Industrial Safety Engineering
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Lecture – 15
Event Tree Analysis (ETA)

Hello, welcome to this lecture. Now, we will discuss Event Tree Analysis.

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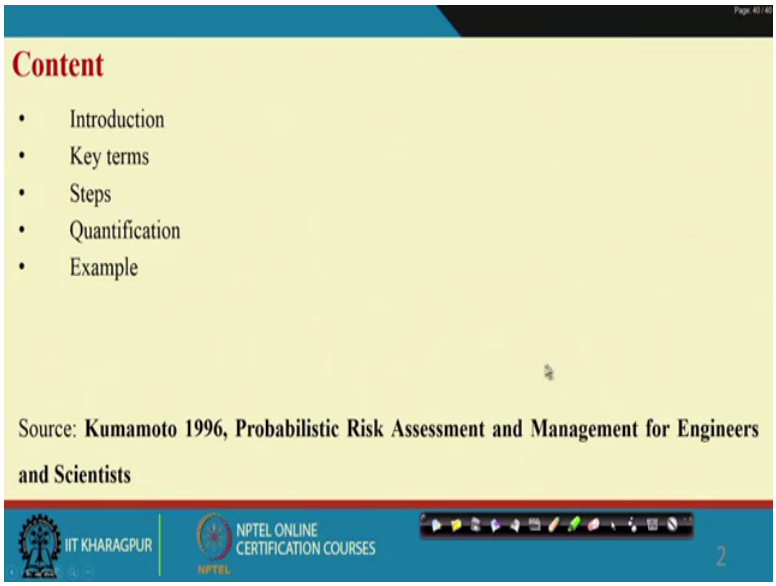

So, the contents of today's presentation: introduction, key terms, steps, quantification and example. You can go through the book Probabilistic Risk Assessment and Management by Engineers it is Kumamoto and Henley.

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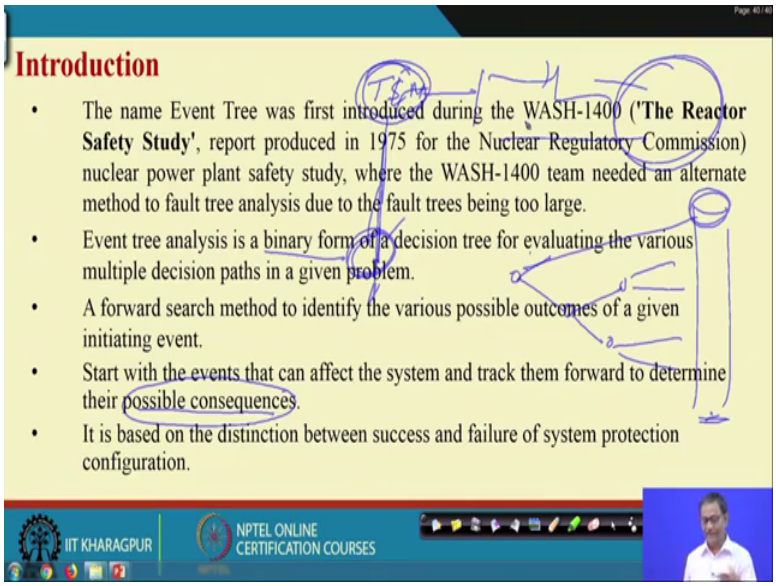

So, let us see the some historical issues that the Event Tree name was first introduced during the WASH-1400, report produced in 1975 for the nuclear regulatory commission; this is basically the reactor safety study. And, it is basically the WASH-1400 then nuclear power plant safety study and WASH-1400 team needed an alternate method to fault tree analysis due to fault trees being too large.

Obviously, you have seen already that for the simple gas oven in a kitchen the fault tree is we have developed and we have seen that the fault tree yy nature, it can become a very big one if you consider large system or even a medium large system also; what will happen fault tree that decomposition up to the compound level it will become so cumbersome. So, then it could be also as fault tree use deductive approach, so it is very very it will be very difficult to handle. So, people searched for that alternatives that can there be some alternative which will which may do the similar thing, but in uses some kind of approach like inductive approach.

So, that event tree is that inductive approach and it is basically a binary form of decision tree when you start with a event and then ask what will happen next given a system configuration. Then, if the system configuration successful something will happen if it is failed then something else will happen by system configuration I do mean; that means, given an event occurs the there may be one a sub one component or subsystem which will ultimately and ultimately what I can say response to that state. So, that response can

be a successful response can be a failed response. So, as a result there is binary form that fail or failure or success.

And, you go forward in that manner at every if the first that means, configuration or first layer fails then what is the second item or second subsystem which will act depending on the first one fails. So, then there also failure and success will take place and eventually you will have a have a tree like structure. Suppose, in the kitchen there is leakage of gas so, then there must be detection system. So, detection system may be successful or failure and again if decision system is successful then what will happen the immediately that means, the some actions will be taken and that other actions will become successful or failure and in this manner it will continue.

So, finally, at the end you will find out lot of branches and this branching at the end you will get lot of states these are known as accident states with reference to event tree analysis and with reference to safety studies. If it is not safety studies some other kind of study there also you can use this branching and end states will be called the scenarios. It is a forward such method, start with events that can affect the system and track them forward to determine the possible consequences.

You see the difference between fault tree and event tree. In fault tree giving a top event we try to find out the causes and then we dig down using deductive approach and we have gone up to the bottom level causes, that is the basic events and event tree we are not going to that. What we are happen what willing if something goes wrong in a system what is next; that means, the consequence of that going wrong. So, that is the difference.

So, fault tree top level mishap and you dig down and event tree if that suppose if that mishap happen how system will be and what will happen next. So, consequence side is usually taken care of by event tree and causes side usually taken care of by fault tree. Now, if someone not use the top level may be at the some bottom level failures they will start from here. Then also from here also similar branching is possible means event tree can do the work of fault tree also, ok. So, that is why it is alternative approach it is developed.

