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

Lecture – 21
Remediation of Contaminated GW Permeable Reactive Barriers: Case Study

Hello everyone, again welcome back to the latest lecture session, again quick recap of what we have been up to so, we are talking about how to remediate contaminated groundwater and that context we looked at you know a passive technique which is the permeable react to barrier, right and in that context, we looked at the relevant aspects and looked at the relevant design with respect to the thickness, yes.

And how did we do that by considering this particular PRB or the permeable reactive barrier to be a plug flow reactor, we looked at the relevant basics of mass balance, applied the mass balance, right and then came about with a way to calculate the thickness required for a certain removal of the contaminant, right so and then, we moved on to looking at a particular case study, right.

So, we are again going to obviously spend more time on that in today's session yes, so again the objective is to familiarize ourselves with some of the aspects that you come across on the ground and also look at some of the measurements let us say of the relevant variables let us say or the concentrations of some of the variables that are relevant, right and then we are going to try to understand let us say, the change in these variables or concentrations of these relevant compounds in the context of our background and the relevant chemical or physical or biological process, right.

So, let us go ahead with that and I believe you are talking about contamination of a particular mine or you know locality let us say, in fry canyon, right in Utah, right and I think it was contaminated among other I mean, among other heavy metals, we do; we also had uranium radioactive compound let us say, right and in that context we did see that we had adsorption and thus we would also expect these option of the relevant uranium from the soil, right.

And thus pump and treat may be not a good idea and also it is radioactive, so taking it out of the subsurface and exposing the relevant workers or the people in that particular area to the radioactive substance or to radioactivity is not a good way or an efficient way to go about it right, so in that context we were discussing how to set up or what are the aspects we need to consider when we tried to think of setting up PRB, right.

And for this particular context, we looked at groundwater flows right, we looked at how the situation changes when there is rainfall and when there is no rainfall or between the monsoon and non-monsoon periods, right, we know that the contours change that is something that we looked at in the last session, yes and also we considered the relevant aspects with respect to the different concentrations yes as in the maximum mean and minimum, right.

And in that context, we briefly talked about risk assessment something we touched upon and or we looked at in the initial sessions, right and what was that? For example, if we took the median or let us say the mean value of uranium concentration and look at the relevant, what is a risk assessment let us say, you are going to have one particular scenario but obviously, if you consider the mean or the spread of this particular concentration let us say, right then you are going to have a different profile.

And in that context, you know I would like to recalculate about the stochastic and deterministic approaches; deterministic approaches as in for a particular variable like concentration of uranium, we considered you know, we look at point estimates like average let us see but obviously, in the stochastic estimate or you know approach, pardon me, we consider the relevant variables to be variables and look at distributions.

Typically, we looked at normal and log normal distributions and so on right, so let us go ahead in this particular aspect.

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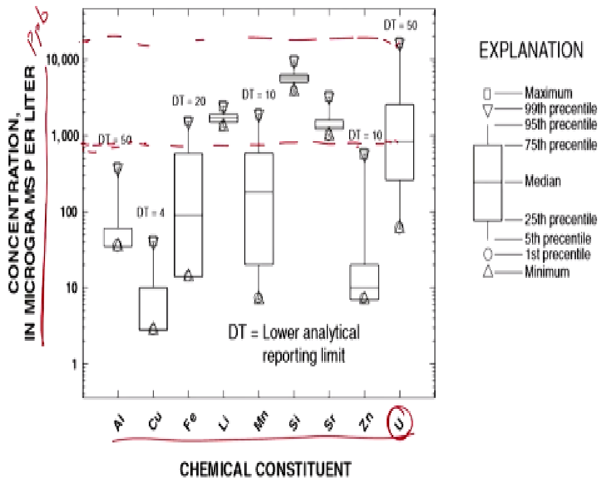

Pre-installation trace-element concentrations measured in groundwater samples collected during December 1996, February 1997, and April 1997

So, here we have concentration and milli or micrograms per litre, ppb, right and here we have different concentrations of the relevant contaminants and here uranium let us say, the mean or median pardon me, is around I think 800 or 900 let us say, right, 800 maybe and the maximum as you can see is pretty high maybe 15,000 or so, right so again, maximum minimum 25th percentile, 75th percentile and so on.

So, obviously what is percentile now when I say you know, let us say when I give out this course in class let us say and we say I give out the mean and also 25th and 75th percentiles because that will give me a generic idea about the spread obviously, I have standard deviation but you know, when the at least for my case, when the sample size is small I sometimes prefer this again, 25th percentile what is that about, what does that mean?

That 25% of the relevant samples or the grades in that particular class were lower than that particular 25th percentile similarly, what does the 75th percentile value correspond to let us say that would mean that let us say if I have 60 marks out of 100 to be the 75th percentile that means that 75% of the relevant students in the class scored 60 or less, right again that is something I said I guess.

So typically, here in this case people who are looking at removing uranium here, right and keep in mind I think this was in late 1990s, 97, 98 or so, right and people; that was the initial phase when people were looking at PRB's, yes and since then obviously as I mentioned or we as we discussed the application of PRB has taken off so, we are looking at one of the earlier cases of application of or field application of the PRBs, right.

So, in that context what did they do; they chose different compounds you know and conducted the relevant test in the lab, yes and then column tests and then field tests, right so we will go through that in relevant relatively greater detail.

