Introduction to Explosions and Explosion Safety
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Lecture - 3
Typical Examples of Explosions and Classification

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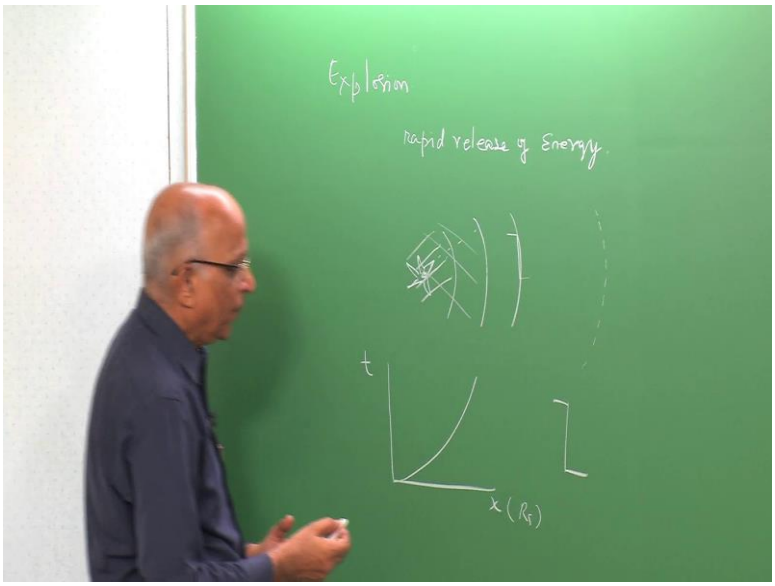

Good morning, in the last two classes we defined an explosion as being produced, when a blast wave is generated, and this blast wave is generated due to impulsive or rapid release of energy. Let us qualify it a little better, you know supposing I have a region or a zone or a small volume, in which let us say some energy gets released. And then what happens is this energy release, drives the blast wave which propagates out. And then what is happening is the energy release gets redistribute, this energy release in this small volume gets released or gets redistributed by the lead shock wave.

And this energy is at this particular time when the blast wave is here, the energy released gets redistributed here, when the lead shockwave is here the energy gets redistributed in this zone, and so on. It is essentially the redistribution of energy which is impulsively deposited, which leads to an explosion. Now, when we say about this redistribution of energy, it is this potential energy of the explosive or what is being released here which gets converted into kinetic energy and potential energy, but it is all contained within the lead blast wave as it were.

There is something important in this, and we have been telling this repeatedly in the last two classes namely that the material does not move, it is the energy gets redistributed, I think this point must be kept in mind as we go along. We also told ourselves, well the way two points we said, if this energy release gets into the thermal energy of the medium. Well, it is unavailable energy this is unviable for deriving the blast wave. Second, we also told since the energy is redistributed, when the blast wave or when the wave continually decays out and reaches a faraway point.

Let that means, we are looking in the far field, well the energy could get conserved, we will take a look at it in the subsequent classes. Therefore, this is the way we defined an explosion, and we found that anyway the lead shock is something which is continually decaying. In other words what did we tell ourselves, on a streak diagram in which the y axis is t, the distance is x or very often we will define it as the radius from here, let us say R s. Well, they it decays out initially it travels a longer distance for a short time, then it becomes an acoustic wave in the far field.

Now, what is going to happen? See it is continually decaying the energy gets redistributed it is a terrible tangent problem, unsteady and therefore to be able to solve it was difficult, and therefore what did we do? We went through the non dimensional analysis through which we looked at the parameters, and we got the dependence saying.

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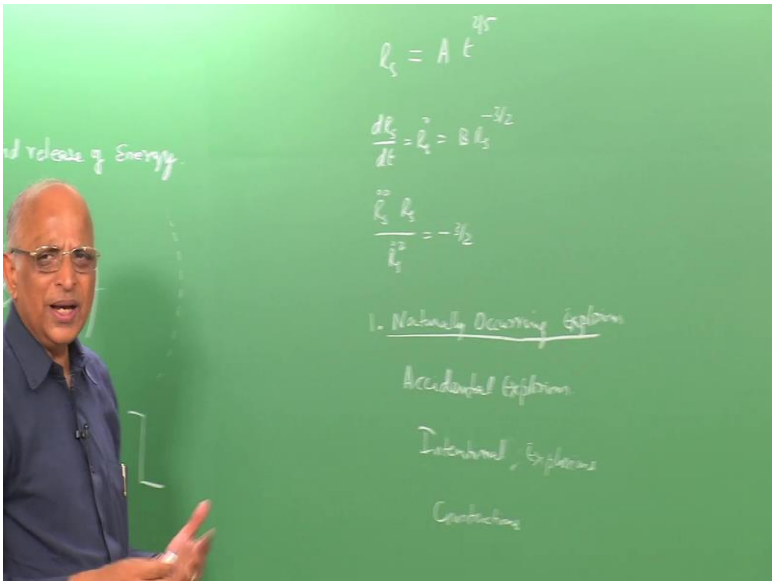

Well, the distance by which the lead shock travels at some time t, after the impulsive release of energy can be written as R s is equal to A t to the power 2 by 5. The second point, we also said the velocity with which the lead shock moves d s d R s by d t, which we said is equal to R s can B written as a constant here A is a constant, t is the time can be written as R s to the power minus 3 by 2. We also found out the rate at which the blast wave decays and we found. Well, denoting it by R s dot and we say well I am looking at R s 2 dot that is d 2 R s by d t square into R s divided by R s dot square, we got it equal to minus 3 by 2.

In other words, R s is positive, R s dot squared is velocity which is anyway it is a positive number, therefore it continually decays, and this is what we got from dimensional analysis. We will also recall, we said there are different types of explosions, we said there explosion could be occur in nature, we said naturally occurring explosions naturally occurring explosions. We also talked in terms of accidental, we said well in the kitchen something leaks, gas leaks and all of a sudden we have something like accidental explosions.

We also talked in terms of intentional explosions, may be intentionally may be the during warfare somebody goes and drops a bombs at some place or may be of flake we have these antisocial elements like terrorist. Who go and plan some minds or by explode bombs in some crowded localities, we say these are intentionally created explosions or we say well intentional explosions. We also told, well an explosion could be use for constructive purposes like air bags in a for surgery may be for making kennels and all that, well these were the different types of explosions we talked off.

Now, in today's class to be able to relate to the theory, which we must develop mind you see we just developed some value of the shock based on dimensional analysis without going into the detail physics of the problem, but we also found. Well, when I have this lead shock across the lead shock there is a jump in pressure, a spontaneous jump in pressure, because the shock wave from the ambient pressure it jumps to this value. Behind it, you have the momentum of gases or the impulse of gases, it is necessary for us to determine these quantities to find out, what is the effect of the explosion on the things around it.

Therefore, to be able to do that, if we can go through some of these examples of different types of explosions, maybe we will be better equip to understand the theory. Therefore, in today's class what I do is, we will take a look at different types of explosions, and see how they behave. And based on that, we will go back and try to again revisit the blast wave generated from the energy source, and find out the parameters of a blast wave which could cause some damage.

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Having said that, let me come to the first slide which I want to show, I will get I will start with the naturally occurring explosions one. You know let us get started with the slides over here, may be the first type of the naturally occurring explosion, which all of us are familiar is something like a lightning, see this particular slide shows a lightning here what happens is here?

The clouds which move, and during the movement at high velocities they pick up a charge, become a charged as it were developed high potential or high voltage and it hurts to the ground, and you have something like an arc discharge. I took this slide from national geography, and what you have to find is something like a like an arc discharge over here. And what happens? The arc discharge releases rapid energy over here, and therefore what would happen then let us go back and see what could happen? See you have something like an arc discharge taking place, something like a line discharge.

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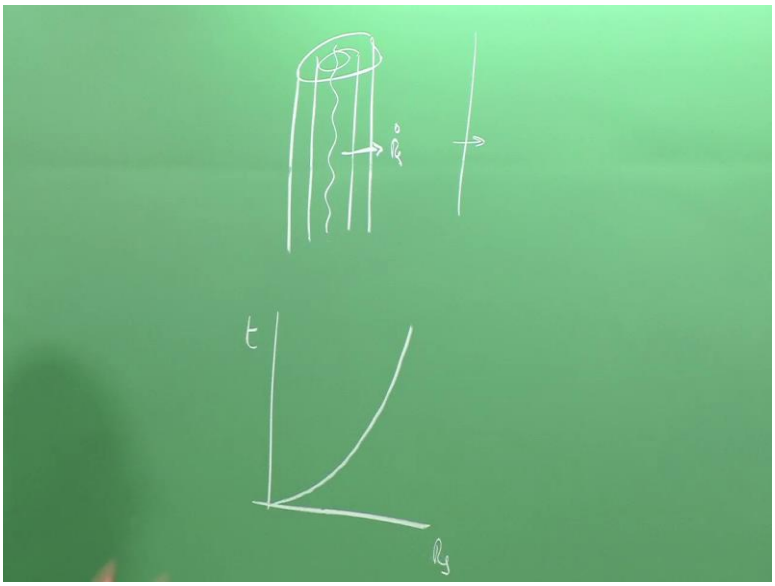

And therefore, I will start creating something like a cylindrical wave, which propagates out from here this is R s dot that is the velocity with which it goes, in the near field what is going to happen? You have I again plot that t versus the x or the distance let us say R s over here, initially it is start with high velocity decays out in the limit, where in the wave travels to far away, I hear rumble of thunder, if I am near to this I hear extremely loud bang loud thunder, and far away I just hear the rumble of the thunder. We looked at this, well this is the first naturally occurring explosions, lightning's are frequent in some places it occurs more often than known. Well, this is the first type of naturally occurring explosions.

