Chemical Process Safety
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Module 9
Lecture 45
Bow-Tie Analysis

Welcome to the module related to the Bow-Tie Analysis, now previously we have gone through the HAZOP analysis, risk assessment analysis, event tree analysis, fault tree analysis then we have gone through the detail study about the cause consequences and then LOPA now this is the analysis or ultimate analysis we carried out in the chemical engineering operations related to safety aspect.

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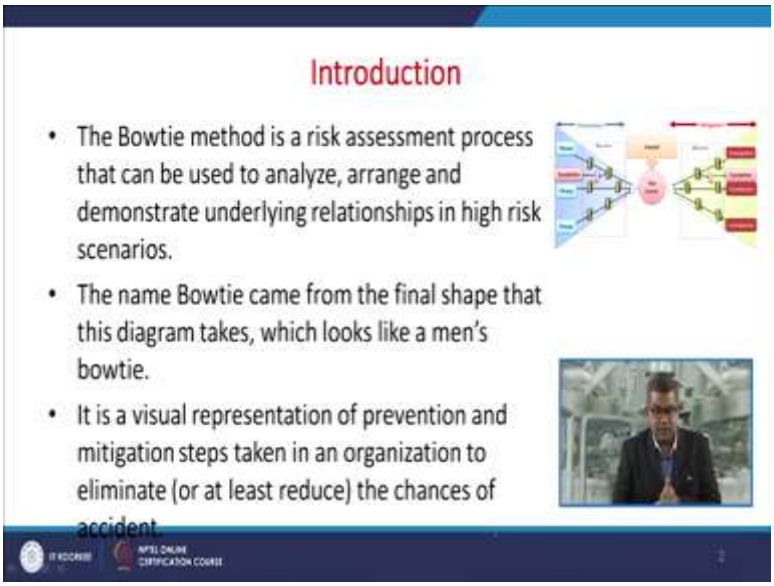

So let us have an brief introduction about this Bow-Tie methods. Now this Bowtie method is a risk assessment process that can be used to analyze, arrange and demonstrate underlying relationship in high risk scenario. So as the name Bowtie came from the final shape this final shape that this diagram takes which looks like men's Bowtie like this. Now it is a visual representation of a prevention and mitigation steps taken in an organization to eliminate or at least reduce the chances of any kind of accident.

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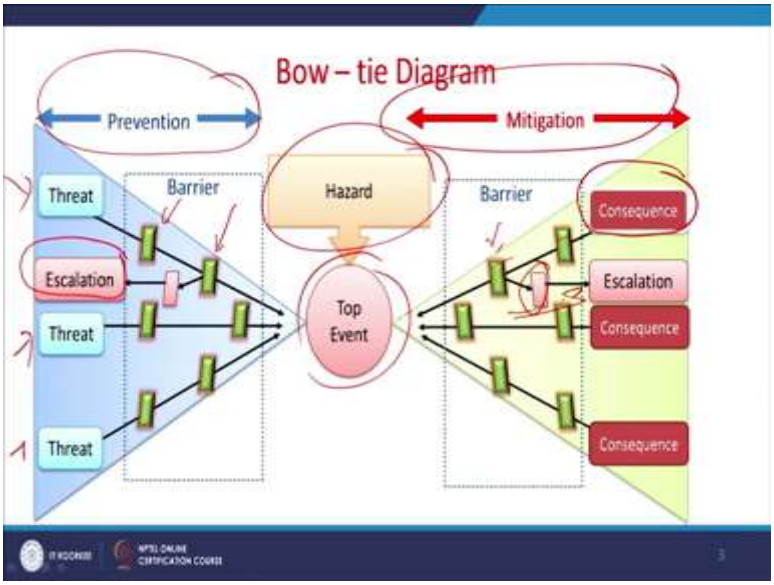

Now this is a typical Bowtie diagram now here you are having two different aspect like prevention and mitigation. Now there are various threats related to the process and these threats are supplemented by these barriers. So this is the hazard and this is the top event so this threat is coming through the different kind of barriers and sometimes these barriers they prevent all this things to escalate the things and similarly there are several consequence and this consequences again they are approaching to the top event and sometimes they are inhibited by the various barriers like this then it may go to the escalation. Now as shown in the figure the broader sense this diagram represents two factor now we are going into detail of this particular figure.

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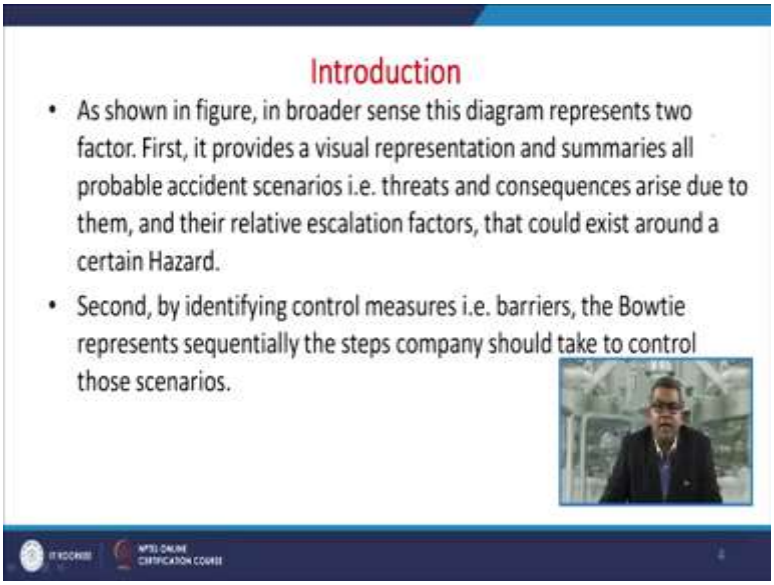

First its provide a visual representation and summarize all probable accidents scenarios like this that is the threats, consequences they are arises due to them and their relative escalation factors that could exists around certain hazards and second aspect is that by identifying the control measures these are the barriers these are the control measures you can say. So by identifying the control measures the Bowtie represents sequentially the steps the company should take to control those scenarios. So it gives a broader spectrum of the steps the company may require for to control all those scenarios.

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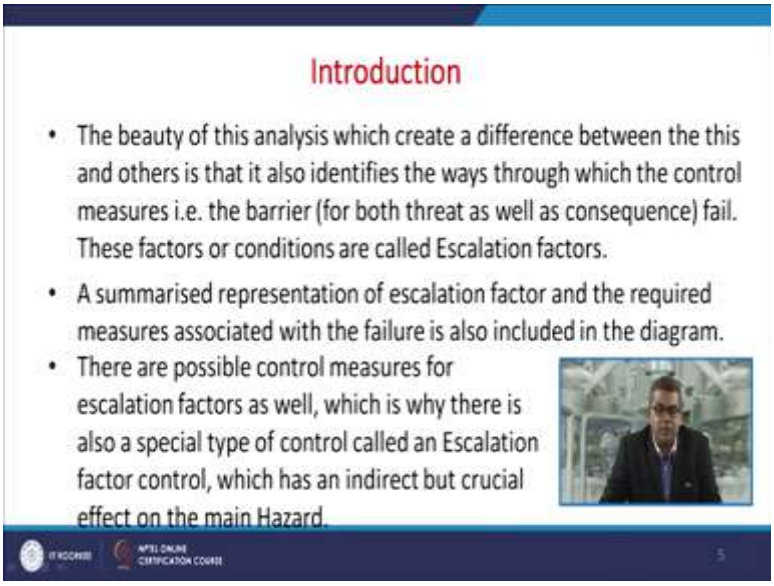

The beauty of this particular analysis which create a difference between this and others is that it also identifies the ways through which the control measures that is the barrier in the diagram for both threat as well as the consequences they fail. Now this factors or conditions are called the escalation factors it is very much represented in this both the preventive and the mitigation aspect.

So summarize representation of escalation factor and the required measures associated with the failure is also included in that particular diagram. So there are possible control measures for the escalation factors as well as which is why there is a also special type of control they are called an escalation factor control which has an indirect but crucial effect on the main hazard.

