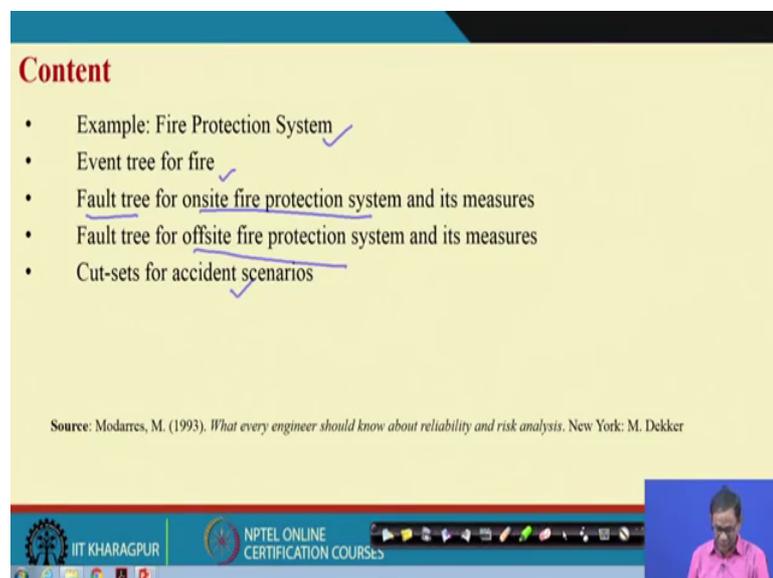


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**Lecture - 20**  
**Bow – Tie: Cut - Sets for Accident Scenarios (Contd.)**

Hello welcome to the lecture which is continuation of the last lecture that is Cut Sets for Accident Scenarios. In last lecture I have explained you that the detail of this that how the cut sets for accident scenarios will be developed.

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**Content**

- Example: Fire Protection System ✓
- Event tree for fire ✓
- Fault tree for onsite fire protection system and its measures
- Fault tree for offsite fire protection system and its measures
- Cut-sets for accident scenarios ✓

Source: Modarres, M. (1993). *What every engineer should know about reliability and risk analysis*. New York: M. Dekker

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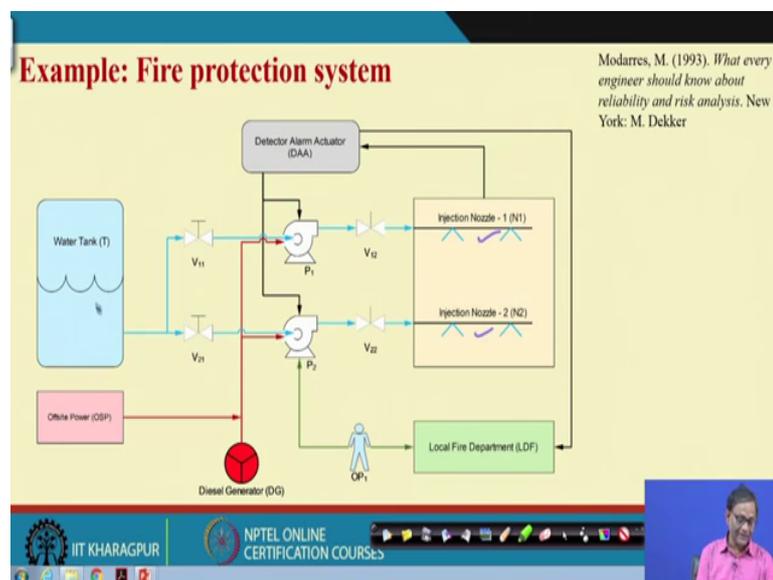
In this lecture we will basically see that with reference to a example case type, case study type although I cannot say this is purely case study, because I have taken from this book Modarres book, that is fire protection system. And we will see that how the that concept cut sets along accidental scenario can be developed for the fire protection system. And at the same time that several important measures what we have discussed earlier and that can also be discussed further ok.

So, it is in one hand I can tell you that it is a some kind of reputation of the previous two three lectures, but it is required because, it is related to a good example which is a fire protection system, when fire breaks out ok. So, the contents we will not discuss in detail we will just touch the protection system, the what we are considering because already we

have discussed this. Then the event tree will develop, then we will link with the fault tree for one side fire protection and also offside fire protection.