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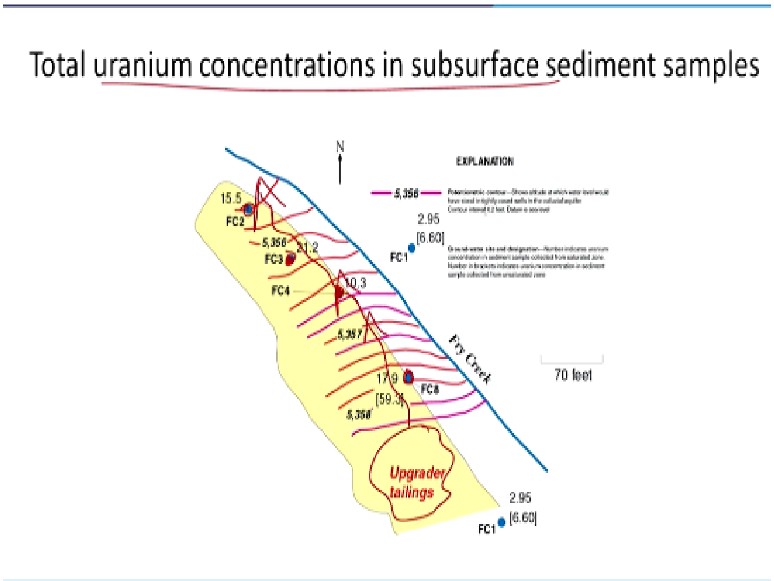

Total uranium concentrations in subsurface sediment samples

So, we did look at this but you know, quick recap again, uranium concentrations in subsurface right, so you see this is I believe my contaminated area, right and groundwater is flowing I guess in this particular direction, right and I guess we have samples at different locations for various reasons we do you know, have what do we say different concentrations of the relevant compound uranium let us say again, these are soil samples not the groundwater samples.

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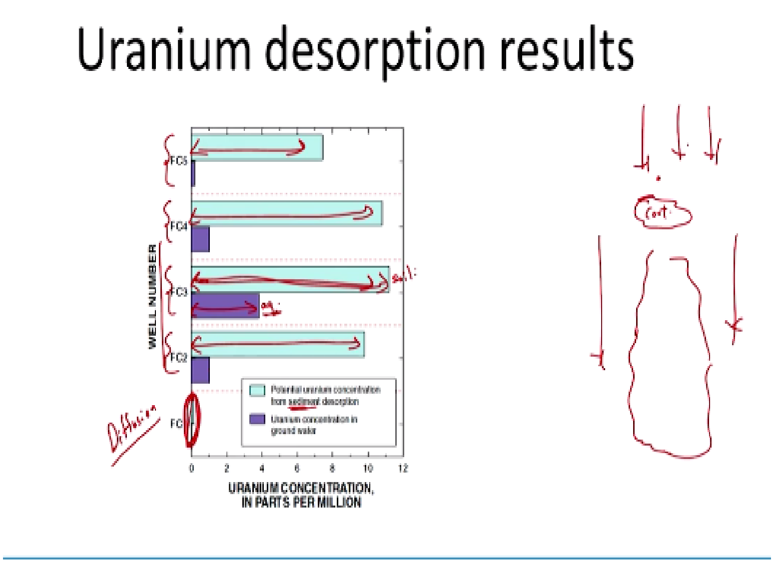

Uranium desorption results

And I believe they are ppm values right, I think we did look at that in the next slide, so we have different well numbers or wells here, right, 1, 2, 3, 4 and maybe 5 upstream, so the upstream one obviously as you see the concentrations are relatively lower if any what detected it is possibly due to diffusion let us say, the transport upstream let us say so, what I am talking about here is let us say this is my contaminated zone and my groundwater is flowing in this direction, right.

Typically, due to advection let us say and dispersion, my particular contaminant will let us say move in this particular direction, right in this direction but I guess you can, if you take a sample out here you can still detect some concentration let us say depending upon the relative transport of the contaminant due to both diffusion and advection let us say, advection is flowing in one direction but diffusion in the other direction.

Again keep in mind that diffusion is random let us say, right, so how what is the driving force here; it will always go from a place of concentration; higher concentration to a lower concentration, so if anything is observed upstream typically, it could be that it is the background concentration at that particular site or if there are no such background its and the only source is this particular contaminated source, it could be due to diffusion anyway, let us skip that now.

And then as you see downstream though you have what do we see 4 samples and you see the concentration in the relevant sediment let us say is pretty high, right so obviously as we discussed in the last session if you are trying to look at pump and treat and such than the time required for pumping out the relevant water especially in the case when you have desorption and considerable quantity or mass of the contaminant adsorbed onto the soil compared to mass in the aqueous phase.

This is the concentration or mass let us say in the aqueous phase, right and this is the concentration in the or on the soil or sediments now, right so, as you can see you know considerable mass is present in the soil or adsorbed onto the soil so, desorption will take place and you know thus issues so again, in that context PRB is a much better idea.

