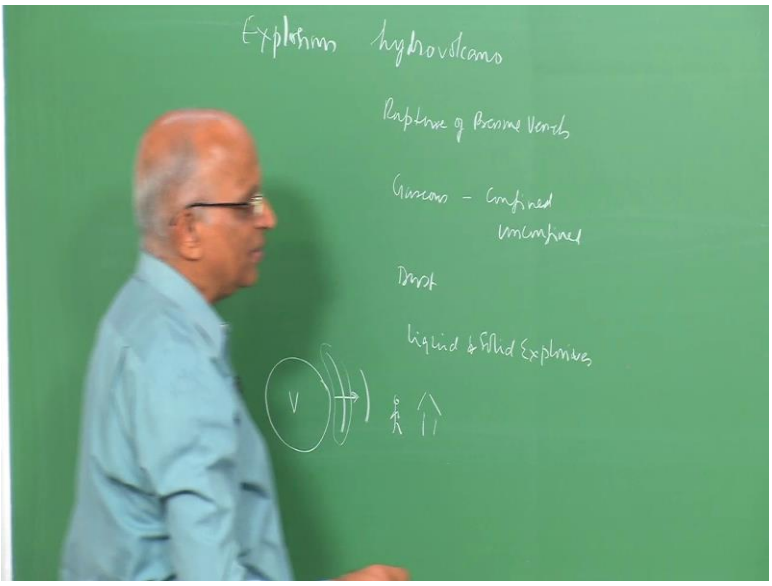
Introduction to Explosions and Explosion Safety
Prof. K. Ramamurthi
Department of Mechanical Engineering
Indian Institute of Technology, Madras

Lecture - 35
TNT Equivalence and Yield of an Explosion: Non Ideal Explosions, Energy and Blast Equivalents, Typical Examples

(Refer Slide Time: 00:18)

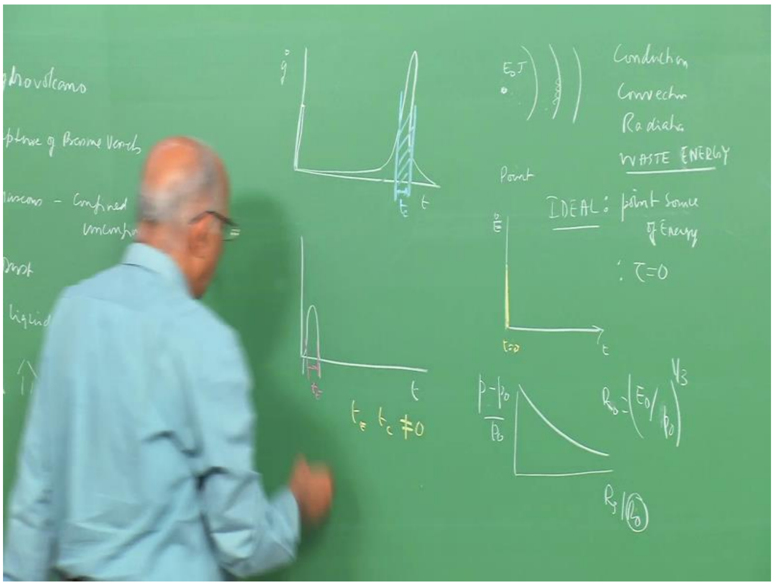


Good morning, you know we talked of different types of explosions, and we talked of explosions involving let say hydro volcanic explosions in which case you had water getting into a volcano. We talked in this involved flash vaporization; we talked in terms of rupture of pressure vessels. We talked of gaseous mixers in both confined and unconfined mixers, gaseous mixer of fuel and air both in confined and unconfined geometries.

We talked in terms of dust explosions again involving confined and unconfined geometries. We also talked in terms of may be the liquid and solid explosives. See whenever we talk in terms of these explosions, what did we say? Well, we have the energy release taking place from the flash vaporization in a given volume, high pressure gas in a given volume or when you have a confined gaseous air mixer in a given volume, I have solid explosives in a given volume.

They burst generate the blast waves, and when it affects let say somebody or some building somewhere, well it causes damage or it also causes any other form of damage, but we say build damage to human beings, damage to buildings, and damage to other establishments around it. It is the blast wave which cause the dead causes the damage, but then what happened is you have a finite volume source which releases the energy, and this energy is not released instantaneously.

(Refer Slide Time: 02:20)



Like for instance, when we had gaseous air mixer we said when most of the explosive mixtures have a large activation energy. And therefore, the rate of energy release has a function of time is not something which abruptly releases energy at 0 time, but it takes some time for the induction reactions to take place. Thereafter, you have spontaneously a large increase in reaction, and then the rate comes to 0. In other words if I were to look at this particular the time taken for release of energy, the chemical reactions effectively start here, chemical reactions terminate here, well this is the time over which this particular time is the time over which the energy gets liberated.

So also when I talk in terms of let us say a burst of a pressure vessel or a hydro volcanic explosion, what is going to happen? I have the time axis over here, you know over a small period of time I have the energy release, and the effective duration of energy release is may be something over here, this is the duration over which the energy gets released. Now, therefore we are talking in terms of all these explosions namely a finite volume associated with energy release, and a finite time of energy release.

But, when we talk in terms of let us say blast waves we modeled it, we what was the assumptions we made? We made an assumption that at a particular points some energy E 0 joules is impulsively release, and this sort of drives the blast wave. In other words we are talking of energy which is released at a point, but in practice what is it we find? Energy is released in a given volume point one, point two it is impulsively release rather if I were to take the time over which energy rate at which energy is getting released.

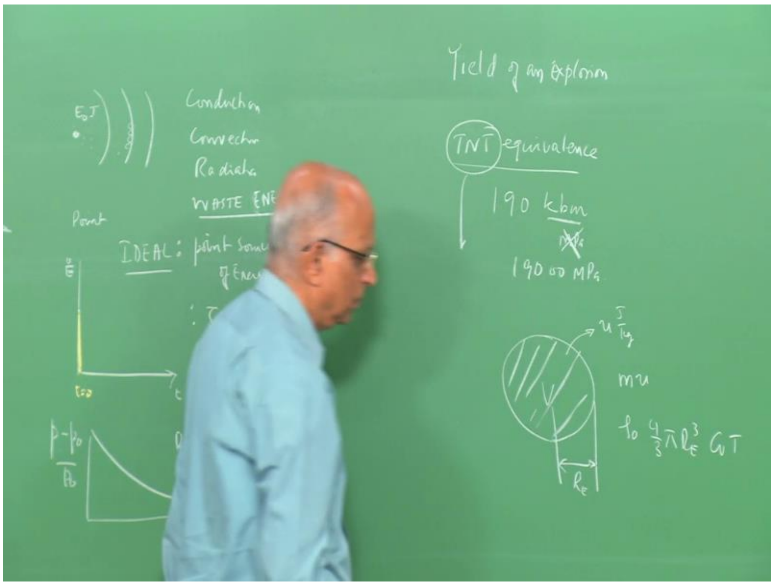
I find, well all the energy is released impulsively at time t is equal to 0 that means, the energy release is at t is equal to 0 itself. Therefore, I cannot have point release in practice, I cannot have totally impulsive energy release or spontaneous that means that duration of time t or duration of energy release t c is not equal to 0, as is as for assume when we calculated the blast wave from a point source, and that point source releasing energy spontaneously, and what did we do to calculate all this?