Then finally, with the concepts and the Boolean method algebra what we used in the last lecture, using these how the different accident scenarios are developed. In addition what happened? In case of common cause failure that what is the change in cut set that will be discussed also more precisely the common cause failure will be considered here ok. So, let us hope that by another 20 minutes of time will be able to finish it.

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So, this is what is our system, so there are two injection nozzle 1 and 2. Primarily injection nozzle 1 works injection nozzle 2 works when injection nozzle 1 fails, both the nozzles are filled by filled by identical pumps that P 1 and P 2 and they are getting water from the water tank with several bulbs.

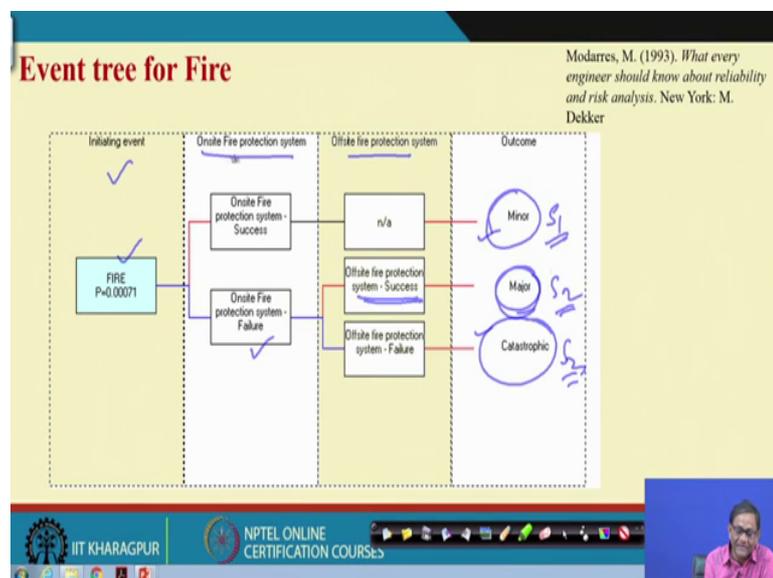
So, that inlet bulb and outlet bulbs are there and in case in case of the nozzle 1 fails particular the pump 1 fails in that case what will happen there is along actuator, which will basically make the other system to work. And ultimately there is operator who will heap both the things fills ultimately the pump 1 and pump 2 both fills or other way I can say that to system fills here on side protection measures.

So, then the local fire department will be called by the operator, please not then there are two things one is onsite protection measures another one is offsite protection measure.

Onsite protection measure is the injection nozzle 1 and 2 or fed by pump 1 and pump 2 that by standby system.

And you will find out that the pumps are basically sourced by offsite power most of the time and if there that power is not available there is diesel generator, which will ultimately in case of power goes off, then diesel generator will ultimately what can the pump will be pump will be feeding the power. And the alarm actuator is better interval so even if there is no power, but that will work so, we have we have discussed this earlier. Now let us see that what are the fault tree first ok.

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Event tree first, what is event tree here? That initiating event is fire and then onsite protection measures should work. And if onsite protection measure is successful, then offsite protection measure is not required because the operator will not call; offsite protection measure. So, in this case because there is fire breaks out what will happen? There will be some loss, we are writing minor loss. Now if onsite protection measure fail then, offsite protection system will work which is basically the local fire brigade.