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Let us got to the next type, the next is the volcanic eruptions, and you know in this picture again from national geography, I show a volcano spoofing out fire, as it where I have a huge fire. And in this hot gases are generated, the hot gases sometimes are charged, and therefore I could get arc discharge and something like a lightening I could get a blast wave, but very often what happens is? Some of these volcanos when they here up there is also some seismic activity, like there is some tidal waves and or else the volcano is in the ocean.

And very often during the volcanic eruption some sea water enters into the volcano, the volcano is pulling out these hot gases hot lava is what is there, molten lava is there. When water enters, you know this water see this huge hot mass of lava and hot gases, it is spontaneously flashes into vapor it become superheated, and the type of energy is so high, that it creates an explosion something like a physical thing wherein the phase of the water changes. And we had this very famous explosion at Krakatau, this was something like 40 kilometers west of java, and this happened on August 26 1883 mind you it is quite old.

But this explosion is extremely famous, in fact what happened in this volcanic eruption is, something like over a distance of something like 5000 4500 kilometers away the blast could be heard point one. Point two something like over a distance of something like 500 kilometers, the buildings got shattered that is the power of this particular explosion that

is the blast wave generated, created real lava in this naturally occurring volcanic eruption. Such type of eruptions do take place now, and then and of late we have the tsunami, we have water in gracing and all that therefore these are the types of sea second type of naturally occurring explosions.

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We come to the third one and this is of particular interest, because of late. We talk in terms of comets.

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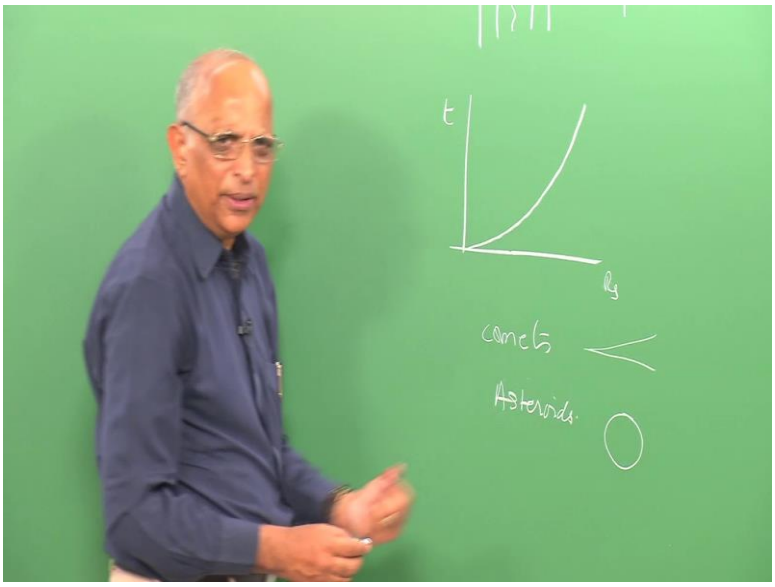

We also talk in terms of asteroids in space, what is the difference between an asteroid under comet, you know these are all loosely from objects in space, and what happens is? When these are not planets actually, they do not have a particular type of a trajectory and they the asteroid consists of metal and rocky material. Whereas a comet consists of may be ice, dust and also some rocky material with a result, when the comet approaches the sun or near to the sun, you know the ice evaporates under comet as a long tail as it were. Whereas an asteroid having metal is something which is more solid, sometimes these comets and asteroids enter into the earth, like for instance.

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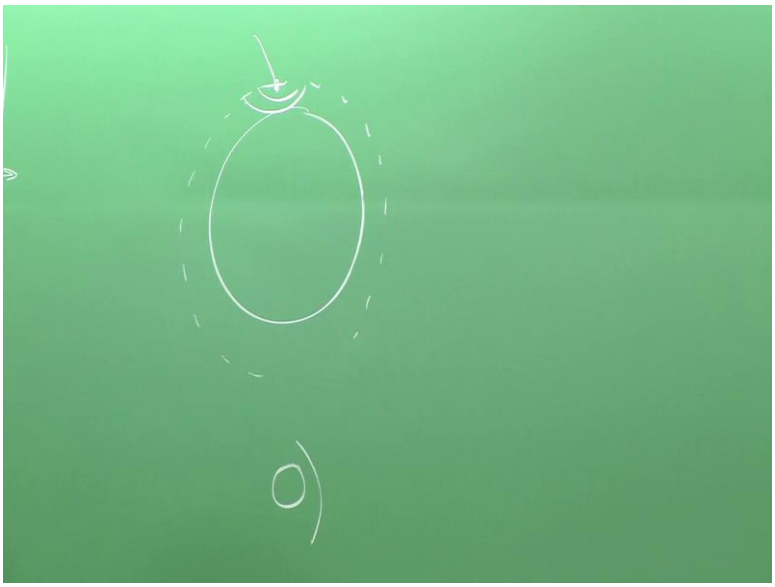

I say well the earth is here, above the earth we have atmosphere for something like 15 to 20 kilometers high. And suppose some of the comet or asteroid enters into the atmosphere, it immediately creates the kinetic energy creates a blast wave something like a comet is entering, I have a blast wave here to be able to equalize the velocity here, and the velocity here the energy release is so high that it creates a blast wave. And this blast wave can cause damage and one such comet, one such asteroid you know in this slide, I show a comet or perhaps an asteroid it is not very clear, whether it is really a comet or an asteroid.

It enters the atmosphere at a distance of around 8 to 10 kilometers over a place known as Tunguska in Siberia on July 30, 1908. You know the blast wave it got generated during this re entry was so strong, that over a distance of something like 150 kilometers, the

trees just got fell unfortunately for a Siberia being a desert there were not many buildings around, but buildings got demolished over a distance of something like 5 kilometer and that is the type of the explosive energy released that take place during the entry of an asteroid into the atmosphere.

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15 Feb., 2013: Yekterinburg: Chelyabinnsk 200 km away impact felt

It is not that there is just one case of this, you know you will recall around a few months back on 15th February 2013, over the Russian town of Yekaterinburg. You know we had a comet entry, and this comet entered the atmosphere at a distance around 5 to 7 kilometers above the surface of the earth. And the blast wave which created the impact was felt at a city known as Chelyabinsk, which is 200 kilometers away from the place where it really entered. In fact, due to this blast wave or the impact something like 200 to 300 buildings got broken, hospitals got damaged. And in fact, you know this was the big news in all the newspaper saying, meteor rattles Siberian city fortunately nuclear and chemical facilities are safe, there were switched off for some time.

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And let us go ahead, you know the big bang from this mid from this comet was such that as it strict over Russia. Well, it really cause shockwaves, shatter windows, buildings got broken, and it let to something like services like internet mobiles and all being affected.

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You know this is the type of power, which is associated with a comet re entering, and there is lot of interest in comet and asteroids. And in fact, it was told that it is about the larger size, and now if I look at the size of this particular mean size of this comet, it is around something like 17 meters or so in diameters, so very small one. Compared to

what was there, over Tunguska it is something like 30 meters diameter. And mind you these are all small things which can really cause so much of damage.

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Meteor fall a warning against space threats

And therefore, there is quite a lot of interest on the blast waves generated, when a meteor or a meteor, let us say a comet or an asteroid enters the atmosphere.

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In asteroid's aftermath, a sigh of relief

Using a mix of data, scientists now have a better picture of the space bullet that grazed Russia

CLOSE ENCOUNTER: *A frame grab of the small asteroid.* — PHOTO: AP

Henry Fountain

Using an eclectic mix of crowd-sourced video, information

calculate the mass of the meteor, about 11,000 metric tons. "It's all about the kinetic energy of that body," which is related to its mass

And you know we have this problem like, when this asteroid re entered here you find this brilliant flash due to energy release over this Russian town as it were, and the blast wave creating the damage.

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And since some asteroid is supposed to re enter the earth, may be a comet is supposed to an asteroid is supposed to re enter the earth, around let us say 2036 may be there is some interest. I must also point out that one such huge asteroid is set to have re enter the earth around 6 million years ago. And it is responsible for the extinction of life at that time, including extinction of the dinasors. Well, this is the third type of naturally occurring explosions.

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And the last one let us see what it is like. We talk in terms of stellar explosions, explosions in the star, well you have the star which is whose life is going to get over, it is fuel is consumed. Therefore, it has just neutrons in it, they because of gravity the neutron shrink it becomes very dense over here. And because of the density it explodes, high density the neutron explodes lot of energy gets released, you have a brilliant flash over here.

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And I also show something like a super nova that is a stiller explosion in this; this is again taken from the national geography. And what you find in these stellar explosions is you know the type of temperature, which is reached during the explosion is so very high, that the atoms or atoms combined to form heavy substances like gold, silver, may be platinum. And you know the source of these materials are set to come from on earth, is supposed to come from the stellar explosions.