We said well we had the plot of R s divided by the explosion length. We had something like over pressure p minus p naught divided by p naught we had a curve like this. Well this curve was for the particular case when the energy, the explosion length R naught was equal to the energy released spontaneously at time t is equal to 0 divided by ambient pressure to the power 1 by 3. Therefore, whatever we did for blast wave was for an ideal case, and what was this ideal case? Ideal case was for point source of energy, and second the duration of energy release is equal to 0.

This is the ideal case where as all the explosions which we studied have a given volume, they have a finite time, and therefore they are terribly, terribly non ideal. While studying blast waves we also found that, well if the energy from the source over here does not go to drive the blast wave, but it the manifest itself as heat, let us say it is release somewhat slowly. Then it could go to heating the medium, and how could it heat the medium? By conduction it could heat may be the by convection by turbulence may be the heat could travel at some velocity namely by let say conduction heat transfer you could have, you could have convection, you could also have a radiation of heat.

You know such types of heat which is energy getting radiated away from the source does not drive the blast wave, and we said it is something like waste energy as regards the blast wave is concerned. But the problem is in practice yes we will have waste energy, all the energy does not go into the blast, we also do not have an ideal source or an ideal blast wave in which case an ideal is something which is driven by a point source of let say the time of deposition of energy is 0, whereas in practice I have a definite duration and a definite volume. Therefore the question is how do I reconcile these two now? My predictions must be for an actual explosion, whereas what we predicted was for an ideal case we for which we predicted.

(Refer Slide Time: 07:51)



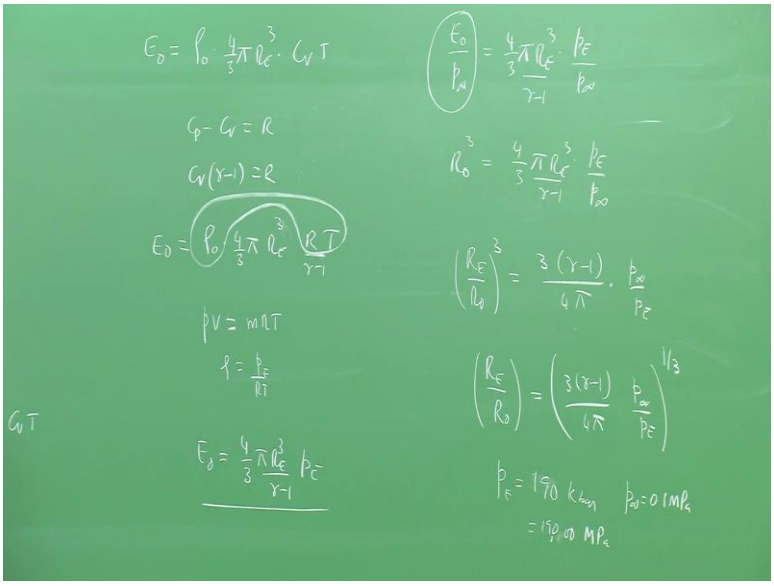
Therefore, we wish to put things together therefore, in today's class I want to look at what we call as an yield of an explosion y i e l d yield of an explosion, and we also will look at may be the TNT equivalence of an explosion. We talk in terms of TNT equivalence, because now the movement I say TNT is a condensed faced explosive which has a high value of let say the detonation velocity, it also has a high value of the ((Refer Time: 08:20)) order of 190 kilo bar. You know in the last class I may be instead of 190 kilo bar, I expressed it as m Pa may be it is not right.

Actually in terms of m Pa it should be 190 into two 0 m Pa, and the pressure behind a detonation is typically in terms of kilo bar that is 190 kilo bar and I had denoted it by m Pa. Well anyway, we would like to have TNT equivalence, because when I have the detonation of an explosive like tri nitro toluene what happens is there? ((Refer Time: 08:57)) velocity is quiet high of the order of almost 7000 meters per second, the pressure is very high, and this TNT is used as a standard by which may be I can represent an actual explosion, they will see what is to be done? And the for in today's class we consider TNT equivalence and yield of an explosion.

To begin with, let say I have a given volume in which energy gets released, and I want to find out, can I put this in terms of pressure which is created by the particular energy release in a particular volume. Well, the internal energy in the volume is u so much kilo joule per kilogram or rather the total mass of this is mass into the internal energy so much joules, because mass of this volume is so much.

The mass of this volume is equal to the density of the volume, and let us consider a spherical volume whose let say the radius is R E radius of this spherical volume in which energy is getting released is let us consider R E, because I want to consider the effect of the volume of the source or volume of the energy release. Therefore, the volume of this spherical vessel whose radius is R E is equal to 4 upon 3 by R E cube into the density is a mass into u and what is u, C v into T.

(Refer Slide Time: 10:41)



Therefore, I get the energy which is available in this source let us put it here, energy which is available in this source is equal to rho 0 into 4 upon 3 pi R E cube into C v into that temperature of the particular gas over here. See we have been looking at C v earlier, we said C p specific heat at constant pressure minus specific heat at constant volume is equal to R taking C v outside I have gamma minus 1 is equal to R.

Therefore, I can write C v is equal to R over gamma minus 1 and therefore, the energy as equal to rho 0 into 4 upon 3 pi into R E cube into I have R divided by gamma minus 1, C v is equal to R divided by gamma minus 1 into T. And therefore, if I look at this particular combination of rho 0 and R p over here, I know from the perfect gas equation or an ideal gas equation p v is equal to m R T, m by v is equal to your rho, and rho is equal to m by v is rho is equal to p by R T or p is equal to rho R T or rho 0 R T is the pressure initially, and let the initial pressure in this volume we let say p of the explosive.

Therefore, I have rho is equal to p by R T is a initial temperature and therefore, I can get the value of E 0 as equal to 4 upon 3 into pi, the radius of my volume 4 upon 3 pi pi r cube this should have been 3 R E cube here, 4 upon 3 pi R E cube divided by gamma minus 1 into I have rho 0 R T is equal to p this is my value. Now, I want to get some idea on the influence of R E therefore, I divide both the left hand side and right hand side by the ambient pressure, and what is it I get? I get E 0 by the ambient pressure which I call as p ambient is equal to 4 upon 3 pi R E cube into the pressure of these source which is driving it divided by the ambient pressure.

