Environmental Remediation of Contaminated Sites

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Lecture – 22
Case Study-PRB (Utah)

Hello everyone, again welcome back to the latest lecture session again a very quick recap of what we have been up to, so we were discussing remediation of groundwater contaminated with uranium and we are looking at a particular case study from, I think Utah or in Utah rather, right and I think they had what do we say over processing or upgrading facility and among other heavy metals they had let us say radioactive what do we say material uranium too I guess right.

And in that context, we are looking at PRB and what have we looked at thus far, we looked at the relevant batch tests let us say or some information regarding batch test and then moved on to the relevant data from the column test right so, this is data obviously you need to have to be able to design your thickness of your particular PRB, right and that is something we have looked at, you can get the rate constant or such or the pseudo rate constant for the relevant removal of these compounds.

You also can get the extent of removal or the maximum extent that you can expect and obviously, you can also look at the desorption studies for some of these relevant compounds and we looked at that data, right.

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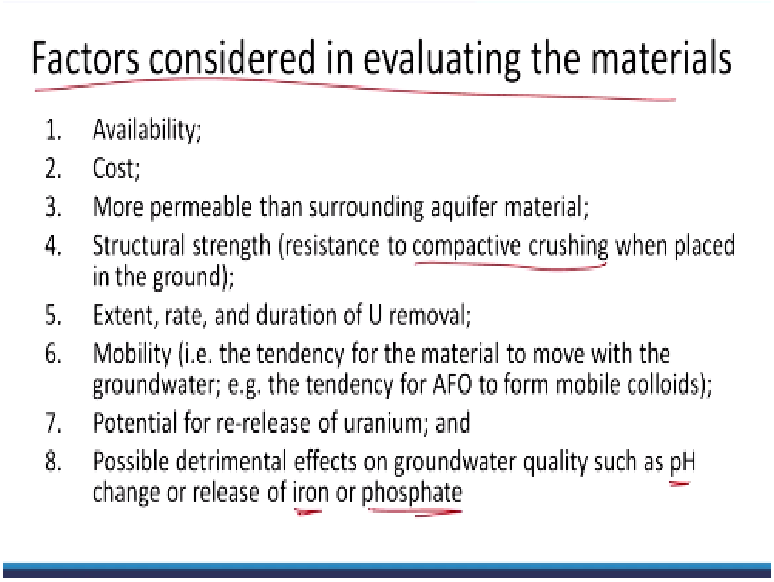

Factors considered in evaluating the materials

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

And so then we moved on to the relevant aspects as and we looked at what are the factors that we consider in evaluating the materials, so quick recap of them so obviously, availability and I believe cost right, so permeable than the surrounding aquifer, so that is one particular aspect as in with respect to phosphate materials, we saw that the what do we say the based on the way we look at it or analyse it as in the uranium concentration per gram of phosphate material or uranium concentration per area of phosphate material, the performance you know seems to differ, right.

But obviously, you know we cannot just look at only surface area obviously because you know we have issues with respect to the amount of what do we say the PRB material you can put in and also let us say way to smaller size you are going to have issues with permeability right so that is something to keep in mind and again, structural strength obviously right because you want to you know depending upon the depth which you are going to place the PRB right you need to have resistance to compactive crushing.

And then extent, rate and duration of uranium removal the something you will get from the column and batch test, right and mobility right as in the relevant PRB material should not be mobilites or should not be made more mobile once it interacts with the relevant contaminant, right and potential for desorption or release of uranium once the uncontaminated groundwater comes in contact with your PRB that something else.

And then obviously, you know you are going to have issues with respect to pH, change or iron and phosphate release because that is what we are looking at as in; in the case of zero valent iron, what do we have; Fe0 going to Fe 2+ or 3 +, right so Fe 2+ is released but obviously you do not want to have way to high concentrations of iron and the water, you will have the relevant standards for that particular compound too or iron too, right, so these were the aspects we looked at.

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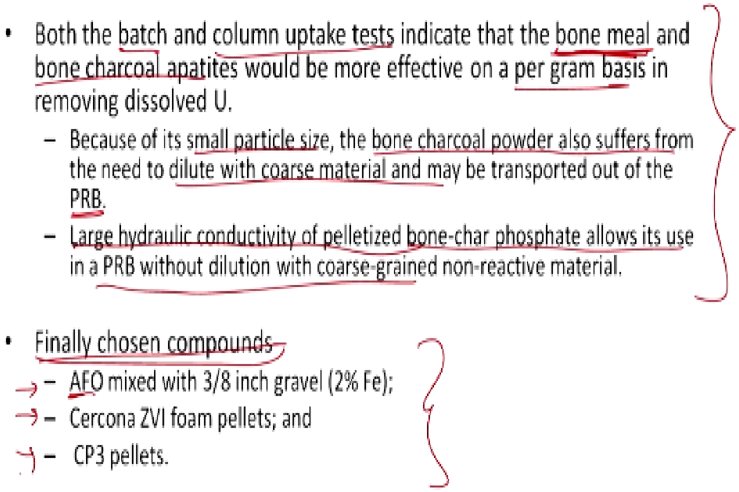

- Both the batch and column uptake tests indicate that the bone meal and bone charcoal apatites would be more effective on a per gram basis in removing dissolved U.
  - Because of its small particle size, the bone charcoal powder also suffers from the need to dilute with coarse material and may be transported out of the PRB.
  - Large hydraulic conductivity of pelletized bone-char phosphate allows its use in a PRB without dilution with coarse-grained non-reactive material.
- Finally chosen compounds
  - AFO mixed with 3/8 inch gravel (2% Fe);
  - Cercona ZVI foam pellets; and
  - CP3 pellets.

So, let us just try to look at you know some of the summarized data here, so both batch and column uptakes test indicate that what now, so if we look at the data or you can remember the data, the bone meal and bone charcoal did pretty well on a per gram basis, right and because of its small particle size, bone charcoal powder suffered from the need to dilute with coarse material because look like the size was too small.

And thus you know permeability issues, so it had to be diluted with coarse material and then again transported otherwise it would or maybe transported out of the PRB and also the hydraulic conductivity of the pelletized bone char phosphate you know, right what would that or how is that useful because now you do not need to add any other what do we say, relatively more porous material or such.

Because the hydraulic conductivity of the relevant pelletized bone char phosphate is high enough obviously that it can be used in the PRB without dilution, right again these were mostly with respect to the bone char or the phosphate materials but based on the relevant aspects you know and some of the data we looked at, these were the finally chosen compounds right, finally chosen compounds.

Again, what were the 3 process; one with respect to phosphate, it was just precipitation uranyl phosphate phase I guess, right for that obviously you need calcium and such what we do say cations too, right and we also looked at zero valent iron but the process which that first reduction from +6 to +4, so thus you need to provide a source of electrons, where are the electrons coming from; obviously from your reducing agent which is the zero valent iron, right.

And then for the precipitation and then the third mode which is just adsorption not just let us say adsorption and the adsorbent was the ferric oxy-hydroxide I guess right, so based on the relevant test they chose what do we say one material for each of these 3 kinds of process that we talked about you know, these are the final; were the finally chosen what do we say compounds.