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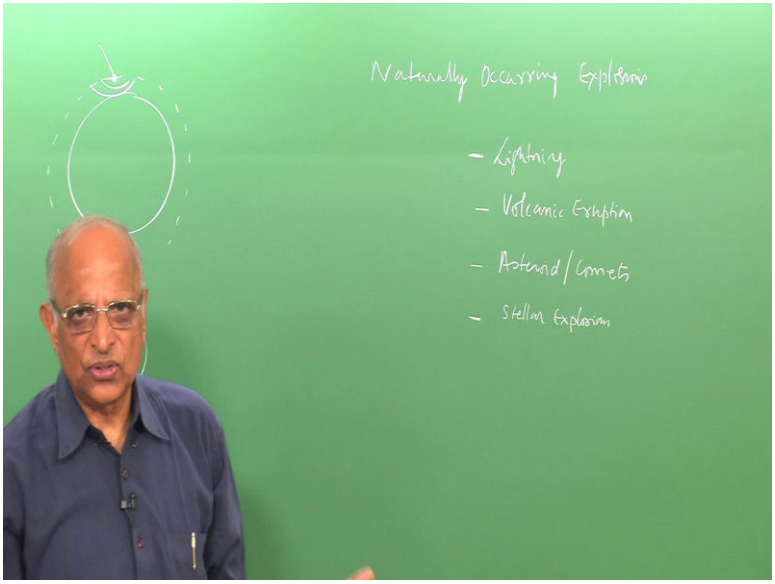

Well, these are the four types of naturally occurring explosions having seen these four types of explosions. Let us quickly summarize over here, the naturally occurring explosions are either, let us say lightening. Second we say volcanic eruption volcanic eruptions in which some physical explosion like sea water entering the volcano, can release huge amount of energy like the one at Krakatau. Maybe we talked in terms of the third type, in which we have asteroid comets entering the earth.

And the last one we said, well it could be stellar explosions. You know the stellar explosions cannot be heard for the simple reason, we have vacuum between the star and us. And therefore, there is no question of sound reaching us, there is no question of a blast wave reaching us, but we must remember it is the light intensity which is seen. And also we have the electromagnetic waves in form of the cosmic radiation, which we perceive from the stellar explosions.

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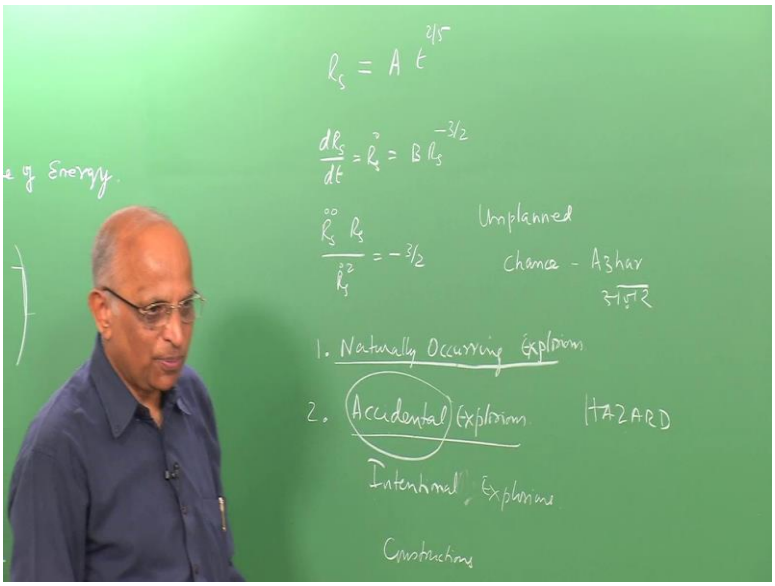

Having said that lets come to the next type of the explosion namely the accidental explosions, these accidental explosions are occur quite frequently whatever be the type of precautions we take some over the other an accidental occur, how do we define an accident? Let us first be very clear what an accident means, when we say an accident it means something like an unplanned event, something which we have not planed accident. And how do you say well, anything can I go cross the road; something comes and hits me say I meet with an accident.

Therefore, for unplanned activity there is always a chance that an accident takes place, and the word chance in Arabic is given by the word azhar, something like azhar is a Arabic word. And therefore, whenever we talk in terms of an accident likely, we associate the word hazard, whenever we move substances which are somewhat likely to cause an accident. We say these are hazardous substances and we must be careful. And most of the substances are hazardous under some condition or the other. Therefore, let us take a look at some of the accidental explosions and mind you, when we do risk analysis we will address the hazardous nature of substances. And say how to take precautions to avoid accidental explosions.

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Therefore I come back to the slide, I talk in terms of accidental explosions mind you in the first talk I said about, cooking gas exploding in the kitchen maybe there is a stove, may be a cylinder the gas leaks mixes with air, somebody goes and pushes puts on the switch or creates an electrical spark and bang, the entire building is there. These accidents even in a metro like Chennai keeps occurring, and there are something like 3 to 4 such accidents in a year, and you see the building getting demolished, the neighboring building getting demolished.

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We go to the next one this also shows the same accident, wherein the liquid petroleum gas stored in a cylinder getting exploded over here.

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Well, it is not only the gas from the cylinder which explodes. You know in the previous one, well the gas leak it created within the confinement of the kitchen mixture which could explode. Well, when we transport may be some substances, which are reactive in this particular case, this happened on something like 24th march 2012 about a year and half back.

What happened is this is a Korean ship, which was carrying an explosive substance or a reactive substance which was toluene. And this toluene is somewhat volatile it formed a vapor and it exploded. And it resulted in a killing of a person mind you, at that particular time there were not many people in the ship, but still it cause an explosion created havoc. And therefore may whenever we say, well we transport energetic substances we have to be careful, list an explosion or a blast wave is formed.

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This is something which has been in the news for quite some time on July 9 2013; there was this huge number of oil cars or oil tankers being taken. There were something like 72 wagons being pulled by 9 locomotives in the township near to Quebec in Canada, and what happened was? May be after parking these wagons safely the breaks were put on according to the drivers, but somehow the break got released, and the wagons freely rolled. And when the wagons freely rolled they picked up some velocity, and they derail one wagon on top of the other.

And during this process a leakage of the oil took place, and when leakage of the oil took place it caught fire, and not only did it catch fire, the heats from the fire increase the evaporation or the pressure in the containment of the wagons, and it led to a huge blast. And in fact, the a township near Quebec by name last magnetize got totally devastated, mind you the death rate was not very high, but even then it was a major explosion.

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NATIONAL

Quebec blast cause a mystery

This shows the burning after the explosion may be the oil spill getting burned, but remind you it is a major tragedy that means, the spillage of oil from tankers causing an explosion, I will examine this a little later.

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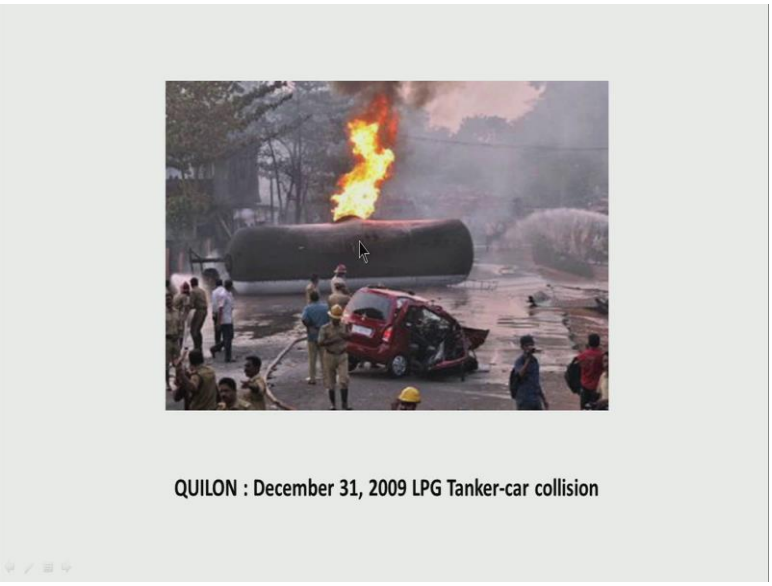

But in our own country, you know we have these on the roadways we move liquid petroleum gas in tankers, and when it heat a particular vehicle in the Kerala's state near Quilon, this was on December 31 2009. The LPG spill caught fire, but somehow the fire personal where able to douse the fire without really exploding. Mind you therefore may

be some it points towards some precautions which we must take, while handling the spills from tankers oil tankers.

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Well, this is what really happens? what happens is a vapor gets generated, the vapor burns or rather you gave hot vapor which rapidly burns forms a blast wave, and this is what happens in these oil tanker explosions, namely a vapor cloud gets generated.

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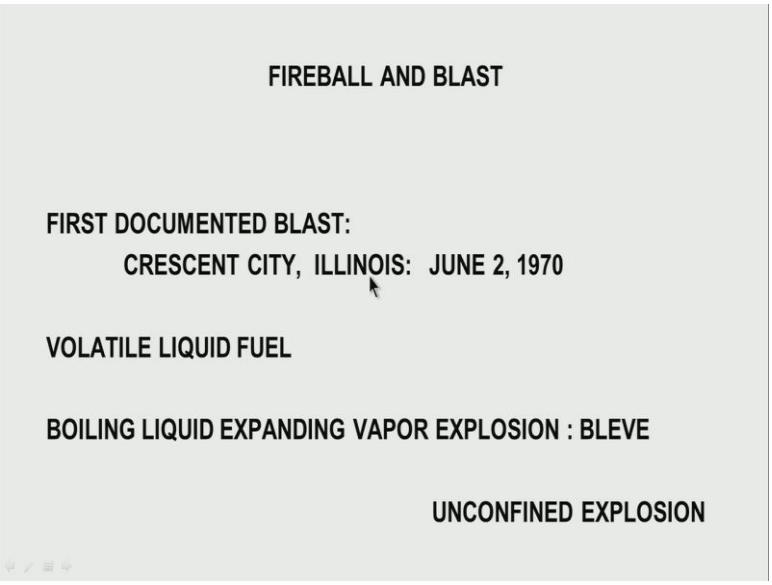

You know one of the well documented oil tanker explosions, this happened in the city of Illinois in US this was in crescent city. And this was done by professor stellar in fact the

previous picture which I show is also from him. And what was done was, he was the first person who looked at accidental explosions in a major way. And what let us take a look at this particular explosion in the crescent city at Illinois. It was again a number of wagons, which derail and what happened? Let us take a look at this happened on June 2 1970.