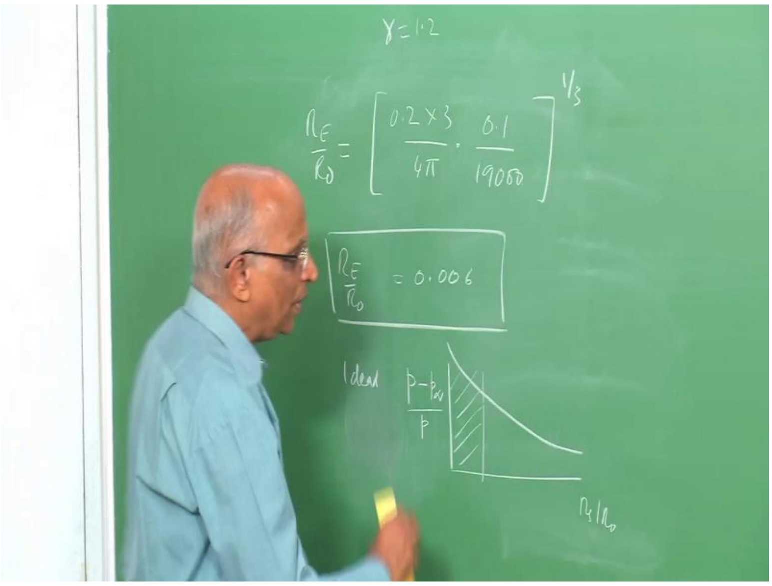
Now, if we go back and say well this is my energy which is getting release this is p 0, and this is something like an explosion length mind you, when we talked of explosion length we did not consider a given volume, but this energy is released in a given volume. Therefore, E 0 by p infinity to the power 1 by 3 was R naught, this is therefore equal to R naught cubed over here.

And therefore, you get this is equal to R naught cube that is the explosion length cube is equal to 4 by 3 pi into R E cube into the explosion pressure divided by the ambient pressure or rather from this, I get the value of the source radius that is the a radius of the source releasing the energy divided by R naught to the power 3, I take R naught on this side R E by R naught cube is equal to 3. Somewhere I have missed of gamma minus 1, well I had gamma minus 1 here; I had gamma minus 1 over here. Therefore, I should I had gamma minus 1 over here or rather gamma minus over here.

And therefore, I will have 3 into gamma minus 1 divided by 4 pi let see if it is All right, R E divided by R naught is equal to 3 times gamma minus 1 divided by 4 pi into p ambient divided by p E over here. Now, we take the value therefore the energy release takes place in a radius R E divided by the explosion length R naught is equal to I get 3 gamma minus 1 divided by 4 pi into p by p ambient divided by the pressure of the explosive, let us put it down I will give the number shortly into explosive to the power 1 by 3.

Now, in the last class when we looked at detonation of TNT let us apply this for TNT in specific, and what we find is p infinity or rather p explosive for TNT is equal to we said 3 something like almost of the order of I just gave a number here saying that it is of the order of 190 kilo bar is the value which comes out to be 190 into 2 0 may be 3 0 bar and this 190000 or 19000 so much m Pa. The ambient pressure p ambient is equal to 0.1 m Pa, and therefore if I were to solve this equation for R E by R naught what is it I get?

(Refer Slide Time: 16:14)

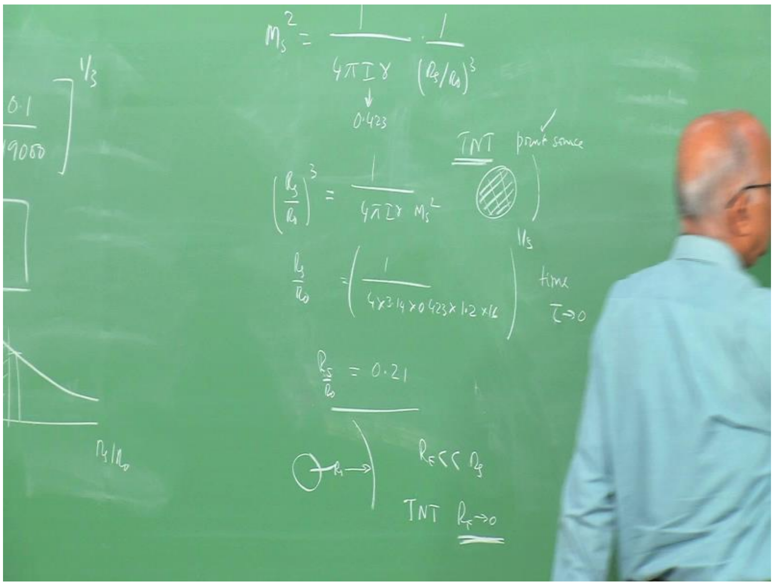


I get the value R E by R naught is equal to I get gamma minus 1. Let assume for the hot gases in the particular volume gamma is equal to 1.2, gamma minus 1 is 0.2, I get into 3 divided by 4 pi into the value of 0.1 is the value of p ambient, the value of p inside is equal to 190 2 0 over here to the power 1 by 3. And if I simplify this I get the value as equal to 0.006 that is the value of R E by R naught. Therefore, you find when I use TNT as a source for generating the blast wave or as an explosive.

The value of the radiance of TNT divided by the explosion length comes out to be this particular number, but I cannot draw any conclusion from this number by itself, because all I want to say is what is the effect of the radius of the explosive on the blast wave and therefore, I go back again to my ideal case of a blast wave. And when we considered the ideal blast wave what did we tell? We said well we found out what is the value of p minus p ambient over pressure divided by pressure as a function of R S by R naught as coming from a point source, and we had a curve like this.

We said when in the strong blast region for which the over pressure are quite large, that means equivalent mark number of the blast wave is greater around 4. We could write we could have a closed form expression relating the mark number of your shock wave or the mark number of the blast wave with the R S by R naught, and the expression what we had was?

(Refer Slide Time: 18:14)



We had M s square is equal to 1 over 4 pi I gamma into 1 over R s by R naught cube. In other words we had an expression for R s the value of mark number at any value it is mark number m. And we had the value of R s by R naught, and we had the relation M s square is equal to where I was a constant we said it was an integral, and we had the constant as 0.423, and let us plug in the values and see. Let us considered the case when the when I consider case where in my over pressure is quite strong, and what is I get?

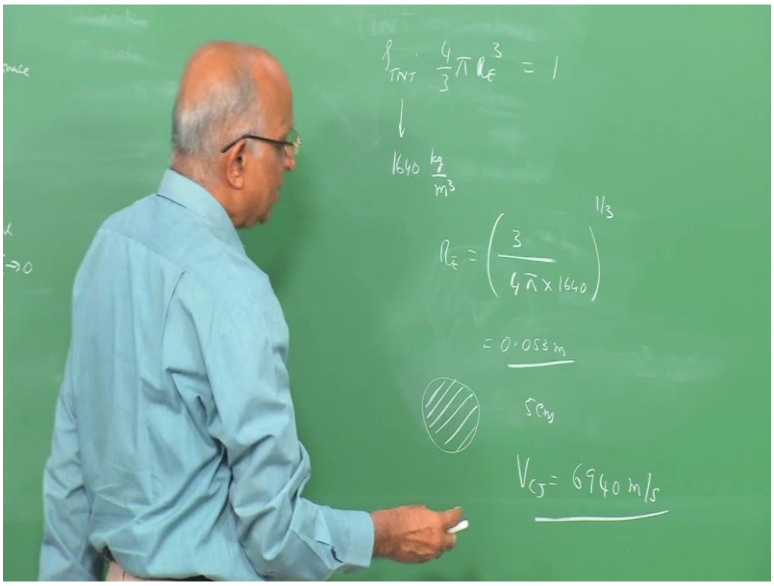
I get the value of R s by R naught cube from this particular expression is equal to 1 over 4 pi I gamma into M s square taking a strong blast wave M s is equal to 4, the value comes out to be 1 over 4 into pi 3.14 into I 0.423 into gamma let us take the same value 1.2 or 1.3 over here, and m s square is 16. And if I calculate the value of R s by R naught based on this, this is equal to R s by R naught is equal to one third of the particular expression, because I brought M s square here this is one third, and the values of r s by R naught comes out to be around 0.22 or 0.21 let say.