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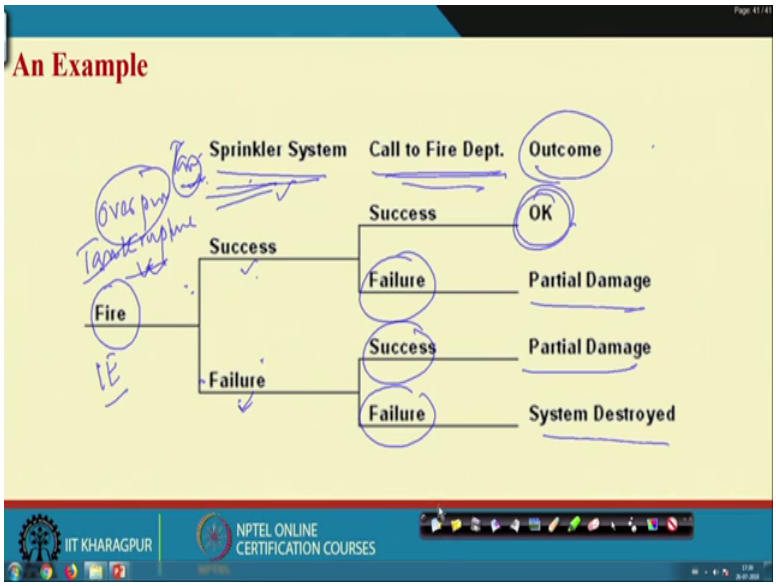

Let us see one example first – fire: this is top event, now it is we want to explore if fire will occur fire what way the system will be behaving against the fire. There will be sprinkler system then sprinkler system may be successful, may be failed. Is sprinkler system successful that time what will happen, you can you can call the fire department also depending on the quantum of fire and they will come and they become may be successful and then outcome is means maybe minimal damage.

If sprinkler system work fire department does not come then there will be partial damage because of sprinkler system works is sprinkler system fails fire department successful then what will happen it may be partial damage and if it fails and this also fails system will be destroyed. So, what does it mean means there is an initiating event, fire. What is the need of considering fire as initiating event? There is no need you can go back and also see some other things that may be the fire initiating event.

For example, I can replace this by tank rupture. If tank rupture takes place how the system will behave? That will be the system behaviour will be will be branched using binary class success – failure, success – failure you will get the end outcomes. Someone may say I will not start with tank rupture as the top event maybe some rapture over pressure. When over pressure is there then this tank rupture will be a will be the tank will be behave against over pressure. So, here will be tank will be coming and then after tank if tank rupture will be there or not, failure means rupture not means not means there is no

failure; if rupture then again it will continue so, like this.

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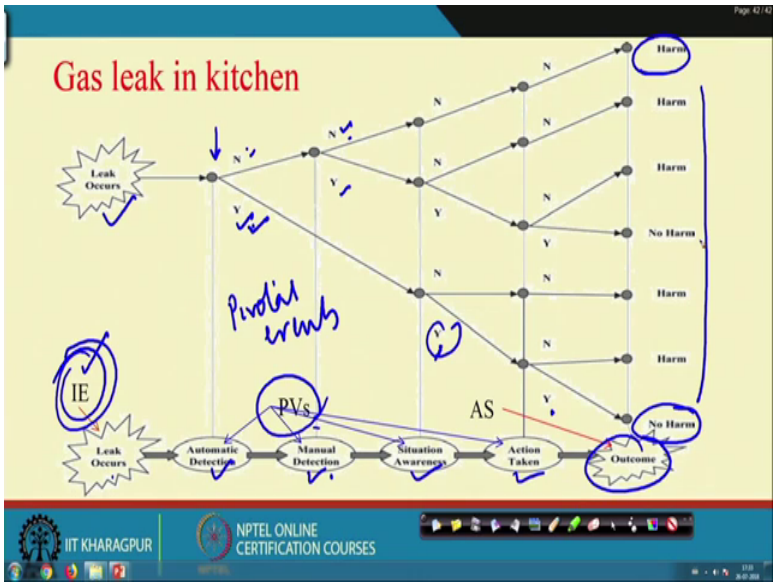

So, essentially what happening here you are basically using some inductive approach in the case of leakage, what is there? You see, leak occurs. So, if there is leakage there must be detection this is the first level behaviour. So, is there automatic detection? Suppose, yes or no; yes means success, no means failure. If automatic detection fails is there possibility of manual detection? That can be no or yes, it fails. If manual detection fails then no situation awareness is also not there then action will not be taken. There will be no situation awareness action will not be taken there will lot of harm will be there.

Suppose, leak occur manual detection automatic detection, successful then manual detection here is not required, so, automatic detection then situation awareness. You are aware of the situation what will happen? If yes then what will happen fine, but you are aware of the situation the leakage can cause harm, but whether action taken? If yes, there is no harm. So, that mean what happen there will be there will be different in state from no harm to harm and this is what is basically branched here.

So, start with the particular event which is known as initiating event which is leak and then what happened, in order to because the system once the equilibrium. So, what system will do system will behave if leakage is an disturbance, it is a deviation. So, system wants to fight against it. So, if positively fight then it will be lead to no harm case, if fail the it will go to harm state. So, that means, the system level different

different measures like this automatic detection, awareness, actions they may fail they may be successful. Depending on which one is successful at what time and the severity of the means the end accident states will be like this. So, this initiating event and the accident scenario the last one the outcome in between whatever acts whatever events occur they are basically known as pivotal events.

So, initiating events and these are PV means pivotal events. So, initiating events start the situation or lead that will lead to final accident states and pivotal event for against this initiating event and it may be successful may be failure. And, depending on the that success or failure and their combination different in scenarios will be generated and the event tree is used to find out this path up to end state.

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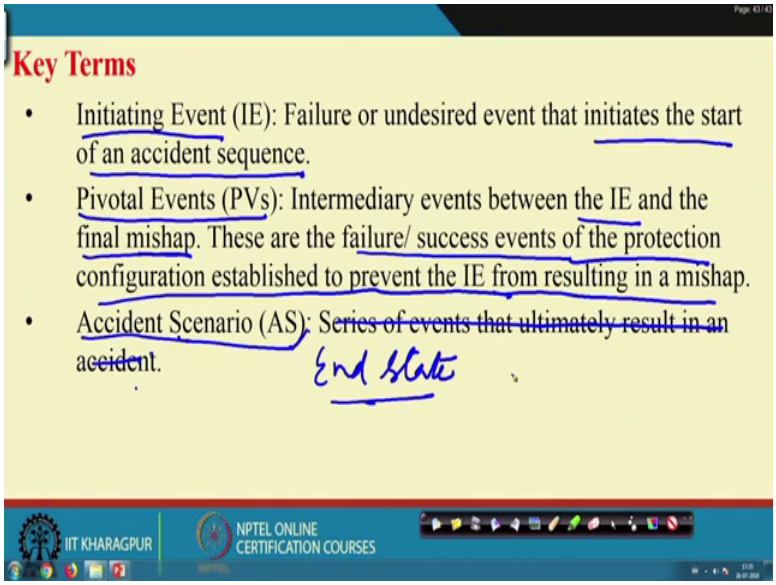

So, some terminologies; one is initiating event: failure or undesired event that initiate the start of an accident sequence. What are pivotal events? Intermediary events between the IE and the final mishap, that is the final outcome. These are failure or success of events of the protection configuration established to prevent the initiating event from resulting in to mishap. You can very easily relate this to my hazard triangle where what I have said there will be some initiating event and after that there will be lot of mechanisms, hazard element will be there will be starting point lot of initiating mechanisms in between mechanisms these are all pivotal events. So, that will take place and finally, the chain will be or the all the failures all the holes will be lined up final mishap will take place.

