Environmental Remediation of Contaminated Sites
Prof. Bhanu Prakash Vellanki
Department of Civil Engineering
Indian Institute of Technology – Roorkee

Lecture - 07
Risk Assessment
Deterministic Approach

So again hello everyone, welcome back to the latest lecture session. So let us have a quick recap of what we have been up to in the last couple of sessions and then move on to the aspects that we plan to discuss today I guess the deterministic approach in greater detail and then the stochastic approach right. So again looking at what we have been up to, we have been looking at risk assessment.

And before we look at the summary or you know try to summarize risk assessment let us try to again recap why we need to look at risk assessment. So in this course, obviously we are talking about remediation of contaminated sites right. So before I put in time and resources, I need to know let us say you know what is the level of risk that this particular contaminated site would pose to my exposed population here let us say right.

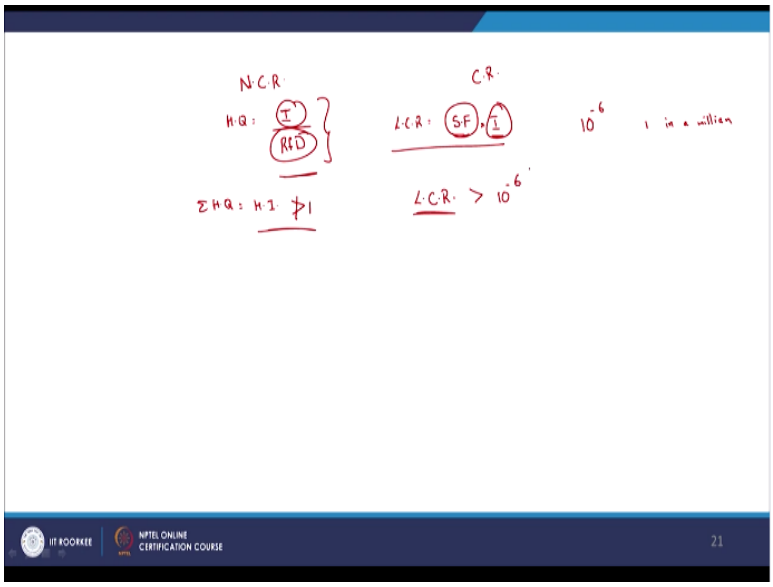
So to be able to do that obviously I need to be able to come up with risk assessment or you know conduct the risk assessment here and obviously we looked at 2 different cases, one the quantitative and other the qualitative. Qualitative obviously pretty subjective right, as in somebody says you know the risk assessment, the risk posed by this particular contaminated site to the relevant exposed population is very high, high, low and so on.

But that subjective right I mean depends upon the interpretation or such of which differs from person to the person from one person to the other right. So to rule such issues out and also to allow for more scientific analysis when we look at remediation let us say specifically, we are going to look at let us say risk assessment and its quantitative or the relevant quantitative aspects I guess yes.

And in that context, we looked at 4 major aspects; I think data assessment, exposure assessment right, toxicity assessment and then risk characterization I guess right. So these aspects more or less we looked at them in some detail but major aspects or take-home messages were that we need to look at the uncertainties let us say and toxicity assessment and

also in exposure assessment right but as of now we have not yet looked at those uncertainties but we are going to.

(Refer Slide Time: 02:26)



And then once we look at those aspects for non-carcinogenic risks, we calculate the hazard quotient right. How do we calculate that? We calculate the intake right divided by the reference dose right and for the carcinogenic risks, what do we get? We can calculate the slope pardon me not slope factor but the lifetime cancer risk as slope factor*intake right. So intake site-specific right, both the intakes are site-specific.

But these two what do we say standards not standards pardon me standard values which are slope factor and reference dose where do we get them from? From the relevant toxicity assessment or you know from the toxicity studies and so on right. Again, we discussed that in relative detail again here right. So here obviously the sum of all the hazard quotients over the different pathways and such right, we call that to be the hazard index.

And similarly here it is a lifetime cancer risk right and what are the thresholds? Obviously, if we look at the way that they were set up here in the case of non-carcinogenic risk right, what do we see that the hazard index should not be >1 right. So if it is >1 that means that the relevant affected population has what we say greater than what do we say acceptable risk more or less right.