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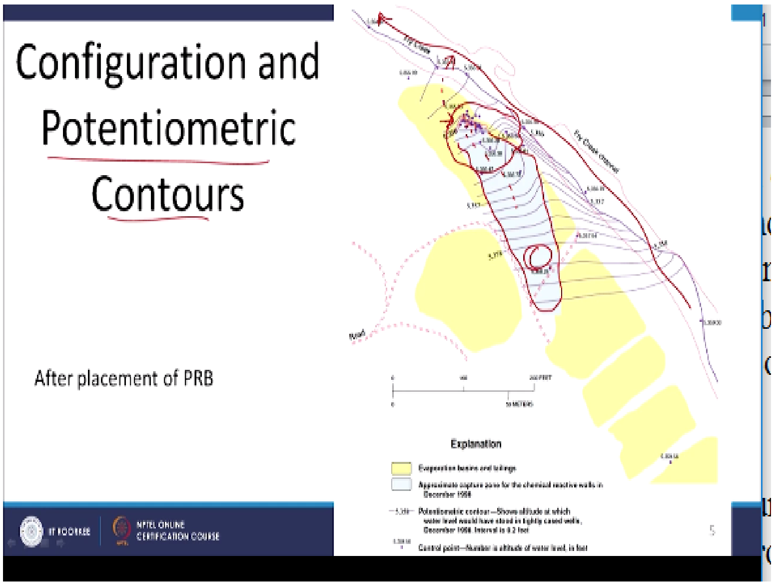

Configuration and Potentiometric Contours

After placement of PRB

And here you see the actual placement of the relevant PRB as an out here, you can see that out here and the PRB, right and now the key aspect is to understand let us say that you know the contours of the relevant what do we say groundwater or the potentiometric contours change it too, right if you can you know bring up the relevant contours before installation of the PRB and compare it to what we have here, you would see that the contours would change in this particular zone or the capture zone.

Obviously, this I think is supposed to be the approximate capture zone, right and I think we had uranium tailings somewhere out here if I am not wrong and obviously as you see this is the channel or the stream fry creek let us say, the fry creek channel, so earlier the groundwater was this containment ground water was flowing into the stream here and so again thus you know depending upon this particular groundwater flow and the prospect of further transport of the contaminant they place the relevant PRB here.

And so that is what you have see here and I guess they have the different control points, right before, after and inside the relevant PRB, right so that is something that you see here.

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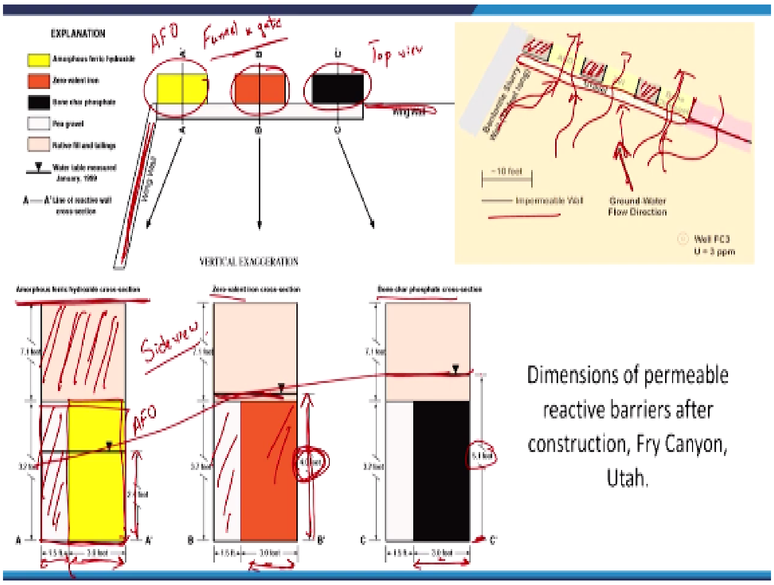

Dimensions of permeable reactive barriers after construction, Fry Canyon, Utah.

And again here we have the top view here, right, top view I guess, yes so, here we have the wing wall again what is this system though; it is funnel and gate obviously not; it is funnel and gate system obviously not the continuous, so here you can see the wing here, right so you can see the wing here, yes and 3 PRB materials were placed here in series now, right so where are they?

This is the wing out here and so here we have AFO, the ferric oxy-hydroxide or a ferric hydroxide and here we have zero valent iron and here we have the zero bone char phosphate and another wing wall out here, I guess right so, what did they have here; so they had gravel here that is relatively more porous and high hydraulic conductivity obviously, you want to have groundwater flow in this particular direction.

And they had fill let us say impermeable layers I guess between this PRB material and now obviously, the ground water will flow through the AFO, right through the ZVI and through the bone charcoal let us say, right and this is what we have out here, this is the set up anyway, so again impermeable wall out here that is something that you can see obviously, you do not want to have the ground water flowing around the particular system, right.

You have the impermeable wall and typical groundwater flow direction as they say is in this direction as you can see from the contours too, I guess they say it is in this direction right, so keep in mind that because of the what do we say placement of the; the type of placement of the

PRB the groundwater table might not be uniform across the three types of the PRB, let us say, right.

And also keep in mind that the contours change you know pretty rapidly here let us say or the gradient is pretty steep here and why is that because we have a stream nearby that is obviously one particular case so, obviously this is the side view from here, side view; what do we have here, we have at the fill here, this is the what do we say, soil surface here and then I guess the fill and this is the PRB material.

So, 1.5 feet thick gravel that is what we see here and this is your PRB material and looks like they designed it for 3 feet, right and in this AFO, the groundwater is at 2.4 feet approximately and you know obviously the fill and such will be the same for zero violent iron and bone char phosphate but looks like the groundwater table seems to be you know as you can see it is not uniform out here, right.

Again, you know the fill here but here the height of the PRB too is greater as you see but keep in mind for compared to analysis, you will have to have similar thickness of the PRB and that is something you see 3 feet, 3 feet, 3 feet but because of the differing height of this particular contaminated groundwater you know, you have different what do we say, heights of the AFO, zero valent iron seems to be 4 feet.

And bone char seems to be around, okay they have the relevant what do we say 4 feet is the height of the table, I guess, ground water table, pardon me right from the base of that particular PRB, they did keep the height the same, the 3.2 feet, 3.7 approximately here and 3.2 feet, right but again, if you are actually designing it for the complete removal, you will have to have your PRB extending to such a height that you know it can cover the entire contaminated plume.

But again this is for field analysis to see whether it works or not and how does it work and such, right so this is what we have out here and let us move on.