So, event tree is a technique that gives you gives you those paths, ok.

And accident scenario is another one series of events that ultimately result in an accident. So, actually this is accident scenario is the basically end that the end state end state. So, it is not series of events this since it is end states. What happen, whether it will be safe it will be unsafe or it will be partially damage something like this those end states are accident scenario approach.

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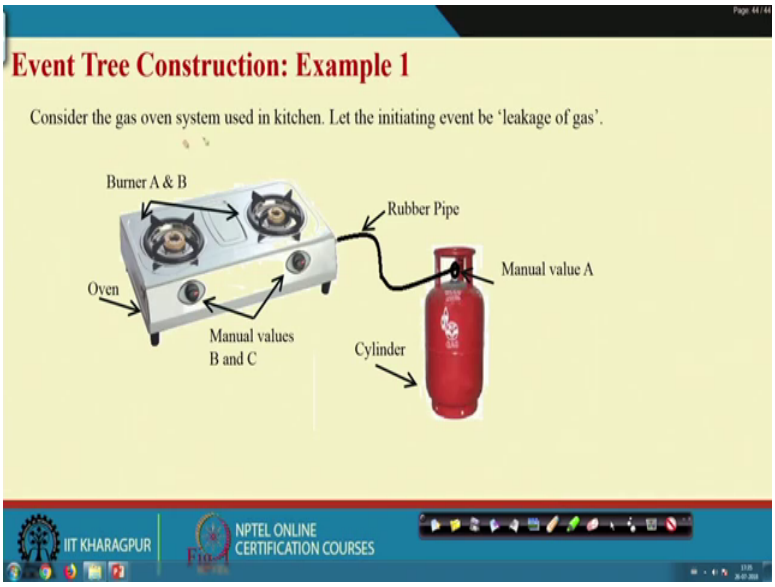

Now, let us see this. This example we will explain in. So, you know all those things, I will not explain it further what is it.

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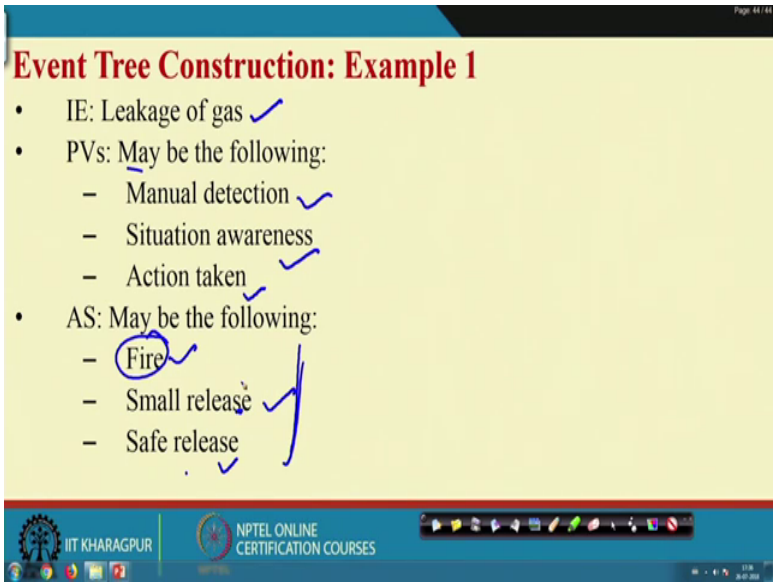

So, now, let us see initiating event is leakage of gas. What are the PVs? Manual detection, situation awareness and action taken, this is what is the system given. There is no automatic detection. What are the accident scenarios? There can be fire, there can be small release, there can be safe release. So, how do you find that these are the accident scenarios?

We have used event tree and depending on and we know if the pivotal events occur that mean the manual detection fails, situation awareness fails, action taken fails and as you have the have the hazard knowledge design knowledge and lessons learned already. So, you will be able to find out under which path fire will occur, under which path say release under which path small release will be there. This is a simple example, but the concept and philosophy holds for even complex example.

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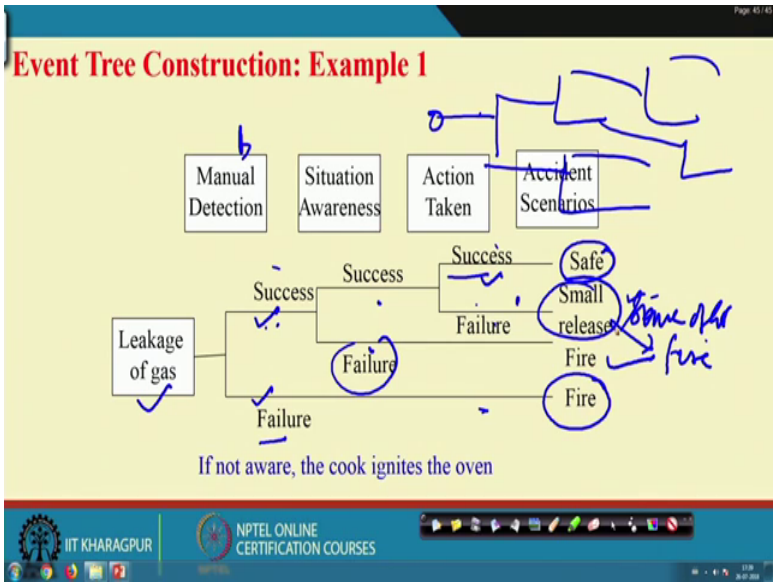

You see, leakage of gas, manual detection success, manual detection fails. If manual detection fails, these things will not happen. So, as a result it is the fire situation. Leakage, obviously, there will be there will be fire source so, ignition source. So, then leakage of gas manual detection successful, but the coop there he does not know what is happening he is not aware so, failure lead to fire. Then if this is success action may be taken, may not be taken if action successful safe, there is no fire. If action is failed then small released of gas will be there means some actions are taken fire is mitigated, but release of gas is already there or maybe some other scenario some other scenario, you may say this will lead to fire also.