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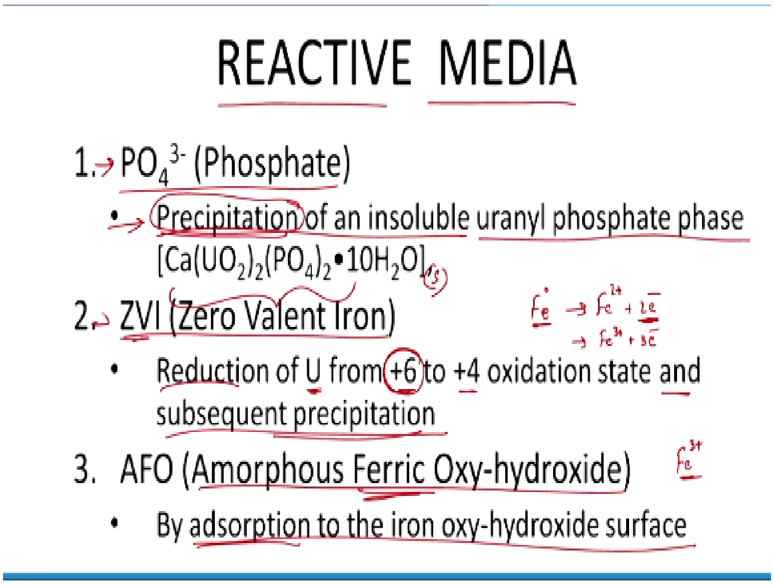

REACTIVE MEDIA

1. PO_4^{3-} (Phosphate)
    - Precipitation of an insoluble uranyl phosphate phase $[Ca(UO_2)_2(PO_4)_2 \cdot 10H_2O]_{(s)}$
2. ZVI (Zero Valent Iron)
    - Reduction of U from +6 to +4 oxidation state and subsequent precipitation
3. AFO (Amorphous Ferric Oxy-hydroxide)
    - By adsorption to the iron oxy-hydroxide surface

$Fe^0 \rightarrow Fe^{2+} + 2e^-$

$\rightarrow Fe^{3+} + 3e^-$

Fe^{3+}

So, reactive media how did they go about that so, they looked at some literature looked at the availability and some other aspects which we are going to discuss later, right so, they chose different or many kinds of reactive media and conducted preliminary tests let us say, right and I believe they are published you know, elsewhere so, you can obviously dig them up if you want to and based on that they you know screen some particular modes of removal of this particular uranium.

So, one was with precipitation or you know one mode is due to or by precipitation of an insoluble uranyl phosphate phase let us say, so you know uranyl phosphate, okay so this is precipitating out let us say, right and that is one particular case again, the key is that we have phosphate here let us say and we are trying to precipitate out, it is only precipitation not degradation let us say.

And the second way I believe is due to zero valent iron, so first we are reducing it has an uranium from oxidation state plus +6 to +4 as you know zero valent iron right, pardon me can go to Fe2+ + 2 electrons or Fe3+ + 3 electrons, right depending upon you know the extent to which the reaction proceeds let us say, as you can see zero violent iron is a reducing agent or an electron donor, it is giving out the relevant electrons.

And as you can see uranium is in its relatively more oxidized form of +6, so to go from +6 to +4, it needs electrons, right the oxidation state is decreasing, what is that typically mean; it typically means that it is accepting electrons, right so, it needs an electron donor only then will the redox process go through and the electron donor in this case seems to be zero violent iron, right and subsequent precipitation, right.

So, keep in mind that you know some of the process that we are talking about are not as straightforward or as simple as we what do we say are discussing, there might be many intermediate steps involved but it is believed that in the case of what do we say PRB remove, PRB with zero valent iron, the process involved are reduction first and then precipitation let us say, right.

And then we have amorphous ferric oxy-hydroxide, again ferric you know we already have it in its ironized most oxidized form, so reduction is not a you know an option here obviously, right so, the key here is that you have adsorption and then the removal from groundwater, so you have this AFO; or the amorphous ferric oxy-hydroxide right, AFO as we call it here and then the ground water flowing through the particular PRB comes in contact with your particular AFO.

And then you have adsorption of the relevant uranium on to the relevant AFO, I guess, right so again, the 3 kinds of process were precipitation, right, one is; the other one is reduction and precipitation, the other one is adsorption yes, so you know these three process they chose different kinds of material as in different kinds of sources for phosphate, zero valent iron and amorphous ferric oxy-hydroxide and they conducted further lab test, let us look at what they are.

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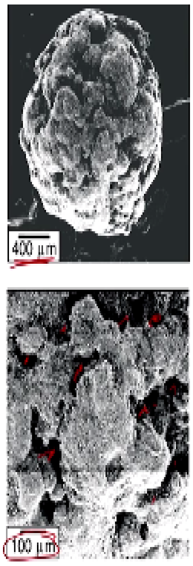

Electron micrograph of bone-char phosphate pellets (CP5)

So, just a particular example here though, so we have the source of phosphate in the form of bone char phosphate pellets, so I guess I think this is from the relevant SEM analysis or okay it is an electron micrograph analysis, right and the scale is given here, so as you see you know you can look at the relevant structure and also that it has sites for what do we say, precipitation let us say, right or it is pretty porous.

And you have relevant sites for and at a you know much low scale let us say or magnifying it further you know you have the relevant sites out here let us say for precipitation and such let us say, right again, you know just to give an idea about how it looks up close with respect to the phosphate pellets I guess, right and again what did we how, what was the sequence or chronology now?

