Introduction to Explosions and Explosion Safety

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Lecture - 40
Risk Analysis for an Explosion

Good morning, now this will be the concluding lecture in this course on an introduction to explosions and explosion safety as we discuss during the earlier 38 to 39 lectures.

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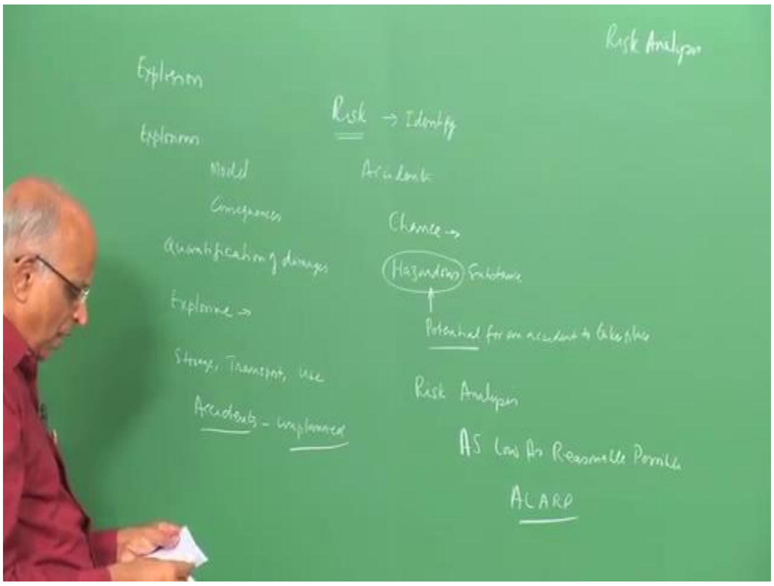

Something on what constitutes an explosion, what are the different types of explosions and also how to model the different types of EC explosions. Be it a gaseous vapor mixture in confined unconfined geometry, be it a solid explosive, be it a liquid explosion be it something like a physical explosion. We look at the modeling of the explosion and also determine what are the consequences what are the damage, what is the type of the blast wave, what is the type of over pressure, what is the type of impulse what you get from an explosion namely the consequences. By now, we are very clear about explosions in general and also we talked of inert events and all that to bring down the destructive nature of the explosions. Having said that, we also in the last lecture looked at quantification of damages from explosion quantification of damages we looked at those response curves we looked at the probity.

Now, we are in a position to say that an explosion is something undesirable and an explosive, it could be a gas, it could be a liquid, it could be a mixture, it could be anything. It must be handled with care that means the storage of the explosive may be the transport of the explosive also may be the generation of the explosive plus storage plus transport plus the actual use. That is in application must be done with some safety precautions in mind, but whatever be the type of safety criterion be used accidents do happen.

For instance I am very careful to cross the road, I am very fearful of the traffic, I take all precautions since somebody can come and hit me and I could still get hurt. Therefore, accidents are something which are unplanned activity being unplanned, I think it is necessary to see under what conditions accidents can take place and also ensure that these accidents in the use of explosives do not generally occur. Therefore, let us get into some little more details of accidents when we say an unplanned activity is an accident and there is always a risk involved in whatever we do.

There is a greater risk in use of explosives, therefore if there is a risk can, you evaluate or identify the risk like for instance identify what is the probability with which an explosion can take place in a given set of conditions. If you are very clear about it, then maybe we can take some steps to contract the occurrence of these explosions having said risk. You know having said something about accidents, you know there is always a chance that an accident will occur when I say chance what is it, I mean well there is a possibility and when we say chance in Arabic the word chance is known as hazard.

Therefore, we say a substance is hazardous from the word hazard you say hazardous and when we say hazardous substances we say well explosives are hazardous substances and have to be have to be handled with care. When we say hazard, we mean further potential for an accident to take place that means we need to re reduce the potential and that is where we see you know all the substances like liquid fuels when they are being transported. They say hazard hazardous substances are please be careful and we in case there is a spill may be it could form an explosive substance. Therefore, we talk in terms of hazard hazardous substances and potential for an accident to take place is always there and that is the meaning of the word hazard.

When we talk in terms of risk, well the risk should be so small that means the chances of an accident to take place must be so small that maybe we should be able to ensure that an accident involving these explosives do not take place. That is why we do the risk analysis, having said this, let us also take a look what is it we are looking for we said we cannot zero the or z make the chance of having an accident to be 0. Therefore, all what we can say is make is as low as practically possible or as low as reasonably possible or we call it as a l a rp.

This is the word we use namely we would like the risk to be as low as reasonably possible. Let us work towards this and in this class today we will do work on this subject of risk analysis of the hazardous substances namely explosive, you know there are different types of doing a risk analysis.

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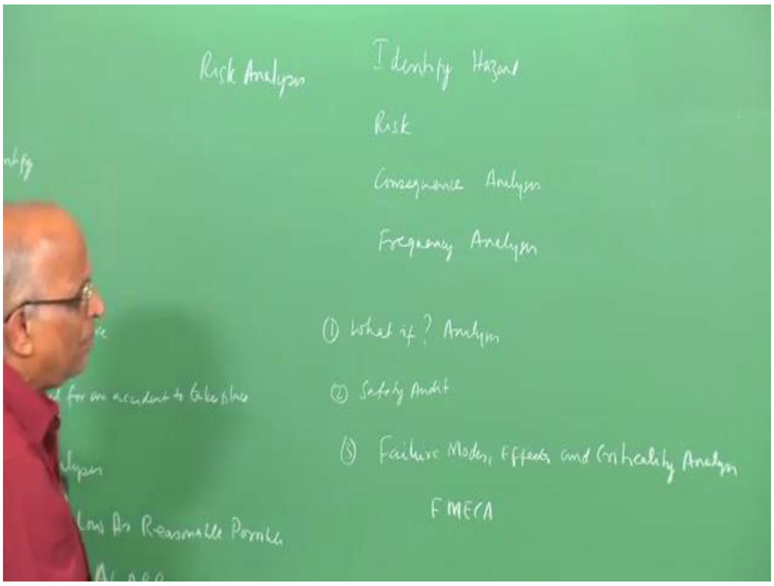

For instance, you have methods like risk analysis may be you have to be able to identify the potential for causing an accident, let us say identify the hazard we also need to be able to carry out the precise quantification of risk in the risk analysis. We should be also able to do what are the consequences if you do have an accident and therefore, there may be the analysis of the consequence has to be done and we must also not forget if an accident can occur more frequently. Well, it leads to more chances of an accident taking place something like a frequency analysis has to be done. There are different ways of quantifying all this and the types of risk analysis which are which are done are something like we say you know you do you say what if analysis.

You know it is something simple what if a spill occurs, will it explode under what conditions will it explode maybe I could use this, but it is not very quantitative though I could also talk in terms of something like second may be a safety audit or a safety check. In this case, maybe I will make sure that all the safety procedures are built in, but again the safety audit cannot really quantify the type of risk involved. I want to find out what is the probability of having a risk may be the third could be we can talk in terms of failure moves effects and criticality analysis.

This is known as f meca failure modes effects and criticality analysis, but these three cannot directly give you what is the type of the quantification of the risk involved. You know they are necessary because it helps you to understand what are the reasons for the explosion what are the safety feature which need to be followed also the different failure modes effects and critical. A criticality analysis can come out with something like standard deviations and the type of probability of an explosion, but what I do is I do something which is little bit different.