Therefore, we are saying that as very strong blast wave is formed at a radius divided by R naught R s divided by R naught of 0.21, while when I look at the source energy which is divided by R naught gives 0.006, what is the conclusion we draw? Well I have a source of radius R E. I am looking at a blast wave I find a very strong blast way is formed at this particular R s, this R s by R naught is 0.21, R E by R naught is equal to 0.006 or rather we find R E is very much less than R s at which very strong blast wave is form, and it is almost 3 orders of magnitude smaller.

And therefore, may be as I go further and further, and the blast wave decays my R s further increases, and I am interested in these regions. Therefore, for the regions of interest at which I am interested in a blast wave creating damages. I find that my source is extremely, extremely small. And therefore, for the case of TNT in which I have a huge pressure that is the detonation pressure whether ((Refer Time: 21:09)) pressure behind that definition wave, I can assume that for TNT the value of R E tends to 0, because it is very small.

Well this I say therefore, whenever I have an explosion involving TNT even though I have a sizeable mass of TNT and a sizeable volume which drives my blast wave. Compare to their distances involve for blast waves, this particular radius is so small I can considerate to be a point source. Therefore, an explosions involving trinitrotoluene or TNT we can consider to be a point source. But then it is not only point source which besides with an explosion is ideal, but also the time over which the energy release that this tau must also tend to 0. Therefore, let us take a look at what is this typical time over which energy is released in TNT, and what is it we find?

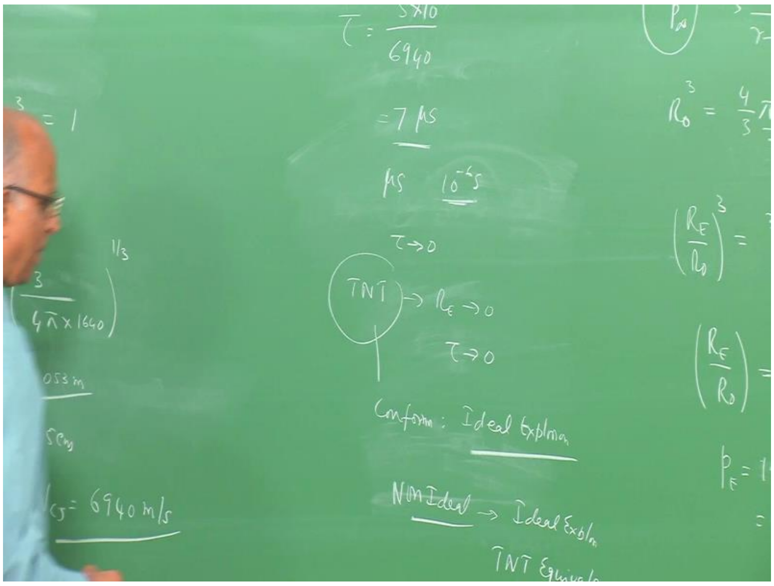
(Refer Slide Time: 22:19)



Well, let us assume let us say I have an explosion involving just a number 1 kg of TNT. Therefore, if I consider 1 kg of TNT, well that I have density of TNT multiplied by let us say 4 upon 3 into pi R E cube is the volume of TNT, this is equal to 1. Well the density of TNT is around 1640, we saw this yesterday in the last class kilogram per meter cube. And therefore, if the mass of TNT is 1 kg, I know have pi I need to calculate the value of R E.

R E is equal to 3 divided by 4 pi into 1640, so many meters to the power I have 1 by 3, and what I get is this is equal to something like 0.053 meters, that means the size of this is something like radius is something like 5 centimeters is the type of radius. And since we are talking of detonation of this TNT, the detonation velocity of TNT V c J that is the ((Refer Time: 23:38)) the velocity of detonation is something like 6 9 4 0 meters per second. Therefore, the time taken to be able to dead need the solid of mass 1 kg is something like I have 5 centimeters, let us put an order of magnitude here.

(Refer Slide Time: 24:04)



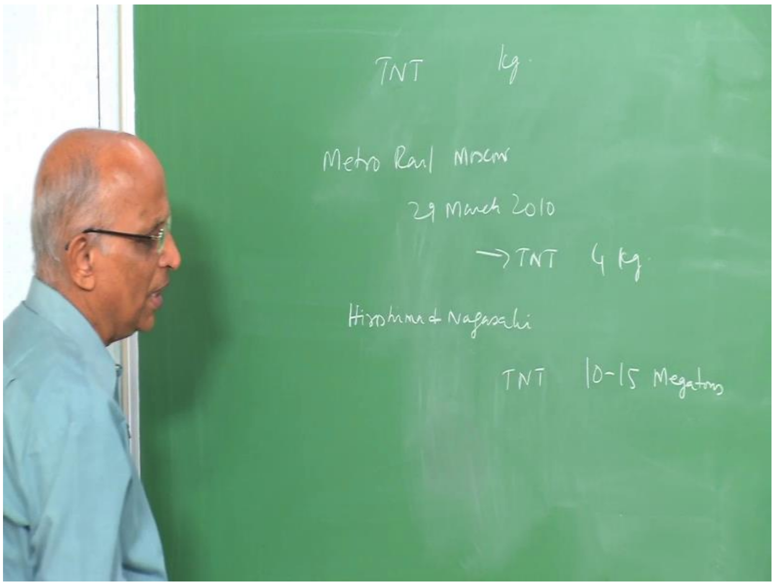
We have that time duration over which the energy of TNT is released namely tau. Assuming that may be the detonation propagate like this and finishes the whole thing is I have a characteristics length of 5 into let say 2, if it is detonated at the center it is just 5 divided by I have the value of 6 9 4 0, 5 into 2 or 5 divide by 6 9 5 0 that is this is 5 centimeter therefore, I have 5 into 10 to the power minus 2 divided by 6 9 4 0, and this comes to something like 7 microseconds. If it was from end to end it would have been something like 14 microseconds.

Therefore we are talking of time over which energy is released is a few micro seconds that is 10 to the power minus 6 seconds, and these times are so small. We are talking of detonation velocity blast waves of something like mark 4 mark 5 which are something like 1500 meters per second, whereas these time skills are much, much smaller. And therefore, we can say it is released that is tau tends to 0.