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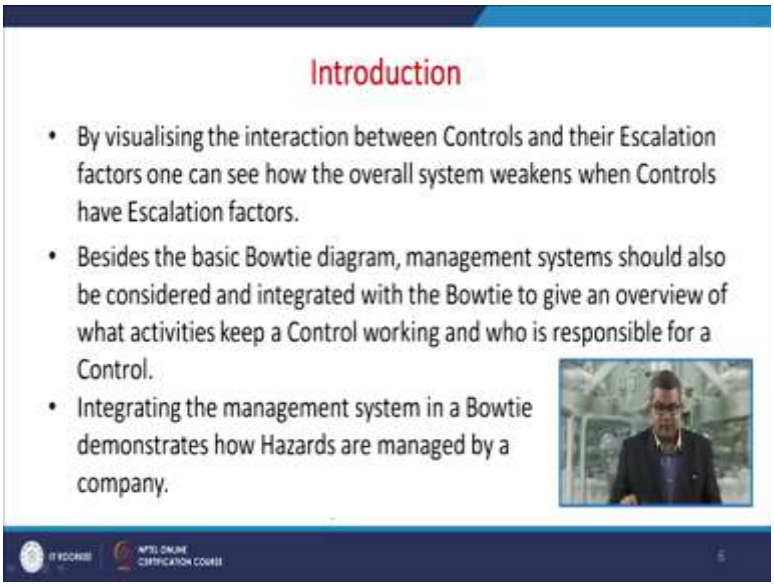

So the by visualizing the interaction between the controls different controls and their escalation factor one can see how the overall system weakens and when control have escalation factors. So beside the basic Bowtie diagram management system should also be considered and integrate with Bowtie to give an overview of what activities keep a control working and who is responsible for those control because you are having various control zones in that particular Bowtie diagram. Now integrating the management system in a Bowtie demonstrates that how hazards are managed by a company.

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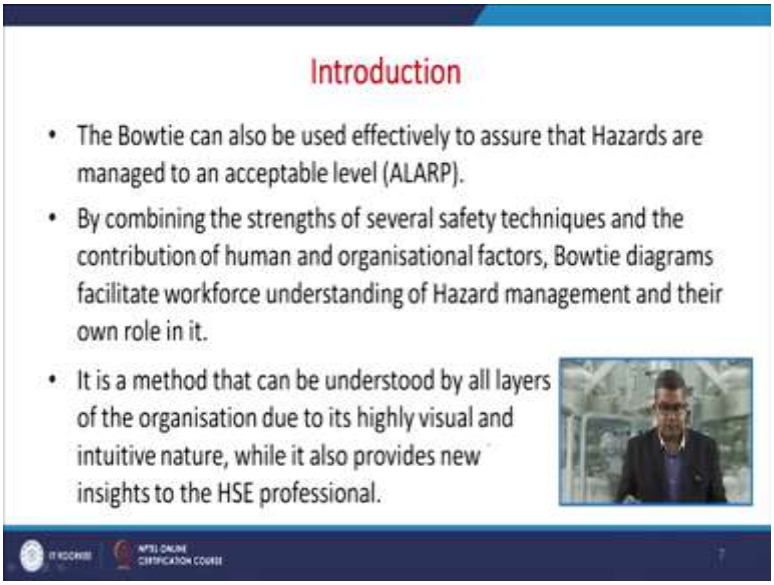

Now this Bowtie can also be used effectively to use that hazard are managed to an acceptable level ALARP which we have already discussed in other modules. So by combining the strength of several safety techniques and the contribution of human and organizational factor this Bowtie diagram facilitate workforce the understanding of hazard management and their own role in it that is very important this what is your role to control that hazard. So it is a method that can be understood by all layers of the organization due to its highly visual and intuitive natures. While it also provides new insides to the hazards safety environmental professionals that is sometimes referred as HSE professional.

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So let us have a look about the history of this Bowtie. So it is usually said that the first real Bowtie diagram appeared in the imperial chemical industry (UK) it is a UK based company this course notes on of a lecture on HAZAN that is Hazard Analysis given at the University of Queensland Australia in 1979 but how and when this method found its exact origin is not completely clear. So the catastrophic incident on the Piper Alpha platform in 1988 awoke the oil and gas industry.

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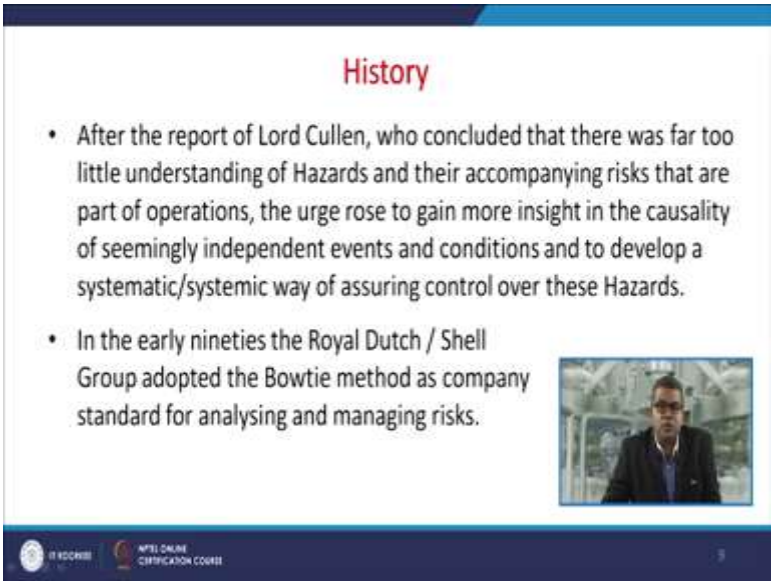

So the after the report of Lord Cullen who concluded that there was far too little understanding of hazard and their accompanying risk that are the part of operation the urge rose of gain more inside the casualty of seemingly independent event and condition and to develop a systematic or schematic ways of assuring control over these Hazards. So in early 90s the Royal Dutch or Shell group adopted the Bowtie method as a company standard for analyzing and managing risk.

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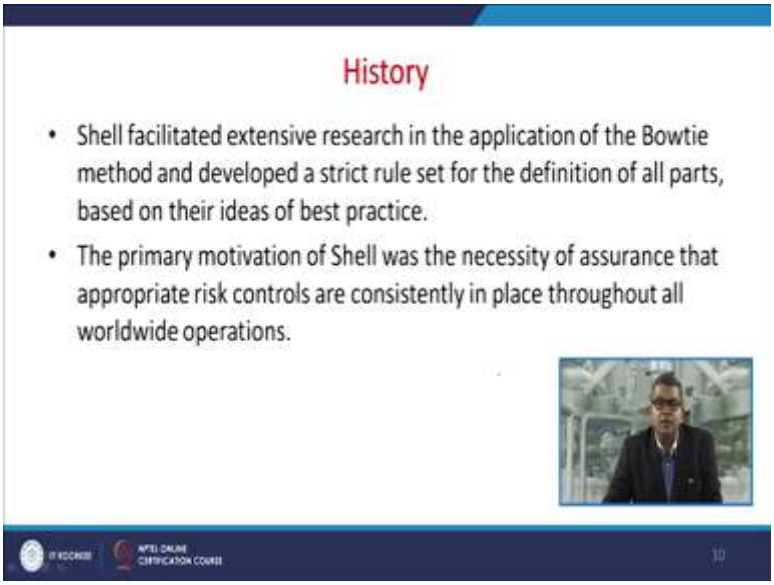

Now this Shell company they facilitated the extensive research in the application of the Bowtie method and developed a strict rule set for the definition of all parts that is based on their ideas of best practice. So the primary motivation of the shell company was the necessity of assurance that appropriate risk controls are consistently in placed throughout all worldwide operations. Now remember when we talk about the world wide operation the ground scenario is all together different in all operations because they are located at various zones various different countries etc.