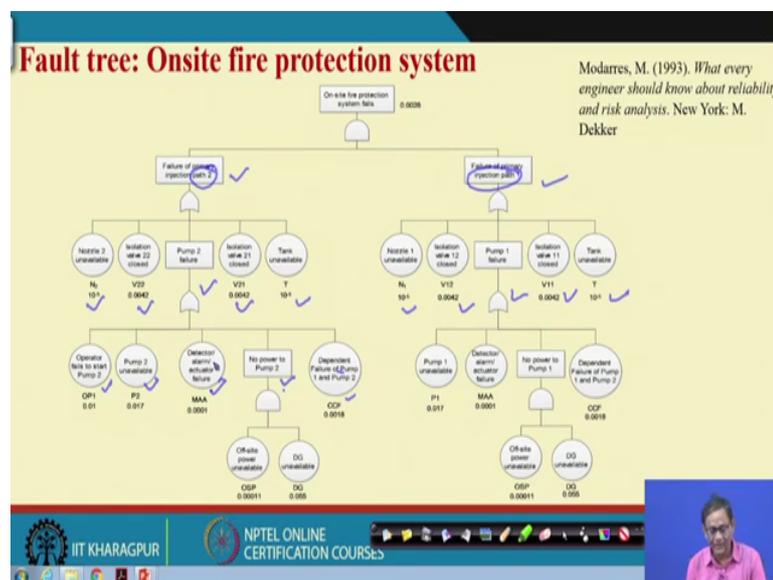
So, they will come an ultimately there will be time delay. So, as a result what happen even? If the offsite protection system will be successful, but there will be there by that time sufficient time may elapsed and ultimately there will be major accident what major impact will be there? And if the outside offside fire protection system also fails, then

what will happen it will be catastrophic on the total system will destroy including lose of people and other things also.

So, now, this is our basically accident sequence in terms of fire event occur and the our how our fire protection system works and accordingly the scenario is developed so, this is S 1 this is S 2 and this is S 3. You may you will be interested to know what is the probability of S 1 probability of S 2 and probability of S 3 and you will also be interested to know suppose S 1 occur.

Then what are the basic bend related to fire protection system on set fire protection system, they are responsible which one is more important, which one is less important, where we will focus more or what preventive measures should be there all those things will be with reference to maybe catastrophic maybe major, may be minor. Those kind of information can be generated from the, if you know the cart sheets along the accident sequences by linking the fault tree of the pivotal events ok.

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So, let us see the fault tree for the first one onsite, onsite fire protection system fails. So, when onsite fire protection system will fail, when both the system fail onsite first one is a primary injection path fail secondary or the second secondary injection path or failure of the injection path 2 failure of injection path 1 ok.

Now you see that they are identical so, that is why here what happened the nozzle, then bulb, then pump, then bulb, then tank, nozzle, bulb, pump, bulb, tank, because these two system are similar system. And then why pump fails that pump failure operator fails to that pump, pump available alarm alarm actuator failures no power to pump and dependent failure of pump 1 and 2 ok.

So, why this dependent failure, because, you will find actually these two are these two pumps are pumps are sharing common cause. So, that is why when you are if you have such standby system or identical system and which are basically susceptible to common cause failure. So, what will happen? The failure of any unit will be because of it is own failure, the independent failure, plus the common cause failure that is what we have seen in last one class may not be the immediate last class, but in one of the classes we have seen. So, as a result that is to be added that dependent 1. So, that is what I said that dependent or common cause is also added here so, this is the fault tree.

Now what will be the cut set for this? So, as this one is your or gate then these plus these plus these plus these plus these into because it is and gate this all. So, this occur and this occur this will occur so ultimately find out the cut set for all this side and this side. And then if you multiply the two you will be getting the common external cut sets for this one. And again for this you have to follow or gate and again for this and gate and the same manner may be MOCUS algorithm illusion find out the all the cut sets.

So, now given the different values basic given probability values like; operator fails to start pump available all those values then ultimately your the onsite protection system feel the probabilities 0.0028.

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**Cut-set of fire protection system**

*By Cut Sets*

N	Failure probability	%	Order	Event 1	Event 2
1	0.0018 ✓	63.92	1	CCF ✓	
2	0.000289 ✓	10.26	2	P1	P2
3	0.00017 ✓	6.03	2	OP1	P1
4	0.0001	3.55	1	MAA	
5	$7.14 * 10^{-5}$ ✓	2.53	2	P2	V11
6	$7.14 * 10^{-5}$	2.53	2	P1	V21
7	$7.14 * 10^{-5}$ ✓	2.51	2	P1	V22
8	$7.14 * 10^{-5}$ ✓	2.53	2	P2	V12
9	$4.20 * 10^{-5}$	1.49	2	OP1	V11
10	$4.20 * 10^{-5}$	1.49	2	OP1	V12
11	$1.76 * 10^{-5}$	0.62	2	V12	V21

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Now, let us see that ultimately what are the cut sets? There are 24 cut sets, that cut starting from CCF, CCF alone because common cause both side pump 1 and pump 2 both side it will work. So, that one unit order one that is one cut set. Then pump 1, pump 2 independent failure, then operator 1 pump 1 like this, like this what happened how many cut sets there are 24 cut sets identified. And we all know the probability of the basic events so the probability of the cut sets as also found out you can check.

