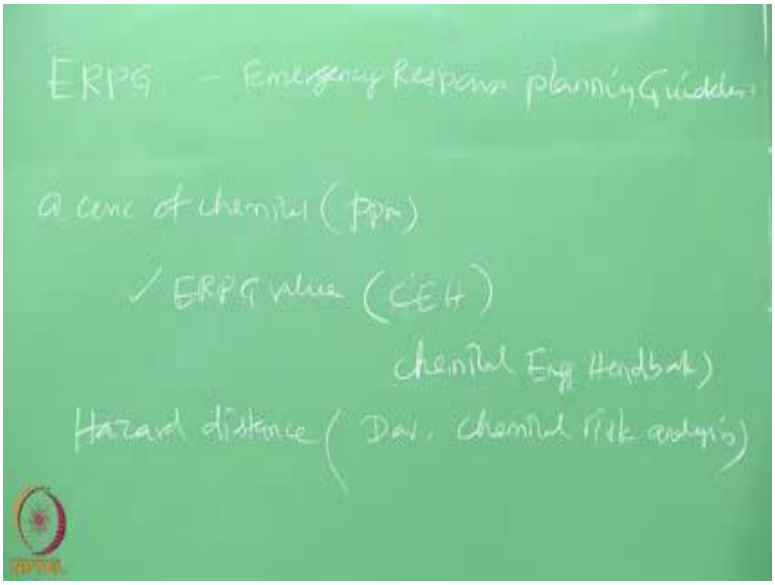
(Refer Slide Time: 31:11)



You handle of course, a method by which this is handled. So, various factors could be the phase of the material whether it is gas vapor liquid or sometimes even solid then the flammability characteristic of the material whether is it explosive or a simple toxic chemical the third character should be the storage temperature and pressure at what temperature is being stored then the release type how it is released whether it is by controlled out flow or it is catastrophic failure.

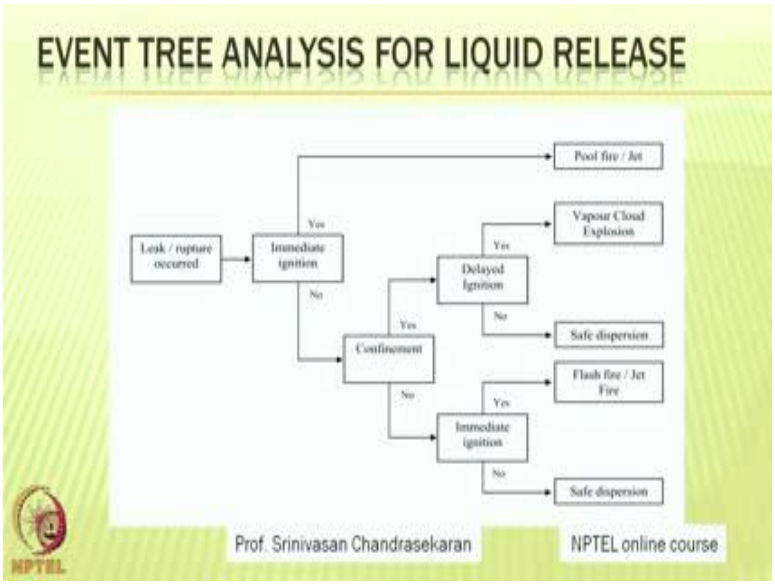
If it is a controlled outflow then one should also bother about the pump capacity your train need to pump it out or the capacity of the pump the third could be the damage distance how far the damage will spread for every chemical or gas being released there are different guidelines given by the international regulatory bodies which are called as emergency response planning guidelines for the concentration of the chemical for a concentration of chemical in parts per million.

(Refer Slide Time: 33:25)



What would be the ERPG value which is available in chemical engineering handbook based upon the ERPG value one can compute, what is called hazard distance using the equations given by Dow chemical risk analysis? So, one can also compute the damage distances as a apart of the consequential calculations which you have done in the risk assessment now kindly pay attention to a specific event tree analysis or a liquid release is being plotted on the screen now.

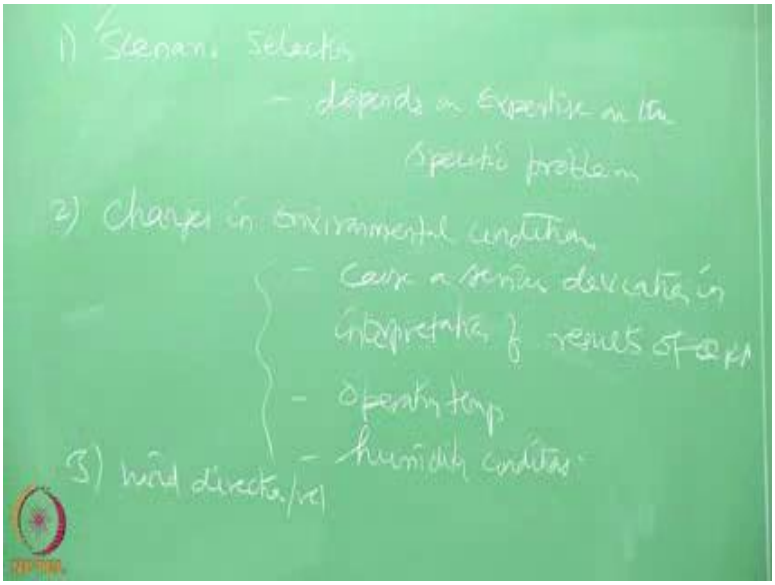
(Refer Slide Time: 34:41)