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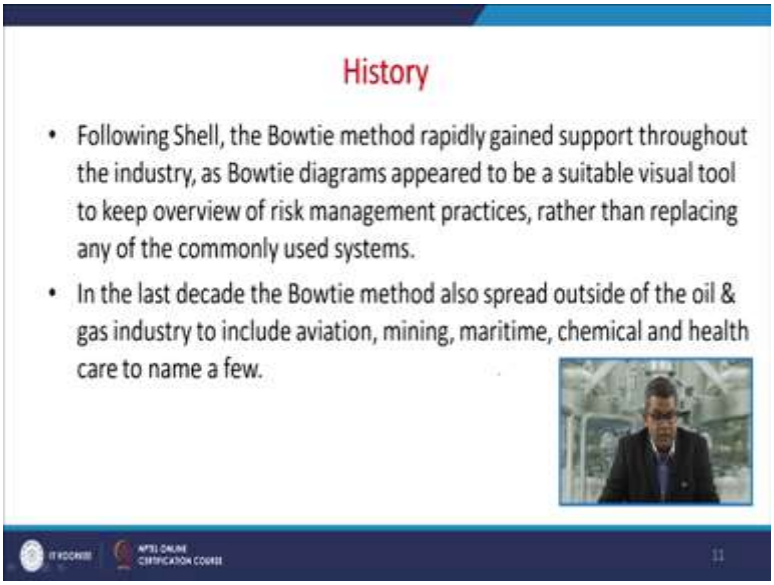

So following the shell the Bowtie method rapidly gained support throughout the industry now as these diagrams they appeared to be suitable visual tool to keep overview of risk management practices rather than replacing any of the commonly used system. So in the last decade the Bowtie method also spread outside the oil and gas industry to include aviation, mining, maritime, various chemicals and health care etc.

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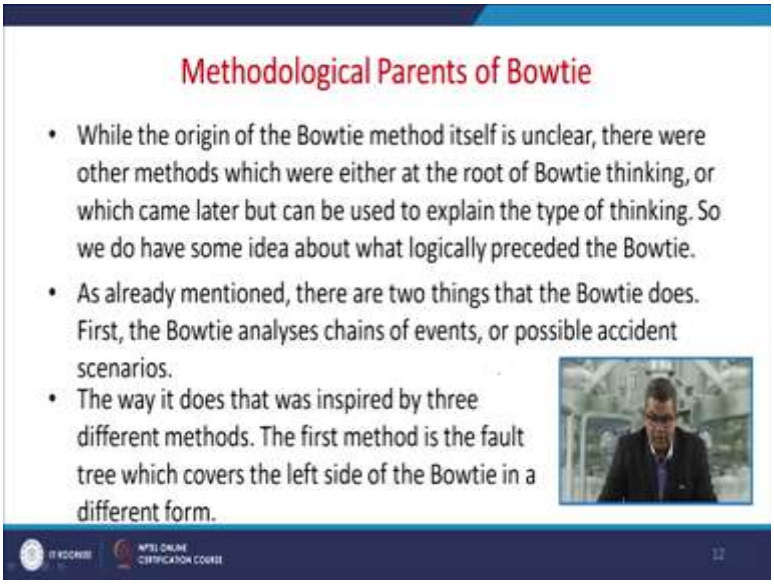

Now the methodological parents to Bowtie are that while the origin of Bowtie method itself is unclear there were other methods which were either at the root of Bowtie thinking or which came

later but can be used to explain type of thinking so we do have some idea about that what logically preceded in the Bowtie. So we have already mentioned that there are two things that Bowtie does first the Bowtie analyzes chain of the event or the analyzes chain of various event or the possible accident scenarios so the way it does that was inspired by three different methods the first method is the fault tree which we have already discussed which covers the left side of the Bowtie in the different form.

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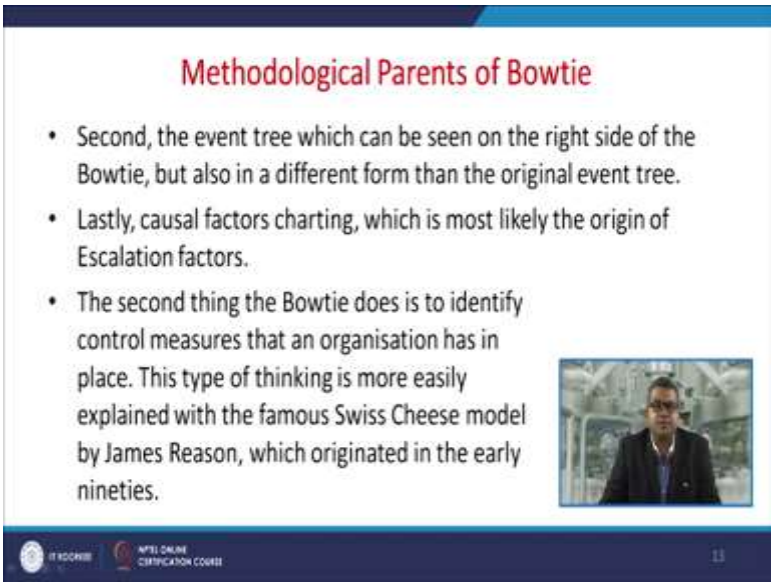

The second is the event tree again we had a previous discussion about this event tree so which can be seen on the right hand side of the Bowtie. So we are recalling the figure again like this this one this is the right hand side of the figure so but this also different from the original event tree so do not get confused while referring the original event tree it is bit different from the event tree lastly the casual factor that is charting which is most likely the origin of escalation factor. Now the second thing the Bowtie does is to identify control measures that an organization has in place now this type of thinking is more easily explained with the famous Swiss Cheese model by James Reason which is originated in early 90s.

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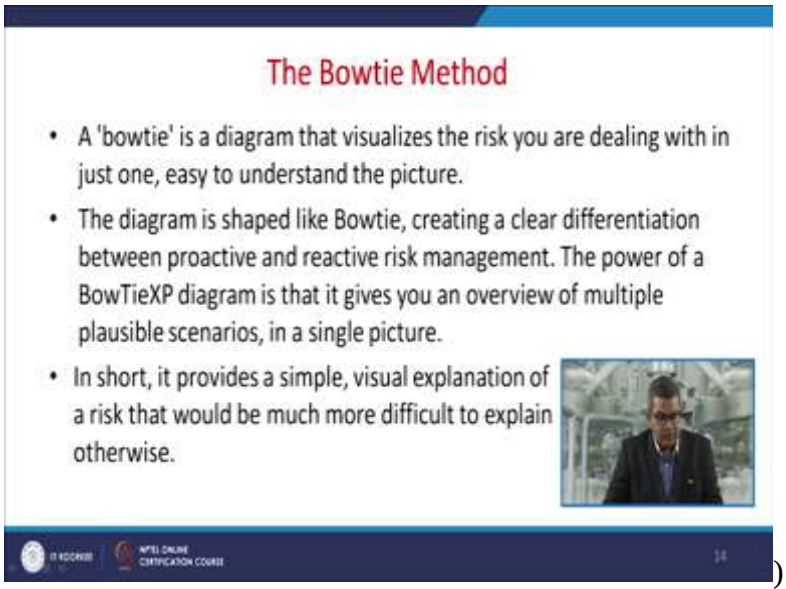

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Now a Bowtie diagram that visualizes the risk you are dealing with in a just one easy to understand the picture so it is small and easy to understand figure. Now this diagram is shaped like Bowtie creating the clear difference between the proactive and the reactive management. The power of a Bowtie XP diagram is that gives you an overview of a multiple plausible scenario in a single picture, so in short it provides the very simple visual explanation of risk that would be much more difficult to explain otherwise.

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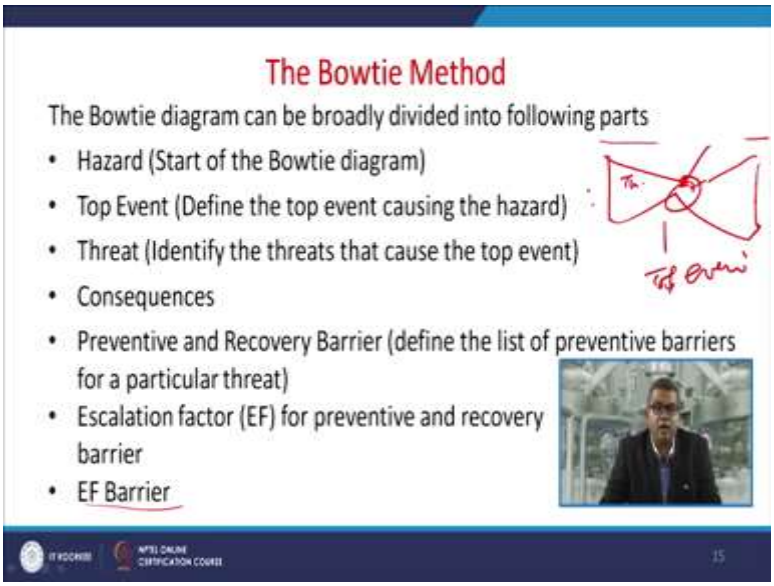

So the Bowtie diagram we can divide broadly into different parts one is that hazard that is the start of the Bowtie diagram so you need to identify because we have already discussed the hazard identification tools. The top event this define the top event causing the hazard there is a threat that is you need to identify the threat that cause the top event then there is a consequences there may be several consequences or a single consequence then preventive and recovery barriers define the list of a preventive barriers so for a particular threat if you recall the figure we have enlist.