Now in the percentage contribution with that total failure, then you will find out that this one is very high. So, that mean common cause as you know that common cause failure probability is far more than the neutral event failure probability that is established here also.

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**Cut-set of fire protection system (Contd...)**

N	Failure probability	%	Order	Event 1	Event 2
12	$1.76 \times 10^{-5}$	0.62	2	V11	V21
13	$1.76 \times 10^{-5}$	0.62	2	V11	V22
14	$1.76 \times 10^{-5}$	0.62	2	V12	V22
15	$1.00 \times 10^{-5}$	0.35	1	T	
16	$6.05 \times 10^{-6}$	0.21	2	DG	OSP
17	$1.70 \times 10^{-7}$	0.007	2	N2	P1
18	$1.70 \times 10^{-7}$	0.007	2	N1	P2
19	$1.00 \times 10^{-7}$	0.003	2	N1	OP1
20	$4.20 \times 10^{-8}$	0.001	2	N1	V21
21	$4.20 \times 10^{-8}$	0.001	2	N2	V11
22	$4.20 \times 10^{-8}$	0.001	2	N2	V12
23	$4.20 \times 10^{-8}$	0.001	2	N1	V22
24	$1.00 \times 10^{-10}$	0.000004	2	N1	N2

So, see I said that 24 so, ultimately 24, 24 cut sets some probability values are very low. So, we may ignore those probability values or those cut sets you can ignore, but it all depends on the impact. So, whether that probability is low, but maybe impact is high so then, you require more protection because risk is important here.

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**Importance Measures**

S.N	Code	Name	Unavailability	FV importance	RDF	RIF
1	CCF	Dependent failure of Pump1 and pump 2	1.80E-03	6.40E-01	2.78E+00	3.55E+02
2	DG	DG unavailable	5.50E-02	2.15E-03	1.00E+00	1.04E+00
3	MAA	Detector/alarm/actuator	1.00E-04	3.55E-02	1.04E+00	3.55E+02
4	N1	No 336-1 unavailable	1.00E-05	1.26E-04	1.00E+00	1.34E+01
5	N2	No336-2 unavailable	1.00E-05	9.03E-05	1.00E+00	9.97E+00
6	OP1	Operator fails to start pump 2	1.00E-02	9.03E-02	1.10E+00	9.88E+00
7	OSP	Off-site power unavailable	1.10E-04	2.15E-03	1.00E+00	2.05E+01
8	P1	Pump 1 unavailable	1.70E-02	2.14E-01	1.27E+00	1.32E+01
9	P2	Pump 2 unavailable	1.70E-02	1.54E-01	1.18E+00	9.82E+00
10	T	Tank unavailable	1.00E-05	3.55E-03	1.00E+00	3.55E+02
11	V11	Isolation valve 11 closed	4.20E-03	5.29E-02	1.06E+00	1.34E+01
12	V12	Isolation valve 12 closed	4.20E-03	5.29E-02	1.06E+00	1.34E+01
13	V21	Injection valve 21 closed	4.20E-03	3.79E-02	1.04E+00	9.94E+00
14	V22	Isolation valve 22 closed	4.20E-03	3.79E-02	1.04E+00	9.94E+00

Then let us see the importance measures, what happened with reference to this fault tree so different basic events are there how many basic events are there? I think there are 14 basic events yes, 14 basic events with reference to the first onsite fire protection system.

So, you have already seen that the, what is the probability 0.0028 that is the top event probability that fast that onsite protection system fails. Then you are interested to know that what are the how this basic events they are basically contributing which one is contributing maximum.

So, we are earlier seen that that minimum important measure, first labor cell important measure risk reduction decrease factor risk increase factors we have discussed earlier. So, ultimately I will little elaborate in on risk red decrease and risk increase factor what is the message your suppose risk, when what is risk decrease factor and what is risk increase factor? So, for example, the CCF the availability un availability probability is what is this 1.8 into 10 to the power minus 3 ok.