The job your job is here to understand given an initiating event how the protection configuration of the system work; means protection configuration is not a only a single layer or single barrier, it will be multiple barrier may be in sequence one after another. And, then first barrier if first barrier fails this is barrier one first barrier fail what will happen, you must have the system knowledge that knowledge. If first barrier is successful then the second barrier may fail if second barrier is successful third barrier may fail may be all that that branching will take place. So, lot of branching will be there.

So, now here what happen leakage of gas then failure I said the early fire, but even if manual detection failure case there can be another kind another branching possible if your system configuration uh is such that there are certain responses which lead to

another kind of branching, ok. So, we start with first branching second branching it would be multiple branches, but usually under failure case the branching is not done because it is obvious that if the first level fails may be the second level an onwards they may not may not be successful, ok. Ok, but please remember this is this is the concept only, whether you end this and this here you do not do branching or you go for branching again you work brainstorm with the team and find out, but this is what is the procedure.

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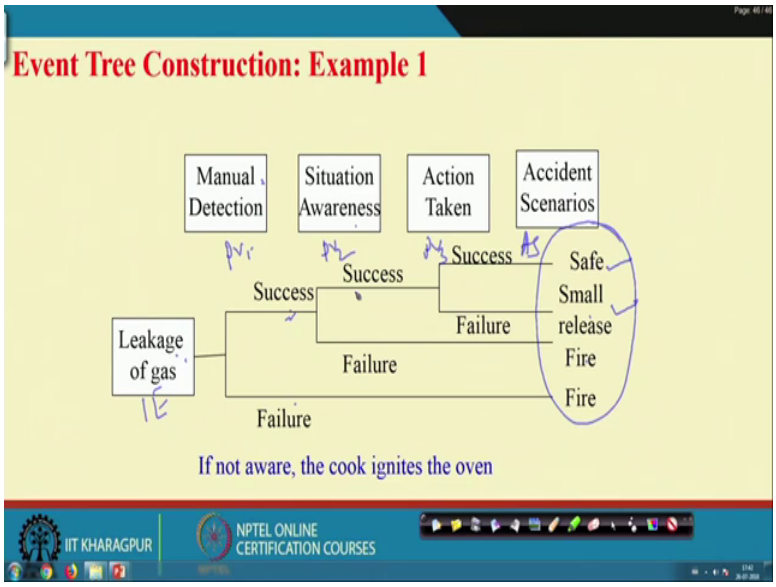

Now, you have seen that that I have I have this many accident scenarios. So, for the time being let us consider this is correct. So, there will be safe there will be some small release safety means almost negligible release where nothing will happen. Small release; so, what happen, you that people will be out and then the that place will be slowly that gas will be evaporated or gas will be dispersed and otherwise there will be fire; so, three things 1, 2, 3.

With these example we I want to show you the quantification, ok. What is the quantification here? You see there is one initiating event then pivotal event 1, pivotal event 2, pivotal event 3 then accident scenarios like this. Now, if these events occur then this one start now, if the success and failure of these depend on these, then that is conditional. But, irrespective of what happened when it ultimately start working then what happen then they will be independent if success and failures does not depend on the amount of gas release released leaked.

A small gas manual detection is not successful only for large amount of gas leak it is successful, then it is depend on the amount of gas here then that is basically a conditional way so, but other way given this situation ultimately this will work this will be able to make it or find it out and then it is independent. For example, manual detection that means leakage is there then the situation awareness that mean what action to be taken or what not what action to be taken only, what will happen that in the situation awareness if that is dependent only on manual detection then that is conditional.

Otherwise what happen we know that if there is gas leakage obviously, it leads to fire on that awareness is there we have to take action. Then, irrespective of the previous issues or previous barriers success or failure it will ultimately work independently and these are independent events. So, that mean there will be accordingly there will be conditional probability and independent probability. So, I will discuss this conditional and independent probability first then we will come back to this example again.

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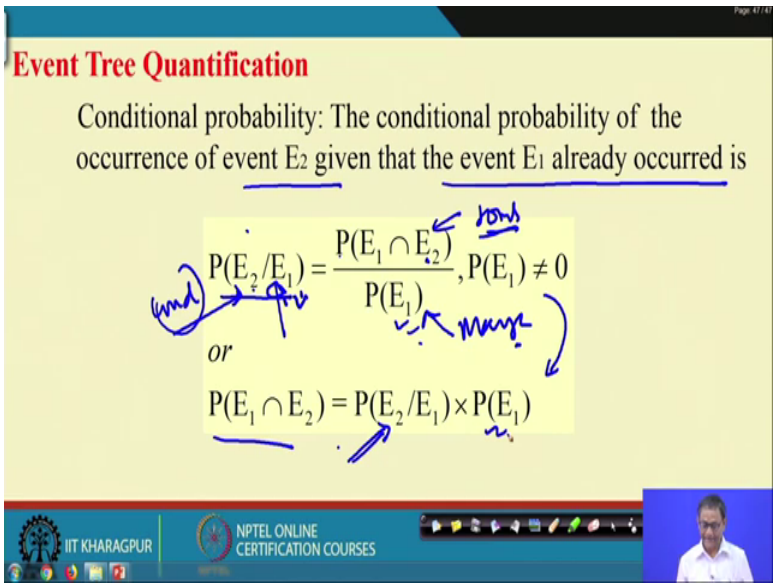

So, what is conditional probability? Conditional probability of the occurrence of event E 2 given that even E 1 already occurred is this. What is this? P E given E 2 given you are not does it mean probability that even E 2 will occur given that if E one has already occur then this is probability of E 1 and E 2 both occur that is joint probability divided by probability of event E 1. So, this is the formula we use to define conditional probability.

What is this? This is conditional this is marginal probability independent of E 2 and all those things and this is the joint probability that mean both E 1 and E 2 will occur. So, conditional probability is equal to joint probability divided by the marginal probability and with reference to what the conditions given. Or you can you can write this in this form that mean the joint probability is conditional probability times the marginal probability, ok.