We have pointed out several threats they are supported by the barriers those are the preventive things for a particular threat then there is an escalation factor for preventive and recovery of those barriers. Then they are certain EF barriers so we have already this escalation barriers, escalation factors etc. we have already enlisted in that Bowtie diagram if you recall this diagram. We were having the top event and there are various things like threats, escalations etc. they were included in that particular Bowtie diagram.

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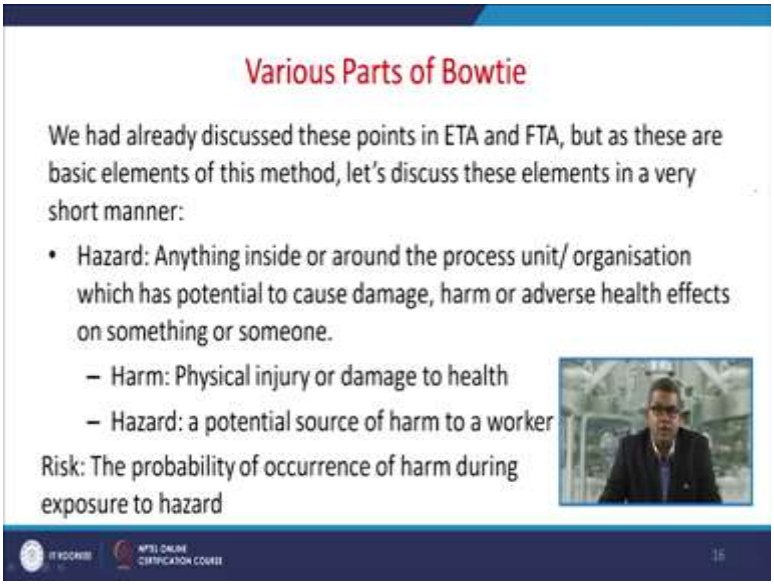

Now there are various parts of this Bowtie so we had already discussed this point when event tree analysis and a fault tree analysis but as these are basic elements of the math let us have a discussion about this elements in a very short manner like hazard anything that is inside or around the process unit oblique organization which has the potential to cause the damage harm or adverse health effect on something or someone, harm that is the physical injury or a damage to

health. Hazard, a potential source of a harm to a worker there is a risk that is the probability of occurrence of harm during the exposure to hazard.

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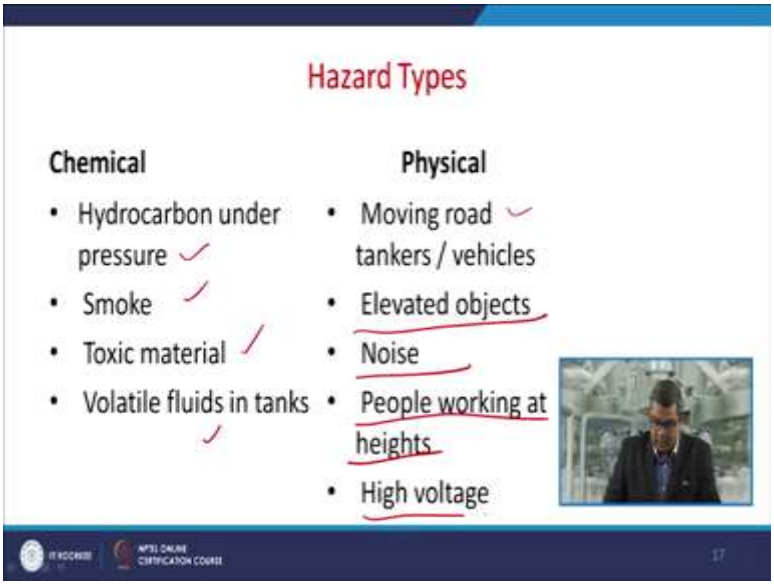

Now there are various type of hazards like chemical hazards and the physical hazards couple of examples are chemical hazards that are hydrocarbon under pressure, smoke, toxic materials, volatile fluids in tanks there may be certain physical hazards like moving road tankers or vehicles, elevated objects, noise, people working at height and sometimes the high voltage.

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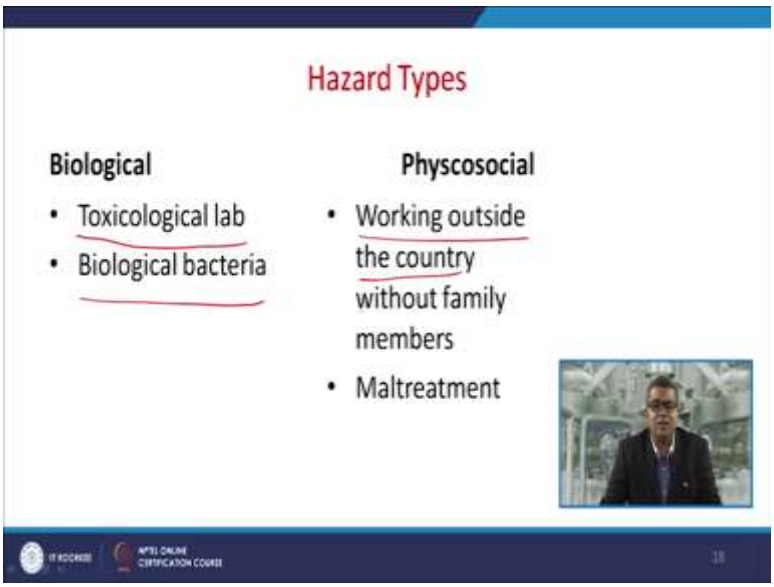

There may be certain biological or other hazards like biological hazard some toxicological lab hazards, biological bacteria sometimes pathogens etc. Sometimes you may experience the working outside the country without the family members that is the physiological hazard then sometimes maltreatment or sometimes miscommunications etc these are the other hazards.

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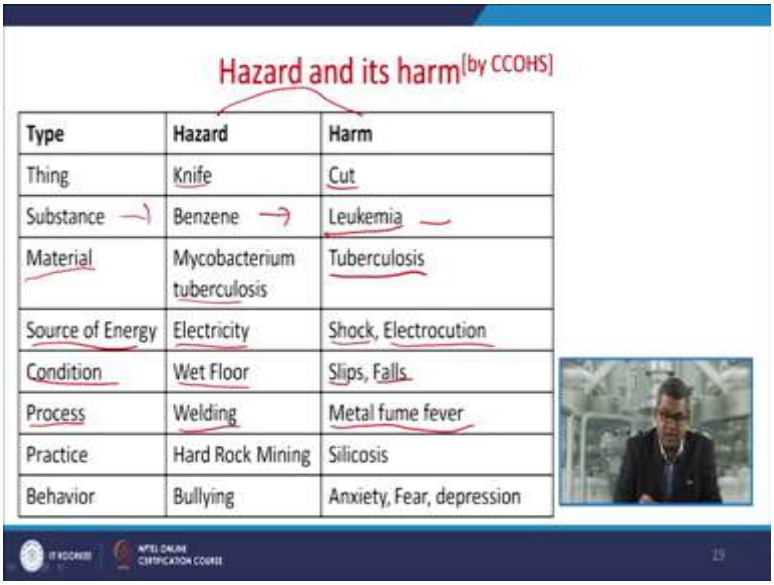

So we have enlisted several hazards and its harm like different things may be attributed to the knife it may create the cut sometimes bleeding etc then it may be attributed to a substance like benzene it may create the leukemia or carcinoma then it may be attributed to several material aspect that mycobacterium tuberculosis is may lead to the tuberculosis, may be attributed to the source of energy may be because of the electricity sometimes you may have shock or electrocution.