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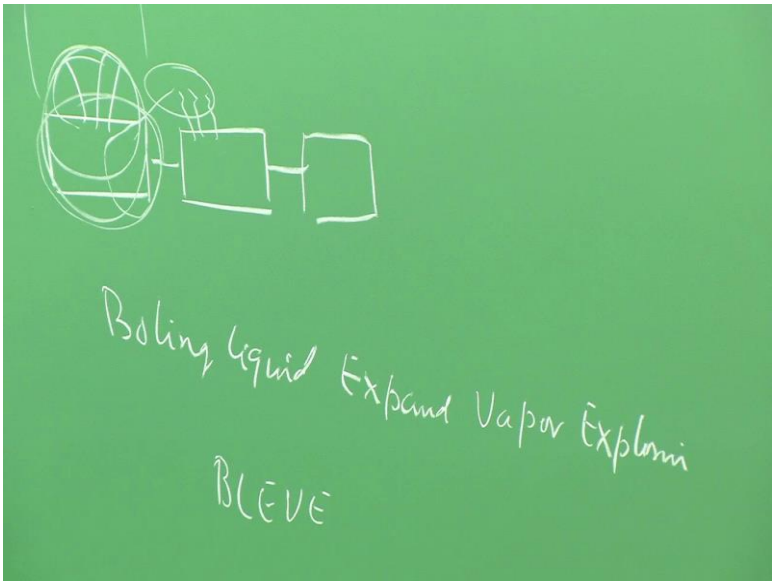

In this particular case, you have these wagons carrying in this case what was being carried was liquid propane, one after the other. There is derailment one of the wagon jump against the other, and there is a spill of liquid propane gas propane is essentially a liquid, and when it meets the when it spills it evaporates you form a vapor of propane. And when you have spill taking place, you have a fire and this fire if it heats this particular wagon, the pressure inside it increases you have hot propane here.

And it when the pressure increases I said the wagon burst, you have a huge quantity not only does the wagon burst, but have a huge quantity of vapor which gets generated. At least to a huge ball of fire and this creates a blast wave, and this is known as a liquid which is getting heated from some other source. You have something like a boiling liquid, which expands expanding vapor explosion it is known by the word BLEVE, boiling liquid expanding vapor explosion this is what cause this explosion. We have such explosions happening in our country at BLEVE, at Jaipur BLEVE happening in Jaipur,

but it is happening in open atmosphere. It is an in an unconfined gaseous explosion, and these required some particular attention, we go to the next one.

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In addition to having something like wagon exploding, when we have pipelines conveying, let us say liquid petroleum gas, liquid natural gas, liquid propane and all that. It is quite possible sometimes some leakage occurs in the pipeline, the vapor is released or the liquid is released, it vaporizes over here catches fire and it creates an explosion.

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You know there are some typical explosion which I would like to say one is, one happened at port Hudson in Missouri, this picture I got from professor stellar. You know you have at port Hudson in Missouri, wherein pipeline which was carrying, which was carrying again I think it was again liquid propane, let us come back to this example.

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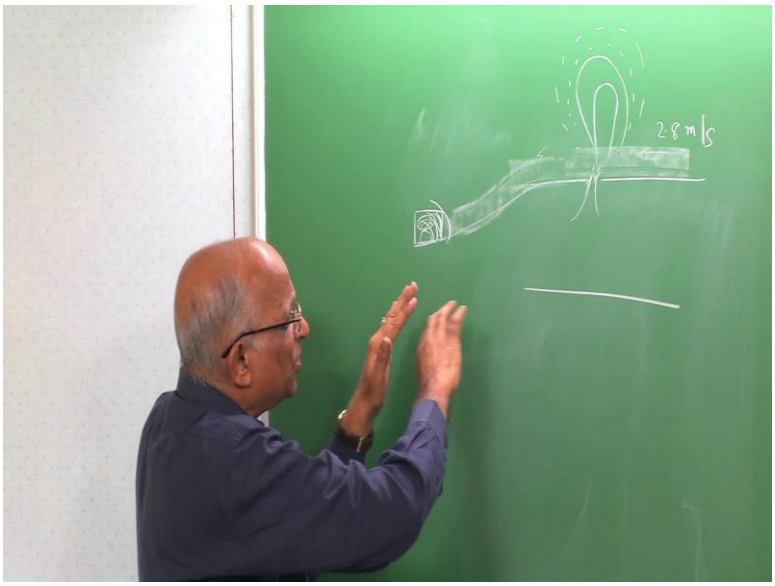

You know you have pipeline, this pipeline was something like point 2 meter diameter, the pressure was something like 50 bar are so at which it is communicated. There has been some rapture in the pipeline, and the liquid propane is a liquid under atmospheric conditions at temperatures less than around minus 45 degree centigrade. Therefore, may be liquid propane escapes, it forms a huge fountain of liquid.

And then it evaporates I get a fog and a smog over here of propane, but this accident as is seen their happens in the month of December, when it is quite cold. And the surface wind at that condition was not very high; it was around 2.8 meters per second. And therefore, the cold propane just collected on the ground as it were over the captured pipeline. And it gradually move, you know there is no ignition source of the point where the accident took place, and therefore it just moves it keeps mixing with air.

And downstream you know this is something like a value was there, there was a building over here a concrete building, which housed some refrigeration units, such that may be the food stuff could be kept cool, there was a refrigerator inside or a something to keep the substances cold. And therefore, what happened is the gas, the vapor moves here it

through the crevices in the door in window, it moves in over here mixes well with air. And since there are some motors in the refrigeration unit, well it catches fire develops a blast over here, and you know there are so many different units here, that the fire the flame becomes something like an explosion or a detonation.

And we have the blast which takes place, and this blast took place around 13 minutes, it took for the mixture to come and found this blast. And once this blast comes this ignites the whole thing, and you had a huge explosion. And this explosion was such that it could be heard something like 50 kilometers downstream, and also it just annulled just designated the place as it were. This is the explosion, which is involving liquid propane as it happened at port Hudson, I come back to the slide again port Hudson on December 9 1970.

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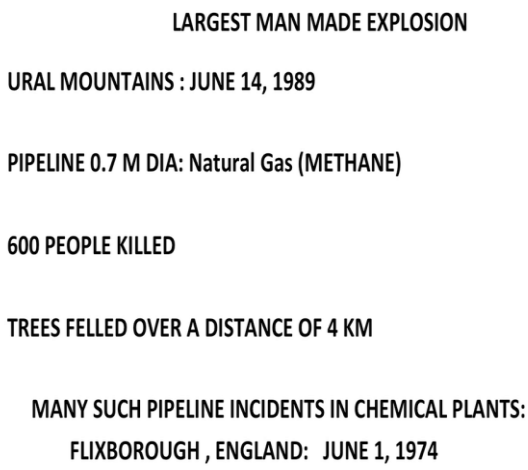

We have a number of such explosions, and one such explosion is sort of cataloged in literature, as being the largest man made explosion ever. This happened in the Ural Mountains in Siberia and you know what was done, you know you had a pipeline around 0.7 meter diameter. It was convey natural gas which is essentially methane. And in this you know the pressure it was I think it was designed for a pressure of something like 25 bar, it was operated at 12.5 bar, but then over a distance of something like, almost like pipeline or something like 1 kilometer.

There was this pipeline ruptured, and it was downstream it was something like 1500 downstream of the supply point of the gas to this pipeline. Nobody really notice that gas was leaking, huge quantity of a leak and mind you it was June 14 1989, the spill accumulated on the ground and does not mix well with air. And at that point what happened is? You know as fate would have it. Let us go back and take a look at this particular accident, and how it took place you know what happened is? We told ourselves well you have the pipeline conveying this, conveying l and g.

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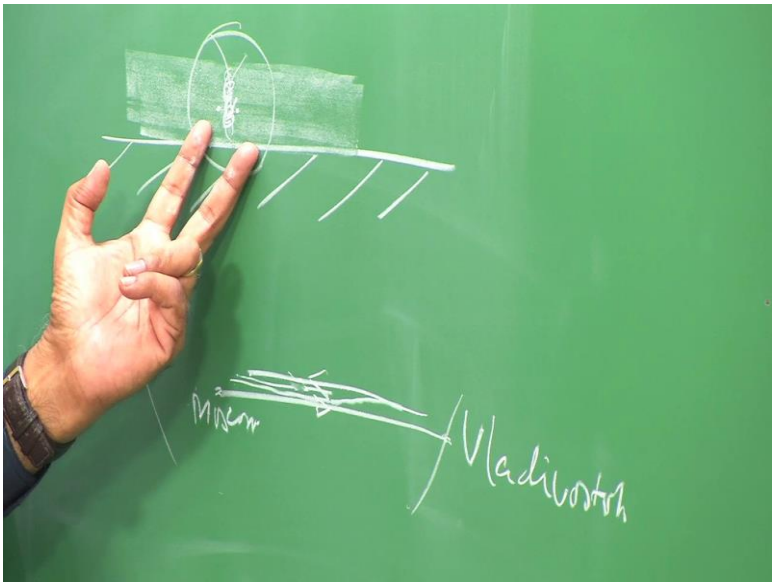

Therefore, over the ground you have I will methane low temperature methane accumulating, it does not really mix such so well with air. There is no accidental source after all it is a Siberian plane not very well populated. And there are not no houses or anything which can lead to ignition sources like spark over here. But, you know you will also remember that if you look at the geographical part may be on the east you have Vladivostok. And there is an train which runs from Vladivostok to Moscow, this is the trans-Siberian railway, and this is the double railway line. And as fate would have it you know this sort of spill took place over a long distance.