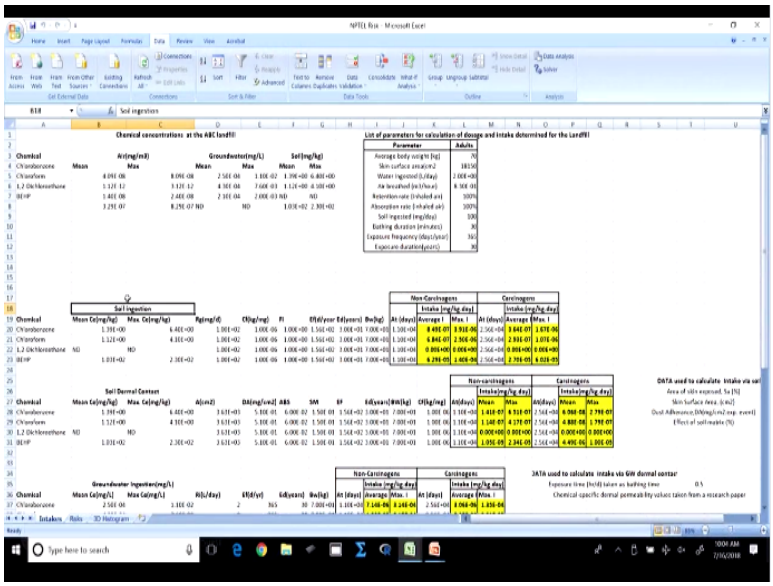
So in the case of lifetime cancer risk as we talked about it, typically the thresholds are 10 power -6 meaning one in a million right. So if the life time cancer risk is greater than let us

say 10 power -6, we deem that to be unacceptable as in the relevant population has a chance of what do we say contracting cancer right say or additional chance of contracting cancer and exposed to the relevant conditions we have looked at in the relevant scenario I guess right.

So in some cases, I believe they also looked at the threshold of 10 power -4 right. So again different cases but typically 10 power -6, so these are the thresholds in these two contexts right. So in that context, I believe we looked at a particular example as in we started discussing I believe kind of soil contaminated not soil pardon me contaminated what you say area and I think in the example that we looked at, we calculated the risks posed to a particular set of population due to ingestion of or accidental ingestion of soil right.

So in that context, we went through and calculated the relevant values I guess right. So today before we go into further aspects, let us look at relatively similar scenario but in this case or in this particular scenario rather than looking at just accidental ingestion of soil, we are going to look at the other pathways to right and try to look at the comprehensive picture right or the holistic analysis I guess.

(Refer Slide Time: 05:18)



So let me take you to the excel sheet that I have here right and let us just try to understand what we are up to. So it is still the concentrations, chemical concentrations at a particular landfill and different parameters we have them here, so the body weight, skin surface area and then these are from where are they from let us say right. Body weight let us say, it depends upon let us say the country, the location and such.

So typically let us say these point estimates, I am calling them point estimates for now right. How do we arrive at them let us say by some data collection exercise from the site right? So some values obviously let us say skin surface area and such you know they can be the standard values that were collected in that particular locality or specific to that particular region I guess right.

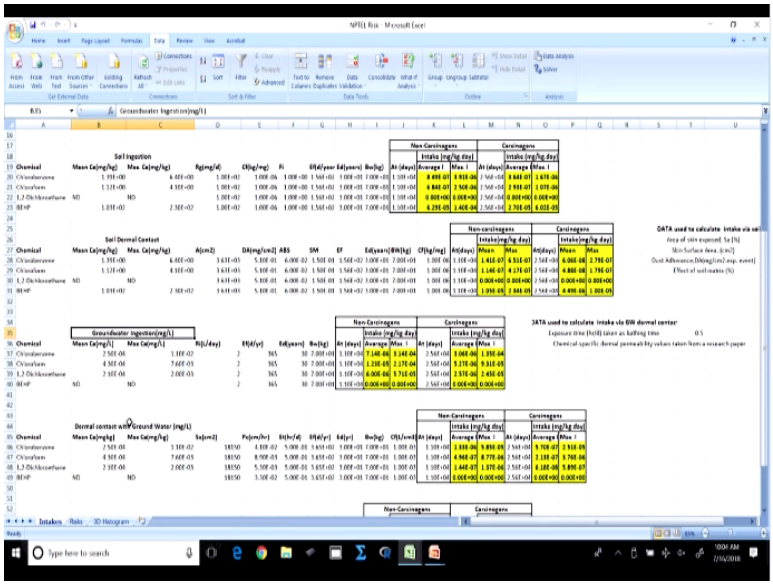
But body weight and some of the other values here let us say they can be collected from the site and you know the relevant point estimates then be arrived at right. So again we have different what do we say values that we are going to look at, water ingested 2 liters per day I guess, air breathed yes, retention rate of the inhaled air, absorption rate of inhaled air, these are typically conservative estimates as is the case in most risk assessments.