Then there may be conditions sometimes may be wet floor you may slip, fall, injured etc. then the process attributed to the process may be related to the hazard associated with this welding and the harm is the metal fume etc. So you must have a clear cut picture or you must be in a position to differentiate between the hazard and harm.

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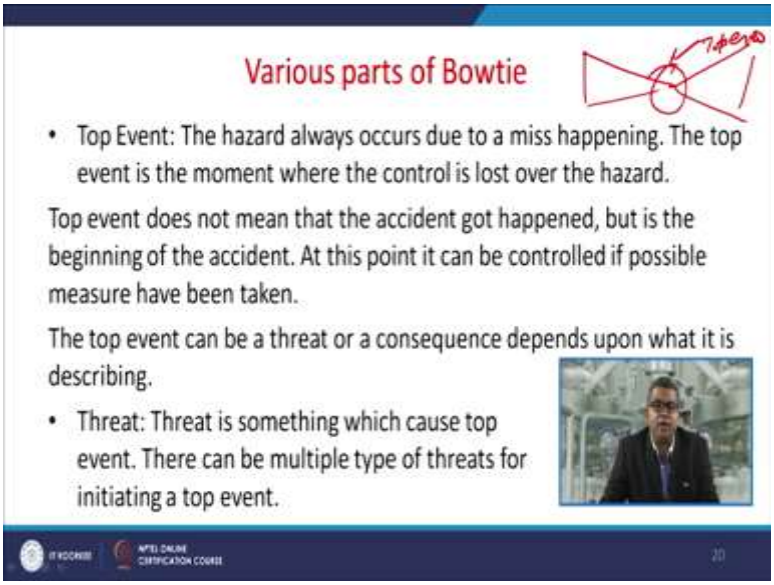

Next aspect of the Bowtie part is the top event the hazard always occurs due to the miss happening the top event is the moment where the control is lost over that particular hazards. So you are not having any kind of things which you need to control. Top event does not mean that the accident got happened but is the beginning of the accident.

So at this point it can be controlled if possible measures have been taken or sometimes you may referred as a near missed type of thing. The top event that can be a threat or a consequence depend upon what is describing and that is why the top event is enlisted over here. Now threat the definition of threat is something which caused top event and this can be the multiple type of threats for initiating a top event.

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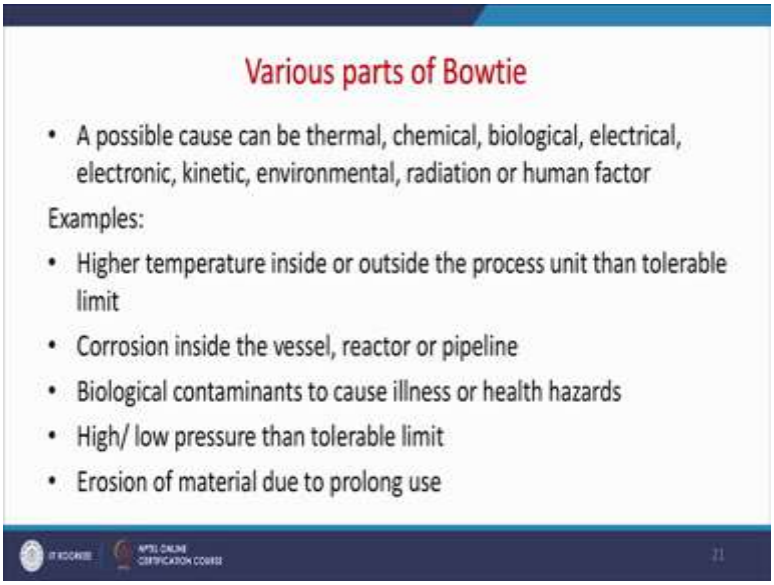

A possible cause this can be a thermal, chemical, biological, electrical, sometimes electronic, sometimes may be attributed to kinetic environmental radiation or human factor. So there are several examples like high temperature inside or outside the process unit then tolerable limit, sometimes the corrosion inside he vessel reactor or a pipeline. The biological contaminants to cause illness or health hazard sometimes high or a low pressure than the tolerable limit, sometimes erosion of a material due to the prolong use.

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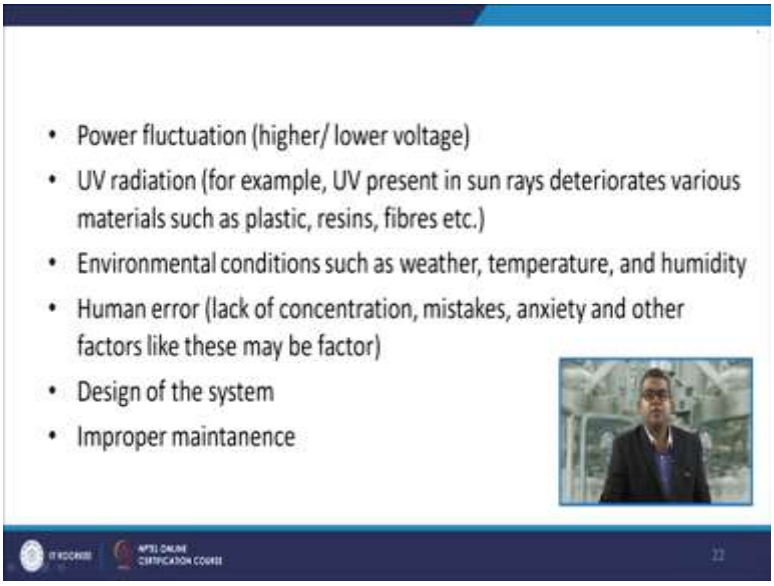

Sometimes it may attributed to the power fluctuation may be higher or a lower voltage, sometimes ultra-violate radiation, sometime like UV present in some rays deteriorates the various materials such as plastic, resins etc. there may be certain environmental conditions such as whether, temperature or humidity, sometimes human error that is lack of concentration, mistake, anxiety and other factors. Sometimes attributed to the design of the system, sometimes the improper maintenance may lead to this kind of scenario.

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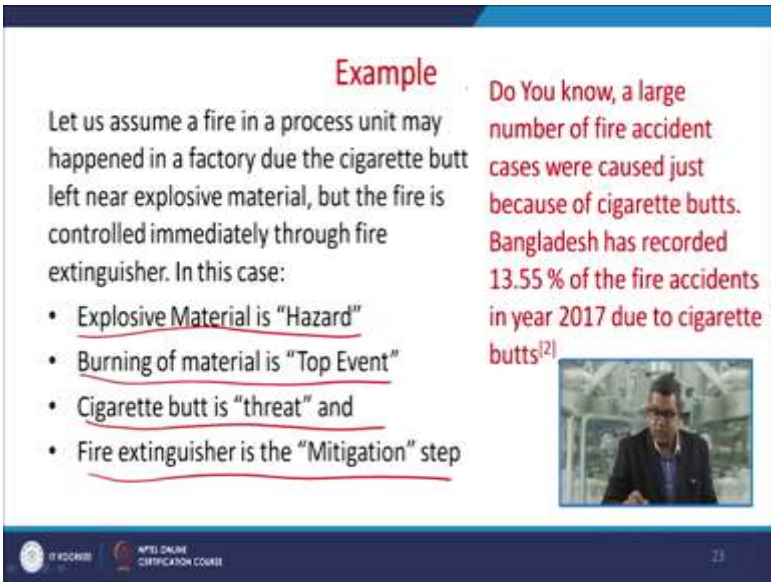

Now let us have an example so let us assume a fire in a process unit they may happen in the factory due to the cigarette butt left near the explosive material but the fire is controlled immediately through the fire extinguisher in that particular case the explosive material is hazard the burning of the material is the top event, the cigarette butt is the threat and the fire extinguisher is the mitigation step. So do you know the large number of fire accident cases were caused just because of the cigarette butt so Bangladesh they have recorded 13.55% of the fire accidents in year 2017due to cigarette butts. So this is for the sake of the example.