And there were this two tracks which was there, and along both the tracks in one the forward train is going from Vladivostok to Moscow. In the other the train going from Vladivostok to Moscow in one train, is going the other one along the other track you have the train going from Moscow to Vladivostok. And both are adjacent to each other

and because of this turbulence which is developed, when two trains pass each other and it has it is ability to mix the gases a good mixture got generated over here. And this being electrical trains over overhead, we have the electrical spark which ignites and huge bang took place, and this is the largest man made explosion ever.

It killed all the inhabitance of both the trains and something like. Let us get back to the slide, something like 600 people got killed, trees were decimated over a distance of 4 kilometers. I needs not only this pipeline, you know in many chemical industries you have pipelines conveying explosive substances from one container to the other, such many such incidence do occur in chemical plants. One typical example which is often quoted in literature is the accident at Flixborough in England on June 1 1974. Wherein it just created a goes down in England and that town still continues to be a goes down, because of the damage it cause there.

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Let us go to the next example. Well, so far what is it have done, I have looked at may be the explosions accidental occurring from gas in a confinement, occurring from may be a vapor unconfined geometry, we looked at pipelines, we looked at wagon derailment. And now, we come to something like solids substances, like in this particular case this accident took place on something like April 18th this year, something like 5 months back. And what really happened? This was the factory in the town of west in Texas in US. And there were making there were storing ammonium per chlorate, it is not very

clear the thing is a still under investigation, but apparently the ammonium per chlorate which let us say ammonium per chlorate is a condensed phase substance.

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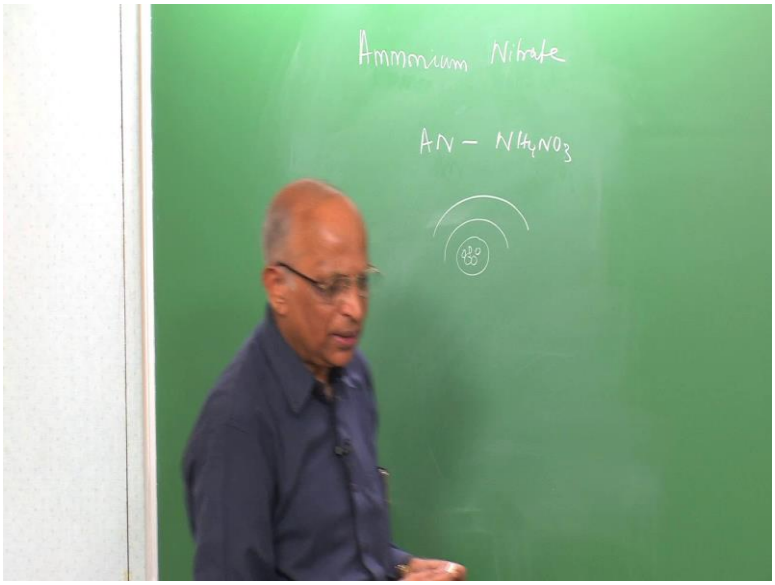

Let us take a look at it, we will be looking at some of the explosions involving such substances. It is not ammonium per chlorate; it is ammonium nitrate which is use as a fertilizer. You know this substance has both fuel and oxygen unit, and if it begins to catch fire may be it gets heated and the rate of releases high, and when a particular large quantity of ammonium per chlorate it is involved. It goes into this chemical reaction which keeps on feeding back heat to it, and you have such a powerful rate of energy released that a blast gets generated. This is what happened in this particular case at the Texas factory in the town of west, and the entire town of west got decimated. Well it is a case of a solid substance like ammonium per chlorate; we say it is a condensed phase explosion.

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THE TIMES OF INDIA, CHENNAI
SATURDAY, JANUARY 12, 2013

3 die as blast rips through fireworks unit near Sivakasi

REGION DIGEST

Cancer centres in Madurai, Coimbatore

Chief minister J Jayalalithaa on Friday announced establishment of zonal cancer treatment centres in Coimbatore and Madurai at a cost of ₹28 crore. She also sanctioned ₹5.78 crore for setting up of a tissue bank at the King Institute of Preventive Medicine and Research, Chennai. The government has allocated ₹1.39 crore for purchase of medical equipment for the Thanjavur Medical College and Hospital.

16 reservation counters opened at Koyambedu: State transport minister V Senthil Balaji on Friday opened 16 special reservation counters at the Koyambedu bus terminal to clear the extra rush of passengers heading home for Pongal.

Cong core group discusses Cauvery issue: The Congress Core Group met on Friday in New Delhi to discuss the Cauvery dispute issue amid indications that Prime Minister Manmohan Singh will take a final call on notifying the final award of the Cauvery Water Disputes Tribunal by month-end as demanded by Tamil Nadu.

We take a one or two more examples of this, let us say you know in our own country at Sivakasi in Tamil Nadu, where we make this cracker industry. The cracker industry involves some substances like carbon, sulfur and ammonium nitrate mixed together, which are used in making crackers or making fireworks. And to handle them even though they handle small quantities, very often we find that not handling them properly leads to the accidental explosion. Wherein people die every time we hear 3 people dead 10 people dead, the entire building gets decimated like.

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Explosion in Sivakasi fireworks unit kills 4

Sixth Such Incident This Year, Toll 30 So Far

What is shown over here, the due to a small amount of this composition accidently igniting a blast is created the entire building gets decimated people die.

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And one such case, which is very well cataloged in literature involving ammonium nitrate is something which I will spend some time on.

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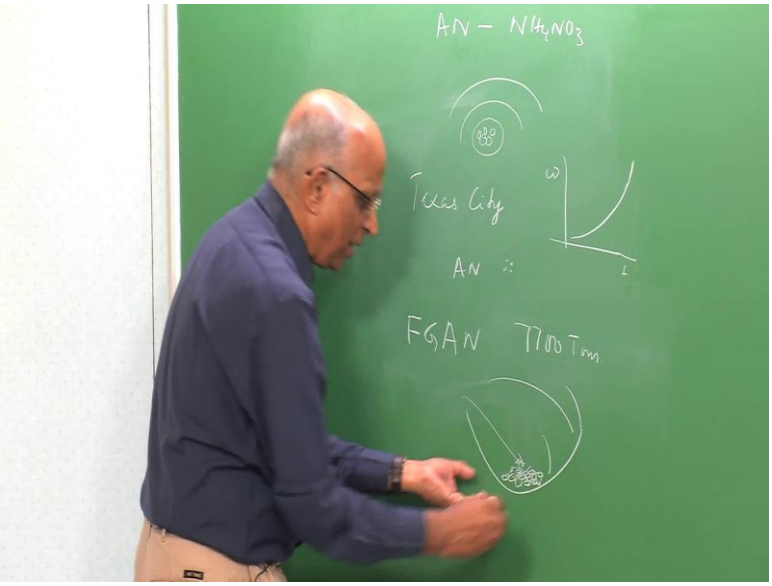

This accident in was in the Texas City in US, this is the southern it is a port city in southern US. You know this happened in 1947, what is the thing what we are talking? Again this involved ammonium nitrate, see ammonium nitrate if you see we said it is

NH4NO3 it contains lot of nitrogen, it is used as a fertilizer. You know and there is lot of demand for fertilizer, because you would like to a fix nitrogen in the soil. Now, in this particular case you know we do not want to use the real ammonium nitrate, but we would like to make it a little more resistance to explosion.

And therefore, you have wax being coated on the ammonium nitrate crystals, such that it is intensity of explosion or is susceptibility to burning and explosion is reduced. Therefore, you have instead of AN ammonium nitrate, you have what is called as fertilizer grade ammonium nitrate, which is essentially coated ammonium nitrate and normally it is coated with wax. In this particular case, you have something like 7700 tons of ammonium nitrate all in cartons or bags stored in the hull of the ship; you have all these cartons of ammonium nitrate being stored in the hull of the ship.

Now, the hull of the ship is somewhat insulated you know heat cannot really go from inside to outside or outside to inside, and if some temperatures increases over here, you know it keeps heating it up. And therefore, what was observed was may be at that in that particular accidents some temperature increased due to some chemical reactions taking place inside, always there is some element of reaction taking place. And when they found some smoke in the ship you have steam which is available people spreads water, and steam on to the smoke which was being created.

Now, the temperature is going up, the steam further contributed to the reaction. And therefore, you have something like a chemical reaction gets terribly increased, because of this there is the spiraling of the chemical reaction rate of chemical reaction if I say, whereas time progresses builds up. And the rate of chemical reaction becomes so much, that high intensity energy is getting release spontaneously, and you have a huge blast wave which gets generated. The blast wave in this case was so strong, that the entire hull of the ship got blown off.

And it carried over a distance of a few kilometers, why something like almost 600 people died the over a distance of 16 kilometers from the sight of the explosion. Well nothing remain people got knocked down, buildings got destroyed, over a distance of 60 kilometers trees were uprooted. And this explosion from Texas City could be heard at a town 400 kilometers away, and that is the intensity of this explosion. Well, pictures

shows the damaged cars, may be the hull of the ship, and the buildings being damaged, which I again show in the next slide.