They conducted lab test and saw that these 3 processes were relatively better and for these three process they chose different kinds of materials let us say, right.

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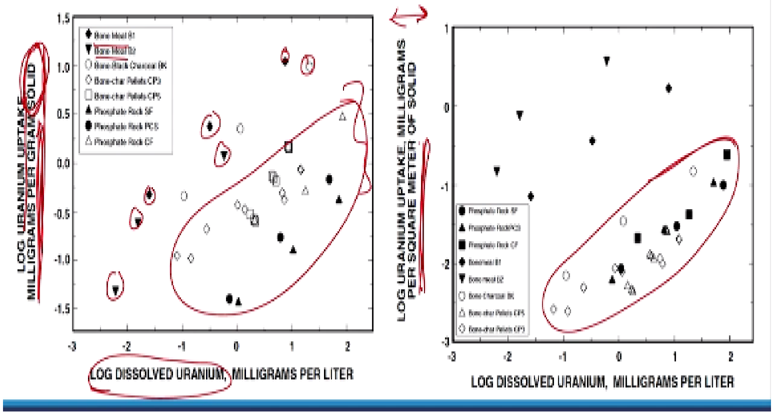
Batch Uranium (U) Uptake
on various Phosphate Materials



So, in this context we are looking at batch uranium uptake on various phosphate materials let us say some of the other data let us say and on the y axis here, we have uranium uptake or milligram per gram of solid, so this is the concentration of the relevant contaminant which is uranium on the solid and here obviously is the dissolved uranium concentration, right so, here on the y-axis we have concentration on the what is this now; the solid of the concentration of uranium on the solid, on the x-axis concentration and groundwater.

So, where do you think the slope should be now; obviously, the slope should be higher as in that you would prefer that you know the concentration of the relevant contaminant on the solid phase which is your PRB material here is higher, right so, if I look at that data and I see that bone meal I guess right, bone meal b1, bone meal b2 or you know performing relatively better compared to the other what do we say, types of material, right as and what does that mean?

They are able to have what do we say are you know, achieve greater removal let us say in this case it was precipitation right, per what is this; per gram of the particular contaminant, right so but as we looked at earlier with respect to the electron micrograph here, what do we look at; we see that surface area is of considerable importance here right, so now we just looked at it with respect to per gram right, uranium per gram.

So, instead of looking at it per gram, we look at it per surface area or per square meter of solid so, now how do you see the data transforming here, we have a great spread but now you see that a lot of these particular what do we say, types of materials have or you know have similar performance or have exhibited similar performance, keep in mind that both these data sets are the same except that the y axis is different.

In that the first case, we looked at uranium per gram and the second case we looked at uranium per square meter of the relevant what do we say PRB material let us say, right and in this case it is the phosphate material I guess, yes and thus as you see you know surface area place a considerable role or you know obviously is relevant and let us say depending upon that you see that if when I normalize it per surface area or by surface area, you see that the performance is more or less same, there is not a great deal of difference.

So, the key aspect as in the differing aspect with respect to or between each of these phosphate materials, what is that let us say, it is the surface area now, right but obviously I guess people also you need to consider that it should be per; I mean also the per gram remove because when you are putting it in PRB, you cannot have particles that are way too small or such to right and also its per gram is what you are putting in for example, when you have a particular volume let us say and you know obviously, density of the PRB is a remarkable aspect.

So, thus again people look at what is this now; the per gram remove but again take home message is that surface area is important out here right.

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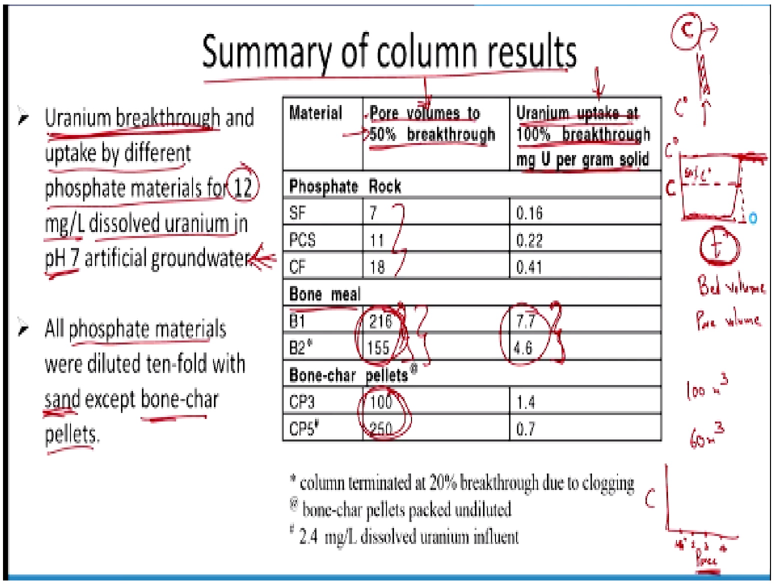

Summary of column results

- Uranium breakthrough and uptake by different phosphate materials for 12 mg/L dissolved uranium in pH 7 artificial groundwater
- All phosphate materials were diluted ten-fold with sand except bone-char pellets.