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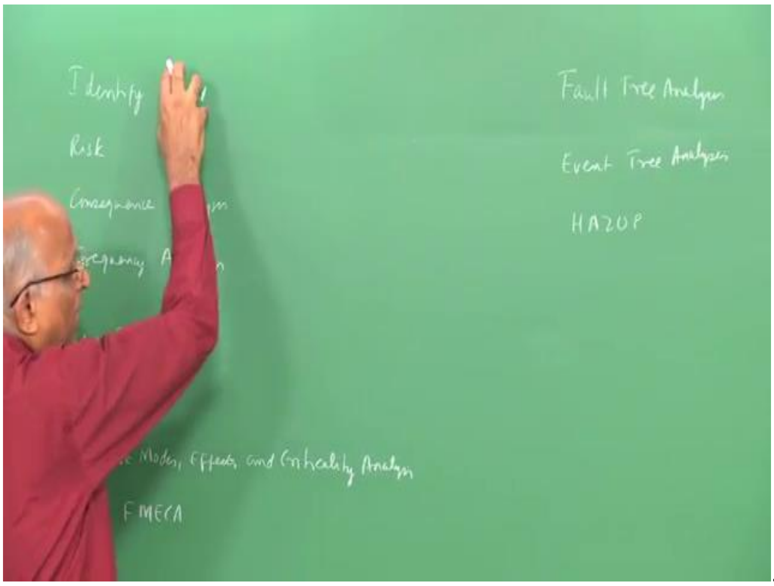

In the class today, I took three types of risk analysis only, let us say fault tree analysis the second one which I do is event tree analysis and the third which I do is known as Hazop hazards and operability analysis. These are the three and may be in the two we will be able to identify the risk involved and also identify in the process looking at the tree diagram what are the type of hazards and what type of hazards constitutes most to having an explosion. While in Hazop, we will be basically looking at the consequence analysis and frequency analysis and coming out with suggestions on having a plant operate under conditions under which the risk is as low as reasonably possible.

Having introduced the subject, let us go to the fault tree type of analysis, in this what is done is we look at something like a deductive logic namely the final scenario, what you have is an explosion taking place.

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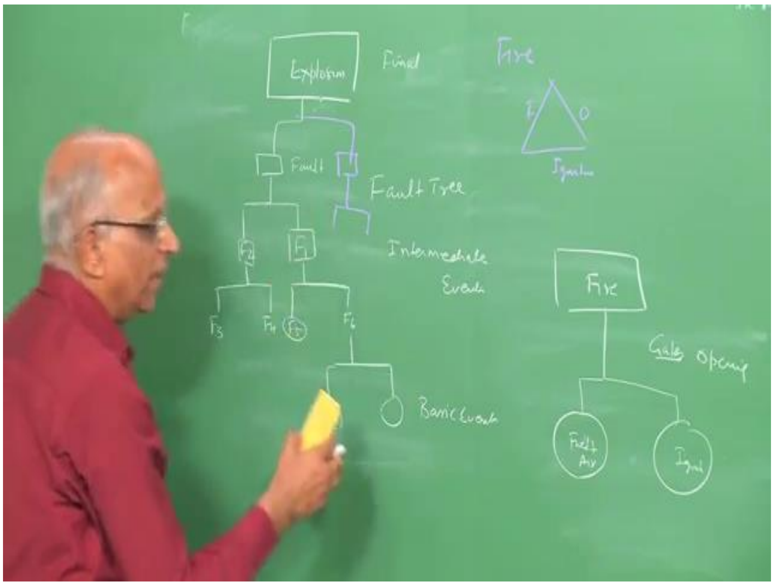

Let us say that the final event is an explosion you know we tried from the start from the final event let us say this is the final event which is an explosion. We tried to identify the faults or the precursor events which ultimately lead to this explosion like for instance may be this explosion could have result out of some fault over here. Some may be mismanagement, some mishandling may be an ignition source coming in contact with the fuel, which it should not have done may be this fault could have come from some other fault. Let us say f 1 and f 2 may be these faults could have come from something like f 3 fault and f 4 fault and some more basic events and so on, this could have come from f 5 and f 6 may be these things could have come like this.

Therefore, we start from the final event and keep working out what are the basic faults which could result in this particular explosion point one point to when we look at the basic events we also say a basic event.

I can always say from generalities like it occurs in nature, so many times like I can put a probability to the basic event and workout the probability of each of the intermediate faults or intermediate events which are taking place. Then, we arrive at the final probability of an explosion, therefore you have something like branching out like something like a tree branching out and it is known this diagram is known as a fault tree. Having said that, you know the events which are ultimately the last set of events which cannot be broken down any further are known as basic events and the intermediate faults are known as intermediate events.

Now, the basic events lead to an intermediate event this intermediate event and this may be a basic event could lead to an intermediate event this intermediate event and some other intermediate event leads to some other intermediate event. This finally, leads to an explosion let us say may be I could have another chain coming over here may be another fault over here another fault over here. Therefore, you have a tree and therefore you workout using deductive logic going from the final event to the basic events let us illustrate it through an example namely let us say I have let us say a fire and what happens in a fire.

Well, I need a fuel, I need a may be both have to mix, I also need an ignition source and therefore, if I say I want to create my fire is my final goal or this is my final event is a fire and let us say my base. The basic events what I have are let us say a fuel and air which are mixed which is available to me which is basic. I also have something like an ignition source over here, well these two lead to my final event of a fire, but how do these two basic events relate to this.

That means there has to be an opening for it to communicate with each other, therefore the basic events and also the intermediate events communicating with the next intermediate events. These intermediate events communicating with the final event is through gates like for instance we enter a house through a gate. So, also gate is an opening and the basic events are communicated to the next set of events through gates or openings there are different types of gates which are possible and that is what makes this particular method essentially very challenging and fruitful.

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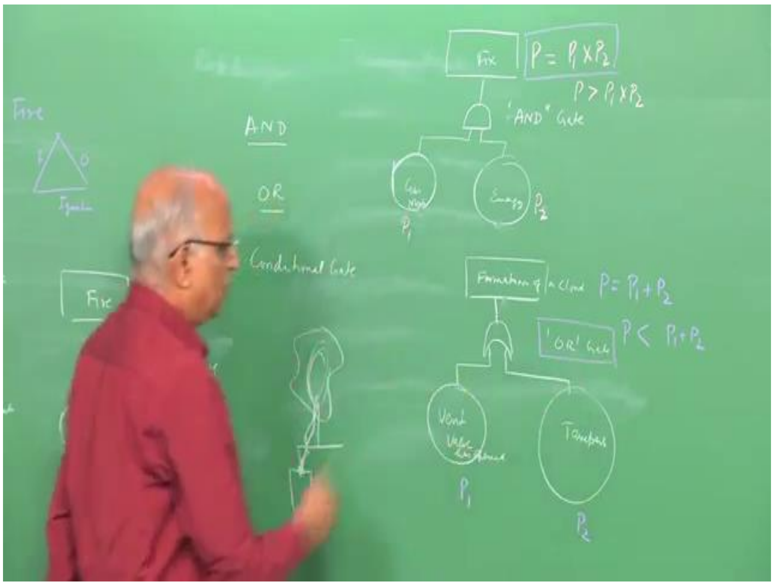

There are three types of gates possible, one is we can talk in terms of an AND gate we can talk in terms of an OR gate we can also talk in terms of a gate which has some conditions imposed on it like for instance we can talk in terms a conditional gate. What do we mean by these three gates are opening by which the basic events gets into the final event. Let us say I have fire to have a fire, I go back to this particular example may be I have a basic event in which my gas mixture is available. I have the basic event in which the ignition energy is available and I am talking in terms of event in which I have a fire taking place you know to be able to form a fire we talk in terms of a fire triangle or an explosion triangle.

We need all the three together we need the gas we need this, then only I can result in a fire. Therefore, we say both of these things are required in the opening to be able to form a fire and this and gate is represented by something like an ellipse with a curve like this is what specifies an AND gate. Therefore, we have something like an and gate we also have something like an or gate or gate means supposing I want to found a cloud of explosive or I am able to form it. The different ways in which this cloud could have been found out may be there is a tank an LNG tank.