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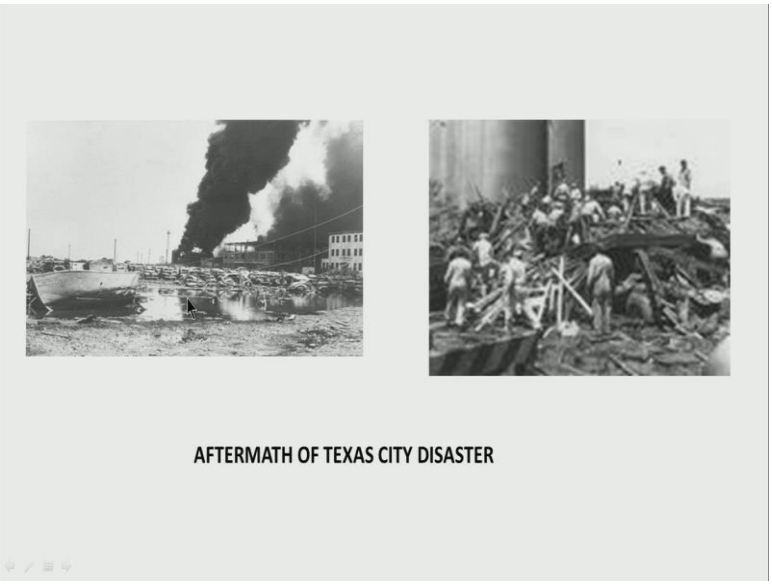

Wherein after the aftermath of this Texas City disaster, well nothing really remains.

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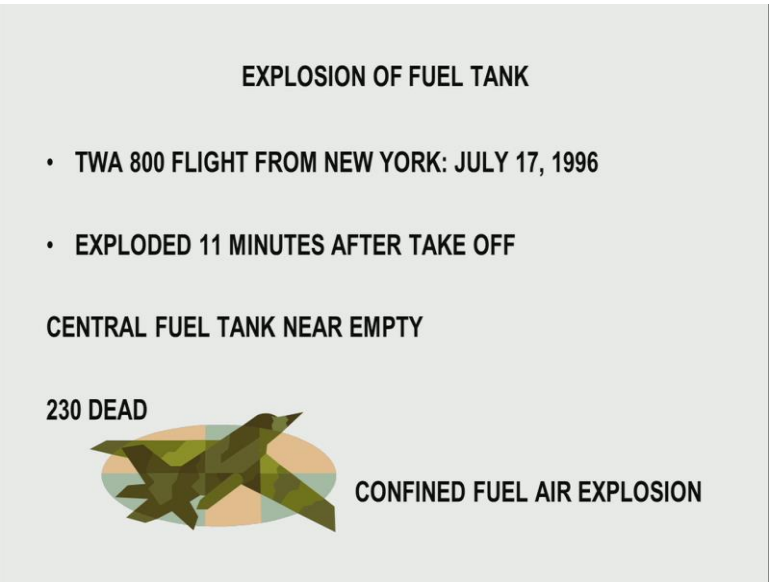

Therefore this is the type of explosions which keep taking place, and what is it we have considered so far. Let us quickly review ourselves such that we are, we can look at some other explosions and draw some examples.

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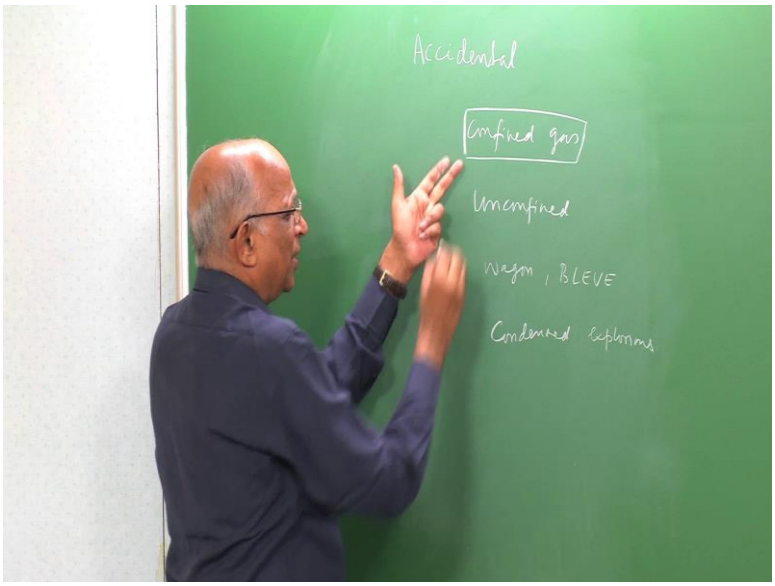

We tell ourselves, well the accidental explosions maybe we say yes an accident is an unplanned event could be something like a confined one using gases, it could be unconfined it could be something like wagons, derailing. And have something like BLEVE boiling liquid expanding vapor explosions BLEVE. We could also have we said solid substances like condensed explosions, in which may be some chemical reactions occur like an in Texas may be at Sivakasi, we have all this condensed explosions.

We could also have the confined gaseous explosions in a slightly different context, and a very deliberately brought this point out in the next slide, wherein I show the example of the explosion of a fuel tank. There was this particular aircraft which took off from New York on July 17 1996; it was the TWA 800 flight. And since it was supposed to go over a short distance, not all the fuel tanks in the air craft where fully filled with kerosene or what we call as a jet fuel in New York. It was the summer month minds you it happened on July 17th.

And therefore you know what was done was one central fuel tank was near empty, because that much of fuel was not required for the flight from New York, I think it was going to Europe. And therefore, the quantity of fuel which was loaded was not in all the tanks 11 minutes after takeoff, the aircraft just exploded and it was a huge fireball. And an analysis showed that the since the central fuel tank was near empty that there was small amount of kerosene in it, aviation kerosene. And you know on the ground, wherein

you have lot of air available and explosive mixture could not be generated, but the moment it goes to higher altitude, wherein the air is small combustible mixture with air got generated.

And therefore, at that point some electrostatic spark could have resulted in this particular explosion, it is again a confined fuel air explosion. In which you had a huge fireball all the passengers and crew of this flight, where killed in this particular explosion. You know this is something which we will deal with in some detail, we will look at limits of flammability of substances under what conditions you could have an explosion. And we will we have to address some of these points including the flash fire point of the volatile liquid fuels.

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You know it is not only the gas, the liquid and the solids energetic solids, but dust can explode. I would like to qualified further that is what did we tell now.?

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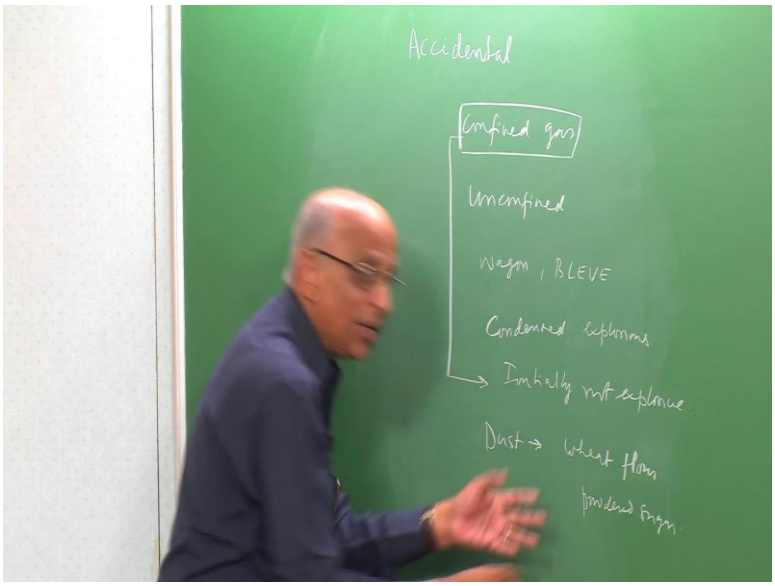

Well, I could have confined explosions, because of may be some tankage may be you have gas which is mixture which is formed, which is initially not flammable or initially not explosive, but which becomes explosive under certain conditions. We tell ourselves not only solids and liquids and say gases are explosive. You know that dust like for instance we consume wheat flour, we make bread out of wheat flour may be we use sugar, maybe we use for icing fine powdered sugar all these are explosives substances.

If it is mixed with air in sufficient quantities, it could explode and one such thing which is the first recorded explosion was in Turin in Italy this was on December 14 1785. Wherein you know you had this particular baker, who sends a boy to the godown collect some flour, I think it was wheat flour or maize flour I am not very sure about it. And this particular boy you know this was December month, you know it is an evening quite dark, therefore this boy takes a candle in his hand, and in the other hand he picks up the flour as it were being a boy he is playful, he tosses the flour and this flour when it mixed with air exploded, and this was the first recorded dust explosion.

We have such explosion involving dust in large number in US, wherein they handled the food crops in confinement we had this in Wichita in US, wherein you have 7 people being killed in a dust explosion involving. I think it was a wheat dust; you also have an entire port terminal being destroyed in Brazil in November 2001, which was conveying

the grain was being unloaded in the particular port. Therefore, dust explosion is also an a type of explosion which could occur.

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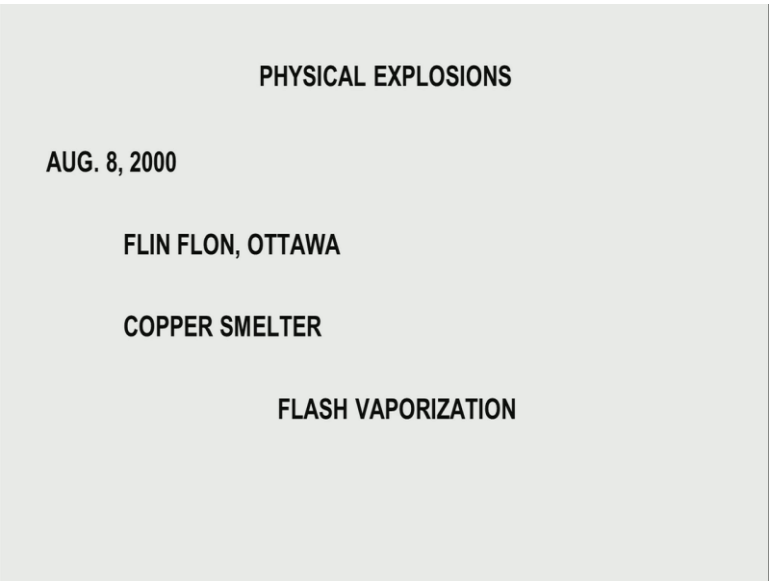

Having said that, we spend a minute or 2 on the last type of explosions, which we said well it could be accidental.