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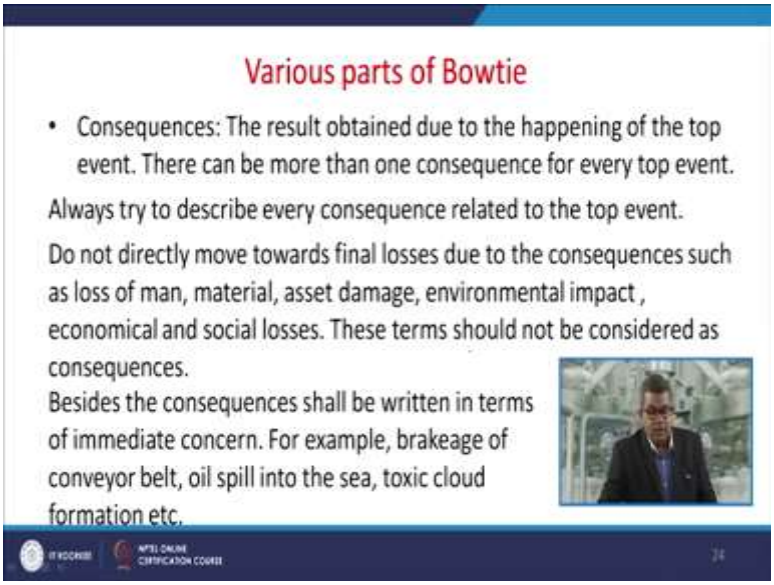

Then again go back to the different parts of Bowtie the consequences, the result obtained due to the happening of the top event there can be more than one consequence for every top event so always try to describe every consequence related to the top event and do not directly move towards final losses due to the consequence such as loss of man material as a damage environmental impact, economical and social losses so this term should not be considered as consequences. Now beside the consequences shall be written in terms of immediate concern like for example the breakage of conveyor belt, oil spill into the sea, toxic cloud formation etc so there may be so many.

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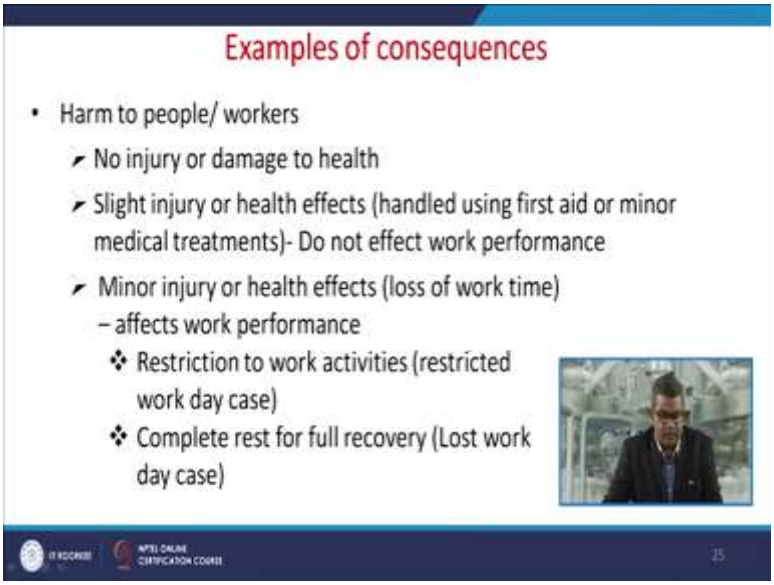

Sometimes it may create harm to the people or a worker maybe attributed that no injury or damaged to the health slightly injury or injured or health effect handled using first aid or a minor medical treatment they do not affect the work performance sometimes minor injury or health effect loss of work time etc. they affect the work performance, restriction to work activities restricted work day case etc. the complete rest of full recovery that is the lost work day case because sometimes the worker maybe ask to go for the complete rest for the full recovery.

So that is attributed that is a lost work day case. Similarly sometimes the restrictions to the work activity sometimes they are (not) they are assigned to a temporary job or sometime they are away for the activities for which they are trained then in that particular case this is termed as the restricted work day case.

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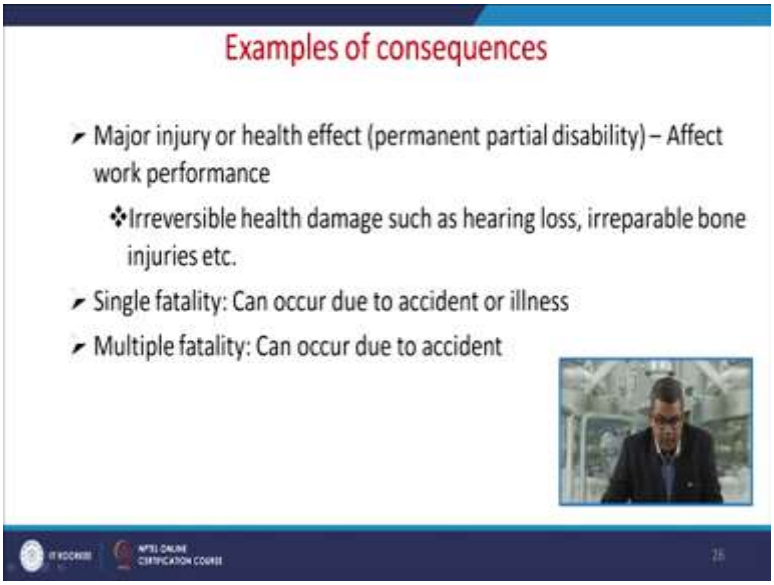

Now there are several examples of consequences the major injury or health effect that is the permanent or a partial disability they effect the work performance ultimately lead to the economic losses of the company. Sometimes a reversible health damage such as hearing loss, irreparable bone injuries etc. this may happen. There may be a single fatality that can occur due to the accident or illness. Now illness maybe attributed to the malfunctioning. There may be certain multiple fatality like in Bhopal death can occur due to an accident.

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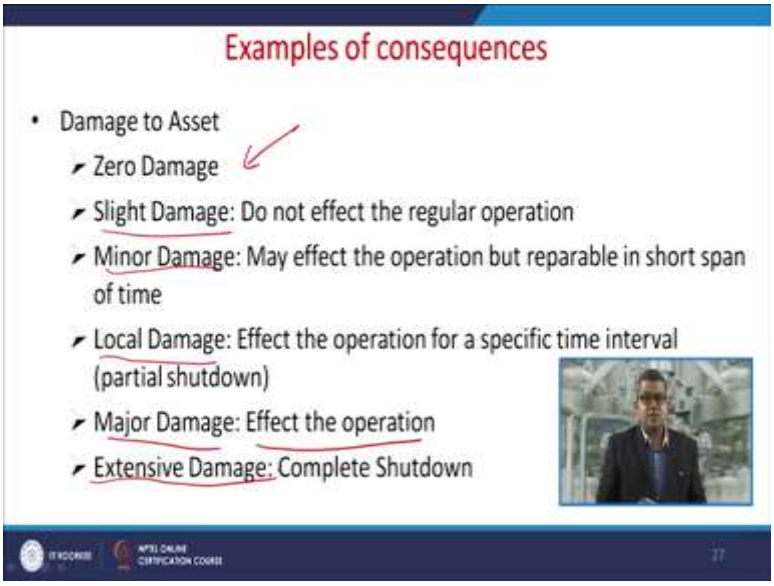

Other examples of like that damage to asset sometimes it may happen that there is no damage at all in the plant then there may be a consequence of slight damaged they do not effect the regular operation so slight effect may take place and then there is no process loss or any kind of hampering towards the regular operation. There may be certain minor damage this may affect the operation but it can be repaired in a short span of time.

There may be certain local damage this is the effect of effect operation for a specific time interval there may be a chance of partial shutdown. There are certain major damages they severely affect the operation but still something is going on. Then there is a thing of related to the extensive damage that means it this extensive damage may lead the complete shutdown of the process. So the severe economic loss so this are the consequences or example of the consequences.