In the LNG tank, I have a vent valve which gets opened and well the LNG rushes out mixes with this and forms a cloud. Therefore, one of the basic events, I can talk is may be the vent valve has by mistake opened. I could also think of a situation where in somebody tampers with the some of the check valves over here and allows the gas to pass through that means somebody tampers with your tank and allows the gas to come. My final event I am talking is formation of a cloud, therefore my final event is let us say is cloud formation of a combustible cloud. Now, I find if the vent valve by itself opens, well I could release the gas and I could have a cloud being formed mixing with that if somebody comes and tampers with it also it releases.

Therefore, how is it going to get communicated with the vent valve how is it going to get communicated with the tampering things which is a basic event. It could be either one of them can result in a the formation of a cloud and the forma and this which is either or is what is the or gate and this or gate is shown in the form of a fish. This is an or gate that means either one of them can do the job the third type of a gate which we call is a conditional gate is one in which may be I have an event over here. I have the final event over here this is the final event and before this may be unless the pressure exceeds some limit.

Well, I cannot have the final event taking place and therefore there is some condition associated or rather we say well some condition is associated for the final to go through. This particular gate is represented by a condition under which the intermediate event or the basic event can go the final. That means this is the intermediate case that means the pressure must exceed some limit temperature must exceed or concentration must exceed. This will be the condition and this is known as the conditional gate, we use all these three gates to be able to drawback the diagram of the fault tree diagram, which I just now said, but in practice you know the conditional gates are not that much used.

We will talk in terms of the AND gate and OR gate, but we do recognize the final the conditional gate could also be similar in applications. Now, before I come back to the to the fault tree diagram, let us assume what is the distinction between an and gate in which in which both are required to perform the event in which case on of the two events can lead to the formation of the event.

Therefore, how will I look at it, let us say that the probability of an event that is a gas mixture being formed is p 1, the probability of an ignition energy being available is let us say p 2. Now, the final probability of forming a fire is equal to has to be less than this probability and less than this probability because both are to be equal. Therefore, p is equal to p 1 into p 2 over here in case the formation of the gas mixture is related to the energy requirements which are not possible. In case let us say one of the events basic events is related to this event here, well the probability will be greater than p 1 into p 2 in case of an AND gate what is going to happen?

Well, let us say that the probability of forming the a vent valve opening is p 1 somebody tampering with this is p 2 this can independently give raise to this can independently give raise to this. Therefore, probability of forming this event is equal to p 1 plus p 2, this is probability and in case this is related to this namely the while tampering the vent valve automatically opens or something. Then, in this case the probability of getting final event based on these two event is less than p 1 plus p 2.

Normally, the events are so chosen that they are independent of each other and the probability is given by the p 1 in into p 2 in case of an and gate and p 1 plus p 2 in case of an OR gate. Well, this is about it let us now go back and try to found a fault tree and try to calculate the probability of an explosion. Let us try to do it through an example and the example which I take is maybe forming an explosion from let us say a spill at home.

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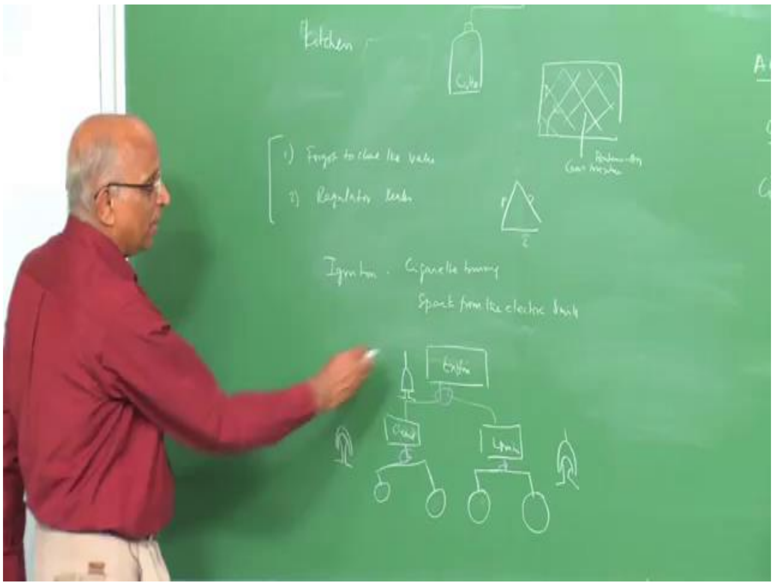

Let us assume I have a kitchen being a winter month that the doors and windows are all closed in the kitchen I have a cylinder a gas cylinder and the gas cylinder we know contains essentially butane C 4 H 10 you have a pressure evaluator. You have a rubber hose connecting to my stove over here and the stove essentially consists of burner heads and you have control valve over here. Therefore, this is a way I light a stove, it is quite possible, let us put down some clauses, it is quite possible that may be the person using the kitchen forgot to close a valve of the stove. The result may be the gas comes and into the kitchen, which is locked which is closed windows are all closed doors are closed may be in the particular volume of a kitchen I have.

Let us say I form a gas mixture, what is this gas mixture may be the butane air gas mixture scenario 1. Scenario 2, you know you have these cylinders which are recycled all the time it is quite possible that the regulator of this gas cylinder is so old may be the person who supplies it gives me a defective regulator and the regulator leaks. I could also form a cloud in the kitchen coming from the regulator leak, these are the two sources of the leakage and well these two sources of the leakage formed a cloud a butane air mixture in my kitchen.

As usual people do not observe it, well the man in the house he is used to smoking he smokes a cigarette while coming into the kitchen. Therefore, the ignition source or energy source could be his cigarette burning or the children in the house they just come and there they find some smelling kitchen something is there in the kitchen. They try to put on a switch and the spark from the switch or the electrical switch can result an electrically spark from the switch can cause the gas mixture to ignite and it explodes. Therefore, we say well in this particular example you have an explosion taking place and the explosion could come either from a gas cloud, which is formed either from a valve which was left open unintentionally.

You also see a regulator can cause this these two are basic events formation of a cloud is an intermediate event. Similarly, I could also have something like an ignition source, which is an intermediate event. This ignition energy could come either of the basic events like for instance a cigarette burning, the man smoking or let us say a child comes and puts on a switch and releases some energy. Therefore, these four are the basic events these two formation of a cloud and this ignition energy are the intermediate events and these two intermediate events feed into the explosion, how they feed?

They have to feed through the gates over here gates over here I have a gate over here what should these gates be let us let us not plot it in terms of the gates we say this or this can lead to this because either the valve opening or a regulator can lead to this cloud. Therefore, I will have something like a gate like this over here, I will have either the smoker who relieve who has the ignition energy because his cigarette is running hot. It can start a fire or it can start the explosion or the electrical spark can start an explosion, I have something like an or gate over here leads to the intermediate event and I will find. Well, now I am left with this intermediate where in a cloud of the gaseous mixture is found, I also have ignition.

Well, to form an explosion, I need both a fuel triangle fuel and oxidizer, which is found over here. I have the ignition source over here, this is also required, therefore I have AND gate over here and therefore if I have to draw the fault tree diagram for this, I will have the following.