So, now if you make it fully available, that mean probability become 0, un availability become 0, then what will happen how much risk is reduced? So, that will be the contribution of CCF and that value is written here like this so, some more values are there ok. Although most of the values it is almost near about 0 it is written here, but some point values are some values are thereafter 0.

So, now what happened what happened actually here, suppose you may find out that for out of so many basic event in some cases, the risk decrease factor is very high some cases may be negligible, but some cases may be medium. So, if you prioritize them the basic event having the having reasonably high value of RDF Risk Decrease Factor what is the physical meaning of it. So, that mean if you make it available so it will reduce the risk to a large extent.

So, that is why you focus on it is improvement, focus on it is improvement so, that it will be available. Now what is risk increase factor here? Risk increase factor means, if it is not available all the time if you make it one what will happen how much risk is increased? So, one end risk decrease factor you make it available make probability of failure is 0.

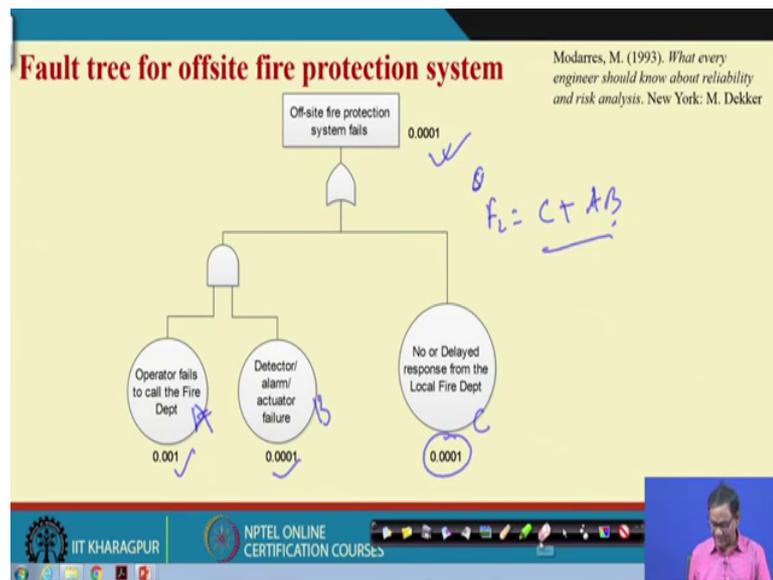
Risk increase factor make it completely unavailable probability of failure is 1 so, that time what will happen that how much risk is increased their ok? So, what you required to do then, you required to maintain the health of the system status go for the component to the risk increase factor is high, physically that is the message for risk reduction and risk

decrease factor and risk increase factor. So, I hope that this is in a not a difficult one for you because already you have seen all those things.

Now I am just elaborating more so, that you will you will get a revisit opportunity. And I request all of you to calculate all those things given the data, this one we have taken from another book written by Modarres. So, Modarres book you just go through Modarres book and see this case and you their data also given. So, using the data maybe if you can develop program or if you have some software used it and find out those values ok.

The prime the main so, main purpose here is basically to tell you that how the importance measures will be will be interpreted because, the computers now important measures I have given you in earlier slides earlier lectures.

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So, then another one is what is this that fault tree for offsite fire protection system. So, this is our system two along the fall even tree and it is basically fault tree is like this. So, here is end or so, if I say this is A this is B and this is C, then this will be A B and C. So, basically the system failure if it is F 2 it is C plus A B, if you know this one and this one multiplied this add this finally, we will be getting the this probability well that part you would know ok. Now you can develop it is importance measures and other things.

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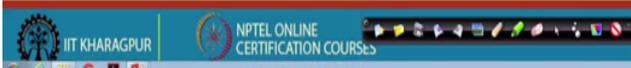
### Cut-set and importance measures for offsite fire protection system

**Cut-sets**

N	Failure probability	%	Order	Event 1	Event 2
1	0.0001	99.9001	1	LFD	
2	1.00E-07	0.0999	2	MAA	OP2

**Importance measures**

N	Code	Name	Unavailability	FV importance	RDF	RIF
1	LFD	No or delayed response from the local fire department	1.00E-04	9.99E-01	1.00E+03	9.99E+03
2	MAA	Detector/alarm/actuator	1.00E-04	9.99E-04	1.00E+00	1.10E+01
3	OP2	Operator fails to call the fire department	1.00E-03	9.99E-04	1.00E+00	2.00E+00




And then, then what happen, you see the cut sets for the second one and the importance measures you are able to calculate like this.