Therefore, we tell ourselves when we consider this specific case of a TNT, the source radius tends to 0, the time over which energy release tends to 0 or rather TNT seems to confirm to the case of a point explosion taking place spontaneously or rather this seems to correspond to an ideal explosion. And since, we know how to deal with an ideal explosion namely we derived the equations, we saw on the chart how the impulse behave with R s by R naught. Well, these I well TNT is something like an ideal explosion.

And therefore, it becomes necessary for us to be able to convert are non ideal explosion involving a large volume may be involving a large or relatively large characteristics time of heat liberation or energy libration into something like an ideal explosion. We have to transform this and that is where we talk in terms of TNT equivalence. Let us do this, but before I do this let me give one or two small examples, you know whenever any explosion occurs anywhere.

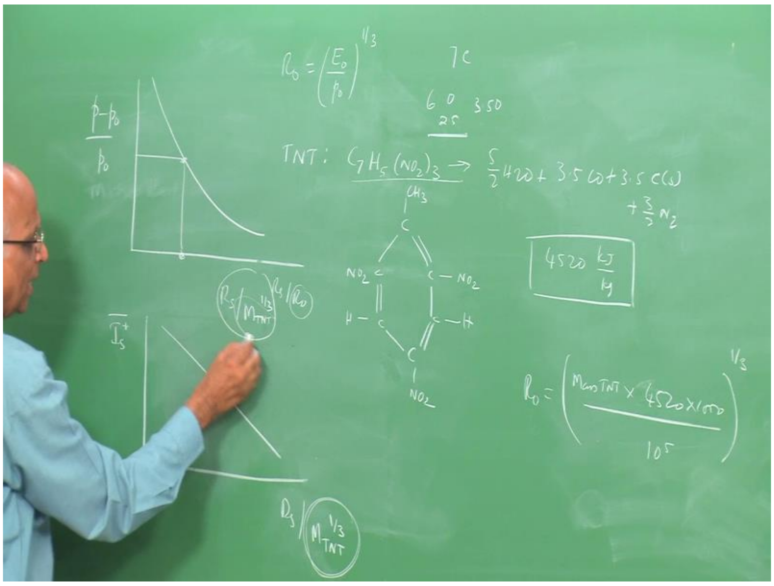
(Refer Slide Time: 26:46)



You know in when some news comes of the explosion automatically we say, well the TNT equivalence of the explosion is so much kg. Like for instance, let me take one particular example. I take the example of let us say we had an explosion in the metro Rail in Moscow, this was on 29th march 2010 you know some ((Refer Time: 27:15)) rebels, they planted some bomb in the metro rail and it kill a few people.

And what was reported was? The metro rail explosion in Moscow had a TNT equivalent of 4 kg, why look at this small example? If we look at the bomb which was dropped over Hiroshima and Nagasaki, the TNT equivalent of this particular explosion is set to be between 10 to 15 mega tons. Therefore, explosions are all categorized in terms of some equivalent mass of TNT and in fact, instead of having figures like what we drew?

(Refer Slide Time: 28:14)



You recall whenever we talked in terms of blast waves and ideal explosions. We had 2 figures p minus p naught over pressure divided by the ambient pressure divided by R s by on this x axis we are R s by R naught. We had a curve for the over pressure as a function of R s by R naught. We also had a curve for the non dimensional specific impulse, let say positive impulse verses R s by R naught we had a curve like this. Now, if we had talking in terms of equivalent TNT, well R naught ideal point source 0 time.

Therefore, I can always write R naught as equal to R naught is defined as energy release by the explosion divided by the ambient pressure p 0 or p ambient divided by 1 by 3, and what is the energy release? We said well TNT, the chemical formula for TNT was it had the benzene ring it was methyl benzene, methyl benzene in which you had at NNO2. Therefore, it was something like C7H5 (NO2) 3 times that means, what was there let us again go through the structures such that we do not commit a mistake on the chemical formula, because that is required to be able to calculate the energy over here.

This is the formula you had methyl benzene, and what did we do? We took 3 of the hydrogen atoms we replaced it by NO2, NO2 we replaced here an NO2. Therefore, we had 7 C 3 plus 1 2 hydrogen, 3 plus 2 5, NO2 3 this is the formula for TNT. And when it burns or when it dead needs, we form products of the combustion. We found yesterday or in the last class that TNT is a fuel rich substances, and what we form is a something like 5, 5 corresponds to let us write the product equation.

You have 5 by 2 H2O that means I have 6 of oxygen, I removed 2.5 of them, I am left with 3.5 of oxygen it is fuel rich I have 7 of C, 7 of C can only form 3.5 of carbon monoxide plus 3.5 of carbon as the solid plus I have nitrogen which is equal to 3 N that is 3 by 2 of N 2. I know the heat of formation this is an element, this is an element, and therefore heat of formation of this elements at standard state is 0, CO is around minus 110 we know the heat of formation of TNT, I know the heat of formation of water has been something like minus 286, this is minus 110.

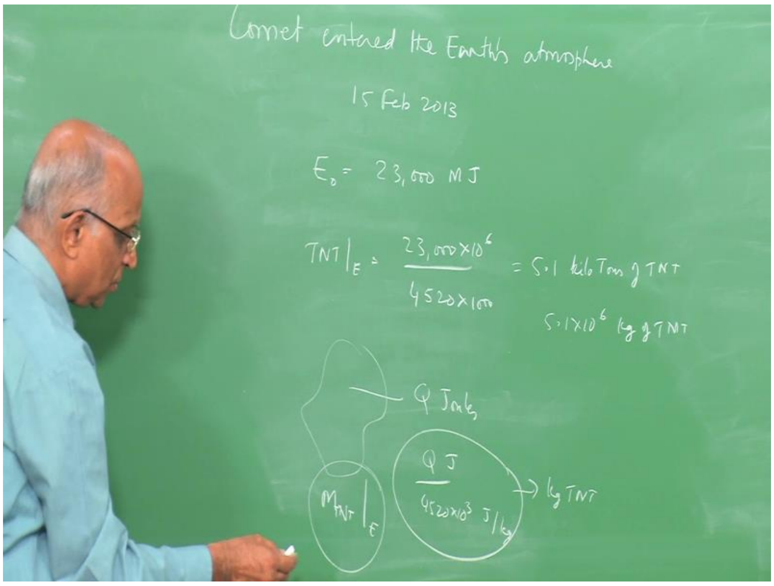
The energy librated per kg of TNT comes out to be 4 5 2 0 kilojoules per kilo gram. I find out the energy release for 1 mole, in 1 mole I have this is the molecular mass, and that divide the energy release for the reaction divided by the molecular mass comes out to be this value. Therefore, you have 4520 kilojoules per kilo gram is the energy liberated in TNT.

And therefore, if I were to write R naught I can write it as equal to mass of TNT into the energy liberated as equal to 4 5 2 0 so much kilojoules into 1000 kilojoules divide by 10 to the power 5 to the power 1 by 3 becomes my R naught or rather all these things you know 4 5 2 0 of constant, heat release this is the constant number 1000, this is the ambient pressure 10 to the 5 Pascal. And therefore, I can also write R s by R naught over here.