So, what is conditional probability? Conditional probability, that probability of occurring some event given that other event as already occur. For example, you are you are going out rain has started you can use the rain or not use the you can use an umbrella or not use it depends on the amount of rain. If it is small, drizzling then you may not use. So, that mean use of umbrella depends on the rain, ok. Similar many example you can create you create example with respect reference to the your system with reference to safety studies.

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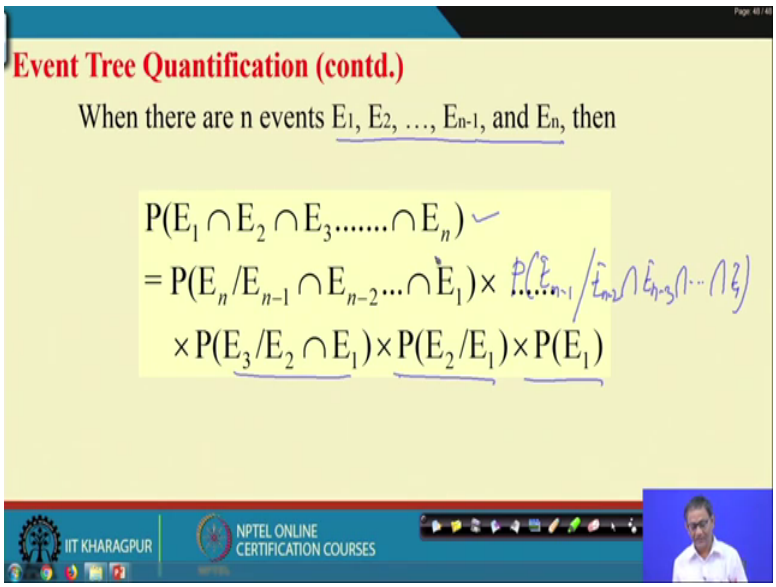

Now, it is basically two event now there may be series of events. So, what will happen to this equation? When there are n events when there are n events event E 1 to E n and then what will happen we want to know the joint probability that all the event will occur, then you required to know the conditional probability. How? probability of E 1 intersection E 2 intersection E 3 intersection E n these can be written by probability of E n given that other events as joint events have to occur into probability of E n minus 1 these into probability of E n minus 1 given E n minus 2 intersection E n minus 3 intersection like

this up to E 1 and then E n minus 2 and this manner when reducing n.

Finally, E 3 given E 2 intersection E 1 then E 2 given E 1 E 1 and this is the formula for finding out the joint probability of events and you know the conditional probability or the other way if you know the joint probability then the conditional probability can be computable. This branching is done. This is basically from two event to n event that is what is conditional joint probability and conditional probability relation.

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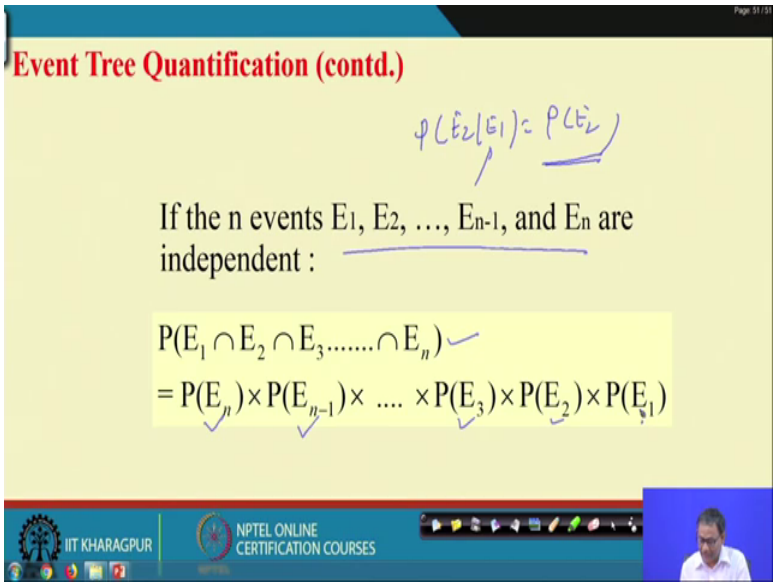

Now, what will happen E when the events are independent if events are independent then I can write that P E 2 given E 1 is nothing, but P E 2 because whether E 1 occur or does not occur it does not matter E 2 will E 2 will does not matter mean it does not contribute to E 2 event to occur. So, probability will be like this and that is what this one we have written like this purity of en conditional all the other joint that E n minus 1 to 1 that joint is joint probability that is immaterial.

So, we will write P E n, P E n minus 1 P E 3 P E 2 P E 1. So, when you develop the event tree you must know that whether the that pivotal events they are independent or conditional and accordingly find out the probability and then find out the probability of the accident scenarios.

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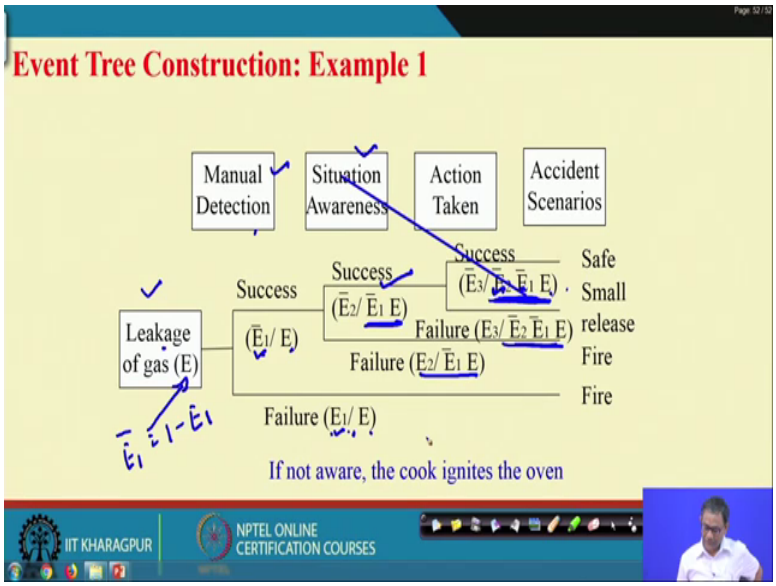

Let us see this one. Suppose, event leakage of gas is E, success and failure, suppose failure is E 1 here success will be E 1 bar. Why E 1 bar? E 1 bar equal to 1 minus E 1 because this is the binary case either it will be successful or it will be failure. So, event E E 1 bar means 1 minus E 1. So, in that way manual detection failure here then here E 1 bar given E here also E 1 given E. Why we are given E here? We are saying that leakage is there. The in that case what will happen the second case leakage manual detection E 1 bar E, here E 2 given E 1 bar E and like this.