Material	Pore volumes to 50% breakthrough	Uranium uptake at 100% breakthrough mg U per gram solid
Phosphate Rock		
SF	7	0.16
PCS	11	0.22
CF	18	0.41
Bone meal		
B1	216	7.7
B2*	155	4.6
Bone-char pellets@		
CP3	100	1.4
CP5#	250	0.7

* column terminated at 20% breakthrough due to clogging
@ bone-char pellets packed undiluted
\# 2.4 mg/L dissolved uranium influent

So, up next, so summary of the column results let us see, what we have, we it seems uranium breakthrough occurred, so what is this breakthrough about as in let us say I have a column of the relevant PRB material and let us say I am passing the relevant contaminant here and this is how it is coming out, so this is contaminant initial concentration and this is the concentration let us say coming out let us say, right.

And I monitor this concentration of the contaminant leaving the particular column with time let us say, right so, initially, let us say most of it might be adsorbed, right you know the compound let us say uranium let us say, it can be adsorbed or you know precipitate out on the relevant material the PRB material but over time what would happen there, right, over time you know all the sites might be used up or such and you are not going to have any more active sites let us say, right.

And then what do you see that you would see that the concentration leaving the system or the column let us say in this case which would be in the field scale be similar to the PRB, right would keep increasing let us say and then depending on the type of material you can have a sharp breakthrough and it might reach C0 again right, so this is the breakthrough that we are talking about so, uranium breakthrough and uptake by different phosphate materials for 12 milligram per litre uranium dissolved uranium at pH 7.

So, this is artificial groundwater right not the actual groundwater, all phosphate materials were diluted tenfold with sand again because of issues with respect to porosity except bone char pellets let us say right, so some were diluted with sand or a mixture of sand and phosphate material except bone char, so let us try to understand some of the data we have here, so pore volumes required to for 50% breakthrough.

So, typically I guess again what we have here typically, instead of time and the x-axis we have either the bed volume or pore volume let us say, right, so this pore volume is nothing but let us say obviously the amount of space occupied by the voids are the pores let us say right, so when I say pore volume let us say it means that these many runs off for example, let us say I have 100 meter cube let us say and let us say 60 meter cube is occupied by the relevant pores let us say, right.

And I am looking at this particular graph again C and here, pore volume let us say, right so, I have 1, 2, 3, 4 or so what does that mean here; 1 means 1 times 60 meter cube, 2 times 60 meter cube, 3 times, 4 times, right so, how much volume that would be similar to the pore volume, how much volume of water which is similar to the pore volume let us say has pass it through the relevant column now, right.

Again something for you to understand here instead of time, how much pore volume can it take? So, what does that give an idea about; that gives you an idea about how much volume of water can it or the column treat let us say before you observe breakthrough let us say right, so that is something out there, so here you can compare that and you see that typically bone meal as we discussed earlier seems to have better performance.

And also slightly bone char pellets, this is something we looked at in the previous graphs, right so, you see that bone meal typically did better, yes and that is what you see out here too, bone meal and uranium uptake at 100% break through as in what does this give you an idea about, when you have 50% break through, so 50% of C0 let us say 50% of C0, how much volume of water was it able to treat let us say, right.

See, here as you see bone meal was able to treat a relatively larger volume of water, right that is this particular set of data now and what is this data going to give me an idea about; uranium uptake at 100% breakthrough in terms of milligrams of uranium per gram of solid, right, so at 100% breakthrough which is this particular case let us say at 100% breakthrough, right at 100%

breakthrough, how; what is the maximum or what is the concentration of the relevant uranium on the particular material?

So, obviously again as you can see you know it is relatively correlated obviously, I am going to see that for bone meal, it is relatively higher out here, right again that is something in line with what we observed here, right in both these two graphs, yes and that is something out here.

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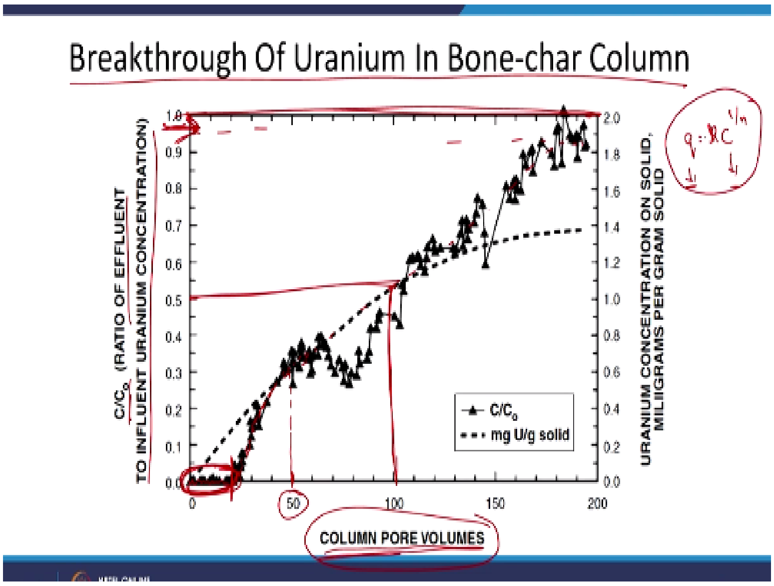

Breakthrough Of Uranium In Bone-char Column

So, let us move on to the next aspect again, just data with respect to breakthrough of uranium in bone char column, bone char though, so as I mentioned earlier we have column pore volumes here right, column pore volumes, so what does this particular data mean, a data point on the x-axis mean; it means that 50 times the column pore volumes have been passed through the relevant column now, right.