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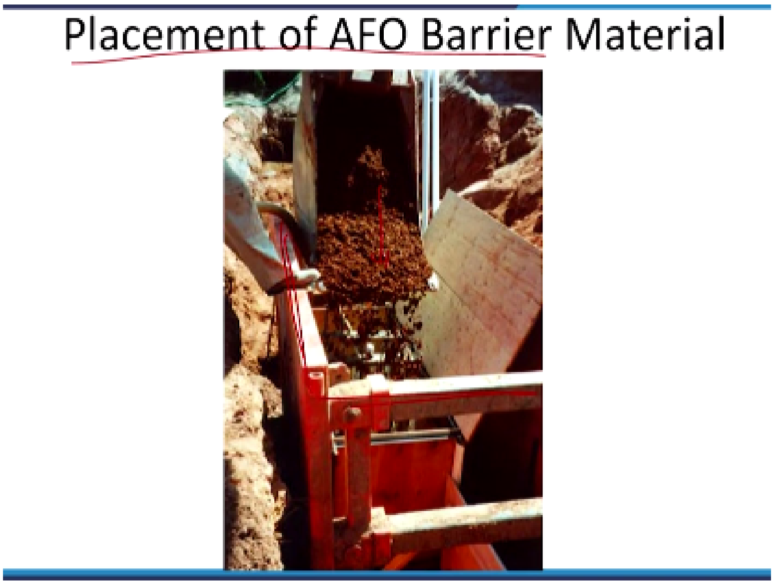

Placement of AFO Barrier Material

Obviously, here we have the placement of the AFO barrier material, so for that obviously, you need to also design for this sacrificial frame I think I have pictured, I think this is where they were putting barrier material or I think this is the film, right.

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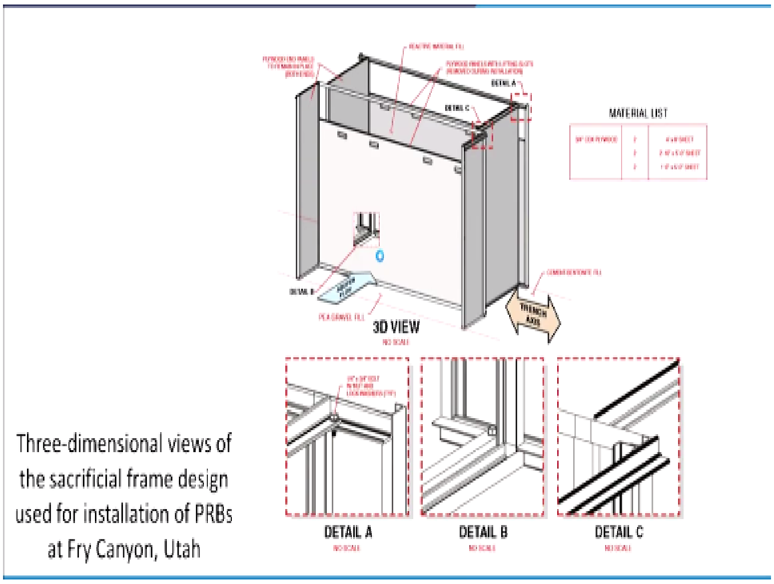

Three-dimensional views of the sacrificial frame design used for installation of PRBs at Fry Canyon, Utah

And here this is the sacrificial frame and again designed for that but obviously, the design of this sacrificial frame anyway is outside or per you but you know just to be able to understand I guess I am providing this particular graphic again, as I mentioned all this particular graphs that I have are not the data that high a source but from the relevant reference that I presented in a couple of sessions ago, right so that is something to keep in mind.

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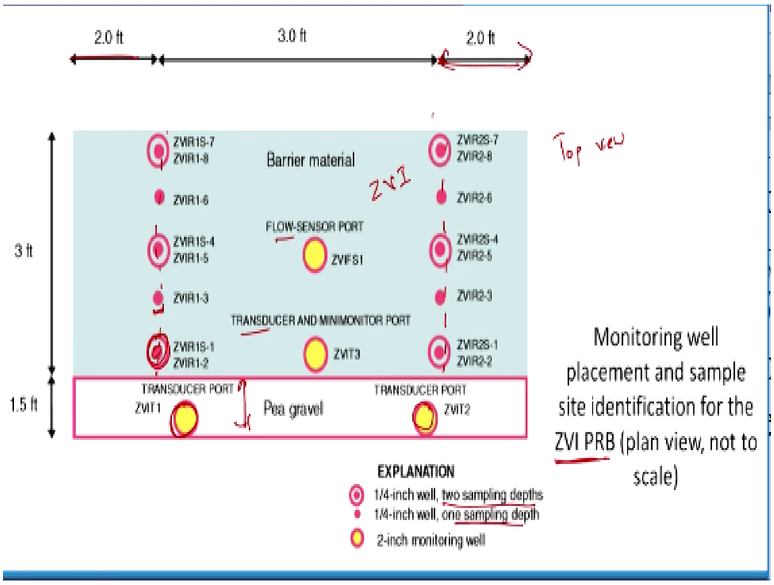

Monitoring well placement and sample site identification for the ZVI PRB (plan view, not to scale)

And that is available in the public domain, so here it is the top view in greater detail obviously and here we are looking at it with respect to the Z; zero valent iron PRB, right as we looked at earlier let us say, what do we have here we have 1.5 feet thick gravel which is this obviously right, 1.5 feet thick gravel and that is what you see out here. 1.5 feet thick and obviously they have a monitoring well within that particular gravel to obviously look at what is the concentration of the contaminant coming or you know the influent concentration of the; what do we say, contaminant right.

And then they have monitoring wells different kinds as and 2 sampling depths, one sampling depth, right one sampling depth and two sampling depths, so different kinds of monitoring wells inside the PRB, right inside the PRB you have 2 rows of them; row 1 and row 2, right and again barrier material obviously all this is zero valent iron, right all this is zero valent iron and you have different sensors here again, yes.

And 2 feet from the sides you know that is the placement of the relevant rows, this is with respect to zero valent iron.

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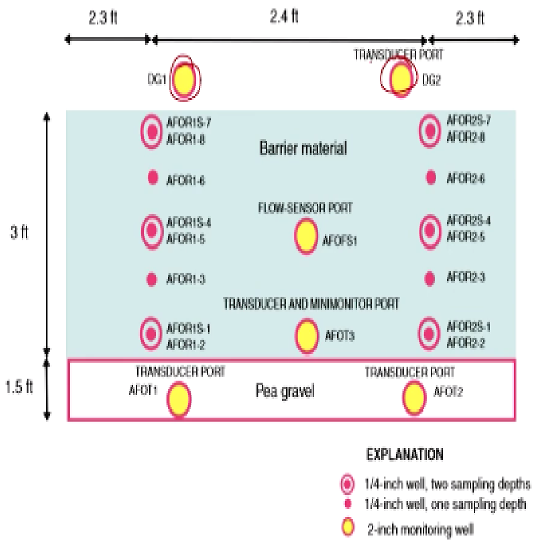

Monitoring well placement and sample site identification for the AFO PRB (plan view, not to scale)

And for this particular same case more or less with respect to the AFO PRB, right more or less right, again they have what do we say monitoring wells or ports outside or you know after the exit of the relevant PRB, you know.

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Two-inch monitoring well, Fry Canyon, Utah

Workers during installation of the PRBs at Fry Canyon, Utah

And here let us say to be able to understand the; what do we say actual case of or what are the advantages of PRB as you talk as we discuss them earlier, one aspect is that you know above ground structures are remarkably minimal and so what do we see here this is all the above ground structure that you have for your particular PRB for I think maybe zero valent iron or AFO though, right so this is a 2-inch monitoring well, okay.