But obviously again there are uncertainties here too right. So soil ingested I believe it is 100 milligram per day right that is reasonable. Bathing duration, here we have taken that to be 30 minutes could be greater too obviously. Exposure frequency and duration, though here we are taking that to be 30 years here for now right. Again, we just went through some of the typical values associated with this particular site and the relevant what we say values for calculation of the intake I guess right.

So again this should sound familiar as in we have the 4 compounds and we have the relevant concentrations in air both mean and maximum groundwater, mean and maximum soil, mean and maximum right. In our case, for intake I guess in the example we looked at, we calculated the intakes for both the mean and maximum, so we are going to look at the same case.

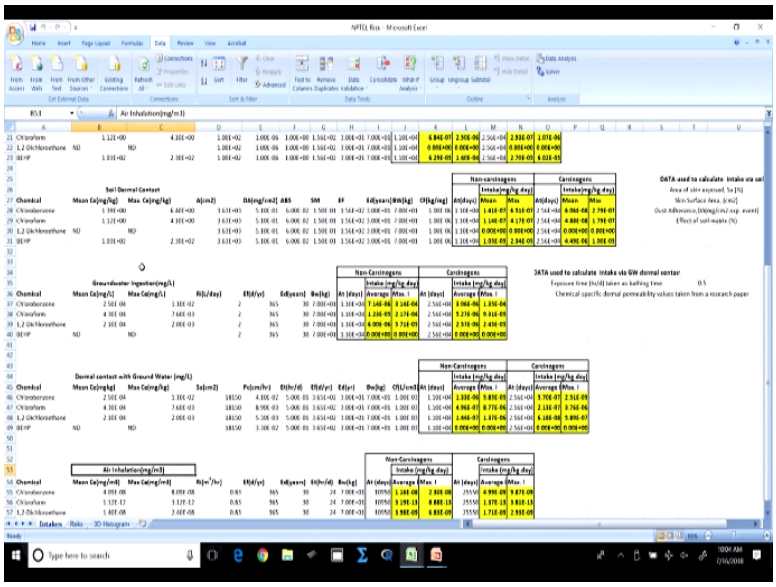
But for the risks though obviously we are going to look at only the case which takes into account the intake at the mean I guess right or the mean intake value right. So going through that right chemical and here we are going to look at different pathways.

(Refer Slide Time: 07:40)



So what are some of these pathways? Let us just try to look at them. So soil ingestion and soil thermal contact right, groundwater ingestion let us say yes and also dermal contact with groundwater.

(Refer Slide Time: 07:50)



And I believe I have air inhalation out here, so we are looking at 1, 2, 3 and 4 and 5 pathways here right. So let us look at some of the aspects here. So for each chemical let us say so we have a mean and maximum value, I think rate of ingestion right and I think exposure concentration is it, not really I guess. This is conversion factor and the next one is fraction of ingested soil that is from the contaminated soil, exposure frequency, exposure duration, body weight, average time and such.

So again depending upon the type of pathway, we have what we see a slightly different variations of the generic formulae and I guess they are supplied to you I guess right and here we have the averaging time and that is calculated as 30 years*365 days and why do we have that here because in the non-carcinogenic risk assessment, we will consider that the averaging time is equal to the exposure duration.

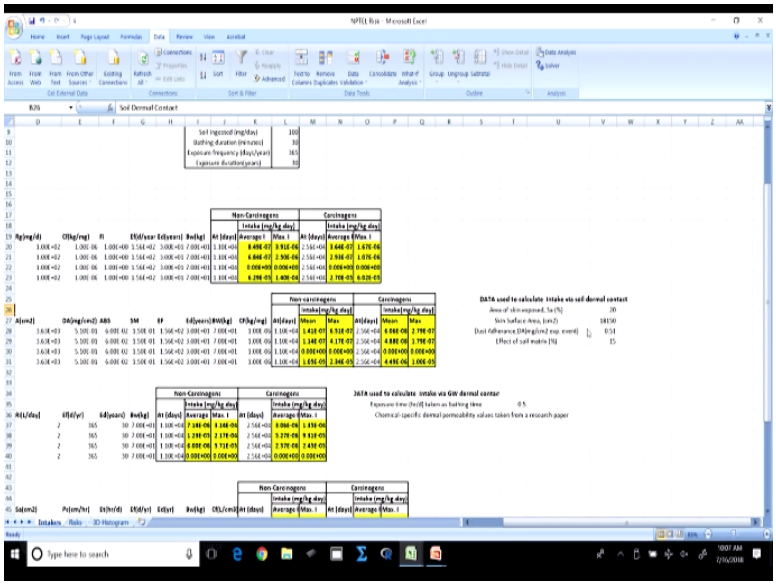
But obviously if you try to compare that with the case for the carcinogens, you see that we have a different value and that is because we assume that the averaging time is equal to the life time which is the 70 years and thus the 25,550 days out here I guess right. So again coming back to what we have so average time and then the intake right, plugging in the relevant values, one for average and one for the maximum value I guess right.