If pore volume is x meter cube, so 50 times that particular volume have been has been passed through the column right so, obviously here I see breakthrough somewhere out here maybe right, C/ C0 ratio of effluent concentration to influent uranium concentration so, obviously breakthrough is somewhere out here, right when C; the effluent concentration is the same as the influent concentration, right again this is the relevant profile out here.

But this is typically not a great profile because complete removal or such was observed only for a relatively smaller volume of water but for most volume let us say you had some level of breakthrough and here if I see that 50% breakthrough occurred at a relatively lesser particular column pore volume I guess, right so that is something that we need to understand again what is happening here?

So, out here let us say all the uranium that you are passing through your column is adsorbed or precipitated on to the relevant site on the bone char, let us say right but slowly but surely though as you see here the relevant sites have are relatively less available let us say and now you see that you know you do not see complete removal in the effluent but you see some uranium appearing in the effluent now, right.

And again that keeps increasing as you have less and less number of active sites let us say and again there are different models obviously, once the linear model most simplest but that is as you can see this is probably not linear and then you have typical models like Langer or Frohlich, these are the equilibrium models that give you an idea about what is it the relationship between the concentration of uranium on let us say or any other compound that is adsorbed let us say on particular solid phase to the concentration of that compound on the or in the aqueous phase.

As in we have let us say one of them to be q = k C to the power of 1/n, q is the concentration of the contaminant on the solid phase and C is the concentration of the contaminant in water let us say, so what is this giving me any idea about; it is giving me an idea about the equilibrium relationship between the concentration of contaminant what do we say in the or on the soil phase and the concentration of contaminant in the aqueous phase.

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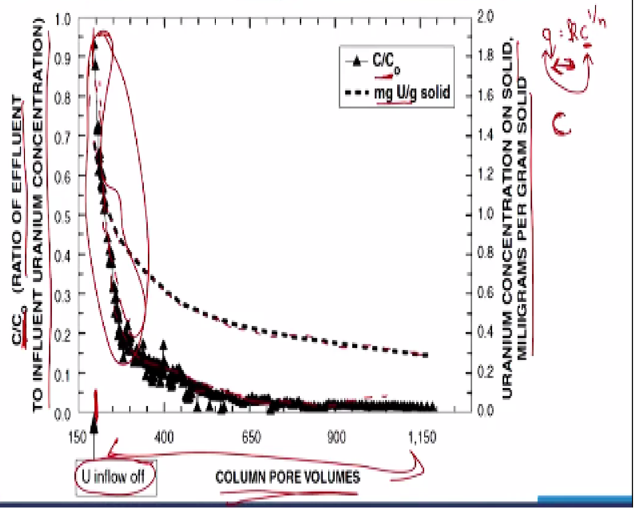
Release Of Uranium From Bone Char Column



Again some other aspects for you to understand here and again but the key aspect with these what do we say adsorption, desorption or precipitation then releases that you know or dissolution is that you know let us say I have groundwater let us say and my PRB is out here the contaminated groundwater is flowing through and let us say as it flows through the relevant compound is adsorbed onto the relevant material here.

And now, the groundwater leaving the system does not have uranium at high level or has no uranium let us say, okay but what would happen let us say, when all the contaminated groundwater has passed through, you now are going to have uncontaminated groundwater coming in contact with your relevant PRB material which has now the contaminant adsorbed onto the material now, right.

For example, let us try to also understand it mathematically, you have kc power of 1/ n, right so there is a relationship here right, so initially let us say the relationship let us say the C in the water let us say is such that adsorption takes place now but let us say now the containment groundwater comes in contact, so C in the water is less than the equilibrium value, so what will happen now; it will desorb from the solid phase into the aqueous phase, right.

So, your uncontaminated groundwater will now have uranium or can have uranium depending upon the desorption properties of that particular what do we say PRB materials, so that is what we see here so, we have release of uranium from bone char column similar to the material that we looked at earlier, so again we have C / C0 influent to effluent to influent so, here the uranium inflow or there was no more uranium from out here.

And here you have column pore volumes, if I look at the scale here keep in mind that this is for 200, the uptake; uptake of the relevant contaminant which is uranium from the aqueous phase or from the water on to the solid phase you know, require relatively less, so what do we say pore volumes compared to obviously desorption but still as you see here, you know you have desorption here, right.

So, you see that you know this is the ratio of effluent to influent uranium concentration, right and now you see that there is desorption out here, C/C0 here, right so, we have a case where we had I guess the system had breakthrough out here and then they stopped the; they are not putting in inflow anymore but just you know pumping water through that but obviously, you see that there is concentration or some concentration of uranium coming through this uncontaminated water here, right.

Or so what does that mean; you have desorption here, right so you can observe desorption out here, so also if we look at the estimated uranium concentration on the solid milligram per gram of solid let us say, right, the dotted line, so what do you see here slowly but surely the amount of uranium present on this solid is also decreasing, right what is obviously happening now; this dotted line, what is it telling you that it is coming down or decreasing now, right.