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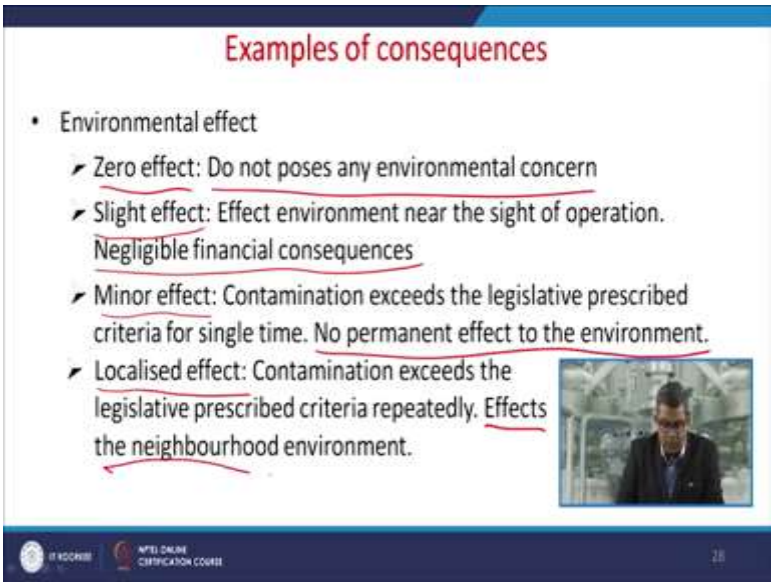

Apart from this because we had discuss this thing related to the asset which is within the plant side or within the company. Now there may be certain effects they are attributed to environment so the environmental effects are like zero effect, they do not pose any kind of environmental concern that means they are within the limit as prescribed the various regulatory bodies.

Then they may have a slight effect that effect environment near the sight of operation so there may be negligible financial consequences. There are certain minor effect the contamination exceeds the legislative prescribed criteria for single time and there is no permanent effect to the

environment so you can repair it or (repair) the environment itself repair that thing in C2. Then there are certain localized effect that the contamination exceeds the legislative prescribed limits and effects this severely effects the neighborhood environments.

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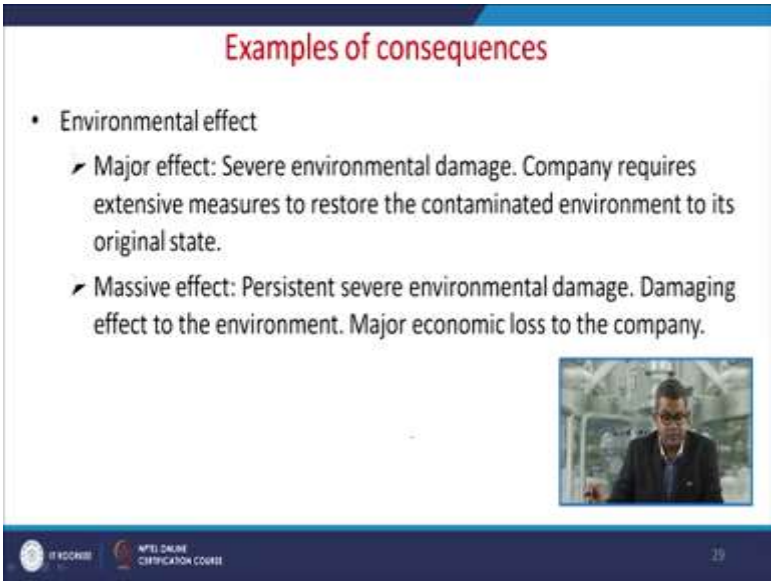

There are several major effects the severe environmental damage and company requires the extensive measures to restore the contaminated environment to its original state that means heavy economic loss. Then there is massive effect that persistent severe environmental damage and damaging the effect to the environment and the major economic loss to the company and sometimes the regulatory body may ask to shut down its operation so that is the massive effect.

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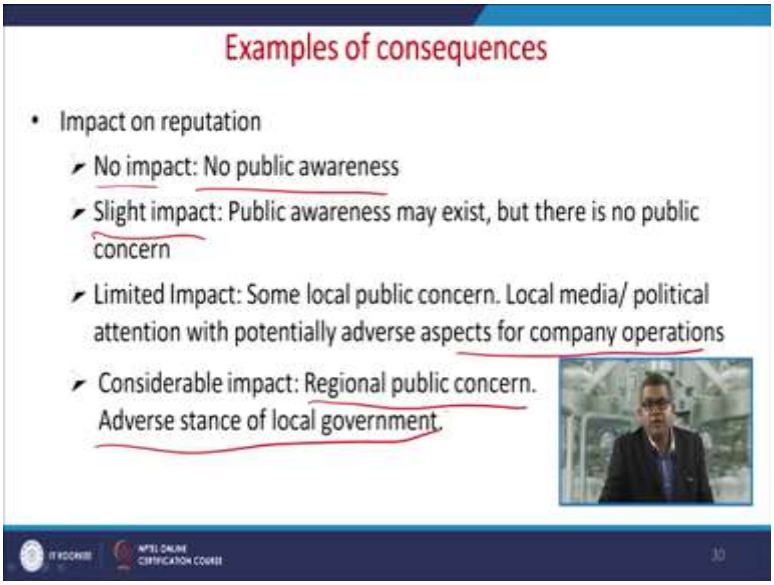

Apart from this one psychological factor is that the impact on reputation so if there is no impact then may be attributed to that more public awareness there may be slight impact that public awareness may exist but there is no public concern so nobody bothers. There is a chance that you may have a limited impact so some local public concern and local media or the political tension with potentially adverse aspect of the company operation so sometimes it may reflect there may be chance of considerable impact that is the regional public concern and adverse stance of local government so again it may lead to the several negative aspect to the company.

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Then there may be a chance of national impact the national public concern so extensive adverse effect or effect on the functioning of the company the national media and the political tension attributed to the regulatory laws and sometimes you may experience the mobilization of various action groups there may be a chance of international impact. The international public attention extensive adverse attention in international media with potentially severe impact on access of to new areas, grants and legislation. So you may recall or you may refer to the Bhopal gas tragedy when it was an international impact as well as the national impact on the company called union carbide.

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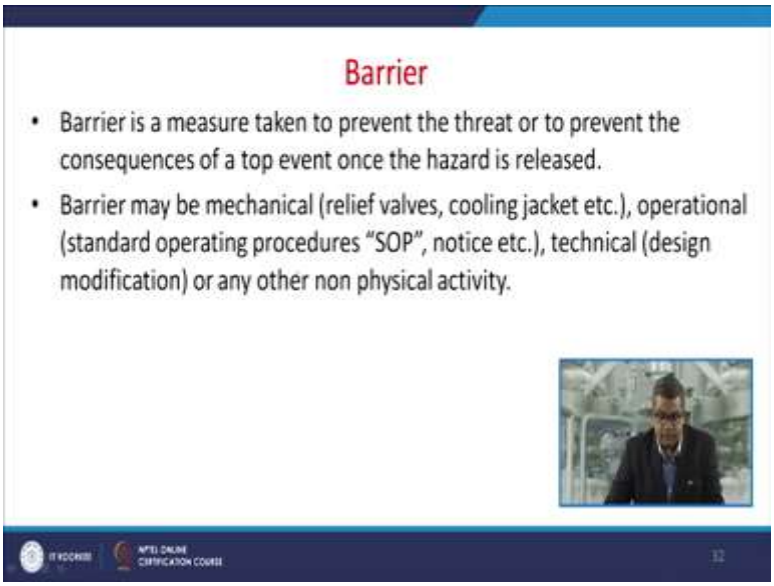

Now let us have a look about the barriers so the barriers they are the measures taken to prevent the threats or to prevent the consequences of a top event once the hazard is released. So this barriers may be mechanical like relief valve, cooling jackets etc. operational like standard operating procedures SOPs, notices etc. there may be technical that is the design modification or any other non-physical activity.