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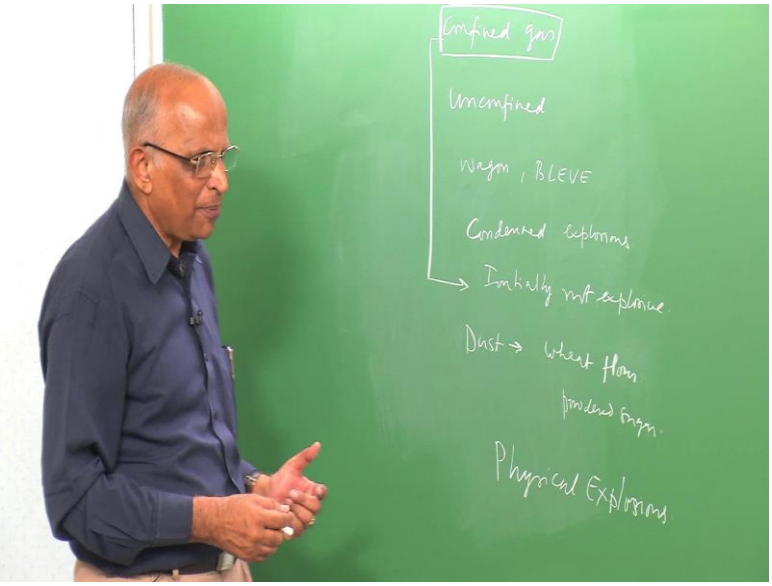

We call so talk in terms of physical explosion, we already talked in terms of physical explosions, when we talked in terms of the volcano in which the water get got into the volcano, got terribly heated up super heated vapor formed where is an explosion. And in

physical explosions is essentially a substance which is not combustible or a high energy substance like water, which can create an explosion. Let us take an example in a particular place in Canada near at Ottawa at place known as Flin Flon. You know you had this copper smelter, and you know towards the evening you know on a weekend day, you know people want to go home early.

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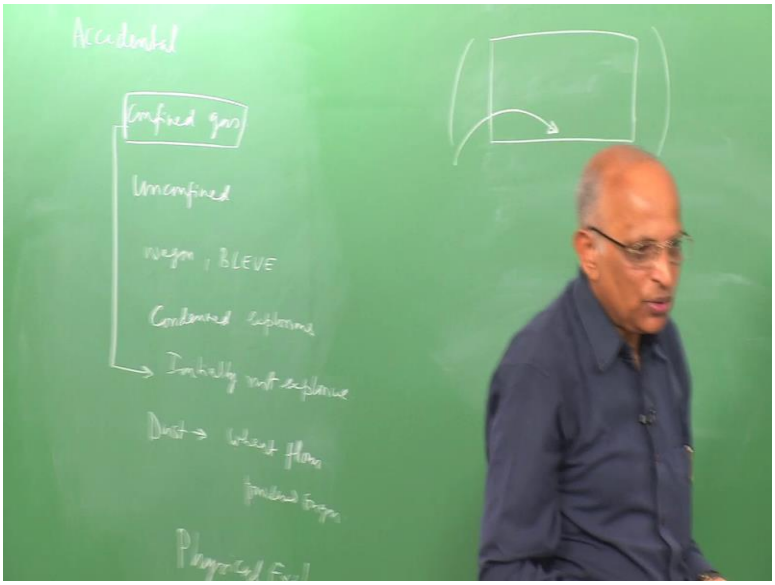

You had this smelter you have a evaporated furnace or a furnace crucible furnace. And the furnace is hot people want to leave early, but they have to cool down the furnace before they leave the work is over. Therefore, to cool it further may be the operator he takes water in a pail and pushes into the furnace, which is quite hot at that point and time. And all of a sudden, because of the thermal inertia of the furnace the water just flashes into vapor and creates a blast wave and injures people.

This is the type of explosion which I said happened on, I come back to the slide on August 8 2000 at Flin Flon a town near Ottawa in Canada, wherein in a copper smelter we had flash vaporization driving blast waves and an explosion. You know such type of explosion was also, we must remember in the case of natural explosion at Krakatau, wherein you had the huge explosion and this is the type of examples, which I collected under accidental explosion.

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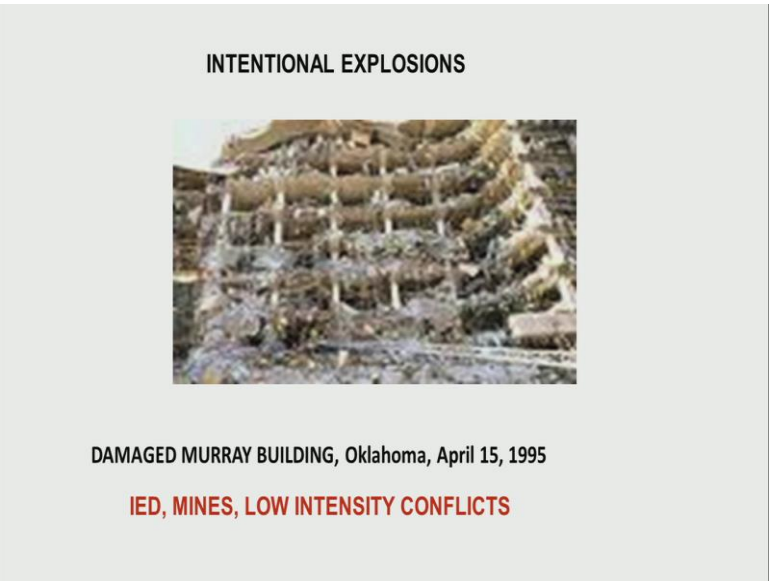

Now, I just spend a minute or 2 on intentional explosions, lets come back to this.

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Unfortunately, you know the of late we find these terrorists and the antisocial elements, engaging in this type of affair. And one such example which I show here is happened on at Oklahoma City on April 15 1995, wherein nice posh building which house may be children; a nursery you know was brutally damaged by a blast. In which case you know a truck carrying solid explosives was sparked nearby. Well it was ammonium nitrate, it was little bit more energetic, we will get back into the details when we study the

condensed phase explosion. And the blast wave just ripped of this building, it is not only thus ((Refer Time: 49:16)) keep happen, it is keep happening all over the world of late in Afghanistan, in Iraq may be while in India. We have this improvised explosive devices, we have minds being planted. And nowadays, we talk in terms of these explosions as low intensity conflicts, and we have to design the system such that may be the buildings or the type of the blast wave could be controlled or may be this structure should be so strong, such that it does not really get affected by this. Well, these are the intentional explosions.

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And you will also remember at the Boston marathon a few months back, we had the terrorist putting the explosive or energetic substance in a pressure cooker and killing people. Well these are the type of intentional explosions.

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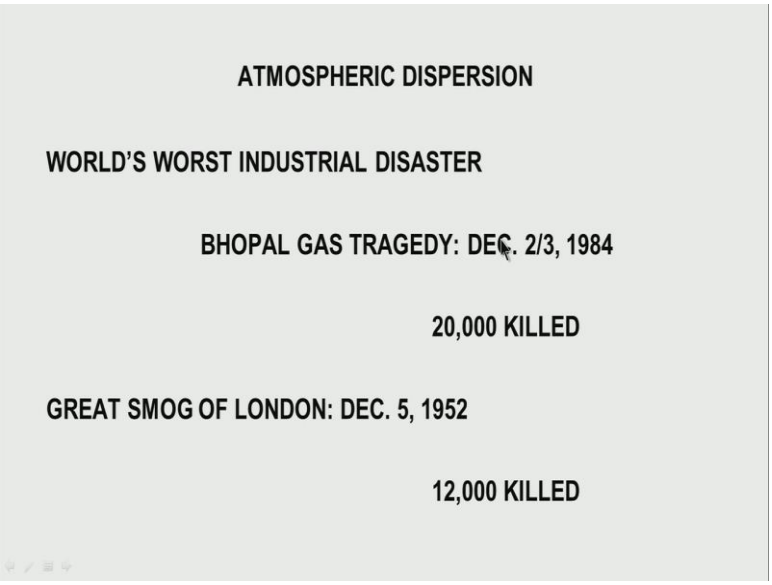

And before we complete this, I deliberately brought this point of atmospheric dispersion, why is it atmospheric dispersion? You know in the example of the Hudson explosion, wherein liquid propane went into the building, it is by atmosphere that it is going. And in fact, you know we have some cases of atmospheric dispersion causing disaster, one is in our own country we had the Bhopal gas tragedy, which is stated to be the world's worst industrial disaster this happened on a cold day December 2 to 3 1984. And what really happened, let us take a look at it, because it give some room for thinking.