As in the concentration of the uranium on the relevant PRB material is decreasing, right, what is it, where is it going now; it is obviously changing phase into the aqueous phase and that is what you see here, so when we look at the type of PRB material obviously, we also look at the effects of you know desorption let us say, right so that is something we need to look at, so keep in mind that you know that is one of the factors as in desorption that obviously is considered when you evaluate the relevant material you know.

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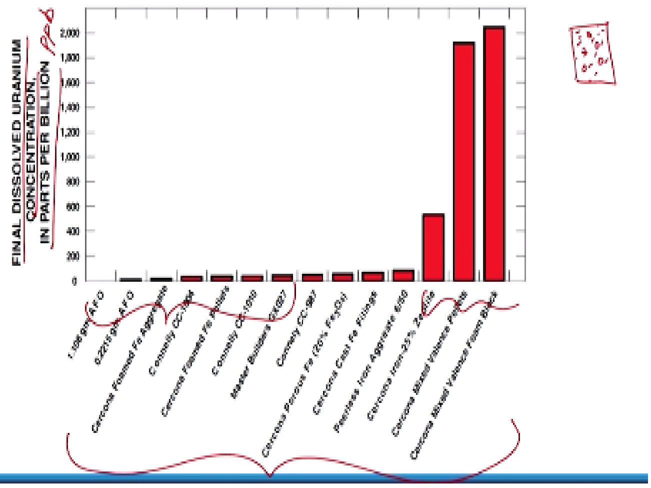
Uranium Concentrations in 3-day Batch Tests



Just for illustration purposes, I brought up this particular data, so again some more what do we say, data that would allow for relative comparison, so you have uranium concentrations in 3 day batch tests and what do we obviously have; final dissolved uranium concentration in ppb, right so on the y-axis, you have the final dissolved uranium concentrations in ppb and on the x-axis you have different materials now, right.

So, obviously what did they do; they did batch test as in no flow coming in or going out and they had different kinds of compounds, PRB material what let us say and you know that were with in contact with contaminated; water contaminated with uranium, so obviously after 3 days let us say what would you want let us say you would want the material to adsorb more of it and obviously, you know the concentration of the relevant uranium or the contaminant in the particular water in contact with this PRB material should be low, right.

So, typically then these particular what do we say, types of materials did well maybe some obviously you can rule them out here right, so let us see if we read that right, final dissolved uranium concentration in ppb right so, obviously the lesser the better right.

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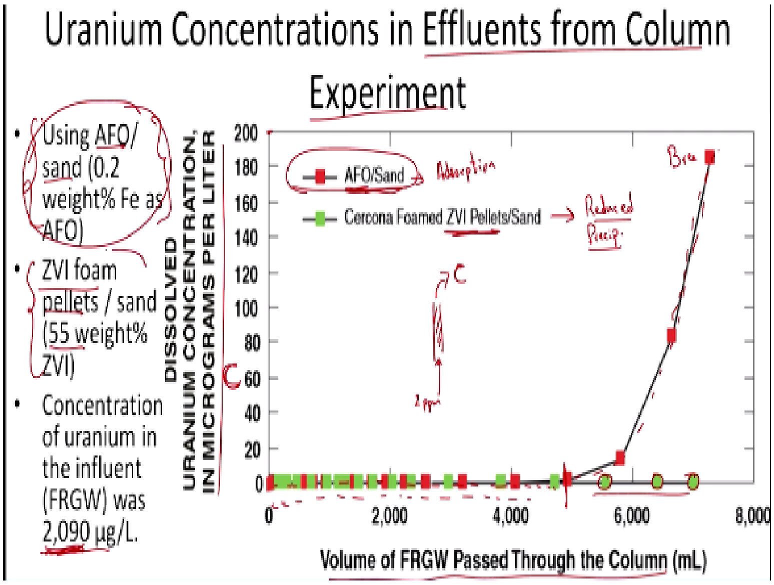

Uranium Concentrations in Effluents from Column Experiment

- Using AFO/ sand (0.2 weight% Fe as AFO)
- ZVI foam pellets / sand (55 weight% ZVI)
- Concentration of uranium in the influent (FRGW) was 2,090 µg/L.

So, let us move on, so again one other what do we say data set, uranium concentration effluent from column experiment but unlike the case where we looked at phosphate relevant material we are looking at the iron relevant materials which are zero valent iron and the amorphous ferric oxy-hydroxide, right, so one is the AFO ferric oxy-hydroxide and sand where the key what we say removal was due to adsorption, right adsorption that was the mechanism for removal and for the one with zero valent iron pellets, right say what was the pathway?

That the uranium was first reduced and then precipitated out right, so this was the pathway, so let us look at the comparative data, first we have AFO and sand, right ratio, again ZVI foam pellets and sand right, again different ratios here, concentration of uranium in the influent was you know 2000 ppb or 2 ppm, I guess right, so what do we have on the y-axis now, dissolved uranium concentration in microgram per litre, we are talking about the effluent here obviously.

And here we have volume of the relevant water that is passed through the column you know earlier we had pore volume let us say or came across the term bed volume that something else or something different from pore volume but here they explicit in terms that you know is slightly unusual but easier to understand volume of the water that is passed through the column here.