So, this is the only structure and again, workers during the installation I guess you know different depths and so on but keep in mind that one of the obvious advantage of PRB is that we are going to have relatively little what do we say above the surface structures, right or not little, pardon me less number of above ground structures, so typically you know you can either not either let us say have somebody come in and take the readings manually.

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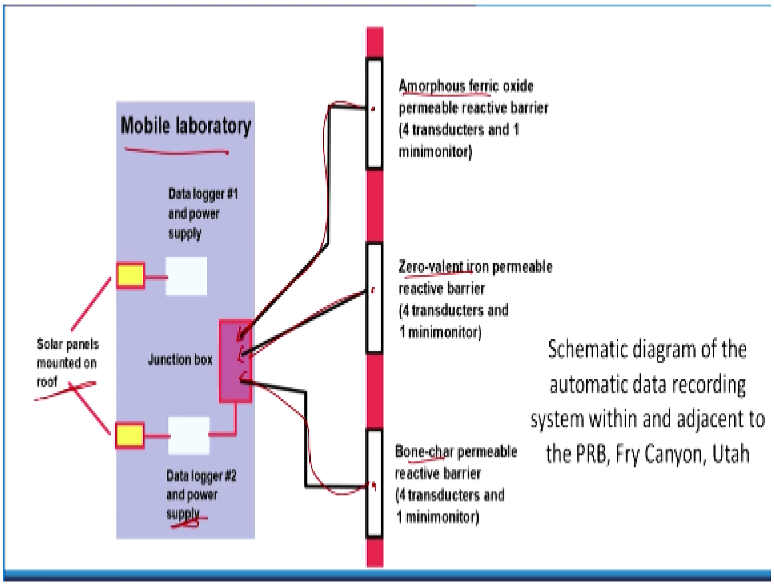

Schematic diagram of the automatic data recording system within and adjacent to the PRB, Fry Canyon, Utah

Typically, you will have the automatic data loggers that is what you see here, so AFO, zero valent iron and bone char, right, we have saw the relevant what do we say data loggers, not data loggers I guess, the ports for data gathering I guess, if I can call them and they are connected to this mobile laboratory let us say and data logger; automatic data logger and they have the solar mounted panels and such.

So, again key aspect is what is it that we have; we have just collecting the data automatically and we obviously do not need to have any regular or continuous monitoring obviously, so from time to time let us say somebody remotely can look at this particular data or you know analyse that from time to time obviously, there is no need for continuous monitoring or such though, continuous manual monitoring anyway, right.

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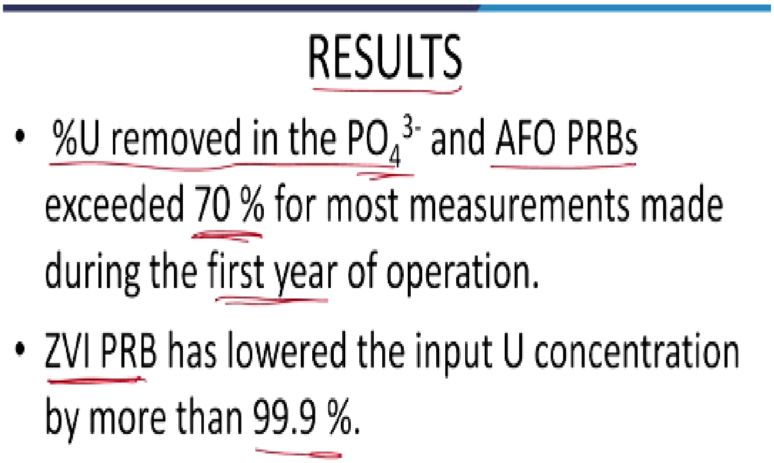

RESULTS

- %U removed in the PO_4^{3-} and AFO PRBs exceeded 70 % for most measurements made during the first year of operation.
- ZVI PRB has lowered the input U concentration by more than 99.9 %.

So, again what do we have here, what are the results that we have had or let us look at that so, uranium removed in PO4 3 - or the phosphate in AFO PRB’s was more than 70%, right and they looked at it for 1 year and this is in line with what we saw in the particular column test and such, so this is the data from the actual placement of the relevant what do we say PRB's right.

But as you can see again as expected from the relevant column test, the zero valent iron PRB has lowered the input concentration by more than 99.9% for more or less the whole year though, obviously we do not know, they have run it, since then for greater time and even for that I believe for 10 years or so, it worked pretty well but keep in mind now that now you can see apparent differences in the performance of the relevant PRB's.

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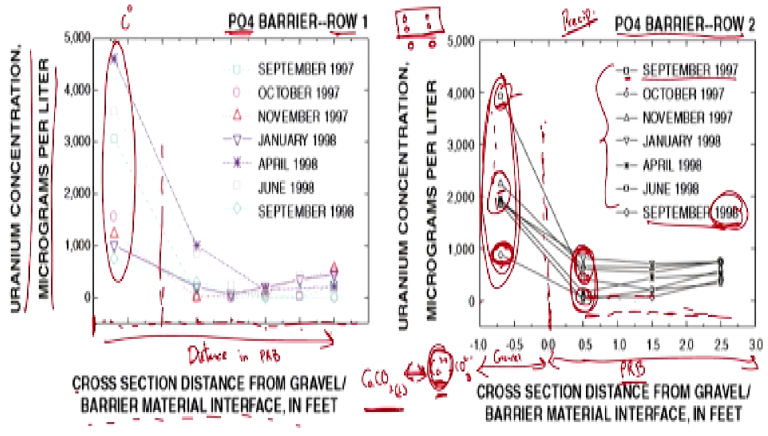

Changes in dissolved uranium concentrations in the bone char phosphate PRB from September 1997 through September 1998, Fry Canyon, Utah

So, let us look at these aspects in greater detail so here, I have uranium concentration and microgram per litre and this is for the PO4 or phosphate relevant PRB row 1 as in if you can remember PRB we had row 1 and row 2 monitoring locations and again, row 2 here, so cross-sectional distance from gravel, barrier material interface in feet, so this is the so as you go along this is the distance and the PRB or inside the PRB, right.

So, this is the gravel and PRB interface and as this as we move along obviously inside the PRB let us say I think the thickness was around 3 feet I guess, right so this is more or less the 3 feet relevant thickness, right the distance, so same case out here but I guess here I have the better scale here so, here is 0 as in her, so what does this data correspond to; if you remember we had relevant what do we say sampling ports before the PRB.

So, this gives me an idea about the uranium concentration coming in, C0 let us say and obviously, you know these are the ports we had 1, 2, 3, 4, 5, I guess row 1 and row 2, right and that is what we have out here because I have the graph here let me try to analyse this particular case, right so, this is the interface here, so this is the inlet concentration, so as you see the concentration at what do we say particular, the first set of wells in row 2 let us say, it is relatively what do we say less.

But as you can see it is not 0 for all the what do we say, sample time zones, I guess as in they start sampling from September 1997 to 1998, so obviously depending upon the type of flows or groundwater flows, different concentrations were experienced upstream of the relevant PRB, so that particular removal percentage seems to be obviously well correlated to the influent concentration, right for if the concentration was relatively high you know, typically anyway you know the performance seems to be differing let us say.