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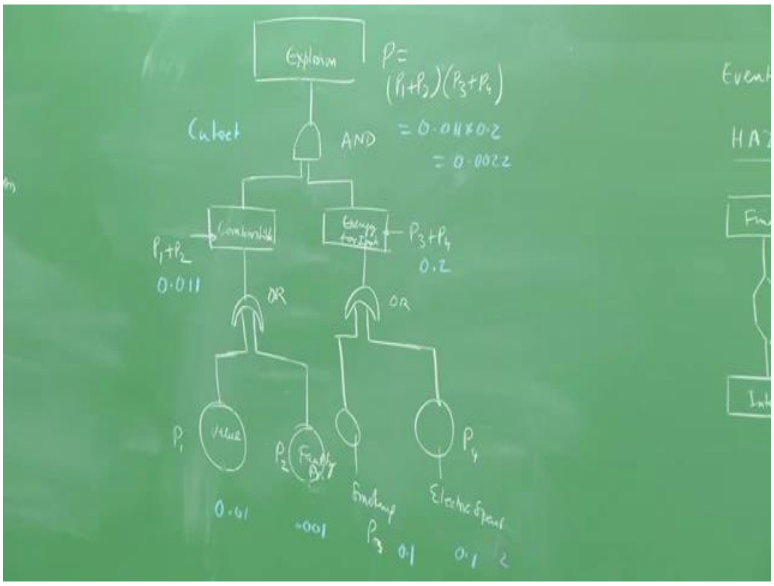

Let us say the final event is the explosion in the kitchen, well I do through it through the and gate and the and gate comes from two intermediate events the intermediate events are having a combustible mixture or cloud one having the energy for ignition. How did the combustible get cloud got formed through the or gate? I have either the basic event of may be a valve of the stove being left open or may be a pressure regulator being faulty. Similarly, I have another OR gate over here and what are the two basic events coming over here one is may be somebody smoking the man in the house smokes and the other thing is may be a child puts on the electrical switch and causes an electric spark.

Therefore, this is the way we are able to get a tree diagram for the final event in terms of the intermediate events and in terms of basic events through an and gate through two or gates. Now, I want to calculate the probability of having an explosion, let us say probability of the lady in the house forgetting to switch off is let us say p 1 probability of the cylinder being supplied with a faulty pressure regulator is p 2. Then, in this case the probability of forming the combustible cloud is through or gate is p 1 plus p 2 and therefore, I come up to this, let us go to this the probability of something somebody smoking is let us say p 3.

The probability of having a electrical spark is p 4, therefore the probability of having an energy release coming from both these things which are through or gate is p 3 plus p 4. Now, I have these two intermediates this is having the probability p 1 plus p 2 energy release has a probability p 3 plus p 4, this is through AND gate. Therefore, the probability of forming the final event or which is the explosion is equal to p 1 plus p 2 into i have p 3 plus p 4. Now, all I have to do is I want to calculate a net probability if I know p 1 p 2 p 3 p 4, I can get my net value of the likelihood of a fire or an explosion. Therefore, let us put down some numbers we will we will try to see normally when we when we do this.

The probability for these things can be conjugated or can be taken from the large number of data which is available the probability of somebody leaving the valve open. You know the absent mindedness maybe tiredness could be something like point 0.01. The probability this is quite low because the pressure regulator there are some standards to which the manufacturer has to associate maybe the gas people have to give better one, but still in some cases they do give faulty one, let us probability is 0.001. The probability of somebody smoking is quite large, let us say 0.1, the probability that the child you know finds something smelling and tries to switch on the switch and see what is wrong could be again let us say 0.1.

Therefore, the probability of having this is p 1 plus p 2 that is equal to 0.01 plus 0.02 over here, the probability here is 0.01 plus 0.001 that is 0.011 over here and that I multiply these two over here, p 1 plus p 2 into this. It gives me a net probability equal to 0.011 into 0.2 which is equal to 0.0022 and this is how we get the probability of finding getting an explosion from these values of probability This is what we do in a case of a fault tree analysis when we talk in terms of fault tree analysis, we find well basic events cannot be broken any further. If I keep on going further and further like this if my length of my faults and progressively increased, then my final probability will probably come down because you know each stage requires something.

If I can calculate something like a lot of process is involved or if the final explosion involves a lot of faults, then probably my probability will be lower 0.1 second. You know the minimum set of these faults is what we call as a cut set.

We know if we can from such type of examples we can also find out which are those pockets or which are those gates or which are those basic events which are the largest value of probability. These lead to higher probability number and we can focus on them to bring the probability or the risk of having an explosion this is what we do in the fault tree analysis having said that, let us take through one more example which I show on the slide over here.

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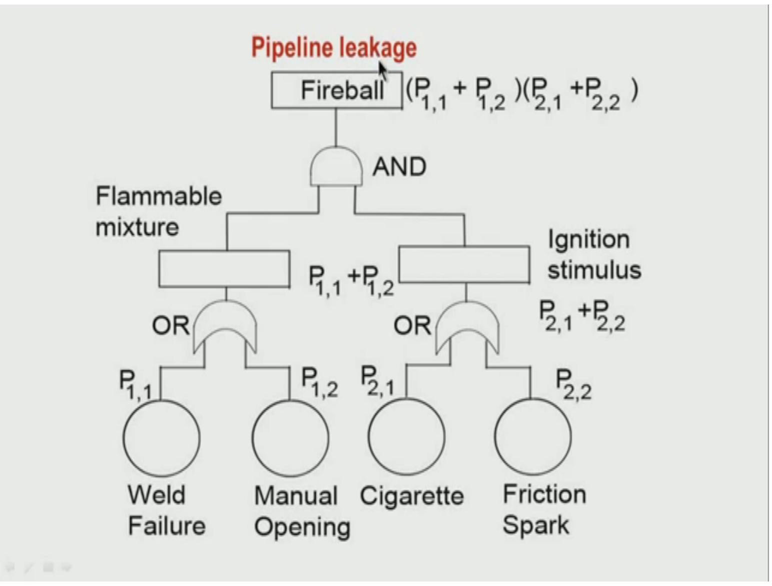

I will consider maybe a pipeline you know we talk in terms of pipeline bursting, we say that propane liquid propane this happened at port Hudson we said in Siberia, we had the LNG in I am sorry gaseous methane line which gave way and there was a huge spill. Therefore, we are interested in finding out the final event is let us say huge fire which results out and how did the flammable mixture get formed. Well, in those cases it was essentially a weld failure, it is also possible that you could have a manual opening you have at some places in the in the pipeline. You have seen the gate valve or valves are there somebody might have might have opened it out. Therefore, you have probability that a weld failure is p 1 1, the probability that a manual opening takes place is p 1 2.

Well, both of them either one of them can result in a flammable mixture that means I go through the OR gate you see the shape of the or gate over here the probability of forming a flammable mixture is p 1 1 plus p 1 2. Similarly, maybe along you have a gaseous cloud, somebody can walk with a cigarette in his hand and ignite the cloud and this has been the case in case of most forest fires all over the country in different places. Well, cigarette seems to be a cause of hmm majority of the fires, I could also have a car which travels next to the leakage line. The friction spark because of the car tire hitting some stone or hitting the road or hitting some place create a spark the probability of having a cigarette burning is p 2 1 p 2 2.

Therefore, the possibility having an ignition stimulus is p 2 1 plus p 2 2 being a or gate and I need both these things. Therefore, I have an AND gate which communicates to my final fireball and I have the probability be p 1 1 plus p 1 2 into p 2 1 plus p 2 2 that is the summation of these probabilities. The summation of these probabilities multiplied together is what gives me the final probability and this is how we do the risk analysis for in involving a fireball an explosion.

In other words we try to go from top down through a deductive logic come to the basic events and keep on progressing till a final explosion is formed. This is what we mean by a fault tree analysis it is very successful it has been applied for space for being able to find out what is the what are that defects which could have which could lead to a loss of machine.