So, you are considering these and these and these and accordingly what happen this side the condition given condition is increasing; means leakage occurred manual detection is successful, situation awareness is successful in this case and then action take and E this one E 2 situation on successful E E 1 bar manual detection successful and E leakage occurs. So, that is: what is the conditional event.

Now, if we see that that ultimately they are independent particularly the pivotal events leakage must occur, then only this will be activated, but the activation is not depending on the amount of leakage then it is similarly situation awareness should not be should not the probability should not be dependent on this. So, if these case occur then what will happen?

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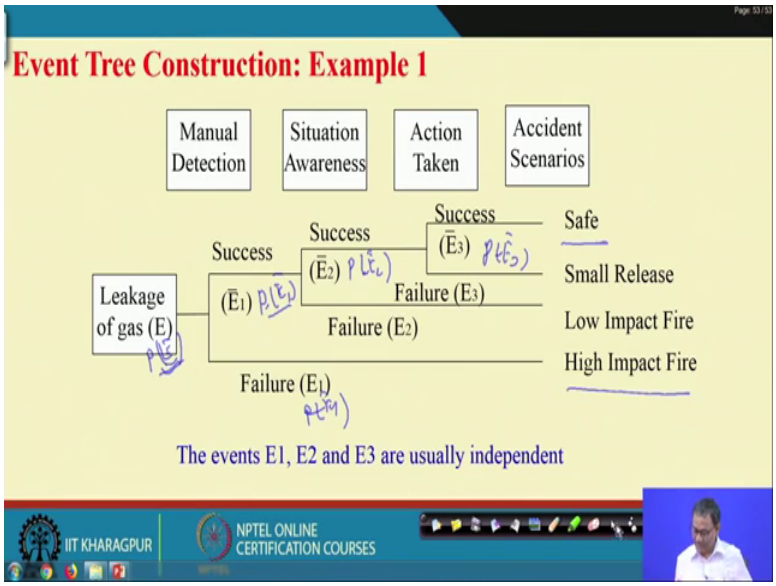

All those things will be written as E, E 1 bar, E 2 bar, E 3 bar, E 3, E 2, E 1 like this because they are independent. So, the conditional the given part will not be written. Now, actually what happened if you if you design system like this when the protection configuration they work independently that is a better system because, that is the independent system and you must try to do this independently that system or independent design is the best design and dependent one is the coupling one; coupling design is problematic one.

So, suppose for the time being we assume this independent, then what is the probability of safe situation? What is the probability of role small release? What is the probability of low impact fire? What is the probability of high impact fire? In earlier case, you have seen that I have given both cases fire, but considering the situation like here situation awareness is successful so, it will be low impact fire not may be high impact fire. So, that demarcation we have made and you have to do like this.

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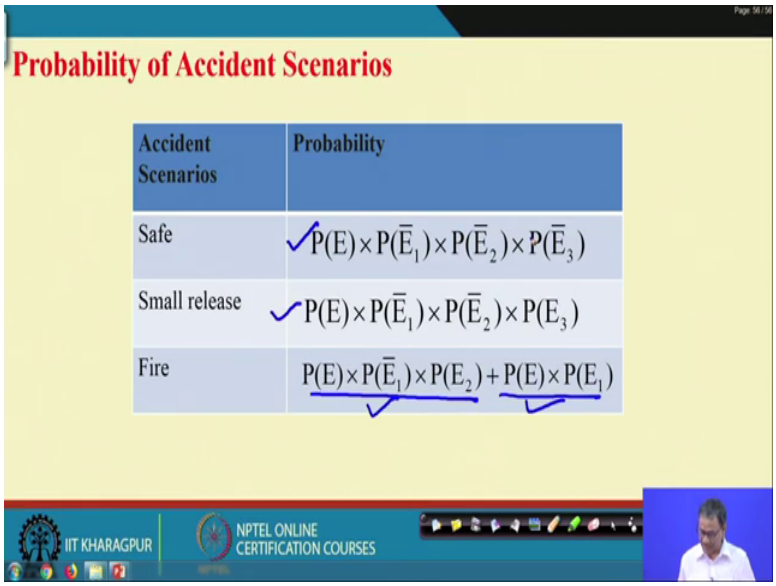

So, then what happen you see safe probability of leakage occur, then E 1 bar E 2 bar E 3 bar. You see what is E 1 bar? E 1 manual: detection successful, situation awareness successful, action taken successful. Probability of this, probability of P E here is the probability that one is P E 1 bar this is P E 1. So, that mean these into this is high impact fire these P E into these into P E 2 bar into P E 3 bar this multiply by this multiply by this multiply by this will be the safe situation. So, like this ok.

So, in this manner if you compute, what you are getting now. So, safety safe situation this is the probability, small release this is the probability, but fire case there are two situation, low and high impact both we are combining in fire. Otherwise if you write low impact fire high impact fire two probability separately, but in fire case one and two because there are two branches where end result is fire. So, that mean the probability of fire is these probability small release is this probability of safe situation is this.

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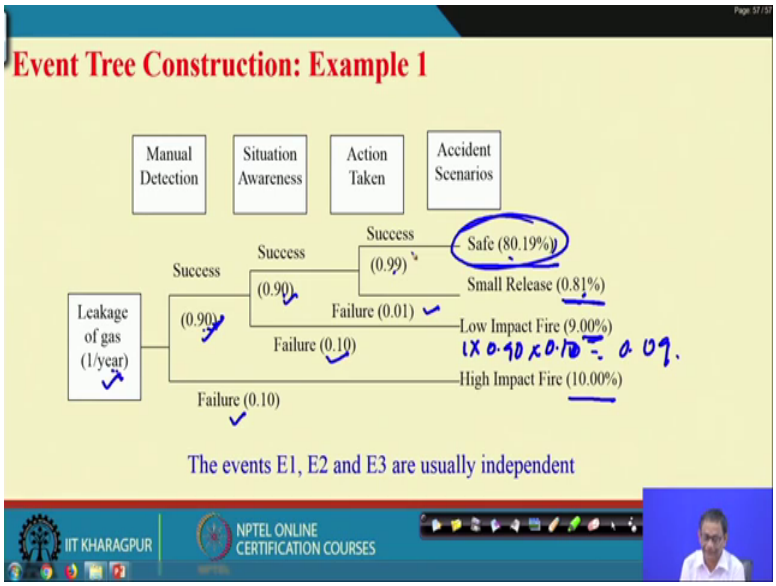

Now, I have given you the value. Leakage of gas 1 per year success 90 percent, failure 10 percent like this. So, multiply these into these into these in to these that mean 80.19 percent time it will be it will be a safe situation and then small releases what 1 multiplied by these multiplied by these multiplied by these this is 0.81 then low impact power is 1 multiplied by 0.90, 0.1 in this one this one is 1 multiplied by 0.90 multiplied by 0.10.