And again same case for carcinogens and so on, so in here I guess obviously we see that the issue here is that the maximum you know is greater than the average value by order of magnitude right. Here we have 10 power -7 and here we have 10 power -6 right, so again how do you take this into account in your analysis right. Again, please keep this in mind because you are going to come back to this later.

As in, here we have a case of maximum concentration and mean concentration and thus obviously we end up with mean intake and maximum intake right. So obviously if I you know take this further right, I can again calculate the risk assessment based on this intake calculated from what is this now the mean value of exposure concentration and similarly for the maximum value of the exposure concentration right.

So how do I compare both the risks in that case right or you know which one do I need to consider in such right? So again, there are issues obviously involved but keep in mind that we are going to come back to this later but let us understand some of the issues at this stage itself. So similarly, I believe for you know soil dermal contact and such, skin surface area and such I guess, different factors.

(Refer Slide Time: 10:36)



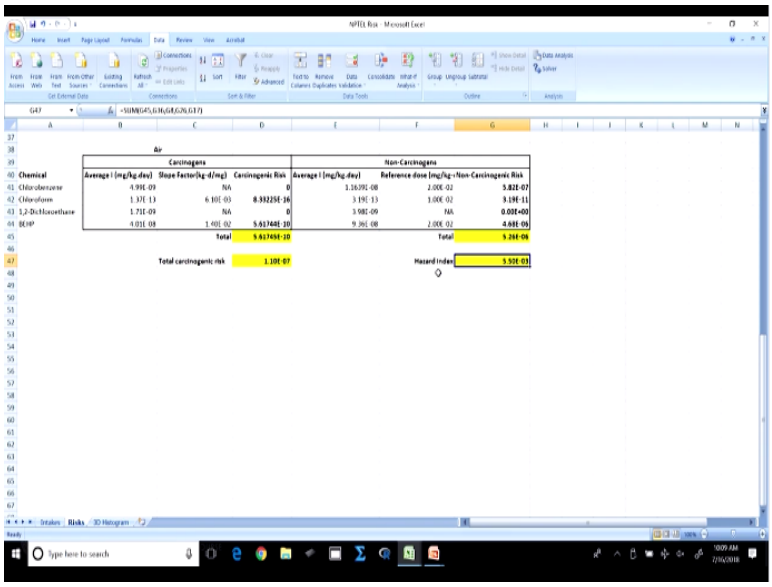
Again, what are the factors given here? Area of skin exposed, skin surface area, dust adherents I guess and effect of soil matrix. So some of the values that you typically see in that particular formed layer I guess and again we see that we have the mean and maximum intakes for both the non-carcinogens and carcinogens. Again, why do you have different intakes for non-carcinogens and carcinogens I guess right?

It is because of the way we consider the averaging time right and again same case I end up calculating it for ground water ingestion and some of the data exposure time we took it to be due to bathing anyway 30 minutes right. So again from research paper I guess, the dermal permeability values right. As in, you are particular what we say compound is now what we say in contact with your skin.

So you are going to have different dermal permeability values I think. Where do we have them out here? Groundwater dermal contact with groundwater and I think these are the different permeability values and looks like we took them from a particular research paper. So again the reason I am looking at this or talking about this in relatively greater detail is that again obviously there are going to be uncertainties with this value or there are going to be variations you know from this value for each person out there.

As in, my skin might have a higher what we say permeability value for a particular compound when compared to your skin right. So again but here keep in mind that we are for now only looking at a point estimate, again we will come back to this later. So in same case, we calculated the intakes and so on.

(Refer Slide Time: 12:16)



So then if we calculate the risk let us see what we have here, so we have the average intake right and we have the slope factor and I guess for carcinogens, chlorobenzene is not being considered as a carcinogen and thus we have no slope factor. So risk associated with that is zero and again we calculate the carcinogenic risk, again this is from just the air pathway typical example here right.

And again from here from the non-carcinogenic risk, so from the pathway of air inhalation anyway right, we have the carcinogenic risk and we have the non-carcinogenic risk here right. So obviously, I should not have used the term hazard index, maybe hazard quotient at this stage. Hazard index typically looks at the sum of the hazard quotients for all the pathways I guess.