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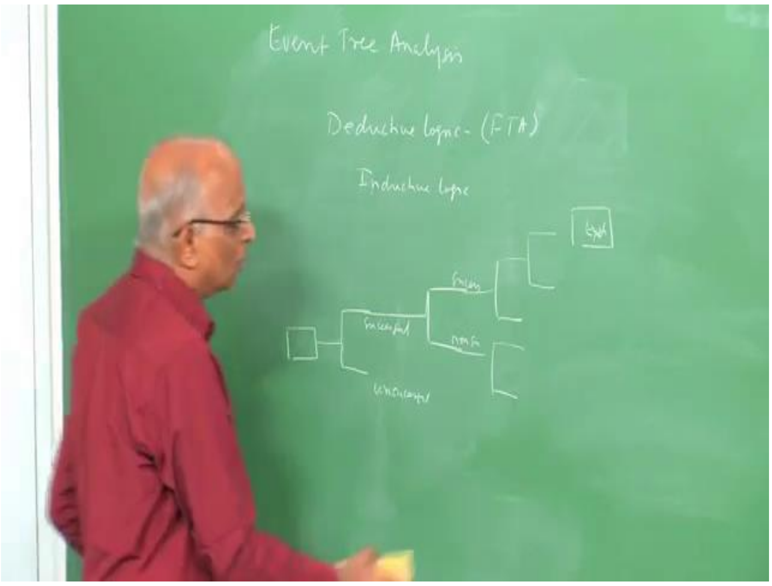

Having said that, let us go the next one namely the event tree analysis you know this is also something like a tree, but rather than using the deductive logic which we use in the fault tree analysis. We use the inductive logic what do we mean by inductive logic what we do is we start from the basic event and proceed further till we get the final explosion. How do I do this? Let us again take a look at it let us say my basic event is over here and I start from the basic event I go to the next event may be the basic event could either outcome could be let us say a successful event or unsuccessful event. Let us say what is it I mean may be the I have a gas mixture, it either ignites or does not ignite successful non successful.

From this successful, I could have again another success over here other nonsuccess event over here I could again have another success or nonsuccess, I could again have another one and so on till I have my final explosion. Therefore, I march from my basic event till the final event which is an explosion and this is what is done in an event tree analysis for each of them I could have a probability of this happening over here. This leads to this probability here this probability leads to these two probabilities here and I calculate my final value.

Therefore, what is done in an event tree analysis is let us try to put it down, I have let me take an example and nothing better than through examples we study let us take the example of an LNG in a pipeline catching fire and exploding.

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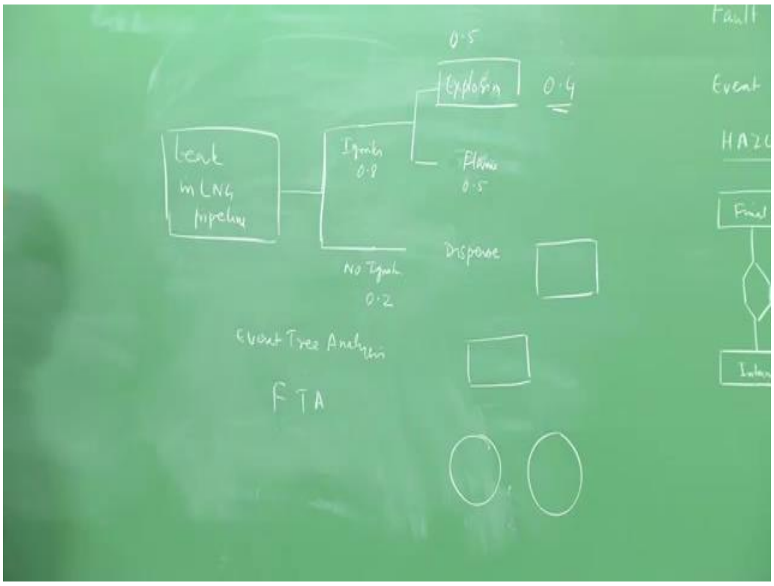

Therefore, let us say there is a leak in LNG pipeline conveying a pipeline conveying LNG this is the basic event well what happens is may be the LNG leaks forms a cloud and the cloud either ignites or it does not ignite no ignition is point one. The gas that ignites could either explode that means forms a strong blast wave that means it explodes something like a detonation well it just forms a fire and burns out. Let us say that means it forms something like a fire or a flame when it is no ignition, let us say just disperses out I will come back to this a little later a more better example of even this a disperse gases can again create a havoc.

Let us just put down this, therefore we say well the final event is an explosion just to illustrate this is the explosion in this case it burns out no harm is done. Therefore, I want to calculate the probability of this therefore, I say the probability that an LNG pipeline coming out and ignites is quite common may be in summer month I have a cloud.

Definitely, it is going find an ignition source, let us say the probability is 0.08, then no ignition is the balance 0.2 is the probability that it does not ignite. Well, it just disperses off when it ignites well the possibility of having an explosion if there are lot of blockages like trees buildings and all that. Well, the probability is 0.5, well the probability of getting a flame is 0.5 well the probability of forming an explosion is 0.8 into 0.5 that is 0.4 is my probability of forming an explosion. In other words, we start from the basic event go forward and go forward till we reach the explosion and this is what we call as an event tree analysis.

Why in the fault tree analysis, we denote the basic events in circles and the intermediate events by rectangles and the final act final event by a rectangle in case of the event tree. We show all by rectangles and just keep on multiplying the probability till we come to the final event. Let me take one example or more strategic example more illustrative example of having some more links in the event tree and this I show in the slide over here.

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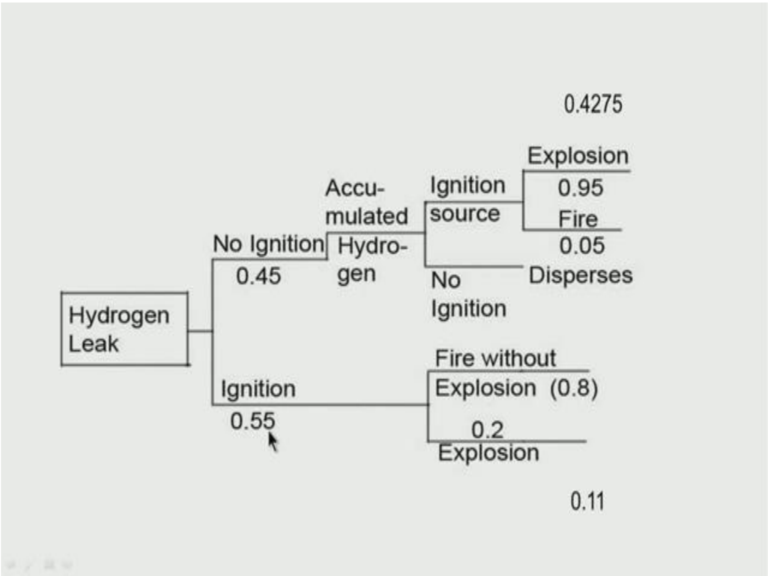

You know I am considering the case since there is so much interest in hydrogen you know supposing there is an hydrogen leak the hydrogen leak comes out. There are two possibilities, either it finds an ignition source and gets ignited the probability of this ignition is 0.5, it does not find an ignition source. Therefore, it gets accumulated let us assume in this particular example that a cylinder of hydrogen is being carried through a tunnel and this tunnel is a long tunnel. Therefore, in the tunnel the hydrogen leaks like what happened at stock home in the in the down town area, there was an hydrogen leak and therefore you know may be it does not ignite the hydrogen.

It accumulates within the tunnel or within the space and this accumulated hydrogen after some time finds an ignition source and if when it finds an ignition source, it could either explode or it could form a fire, but the accumulated hydrogen is more dangerous because it has had a lot time for it to mix and prepare itself. Well, when it catches when it burns in a confinement well it is generally going to explode rather than form a fire. Therefore, the probability of forming an explosion is 0.95 while forming a fire is lower at p0.05 or may be this accumulated hydrogen does not really meet an ignition source. It just disperses well the hydrogen leak which immediately ignites well, it burns without an explosion.

That means as a flame the probability of this is higher because it immediately ignites therefore, it just catches fire and the probability of having an explosion is much smaller at 0.2. Therefore, you find in this case if the hydrogen leak immediately ignited the probability of forming an explosion is 0.5 into 0.2 which is equal to the net probability of an explosion is 0.5 into 0.2 which is 0 while it forms an explosion here ,well no ignition probability is 0.45 and 0.45 into 0.95 gives me point 0.4275.

Therefore, this accumulated hydrogen is capable of having a higher probability of an explosion compared to the hydrogen leak which immediately ignites. Well, this is also a case of an event tree you are going from base to this, but we do find well you should not really accumulate gases especially in confined geometries or semi unconfined geometries like let us say a tunnel or so in which I would have an explosion.