I can also change the scale suitably, I can write it as mass of TNT to the power 1 by 3. Instead of writing R s by R naught I can also rub it out, I can write it as R s divided by mass of TNT in kilograms to the power 1 by 3. And very often in most of the handbooks on explosions, we show the x axis in terms of the distance travel divided by mass of TNT to the power 1 by 3 instead of writing it in terms of the explosion radius, so also for impulse diagram.

And therefore, you know the TNT is use to represent an explosion, and if from this I find an explosion as a certain over pressure at some particular distance. Well, I know the value of R s divided by mass of TNT corresponding to this, I know the distance at which physical distance at which this over pressure is felt I can calculate the mass of TNT, and this is how we calculate the equivalent mass of TNT. Therefore, let us do one example to be able to precisely find this out.

(Refer Slide Time: 33:48)



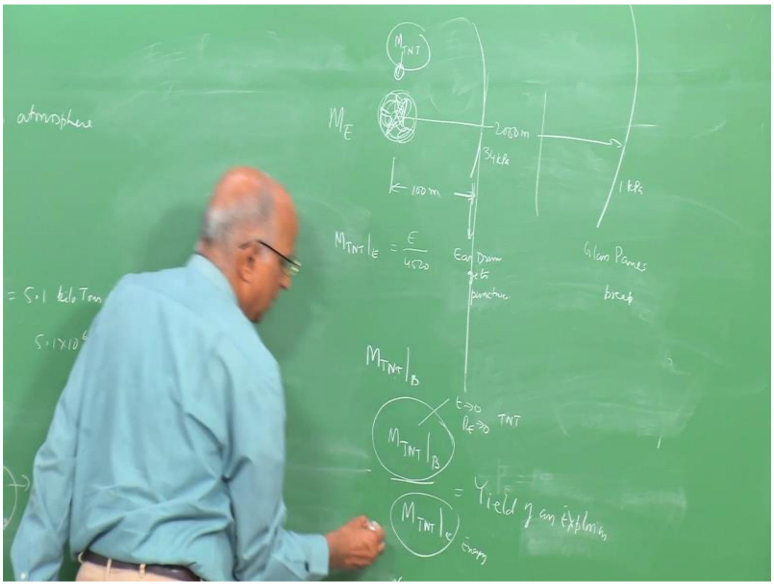
Let us take the example of the recent the comet which entered the earth atmosphere at ((Refer Time: 34:02)) just close to the city of ((Refer Time: 34:06)), and what is at this happened on 15 February 2013 last year. And the when the comet enters the earth atmosphere at very high speeds lot of energy gets generated, because the kinetic energy of the comet is stop and the energy released in this particular reentry was estimated to be equal to something like 23000 mega joules. Therefore, instead of saying 23000 mega joules is the energy associated.

The mass of TNT which has the same energy as this particular explosion comes out to be 23000 divided by per unit mass of TNT, the heat the energy released is 4 5 2 0 kilojoules per kilogram into 1000 joules over here, this is into 10 to the power 6. This is the TNT equivalence, and this comes out to be equal to 5.1 kilo tons of TNT that is 5.1 into 10 to the power 3 kilograms that 5.1 into 10 to the power 6 kilograms of TNT or it is equal to 5.1 kilo tons of TNT over here.

Therefore, this is how you get for an equivalent energy how much what is the value of TNT? Like for instance, I have let us say some particular explosion which gives you an energy let us say Q joules, then what is the equivalent TNT for this particular energy is equal to Q divided by 4520 into 10 to the power 3 joules. And therefore, this gives me Q this is this value is so much joules per kilogram, this is so much joules, and this gives me so much kilogram of TNT based on the energy equivalent that is mass of TNT based on the equivalent energy level.

See, but then I must also remember that well this comet entered it release so much of energy or else have an explosion which releases Q joules, and I have an equivalent energy in terms of mass of TNT as saying so much kilograms of TNT. Well, this energy need not be spontaneous it might be slow, it might be fast. And therefore, this mass of TNT may not be the correct picture, because TNT we said is something which is spontaneous, whereas this energy must be slower what do we mean by this?

(Refer Slide Time: 37:10)



Let us take an example, let us consider the following example namely I consider some explosion taking place over here, and at a distance let us say 100 meters away from the explosion. I find may be the explosion is so strong that 100 meters away all the people who are standing over here lose there here, that means their ear drum gets punctured. May be another distance away let us say at a distance of let us say 2000 meters away quiet far away, the building which are all there you know here everything is damage, the glass windows of the building or glass panes of the building they break.

We had told earlier while starting blast waves that 34 k Pa over pressure causes the eardrum to rupture, and something like 1 k Pa something like 700 Pascal or 1 k Pa near about causes the glass panes to rupture or break. And therefore, we say well the over pressure from this actual explosion may be it is very non ideal is such that at a distance of 100 meters away, I have 34 k Pa over pressure at a distance of 2000 meters away I have a over pressure of 1 k p a. And now, instead of this particular explosion which has let us say a mass of the explosion is M E that is some non ideal case, and how do I convert M E to TNT mass of TNT which has the same energy basis.

Well I find out what is the energy released in this particular explosion divided by 4 5 2 0 into 1000 so much joules per kilogram, I get the equivalent mass of the TNT based on the energy release. I do one more thing, I find in this explosion at this distance the over pressure is 34 k Pa, at a larger distance may be the over pressures is 1 k Pa maybe I am focused on this I want to evaluate this damage. Therefore, I replace this particular explosive by some mass of TNT, M lets say TNT, and I make sure that this mass gives me this particular pressure.

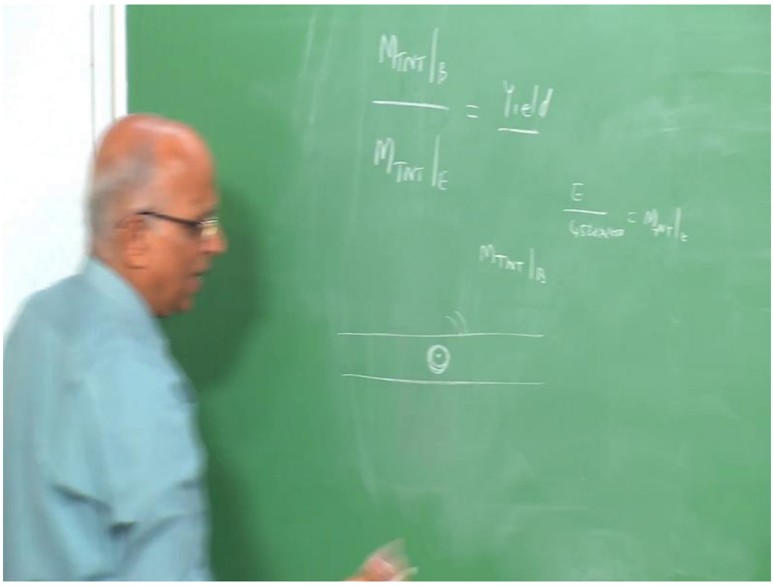
Therefore, I say this mass of TNT I call it as mass of TNT which creates the same blast damage at this particular distance. I am interested in this particular distance, this gives me the equivalent mass of TNT which gives the same blast damage as the actual explosion, but if I write to take the mass of TNT which gives me the same energy. Well, it gives mass of TNT on the energy basis namely the energy of the explosion divided by 4 5 2 0 into the conversion fact of our joules, well that gives me on the energy basis.