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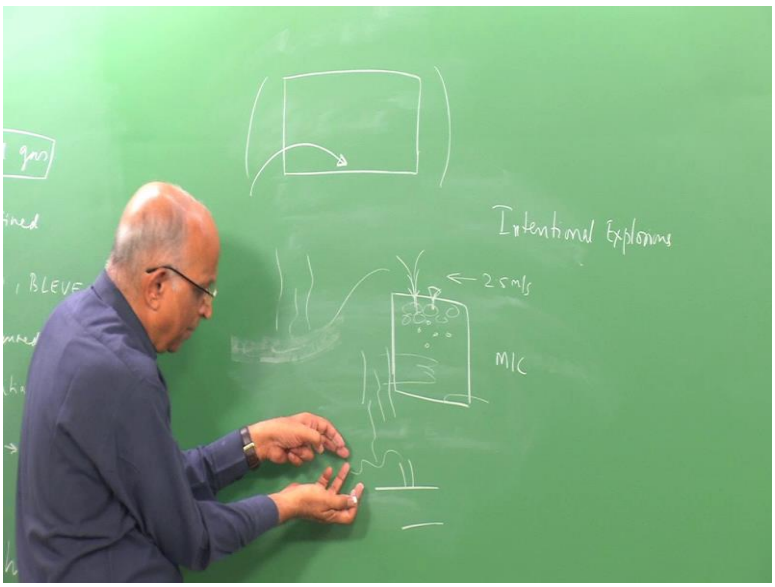

In this particular plan which was a carbide plan, you know you stored methyl isocyanate in tank ages. And you know you have the valves of this, somehow you know the somewhat like a wood, which will prevent water in gracing into this was missing, when it was being clean some water got into the tank, water got into the tank. And also the tank was little dirty you had something like chloroform; you had some ion inside the tank. And when water comes in contact with methyl isocyanate, it begins to react carbon dioxide gets generated, and these impurities further let to the reaction with a result pressure in the tank got increased.

And normally you know in the plants you have something like refrigeration coils, which will control the temperature of the system, it was December it was cold these were not operational at that point in time. Gas got generated, the pressure went up through the went valve a mixture of MIC and MIC gas got released, the scrubber was unable to control the mass flow rate of it; the wind velocity was low at around 2.5 meters per second.

And being winter time the temperature on the ground was lower than above with a result, we say atmospheric inversion the gas was not able to diffuse up diffuse out into vertically. And prevent the methyl isocyanate affecting the people downstream with a result it drifted, and whenever it came in contact with people either they got blinded or when the dosage went up they just die over here. That means, we are talking of the atmospheric affects, you know even when we talk in terms of some gas from a pipeline gases coming out, you know the ability for the gas to go out into the atmosphere.

We say an unstable atmosphere will allow the gas to get lost, does not happen under certain conditions, and therefore atmospheric dispersion is an integral and an important part of the explosion physics. And therefore, we say well we could have accidents due to atmospheric dispersion. And the world's worst case was in the case of the Bhopal gas tragedy in which some 20,000 people killed were killed. Why we had also the great smog of London this happened on December 5 1952, again in the winter time during winter time people burnt more fuel to stay warm.

And in those days may be the type of cold was also not of that good quality, it created sulfur fumes and it got trapped on the over the surface of the earth, this permitted into buildings and something like 12,000 people got kill. You know in addition to may be

pollutants and dispersion, we recognize that the combustible gases could also move mix with air, and therefore atmospheric dispersion becomes important.

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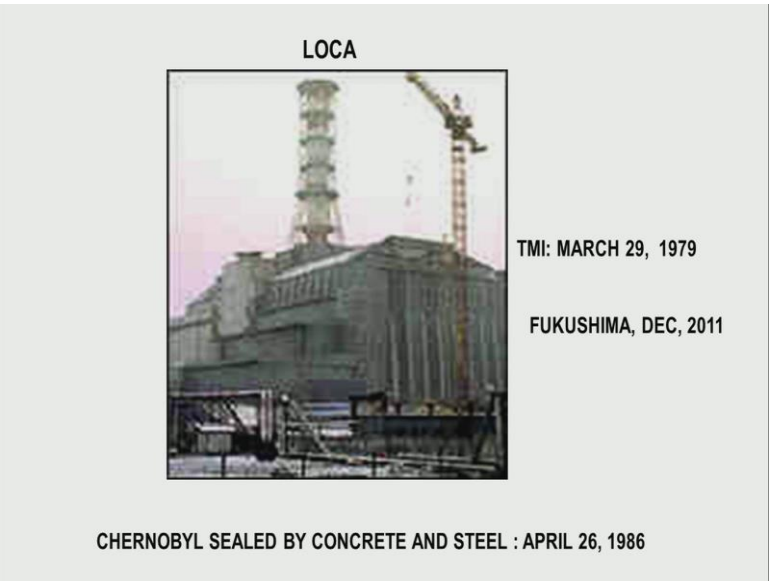

The last one is may be nuclear power plants; you have loss of coolant type of accidents, in which you have hot metal coming in contact with water generating hydrogen, and this hydrogen exploding. we had this in Fukushima in December 2011 around 2 years back, we had this almost a imminent, but it did not explode this was in 3 mile island on march 29 1979. We had this happening in Chernobyl and the only thing which was done was the whole thing was engaged with concrete and steel, and maybe it was it nothing more was allows to happen.

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This is the last slide which I show; this is taken from Professor Dewey. And what is seen here is, you know an explosion taking place, you see the blast wave from the explosion preceding the matter from explosion, this is the blast wave which causes the damage.

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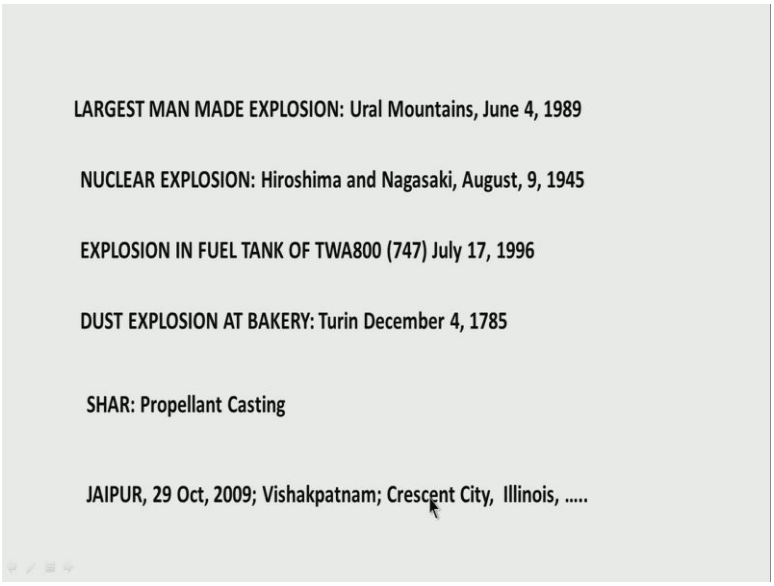

To some of them, you know we talked in terms of different types of explosion. We talked in terms of the largest man made explosion. We talked of nuclear explosions. Well we did not get into Hiroshima Nagasaki which I talked of yesterday. Well, you could also have fission and fusion, and these again generate we will not deal with fission

fusion, but we will look at loss of coolant type of accidents. We talked of explosion in a fuel tank in the TWA 800. We talked of dust being explosive may be the eatable things, which in fine powder becomes explosive. In our own country, we have the propellants exploding in one of the assembly points in a in the Indian space program.

We also have the BLEVE type of explosion at Jaipur in an oil refinery on 29 October 2009, we had several such BLEVE explosions at Vishakpatnam, we also talked in terms of the of the BLEVE explosion at Crescent City in Illinois. Well these are the different types of explosions, and to just sum up the different categories of explosion, I will just put it in a slightly different form. We tell ourselves well, we looked at different types of explosions, we find well the cause lot of damage to life and property.

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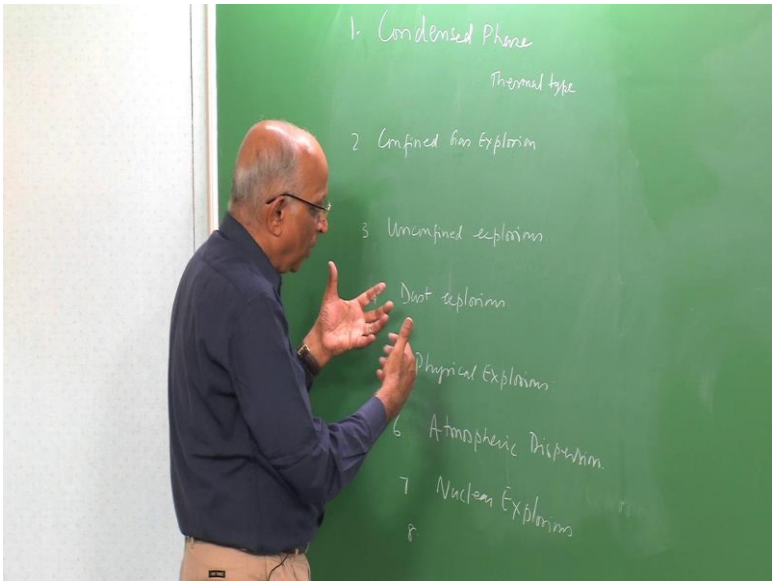

And I can tell myself well, the first type of explosion which I can talk is, maybe a condensed phase explosion. In which solid substance are associated, it creates more and more heat, it is something like a feedback and the rate of reaction goes up. Well, it is a thermal type of explosion. We talked in terms of confined gas explosion in a room, in a confinement. We talked in terms of the unconfined BLEVE type of explosion, unconfined explosions.

The fourth one we said well, why all this even a dust could explode, dust explosions we talked in terms of the physical explosions, that means some vaporization of the substances taking place. We talked in terms of maybe we have finished confined,

unconfined, solid substances. We talked in terms of atmospheric dispersion. We talked in terms of loss of coolant analysis maybe the nuclear explosions. Well, these are the different categories of explosion, and having understood these explosions.

Our next step would be to go back look at the how release of energy from this explosion, drives a blast wave we will try to model the blast wave. And try to find out how to proceed further with calculations of the pressurize, calculations of impulse, which gets transmitted by momentum to the body which is getting affected by the explosion, this is what we will do in the next class.

Well, thank you.