Or relatively, the you know the performance was relatively poor and obviously, for the relevant relatively low concentrations you know coming in you see, what do we say the low concentrations going out but obviously, you know that is a very generic analysis we need to look at the relevant data with respect to what kind of model it follows or what is the percentage removal, I guess right.

But keep in mind that the influent concentrations varied widely with C0, yes so, for example in September 1997, it was 4000 ppb, right and September 1998, I guess as you can see by that time, right the concentration relatively decreased, what does that mean; I guess one of the factors is that maybe the contaminated plume has more or less been at anyway, right that is what you see here, so let us look at that data briefly again, of all of them are bunched together here so that is not a great deal to understand.

But one aspect is you do not have much further removal as you go further into the PRB, this is the 3 feet of your PRB thickness, right 3 feet PRB thickness and you had gravel here, you had gravel, so as we went along you did not actually see much better removal or such and keep in mind that the key aspect here is its precipitation, the process is based on precipitation, right so I mean look at precipitation and dissolution, you will always have an equilibrium concentration, what do we say that will be in the water that will be in equilibrium with the solid phase.

For example, if it is only precipitation you will typically not have what do we say 100% removal, right why is that because the containment is going to be in equilibrium between the aqueous phase and you know in the solid phase let us say, probably that is one of the reasons why probably anyway with this relatively preliminary data that you do not observe 100% removal.

For example, a simple example is what am I saying is that $CaCO_3$ solid can dissolve into Ca^{2+} and CO_3^{2-}, right so if I am trying to remove Ca^{2+} let us say, right and what I am saying is that you will never have 100% or zero concentration of Ca^{2+} in the water, why is that because as you can see the system will be in equilibrium between the precipitate or the solid phase and the concentration of the relevant compound in the water, right so that is something to keep in mind.

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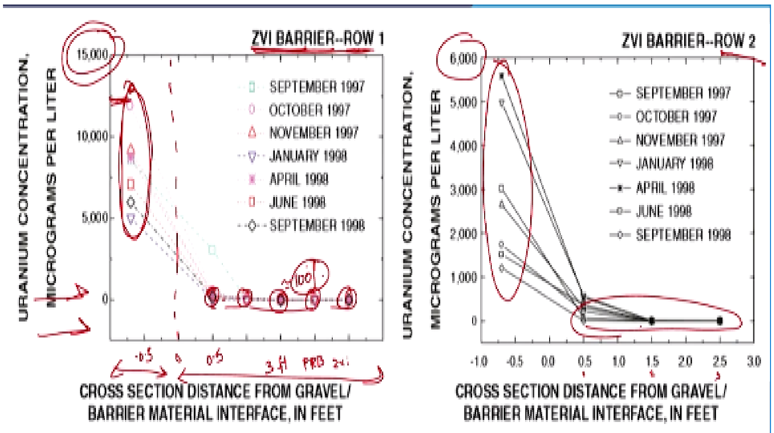

Changes in dissolved uranium concentrations in the ZVI PRB from September 1997 through September 1998, Fry Canyon, Utah

So, let us move on so, we are moving on to the second one which is zero valent iron barrier but keep in mind that the influent concentrations for row 1 and row 2 are different and again why is that obviously, you know that you know the plume what do we say direction let us say and also the groundwater level gradient let us say or the potentiometric contour gradient let us say or the contours let us say, right are not uniform.

So, let us say you know thus you have different concentrations coming in for row 1 and different concentrations coming in for row 2 and also keep in mind looks like zero valent iron row 1 is experiencing much higher inlet concentrations compared to the phosphate relevant barrier right here, the maximum seems to be around 4800 and 4000 here but here the maximum seems to be around 12,500 or 12,000 here, right so that is something keep in mind, right.

So, again we are going to analyse the zero valent iron PRB, right so this is -0.5, this is 0 and this is 0.5, right and thus is the interface out here and this is the 3 feet thick PRB of zero valent iron, so what do you see here though, you see that almost always we experienced 100% removal, right, so this is the influent concentration as you can see observed in the gravel, this is the gravel section and the water is flowing let us say in this particular direction as you can visualize let us say.

And what do we have out here; we see that the influent concentration irrespect of it being pretty high other than the first particular data set let us say in September, all the concentration let us say, all the data sets inside the PRB indicate that the almost let us say 100% removal, right again the mechanism here is that its reduction and then precipitation, right and again same profile more or less for row 2, right.

So, this is the first set of wells, second and third inside the PRB and these are the inlet concentrations and you can see that more or less you end up with 100% removal here, right so that is something to keep in mind again, here you can obviously see or understand the relatively greater efficiency of removal that you come across in the zero valent iron barrier, right.

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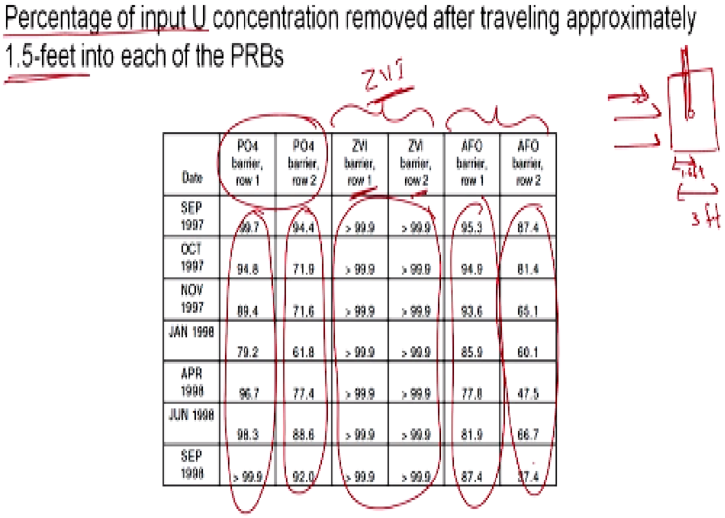

Percentage of input U concentration removed after traveling approximately 1.5-feet into each of the PRBs

Date	PO4 barrier, row 1	PO4 barrier, row 2	ZVI barrier, row 1	ZVI barrier, row 2	AFO barrier, row 1	AFO barrier, row 2
SEP 1997	99.7	94.4	> 99.9	> 99.9	95.3	87.4
OCT 1997	94.8	71.9	> 99.9	> 99.9	94.9	81.4
NOV 1997	89.4	71.6	> 99.9	> 99.9	93.6	65.1
JAN 1998	79.2	61.8	> 99.9	> 99.9	85.9	60.1
APR 1998	96.7	77.4	> 99.9	> 99.9	77.8	47.5
JUN 1998	98.3	88.6	> 99.9	> 99.9	81.9	66.7
SEP 1998	> 99.9	92.0	> 99.9	> 99.9	87.4	37.4

So, here let us look at the percentage of input uranium concentration removed after traveling approximately 1.5 feet into each of the PRB, so what are we comparing; so here we looked at the thickness was 3 feet, so we are comparing the data at after the water has travelled 1.5 feet into each PRB and the groundwater is obviously flowing in this direction let us say, my monitoring well is somewhere out here, right, groundwater flow is this direction.