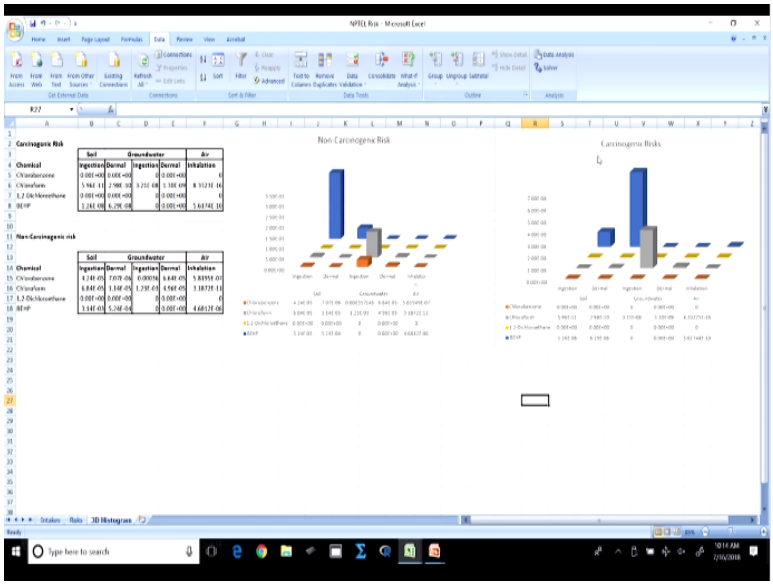
But here obviously we are looking at only the air pathway or maybe I do have it here, yes I do have it here. So for soil ingestion again different cases, so we have the what do we say now the risk associated with the carcinogenic risk for soil ingestion right and again for non-carcinogens right and typically as you see, the thresholds were 10 power -6 as we consider for carcinogens and 1 for non-carcinogens and from what we can see out here though right.

We see that typically they are relatively lower compared to the threshold though right and sum though if we look at the sum the total carcinogenic risk is let us say 1.1*10 power -7 right and our threshold is 10 power -6. Thus, we deem that the level of risk posed to the

people at this particular site is you know acceptable I guess right and if we come back to the hazard index I guess this is the true way because I did sum up all the hazard quotients.

So the hazard index again gives us an idea about the risk posed due to the toxic compounds or the non-carcinogens. So even in that case, we see it is 5*10 power -3, so that is much <1. So obviously here from our risk assessment what can we conclude that you know for these exposure conditions and concentrations and so on, the risks associated with or to the relevant population are lower than the relevant thresholds or are within the acceptable limits right.

(Refer Slide Time: 14:35)



So again let us say just to understand this system better, we have the relevant risks listed here and in a histogram so that we can visualize what do we say in a better manner. So here we have one particular graph for non-carcinogenic risk and on one of the axis we have what we say different pathways I guess right and here for soil, groundwater and air. For soil it considered both ingestion and dermal contact.

For groundwater, again ingestion and dermal and inhalation I mean only for air I guess obviously right. So obviously when I look at this which pathways typically seem to be posing a greater hazard to me and typically it seems soil and also which particular chemical again that is BEHP I guess right. From groundwater, it is typically only the ingestion that seems to be an issue.

So while bathing or such at least for the time taken to be 30 minutes I guess right, it looks like the risks are remarkably lesser or well truly lesser compared to the risks associated with

ingesting or drinking the groundwater right. So that is what I see out here, so again how will this help me, so in general though here the risks were within acceptable levels right as in I think here we are talking about non-carcinogenic risk.

And if you see the maximum is around 3.5*10 power -3 and obviously the total risk too was 5.5*10 power -3. So thus we did deal this particular risk to be within the acceptable level right but let us say if it were higher than what do we say the acceptable level, then what you need to do, you need to go in full remediation right. So in that context, let us say when I look at the risk, you know or understand the holistic picture as I see from this particular graph let us see right.

What we look at? We looked at that the soil pathway poses typically greater risk and then the groundwater ingestion right. So how would I you know look at allocating my resources and time let us say? I would like to look at remediating the effects let us say posed due to soil and the groundwater here right. So I would think of treating groundwater and maybe limiting access to what do we say the soil right or contact to the soil may be excavating soil or washing it depending upon the type of contaminant I guess right.

So again this particular risk would then I mean picture would then help me identify those compounds which seem to be you know which need to be or which are of greater concern. In this case, BEHP for the soil pathway and in the case of groundwater I think chloroform and chlorobenzene I guess right. So it helps me identify also the chemicals let us say that are of greater concern for a particular pathway and such right.

So moving on to carcinogenic risk right, so what do I have here, similar case again and here again the maximum seems to be around 10 power -8 or 6*10 power -8 and as we looked at the total risk associated, it was 1.1*10 power -7. So again our threshold values or what is our threshold value, please it is 10 power -6.