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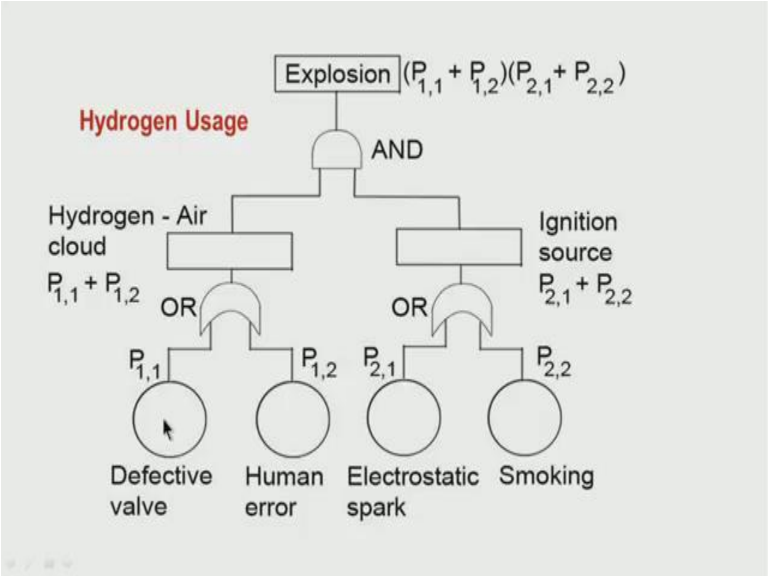

Getting back to something on another example involving hydrogen usage using fault tree is maybe I could have a defective, I could have a tan gage of hydrogen having a defective valve a human error in opening the valve forming a hydrogen air cloud. Its probability through the OR gate is p 1 plus p 2 over here, I have ignition source it could be electro static spark as we said smoking earlier, I could have probability here p 2 p 2 1 plus p 2 2. You have an and gate and the net probability of forming an explosion through the fault tree is this and this and this is the basic difference between this example and an example having the event tree.

Therefore, these are the two methods with which we evaluate the final probability of an explosion, but more importantly we also find while going through the paths which are the paths which are more likely. We try to plug in those things and ensure that the final event of an explosion does not take place with this, let us come to the last part namely the Hazop analysis and what is Hazop analysis.

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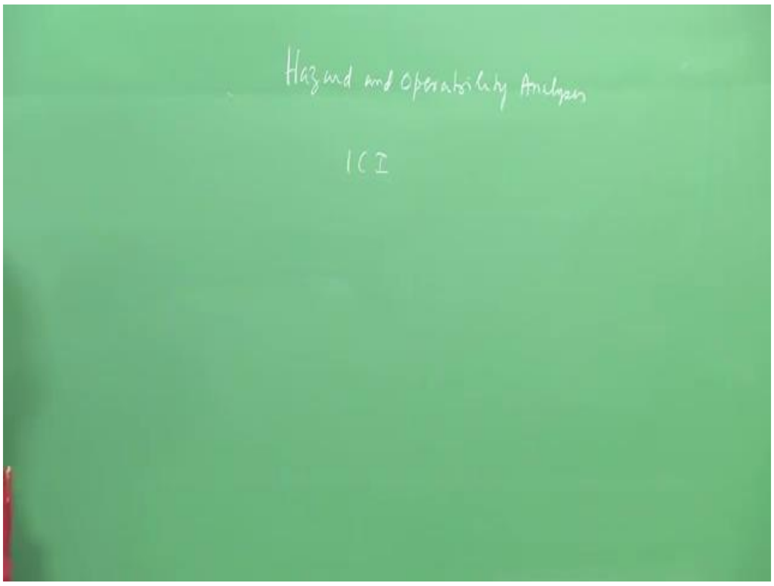

Let us just put on the board, we have hazards and operability analysis; actually you know this got started with chemical engineers in the imperial chemical industries in UK. They wanted to apply it for may be making the plants more safe namely the chemical plants. And therefore, what is done in this method is little different le let me take you through the discussions on the slide.

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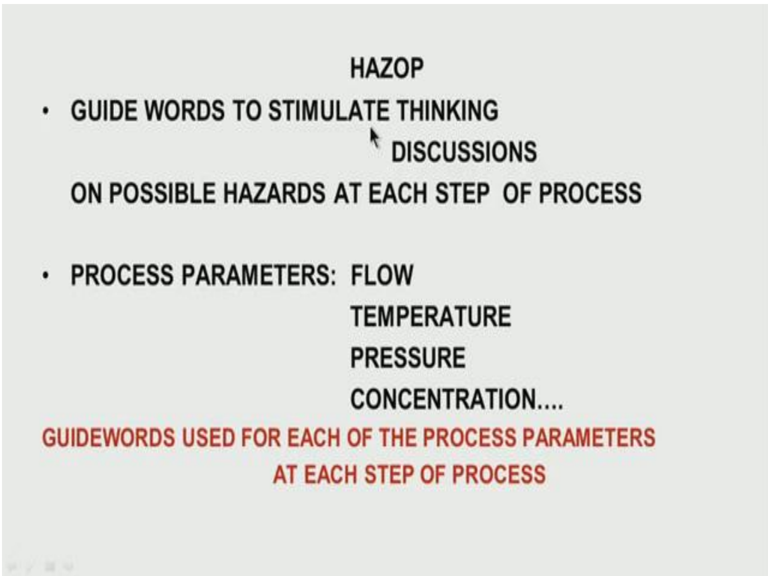

You know in this what is done is may be people sit through on a table discuss what are the different things which can go wrong, but to be able to think and discuss a suitable number of guide words are given with which they can stimulate their thinking. We can discuss on the different types of processes which are possible which can lead to something going, which cause which will cause an hazard. Therefore, to stimulate thinking and discussion on possible hazard on each step of the process are what is done and what they do is for each of the process parameters or each of the processes.

They say what are the process parameters and what are the process parameters normally well we talk of flow so much mass flow rate or so much volume flow rate. We talk of temperature, we talk of pressure, we talk of concentration, and we could talk of some other process parameters for each of these process parameters. We use certain guide words to find out whether some of these we want to see find out whether some deviations in these process parameters and can result in something like a hazard. For that let us take a look at guide words that means at each step of the process we look at may be the flow or the temperature the pressure the concentration using some guide words.

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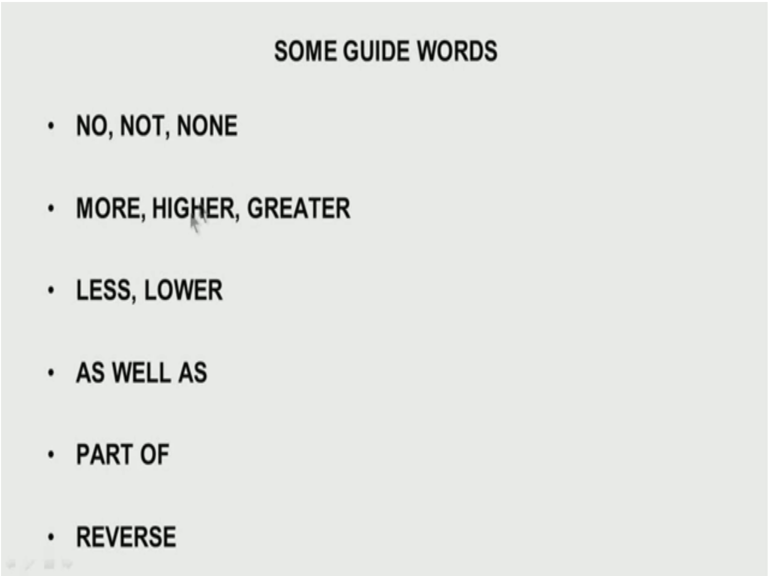

What are the guide words, guide words are no not none first guide word second guide word is more higher greater, third guide word less or lower fourth guide word as well as fifth guide word part of the sixth guide word reverse and so on. Different guide words when I say no not or none, what I mean is implying that there is no pressure that means if I go back the process parameters are there is no flow, there is no temperature, there is no pressure there is no concentration what would be the consequence? Similarly, if I say guide words more higher or greater, what I mean is well the flow or the pressure becomes larger.