So, PO4 row 1 and row 2, zero valent iron and AFO, obviously typically, as we looked at the relevant data until now what, which particular barrier performed pretty well both in the column test and also this in the field conditions, zero valent iron and obviously you see that the removal after just 1.5 feet is almost 100%, right and typically, row 1 did better than row 2 could be due to various factors again, we have not looked at that in detail.

But again, as you see typically I guess same case here, row 1 and row 2 but this is from very general (()) (23:18) but the take home message is as you can see the zero valent iron did pretty well, right both for row 1 and row 2 compared to the other barriers out here, right and do I see any trends here; I guess, I can plot them and look at it but you know not great trends here let us say, I guess, right.

And obviously, with season you know you will have differing conditions of influent groundwater too other parameters or variables and that will affect them and obviously we are going to look at some of those aspects.

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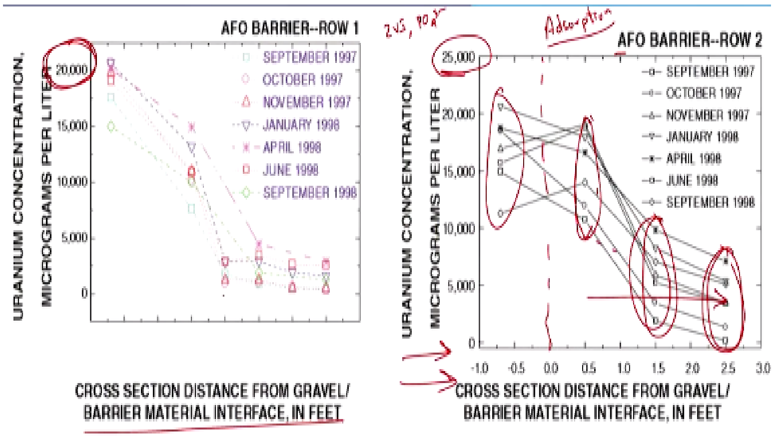

Changes in dissolved uranium concentrations in the ~~ZVI~~ AFO from September 1997 through September 1998, Fry Canyon, Utah

So, what do we have here; we have changes in dissolved uranium concentrations in the zero valent iron from September 1997 through September 1998, so the cross-section distance from gravel barrier material interface in feet, again here so earlier, we looked at the cases for zero valent iron and phosphate and now, I guess we have the case for AFO here, yes so same case here let me look at this data here, concentrations that this particular AFO is experiencing as you can see are remarkably high though much, much more higher.

So, again what was the mechanism here, it was removal by adsorption right, its adsorption, amorphous ferric hydroxide that is what we have here as a barrier material and the relevant compound is being adsorbed onto the relevant material here, right so typically, as you see what do you see here; relatively high concentrations out here in the gravel and this is the interface between the barrier and the PRB again, the groundwater is flowing in this direction.

And you see some revel not a lot but as it moves through yet as in groundwater moves through the relevant adsorbent, you obviously see greater removal, right that is something obviously you would expect right, so it comes in contact yet and the content; containment comes in contact with the adsorbent material and as it passes through the PRB or you can visualize it as a column, you have greater removal along the length of the relevant column or the thickness of the PRB, so that is what you see here, right.

And that is what you see out here yes, so that is something to keep in mind but that is more apparent in row 2 than in row 1, though yes.

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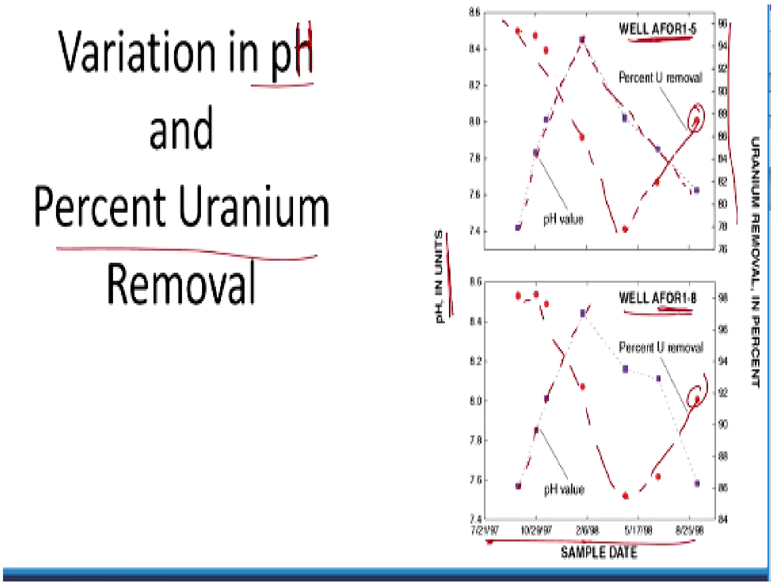

Variation in pH and Percent Uranium Removal

So, let us go ahead, so one of the aspects we mentioned earlier was that we need to look at variation in pH and obviously, percentage uranium and looks like there was a trend here but people could not come up with the worthwhile way to be able to explain this particular aspect but let us look at these aspects as and these are some of the aspects that people should understand, try to understand later.

So, on the y-axis we have pH, on the x-axis no, we have uranium removal on the other axis here and sampling date on the x-axis but the trend here you see is that as the uranium pH increased let us say, the pH increased typically, we see that the uranium percentage removal decreased typically, again found no explanation or people could not come up with an explanation, again keep in mind that this is for the amorphous ferric oxy-hydroxide.

So, it could be that let us say the charge of the relevant compounds are on the adsorbent or the uranium let us say could have change maybe but you know until we conduct greater what do we say are further detailed analysis, we cannot draw any conclusions about the basics or the principles affecting this particular behaviour but we do see that pH and what do we say the relevant uranium removal are interrelated.

Again as pH starts decreasing again, right, I mean pH increase initially and then decreased, right September to February 1998 and then again it decreased and during decrease again typically, we see that the percentage uranium removal increased again that was the case here too for both the wells in the AFO, right again, these are aspects that need to be looked at in greater detail later on or you know you need to draw the conclusions from and go ahead.

But for that obviously we need to understand or you know try to sample the PRB material and see what is happening out there.

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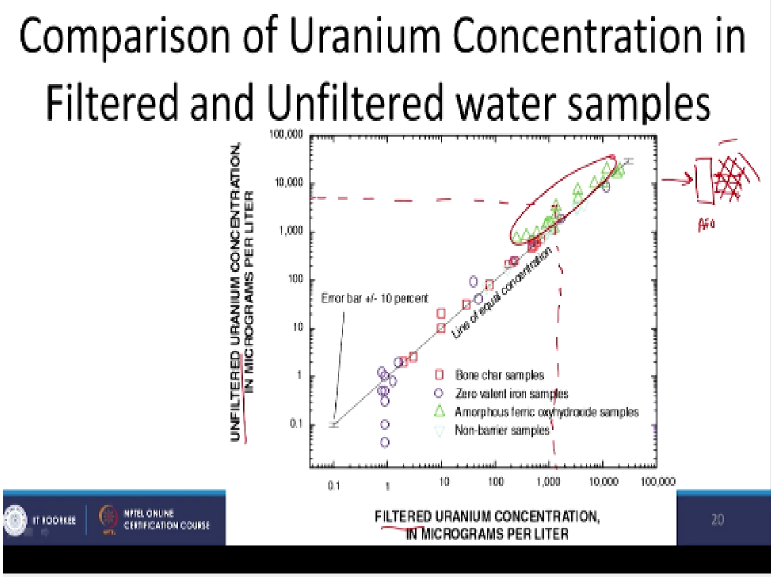

Comparison of Uranium Concentration in Filtered and Unfiltered water samples

And then again, comparison of uranium concentration in filtered and unfiltered water samples so, why is thus important again, what are we doing here; we are going to let us say have, you have the uranium contaminated ground water passing through the PRB and leaving the system and this water you are analysing directly without filtering and once after filtering, so if there are any colloids or such, you are going to be able to see a difference.