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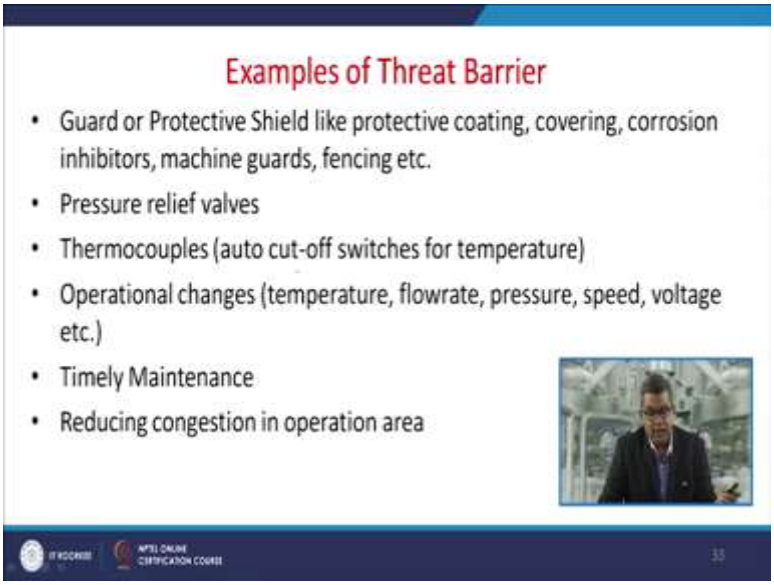

There are several examples of threat barriers the guard or protective shield like protective coating, sometimes covering, corrosion, inhibitors, machine guards, fencing etc. there may be certain PRVs like pressure relief valves etc. The thermocouples maybe auto cutoff for the temperature etc. the operational changes sometimes may this operational changes may be clubbed under the head of threat barriers like temperature, flow rate, pressure, speed, voltage etc. Timey maintenance is also come under the threat barriers because timely maintenance may delay or may prevent the chance of any accidents. Then the reducing congestion in the operation areas so that the release may be neutralized once it happens.

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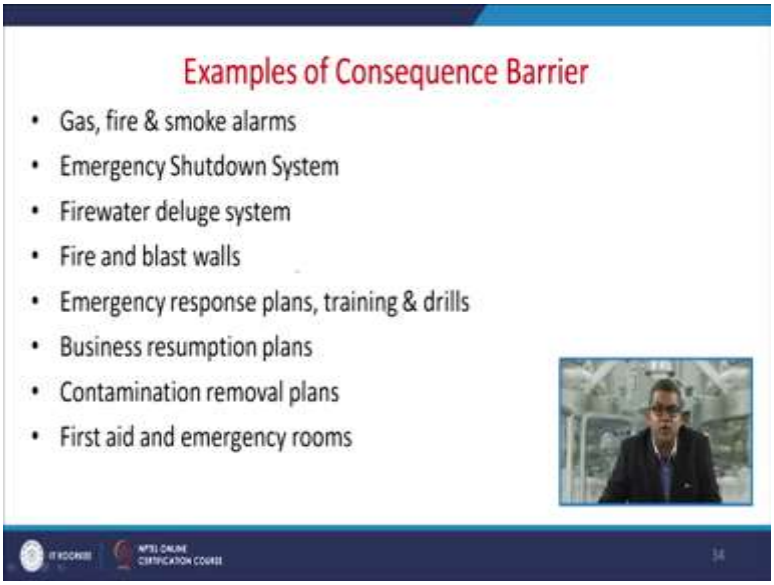

The other example of consequence barriers like gas, fire and smoke alarms, emergency shutdown system. You may have a firewater deluge system, the fire and blast walls, the emergency response plans training and drills, you may have a business resumption plan, contamination removal plans also clubbed under the head of consequence barrier. The first aid and emergency rooms.

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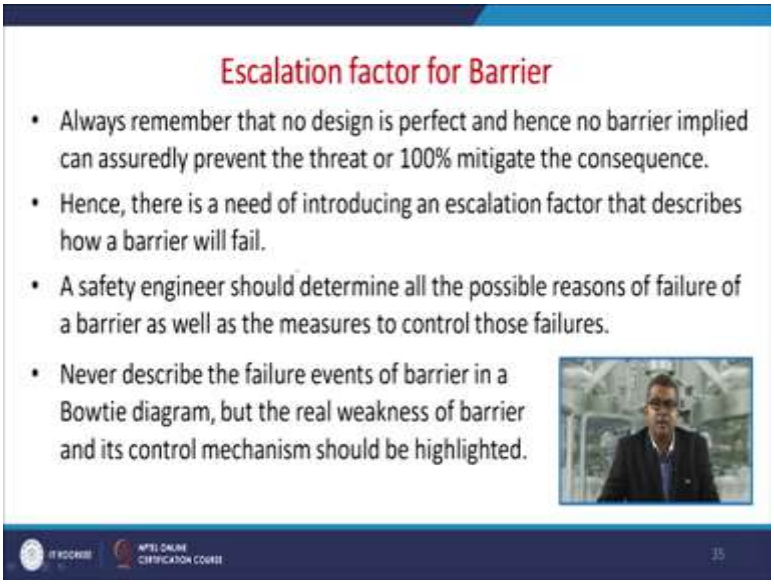

Now let us have a discussion about escalation factor of barriers so always remember that no design is perfect. Hence no barrier implied can assuredly prevent the threats at workplace or

100% mitigate any kind of consequence therefore there is a need to introduce an escalation factor that describes how the barrier will fail. So a safety engineer should determine all possible reasons of failure of a barrier as well as the measures to control those failures. Now never describe the failure event of a barrier in a Bowtie diagram but the real weakness of barrier and its control mechanism should be highlighted any kind of abnormal conditions like critical standby, equipment under the maintenance during an emergency this is the example of escalation factor.

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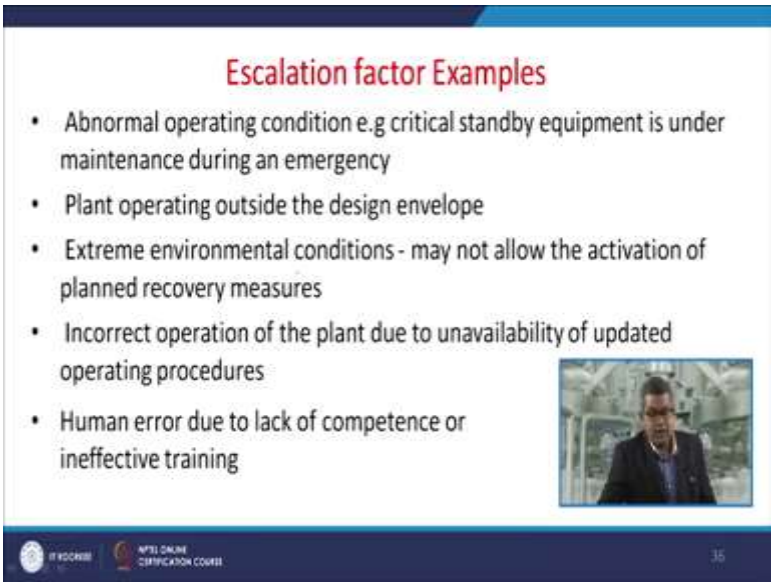

The plant operating outside the design envelope the extreme environmental conditions may not allow the activation of any kind of planned recovery measures. The incorrect operations of the plant that is attributed to the non-availability of updated operating protocols sometimes human errors due to the lack of competence or ineffective training. So in this particular module we had discussion about the Bowtie this is the last you can say the protocol of risk mitigation and we had discussion about the various integral part of this Bowtie diagram.

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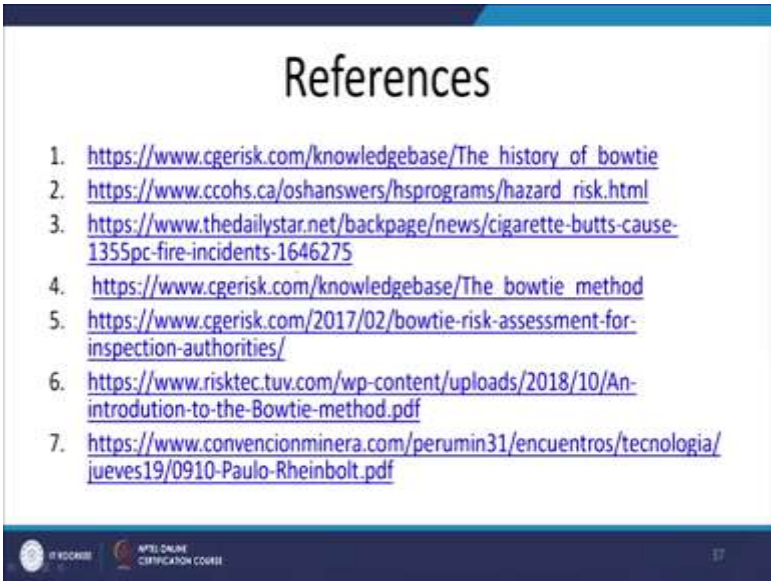

So in case if you wish to study further you may have a look of all the references listed in this slide, thank you very much.