Let us consider that the leak or rupture occurred in a vessel the leak or the rupture of the liquid can result in immediate ignition. If it is yes, then will result in what we call pool fire or jet fire. If it is no, then one should be able to confine it if you are able to confine it then one can delay the ignition if we delay the ignition it can form either a safe dispersion or can result in VCE what we call vapor cloud explosion if the confinement is not possible if you are not able to confine then there is no immediate ignition then you check that is it going to ignite.

Further, if it is going to ignite it result in what is call as a flash fire or a jet fire if it is not going to ignite then you can have a safe dispersion. So, one can easily understand a simple event tree analysis which is also used as a part of the risk assessment which includes more or less the consequential effects of a specific damage the damages are the effect is leak or a rupture. So, even for a single event of a damage like a leak or a rupture one can extend a risk analysis using event tree and try to find out the consequence of that particular event or occurrence of that event in a elaborate manner as you see in this picture on the screen now, but of course, these kinds of qualitative risk analysis where we are talking about consequential analysis have few limitations.

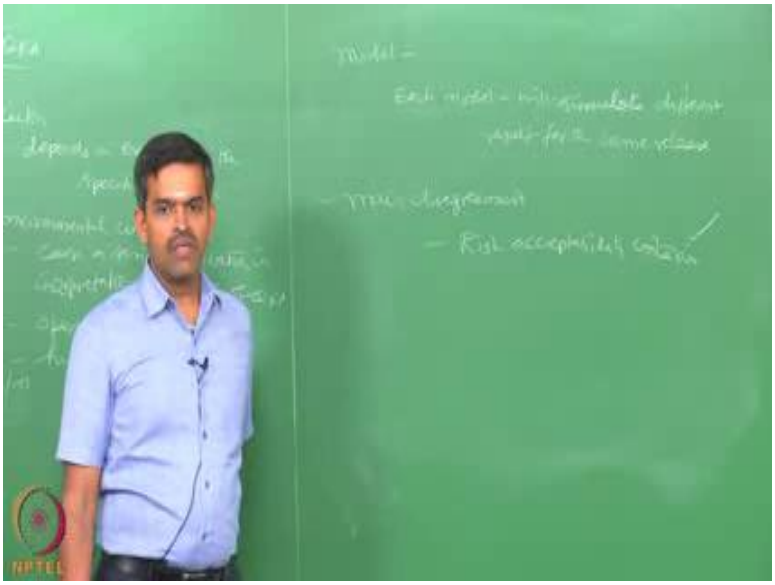
(Refer Slide Time: 36:19)



Let us say, what are the limitations of such QRA studies? There are few limitations of QRA studies as the approach is changed which will give you different results. So, the first one is the scenario selection the scenario selection depends on the expertise on a specific problem in the scenario selection can change their view of the QRA in total the second factor could be which is also a series limitation is changes in environmental conditions changes environmental condition can cause a serious deviation it can cause very serious deviation in interpretation of results of QRA.

For example the operating temperature or the ambient temperature during the release of the liquid or a gas can be a important factor which will tell you what is the serious deviation in the results the next could be operating temperature can be one character the other could be the humidity conditions present at the release which has been assumed in the QRA study. So, all these factors, all these factors can result in different result interpretation from the QRA studies and more importantly the wind direction and velocity because this can affect the result very seriously therefore, what are model we use for consequence analysis is a QRA each model should simulate or each model will rather simulate.

(Refer Slide Time: 38:35)



Different results for the same release scenario for the same release scenario therefore, if the choice of the release model is not appropriate to the above parameters then different models will give different risk assessment statements though there is some commonness between them.

In addition the main disagreement between this the main disagreement will be the risk acceptability criteria as i said in offshore industry the risk acceptance is pre declared for every kind of industry every kind of process unit of an offshore plant. So, depending upon what is the risk acceptability criteria you are proposing then you have to estimate the risk based on this there are many countries unfortunately even they do not define an acceptable risk level for an offshore industry and interestingly the acceptability criteria is different for different countries also therefore, a database that is used for probability estimates can be subjective and they can be different as well.

So, these parameters will; however, strongly influence the results that we obtain from risk assessment studies at we just now followed by different methods. So, in this lecture friends we have tried to understand the consequence analysis which is a part of risk assessment which closely gives you a through window of detailing more understanding towards the consequential effects caused by various failure modes on a given system it

also works out a three stages or a three parts the most important part is the societal risk estimates which come out from the consequence analysis which is very important part of this kind of QRA.

However, this kind of QRA studies have limitations and different methods will give you different results provided what model we have choosing or estimating the QRAs therefore, one need to be very carefully select the choice and release methods in material and accordingly use an appropriate model to get a better and acceptable risk assessment because these also depends upon what is a criteria you want to say the acceptability of risk in a given plant.

Thank you very much.