So, typically with respect to zero valent iron or bone char or these are the non-barrier samples, so non-barrier samples obviously you know they are right bang on the particular centre line right but with respect to the amorphous case, though you see that there above this particular line what does that mean that you have colloids being a form let us say, what does that mean that; in unfiltered concentration is higher than the filtered concentration that I am talking about the amorphous form, here right.

So, amorphous form you see that the concentration of the relevant uranium in the unfiltered samples is greater than the concentration in the filtered samples, right let us say if I look at this data point, then you see that slightly it is you know higher I guess, so what seems to be the case, so looks like you know the relevant mechanism is leading to formation of mobile colloids let us say that are leaving the system, right.

So, obviously these collides will be filtered out you know that is why you see that the concentration in the filtered samples is lower but in the unfiltered it is higher that is what you see so obviously. This is something you do not want as and you do not want your particular AFO or the PRB to be mobile, right you because again you are going to have transport of the uranium.

But if you looking at the particular data which I believe I am not presenting here though is that you know this particular case as in how my PRB here, the AFO PRB and groundwater coming in and so some of the colloids are leaving the system here, right but because I have again the media out here, the subsurface media out here, the concentrations are not you know greatly different down the line though as and these colloids are being entrapped in the relevant subsurface media though.

But still you know this is something you need to be concerned because you do not want to have colloids that can be transported over greater distances let us say, right.

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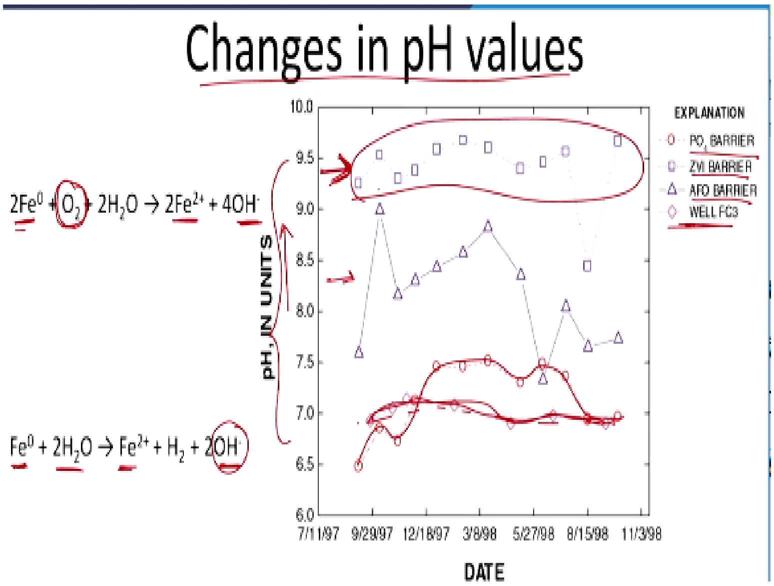

Changes in pH values

$2Fe^0 + O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4OH^-$

$Fe^0 + 2H_2O \rightarrow Fe^{2+} + H_2 + 2OH^-$

So again, changes in pH values again, we are looking at the 3 barriers, phosphate, zero violent iron and AFO and one let us say upstream let us say, so this is the actual trend, upstream concentration let us say without treatment, yes and for PO4 3- which was primarily precipitation this is what we observe and for AFO.

This is what we observe and for zero valent iron though we see that the concentration of the relevant water; treated water leaving the system not concentration part, pH of the water leaving the system is pretty high almost 3 pH units or 2 1/2 pH units compared to the system what do we say that is at 7, right that is something to be concerned about.

But let us try to understand the system or why that is coming about, right again keep in mind that for zero valent iron, what is the what do we say process here that is involved, we have reducing agent, what is that; Fe0, zero valent iron, so if any oxygen is present in the groundwater as can be right, oxygen is going to be reduced and you are going to have Fe 2+ and OH0- released.

Obviously, when you have OH- being released, what do you observe; you observe an increase in pH similarly, even in the case then when you have no oxygen or in anaerobic conditions zero valent iron what do we say can reduce water to Fe 2+ and again you end up with some OH-, so that is what you see out here, both when you have oxygen or even in the presence; absence of oxygen you see that you know OH - is being released or H+ is being taken in let us say if you depending upon how you balance the reaction.

And so that is why you observe this particular change in pH, so depending upon the issues with respect to pH change downstream, you can look at relevant remedial measures but typically, if you are trying to balance it between the uranium concentration removal which is almost 100% in the zero valent iron PRB and the pH change by what do we say 21/2 units and again you are going to have dilution later you know that should be that is reasonable though, right.

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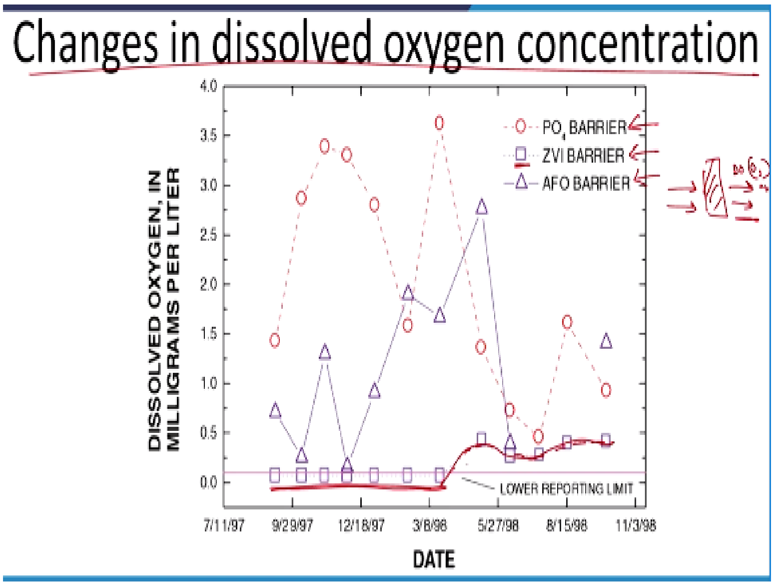

Changes in dissolved oxygen concentration

So, let us move on, so again changes in dissolved oxygen concentration what are we looking at; PO4 barrier, zero valent iron and the last one the AFO, I guess right so, let us look at the datasets here so, obviously what would you expect or for which case would you expect to have lesser zero valent iron, not zero valent iron, pardon me, dissolved oxygen concentrations downstream of the PRB as in what am I asking here, so this is my particular PRB material, groundwater is coming in and leaving the system.