So, what do you see here; as you keep passing volume what do you see; you have your column here and you are passing water through here, so this was at 2 ppm as we looked at here 2 ppm the inlet concentration and C is what we have out here, so this is C here, right and C I guess you know is 0 or almost 0 until constable volume and then for the case of the ferric hydroxide or oxy-hydroxide case, you see that the concentration has started to increase.

So, what does that mean, their breakthrough let us say I mean we have not reached breakthrough because it is still 200 ppb and we start out with 2000 ppb, right so breakthrough has not yet occurred but you see that now the concentration is no more 0 but that you know some of the particles are now leaving the system, right or it is going to approach a complete breakthrough or 100% breakthrough.

But the key aspect here is that if you look at the zero valent iron based system, the green data points let us say, it still has not shown what to say, it still able to what do we say remove all the uranium from the relevant influent and the effluent is you know treated pretty well as in you know, it depends on the method detection limit but looks like they are saying it is 0 or below detection limit right.

So, here you have or this allows for relative comparison but the key aspect is that it is not just the material but the process that we need to look at here let us say the if earlier case, we have an adsorbent ferric oxy-hydroxide, right say, right upon which the relevant uranium is being adsorbed onto, right, in the second case, so you have reduction and then precipitation, so you know obviously you know different pathways and looks like the sites, we are out of sites here right.

And here you know the relevant process is still going through or holding strong right again, obviously one key aspect is the ratio of the relevant you know compounds here, right with respect to sand, yes, so let us move on now obviously let us try to summarize some of the aspects that are going to be relevant let us say when you need to choose your final PRB material now, right.

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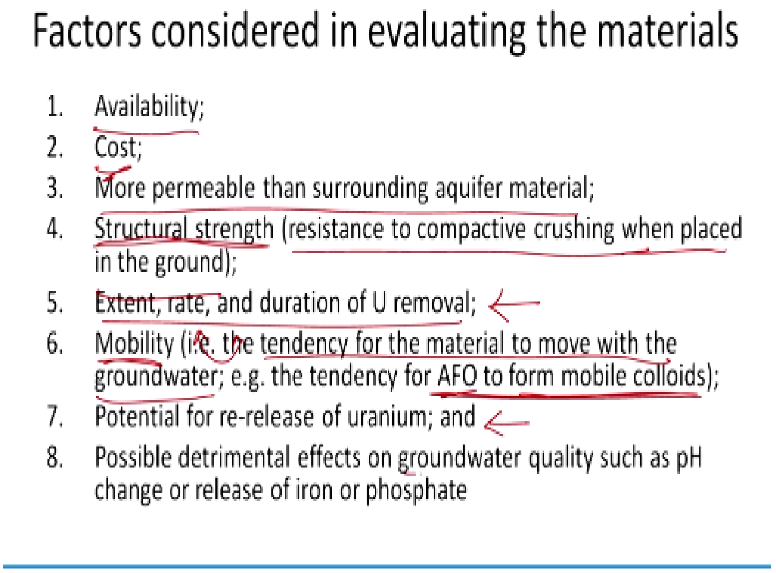

Factors considered in evaluating the materials

1. Availability;
2. Cost;
3. More permeable than surrounding aquifer material;
4. Structural strength (resistance to compactive crushing when placed in the ground);
5. Extent, rate, and duration of U removal;
6. Mobility (i.e. the tendency for the material to move with the groundwater; e.g. the tendency for AFO to form mobile colloids);
7. Potential for re-release of uranium; and
8. Possible detrimental effects on groundwater quality such as pH change or release of iron or phosphate

Obviously, availability as in you know, locally available or you know is it easy to source if not locally available, cost; obviously cost is an issue yes, permeable than the surrounding aquifer material, this is a key aspect obviously, right so if it is not permeable what is going to happen yet as in the PRB material is not permeable what is going to happen, the ground water will flow around it let us say.

So, either you mix it with more porous material let us say or such you know depending upon what do we say the kind of porosity or the hydraulic conductivity, so that is particular that is a remarkably important aspect, so something that we have not discussed in great detail though but it should be logical structural strength, so resistance to compactive crushing when placed in the ground, right.

So that is something that obviously you need to look at to look at and then extent, rate and duration of uranium removal, this is something we have looked at in great detail, extent is in let us say you know the maximum how can, how much can it remove, rate; as in let us say is the desorption from the relevant water relatively fast or slow and also the duration of required for removal but I guess these are relatively slightly what do we say correlated.

And then mobility let us say, right so, one set removed from the relevant what do we say groundwater is the compound or you know the type of removal process decreasing the mobility or again can it what do we say still or the can the relevant uranium still have some mobility for example, looks like the tendency we are looking at tendency of AFO to form mobile colloids now right, so looks like with respect to AFO even after removal let us say, you have some mobile collides being formed so they can be transported further.

Because they can leave the system right so that is something to be concerned about what is it now, the tendency for the material to move with the groundwater and then potential for rerelease from of uranium as in desorption that is something we looked at with respect to the column studies and detrimental effects on groundwater quality such as pH being affected or we have way to high concentration of iron or phosphate in the groundwater that has left the PRB or passing through the PRB, right.

So, these are the generic aspects and again we look at some of the what do we say, details let us say again relate to the relevant applications but in the next session what are we going to look at as I mentioned let us say we are going to look at the actual placement or data from gathered from actual placement of the PRB and the citrate, so I guess I am running out of time and with that I will end today's session and thank you.