When I say less or lower, well the flow rate or the pressure or temperature becomes lower when I say as well as I mean qualitatively additional change is taking place when I say part of it means a qualitative decrease. When I say reverse, well the flow takes place in the reverse direction, just the opposite of what we want to do or logical opposite.

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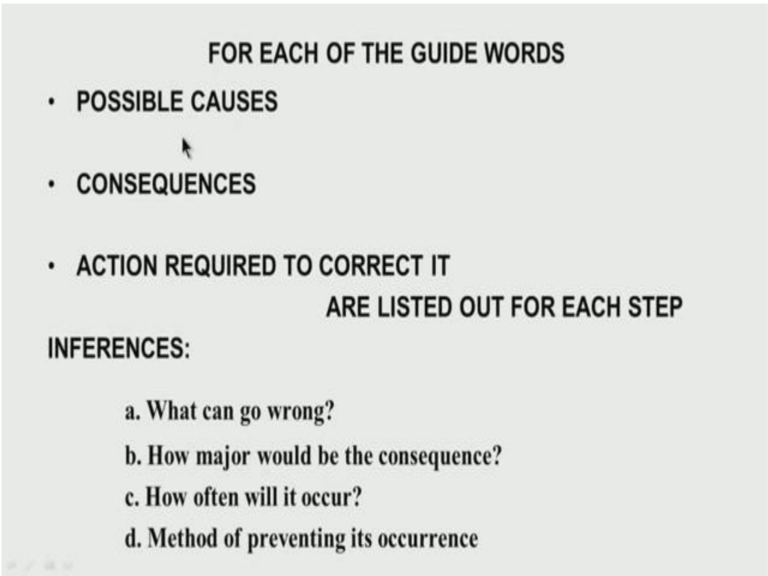

Therefore, using these guidelines and the process parameters what is done is we try for each of the guide words find out well if the flow has to stop or if there is no flow what are the possible causes which can lead to this. Maybe, if there is no flow, what are the consequences which will be there and if there is no flow how do I correct for it and keep listing out at each step of each of the sub processes. We keep doing this for each of the guide words namely no flow higher flow less flow may be part of the flow may be reverse of the flow and so on.

For each of the process parameters you keep looking at the possible cause causes possible consequences and then based on all the listing which is made may be make may be make a set of inferences. Then, what can go wrong how major would be the consequence how often will it occur. That means the frequency of occurrence and based on all the listing done how to prevent it occurring these are the inferences which are done based on the guide words as applied to the process parameters.

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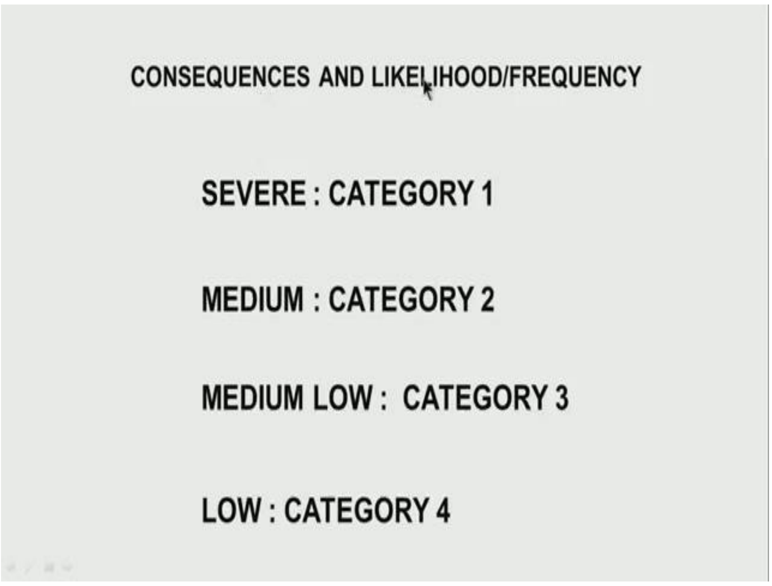

Once this is done, you know we are interested in the consequences, we are interested in the likelihood of the explosion occurring or the frequency. Well, if you find that the consequence is severe that means based on the guide word based on the different process parameters. If we find that the consequence is severe we say it is category one if the consequence is medium we say it is category two. If the consequence is very low something like not medium, but low side of medium we say category three and if the consequence is very low that means hardly any consequence we say category four.

So, also when we see the likelihood of the occurring of the explosion or likelihood of occurring of the final event which is undesirable that means likelihood is something like frequency. We can also catalogue the frequency as being category one when the frequency is large when the frequency is medium category two when the frequency is low medium, we say category three and then the frequency is low as category four.

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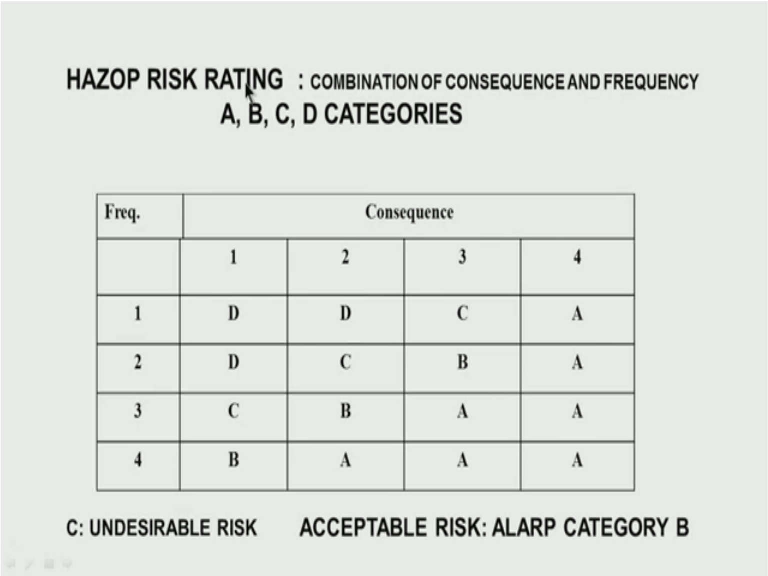

Freq.	Consequence			
	1	2	3	4
1	D	D	C	A
2	D	C	B	A
3	C	B	A	A
4	B	A	A	A

Therefore, these consequences and the frequency are put together in the form of a Hazop hazards and operability risk rating procedure where in both the consequences and frequency are put together to get the net risk rating as either A B C or D categories. How do we do this, well we say consequence one is most severe and if the frequency is also very severe we give it the grading d which is a grading which is a bad grading the risk is very high. Well, I should not go ahead with it if the consequence is let us say medium low and if I say well the frequency is still higher.

That means the frequency of occurrence is still very high, but the consonance still I give the grading low because the frequency is going to occur even though the consequence is less. I still have the problem if my consequence is low medium low and if the frequency is still high, well I cannot operate it because my plant is going to be always shut down because of frequency of occurrence is very large. If my frequency of occurrence is let us say if my consequence is somewhat very low and the frequency is higher, maybe I could still tolerate it because you know it may just result in minor shut downs. I can do it therefore, according to the consequence and let us take may be consequence one.

If consequence is very high, but the frequency is let us say very low, you know you still have a high value of b because the value the b is something which is acceptable, you know once in a way you have a high consequence. This is something which is not very desirable because if I have something like a Bhopal gas tragedy, which occurs which happens once in life time. Well, the consequences are very ABD, therefore B is something which can be acceptable risk.