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### Calculation of frequency of accident scenarios

Scenario No	Cut sets	Frequency
1	$F, \overline{ONS}$	$7.1 \times 10^{-4}$
2	$F.T. LFD, \overline{OP}_2$	$7.0921 \times 10^{-9}$
	$F.T. LFD, MAA$	$7.0986 \times 10^{-9}$
	$F.MAA, LFD, \overline{OP}_2$	$7.0921 \times 10^{-8}$
	$F.MAA, LFD, MAA$	$7.0986 \times 10^{-8}$
	$F.OSP.DG, LFD, \overline{OP}_2$	$4.2553 \times 10^{-9}$
	$F.OSP.DG, LFD, MAA$	$4.2594 \times 10^{-9}$
	$F.N_2, N_1, LFD, \overline{OP}_2$	$7.0921 \times 10^{-14}$
	$F.N_2, N_1, LFD, MAA$	$7.0986 \times 10^{-14}$
	.....	<b>Sum = <math>1.987 \times 10^{-6}</math></b>
3	$F.T.LFD_1$	$7.1 \times 10^{-13}$
	$F.T.OP_2, MAA$	$7.1 \times 10^{-16}$
	.....	<b>Sum = <math>1.988 \times 10^{-10}</math></b>



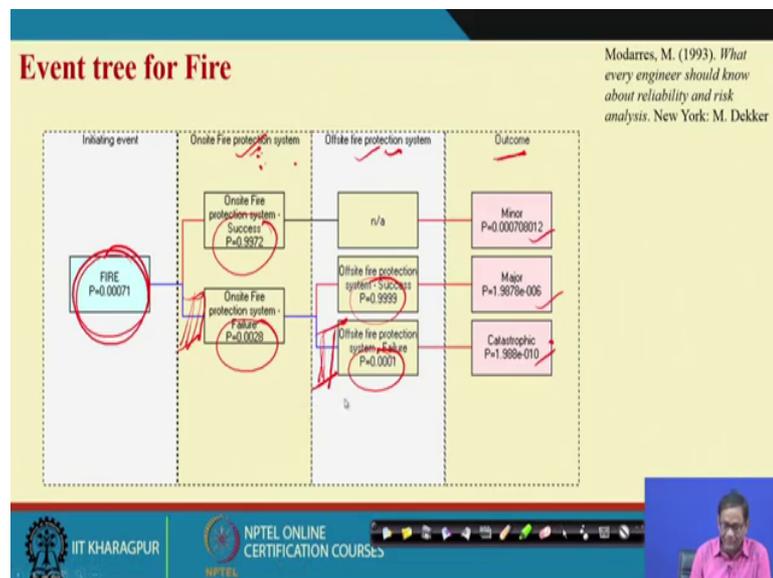
Then what happened, you are interested not interested to know the cut sets for the fault tree of the two different that protection measures like onsite and offsite corn protection measures, not only that what do you want? You want to know the cut sets for the accident scenario, how many scenarios are there? If I go to the event tree how many scenarios are there one to three scenarios are there.

So, there are three sequences this is one sequence this one is another sequence this one is another sequence so if I write the last sequence is this one. So, we are saying that sequence 1 sequence 2 and sequence 3 you want to find out the cut sets for all those sequence these are the accident scenarios that is what we discussed in last class and now with reference to this example also you just see.

And that is what we are saying so, your scenario 1 this is the case probability value is this scenario 2 there are many dot dot dot so many. And you develop you find out how many more are there? And then their probability and ultimately some probability are this, that mean the probability of scenario 2 is this. Given the fire probability 0.00, I think some 387 something. And then the scenario 3 again this 2 plus some more is there we are not writing all those things though you are getting this probability ok.

So, this is what is basically your you your able to your linking, linking the that mean the calculation of frequency of scenarios accident scenario 3 scenarios and like this.