But, this is based on the actual blast damage, and the ratio of mass of TNT which gives me the blast damage or the same blast damage divided by mass of TNT which is equivalent which is gives me the same energy gives me what I call as the yield of an explosion, why should this and this be different? Well this in this, all the energy gets into the blast wave, that means it gives me the blast at this particular distance may be if I were to calculate the blast over here.

Since its non ideal it may not really give me the same value here, but since I am interested in this I calculate this, if I am interested over here or interested in over pressure, I calculate mass of TNT based on blast for that particular type of damage I am looking at divided by mass of TNT gives me the yield. And therefore, this takes care of the actual point source, and the duration of the explosion that means, here for this may be time tending to 0, the radius the source tending to 0 corresponded to actual TNT, this corresponded to only the energy basis.

And therefore, the mass of TNT evaluated based on a particular blast damage which a TNT can TNT explosive can cause divided by the equivalent mass of TNT is called an yield of an explosion. Therefore, we define 2 terminologies one is the equivalent mass of TNT based on the energy equivalence, and the second term which we define is mass of TNT which causes the about the same blast damage.

(Refer Slide Time: 42:28)

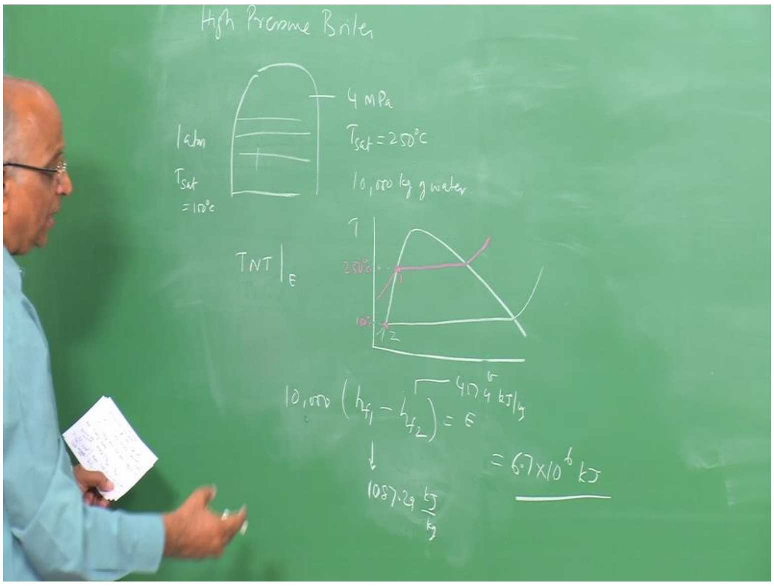


And I think to be able to put things together; we need to do one or two small examples. Let us do a small example or two such that we are very clear, because I think this concept of TNT equivalence both on energy basis and the blast basis, and the ratio of TNT mass based on blast damage divided by mass of TNT, based on blast damage divided by mass of TNT for the same energy what is released is what we call as the yield, yield of an explosion. This is used very well like for instance maybe you have the this insurgencies we have a road, let us say a terrorist plants a bomb on the road.

And we want to find out we find that may be this is this bomb is planted may be a truck or car is going over the road, this bomb is exploded, and therefore it has the damage potential. Therefore, we would like to see, what is the type of damage which this bomb does, and we will find out for the same type of damage which may be the vehicle encounters maybe the building around this encounter, we will calculate the mass of TNT based on the damage which is observe.

We also go back, we determine well what was the type of bomb which the particular person used, what was the energy released in the particular bomb. We divided by the energy release per kg of TNT this is 4 5 2 0 into 1000 joules per kilogram, this gives me the value of M TNT based on energy. And the ratio of M TNT for the blast damage divided by M TNT is what we call as the yield of an explosion.

(Refer Slide Time: 42:11)



Let me first take an example of a boiler bursting. I have let us say a high pressure boiler a fire tube boiler. In a fire tube boiler well you have water at pressure you have lot these fir tubes in at which heat the water. Let us say that the operating pressure of this boiler is 4 m Pa, and the at 4 m Pa the saturation temperature is equal to 250 degree centigrade this comes from the steam table. Now, what it the at the movement of burst let us say the boiler has 10000 kg of water.

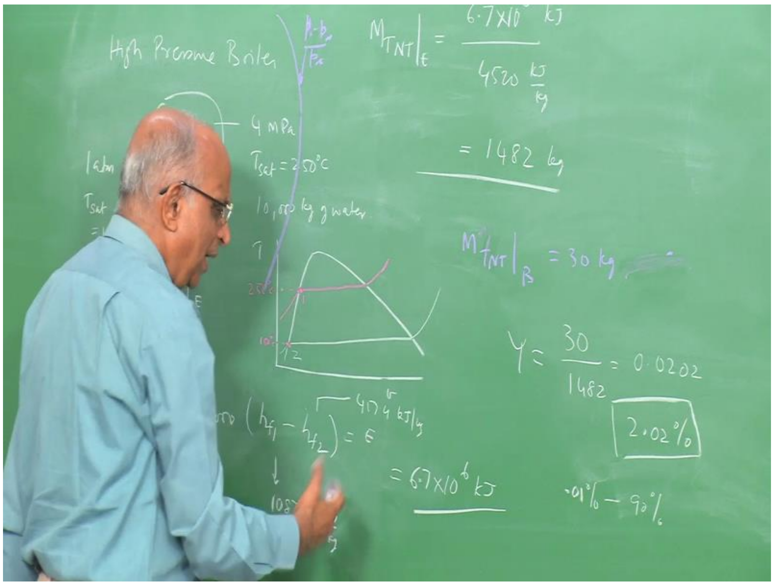
Now, I first want to find out for if this 10000 kg of water which is at this 250 degree centigrade, and when the boiler burst what happens? The ambient pressure of 1 atmosphere is available for this hot water to see. Therefore the water at 250 degrees spontaneously evaporates, because the saturation temperature corresponding to 1 atmosphere pressure is equal to 100 degree centigrade, and therefore some energy is released. I want to calculate, what is the value of TNT for the same energy which is released?

Therefore, I have to calculate the energy of this particular explosion, and what did we do in the case of flash vaporization? We had the T verses v diagram waterline the steam line, we had the 1 atmosphere pressure line, we also had a pressure for 4 m pa, this is the state of water let us say the state of water is 1, and this is at 250 degree centigrade, well this is as 100 degree centigrade. When the boiler burst the temperature which the water can sees only 100 degree centigrade.

Therefore, the amount of energy content at this meta stable state corresponding to this stable state corresponding to 1 pressure corresponding to 100 degree centigrade is let us say h f1 corresponding to state 1 of the lay of the water. This let us say state 2 minus h f2 for water, this is kilojoules per kilogram into something like 10000 kilograms this is the total energy which is available. We may just look up the steam table we say h f1, we find is equal to 1087.29 kilojoules per kilogram.