That means it is as low as reasonably practical it is category B, but we have to take some steps such that we make some checks and balances such that we tend to operate a plant when it is under category B, but we make sure we do some checks on it. The others are all in between when I say that the frequency is very low at four consequence is very low at four. Well, there is no issue at all this is the safe that is no risk involved when I say risk c is undesirable risk may be I have to improve my plant operation. If I say risk is d, well it is a risk v in which it is not worth undertaking this risk is not to be pursued on. You must improve the plant to either B or preferably to A B is acceptable risk and as I said earlier as low as reasonably practical and this is category B.

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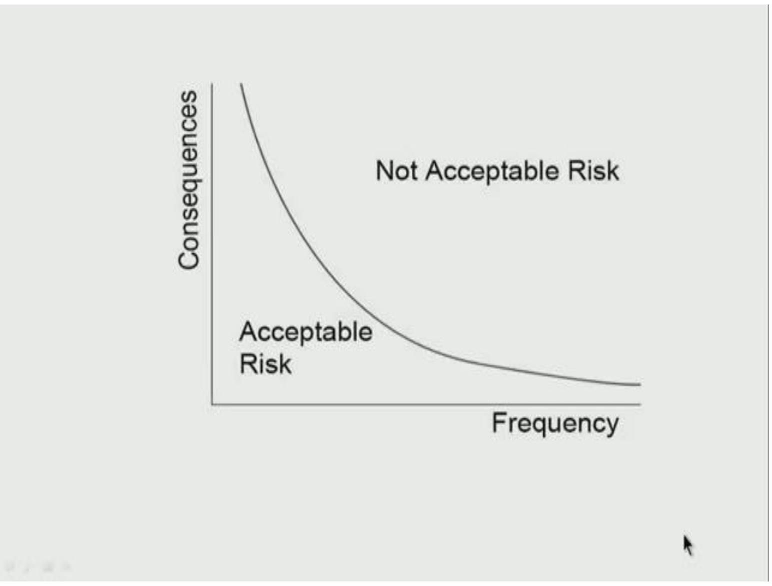

We put all these different categories in the form of a plot in Hazop that is the hazard and operability analysis and what we have is I show the consequences here the frequency over here. What I find is if the consequences are very large well the thing is unaccepted the if the consequences are very large, but the frequency is very small then may be after some checks I still have to accept it if my frequency is very large. The damage is or the consequence is very small, well I have to accept it this is the region in which I have acceptability that is region B over region C.

I am sorry region B is what we said earlier we said acceptable is B, we have region B over here and this is the region C and D, which is not really acceptable. Therefore, the Hazop plot gives a gives the gives the acceptable range of consequences and frequency and this is what is done in Hazop analysis namely you evaluate the consequences. You evaluate the frequencies and put everything together in terms of A B C and D categories and evaluate the risk in these four categories and this is what is done in Hazop analysis.

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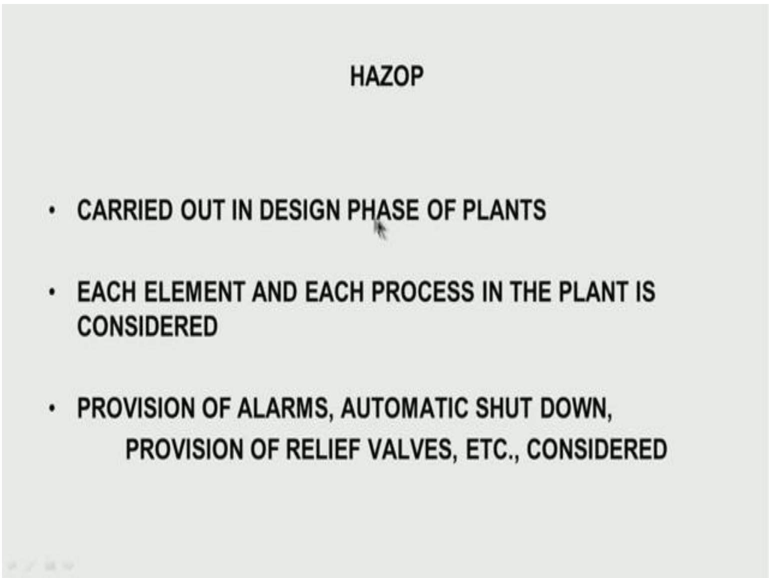

We must remember that the Hazop analysis is carried out may be even before the plant gets commissioned. During the design phase itself we sit on each of the processes of the plant and make sure that no untoward thing is possible each and every element in the plant is considered. Also, maybe provision of alarms automatic shut down automatic starting provision of relief valves etcetera are considered while doing the Hazop analysis and this is the third type of analysis namely Hazop analysis.

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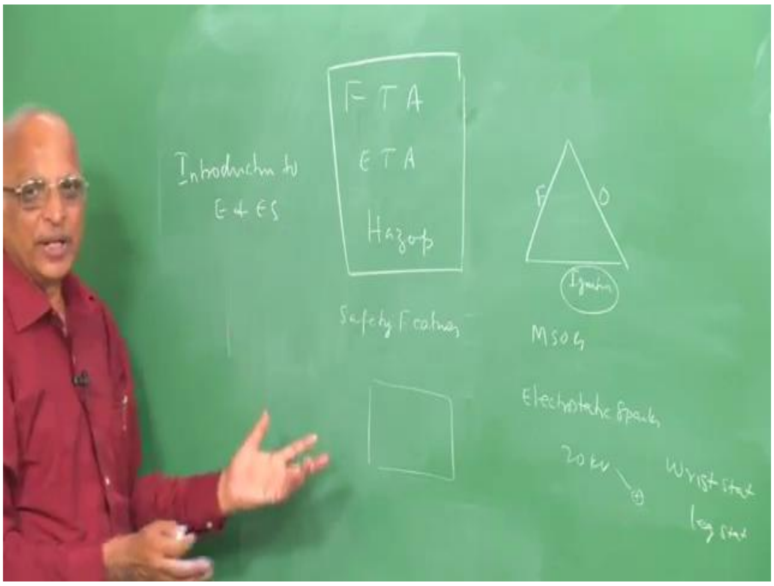

Therefore, to summarize we in this class have done something on risk analysis evaluating the risk through three methods namely the fault tree analysis second the event tree analysis and thirdly the Hazop analysis. These things give a good picture on what is the final probability of an explosion taking place what are the safety feature to be put. While talking on safety features something which we have to keep in mind is whenever we talk of explosions of the explosion triangle may be fuel may be an oxidizer maybe an ignition source we talked in terms of inserting we talked in terms of critical diameter. We talked in terms of maximum safe operating TR operating gap such that an explosion does not occur and does not get transmitted to something else.

When we talk of ignition you know it is possible to inert it is possible to went out the gases it is possible to build in the safety features, but when we talk of ignition sources especially when we talk of electrostatic sparks you know it is possible. You know I work in an environment, I walk the human body can get charge to an voltage of 25 kv and may be my body when it is charged and I touch something, it can also create an electrostatic spark. Therefore, from safety point of view may be if I can wear something like a on my wrist some something a chain which is on the ground, which conducts away the charge, I have something like a wrist stat or something like leg stat on my leg, I have a chain which is in contact with the ground and it gets grounded and no spark is formed.

Well, I can avoid electrostatic sparks, but we also can remember if I have a room and if it is more humid electrostatic sparks are more unlikely. Therefore, we must have device means by which I can isolate an ignition source from an from the combustible mixture and even the combustible mixture by suitable inserting. When I have an explosion taking place by suitably venting out I can decrease the degree of the consequences of an explosion. Therefore, this is all about the course on introduction to explosion and explosion safety. We covered the different aspects including the safety aspects the consequences the reasons for causing an explosion and how to go about preventing an explosion.

Well, thank you.

Announcement, please the last set of lectures between lecture numbers thirty three to forty covered condensed explosives the TNT equivalent of explosives and their yield atmospheric dispersion quantification of damages and risk analysis. Further references on these topics and a few homework problems are given in the downloads of this video course.