Again, so we are thus the risk since the lifetime cancer risk for those particular exposures are for that particular exposure concentration right turned out to be less than the acceptable level right which is 10 power -6. We deem that or we would think that you know no remediation is required right and thus obviously again if I just understand the case here though as you remember let us say when I calculated the risk let us say I need to look at the intake.

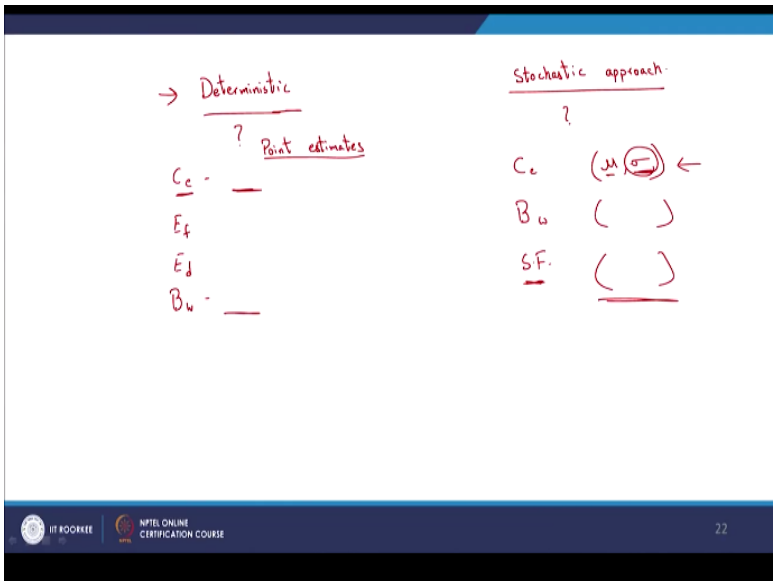
So an intake case let us say if you remember the average was one order of magnitude or 10 times lower than the maximum value. So for example if I did take what we see the maximum value then the risk would be probably let us say one order of magnitude or 10 times higher for this carcinogenic risk right. So 1.1*10 power -7 would then end up being 1.1*10 power -6. So then the risk would be unacceptable right.

So how do I go about you know understanding this particular scenario now right because from the relevant what we say concentrations for exposure I obviously have a mean and obviously a maximum. So the mean value obviously seems to be lesser than the acceptable or within the acceptable levels but the maximum value is I mean if I consider the maximum value for the relevant calculation of risk, the relevant risk seems to be higher than the acceptable value.

So how do I you know go about from here right, so let us see the affected population might say okay maybe the average is less than what is acceptable but there are a few cases let us say where the maximum right few cases as in the maximum values where let us say that risk associated are a little really higher than the what we say 10 power -6 acceptable risk I guess for lifetime cancer.

So let us say how do I go from here right, so to look at this we are going to look at this stochastic approach. So let us see what that is about.

(Refer Slide Time: 19:30)



So here moving on thus until now we looked at the deterministic approach right. As in what have we done? We had various what do we say variables right, body weight typically and so on and what did we do, we took a point estimate for or we considered point estimates right. As in for exposure concentration, we took one particular value or estimated exposure concentration by its mean and for body weight too I think we used a particular value I think maybe 70 kgs in this case.

But let us say if I think body weight instead of a person let us say assume me compared to the average of what is it 70 kgs that we looked at in that particular example. My body weight is higher right, so let us say if I look at the relevant calculation the risk associated from that particular scenario and exposure what we say scenarios concentrations in pathways would be lower to me.

But let us say there are other people out there let us say maybe not children in landfill but there are other workers that are relatively or have lesser body weight right. Then, obviously the risks that are posed to them would be greater right. So how do I take this into account let us see right. How do I take that into account? I am going to look at the stochastic approach right. So how does this differ from the deterministic approach?

I guess it is slightly self-explanatory if I look at the relevant terms deterministic and stochastic approaches. So here unlike the case of the deterministic approach or unlike in the case of the deterministic approach where I looked at point estimates for the different variables, I am going to treat these variables as variables I guess right. So instead of having a point estimate, I am going to let us say consider that.

You know there is going to be what we say inherent variation right in each of these variables. So the exposure concentration let us say rather than being one particular value you know I am going to try to capture it, what do we say variation by looking at let us say it is mean and it is standard deviation I guess let us say right and similarly for body weight maybe for slope factors.

If you remember slope factors and such or reference doses how have we calculated them right, we have calculated them by I believe looking at or you know conducting the studies at accelerated or pardon me at within shorter periods of time right and also at high doses right.

Obviously, built in what we say uncertainties there because you are extrapolating the results from higher doses to the smaller doses right and also from animals to humans let us say right.