The value of h f2 corresponding to atmosphere pressure for water over here is equal to 417.4 kilo joules per kilogram. And therefore, the energy content or the energy released when this water flash evaporate or when the boiler burst is equal to 10000 into 1087.29 minus 417.4, and this comes out to be equal to 6.7 into 10 to the power 6 kilojoules.

(Refer Slide Time: 47:33)



Now, I want to find out what is the equivalent mass of TNT for this energy basis? Therefore, mass of TNT for the same energy is equal to energy is equal to 6.7 into 10 to the power 6 kilojoules divided by 4520 kilojoules per kilogram is the energy content of

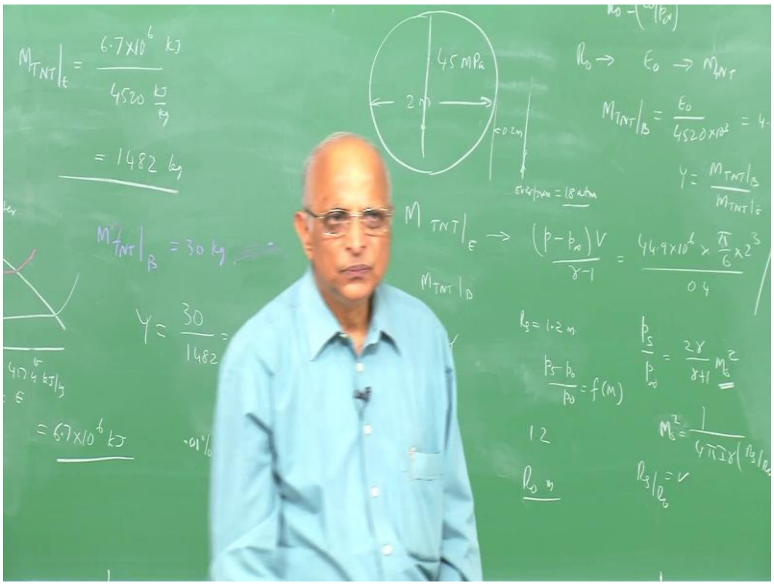
TNT per kilo gram. And therefore, the TNT mass of TNT for the same energy is equal to 1482 kilograms of TNT this is the value mass of TNT. Now, when this boiler burst, we also find yes there is a damage maybe the building around this boiler at a particular distance get damaged.

And for this building to get damage, I know that the value of over pressure p minus p ambient has a certain value to given by p ambient I know the particular damage which is cost. I find out what is the mass of TNT which was if it was available here would cause their same damage, I go back to the curves what I generated, I find that the mass of TNT I use a different color, mass of let us say TNT which causes the same blast damage as when the boiler ruptured or when it exploded is equal to let us say 30 kg of TNT that is 30 kg.

Therefore, the yield of this particular explosion is equal to 30 kg divide by 1482 kg which is equal to 0.0202 or rather 2.02 percent; this is the percentage yield of the explosion. In practice, whenever we have dust explosion or vapor cloud explosion, confined, unconfined or any other form of explosion, the yield changes enormously. The yield could be as low as it 0.1 percent to as I has maybe 90 percent or when I use very powerful solid explosives, the yield could even be greater than 100 percent.

This is the way we calculate the yield the TNT equivalence for the energy basis, the TNT equivalence for the blast basis. Let us do one last problem such that we are absolutely clear, this is an important area wherein not much research has been done, but we need to use the TNT equivalence whenever we talk in terms of non ideal explosions.

(Refer Slide Time: 50:22)



Therefore, let us consider the last problem. Let us consider a pressure vessel, let us say a pressure vessel of diameter 2 meters let us say it ruptures, it ruptures when the pressure inside is 45 m Pa. This is and when the pressure when this particular spherical tank of diameter 2 m ruptures, it is also observed maybe at a distance from the walls of the vessel may be there are some people working near it, maybe at a distance of something like 0.2 meters may be the people are very drastically affected they are totally killed over here.

The over pressure at this particular distance of 2 meters from the walls of the pressure vessel, the over pressure is equal to 18 atmosphere you know extremely I think wherein the there is total damage over here, I want to calculate, well what is that? TNT equivalence of this mass of TNT equivalent based on the energy basis, and also I want to find out what is the mass of TNT base on the blast bases, because I know the over pressure is 18 atmosphere at a distance 0.2 meters away, and then I want to calculate the yield.

Well to calculate the TNT based on energy basis, we know that the energy released in rupture of pressure vessels is equal to the higher pressure minus the ambient pressure into the volume divided by gamma minus 1. And this is already given as 45 m Pa, ambient pressure is 0.1 m Pa, therefore it is equal to 44.9 into 10 to the power 6 Pascal into the volume is equal to the diameter is 2, therefore I have volume is equal to pi by 6 into 2 cube divided by gamma minus 1 let us say 0.44 there.

Well this gives me the energy over here have to convert it to energy of mass of TNT, therefore I divided the by 4 5 2 0 into 10 to the power 3 joules, and this gives me a value of is equal to based on energy basis is equal to 104 kg of TNT. Well, I have to calculate the effect of the blast, and what is it I do? I do a similar exercise namely at a distance of 2 meters away, now my center is over here. Therefore, my R s is equal to 1.2 meters I know the over pressure is 18, therefore I have the relation between p s by p naught divided by p naught as a function of mock number.

I know for a shock wave, if the shock if I have to write the value of shock pressure that is a pressure behind the blast wave divided by the ambient pressure is equal to 2 gamma divided by gamma plus 1 into M s square, I can calculate this is for a strong shock I can calculate the value of Ms. From M s I can again right the value of M s square is equal to 1 over 4 pi I gamma into R s by R naught cube over here. And therefore, for this value of M s which comes out for this value to be around 4 I get for 4, I get the value of R s by R naught, and I know the value of the R s by R naught.

And now, I know that in this case R s is equal to 1 plus 0.2 1.2 I can calculate my value of R naught in so much meter. Therefore, I know the value of the explosion length for this particular problem, and from R naught what is it I calculate? R naught is equal to E naught by the ambient pressure to the power 1 by 3 I know what is the energy which is getting released driving this blast wave.

And therefore, mass of TNT corresponding to this blast is equal to this value of energy divided by 4 5 it I know this value of energy, and this energy is since it is driving the blast wave, I can calculate the mass of TNT which drives this either from tables or maybe from 4 5 2 0 into 10 to the power of 3, because this is not something which is energy equivalent, but this is based on the explosion length equivalent I know the mass.

And therefore, I get the yield as equal to M mass of TNT for this particular blast divided by mass of TNT based on the energy, energy is 104. The value of blast comes out to be equal to something like 4.63 kg, and therefore the yield of explosion is 4.63 divided by 104 which is equal to something like 4.5 percent yield, and this is how we calculated for different problems? The TNT equivalence and the yield of explosions, and this is all about the different types of explosions. In the next class what we do is we will look at may be the dispersion of gases in the atmosphere.

Well, thank you.