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So, then after so, much of calculation what is remaining that this is my initiating event probability, then from the first fault tree you founded the failure fault tree this point 0.0028 success probability you will get. And then here also failure probability and success probability and multiplying this, these are the accident scenarios and different probability ok. So, what you learn then? You have learn in this particular case what we

have related, we have related many things; first we have basically started with a real life problem which is basically fire protection.

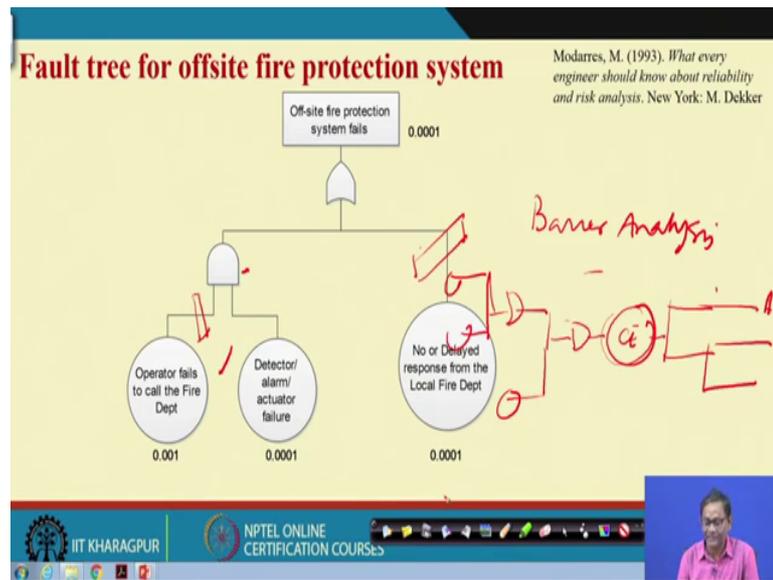
Then we said that there will be two types of protection; one is offsite another one is onsite. Onsite one again having stand by now in the stand by case there are two palms which are identical and susceptible to common cause is. So, the common cause failure is also included there and accordingly what happened when we have developed the fault tree, that common cause failure is also included there and how to include common cause failure that one we have also given, but we have not given you that how the common cause failure is quantified? So, in Modarres book that is there, there are different models to do this, one of the model is beta factor model.

So, those who are interested in knowing dependent failures so, I request all of them to go through that chapter dependent failure by Modarres ok so, then what happened? Then the you have you have developed the fault tree along the along this for this on site as well as offsite. And this is the accident paths; you have to do this along this. So, when once you have the fault tree for this protection measure and this protection measure you know the probability of failure through cut sets. So, you have developed cut sets, cut sets you have developed considering the dependent failure that is the common cause failure also.

Here also you develop the cut sets. So, when you have the cut sets for the two then ultimately any scenario what is that any scenario the outcome any accident scenario or accident sequence? These are nothing, but the multiplication of the individual that system scenarios like here success scenario failure scenario. And then what happened you through Boolean algebra what you have done? You have finally, come down to the cut sets for the accident scenarios and those cut sets are very very important because all those cut sets basically lead to this scenario.

So, what you require? You require protection configuration or maybe you require further measures to improve this means to reduce the probability of the accident happening for particular accident scenario. So, then the barrier analysis will come into consideration so that mean, this fire protection fails. So, what more barrier should be given here what barrier should be given here? Barrier analysis is very very important so, this is this is the utility of this particular model. Now you have seen, you have seen the you have seen the fault tree and I am going to one of the fault tree, let it be like this fault tree only.

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So, offsite fire protection system fails why it fails? If I go by cut set this two this into this plus this so, it there should be barrier. So, that this will not fail this will not happen, similarly barrier should be here also if any one of the two cannot happen, this will not happen so barrier will be there here also. So, this barrier analysis is very very important.

So, as I told you earlier that bow tie, there will be centre event stop event for event fault tree and your event tree. Event tree initiating when event tree. Now we have already shown you that how you will basically quantify this one and then also quantify the scenarios how cut set linking cut set different possibilities that it explained so far. But we have not explained that how to prevent all those things to happen? That concept is known as safety barrier analysis. So, we will discuss in next class that safety barrier analysis.

Thank you.