And there are obviously many other such factors and such uncertainties, so here let us say we instead of using a particular value or a point estimate and as in the case of this deterministic approach, we are going to have let us say or try to capture what do we say the variation of that particular variable I guess right. So obviously mu here is the point estimate here and sigma the standard deviation will give me an idea about the variation let us say of that particular variable right.

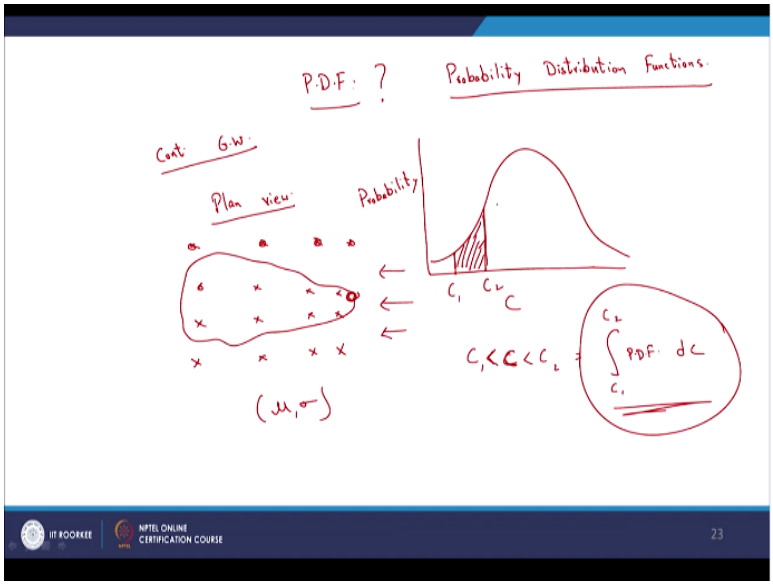
So again the major aspect here though is that while as you are going to view it let us say or it is going to be able to or you are going to be able to understand as we go along right, the major case here though is how do I get these estimates right. As in capture the spread, this will give me a spread of this particular what we say variable here right. So for that obviously I need to collect considerable data.

And so in a way this is a minor drawback, drawback in the sense that it requires considerable resources or time and thus obviously data right to be able to conduct this or go with this stochastic approach. So how do I get this mean and standard deviation, so obviously I need to take a sample that is represent two of the population. Again, there are relevant aspects from statistics I guess that are involved here.

And then take the data from that particular what we say sample right and try to use that to estimate the parameters of what is it now the mean and standard deviation of the relevant population here right. So for example let us say there are what we say around 10,000 people affected. Obviously, you cannot go to each one of these 10,000 people and calculate the relevant data.

So let us say you are going to try to take what we say suitable sample and in this case a sample size of 100 let us say and see that it represent two of the true population, take the data from that particular sample size of 100 and then maybe you know not maybe I guess, get the relevant values and the spread of that particular sample right. So in that case, I can go ahead with stochastic approach. So in this case let us move forth and discuss the relevant aspects.

(Refer Slide Time: 24:25)



So in here we are going to come up with obviously probability distribution functions right. So what are they about? I guess it is (()) (24:31) rightly self-explanatory right. It is the probability distribution functions right, so again as the name indicates that is the distribution of the probability right. So here if I look at a graph let us say and before I go for the graph let me consider a scenario let us say I have a contaminated groundwater let us say.

And that is due to and this is the plan view that I am going to look at and let us say that is due to a particular contamination at this particular source, the groundwater is moving in this or flowing in this direction and if I look at the plan view let us say maybe the plume let us say is going to be something like this right, plume right contaminated plume. So if these are my sampling wells or locations let us say.

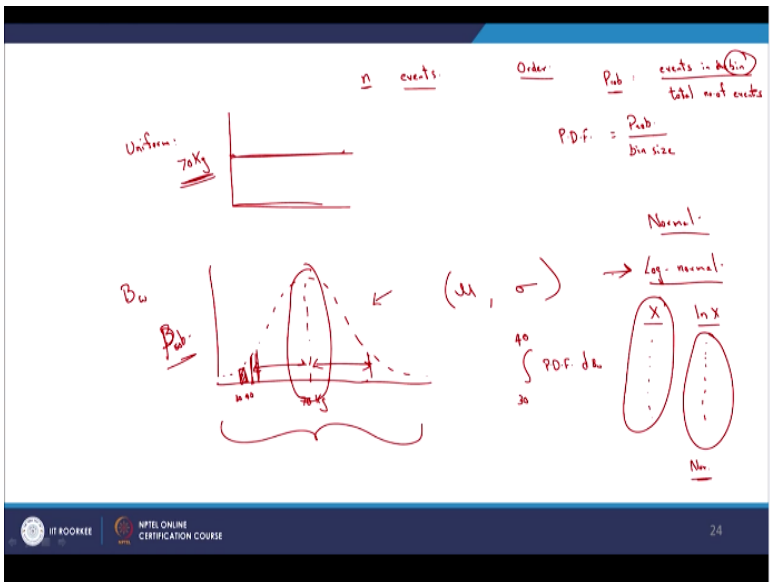
These are my sampling locations right, so from these sampling locations obviously I can get the relevant average let us say and standard deviations let us say or standard deviation pardon me of this contaminated groundwater, the concentration of the contaminated groundwater right and so here what am I going to have on the x-axis the concentration and here I am going to have the probability I guess right probability.