So, this is basically 0.09, 0.09 which is we say 9 percent, 1.01 this is 10 percent and this one is 81 percent 0.81 percent because these multiplied by these multiplied by these and this one is maximum safe situation it should be. So, now you just see the calculation if there is any that computational mistake, correct it accordingly.

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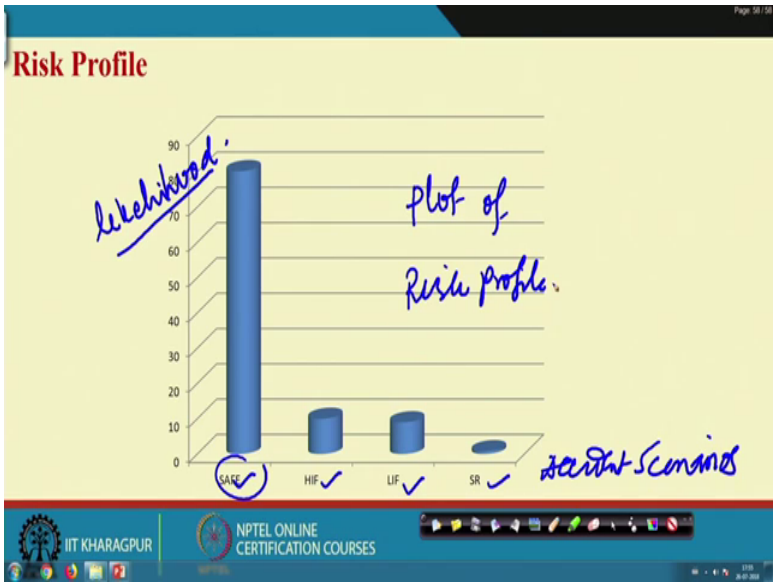

So, now what happened once you have the end scenarios here safe situation, high impact fire, low impact fire and this is basically small release and these are the these are the accident scenarios and this side is likelihood, this is accident scenarios. So, what will happen then than the probability of safe is these, this plot is known as this is a plot of likelihood (Refer Time: 33:47) accident scenarios this is known as risk profile. So, event tree gives you risk profile.

So, let us see now what happen we have come now you know the event tree, you have already seen the fault tree I will give another example where both event tree and fault trees combined.

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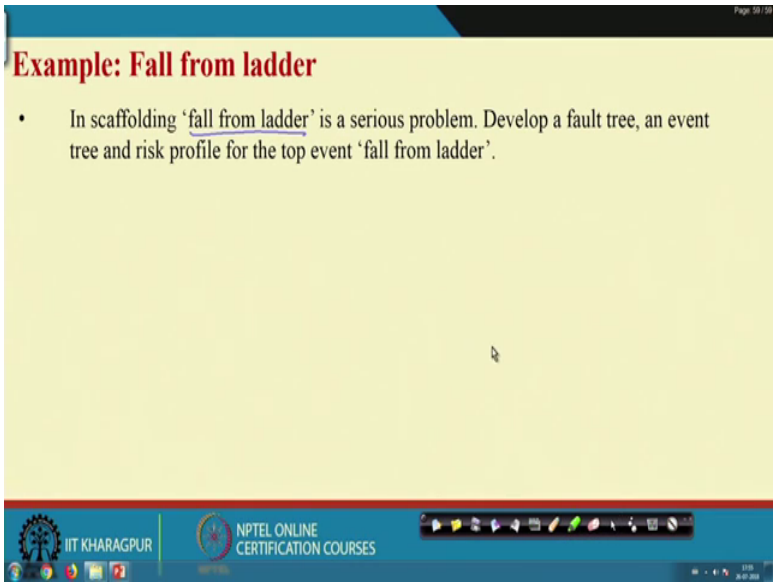

Suppose, our situation is scaffolding fall from ladder and we want to develop a fault tree an event tree and risk. So, let us see that what we are doing here.

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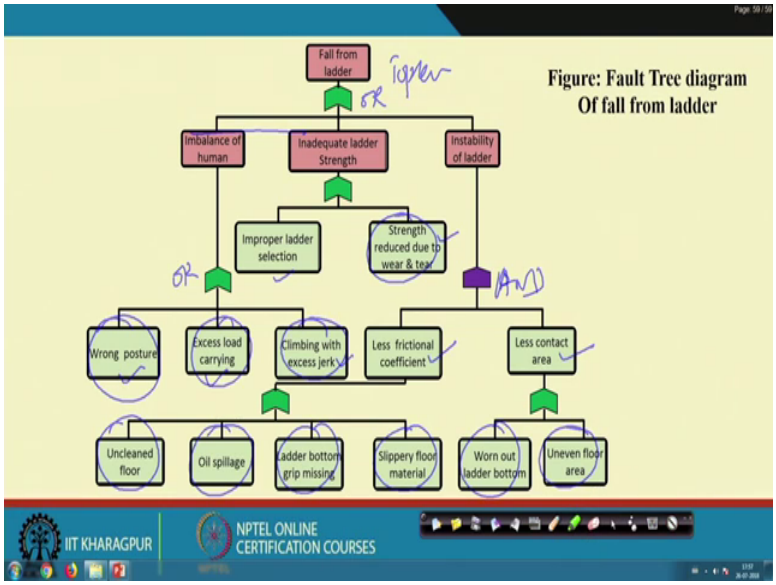

I hope that you all will appreciate this. Fall from ladder; what are the reasons? This is OR gate, imbalance of human, inadequate ladder strength, instability of ladder; any one lead to fall from ladder. Then, when imbalance of human, then this wrong posture, excess load carrying, climbing with the excess jerk this maybe the region with or gate similarly inadequate ladder strength, improper ladder selection, strength is not good and may be

strength reduced due to wear and tear instability of the ladder here it is and gate. Loss of frictional coefficient loss less contact area will lead to this and in this manner ultimately you are getting.