So, in for which PRB will I have obviously lesser DO or dissolved oxygen and the particular downstream phase I guess, obviously it will be for zero valent iron, why is that because zero valent iron is a reducing agent, oxygen is an electron acceptor, zero valent iron reducing agent, it donates electrons and electron acceptor which is oxygen you know, it accepts the electrons and we looked at the relevant reaction.

So, again let us look at the data here as you can see here, this is the what do we say region for zero valent iron and you see dissolved oxygen concentration is below the detection limit but after I think around 6 months or so, you see a slight increase in the effluent dissolved oxygen that could be because let us say as we talked about in one of the cases when we are analysing

PRB, if you have precipitation build up over the zero valent iron material, you will not have as much active surface area available for interaction let us say.

And thus your efficiency slightly decreases and maybe that is the reason why we see some dissolved oxygen concentration leaving the PRB; zero valent iron PRB, right after around 6 months or so, right but obviously for PO4 3- or such you know I think it is varying according to the what do we say influent groundwater dissolved oxygen concentration, right so that is something to understand out here.

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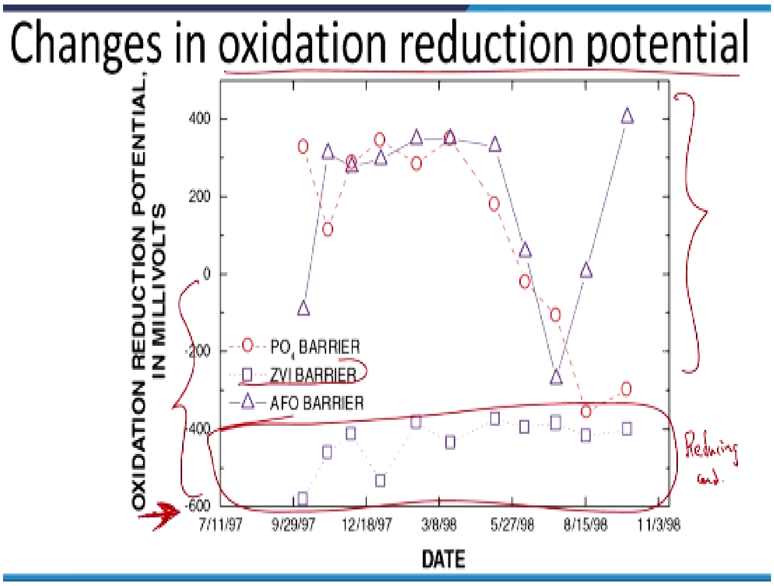

Changes in oxidation reduction potential

And final case, ORP or oxidation reduction potential, right what does this give you an idea; for example, in your labs you will have the ORP probes or such, right, oxidation reduction potential or redox potential, what does that give you an idea about for example, depending on the reading let us say of that redox potential let us say you can understand let us say is it is the water relatively what do we say have reducing conditions or oxidizing conditions or such, right.

So, again that is one way to understand obviously in which case of the 3 PRBS would you, what do we say expect to have reducing conditions or reduced species let us say in the case when the water passes through the reducing agent base PRB which is the zero valent iron, so let us see that out here so, for zero valent iron PRB, you see the redox potential negative and pretty low.

So that means you know reduction potential, so it can reduce the water or any other compound present in that so that is what you see out here, right redox potential is pretty low, right again reducing conditions prevail, so reducing conditions prevail here, right but that is not the case for the relevant AFO or PO4 based barriers and obviously, you know it has differing what do we say, redox potentials.

Again, you can also correlate this with the dissolved oxygen concentration that we observed earlier right, so moving on.

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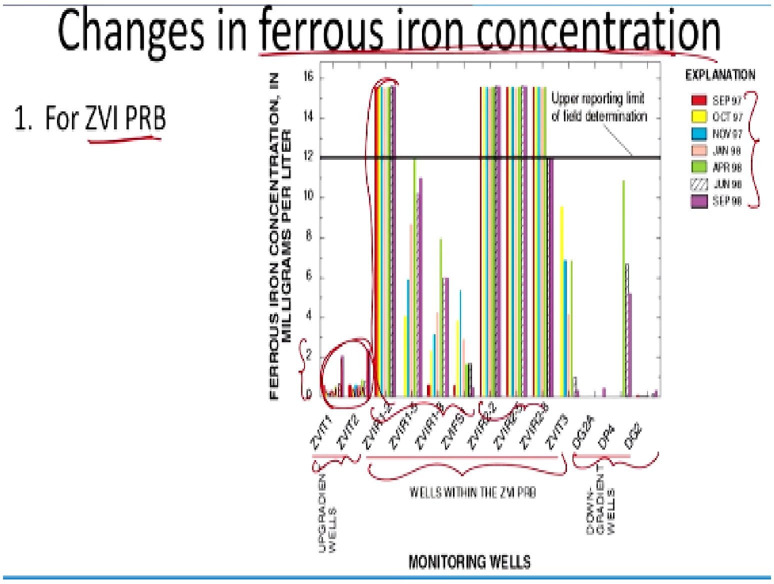

Changes in ferrous iron concentration

1. For ZVI PRB

So, we look at this particular case, changes in ferrous iron concentration, so one particular example before we wrap it up for today, so this is we are looking at it for zero valent iron PRB, so ferrous iron concentration, we have looked at pH, we looked at dissolved oxygen, we also looked at the redox potential, so redox potential obviously when would that be higher; will be lower obviously; when you have reducing conditions obviously for zero valent iron PRB we looked at that.

So, same case your ferrous iron though, when will it be released when Fe0 is oxidized to Fe 2+, so as the containment comes in contact with zero valent iron or oxygen comes in contact or water comes in contact with the zero valent iron let us say, it is going to be oxidized to Fe 2+ and Fe 2+ is going to be released so that is what we see here so, in the up gradient wells right and these are different months obviously, the colours correspond to different months, different sampling dates.

Upstream you see that the ferrous concentration is relatively low but within the PRB, the wells within the PRB what do you see that the concentration is pretty high but obviously, the trend seems to be differing and such right, again downstream concentration relatively low, we are going to look at this but looks like I ran out of time, so I am going to end there but keep in mind that what is the take home message here?

Depending on the type of material that we used, we are what do we say experiencing different downstream conditions or even within the PRB one of which is the zero violent iron but one aspect is as you can see, you know different trend here even within the PRB and this is something we are going to analyse maybe for a few minutes in the next session and then move on to the relevant aspect which is natural attenuation I guess, right.

What is natural attenuation about I mean, I guess it is self-explanatory so, let us say you have a compound out there let us say it is reduce compound let us say that you spilled into the soil and it reached the groundwater, so reduce compound so, it can act as an electron donor let us say and you have oxygen let us say in groundwater that is an electron acceptor and you have microbes that obviously want to grow, right.

And so depending upon the delta G values or the energy that they can get from you know promote in this reaction, you will have this particular reaction or the redox process and then the degradation of this particular contaminant you know, going through right, so that is something I am referring to as natural attenuation, so once I wrap up this particular case study of PRB in the next session maybe for 10 minutes, after 10 minutes we are going to move on to looking at natural attenuation, I guess right and with that I will end today's session and thank you.