And so let us say you know it should not be normal but let us say I am taking that to be a normal distribution but maybe a poor way to understand that. So this would give you an idea about the probability that the concentration let us say would lie within two particular values let us say C1 and C2 and the probability that it would lie within these two values would be given by the area under this particular probability distribution function right.

Again, that is just for your understanding or sake of understanding I guess but let us say if how do I calculate that let us say right. What is the probability that the concentration C is between C1 and between C2 right, what is that? It is the integral of that particular probability distribution function right say from C1 to C2 right. What is this particular aspect about? It is nothing but the area underneath that particular probability distribution function right.

So again how can I calculate these probability distribution functions now? Let us look at that particular minor case.

(Refer Slide Time: 27:10)



Let us say there are different what we say number of or n number of events let us say. So probability for particular case after I order them you know, I am going to rank them or order them let us say right and then let us say what can I do, how can I calculate the probability let us say. The events in my bin or in the bin/the total number of events+1 obviously I guess total number of events right.

And by the definition of probability distribution function, how will I get that particular probability distribution function, is going to be nothing but the probability that I calculate here by the relevant bin size right. So from that I can calculate the probability distribution functions here right. So obviously there are ways you can you know go ahead and estimate or come up with these probability distribution functions.

And typically there are different what you say distribution functions, so let us look at some of the generic examples let us say. So here it is uniform let us say, this is the uniform distribution but typically or rarely do we get such particular cases. For example, let us say if I consider the body weight of all the students in my class let us say or the students enrolled in this course let us say right, what would it be?

Would it be a uniform 70 kgs as I considered it to be the case in or you know estimated it to be the case and the previous example, not really right? So if I look at that, plot it and so on right say I am going to have something like normal distribution right say right. So the mean might lie around 70 kgs where the standard deviation right which will capture the spread right.

Plus or minus sigma I think captures 67% or so of the data right, so thus sigma will give me an idea about the spread of this particular data from the mean let us say and mu will give me an idea about obviously this particular point estimate the mean right. So mu and sigma in this case and this is the case for probability again and or you can use this probability and bin size. If I cancel that as in body weights from 30 to 40 right what would be the probability?

The integration of this particular case from 30 to 40 body weight probability distribution functions right and body weight let us say right or the area within or under this particular graph right. So again typically we come across (()) (29:48) anyway normal and log normal distributions right. So we come across normal distribution which is what we have here a case here and a log normal distribution.

So what do you understand when someone says a particular variable is log normally distributed, it means that the natural logarithm of that particular variable has a normal distribution. For example, let us say if I have a variable X and there are different values let us say right. This is not normally distributed but if I take the natural logarithm of X let us say and then have the relevant values; these values are going to be normally distributed right.

And then I am going to call this particular distribution or variable X to be log normally distributed right. So in this context, we are going to look at a particular example right but since I am running out of time, we are going to look at the relevant aspects in the next

session. So again a quick recap of what we have been up to right. We have thus far looked at the deterministic approach.

And we obviously see that it is relatively easier to calculate that right, relatively less time and resources obviously but the issue here is that you are getting a point estimate since obviously you are using point estimates for the different variables right and in that context we saw that let us say the risk that we calculate for the relevant cases for air, groundwater and soil ingestion or dermal contact, we saw that if he took the mean value right we get a particular risk and if we took the maximum value, we get a different risk obviously.

And in that context, we saw that for carcinogenic risk, the value turns out to be higher if we consider the maximum value right. So to understand these effects and also understand or not understand I guess consider the effects of the uncertainties in let us say coming up with values for slope factor and so on right we look at the stochastic approach and in that context we have looked at some of the variables.

And how they are going to be distributed and typically we look at probability distribution functions so let us say and we just mentioned that we typically look at two cases, normal and log normal and let us see how we are going to use this information to be able to calculate the or you know take the stochastic approach further I guess right and I guess with that I will end today's session and thank you.