So, let us now think that we know the probability of this and this will be circle this will be circle, this will be circle, this will be circle, circle, circle, circle and here this will be circle, this is another circle and this is another circle what happen? We have written in the box because we do not know the probability maybe it may require that why uncleaned floor further breaking down is possible, but if it is if that is not possible then a and also you know the probability of uncleaned floor probability of wrong posture then they will become basic events and we have seen in fault tree that basic event and this is ladder is top event here. This is our fault tree. Now, we will use event tree to see that when fall what will happen if fall from ladder happen?

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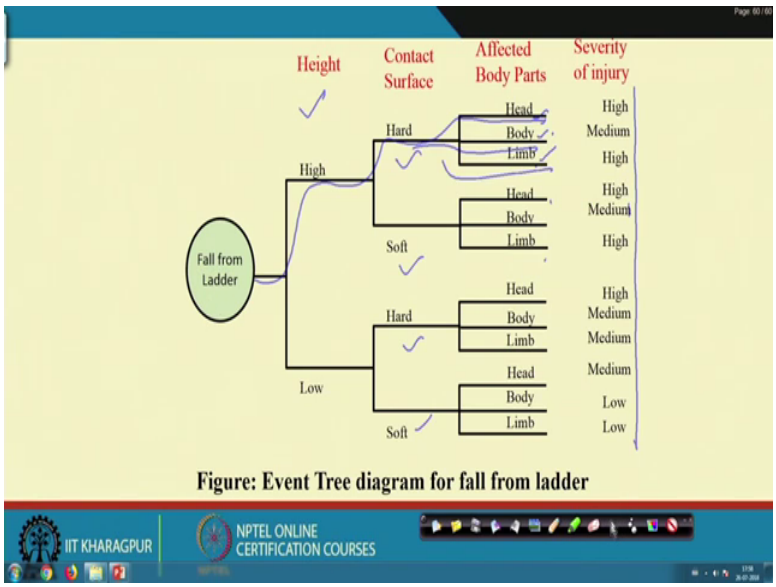

Figure: Event Tree diagram for fall from ladder

Fall from ladder happen, then from which height is important. If it is high or low contact surface where fall hard or soft, hard or soft? Then affected body parts head, body, limb; head, body, limb. So, what happen you just see you are getting different situation another one will be these another will this. So, how many how many end state, there are different end states are there here head injury, body injury, limb injury head body limb head body limb head body limb three different three different situation in status from injury point of view.

So, impact will be high, low, medium; high, low, medium something like this. Now, if you want to compute the probability of fall from ladder then what you do? You will you will know if you know the probability here, you will know the this one use mocus algorithm get this probability. So, that mean fall from ladder is initiating is initiating event for event tree.

So, and you know height and low and fall from ladder from which I did not fall and that sense here also probability you will calculate, but all the time probability is may not be important one. May be the only the relative frequency will work or you may not be interested to go for probability finding probability and calculation of the that probability of that end state, but it is qualitatively it can be use and that is also very important because that will give you the accident path and every path you will see via which barrier fails and accordingly you take the action,.

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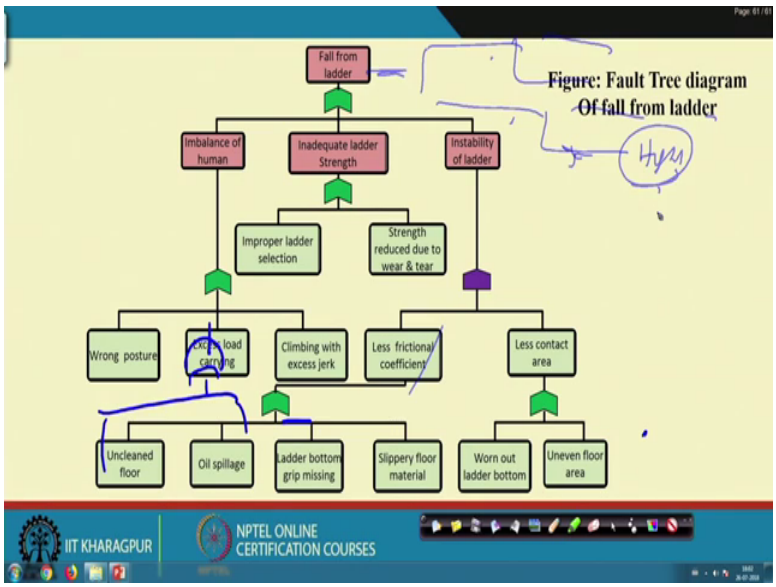

Figure: Fault Tree diagram Of fall from ladder

So, what will happen then if you combine the two these then here is the fault tree. So, this fault tree which fault tree this one, this fault tree high this one. So, this one and here we have used event tree we have used event tree so, different paths you seen already. Now, question is whether you will go for both fault tree and event tree or not? It is better go for both fault tree and event tree instead of only one fault tree or event tree. The reason is if I say that I will I impact is my end state then all those things here everything all the states it will come under fault tree. So, you will start from here then gates will be

appearing.

Again, if you think that the oil spillage is the starting point then if oil spillage what will happen next, then you will get another kind of event tree ok, but it is better you find out a middle path like maybe fall from ladder is the event which immediately comes into notice. Then, for that you just go for the develop the fault tree to find out the why that event will occur and if that event occur what will happen next, then use through event tree. Then fault tree and event tree combine this will give you the total status what will happen, ok.

If you want to prevent for fall from ladder, then definitely this fault tree will help you find out you have all the paths, you develop cut set and you prevent all the cut sets to occur by engineering and administrative control. If you want then want that this accident effect to be minimised or consequence to be minimised then, you look into this event tree and all the path and which of the pivotal events are occurring and with what probability and which path all the paths leading to the accident situations bad scenarios to be to be arrested and prevention or risks barriers can be developed accordingly.

I hope that you got sufficient material related to fault tree, related to event tree and with the examples and you will be able to develop fault tree and event tree for your system where you are working or for the free students you follow the book by Kumamoto and Henley and or any other book of your department, where the safety related examples are there. And, I am sure you will you will be having a very good time definitely you will enjoy the entire exercise.

Thank you, very much. Thanks a lot.